Kraft Lignin as a Fuel for the Rotary Lime Kiln

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Abstract

For many kraft pulp mills the chemical recovery boiler, in which concentrated black liquor is burned, represents the principal obstacle to increased production. However, studies have shown that the removal of even a small portion of the lignin from the black liquor would permit an incremental increase in furnace capacity. Fortuitously, precipitation of lignin from black liquor followed by filtration, washing and drying yields a solid fuel which could be burned in the lime kiln. In order to test the suitability of the precipitated lignin as an alternate fuel, a 0.4 m ID by 5.5 m pilot rotary kiln was modified with a computer controlled screw feed system and a water–cooled lance in order to burn dry powdered lignin, with or without natural gas. In a series of trials, crushed limestone was calcined in experiments using three different kraft lignins at various levels of replacement for natural gas. Lignins precipitated from black liquor by both the mineral acid and the carbon dioxide process were burned successfully as the sole fuel, or in conjunction with natural gas, to yield a stable orange luminous flame. On a basis of constant total energy input to the kiln, comparisons are made of axial profiles of gas temperature, solid bed temperature and percent calcination as a function of the percentage of natural gas replaced by lignin. Gas and solids bed temperatures and percent calcination were found to be slightly higher at a given axial position in the kiln when burning lignin as compared to natural gas. All three lignins tested were found to produce similar results.

Impurities such as sodium and sulphur, which were present in the powdered lignin, did not significantly affect the quality of the lime. All three lignins were able to produce fully calcined limestone with no detrimental effect on the slaking properties of the lime. No significant difference in reactivity and slaking times could be observed between the lime produced with natural gas and with 100% lignin firing. The lignin fuel was found to be more efficient at supplying heat to the solids bed when compared to natural gas and this was reflected in the axial calcination profiles. It was concluded that dry lignin could be an acceptable fuel in either partial or complete replacement of natural gas, without penalty in lime quality or kiln productivity. However, full scale trials will be necessary to confirm these results and to identify any potential long–term effects on white liquor or lime quality.

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Nomenclature

α: constant for refractory, W/m

β: constant for refractory, W/m K

C_p: heat capacity, kJ/kmol K

F: fractional calcination

H: enthalpy, kJ/kmol

k: thermal conductivity, W/m

M: molar flowrate

R: radius, m

T: temperature, K

Z: length of kiln section, m

Subscripts

g: gas

k: axial position

LMS: limestone

w: wall

s: solids

ss: steady–state

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"Experience is what you get when you don't get what you want."

Wanda Webb, Ringgold, Ga.

Introduction

The fossil fuel requirement of the lime kiln remains the last barrier to energy self–sufficiency in modern kraft pulping technology. Many alternative and supplementary fuels have been proposed for kilns, such as pulverized coal and hog fuel, turpentine, stripper overheads, black liquor, gasified hog fuels, crude tall oil, and lignin [1–18,20,24–28,34,36,42,45]. However, all these possible fuels have certain drawbacks. For example, systems using pulverized coal and hog fuel have storage and handling problems. It is not possible to store or stockpile these fuels in the pulverized state because of the potential for spontaneous combustion. In addition, most coals contain sulphur and a moderate ash content which cause problems for kiln utilization [21–23,24]. With hog fuels one must contend with the addition of aluminum and silica to the liquor cycle [3,5]. Mills with turpentine collection facilities often use its fuel value in determining a base sale price and fire turpentine in the kiln when sale prices are low. Therefore the cost saving from using turpentine as a supplementary fuel is offset by the potential revenue from its' sale. Turpentine prices vary widely [45] but have risen sharply in recent years. The use of condensate stripper overheads is not economically attractive because of the cost of installation of a rectification column to upgrade these gases for use as a fuel [45]. The gasification of hog fuel involves a complex drying, pulverizing and gasifying system and as in the case of pulverized hog fuels, but not to the same extent, adds aluminum and silica to the liquor cycle [1–9]. The gasifier temperature is controlled by the flow of inlet air and this flow subsequently becomes the fuel stream for the kiln. The gas flow to the kiln can be increased from time to time by controlling the gasifier temperature, leading to increased entrainment and an altered temperature profile in the kiln [5].

Full scale mill trials have shown that kiln fuel oil requirements can be reduced by up to 50% when wet hardwood chips or screened wet hog fuel are fed with the lime mud into the cold end of a kiln [15–17]. No deleterious effects on mill operation or pulp quality were noticed during or after 44 days of continuous biomass feeding. Although dust losses were high at low kiln loading, when the kiln was operated at 90% of the design

throughput dusting was only marginally higher than for the baseline conditions. Complete fossil fuel replacement was not, however, feasible.

Lignin combustion in the lime kiln could reduce or eliminate the requirement for purchased fossil fuel while permitting increases in recovery furnace throughput [34,36,39–41]. While energy recovery from black liquor is required for the economic operation of the kraft mill, many mills currently operate the recovery furnace at or above its design thermal capacity. Earlier studies have shown that removing a small portion of the lignin present in the black liquor will not adversely affect black liquor combustibility [34,37,38,41] and that reducing the heat load to the furnace could permit increased pulp production [34–42]. A proposed process has been described in which lignin is precipitated by carbon dioxide to produce a 30 wt% lignin suspension. This lignin is partially dewatered on a hot drum separator to produce a wet lignin fuel of undisclosed moisture content [36,39]. The role of moisture content on heating value and fossil fuel replacement potential has been discussed and the adiabatic flame temperature of lignin fuels and conventional fossil fuels have been compared. If lignin moisture content is maintained below 30%, the calculated adiabatic flame temperature is greater than the 1750°C required for proper calcination when replacing a fossil fuel [42]. Drying of the precipitated lignin is undoubtedly expensive, although desirable from the point of view on the heating value of the fuel as fed to the kiln. Should use of recovered lignin as a lime kiln fuel be feasible, the amount of drying done prior to firing will be dictated by the combustibility of wet lignin, handling problems and economic considerations.

Computer simulation has shown that, for the production of modified lignin products, lignin removal by ultrafiltration is both feasible and economical [35]. Payback times of less than one year have been estimated for an acid precipitation plant if the recovered lignin is burnt in a wood–fired boiler or lime kiln [41]. A lignin recovery plant using carbon dioxide for precipitation has been estimated to have a 4–5 year payback time, when 21% of the recovered lignin is sold as a specialty chemical and the balance used as fuel in the lime kiln at 91% replacement of the fossil fuel [43,44].

In the present work dried lignin powders from carbon dioxide and sulphuric acid precipitation were assessed as fuels in a pilot scale lime kiln. The objective of the work was to examine the combustion of the recovered lignins, co–firing at high levels of natural gas replacement and as the sole fuel, in order to determine the impact on kiln operation of changing fuels from natural gas to lignin. The effect of impurities, which are left in the lignin powder after washing, on lime quality and the effects of lignin firing on dust composition were also determined.

Chapter 1

A Description of Wood and its Components

Wood is composed of cellulose (≈45%), hemicellulose (25–35%), lignin (20–25%) and extractives (2–8%) [73]. The precise amounts of these components vary depending on the wood species. The extractive substances in wood are compounds such as terpenes, resin and fatty acids, phenols, unsaponifiables and neutral compounds such as beta–sitosterol, juviabione. Lignin is an amorphous, highly polymerized substance consisting primarily of phenyl propane units linked together in three dimensions [73]. It is the 'glue' which binds the fibers together in the tree. Lignin and the extractives are removed from the wood to free cellulose and hemicellulose, which are used to make paper. The Kraft process uses a solution of sodium hydroxide and sodium sulphide to break the lignin molecule into smaller fractions whose sodium salts are soluble in the cooking liquor.

The Kraft Cycle

The kraft recovery process operates according to the cycle shown in Figure 1. The process begins at the digester, where wood chips are cooked with white liquor (Na_2S & NaOH) at high temperature and moderate pressure to penetrate and dissolve the lignin. Weak black liquor is separated from the pulp on a series of brown stock washers. Using a countercurrent washing scheme, wash water is minimized. The weak black liquor (≈15% solids) is concentrated in multiple–effect evaporators to produce strong black liquor (≈50% solids). During the evaporation process the tall oil soaps become insoluble. Midway through the multiple–effect evaporators, where the black liquor contains about 24% to 28% solids, insoluble tall oil soaps are skimmed from the liquor. The skimmed liquor is then returned to the next evaporator effect. Black liquor is further concentrated into heavy black liquor (≈60% solids) using a direct–contact evaporator or a concentrator. Oxidation is required in conjunction with direct–contact evaporators to minimize the emission of odorous sulphur gases. Heavy black liquor is burnt in the

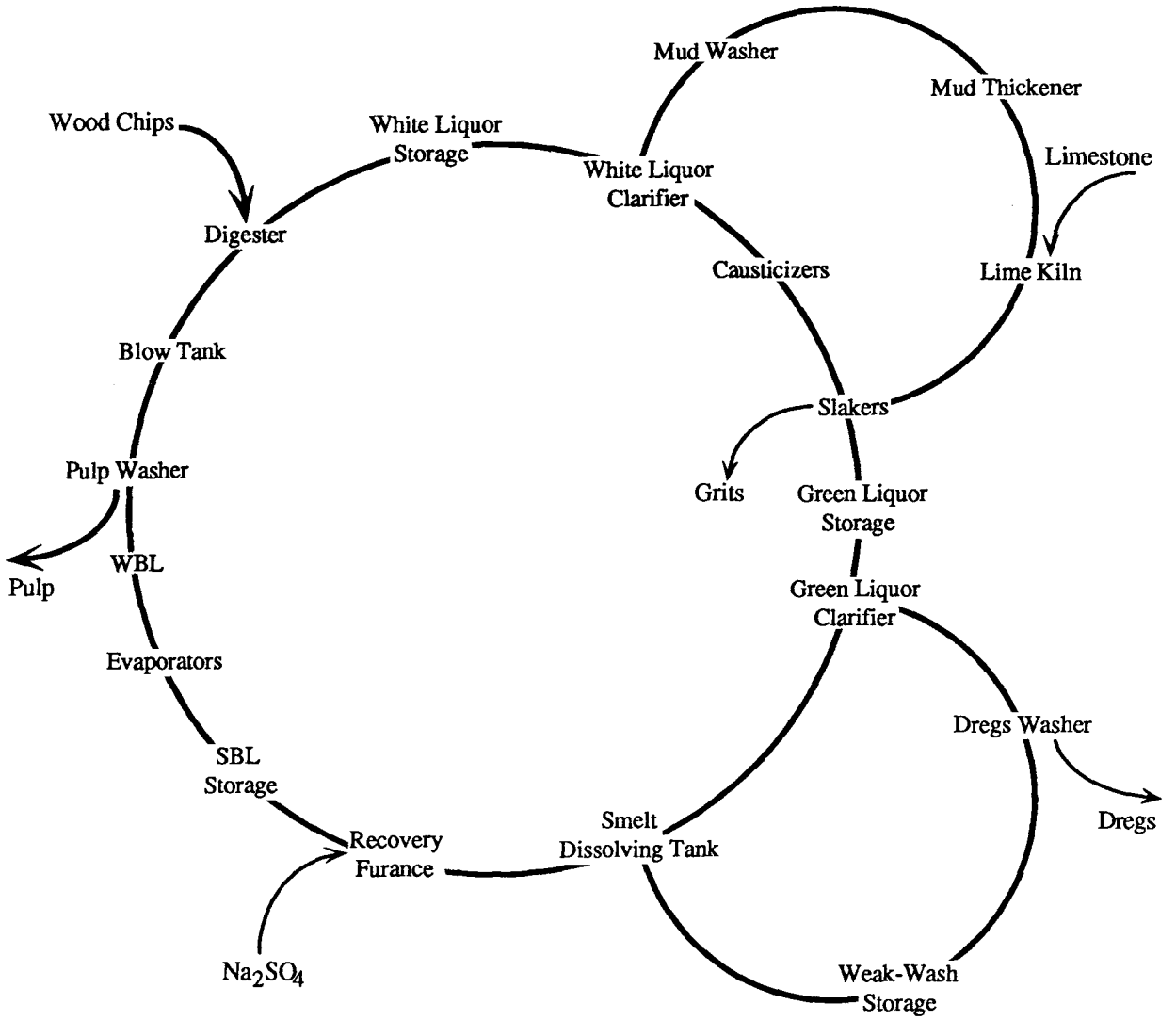


Figure 1. A simplified diagram of a kraft recovery cycle

recovery furnace to produce steam for the mill and a molten inorganic smelt (Na_2S & Na_2CO_3), which is removed from the bottom of the furnace and dissolved in weak wash to form green liquor. The recovery furnace is operated under reducing conditions such that sodium sulphate is converted to sodium sulphide. Insoluble materials consisting of fluffy unburned carbon particles called dregs [65] and inorganic impurities (silca, iron, alumina, calcium, magnesium, chromium and sulphides, [65,66]) are removed from the green liquor in a clarifier. Dregs are introduced from the following sources; 1) incomplete furnace combustion, 2) makeup saltcake and lime, 3) wood chips, 4) furnace and kiln linings, and 5) corrosion and scaling of digesters, evaporators and piping [66]. The dregs are washed with fresh water to remove entrained liquor and produce weak wash, and are then sent to landfill.

Calcium oxide from the lime kiln is slaked in green liquor to produce calcium hydroxide with the evolution of heat (ΔH = -67 kJ/mol @ 100°C), which is further converted to calcium carbonate (and sodium carbonate to sodium hydroxide) by the green liquor in the causticizers (a series of agitated tanks). The reactions by which this occurs are shown below. Both reactions are reversible and heterogeneous, since CaO, $Ca(OH)_2$ and $CaCO_3$ are present as solid phases during the course of the reactions [56]. Calcium carbonate produced during causticizing has a very low solubility and precipitates from the solution. Slaking and causticizing are consecutive but are also concurrent reactions most of the time (i.e. causticizing starts as soon as some slaking has occurred). However, the rate of slaking is much faster than the rate of causticizing [56].

$$CaO + H_2O \longleftrightarrow Ca(OH)_2 + \text{Heat} \quad \{\text{slaking}\}$$

$$Na_2CO_3 + Ca(OH)_2 \longleftrightarrow 2\,NaOH + CaCO_3\downarrow \quad \{\text{causticizing}\}$$

The product solution, called white liquor, consists primarily of sodium hydroxide and sodium sulphide. Lime mud (calcium carbonate) is removed from the white liquor in a clarifier. The white liquor is returned to the digester for cooking to complete the cycle. The lime mud is thoroughly washed on a drum filter to remove any white liquor, then calcined in the rotary lime kiln to regenerate lime via the reaction:

$$CaCO_3 + \text{Heat} \longleftrightarrow CaO + CO_2\uparrow \quad \{\text{calcination}\}$$

The reburned lime is returned to the causticizers to convert the green liquor to white liquor.

Removal of Lignin from the Kraft Cycle

Production in many kraft mills is limited by the thermal capacity of the recovery boiler. Removal of a fraction of lignin from the black liquor would reduce the heat load on the recovery furnace and permit an incremental increase in furnace capacity. Since the gross heating value of the black liquor is reduced by lignin

removal, the flow of black liquor to the furnace can be increased which results in a corresponding increase in pulp production. Approximately half of the organic material in black liquor is dissolved lignin, with the remainder consisting mainly of carboxylic acids [32]. During the cooking process lignin is dissolved by the hydroxyl and hydrosulphide ions present in the pulping liquor to form phenolate or carboxylate ions. When black liquor is slowly acidified the dissolved lignin becomes insoluble and precipitates leaving the spent cooking chemicals in a more viscous solution. Black liquor can be removed easily from the liquor cycle, either just after the soap skimming tank or before the black liquor is burnt. The amount of black liquor diverted for lignin removal will depend on the amount of fuel to be replaced in the kiln by lignin, but no more than 15% of the total lignin need be removed for 95% fossil fuel replacement in the lime kiln by lignin [42]. Removal of 15% of the total lignin will reduce the liquor's calorific value by 12%, but does not affect the combustibility of the liquor [37,38,41]. Proposed methods for lignin recovery made use of either pure carbon dioxide or sulphuric acid [29–39,43,44]. The acid used must not interfere with any of the following recovery operations. Figure 2 shows the process flow chart modified to include the streams required for a lignin recovery process and that carbon dioxide or sulphuric acid are added in the same place regardless of the precipitation method. Generator waste acid (GWA) from the ClO_2 generator might also be used for lignin precipitation, but if more than 15% of the total lignin is to be recovered carbon dioxide may be required [41]. Where GWA is not available, carbon dioxide is preferred because it would minimize the disruption of the mill chemical balance. Flue gases with a high carbon dioxide content can be used, but purchased carbon dioxide may be necessary [29–33,36], if a final pH of <9.3 cannot be obtained using flue gases. A pH of <9.3 is required to produce a coagulatable lignin [29–31,33,43,44]. Residual oxygen in the flue gas is also believed to have unfavorable effects on the properties of precipitated lignin [29].

Removal and acidulation of oxidized strong black liquor minimizes the release of odorous reduced sulphur gases to the atmosphere [41]. Acidification by sulphuric acid is quicker and easier to control, but carbon dioxide from flue gas is cheaper [29]. Careful temperature control is required during precipitation of lignin to avoid fine dispersions or a colloidal solution [30,41]. An optimum temperature of 80°C has been found to produce an easily filtered lignin product [30,31,34]. This temperature will depend on the nature of black liquor and if exceeded, the lignin will melt into an unfiltrable tar [29]. After degassing the acidulated black liquor, the precipitated lignin

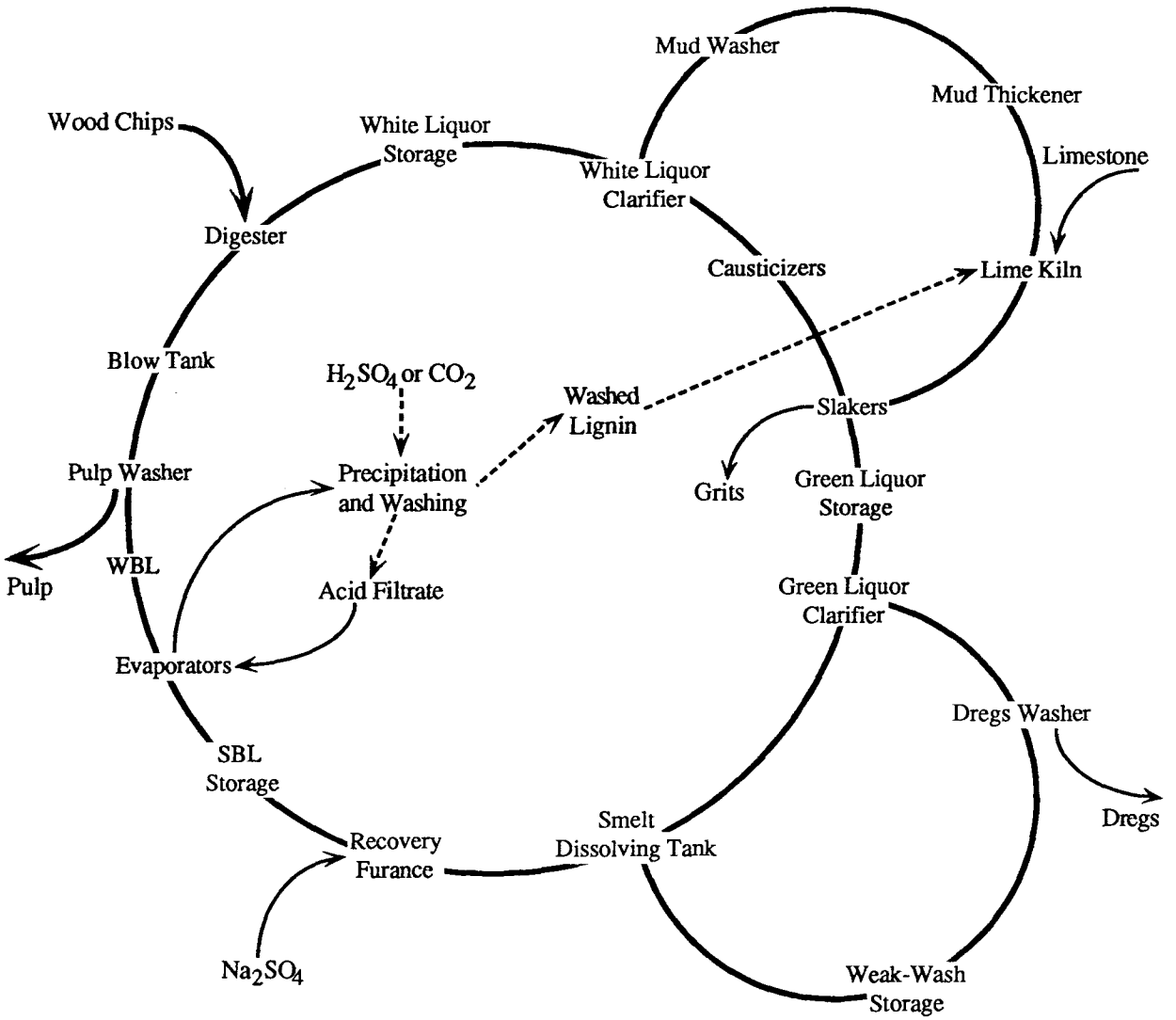


Figure 2. A simplified diagram of the modified kraft recovery cycle with lignin recovery

must be separated from it and the filtrate returned to the chemical recovery cycle for economical operation of the pulp mill [29]. Gases released during the acidulation step contain hydrogen sulphide. By scrubbing these gases with white liquor [41] some of the lost sulphur can be recovered and returned to the liquor cycle. The addition of pH adjusted filtrates to black liquor was found to significantly increase the rate of Burkeite scaling in laboratory tests [41]. Removal of precipitated lignin from the acidified black liquor is desirable to avoid subsequent fouling in the multiple–effect evaporators [29]. Cooling of the lignin after precipitation increases its particle size [40] and will aid the filtration step by preventing the formation of gummy lignin [43,44]. Sodium is bound to the

carboxylic and phenolic groups when lignin is precipitated, therefore it should be thoroughly washed with sulphuric acid (at a pH ≤ 4) and water to reduce the amount of sodium and sulphur in the lignin [30,41,43]. Sodium compounds are believed to cause ring and ball formation problems in the lime kiln [60,67,68]. Water washing of the lignin reduces the low–molecular–weight fraction in the final lignin product [32]. It has been found that washing lignin precipitated by CO_2 consumes more mineral acid than washing lignin precipitated by sulphuric acid [76]. Purchased sulphuric acid or GWA from the chlorine dioxide plant can be used for lignin washing [34,41]. In bleached kraft mills with modified Mathieson chlorine dioxide generators, 10 to 15% of the total lignin may be precipitated and washed using GWA with no net effect on the mill's sulphur balance [41]. The current trend in kraft mills, however, is to replace the ClO_2 generator with a methanol–based process [43] and thus eliminate the waste acid stream. If the acid washings (H_2SO_4) were returned to the chemical recovery cycle [43], the required quantity of pure sulphuric acid needed to wash a CO_2 precipitated lignin would drastically upset the sulphur balance in the liquor cycle of a modern kraft mill. Sewering precipitator dust from the recovery furnace might be necessary to maintain the mill's sulphur balance [44].

Further processing of the lignin may be necessary to improve the combustibility and handling characteristics of this fuel. Although drying the washed lignin will increase the heating value of the fuel, this is an expensive process. The extent to which drying is necessary will be determined partly by the combustibility required of the lignin [42], and partly by handling problems and economic considerations. Wet lignin should contain less than 25–30% moisture to ensure that enough heat is supplied to the kiln to satisfy the overall heat balance of the unit and ensure complete calcination of the lime mud [42]. Until the current work no studies have been reported in the literature on the development of either a lignin feed system or a lignin burner.

The Role of Lime and the Lime Kiln

The slaking of calcium oxide to calcium hydroxide is an exothermic reaction. Since the rate of slaking is much faster than the rate of causticizing, the overall reaction rate is controlled by the causticizing reaction

[56,69,70]. Completeness of the causticizing reaction determines the amount of carbonate deadload in the liquor cycle [69,70]. Slaking rate is an easy and quick test to determine the reactivity of lime. In general reactivity will depend upon porosity and surface area, the impurities present in the lime and whether the lime has been sintered. The test for reactivity involves the measurement of temperature rise as a function of time during hydration of the lime [55,56,69,70]. This value can be related to the limes' surface area [55,56,69] and the degree of causticizing [70]. A highly reactive lime produces a slower settling mud (calcium carbonate) at the causticizing step and the contrary holds true [69,70].

The role of the rotary lime kiln in the lime cycle is to calcine the calcium carbonate (lime mud) to regenerate calcium oxide (lime) for reuse in the causticizing process. Rotary kilns are long cylindrical heat exchangers that are lined with refractory bricks. They are slightly inclined from the horizontal and are slowly rotated. Lime is introduced into the kiln at the uphill or cold end. A burner is installed at the downhill or discharge end to provide heat for transfer to the countercurrent moving bed of solids. Heat transfer from the freeboard gas to the bed material and refractory walls is generally dominated by radiation with convection playing a relatively minor role [48]. Radiation from the freeboard gas occurs from emitting gases such as CO_2, H_2O, etc. and from particulate dust present in the gas. Nitrogen and oxygen in the combustion gas are radiantly transparent and do not contribute to the heat transfer process. Through the formation of radiantly emitting gaseous products of combustion, especially CO_2 and H_2O, all hydrocarbon flames produce significant levels of radiative heat–transfer. However the presence of particulates in the flame can enhance radiative heat–transfer on account of emission from these particles. Flame luminosity is primarily associated with particulate emission. Flames which do not contain particulates (or do not generate significant levels of carbon by pyrolysis), for example natural gas flames, are nearly invisible while flames which contain high levels of particulate loading, for example oil or candle flames, are clearly visible. Since the presence of particulates can significantly increase radiative heat–transfer, the thermal behaviour of the rotary kiln can be expected to change when converting the fuel from natural gas to powdered lignin. Flame shape, colour, emissivity, temperature and a rolling or cascading bed action all determine the efficiency of heat transfer from the flame to the kiln bed [47,48]. The flame shape to some extent determines the production capacity, thermal efficiency, product quality and service life of the refractory. Short intense flames

which are too hot can cause refractory damage and dead–burned lime. Dead–burning is to be avoided because it has a negative impact on reactivity of the lime [49]. The factors which influence flame configuration can be categorized into those which are fixed by the type of burner selected and those which can be changed by the kiln operator [55]. Some of the flame control factors that are fixed by the burner design are:

1) kiln diameter
2) type of fuel
3) fuel delivery tube size

The factors which can be controlled by the kiln operator might include:

1) fineness or atomization of the fuel
2) feedrate of fuel
3) temperature of fuel
4) velocity of transport air for fuel
5) flowrate & ratio of primary & secondary air
6) temperature of inlet combustion air
7) burning zone wall temperature
8) burner position
9) kiln loading

In general for liquid and gaseous fuels the flame shape and length depends primarily on the quantity and momentum of the fuel and air streams rather than on the nature of the fuel [49]. Certain fuels are innately more conducive to producing porous, soft–burned, reactive limes; others tend to yield hard–burned, slow–reactive limes; while others are intermediates. Consequently, selection of the proper type of fuel is vital for optimum efficiency [55]. Quality lime is dependent upon a long, lazy flame, stretched out over a reasonable length of the kiln [47] (constant heat transfer at a reasonable temperature). The retention time of kiln material is a function of kiln speed, slope, length, diameter, angle of repose of the bed material and whether dams are installed. The size distribution of the feed has a strong influence on the exposure of single particles to flame and gas radiation [48,54]. Dead–burned or sintered lime is induced by calcination at elevated temperatures (1540–1650°C) and causes pore shrinkage, which results in reduced porosity, surface area and a loss in chemical reactivity [55].

Because of the high energy (ΔH = 1.70 MJ/kg @ 1173 K) requirements for calcination, low fuel costs and an energy efficient kiln are a must for economic operation. The overall mass and energy balance for a rotary lime kiln depends on its length and diameter, refractory layout, quantity of chain and if satellite coolers are installed [49,50]. In the rotary kiln the material undergoes a thermal sequence consisting of drying, followed by heating to calcination temperature (≈800°C) and finally the calcination reaction itself. The chain section in the rotary kiln aids the drying of the lime mud and decreases the dust lost from the kiln. Dry lime mud is a fine powder that must be agglomerated in the kiln into nodules so that the product can be handled easily [49]. Size and porosity of these nodules can be related to the flame shape and inerts in the lime mud, especially the sodium [49].

As shown in Appendix G, net rates of heat transfer can be calculated from measured temperatures and flows. The complex interactions of firing conditions can be studied by calculating the heat flows within the kiln. The net rate of heat transfer through the shell, from the freeboard gas and to the solids bed require axial temperature and calcination profiles [50–52,54]. The net rate of heat transferred by the gas at the kth axial position over a length of the kiln in the non-flame region, dZ is calculated as follows [54]:

$$QFBG_k = M_g * C_{p_k} * \frac{dT_g}{dZ_k} - \frac{dM_{CO_2}}{dZ_k} * C_{pCO_2} * (T_g - T_s) \tag{1}$$

Net rate of heat transfer to the bed per unit length of the kiln is found by [54]:

$$QSOL_k = M_s * \left(\frac{dT_s}{dZ_k} * (1 - F(k)) * C_{pLMS} + F(k) * C_{pCaO} + \frac{dF_k}{dZ_k} * (H_{CaO} + H_{CO_2} - H_{LMS})\right) \tag{2}$$

Heat transfer from the kiln shell occurs by both radiation and by convection which are functions of the ambient air temperature and wind velocity [48]. This loss can be found by using a one dimensional heat conduction equation applied to a cylindrical body, knowing temperatures at two radii within the refractory wall and the thermal conductivity of the refractory [54]. When the thermal conductivity of the wall varies linearly with temperature according to:

$$k = \alpha * (1.0 + \beta * T) \tag{3}$$

then loss can be shown to be:

$$QSS_k = 2 * \pi * \alpha * (1 + \beta * (Twsav_k + T2_k) / 2) * (Twsav_k - T2_k) / \ln(R_2 / R_{ss}) \tag{4}$$

A detailed energy balance over a unit length of the kiln is described in the literature [50–54].

Lignin as a Lime Kiln Fuel

In Canada and the USA the majority of lime kilns are fired with natural gas or Bunker C oil. However, since these kilns (including those in kraft mills) are consumers of relatively large amounts of energy, numerous attempts have been made to use alternate cheaper fuels, either in combination with oil or gas, or as a substitute fuel. Table 1 list fuels that have been used in rotary cement or lime kilns. The coal/oil mixture has been fired only in a power boiler, however the similarity of this fuel to the coal/oil/water combination should make it suitable for the lime kiln. Although lignin has not been reported in the literature as being burned in the lime kiln as a fuel, the fact that it has a composition of approximately 59–63% carbon, 5–6% hydrogen, 25–26% oxygen, <2% nitrogen, a higher heating value in the range of 24–27 MJ/kg (all on a dry weight basis) and an air to fuel ratio of 7.8 kg/kg make it an excellent potential fuel. Comparing the elemental analysis of the fuels in Table 1 with that of lignin, it is evident that lignin is a highly oxygenated fuel, with a respectable heating value. The heating value of dry lignin is comparable to coal (29 MJ/kg), 21% lower than natural gas and 33% lower than crude oil.

Carbon dioxide precipitation produces a lignin low in sodium but high in sulphur, whereas mineral acid precipitated lignin is high in sodium and only slightly lower in sulphur [30,34]. Both of these lignins would require washing to lower the concentration of the two components so that it may be used as a fuel in the lime

Table 1. Fuels used in rotary kilns

Type of Fuel	Amount Used %	Calorific† Value	Air/Fuel kg/kg	wt Percent (typical) C	H	O	N	S	Na	H_2O	Ash
Crude oil	100	40.61	13.6	87.3	10.5	0.6	0.0	0.8	0	0.0	2
Turpentine	5-25	41.87	13.1	81.2	11.2	2.5	0.0	0.0	0	5.1	0
Tall oil	5-75	36.40	12.3	77.8	11.0	8.8	0.0	0.05	0	1.9	1
Methanol	100	22.68	20.9	37.5	50.0	12.5	0.0	0.0	0	0	–
Ethanol	100	29.67	17.8	53.3	35.6	11.1	0.0	0.0	0	0	–
Natural gas	100	33.50‡	16.7	74.3	23.9	0.4	1.4	0.0	0	0	0
Odorous gases	5	23.35‡	5.8	22.8	5.6	2.0	0.0	49.8	0	19.8	–
Stripper o/heads	10-20	15.26‡	3.9	23.1	6.1	19.9	0.0	0.9	0	50.0	5
Hydrogen	15-75	141.80	34.2	—	100	—	—	—	–	—	–
Producer gas	100	5.25‡	9.8	14.4	26.3	19.3	40.0	—	–	—	–
Coal gas	100	6.70‡								–	
Wood gas	100	6.10‡									–
Bark gas	100	5.85‡									–
Coal dust	50	29.30		70-90	4-6	4-6	1	1-5		1-15	4-12
Coal/Oil	100	36.75								0.5-1	2-4
Coal/Water	100	24.40								2	1
Coal/Oil/Water	100	36.75								0.5-1	2-4
Charcoal	100	27.20								2	–
Bark	100	16.75								1.5	–
Saw dust	100	17.60								0.5	–
Petroleum coke	50-80	29.30		81	1.5	2	1	1		2	13

† MJ/kg ‡ MJ/m^3 References [45,46,55]

kiln. Some of the sulphur present is organic sulphur which is chemically bonded to the lignin and can not be removed by the acid washings. Organic sulphur would produce SO_2 which would react with calcium oxide to form calcium sulphate, an inert compound in the lime cycle. Since sodium is believed to cause ring and ball formation in rotary kilns its level should be controlled. In contrast to the Kraft process, the alcohol pulping process (which has no lime kiln) dissolves the lignin in the wood to produce a lignin free of sodium and sulphur. Although this high purity lignin has the potential to be one of the best lignin fuels, the retail value as a substitute or precursor in the plastics industry is also high which may act as a deterrent for use as a fuel.

Powdered lignin is a nontoxic stable product which should be stored in a cool dry warehouse, but away from strong oxidizing agents, heat and ignition sources. However, like all dry powders, lignin in its dry state does have some disadvantages. For example, accumulation of lignin dust with an ignition source may result in an explosion.

Other fuels listed in Table 1, some of which are used to calcine lime mud, may be found as a supplementary fuel for the kiln in kraft mills. However these fuels are not in wide use, nor do they completely replace the fossil fuel normally used. When these fuels are used in the kraft mill, the process has generally been developed as a means of disposal for the mill, rather than a quality alternate fuel for the lime kiln. A summary of the problems associated with those of the fuels used in the kraft mill follows.

Some kraft mills in Austria, Finland, Portugal and Sweden replace some or all the fossil fuel in their lime kilns by gas produced from gasified woodwaste [1–5]. The gasification temperature is controlled by air flow; the offgas becomes the fuel stream to the lime kiln [1–3]. The use of gasified biomass in the lime kiln has the following effects: 1) Flue gas flowrate in the lime kiln can be increased by as much as 13%. The increase depends on the quality of gas from the gasifier [3]. 2) The biomass for gasification must be dried to obtain a quality gas that has a heating value sufficient for calcination. Because of the poor quality of the fuel the flame temperature is lower, but high enough to calcine the lime mud [3]. 3) The axial gas temperature profile is shifted when a gasifier is used [3]. This is due to the increased gas flowrate through the kiln. Temperatures are lower at

the burner (front) end and higher at the gas exit (back) end. This slight shift in gas temperature profile has no effect on the calcination of the lime mud [3]. 4) Inert material (aluminum and magnesium) carryover in the gas from the gasifier is negligible and is lower than that from makeup limestone. Dust which does escape the cyclone is mostly carbon (≈80%) and burns in the flame [3].

Lime kilns can be fired directly with a suspension of dried pulverized woodwaste and/or bark [10–13]. Flame stability is ensured by maintaining a particle size of less than 1.5 mm with a moisture content of 15% or less [11]. The flame length was found to be twice as long and the temperature cooler (1480°C or 18% lower) when compared to oil firing [10]. The advantages to this type of system have been: 1) 100% replacement of fossil fuel; 2) improved quality of lime mud and lime; 3) no detrimental effects to the lime and liquor cycle by inerts and unburned carbon [10]. Handling of dry pulverized wood waste is not without operating problems, however.

The burning of crude tall oil (CTO) as a fuel in the lime kiln does provide the kraft mills with a simple and economical solution to a potentially serious problem of soap disposal. Pump failures and burner nozzle erosion have been experienced while burning CTO, due to its non–lubricating, corrosive nature and the high pressures required for atomization. The tall oil flame was found to be hotter and more luminous than that of natural gas, however no change in the kiln's energy efficiency was observed [18]. It has been estimated that soap removal is worth 50 t/d of additional pulp production [45]. The use of CTO as a supplementary fuel for the kiln leads to savings of less than 10% [18].

Most kraft mills collect malodorous non–condensible gases from multiple–effect evaporators and digesters in order to comply with atmospheric emission regulations of reduced sulphur gases [25,26,45]. These gases are usually disposed of in lime kilns, power boilers or dedicated incinerators [71]. The lime kiln satisfies the required temperature of 750°C at 0.54 sec retention time for thermal oxidation of these sulphur gases to produce carbon dioxide and sulphur dioxide [28]. If these gases are burnt in the lime kiln, sulphur dioxide reacts with the lime, hence burning the non–condensible gases in the lime kiln does not increase the amount of sulphur gases being emitted from lime kiln by any measurable amount [28]. The sulphate and sulphite ions formed are carried into the

white liquor cycle in the causticizing plant and reduced to active sulphide in the recovery boiler [28]. Reduced sulphur compounds (TRS) present in the non–condensible gas streams will oxidize in a lime kiln to form sulphur dioxide, which can then react with the dust (calcium oxide from reburned lime) to form calcium sulphate [66]. Calcium sulphate melts and becomes sticky at a temperature of 1450°C [66]. Rings starting just downstream of the flame tip were found in lime kilns where NCG were burnt with no scrubbing to remove TRS & hydrogen sulphide [66,67]. Ring formation in the kiln was not a problem after scrubbing was initiated to remove TRS [66].

The recoverable quantities of turpentine from digester condensates in softwood mills vary from 0.5 to 10 kg per tonne of pulp [45]. Variation in yield is due to wood species, season, wood storage and the procedures and equipment used for the relief and condensation of the volatile vapors [28]. Crude sulphate turpentine is an amber colored liquid with a flash point of about 35°C and has toxic vapors [28]. Cost savings from using turpentine as a supplementary fuel are offset by the potential revenue from its sale as a solvent or as an intermediate and precursor to the chemical and rubber industries. Mills with turpentine collection facilities often use its fuel value in determining a base sale price and fire turpentine in the kiln when sale prices are low [45].

The overheads from a steam stripper consist mostly of methanol and TRS compounds, mixed 50:50 with water vapor. The use of stripper overheads is not economically attractive because of the cost of installation of a rectification column to upgrade the fuel for use. This would reduce the amount of water vapor fed to the kiln, but the reduction in fossil fuel requirements is negligible [45].

Pulverized coal is mixed with fuel oil and water in a patented process to form a homogeneous mixture, which is stable for months at temperatures below 55°C. For burning and proper atomization, this fuel must be heated to 99°C. The slurry produced an easily controlled flame in the lime kiln. The flame pattern was found not to be affected by the air flow but by the type of burner used. During an eleven day trial, no changes were noticed in the cooking, evaporation, or recovery areas as a result of burning this mixture [24]. There was no mention of ash problems or the loss of available lime due to sulphur dioxide.

Chapter 2

Effects of Inerts on the Recovery Cycle

Because the Kraft process recycles the cooking chemicals (Fig. 1), the efficiency and operation of a unit process inherently affects that of the next and so on. Thus the introduction of a fuel taken out of one part of the cycle, and carrying with it certain inherent impurities, into another part of the cycle could have an impact on the whole process. The recovery process of most kraft mills is becoming increasingly closed which means that the tendency for inerts to build up in the process has also increased. Reasons for the closure are tighter pollution laws (due to public pressure) and rising chemical costs. The effects of inert material and non–process elements in the liquor cycle include reduced production in capacity limited process units e.g. the recovery furnace and the formation of scales and deposits in the evaporators [58]. The use of lignin as a fuel in the lime kiln represents the closing of a kraft mill for required external energy, however this could lead to problems in other processes.

Effects of Inerts on the Alkali Cycle

The tendency of the various elements to accumulate in an alkali cycle decrease in the following order: K, Cl, Al, Fe, Si, Mn, Mg, and Ca [60]. This trend is also reflected in the accumulation factors given in Table 2. Mg, Ca, Mn, and Fe do not build–up with increasing closure, since they form insoluble compounds in the green and white liquor cycle [59]. These compounds are removed from the cycle by the green liquor clarifier or the slakers.

Table 2. Accumulation of undesirable compounds in the alkali cycle[60]

Element	Accumulation† Factor
Potassium	11.6
Chloride	3.7
Aluminum	1.2
Iron	0.6
Silicon	0.5
Manganese	0.3
Magnesium	0.1
Calcium	0.02

† Accumulation factor = conc. in white liquor (kg/ADt of pulp) divided by the total amount introduced to the chemical recovery system (kg/ADt of pulp).

Effects of Inerts on the Lime Cycle and Lime Quality

The accumulation of non–process elements in the lime cycle decreases in the following order: Mg, Al, Fe, Mn, P, S, Cl [60]. Accumulation factors for the lime cycle are given in Table 3. From this list the most undesirable elements are silicon, magnesium, iron and aluminum. Increasing the silicon concentration in the lime mud may reduce the reactivity of the lime because the silicon compounds melt on the surface of the lime pellets, decreasing porosity [60]. The maximum acceptable concentration of silica in lime is considered to be 4% [60]. Separation of white liquor from lime mud is hampered by the presence of magnesium and iron. Magnesium hydroxide is gelatinuous and plugs the wire mesh on the drum filter. The maximum acceptable content of MgO in lime is 2% [60].

Table 3. Accumulation of undesirable compounds in the lime cycle[60]

Element	Accumulation† Factor
Magnesium	7.5
Aluminum	6.0
Iron	5.4
Manganese	2.3
Silicon	0.6
Sodium	0.4
Potassium	0.2
Sulphur	0.1
Chloride	0.04

† Accumulation factor = conc. in the lime mud fed to calciner (kg/ADt of pulp) divided by the total amount introduced to the chemical recovery system (kg/ADt of pulp).

High concentrations of sodium and potassium cause slabbing and ring formation in the lime kiln due to their adhesive effect [60,67,68]. Low alkali content in the lime mud causes poor pelletizing and increases dusting in the lime kiln. The concentrations of water soluble alkali compounds in the lime mud should be between 0.2 to 0.7% (as Na_2O) [60].

K, Cl, Al, and Si form soluble species in the liquor system [59], that have no distinct discharge point from the recovery system and tend to accumulate in the alkali cycle [60]. Ca, Mg, P, and Mn are transferred from the alkali cycle to the lime cycle and accumulate there [60]. In well designed and operated green and white liquor clarification operations, Ca, Mg, and heavy metals will be substantially reduced by removing the dregs and grits or by lime losses [58,60]. Magnesium enters the lime cycle with makeup lime and smelt from the alkali cycle.

The major drawback with a high impurity level is the required increase of fuel needed for the lime kiln to produce a given amount of calcium oxide [57], as shown in Figure 3 (energy losses shown are typical of older kilns). Impurities in the lime cycle are capable of negating the saving resulting from high purity lime makeup by

wasting heat in the kiln, and impair equipment capacity [57]. The reason for this is that at kiln temperatures above 1200°C, uncombined acid oxides (from the fuel or in the lime mud) are absorbed by CaO to form various complex calcium compounds, such as monocalcium and dicalcium silicates, calcium aluminates, dicalcium ferrite. This produces a slagging effect that tends to cover the pores in the lime and suppress its reactivity [55].

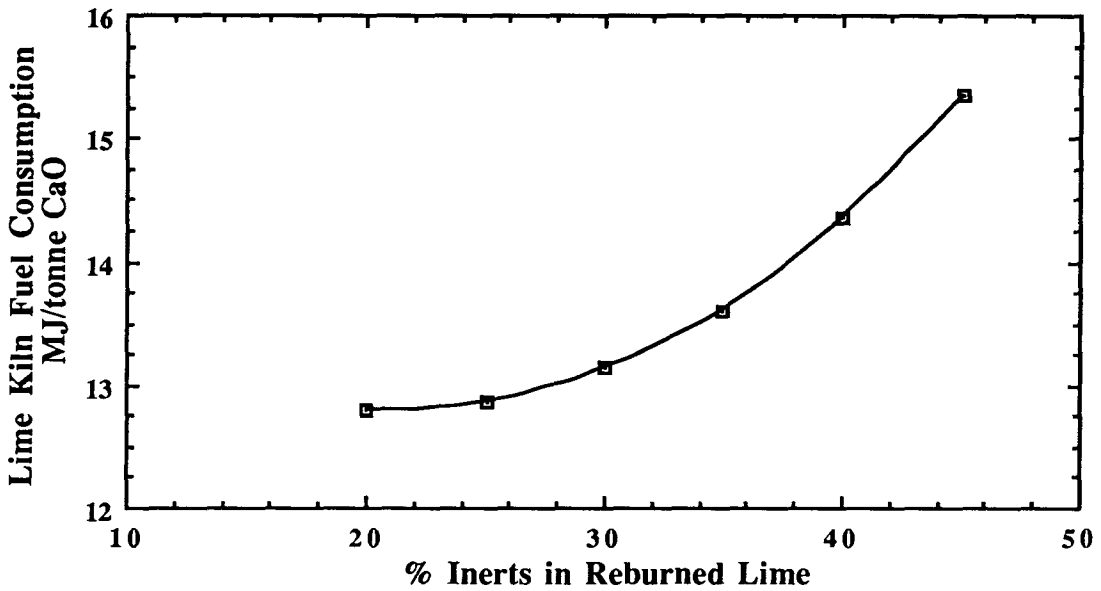


Figure 3. Impact of impurities on fuel consumption in the lime kiln[57]

Dregs and their Effect on the Lime Cycle

It is generally believed in the pulp and paper industry that dregs have a detrimental effect on liquor, lime mud and calcined lime quality. The concentration of dregs in green liquor does not effect the chemical quality of the white liquor (causticizing efficiency, sulphidity and activity) [62]. However, the rate of settling in the green liquor clarifier is increased with dregs concentration which is favourable, but calcium losses are increased at the green liquor clarifier with the dregs [62,63] since the presence of dregs increases the surface tension and water holding ability of the lime mud [62]. High dregs carryover causes highly insoluble sodium in the mud which results in

non–uniform nodule formation and decreased reactivity of the lime [49]. An excess of dregs in the lime cycle can double the sodium loading to the kiln [62].

The Inert Compounds in Lignin

The primary components of concern left in lignin after washing are sodium and sulphur. If the total sodium concentration is above 0.7% (as Na_2O) in the lime mud, then ring and ball formation is possible [60]. Another possibility is for the sodium to react with the sulphur present in the fuel to form sodium sulphate. If reduced sulphur compounds are burnt in the presence of excess oxygen, sulphur dioxide will be formed and will react with the reburned lime to form sulphate. Sulphur that is found in lime and lime mud is present as sulphates of calcium, magnesium and sodium [64]. During the causticizing process most of the calcium sulphate is converted to soluble sodium sulphate, only to leave the lime cycle with the white liquor [64]. If either component sodium or sulphur in any form leave in the dust it will be captured in the chain section by the wet lime mud or by the flue gas scrubber only to be returned to the kiln with the lime mud.

In separate bench–scale simulations of the lime cycle, coal and hog fuel ashes of 3.2 wt% and 1.5 wt% respectively were added to the lime cycle and were compared against an ash–free control series [61]. After six simulated cycles, the following effects were found: 1) buildup of inert material in the lime cycle (greater than the amount of ash added); 2) this inert material increased the settled bulk of the lime mud; 3) reduced the efficiency of separating lime mud solids from white liquor; 4) increased the sodium content of the recycled lime mud; 5) silica and alumina from ash combined with CaO to form calcium aluminosilicates and calcium silicate (at temperatures over 1050°C); 6) iron from the ash remained in the lime cycle. Somewhat similar results should be expected at a larger scale if quantities of ash from a lignin fuel are sufficiently high. It is noteworthy that these findings are somewhat at odds with (or contradict) those of [24].

Chapter 3

Scope of the Work

The objective of the present work was to examine the combustion of dried lignin powder, as obtained from carbon dioxide and sulphuric acid precipitation, as a potential fossil fuel replacement for the rotary lime kiln. To accomplish this, the two types of recovered lignin were co–fired with natural gas at high levels of gas replacement, specifically 60%, 75% and 100%, in order to determine the impact on kiln operation of changing from a natural gas fuel to lignin. The experiments were performed in a well–instrumented, pilot–scale kiln which allowed axial temperature, calcination and heat transfer profiles to be determined. A burner and feed system for dry powdered lignin was developed specifically for this application. The quality of the lime products were determined, with particular attention being paid to the impurities added by the lignin fuel. Temperature data obtained from the kiln made it possible to determine changes in the axial heat transfer profiles of the gas, bed and shell between the two different types of fuels, natural gas and dry powdered lignin.

Chapter 4

The Experimental Program

Description of Pilot Plant Kiln

The experimental work was carried out using the pilot kiln shown in Figure 4, which is located in the Department of Metals and Materials Engineering at UBC. A simplified equipment layout of the pilot plant kiln is shown in Figure 5. The kiln has an inside diameter of 0.4 metres and an overall length of 5.5 metres. The kiln is lined with castable refractory and equipped with 70 thermocouples for temperature measurement. Copper slip rings near the cold end of the kiln provide power for a vacuum pump and data acquisition unit on the kiln, as well as a

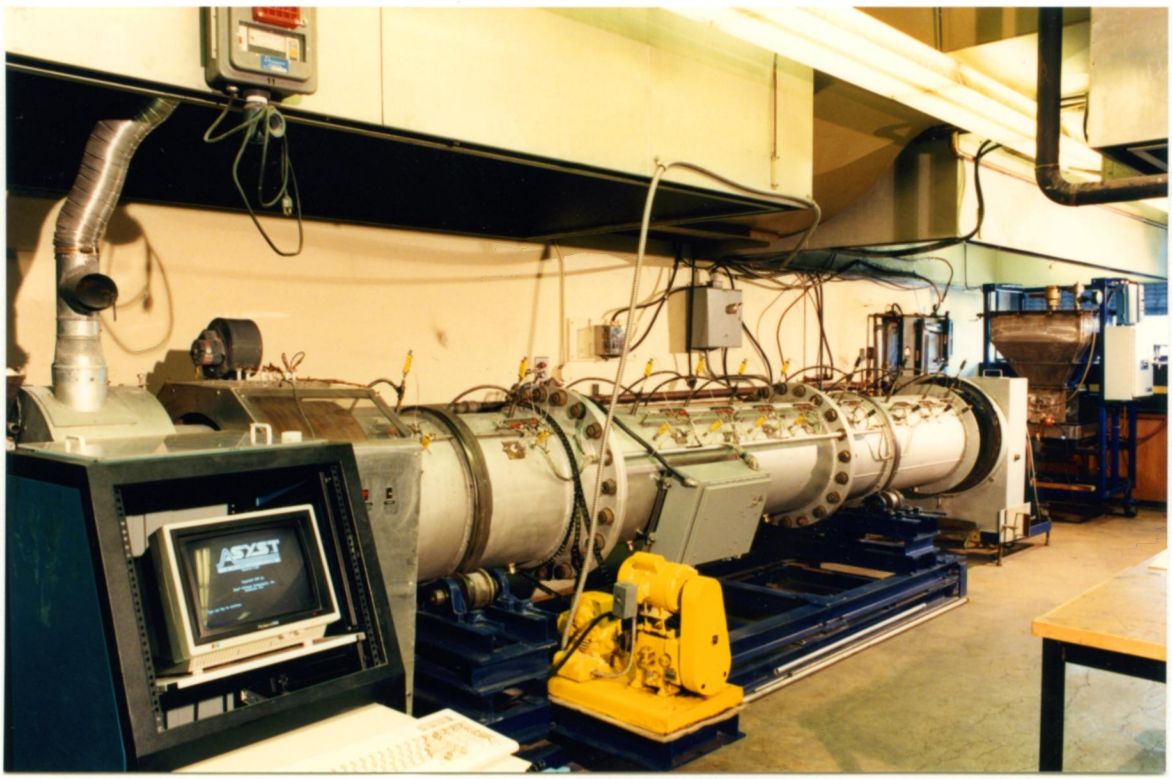


Figure 4. Overall view of the pilot plant kiln

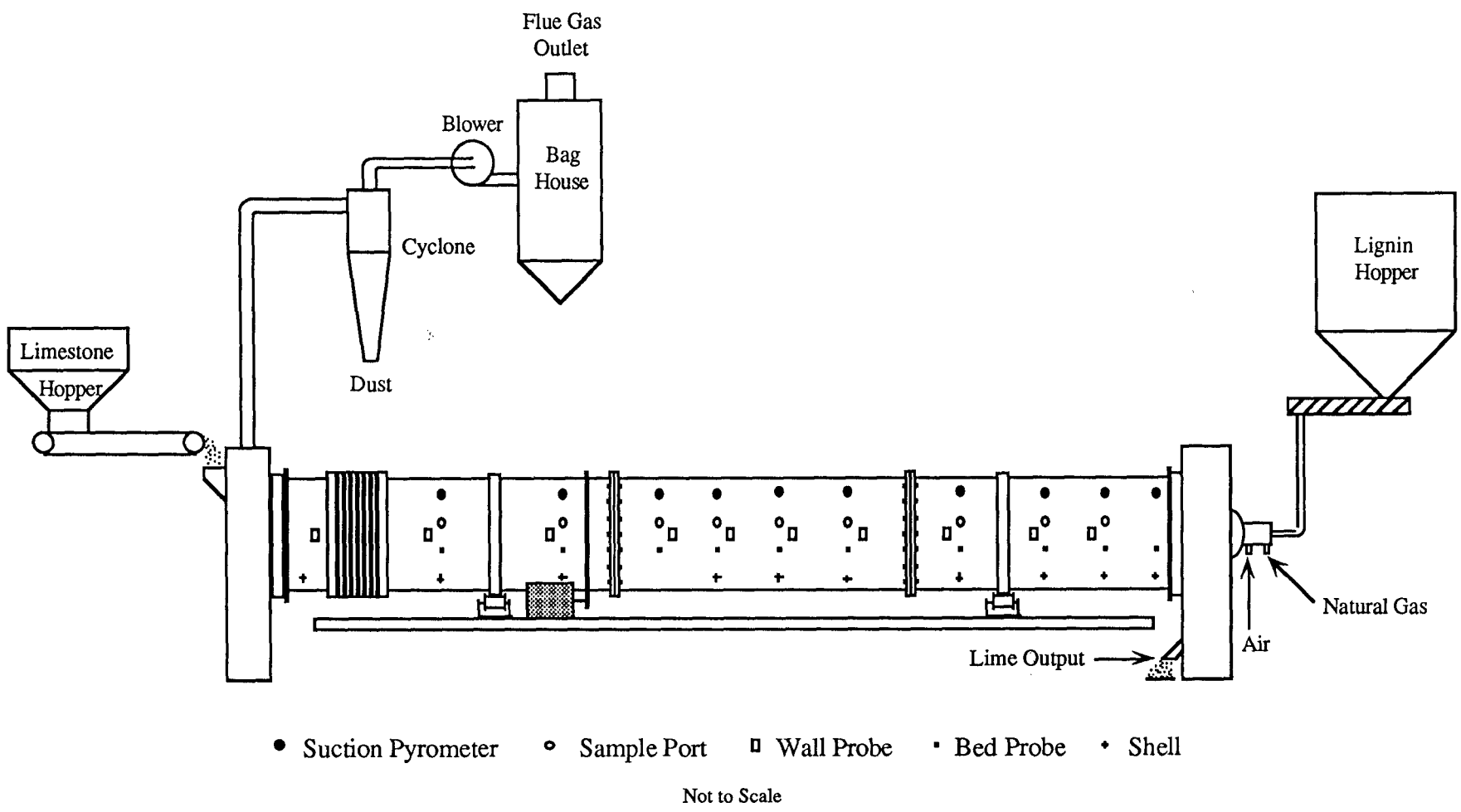


Figure 5. A simplified diagram of the pilot plant kiln

communication link for a remote computer. The facility has been used for industrial trials, the development of burners systems as well as for the verification of mathematical models and for the development of heat transfer correlations [51–54]. The wide distribution of thermocouples and sample ports allows investigations into the effects of changing fuels, on axial heat transfer, temperature and solids sample profiles. Before the experimental work on this project began, the kiln was upgraded with a new refractory lining and all new thermocouple wires. The thermocouples are connected to a data acquisition unit, which is linked to an on–line computer to facilitate the monitoring and data storage of the temperature readings. The data acquisition unit is permanently fixed to the kiln's shell and is protected from radiative heat–transfer. Since the data acquisition unit had a maximum of 61 connections, the first wall probe (described later and by [54]) at the hot end and five randomly selected shell thermocouples were not connected. The program for the data acquisition unit was written by Mr. A. Shook, a graduate student in the Department of Metals and Materials Engineering. Wall probes provide temperatures at the inside wall surface and radially through the refractory lining. Access ports permit sampling of the solids bed along the kiln length while the unit is in operation. The kiln is rotated by an electrical motor connected to a variable speed gearbox and chain drive.

The pilot kiln is normally fired with natural gas through a modified North American Model NA 223G–3 burner mounted at the solids exit end. The rotary unit is sealed and has an air distribution system to provide an even air flow across the kiln's cross–section. For the present work, the burner was further modified by installation of a central lance through which the powdered lignin was conveyed by air. Lignin was fed from a hopper by means of a screw feeder. With this arrangement, lignin could be burned by itself, or in combination with natural gas.

Details of the inlet combustion air and burner arrangement are shown in Figure 6. A water–cooled lance, to feed the lignin, is installed in the center of the natural gas burner. Natural gas is fed through an annulus surrounding the lance while primary air is supplied by eight symmetrically placed nozzles concentric with the natural gas inlet and lignin burner. Secondary air is supplied by eight equally spaced nozzles around a 300 mm diameter circle concentric with the natural gas inlet and lignin burner but outside the burner tile. The secondary air

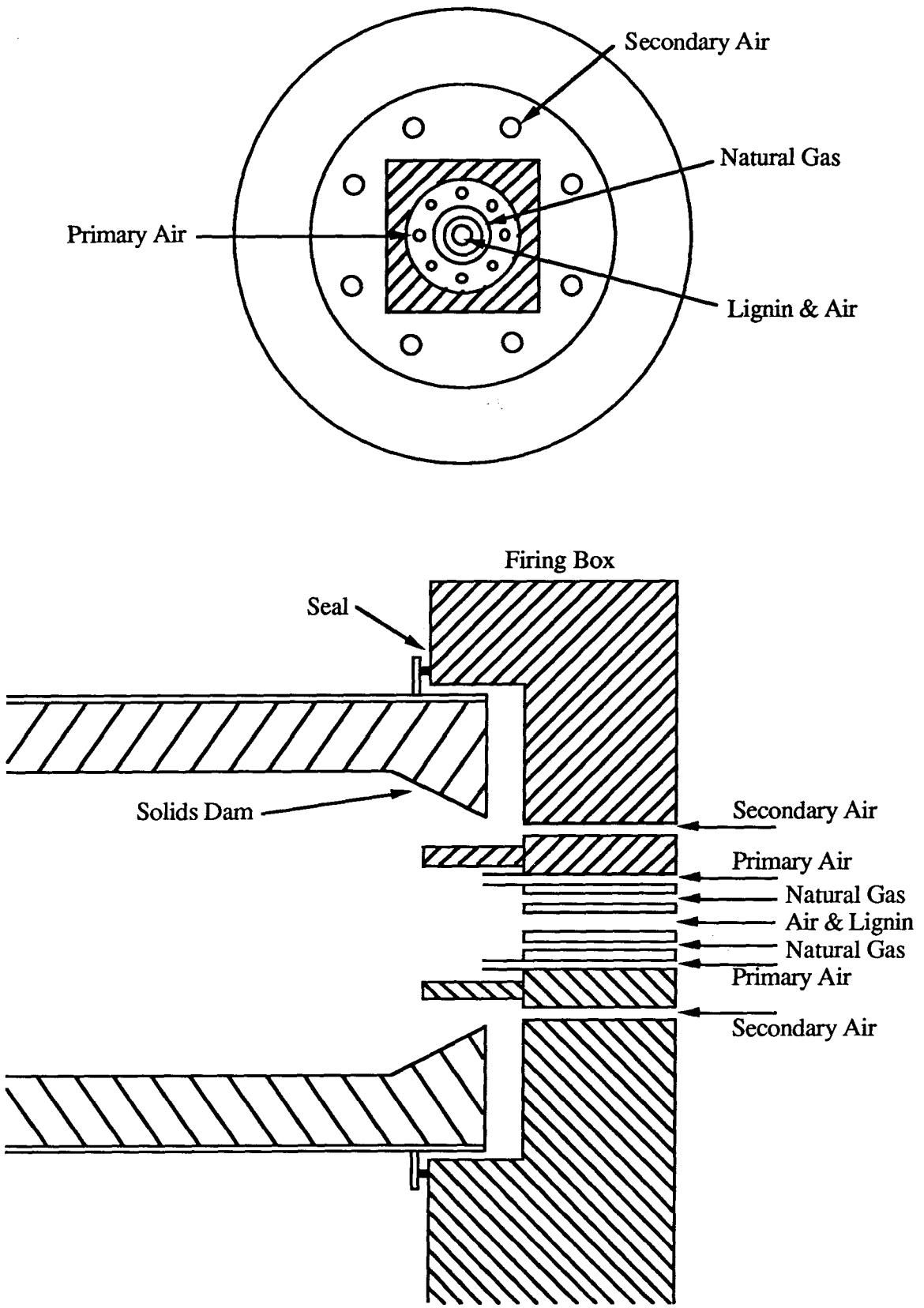


Figure 6. Details of inlet air and burner arrangement

nozzles were originally installed to prevent recirculation within the kiln, but since the seals and discharge chute have been improved, this was never found to be a problem. Therefore, the total air flow required through the secondary air nozzles was never greater than 142 L/min (5 CFM) for all runs. Combustion air flow (primary & secondary), at room temperature, is monitored by a calibrated ASTM standard orifice plate. Primary combustion air bled from the combustion air line is monitored by a rotameter (model #BR–1.5–35G10 with flow tube #R–12M–25–5S). The lignin feed system has a separate air supply delivered by a blower and monitored by a rotameter (model #ED–9–100–1 with flow tube #FP–1–35–G–10/35). The flow of natural gas is monitored by a rotameter (model #BR–1/2–35G10 with flow tube #R–8M–25–4).

Limestone and Lignin Feed Systems

Room temperature limestone (described later) stored in an overhead hopper is fed to the cold end of the kiln by a variable speed belt conveyor and dropped into a discharge chute (Fig. 7). A dam at the back end of the kiln is employed to prevent spill–back of the limestone, while a dam at the solids discharge point is installed to promote a uniform bed depth over the length of the kiln (Fig. 8).

The dry powdered lignin feed system consists of a pressurized hopper with a screw discharge system mounted on a electronic scale, as shown in Figure 9. When in operation, the rate of weight loss is continuously monitored by a load cell and compared to the set point value entered by the operator. If these two values do not match, adjustments are made by the control box to the motor or shaft of the screw. The approximate time for this adjustment is 90 seconds (weight loss calculation to necessary speed adjustment). As noted previously, the lignin feed system has its own air supply and control system separate from that of the kiln. At the discharge point from the screw, lignin falls by gravity into a fitting on the carrier air line. From this point the powdered lignin is conveyed through tubing to the lance located in the center of the natural gas burner on the kiln.

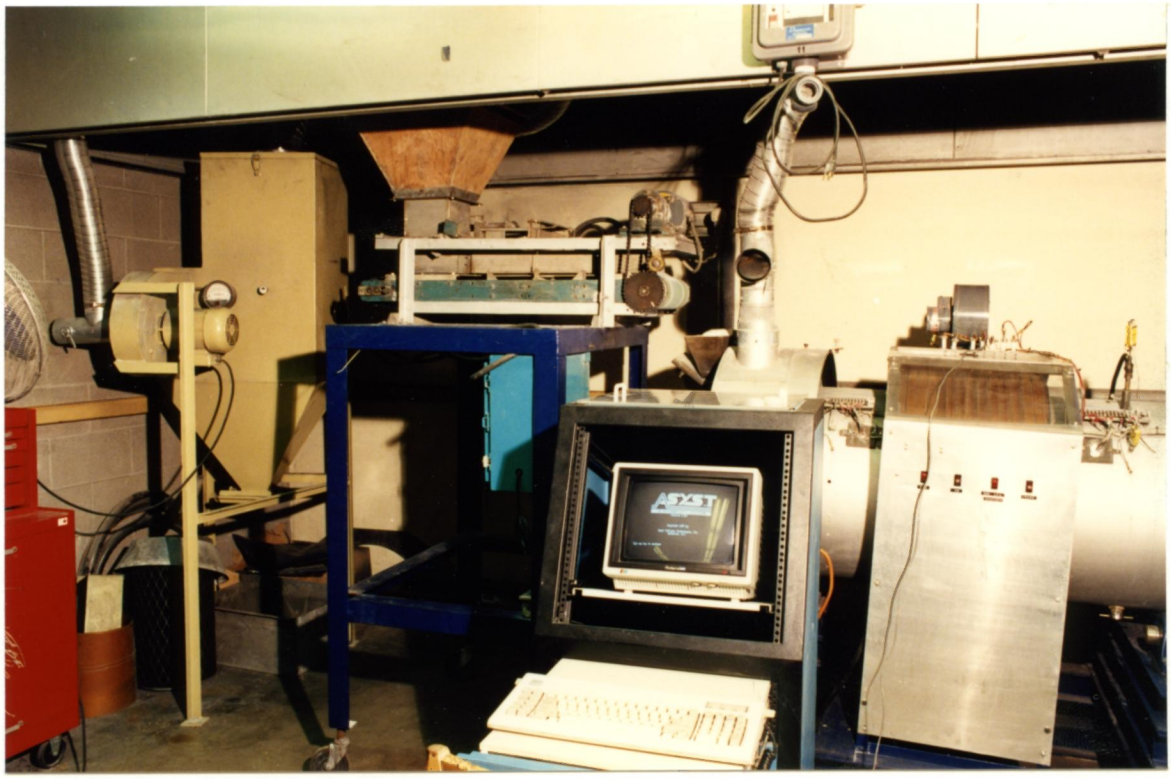


Figure 7. Picture of equipment at feed end of kiln

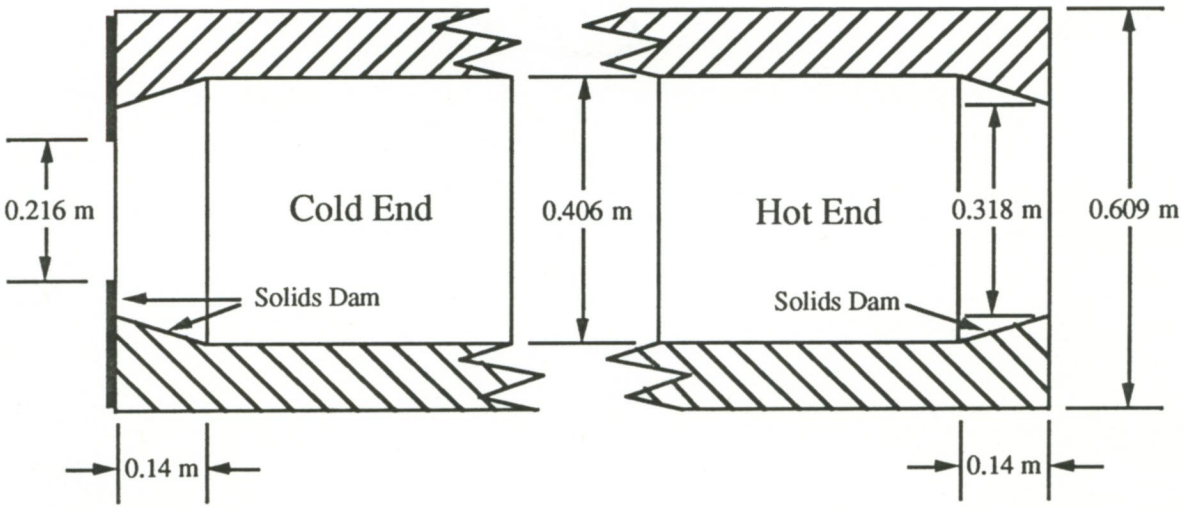


Figure 8. Diagram of dams at hot and cold end of the kiln

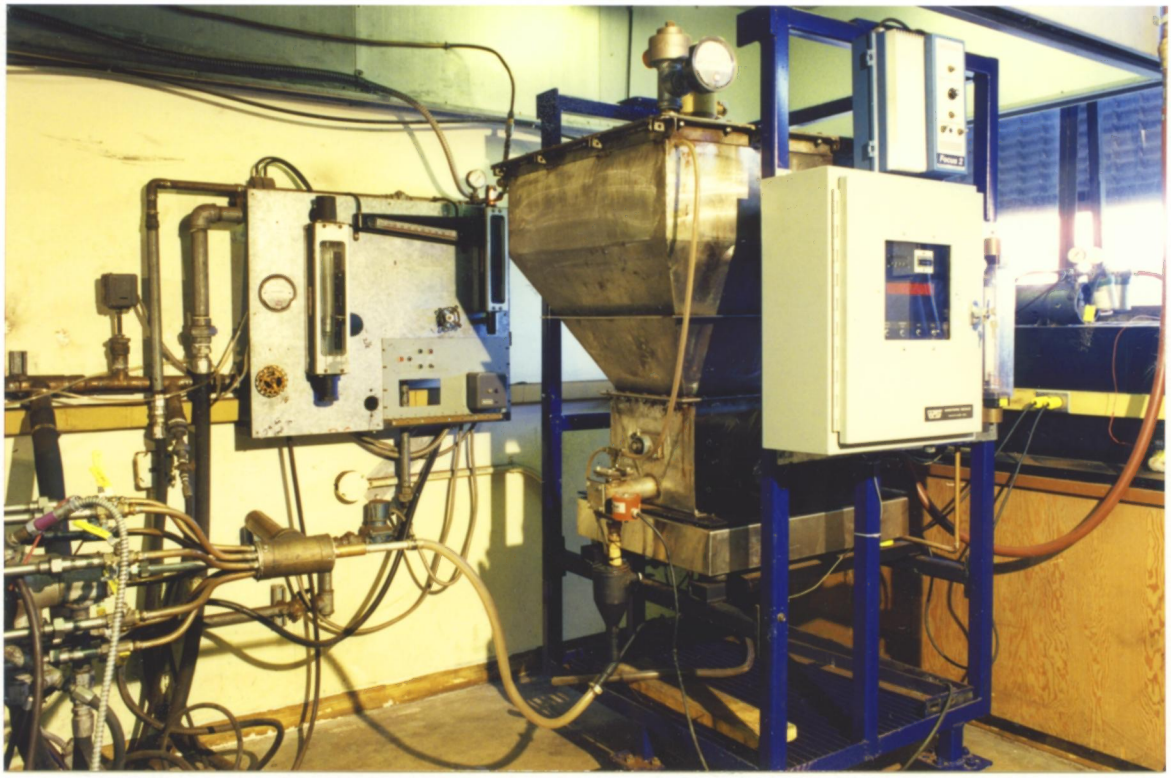


Figure 9. Picture of equipment at burner end of kiln

Temperature Sensors

Gas temperatures were obtained by shielded suction thermocouples located at ten fixed axial positions along the kiln, as shown in Figure 10. The first four thermocouples located at the hot end of the kiln, are type S (10% Pt, Pt–Rh) and six thermocouples are type K (chromel–alumel). These thermocouples are designed to slide radially, thus allowing temperature measurements at various radial as well as axial positions. Each thermocouple is connected by stainless steel tubing with a shut off valve to a single cold trap (crushed ice) before the vacuum pump. Vacuum is provided by a small diaphragm vacuum pump fixed to the kiln's shell and power is supplied via a system of slip rings. The thermocouples are radiatively shielded from the kiln bed and wall surfaces by ceramic inserts, except those located at 2.2 m and 4.0 m from the hot end, which were shielded by stainless steel tubing to eliminate gas infiltration. These two special thermocouples were used for obtaining gas samples from

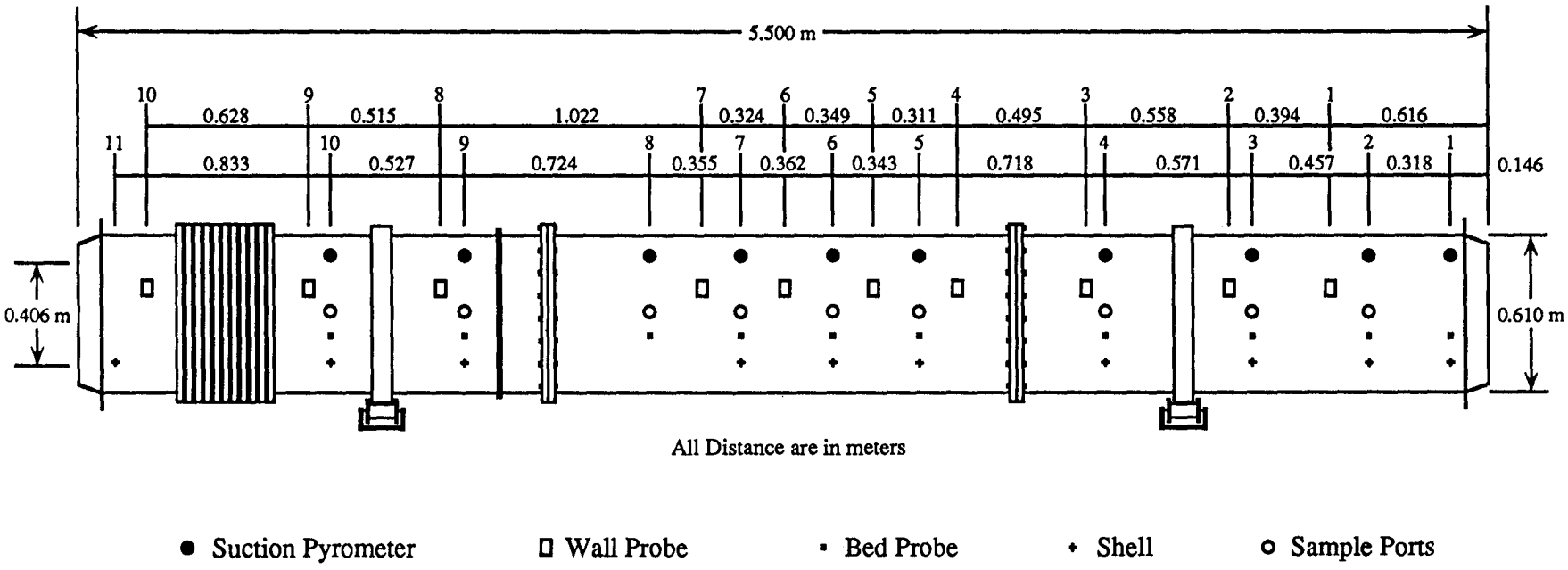


Figure 10. Axial thermocouple layout of the pilot plant kiln

the kiln for gas analysis. In the experimental runs, the gas temperature readings were generally measured 10 cm off the kiln centerline, except at 2.2 and 4.0 m from the hot end, which were on the kiln centerline. This inconsistency was necessary due to interference of the radial path by other objects associated with the kiln. Each gas temperature was recorded for two kiln revolutions, a total of ten data points being obtained during each revolution. The arithmetic average of the twenty temperatures obtained at each axial location was used in generating the plots of axial gas temperature.

Bed temperatures were obtained using ten bare tipped thermocouples located at several axial positions along the kiln, as shown in Figure 10, again with allowance for radial movement. The thermocouples were adjusted such that the tips were just under the top of the solids bed (Fig. 11). The four thermocouples nearest to the hot end of the kiln are type S formed from 31 gauge wire (0.33 mm) and the next six are type K formed from 22 gauge wire (0.7 mm). For each thermocouple, double bore alumina sheathing was used to encase the bare wire portion and support the junction. Swagelok fittings on the kiln shell held these thermocouples in place through predrilled holes in the refractory (Fig. 11). As in the case of the gas measurements twenty measurements were logged for each thermocouple, which again represented two revolutions. From these data, the lowest value was assumed to be the bulk bed temperature at each axial location. Although these do not represent the true bed temperatures, ten measurements per revolution were too few to accurately describe the complicated curve. It was therefore not possible to find the true bed temperature by the lumped capacity response equation as suggested by previous research [54]. However, the axial gradient of the bed temperature which is of primary importance in calculating heat transfer to the bed, will be only slightly affected by the inaccuracy.

Refractory temperatures of the inside wall surface (transient) as well as at various radial distances (steady–state) were obtained from ten wall probes (Figures 11 & 12) located at fixed axial positions along the kiln, as shown in Figure 10. The wall probes were cast in wedge shapes from the same refractory material as that used in the kiln, using a silicon rubber mold. The kiln wall had matched opens which held the probes in place. They were covered with a steel plate cap which had screw tabs to hold them firmly in position. With the aid of a jig, bare–tipped thermocouples are set accurately at depths of 0, 1.0, 2.88 and 4.76 cm in the wall probes, to provide

thermocouples at radius of 0.2030, 0.2130, 0.2318 and 0.2506 m in the kiln (Fig. 12). Starting at the hot end of the kiln, the first three wall probes have type S thermocouples formed from 31 gauge wire (0.33 mm) and the next seven have type K formed from 22 gauge wire (0.7 mm).

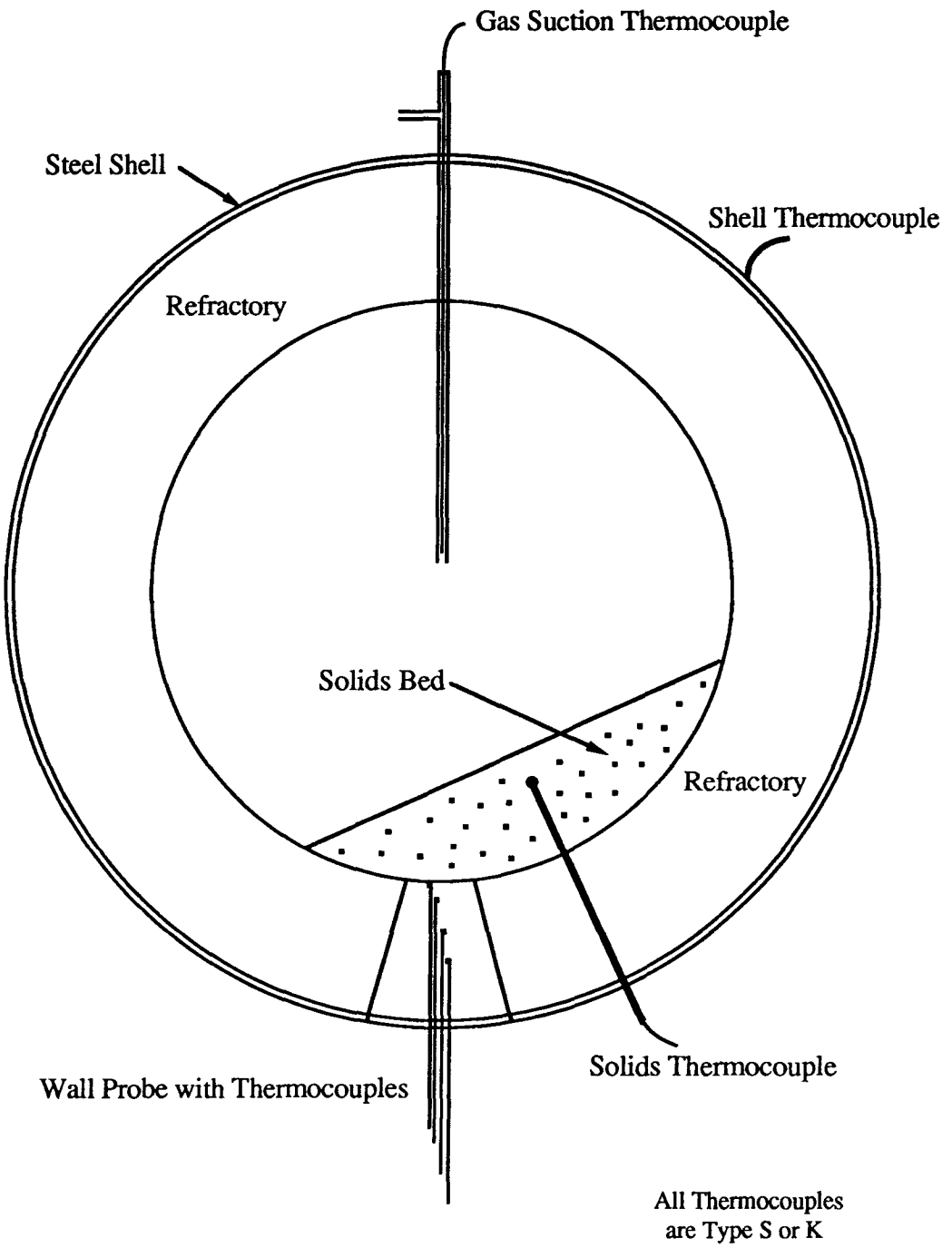


Figure 11. Cross–section of kiln for thermocouple layout

The shell temperatures of the kiln were measured by ten bare–tipped type K thermocouples formed from 22 gauge wire (0.7 mm) set in short pieces of brass tubing located at fixed axial positions, as shown in Figure 10. One end of the tubing was flattened which was attached to the surface of the shell with a bolt.

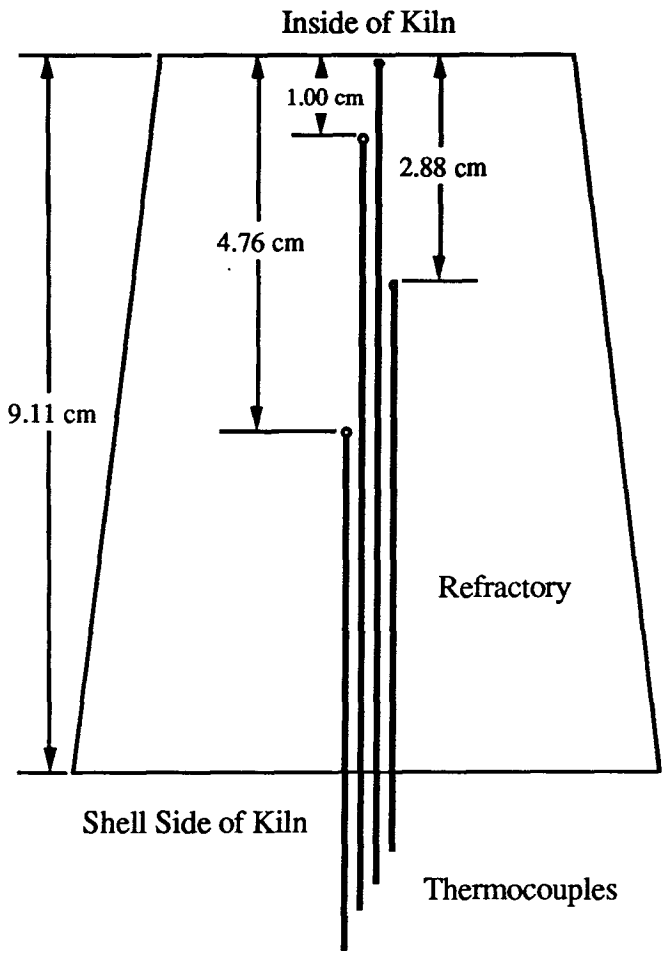


Figure 12. Detail of thermocouples in wall probe

Sampling of Flue Gas and Analysis

The composition of the flue gas was measured using an on–line, Perkin–Elmer 8400 series gas chromatograph equipped with a thermal conductivity detector for nitrogen, oxygen and carbon dioxide. Flue gases

were separated on a 2.4 m x 31.7 mm column packed with 80/100 mesh molecular sieves and a 1.5 m x 31.7 mm Parapack Q column at an oven temperature of 105°C. The instrument was calibrated for oxygen and nitrogen using air. The concentration of carbon dioxide in the flue gas was found by difference. Flue gas samples were taken from the two suction thermocouples described previously (at 2.2 and 4.0 metres) and pumped to the gas chromatograph from the discharge port of the vacuum pump on the kiln. The oxygen content of the gas was used to calculate the percentage excess air. This procedure permitted correction for the small amount of leakage air which entered the kiln through seals, solids discharge and burner. The infiltration of air was promoted by the fan which drew the flue gas from the end of the kiln through a cyclone (dust collection), and a bag house before the gas was discharged. The fan on the bag house was used to drive gas through the cyclone. Dust which was not collected in the cyclone was discharged along with the gas to the atmosphere.

Preparation of the Lignins[§]

Three kraft lignins used for the experimental trials were supplied by: the Irving Pulp and Paper Company in New Brunswick, Canada; the Westvaco Company in South Carolina, USA; and Canfor's Intercontinental Pulp Mill in Prince George, British Columbia, Canada. For convenience the lignins have been renamed as 'IR', 'WV' and 'PG' respectively. Paprican has some staff at a small research station near the Intercontinental Pulp Mill, who produced the PG lignin and further washed the IR lignin.

The Irving Pulp and Paper Company furnish is mostly spruce. Their kraft lignin was produced at the mill from strong black liquor using pure carbon dioxide for acidulation at 690 kPag and 75°C in a 'side–stream reactor' using both a pipeline reactor for sidestream acidulation and a pressurized main reactor for retention time. The lignin was recovered on a 200 mesh belt filter with some water washing to reduce the sodium and ash content prior

[§] Details of lignin preparation for both IR and PG were obtained from personal communication with V. Uloth on Sept. 26, 1989.

to acid washing. Further washing with a dilute sulphuric acid solution was required to lower the sodium and ash content.

The lignin IR was shipped to Prince George for acid washing with the following (approximate) composition: 46% moisture, 14–15% sodium, 2% sulphur and 34–36% ash, all on dry weight. A summary of the washing conditions for this lignin is listed in Table 4. For the first wash, each barrel (170 L) of lignin was added slowly to ≈600 L of 2.0 to 2.5 Normal sulphuric acid for a period of 0.5 to 1 hour. The pH was then checked and the suspension was diluted to ≈900 L with hot water. The final pH was between 1.1 and 1.7. After mixing and heating for about 1 hour, the mixer was shut off and the lignin allowed to settle overnight (i.e. for 16–22 hours). After overnight settling, wash liquor was pumped off the top leaving 225 to 250 L of sludge in the reactor. For the second wash each batch was diluted about 3 to 1 with hot wash water and with 7 to 11 L of concentrated sulphuric acid. The final pH was between 0.8 and 1.5. After about 1 hour of mixing, the mixer was shut off and the lignin again was allowed to settle overnight (i.e. for 16–22 hours). After overnight settling, wash liquor was pumped off the top leaving 255 to 295 L of settled sludge in the reactor. The sludge was mixed and pumped into barrels for shipping, and during the next 2–4 weeks the clear top layer was decanted from the barrels.

Table 4. Washing conditions for lignin IR

	Final pH		Temperature, °C	
Batch	1st wash	2nd wash	1st wash	2nd wash
1	1.2	0.8	41	43
2	1.2	1.5	37	22
3	1.3	1.2	43	43
4	1.1	1.2	43	46
5	1.7	1.1	41	37

The Westvaco Company is a commercial supplier of lignins. The purchased lignin used was Indulin AT, which is a carbon dioxide precipitated and acid washed lignin. This lignin required no treatment prior to combustion.

The Prince George kraft lignin was precipitated in 10 batches using 3 samples of oxidized black liquor (≈50% solids) from Canfor's Intercontinental Pulp Mill. The mill's furnish is approximately 45% Lodgepole pine, 50% spruce and 5% Douglas fir. In each batch, a 530 to 570 L sample of oxidized black liquor was acidulated with pure sulphuric acid at a concentration between 9.2 and 10.0 Normal to precipitate the kraft lignin. Liquor temperature was controlled between 75 and 80°C during the acidulation. Mixing was accomplished with a double blade turbine impeller operating at 120 rpm. Acidulation to a final pH between 7.5 and 8.5 was completed in 90–105 minutes. In 5 of the 10 batches, after mixing for 30 minutes the stirrer was shut off and the precipitated lignin was allowed to settle overnight (i.e. for 17–21 hours). The next day the clear supernatant was pumped from the reactor. In four batches, the precipitated lignin was recovered by passing the acidulated liquor through a coarse screen box (≈15 mesh). When screened, the recovered lignin volume was about 340–400 L versus 455 L by settling. In three of the batches the first wash was performed the same day as the acidulation, with the next two washes on the following day. A summary of the washing condition for this lignin is listed in Table 5. The supernatant liquid from the first wash was pumped off leaving 410 to 540 L of lignin sludge in the reactor. For the first wash approximately 95 L of 1.0 Normal sulphuric acid solution used for acidulation was then added slowly to the reactor with mixing. Hot water was added to the reactor to give a final total volume of 950 L with the mixture having a pH <3. After mixing for 45 to 60 minutes, the stirrer was turned off and the lignin was allowed to settle. After 5 to 6 hours settling time, the supernatant liquid was pumped off, leaving 450 to 550 L of settled lignin sludge. Hot water and 7–11 L of 9.5 N sulphuric acid solution used for the second wash was added to the reactor to give a final total volume of 950 L with the mixture having a pH <3. After mixing for one hour, the stirrer was turned off and the lignin was allowed to settle overnight (i.e. for 15–17 hours). The supernatant liquid was pumped off, leaving 430 to 510 L of settled lignin sludge. Hot water and 7–11 L of 9.5 N sulphuric acid solution were added to the reactor to give a final total volume of 950 L with the mixture having a pH <3 for the third wash. After mixing for one hour, the stirrer was turned off and the lignin was allowed to settle overnight (i.e. for 22–23

hours). The following day, wash liquor was pumped off the settled lignin, leaving 450 to 500 L of sludge. The mixed sludge was transferred to barrels for shipping. Dilution water was used to remove the remaining amounts of lignin sludge in each barrel and after one day of settling this liquor was decanted off.

Table 5. Washing conditions for lignin PG

	Acidulation	Final pH			Temperature, °C		
Batch	Final pH	1st wash	2nd wash	3rd wash	1st wash	2nd wash	3rd wash
1	8.4	3.4	2.4	2.6	57	54	50
2	8.5	This Batch was not washed.					
3	8.2	4.5	1.5	1.8	54	45	50
4	8.2	3.5	3.2	3.4	47	23	48
5	7.6	3.6	2.5	1.8	53	48	20
6	8.1	3.2	1.8	2.2	63	49	53
7	8.2	3.4	2.1	2.5	54	50	52
8	8.2	3.6	2.6	2.9	63	54	54
9	8.2	2.7	2.4	2.5	60	49	50
10	7.5	2.7	3.1	3.2	65	58	46

Further processing of the lignins IR and PG was required, since their moisture content was too high to be handled by the present feed system. Both the kraft lignins IR and PG were dried by Modern Control Services Ltd. of Surrey, B.C. using a pulse combustor. This pulse combustion dryer involves the use of a valveless pulse jet burner for water removal by applying temperature, pressure and vibration to the wet material in a conveyed air stream through a time controlled processing zone. Materials in this zone are subjected to rapidly alternating high and low pressure conditions, high temperature and high intensity acoustical vibration. Under these conditions, a rapid separation of water from the processing material is claimed. Dried material is separated from the gas by aid of a cyclone [75]. Lignin IR was dried to 6–9% moisture and lignin PG was dried to less than 1%.

Determination of Particle Size of Lignins

Particle size distributions of lignin suspensions were analyzed on an Elzone 80XY Particle Analyzer. This is a Coulter–Counter type of instrument. The electrolyte solution to disperse the lignin was made up using filtered (0.45 μm pore size) distilled water, 0.5% tetrasodium pyrophosphate, 0.75% sodium chloride and a few drops of formaldehyde. This solution was filtered (0.45 μm), and the pH adjusted to 5 using dilute hydrochloric acid. The particle size count distribution for each lignin is shown in Figure 13. The mean particle size of the lignins PG, IR and WV are 8.63, 11.96 and 26.05 μm respectively. Of the three lignins, WV has the broadest range of sizes and PG the narrowest. Figures 14–16 are three electron microscope pictures of lignin particles IR, WV and PG respectively, taken at a magnification of 200 times. The procedure for preparation of the samples has slightly skewed the size distribution towards the smaller particles. However the particle size shown in these pictures follows those found by the Elzone Particle Analyzer.

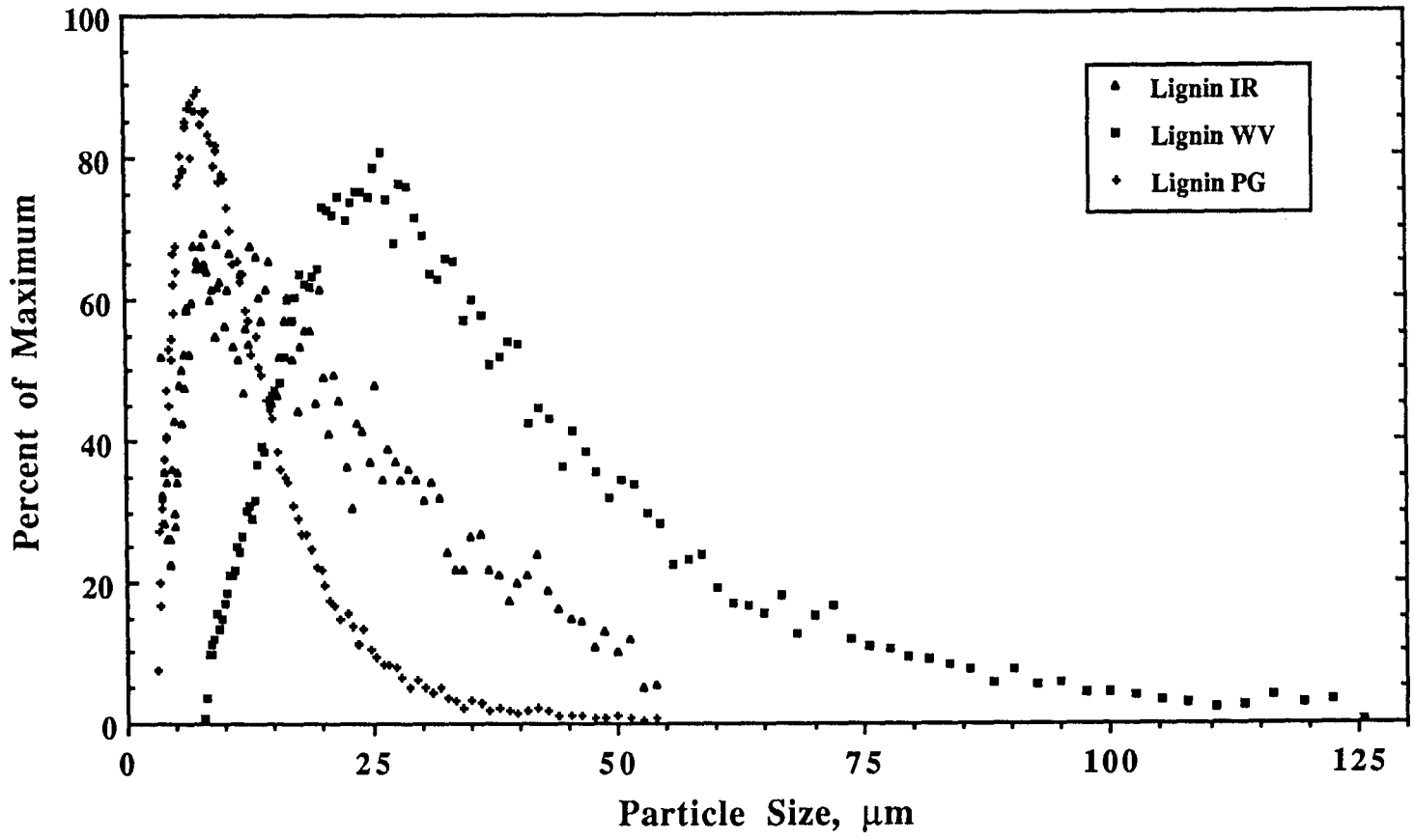


Figure 13. Particle size distribution of the three types of lignin

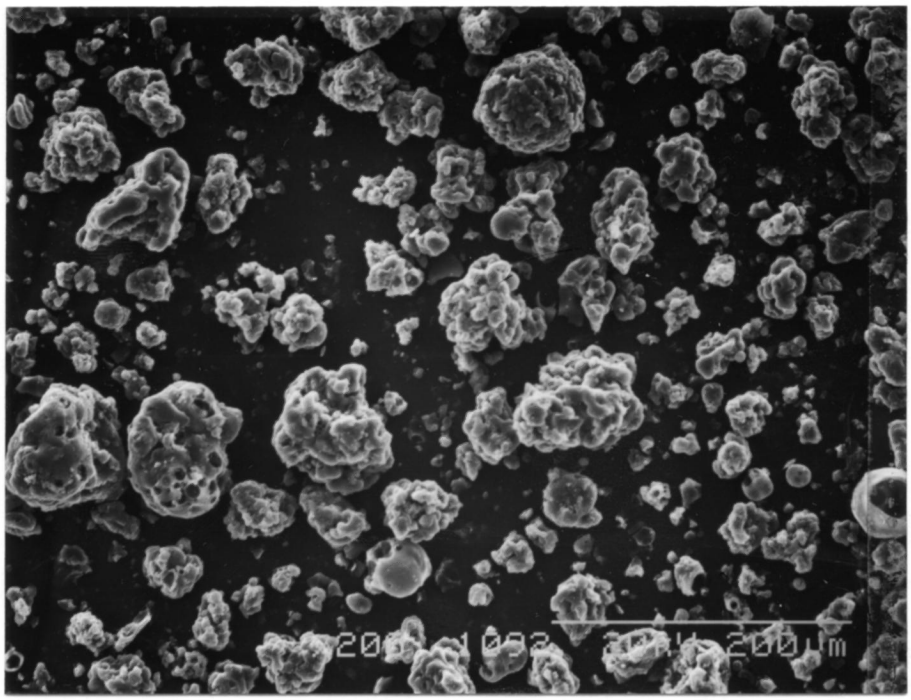


Figure 14. Picture of lignin IR at 200x

Figure 15. Picture of lignin WV at 200x

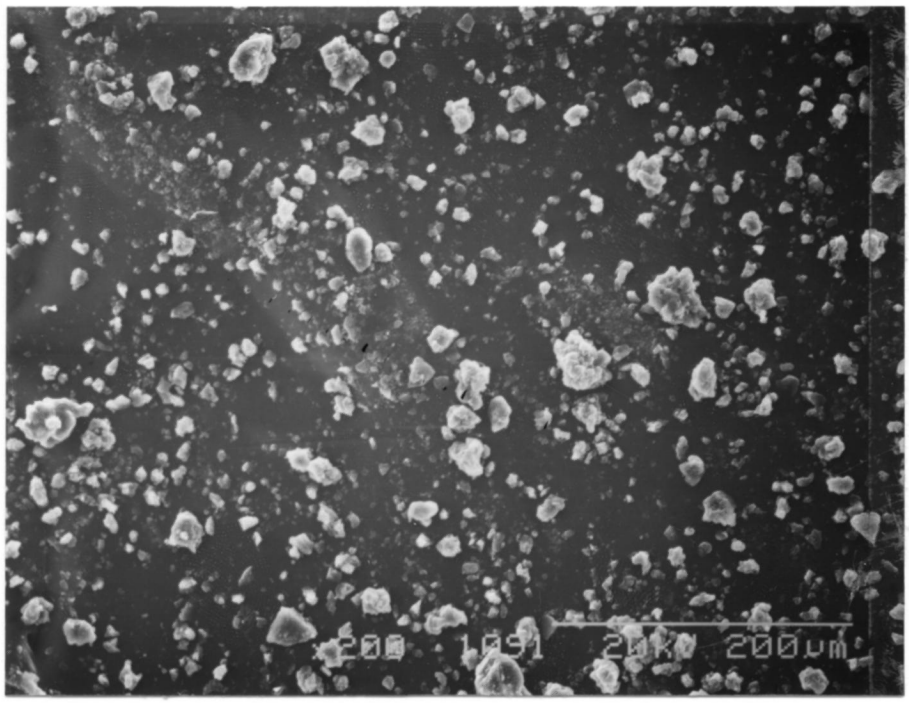


Figure 16. Picture of lignin PG at 200x

Chemical Analysis and Particle Size of Limestone

The limestone used for the trails was obtained from Texada Lime of Langley, B.C.. The particle size ranged from 1.4 to 4.8 mm, with an average mass mean diameter of 2.56 mm (Table 6). Analysis of the limestone, which is reported in Table 7, shows it to be about 98% calcium carbonate.

Table 6. Screening results of limestone

	Sample 1		Sample 2		Sample 3	
Size, mm	Mass, g	Percent	Mass, g	Percent	Mass, g	Percent
-6.30 +5.60	2.05	0.57	1.5	0.88	0.5	0.13
-5.60 +2.83	76.7	21.22	34.9	20.52	43.1	11.08
-2.83 +2.00	165.3	45.73	80.6	47.38	218.3	56.10
-2.00 +1.41	96.8	26.78	45.1	26.51	115.0	29.56
Pan	20.6	5.70	8.0	4.70	12.2	3.13
$\bar{d}_p$, mm =	2.56		2.56		2.37	

Table 7. Chemical analysis of the limestone

Limestone (wt %) $CaCO_3$ (by LOI) = 97.95 %

Sample	Ca	wt% Si	Inerts	Na	Fe	mg/kg Al	Mg	Mn
1	38.0	1.35	3.65	347	970	1070	3500	80.5
2	38.3	1.10	3.15	355	560	890	2890	44.8
3	38.8	0.59	1.95	145	400	530	1800	45.9
Average	38.4	1.01	2.92	282	643	830	2730	57.1

Determination of Percent Calcination

During each kiln trial approximately 0.3 kg of bed material was withdrawn from each sample port (which showed evidence of calcination) along the kiln. In addition samples of the feed limestone and product lime were also collected. After collection, the samples were allowed to cool and then placed in sealed containers. In order to determine the extent of calcination approximately 15–20 g of each sample was weighed out into a crucible and placed in a muffle furnace at 1000°C for a 24 hour period. The next day, the samples were removed, allowed to cool and were reweighed. Analyses of feed limestone was performed in the same manner and the percent calcination was determined by the loss on ignition (LOI) of the samples [50]. The percent calcination was then determined according to the formula:

$$\% \text{ Calcination} = 100 * (1 - \text{LOI product} / \text{LOI feed})$$

Determination of Slaking Behaviour and Surface Area of the Lime Products

The reactivity of lime is an important parameter and one which depends upon processing conditions. Overheating of the lime (dead–burning) closes the pore structure and results in low reactivity. Contamination with fusible ash or other products from the kiln freeboard also reduces pore area and reactivity. Slaking behavior of

product lime samples were determined at the Pointe Claire Laboratories of Paprican as described in [69]. Samples weighing 44 g were slaked in 750 ml of simulated green liquor at a starting temperature of 90°C. The temperature rise of the suspension was recorded with time.

The surface area of the product lime was determined on a Micromeritics FlowSorb II 2300. The instrument was calibrated assuming room conditions of 22°C and 760 mmHg. Samples were dried overnight in an oven at 130°C and, after weighing into sample tubes, were further dried under nitrogen at 120°C. Approximately 1 to 2 g were used for the analysis. All dark coloured particles were assumed to be inert material and were excluded. Nitrogen from a gas stream of 30% nitrogen in helium flowing through the sample tube was adsorbed in the pores of the sample and this change in gas composition was measured by a thermal conductivity cell. Liquid nitrogen was used as an external coolant. The average of absorption and desorption of nitrogen gas was used for the calculation of surface area.

Experimental Procedure

The procedure employed for the kiln trials was standardized to ensure consistency. Each test consisted of two complete parts, one using natural gas which was used first to provide a reference, which was following by a second trial using all or a portion of lignin as a fuel. To begin each test the kiln was preheated overnight. Early the following morning the natural gas, air and limestone flowrates, as well as the rotational speed, were set to their respective operating points. Typically about three hours was then required for the kiln to reach steady–state, which was defined by the condition where successive bed temperatures measured 15 to 20 minutes apart differed by less than five degrees Celsius and the discharge rate of lime was constant. The lime discharge weight was measured over a period of time, which was typically 15 to 30 minutes. Once steady–state operation was verified all kiln temperatures were then logged and solid samples were collected along the kiln. The axial bed samples starting at the hot end were collected in large ceramic crucibles from the sample ports after completion of the temperature

logging. The lime product samples were collected from the discharge tray, usually after the measurement of the discharge. Once cool, samples were placed in sealed containers.

After collection of the data for natural gas firing, the lignin flow was started and the natural gas flow was reduced or stopped entirely. The total energy input to the kiln was held at the same level as for the natural gas trial just completed. Once the change in firing conditions was accomplished the kiln was again allowed to obtain a steady–state. The kiln was not stopped during any of the experiments, unless it was absolutely necessary (e.g. due to vacuum pump failure). After the kiln was shut down, a sample of lignin was removed from the feed hopper and all the dust was collected from bottom of the cyclone. The following day when the kiln was cooler, bed depth measurements were taken for some of the kiln trials. The average bed depth was found to be 6.0, 6.3, 5.4, 5.1, 4.8, 4.8 cm at 0.30 m intervals from the discharge end of the kiln.

The belt feeder used for the limestone was calibrated (Appendix B) at the start of the project and was generally checked again before each test. In addition, the belt feeder set point was also checked periodically during each kiln test.

Chapter 5

Experimental Problems

Considerable difficulty was encountered in obtaining a reliable feed system for delivering a powdered lignin fuel to the kiln. Although all the systems designed utilized a pressurized screw feed hopper (Western Scale Co.) in conjunction with a lance type injection using compressed air as a carrier medium.

The first lance designed, employed a straight 1.9 cm stainless steel tube, worked well during the initial trial in the kiln with no bed and at low operating temperatures. Several trials were conducted under these conditions adjusting the air flows (transport, primary and secondary) to develop the feed system. At low kiln temperatures this simple lance preformed adequately for short periods of time. However, at higher kiln temperatures problems with flame deflection were experienced due to lignin accretions inside the tube. This usually led to a total flame out within a short period. Lignin at temperatures between 80–150°C softens and becomes very sticky [33,34]. Upon further heating it chars to a rigid black mass of carbon. Therefore transport air and exit point temperature are critical factors in determining if a particular lignin will have accretion problems during feeding. Although the lance could be positioned within the burner tile, whether placement was within the burner tile or 2–8 cm beyond, the final result was still accretion growth and clogging.

Plugging of the lance by char resulted in problems upstream in the feed hopper, where a packed cake of lignin usually formed at the end of the screw (due to back pressure). Even small levels of pressure exerted on lignin produced a cake sufficient to clog the feed system, which then had to be dismantled for cleaning. The relatively low bulk density of dry lignin powder (about 0.5 g/ml) also presented problems for the screw feeder. Because the electronic scale could not detect the small weight loss over a short period of time the controller would make only minor adjustments to the feedrate. These minor increases in lignin feedrate would have required considerable amounts of time to reach operating feed conditions. This problem in acquiring the correct feedrate was overcome

by entering a higher set point than that required, monitoring the feedrate and resetting the feedrate to the required rate when it was within a reasonable value.

One objective of the work was to determine the influence of lignin firing on heat transfer to an inert bed relative to natural gas firing. Early efforts to investigate this aspect used coarse Ottawa sand (-2.38 +1.41 mm). No problems occurred during the experiment when natural gas was being fired, however when 60% of the fuel (based on heating value) was replaced with dry powdered lignin, the coarse sand began to agglomerate into large balls at the hot end of the kiln. By observation from the cold end of the kiln, the sand formed balls only in the last metre before discharge or almost directly under the lignin flame. The sand was possibly affected by some inert compound in the lignin or by the change in the amount of heat it was receiving. Sand that was discharged from the hot end of the kiln had changed color from an opaque pink to being almost translucent. The change in colour was probably due to a loss of a chemical element from the surface. Agglomeration of the coarse sand into large balls could have been cause by the formation of low melting point eutectics involving sodium, silica and calcium. However, analyses of the sand using X–ray diffraction showed no sodium on the surface of the samples. Samples of the sand before and after lignin burning were sent for analysis to Acme Analytical Laboratories Ltd. which used the method of Induction Coupled Plasma to find changes in trace elements on the sands' surface. Those elements which had a difference between the two samples or have an effect on the surface properties are reported in Table 8. It can be seen that although sodium increased slightly (by 0.01 wt%) most of the other elements were found to be lower in concentration on the surface after the lignin firing. The decrease in the element Cu is probably why the sand changed colour.

Table 8. Results of chemical analysis on sand

Sand			wt%					mg/kg	
Sample	Na	Ca	Fe	Al	Mg	Cu	Pb	Zn	Mn
without	0.01	0.06	0.01	0.03	0.01	37	8	14	2
with	0.02	0.02	0.01	0.01	0.01	7	3	1	2

Other difficulties with the lignin feeder included the screw feed system. The first screw employed on the lignin feeder was found to have a pitch and diameter too large for the lightest of lignin and was therefore unable to produce the low feedrates that were required (Fig. 17). This also caused an unsteady flow of lignin from the feed hopper to the burner and may have contributed to the plugging in the lance. A new screw, with a smaller pitch and diameter, and a modified hopper bottom were obtained and were found to produce a more even feedrate of lignin (compare Figures 18 & 19). However some pulsing of the lignin flame was still evident. With this new screw the required feedrates could be obtained.

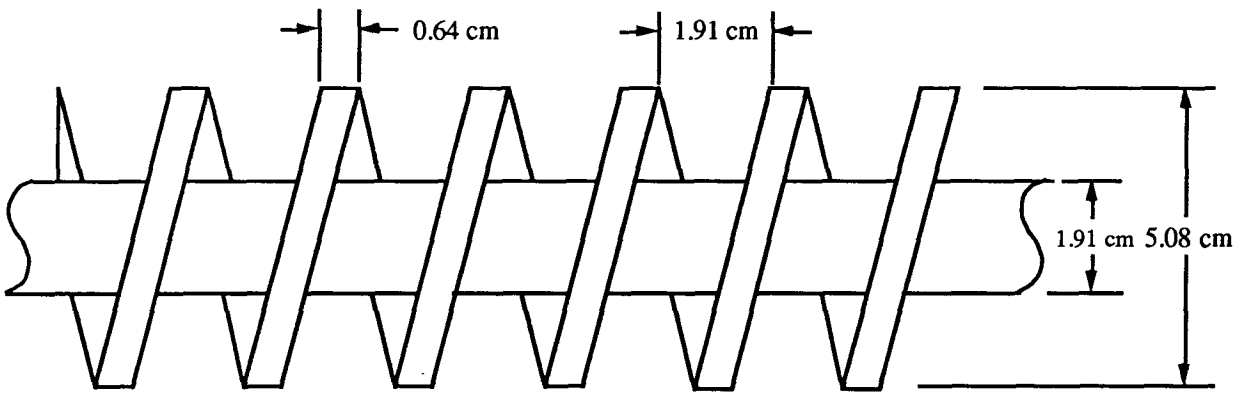


Figure 17. Diagram of first screw in lignin feed hopper

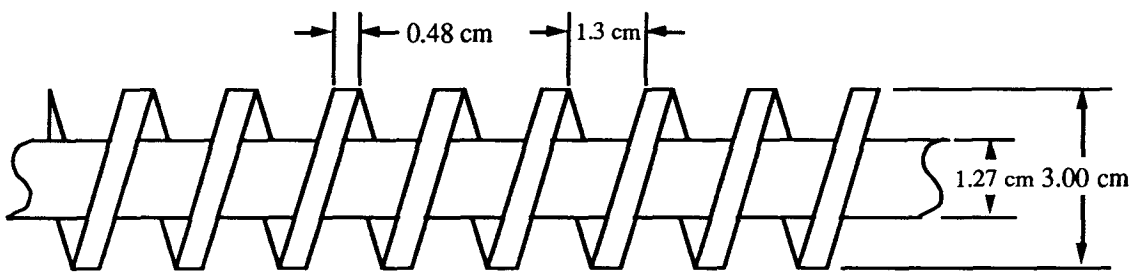


Figure 18. Diagram of second screw in lignin feed hopper

In an attempt to alleviate the clogging problem, a 5 cm ceramic tube filled with insulating material was added to the tip of the lance (Fig. 19). Although the intention of this modification was to reduce radiative heat–transfer

from the flame to the lance, the reduction achieved was not sufficient to eliminate softening of the lignin and subsequent clogging of the lance. After one unsuccessful trial with this configuration design was commenced on a water cooled lance.

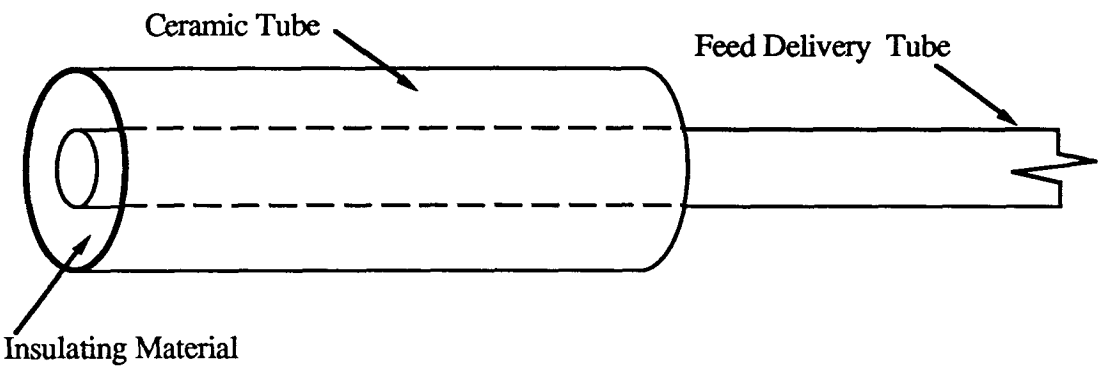


Figure 19. Diagram of second burner design

The final configuration for the lignin lance, which was described in Chapter 4, is shown in Figure 20. The lignin tube is surrounded by two coaxial coolant tubes. Flow of coolant is through the inner annulus from right to left in the figure, and then reverses through the outer annulus, flowing left to right. The diameter of the lignin tube is 1.6 cm, while the coolant tubes are 2.2 cm and 3.2 cm respectively. This water–cooled burner lance which was adopted is a source of heat removal, and the water flowrate was not always the same from one run to the next. A water flow controller was ordered but it did not arrive until after all the experiments were completed. The burner was found to operate successfully at the following conditions; transport air velocity of ≈27 m/s @ 20°C, a lignin feedrate of 240 g/min or less and a burner tip temperature of less than 85°C.

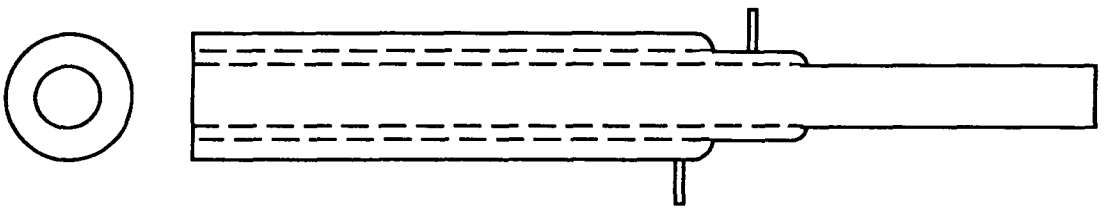


Figure 20. Diagram of the water–cooled lance

During the initial lignin burning trials, lignin of high sodium content (≈3 wt%) was used. At about this same time some very high temperature runs were carried out for an unrelated project. After completion of the latter work and the lignin trials the lining of the kiln was found to be badly degraded over the first 1.5 metres from the hot end. It was not clear whether the sodium from the lignin, or an overheating of the original refractory (Plicast LWI28) was the primary cause of the failure of the lining. The lining was physically removed and replaced with a denser and higher temperature castable refractory (Claycast 60ES). There was no further failure of the refractory lining. Physical specifications of these castable refractories are given in Appendix A.

One final problem encountered was with the burner tile. The initial lignin firing and those experiments conducted with lignin IR used a burner tile of nine inches in length. All others experiments were performed with a six inch long burner tile. The long burner tile had to be replaced due to general deterioration (formation of large cracks, resulting in breakage) but this was most likely routine wear and not related to the lignin firing.

Chapter 6

Results and Discussion

Quality of the Lignins

Analyses on a dry basis are given in Table 9 for each experimental run and type of lignin. As pointed out earlier, lignin is a highly oxygenated fuel which contains about 28% oxygen on a weight basis. For the test lignin, sulphur content was from 1.3 to 3.4 wt% which is mostly organically bound (>55%) can be expected to produce SO_2 and react with the lime. The organically bound sulphur in the lignin was assumed to be the difference between total sulphur and sulphate. Sodium content of the lignin varied from 0.25 to 2.0 wt%. A sodium limit of 0.9 to 1.4 wt% has been shown to be the maximum allowed for a lignin based fuel, at 100% replacement of the original fossil fuel [34], in order to maintain the sodium content (Na_2O) in the lime mud below 0.7% [60]. Ash levels of the lignins are between 1.1 and 4.8 wt%. Some adsorption of lignin ash onto the product may be expected. Although the ash level remaining in the lignin is a function of the precipitating agent used, the final pH and efficiency of the washing, in the present case the levels were not sufficiently high to create any problems in the operation of the kiln or have any detrimental effect to the final product. If necessary, the sulphur and sodium content in the lignin can be reduced by repeated water or dilute sulphuric acid washings [34]. However, there is a practical minimum value to which they can be reduced which is reported to be ≈1.5% sulphur and ≈0.6% sodium [76].

The final concentration of sodium and sulphur remaining in lignin PG as first received was considered too high for use as fuel in the pilot plant kiln. Early in the program it was observed that the kiln lining had deteriorated badly in the region of the flame. The lining was replaced, and although the real cause for the deterioration of the old lining was never established, possible further damage from high sodium and sulphur

Table 9. Chemical analysis of lignins

			wt %										mg/kg		
Run	Lignin	HHV†	C	H	O	N	S	SO_4	Sorg	Na	Fe	Ash‡	Al	Mg	Mn
LG9	IR	26.06	59.72	5.35	26.10	0.11	3.20	1.21	1.99	0.51	0.13	3.90	130	132	182
LG10A		24.42	59.69	5.29	26.17	0.09	3.23	1.31	1.92	0.50	0.15	3.99	130	121	172
LG10B		24.42	59.69	5.29	26.17	0.09	3.23	1.31	1.92	0.50	0.15	3.99	130	121	172
Average		24.97	59.70	5.31	26.15	0.10	3.22	1.28	1.94	0.50	0.14	3.96	130	125	175
LG12A	WV	25.08	61.11	5.58	26.56	1.69	1.60	0.66	0.94	1.08	0.01	3.94	320	106	61.0
LG12B		25.08	61.11	5.58	26.56	1.69	1.60	0.66	0.94	1.08	0.01	3.94	320	106	61.0
LG11		25.28	61.10	5.48	26.21	1.69	1.34	0.59	0.75	1.08	0.01	3.91	340	105	60.3
Average		25.15	61.11	5.55	26.44	1.69	1.51	0.64	0.88	1.08	0.01	3.93	327	106	60.8
LG17	PG	25.43	61.45	5.39	25.83	0.11	2.34	0.21	2.13	0.71	0.20	3.02	190	42.7	26.3
LG16		25.78	62.46	5.39	25.95	0.10	2.32	0.17	2.15	0.42	0.19	1.82	160	35.3	20.6
LG14		26.11	63.15	5.42	25.15	1.24	2.29	0.05	2.24	0.14	0.10	0.84	150	29.7	16.4
Average		25.77	62.35	5.40	25.64	0.48	2.32	0.14	2.18	0.42	0.16	1.89	167	35.9	21.1

† measured Higher Heating Value, MJ/kg

‡ contains Na, Fe, SO_4

containing lignin was assumed to be too risky. Lignin PG was therefore further washed at room temperature using tap water, once in very dilute sulphuric acid (pH <4) and then in water. A small laboratory drum filter worked well for dewatering the lignin after its first washing and not so well after the water wash. After washing the lignin slurry was allowed to settle (two days) in barrels and the remaining liquid was decanted off. The wet lignin was removed from the barrels and air dried for three days on a sheet of plastic. The sodium and sulphur levels for this lignin are given in Table 9. After this procedure the moisture remaining was less than 1%.

Replacement of Natural Gas by Lignin

The run conditions used for the experiments are listed in Table 10. Target conditions for the experiments were; limestone feedrate 40 kg/h, rotational speed 1.5 rpm, and free oxygen 2% by volume in the flue gas (dry basis). The kiln slope was maintained at 1° (0.0174 m/m) for all the experiments. As pointed out earlier the plan for the trials was to compare firing with natural gas, lignin and gas–lignin combinations at a constant total energy input i.e. MJ(HHV)/kg $CaCO_3$ fed. Because of the nature of the solids feed systems, it was not always possible to obtain the desired lignin feedrates, and hence the specific energy varied among the trials. The outlet O_2 content in the flue gas varied from about 2% to 5% and was used to calculate the percent excess air. Better control of dry powdered lignin burning was gained as the experiments proceeded, which is also shown in Table 10, since the measured residual excess oxygen in the flue gas decreased to a more acceptable level as the experimental trials proceeded. The theoretical percent excess O_2 (dry basis) was calculated from the known quantities of inlet combustion air (lance, primary & secondary), natural gas, lignin and the composition of these fuels. This value was corrected for the additional carbon dioxide generated by the limestone, by taking into account the limestone feedrate and final calcination. The theoretical percent excess O_2 is also listed in Table 10.

During periods of lignin firing some pulsing of the flame occurred which was, at least in part, attributable to the conveying of lignin through an increase in elevation (Fig. 8). Solids which tended to adhere to the sides of the plastic conveying line, at the entrance to the burner lance, were periodically swept clear and this was a major

Table 10. Summary of kiln experiments

Run	Lignin	% Natural Gas Replaced	Fuel† Rate L/min	Lignin Rate kg/min	Energy Input MJ/min	Heat MJ/kg $CaCO_3$	$CaCO_3$ Rate†† kg/h	Flue* Gas O_2 %	Excess* Air %	Theor.* Excess O_2 %	Calcin'n Lime %
LG9◊	IR	60	62.3	0.145	5.84	8.92	39.3	5.1	30.6	4.7	98.6
LG10A‡		75	39.6	0.180	5.64	8.63	39.3	4.2	26.6	3.6	98.3
LG10B‡		100	0.0	0.241	5.56	9.27	36.0	4.0	24.5	3.2	97.7
LG12A	WV	60	62.3	0.131	5.61	9.53	35.3	1.9	9.9	1.6	99.2
LG12B		75	39.6	0.163	5.57	9.44	35.4	2.0	10.4	1.7	99.6
LG11		100	0.0	0.218	5.51	9.02	36.6	2.7	16.2	1.5	98.7
LG17	PG	60	62.3	0.132	5.68	8.12	42.0	2.2	12.6	-1.1	97.0
LG16		75	39.6	0.165	5.73	8.24	41.7	2.3	12.8	-0.2	95.6
LG14		100	0.0	0.220	5.74	9.23	37.3	2.8	15.6	-0.8	98.8
	Gas										
LG13	G1	0	152.9	0.000	5.70	10.3	33.2	2.0	10.2	-1.1	98.2
LG14G	G2	0	152.9	0.000	5.70	9.28	36.8	2.0	9.6	-0.5	97.8
LG15A	G3	0	152.9	0.000	5.70	8.47	40.4	2.1	10.8	-1.1	84.8
LG15B	G4	0	164.3	0.000	6.12	9.29	39.5	2.5	13.0	-0.6	98.1

HHV of gas = 37.3 MJ/m^3, average values IR = 25.0 MJ/kg, WV = 25.2 MJ/kg, PG = 25.8 MJ/kg

◊ 6.83% moisture ‡ 5.19% moisture † at 20°C †† calculated based on output of lime * see text

source of the flame instability. Although the pulsing of the lignin flame presented a problem in acquiring an accurate gas sample, comparison of the measured and theoretical excess oxygen in Table 10 suggests the presence of leakage air. There were unknown amounts of leakage air which entered the kiln through the seals, solids discharge and around the burner. Attempts to lower the excess air to approach stoichiometry resulted in an unstable flame due to incomplete combustion between pulses of flame. Under these conditions, residual ash was observed coming from the flame. The higher requirement of excess air was thought also to be a function of burner design.

Figures 21 and 22 provide a qualitative indication of the radiative emissivity for the nearly invisible natural gas flame and for the luminous lignin flame. These pictures were taken at very low firing rates and with the firing box separated from the pilot plant kiln.

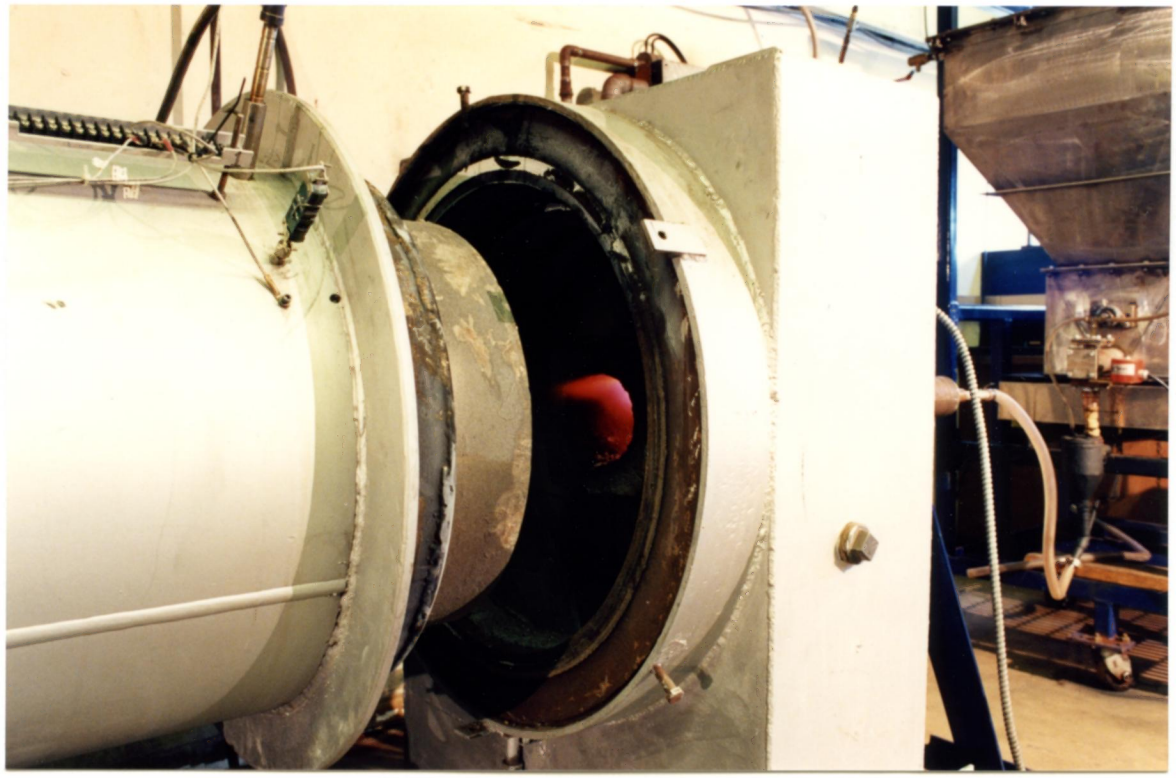


Figure 21. Picture of a typical gas flame

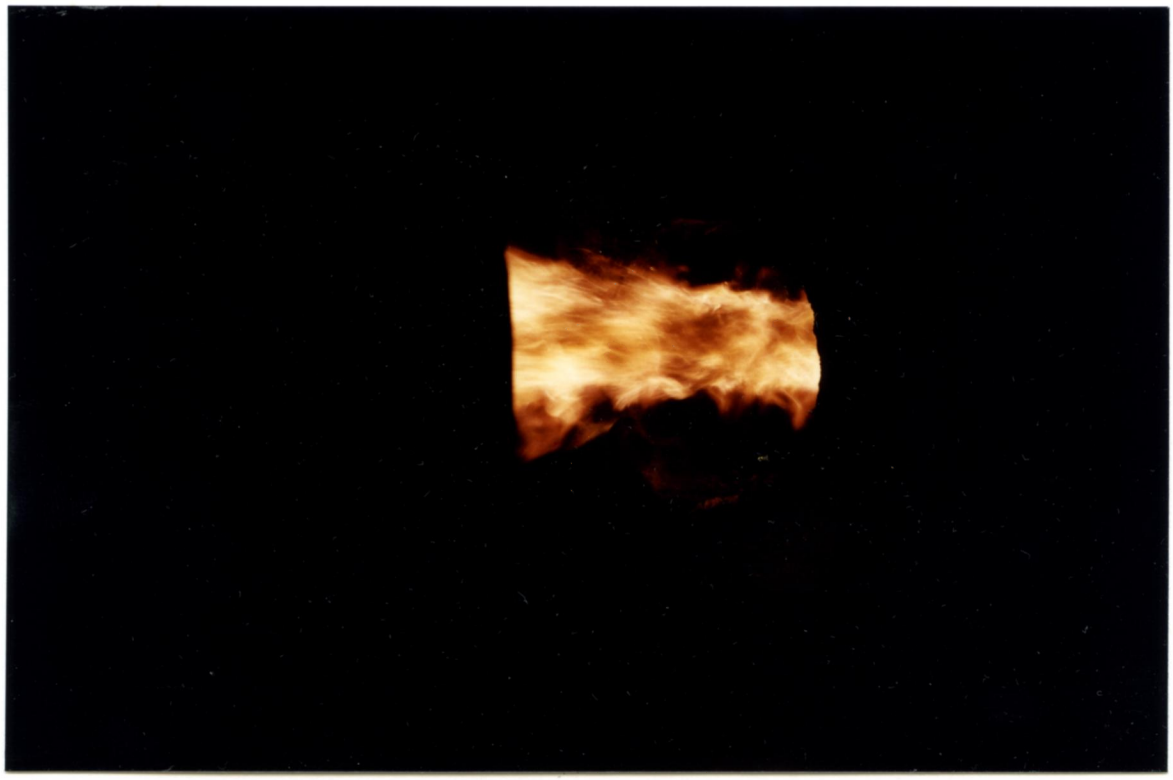


Figure 22. Picture of a typical lignin flame

Figure 23 shows the average gas temperature along the kiln length for natural gas firing, and for different percent replacement of natural gas by lignin WV (60, 75 and 100%). Results for two natural gas fired runs are shown in the figure, one at a solids feedrate of 37 kg/hr and a second at 40 kg/hr. For natural gas firing the flame is shorter, resulting in a distinct maximum in temperature about 0.5 metres from the lime exit point. For the lignin, the flame projects further into the kiln, and the gas temperatures remain slightly above those in the gas firing runs all along the kiln. There is little difference between the temperatures for the 60 to 100% natural gas replacement curves, although the temperatures at any point increase with the percent gas replaced. Observation of the flame from the cold end indicated the natural gas flame was short and blue, while the lignin flame was a longer, brighter, orange flame like that of oil. Some pulsing was evident in the lignin flame, which was thought to be due to unsteady transport of the lignin powder to the burner.

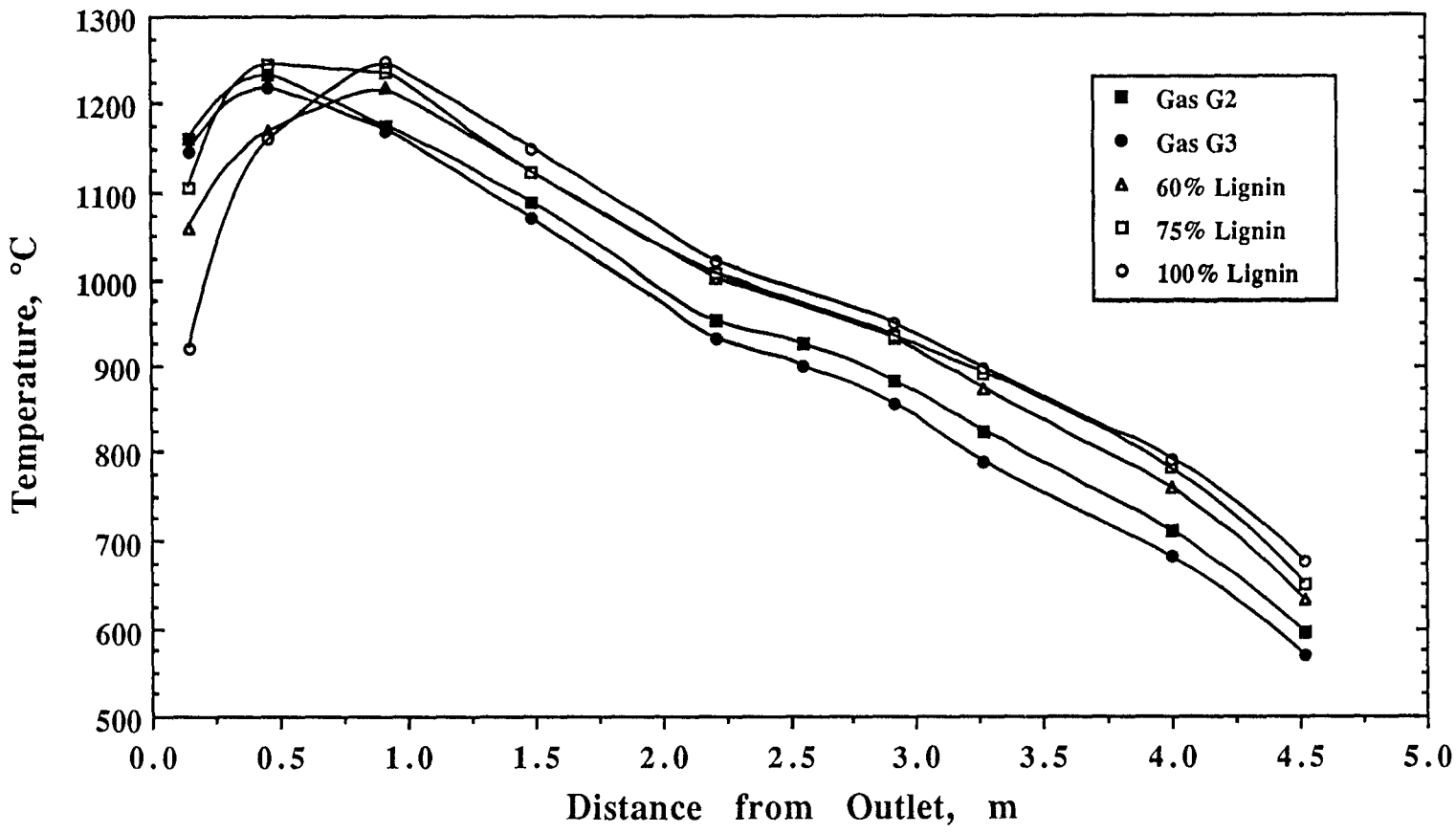


Figure 23. Axial gas temperature profiles for tests with lignin WV for various replacement levels of natural gas

The axial bed temperature profiles for the same runs are shown in Figure 24. The bed temperatures are lowest for the gas–firing tests, and for the lignin fueled runs lie within about 20°C of each other up to the calcination region. The length of the lignin flame is again reflected in the solids temperature profiles, which show a substantial drop as the solids exit is reached. The curves show the characteristic flattening effect of the calcination zone where the endothermic heat of calcination is absorbed. From the temperature profiles, the length of this zone is expected to be shorter for the natural gas firing runs. For the natural gas firing runs the expected drop in solids temperature with the rise in limestone feedrate is evident. The benefit of higher bed temperatures with lignin as fuel may be even more marked in calcining of lime mud rather than crushed limestone, as the drying zone, which is not present in the kiln used, may also be affected. The decomposition temperature for pure limestone is about 900°C. This temperature is reached at distances of about 2 metres from the kiln exit.

Figure 25 shows the percentage calcination plotted versus axial position over the final 3 metres of kiln before the discharge. The profiles rise rapidly in the last 0.75 metres (just under the flame) before the solids discharge point. The comparison of the effects of burning conditions by the exit calcination alone is difficult. As the gas is replaced by lignin the calcination profile is shifted, such that the limestone is calcined further down the kiln from the hot end and over a greater distance. This effect can be explained by the longer flame length and higher emissivity of the lignin flame compared to that of a gas flame. The profiles over the last few metres of the kiln give a better indication of the influence of changing fuels types on the bed. At any axial position in the kiln the percent calcination is highest for the 100% lignin fuel, and decreases accordingly with increasing percentages of natural gas. Calcination reaches 10% at 1.3 metres from the burner for natural gas firing, and at 1.8 metres from the burner for 100% lignin firing. For the lignin firing with its' longer flame, the maximum calcination is reached before the kiln exit, whereas with gas firing, it occurs as the solids pass over the dam into the product receiver.

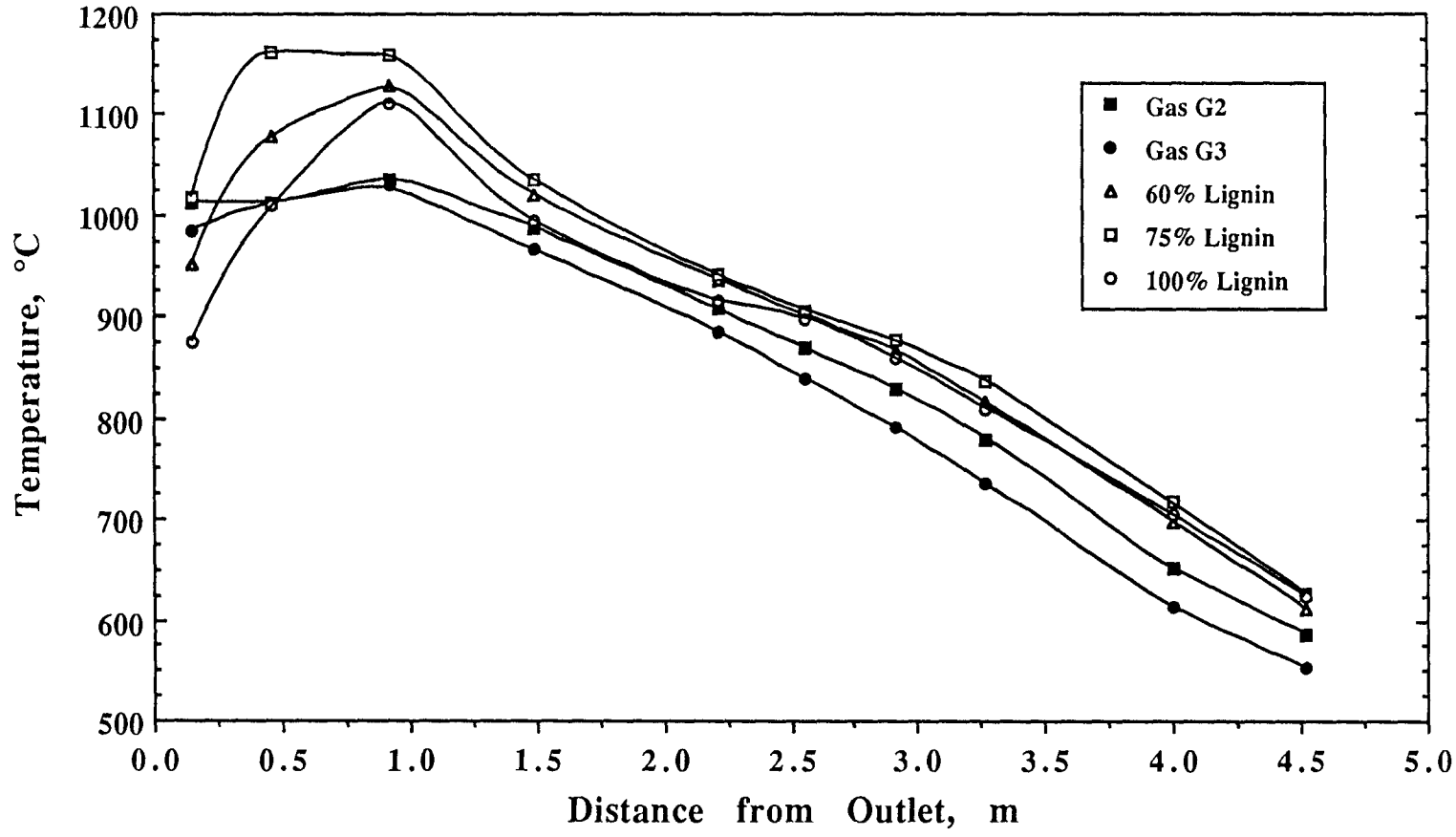


Figure 24. Axial bed temperature profiles for tests with lignin WV for various replacement levels of natural gas

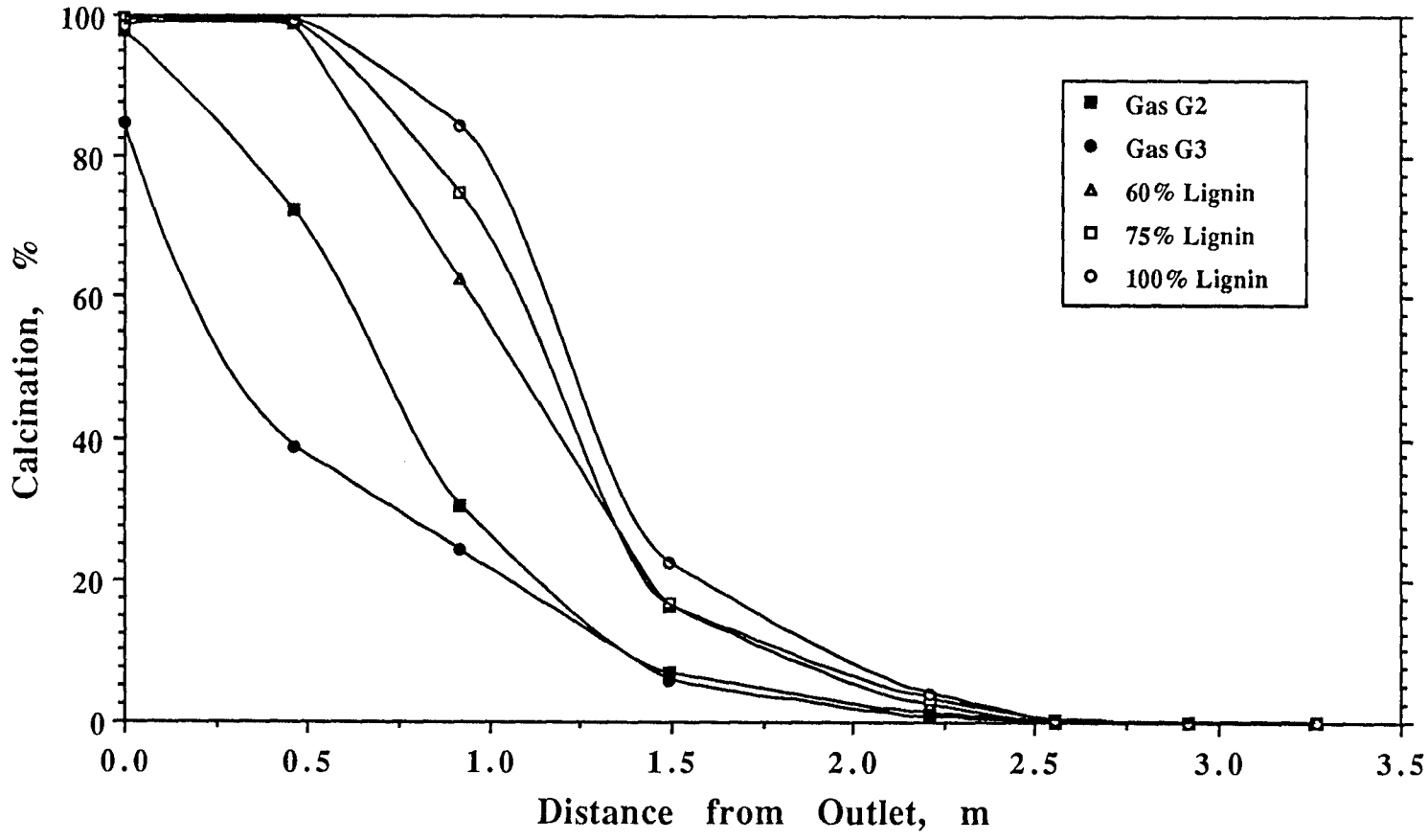


Figure 25. Axial calcination profiles for tests with lignin WV for various replacement levels of natural gas

Experiments for lignins IR and PG which were carried out at slightly higher limestone feedrates (Table 10), gave qualitatively similar results to those of lignin WV. For these experiments, the gas and bed temperatures are shown in Appendix E. However Figures 26 and 27 show the axial calcination profiles in the hot end of the kiln. As is also evident from Table 10, the exit calcination is generally only slightly lower with gas firing, although the percent calcination within the kiln is markedly lower.

In an attempt to match the calcination profiles observed with lignin, additional experiments were carried out using natural gas firing at different specific energy inputs (MJ/kg $CaCO_3$). Figure 28 shows the influence of firing rate on the calcination profile. It is noted that the percentage calcination at any location except at the exit point, increases with the firing rate. As well, the calcination zone gets pushed further into the kiln, but in no case do the profiles match those of lignin where complete calcination occurs before the solids exit the kiln. Again these differences can be attributed to the differences between the gas and lignin flames. As might be expected, decreasing the limestone feedrate to the kiln increased the conversion of the final product.

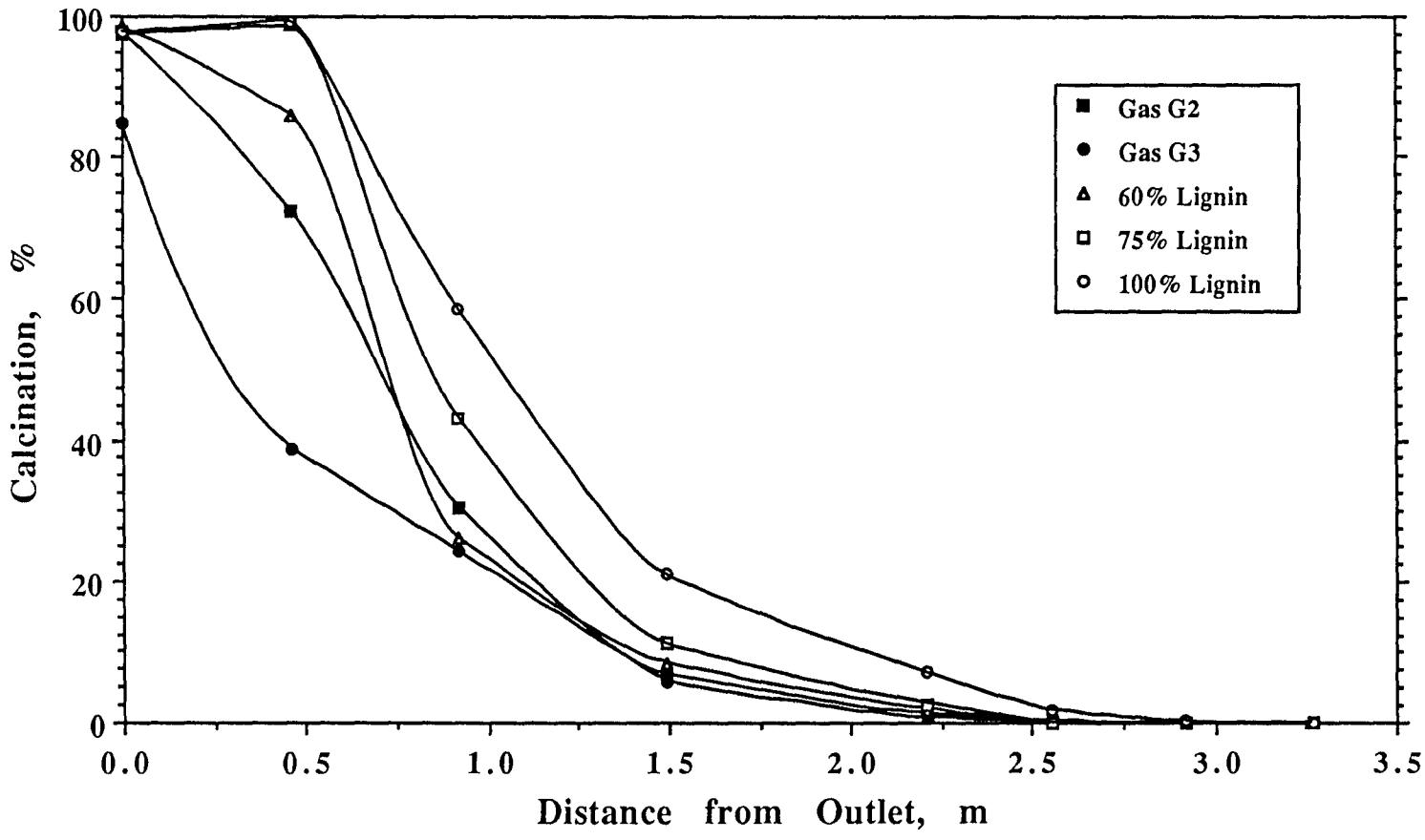


Figure 26. Axial calcination profiles for tests with lignin IR for various replacement levels of natural gas

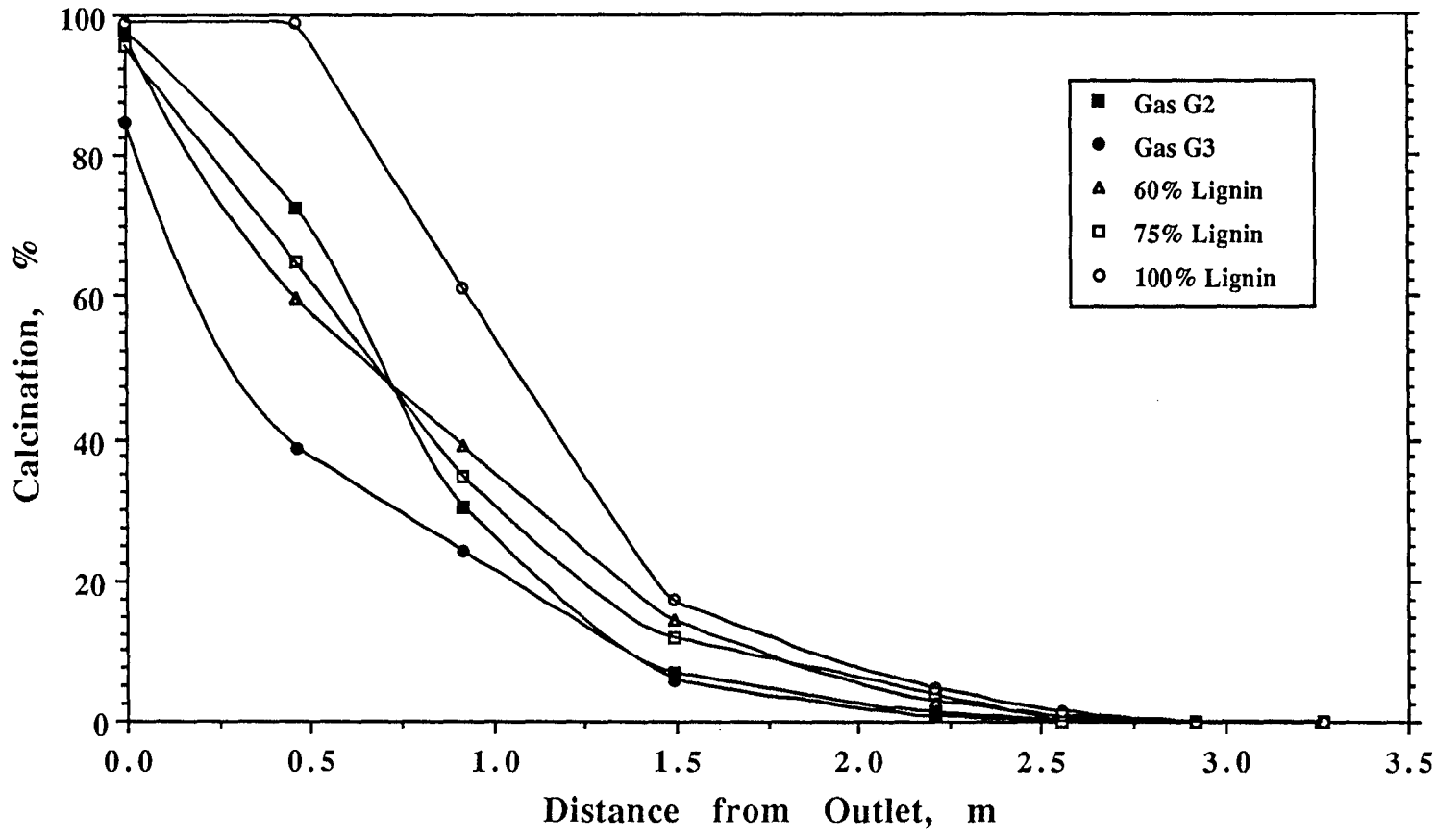


Figure 27. Axial calcination profiles for tests with lignin PG for various replacement levels of natural gas

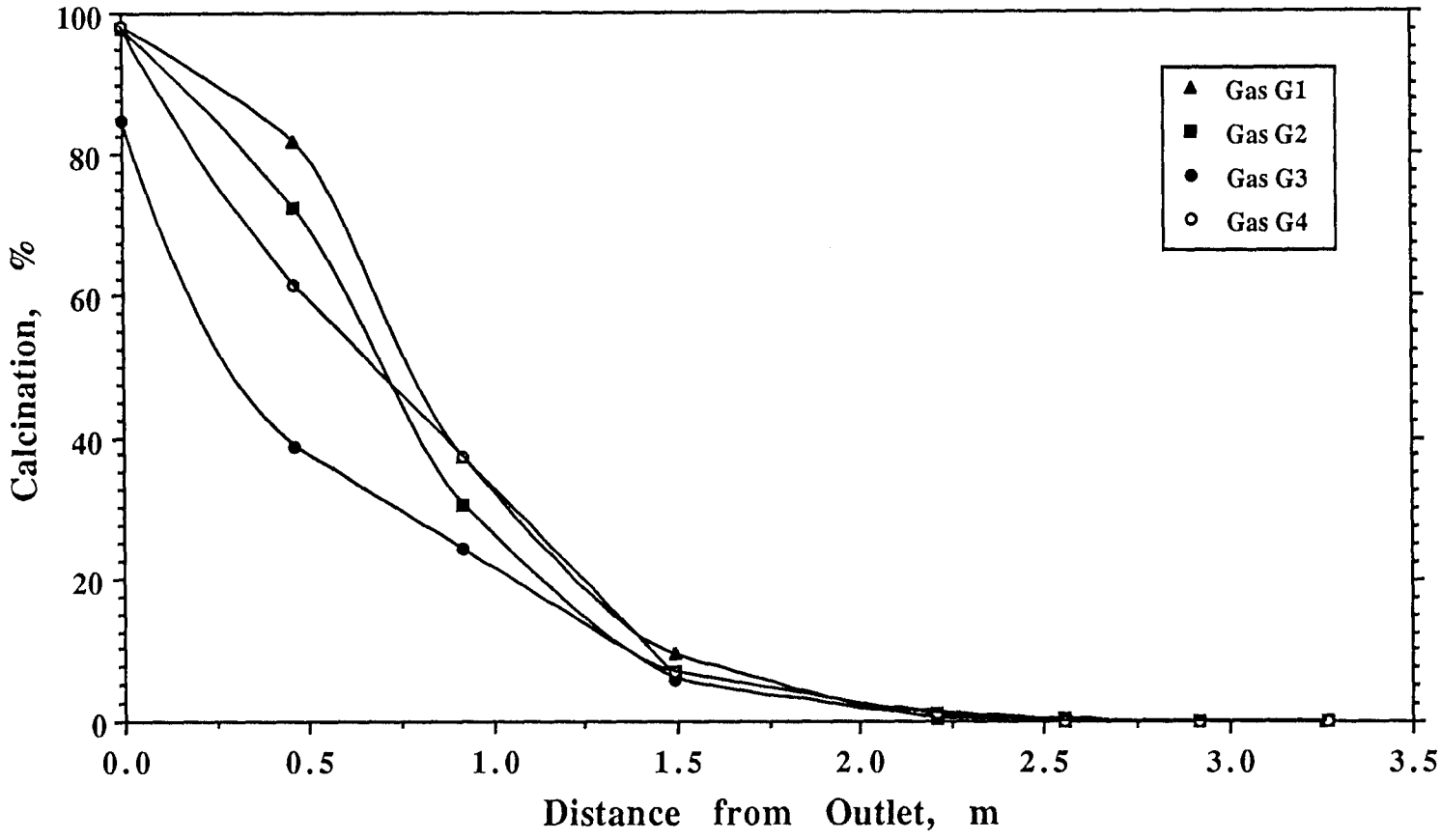


Figure 28. Axial calcination profiles for tests with natural gas firing

Examination of the data in Table 10, and Figure 29 suggests that approximately 0.8 MJ/kg $CaCO_3$ of additional energy must be supplied to the kiln in order to produce fully calcined limestone (relative to lignin firing). The extra fuel requirements are thought to be due to the difference in radiative emissivity of the respective flames produced by each fuel. In the case of the pilot kiln natural gas gives a short nearly invisible flame of low emissivity, whereas the lignin flame is highly emissive due to the burning particles, (similar to a Bunker oil flame). The rate of burning or flame length will depend on the particle size of the lignin. This relationship between particle size and flame length can be seen by comparing results shown in Figure 30 with with those in Figure 15. The larger particle size of lignin WV as compared to the other two lignins, appears to burn further into the kiln, resulting in a bulge on the upward slope of the calcination profile (Fig. 30). The mean particle size of lignin WV is 2.5 to 3 times larger than lignins IR and PG.

During the trials it was found that all three lignins were readily burned as the sole fuel. Figures 29 and 30 compare the bed temperature profiles and the calcination profiles respectively for two runs with natural gas at energy inputs of 8.5 and 9.3 MJ/kg $CaCO_3$, and the 100% lignin runs at about 9.2 MJ/kg $CaCO_3$. The first figure illustrates again the cooler bed temperatures typical of the gas flame, as well as the similarity of the bed temperature profiles for the different lignins. Differences among the calcination profiles for the three lignins are small, except for one axial position where for lignin WV, the calcination is higher than for lignins IR and PG. The indication from Figure 30 is that perhaps some small increment of fuel savings or throughput increase is possible on converting from natural gas to dry lignin as fuel, but the magnitude of the saving is difficult to quantify, especially in this small kiln where shell heat losses are high.

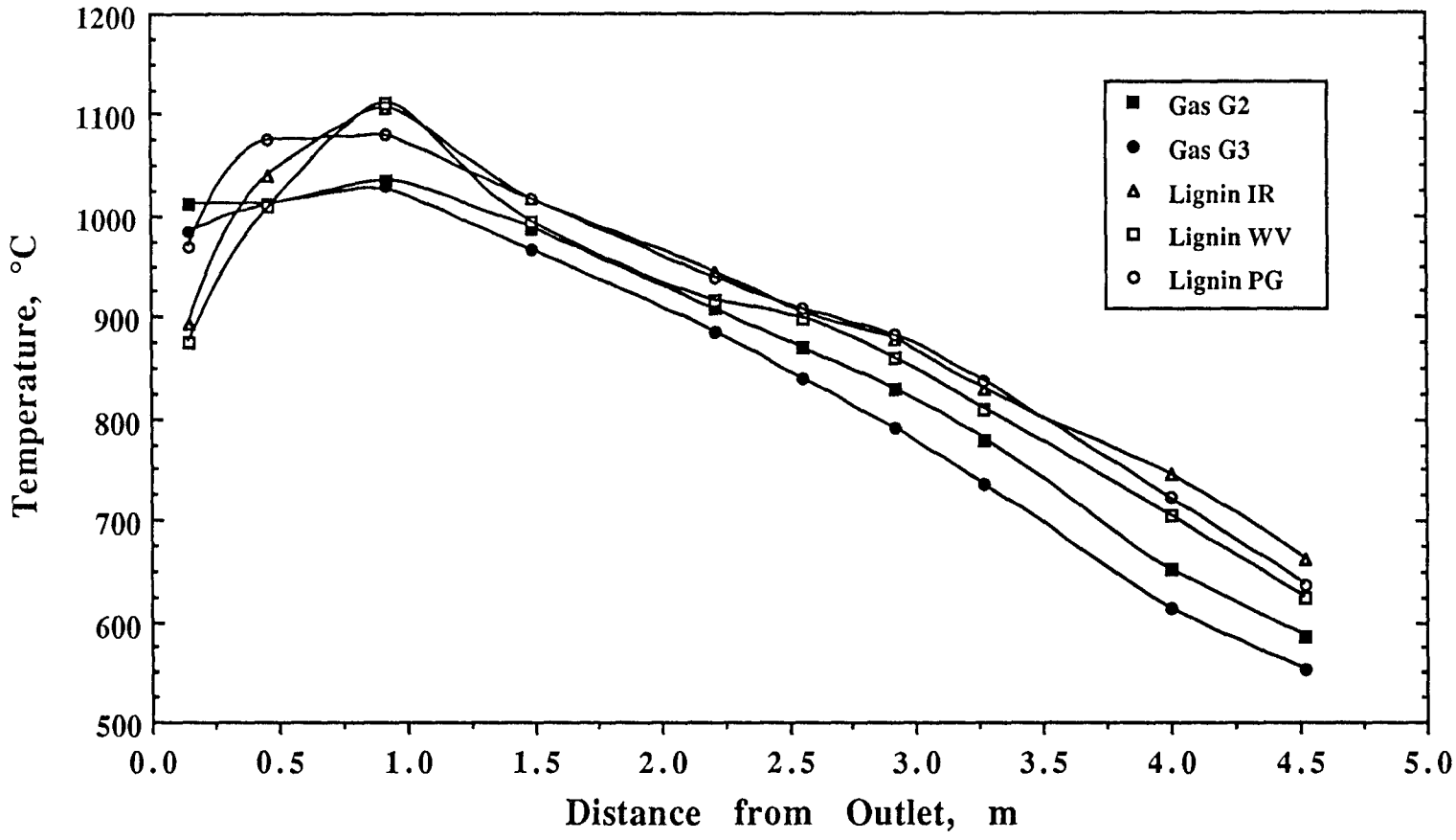


Figure 29. Axial bed temperature profiles for tests with natural gas firing versus 100% lignin burning

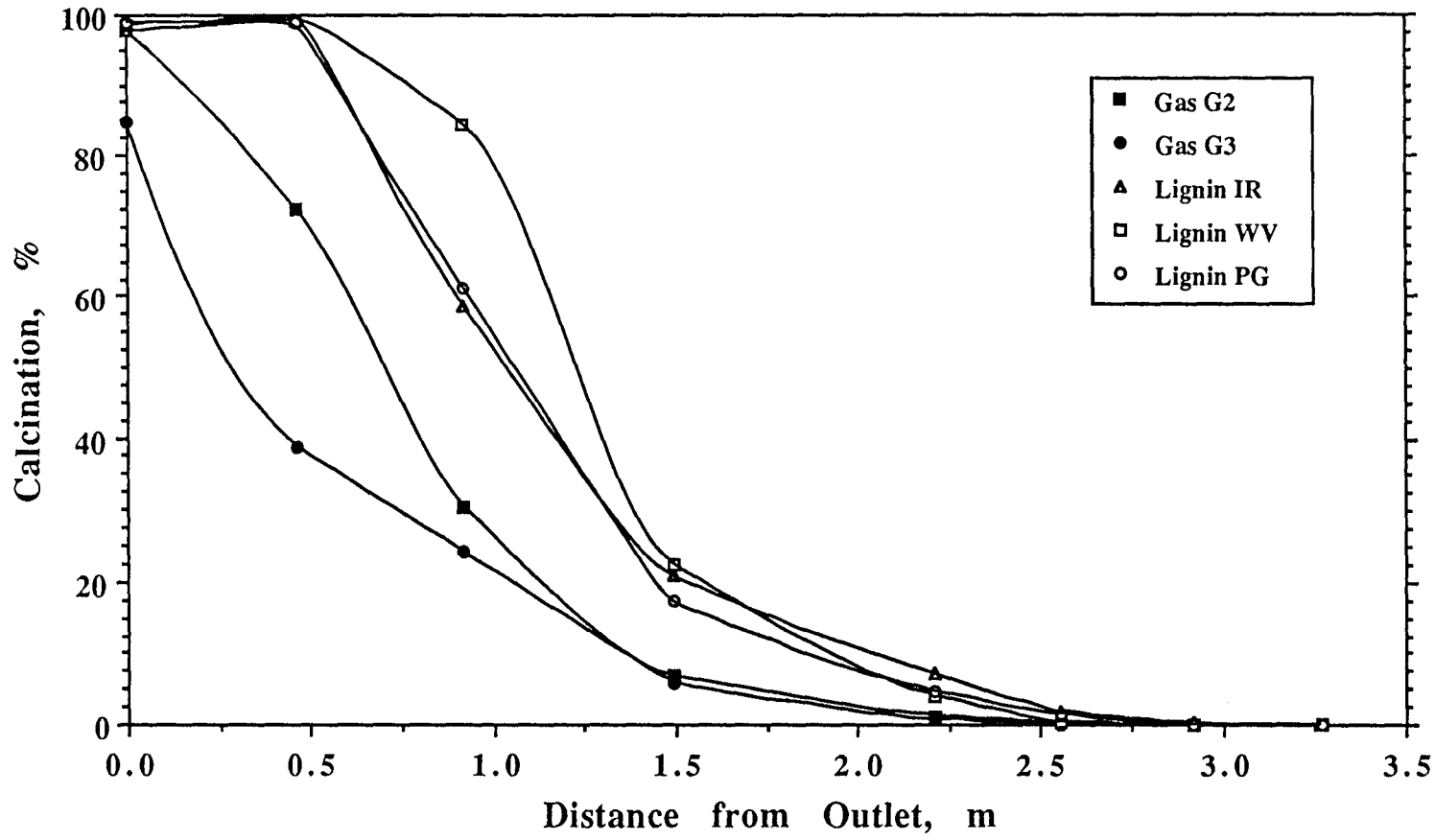


Figure 30. Axial calcination profiles for tests with natural gas firing versus 100% lignin burning

Freeboard Gas Velocity

For the pilot kiln trials the calculated mean freeboard gas velocity through the kiln ranged from 1.06 to 1.28 m/s. The average gas velocity in the kiln was found from the ideal gas equation, using the average of the maximum and exit flue gas temperatures, molar flowrates of the combustion products (including CO_2 from the bed), assuming a total pressure of one atmosphere and using the measured solids bed depth or a fill of 7.9%. Freeboard gas velocity is known to affect the axial temperature profiles within the kiln [1–3]. The average velocity of 1.14 m/s for runs involving lignin as a fuel was slightly higher than that of the natural gas fired runs (1.07 m/s). This slightly difference in freeboard gas velocities in the kiln could be a one reason for the shift in the recorded temperature profiles of runs with lignin over those of natural gas. However, there is probably no significant difference between the two velocities, if the errors in measurement are considered. Mean flue gas velocities, maximum gas and bed temperatures are tabulated in Appendix G.

Slaking and Surface Area Results

Table 11 summarizes the slaking results and surface areas for lime produced from the three lignins, natural gas and the combination of the two fuels. Although there are small differences in both slaking time (time required to reach maximum temperature) and the ultimate value of maximum temperature, within the accuracy of the measurements the slaking behaviour is seen not to be adversely affected by the use of dry powdered lignin as fuel. Some limes were found to have two rates of slaking, an initial dT_1/dt and a final dT_2/dt. These slopes were obtained from the best fit tangent line drawn (by eye) through a linear series of points. For example the slaking rate curve for lignin WV at the 75% replacement level of natural gas has two distinct rates, as shown in Figure 32. The slopes of the slaking rate curves have also been tabulated in Table 11. Attempts to correlate surface areas with the parameters in Table 11, with the inert elements in the lignin or with variables other than the fuel resulted in scattered plots. Surface area of the lime did however increase noticeably when the natural gas was replaced by increasing amounts of powdered lignin fuel for conditions where the product was not dead burned. The decrease in

Table 11. Slaking results of final lime products

Run	Lignin	% Gas Replaced	$CaCO_3$ kg/h†	Percent Calcination	Slaking min.	Temperature °C Rise	Temperature °C Max.	Initial Rates‡ dT_1/dt	Initial Rates‡ dT_2/dt	Surface Area, m^2/g
LG9	IR	60	39.3	98.6	1.01	13.4	103.4	25.6	—	6.45
LG10A		75	39.3	98.3	1.20	13.5	103.5	29.8	—	9.62
LG10B		100	36.0	97.7	1.12	13.2	103.2	31.3	—	6.12
LG12A	WV	60	35.3	99.2	1.46	13.3	103.3	11.3	18.4	3.22
LG12B		75	35.4	99.6	1.56	13.5	103.5	14.4	24.6	2.15
LG11		100	36.6	98.7	1.53	12.9	102.9	15.6	23.3	8.88
LG17	PG	60	42.0	97.0	1.65	13.6	103.6	19.7	—	2.96
LG16		75	41.7	95.6	1.12	13.6	103.6	23.1	—	3.50
LG14		100	37.3	98.8	1.32	13.7	103.7	14.7	24.6	6.68
	Gas									
LG13	G1	0	33.2	98.2	1.02	13.5	103.5	18.0	25.8	3.95
LG14G	G2	0	36.8	97.8	0.99	13.9	103.9	31.2	—	4.46
LG15A	G3	0	40.4	84.8	1.27	11.3	101.3	18.0	31.3	3.96
LG15B	G4	0	39.5	98.1	1.03	14.1	104.1	31.3	46.5	5.68

† calculated based on output of lime ‡ °C/min

surface area for a given set of runs is thought to be due to the sintering of the surface of the lime particles which occurs during over–burning. Lignin IR produced the fastest slaking limes and also had the highest surface areas for all three runs, which could have been due to its moisture content, which was higher than the other lignins.

The temperature rise curves for limestone fired by natural gas at various specific energy inputs are shown in Figure 31. Data in Table 11 and Figure 31 suggest that the maximum temperature rise obtained by slaking the lime is proportional to the extent of calcination, the higher the calcination level the greater the maximum temperature.

Figure 32 shows the slaking rate for the replacement levels of natural gas by lignin WV at 60, 75 and 100%. The slightly lower limestone feedrate for experiments conducted with lignin WV produced slower slaking limes (Fig. 32). Sintering of the lime is suggested from the magnitude of the surface areas, however the small change in limestone feedrate (1.2 kg/hr) for 100% lignin burning seem to be enough to produce a non–sintered lime as indicated in Table 11.

Figure 33 compares the slaking rates for two runs with natural gas at specific energy inputs of 8.5 and 9.3 MJ/kg $CaCO_3$, and the 75% fuel replacement by lignin runs at 8.2 to 9.5 MJ/kg $CaCO_3$. The experiment performed with lignin WV had the highest fuel rate and one of the lowest limestone feedrates, and hence yielded an over burned lime. This over–burning caused some delay for the sample to reach its maximum temperature in the slaking test, but there was little difference in maximum temperature achieved by all lime samples. A sintered particle of lime is shown in Figure 36.

The results of the slaking rate curves for lignins IR and PG are very similar to their corresponding natural gas curves. Slaking curves for limes produced from these two lignins at various levels of fossil fuel replacement can be found in Appendix E.

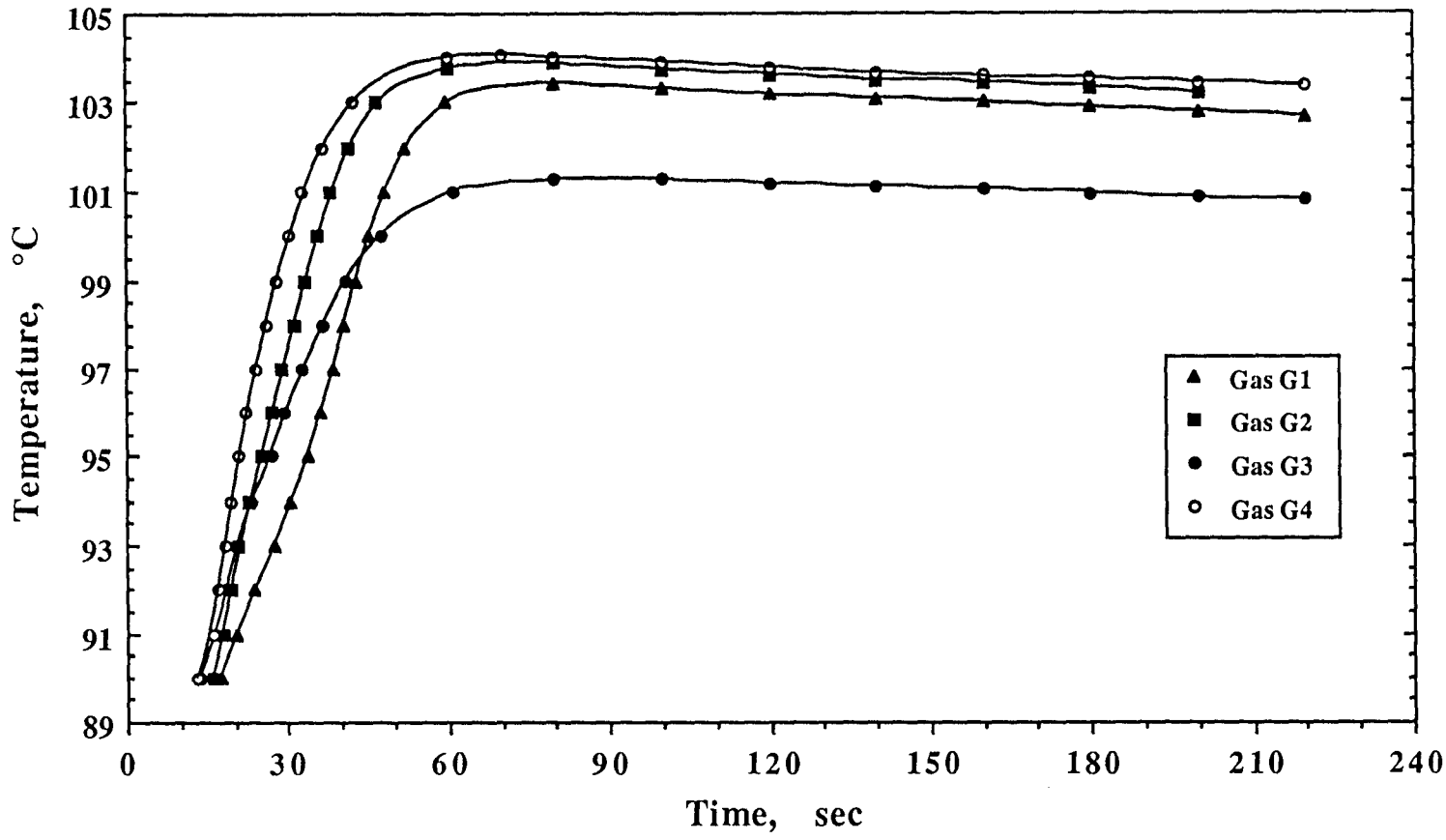


Figure 31. Slaking temperature rise curves for tests with natural gas firing

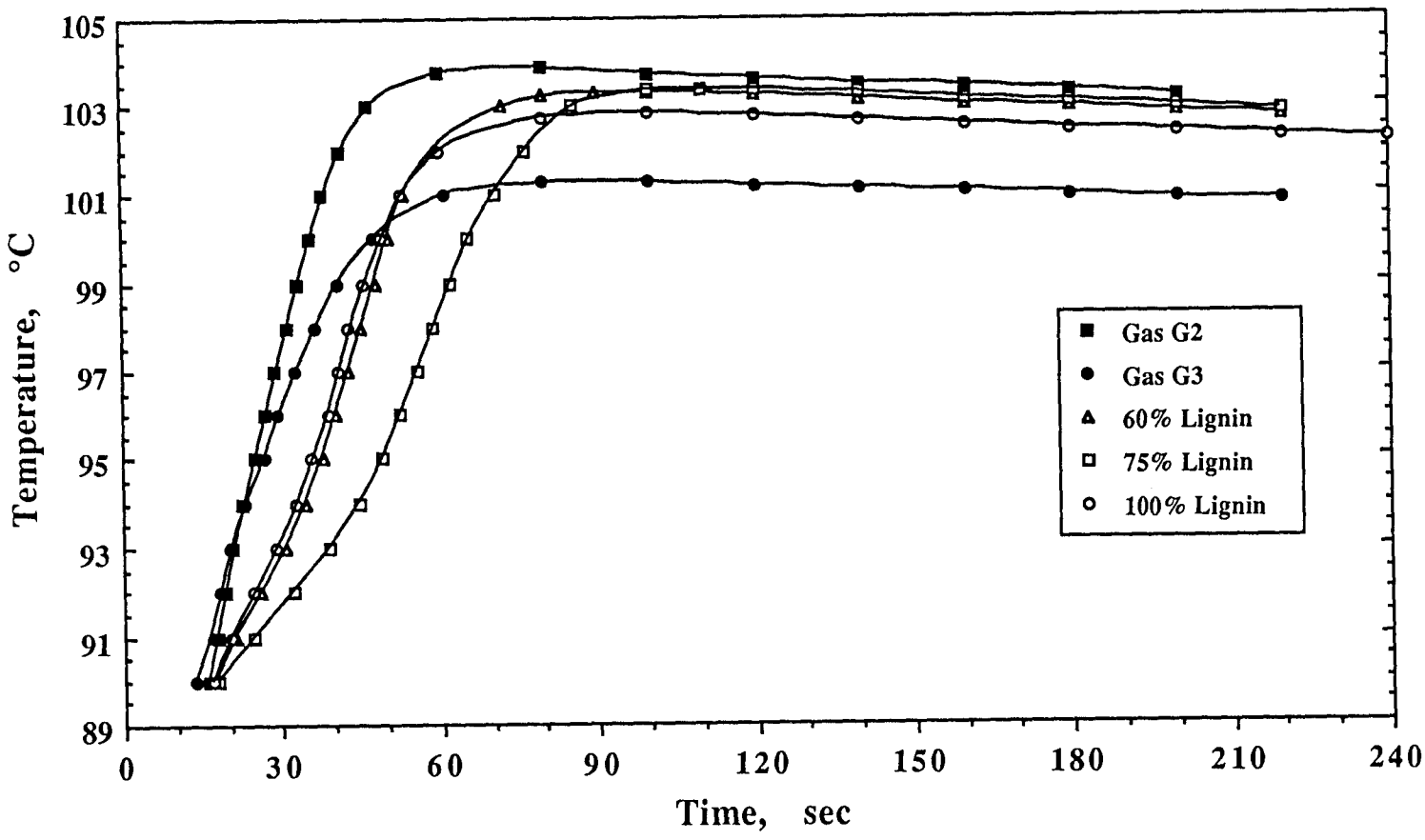


Figure 32. Slaking temperature rise curves for tests with lignin WV

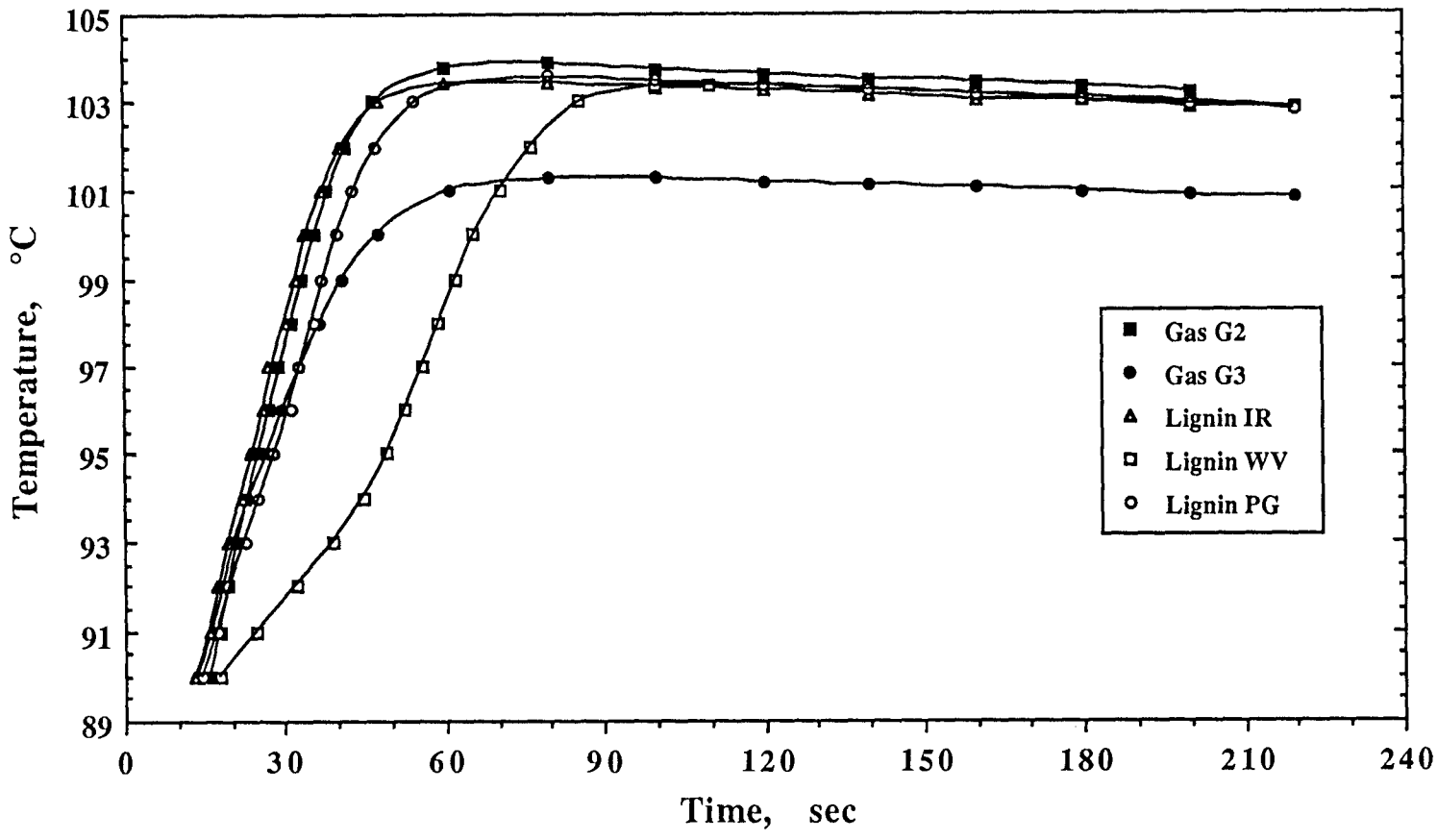


Figure 33. Slaking temperature rise curves for tests with natural gas firing versus 75% lignin burning

Electron microscope pictures of lime particles from runs LG15A, LG10A and LG12B respectively, taken at magnifications of 1000 and 4000 times are shown in Figures 34 to 36. Limestone calcined by natural gas is shown in Figure 34. The sintered grains observed on the surface, at the higher magnification, can be found to be rounded which is evidence of previous melting. Figure 35 shows the fine grain structure of calcium oxide developed when heated with 75% lignin and 25% natural gas. The small lumps on the surface of the particle in the photo indicate the beginning of sintering, which can be seen clearly in the photo at the higher magnification. The grains in this figure are still well defined when compared to those of Figures 34 and 36. Figure 36 is a photo of a lime particle which is highly sintered, and where most of the fine grain structure has melted to form a coarse structure. The formation of this type of structure is due to the intense heat during the period under the longer luminous lignin flame. In contrast, for the same specific energy input the shorter natural gas flame provided a short period during which the limestone was calcined.

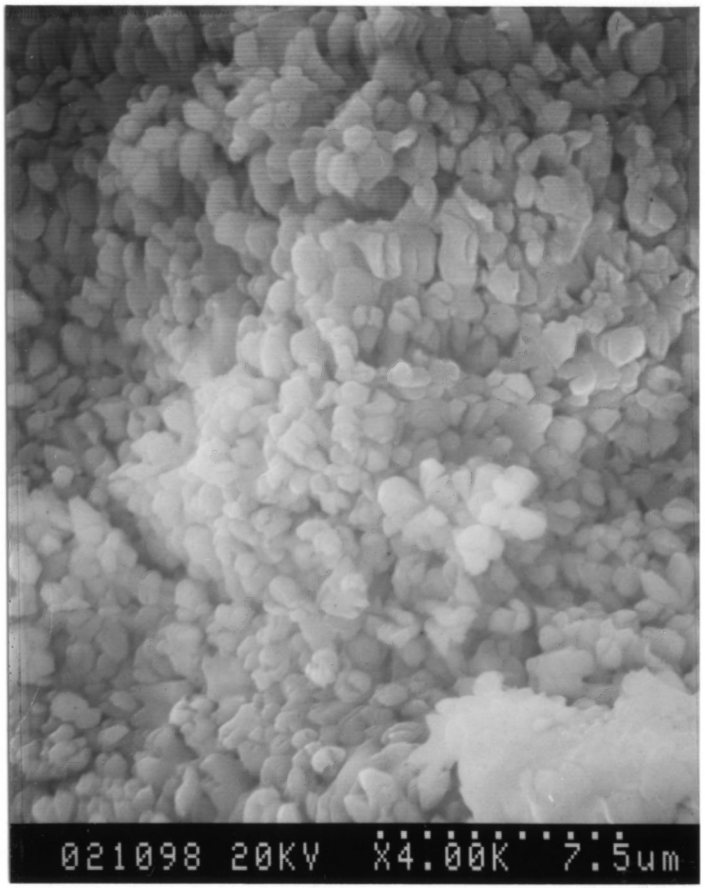
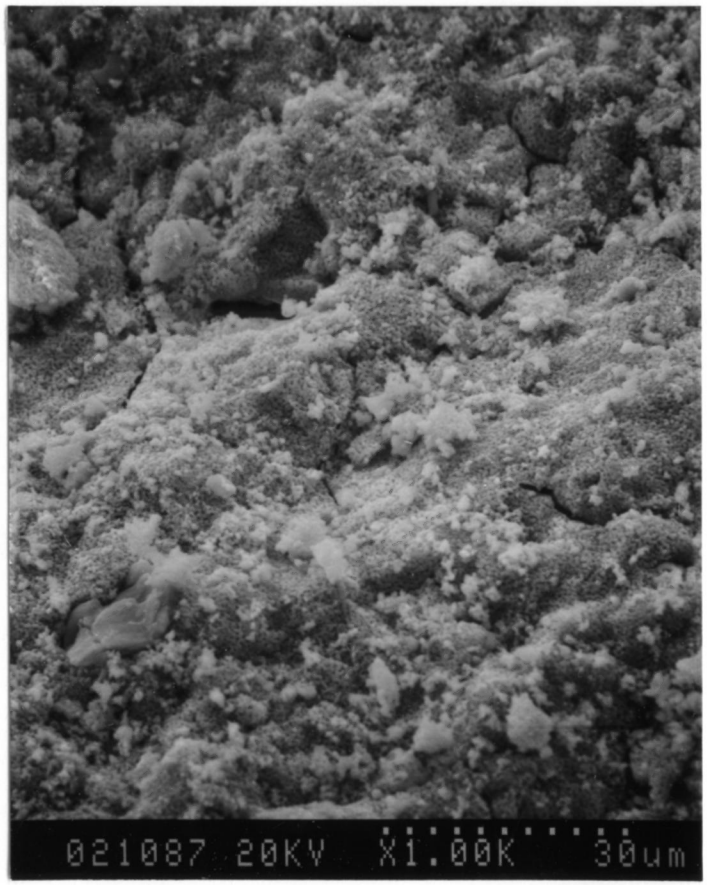


Figure 34. Pictures of a lime particle from run LG15A



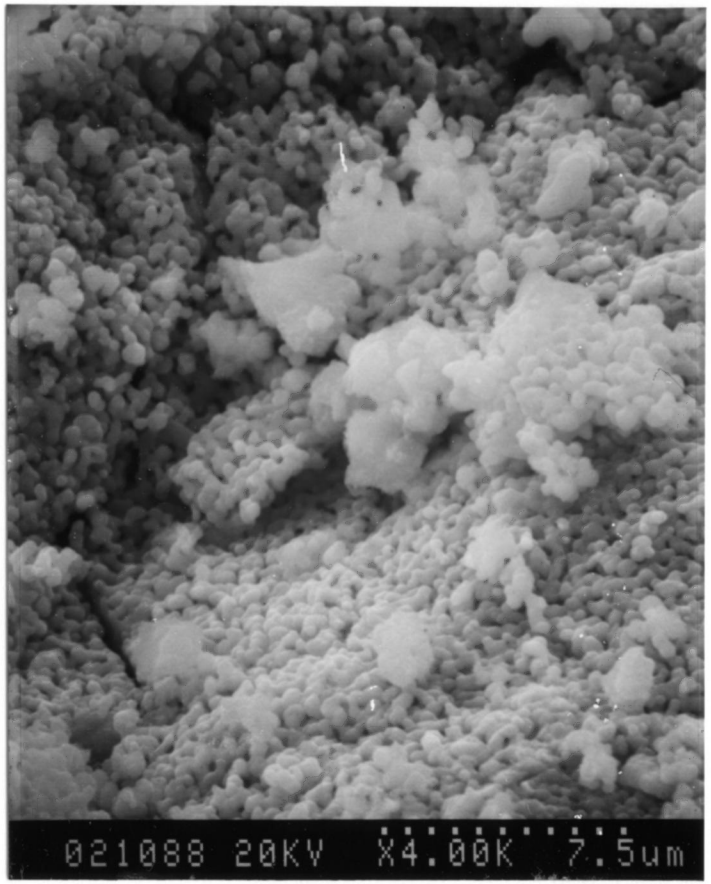


Figure 35. Pictures of a lime particle from run LG10A

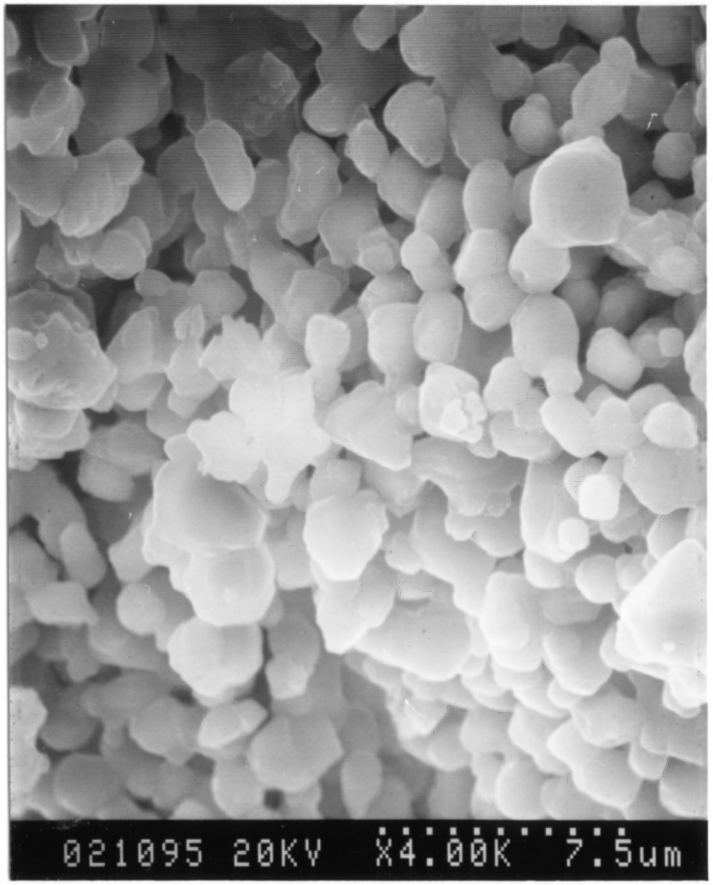


Figure 36. Pictures of a lime particle from run LG12B

Elemental Balances

During the trials it was not possible to collect all dust leaving in the exiting flue gas and therefore a total account for the output of all elements was not practical. However the fate of the inert elements added by the lignin fuel can be determined, in terms of whether they leave with the lime, or are removed from the kiln by the freeboard gas. The limestone used came in 20 kg bags and it was probable that each one was different with respect to the amount of dust it contained. From the conveyer belt of the limestone feed system to the feed funnel on the cold end of the kiln was an open space of 15 cm where some of the finer material was carried out of the feed. When the limestone feed fell down the chute, it was possible for the exiting hot flue gases to remove some fine material just as it entered the lime kiln. Dust samples from the exiting flue gas could only be collected from the cyclone trap. Smaller particles were discharged from the system. Therefore a rate of dust loss from the kiln could not be obtained due to the variation and loss of material. Dust samples collected from the cyclone and product lime were analysed for inert elements, the results of which are shown in Tables 12 and 13. A comparison of the experiments with lignin used as a fuel with those using natural gas indicates that the sodium, sulphur and iron levels in the dust have increased. The iron levels appear to be the result of contamination. Lignin IR was rinsed on a belt filter with water then packed in unlined barrels for shipment to Prince George for further washing. Both lignins PG and IR were washed in Prince George with dilute sulphuric acid and the lignin slurry was packed in unlined barrels for shipping to Modern Control Services Ltd. for drying. The lignin remained in a dilute acid suspension for two to three months before being dried. The lignin settled out leaving a supernatant acid solution, which corroded the inside of the barrels and leached out some of the iron. The lignin was resuspended in the acid and sent to the drying equipment. The iron levels present in these lignins (PG & IR) therefore should not be expected to be the norm during production of lignin. The increased levels of iron in the lime and dust is considered to be due solely to the original contamination of the lignins. The high levels of iron found in those dusts samples collected from runs fired by lignin IR are thought to be due to contamination, since the lignin IR did not have iron concentrations high enough to account for the levels found in the dust. There was however an increase in the elements sodium and sulphur in the lime and collected dust. The other elements showed no meaningful change between the gas fired experiments and those which had some or all the fuel replaced by powdered lignin.

Table 12. Chemical analysis of lime

Run	Lignin	% Gas Replaced	% Calcination	Ca	wt % Si	S	Na	Fe	mg/kg Al	Mg	Mn
LG9	IR	60	98.6	57.4	0.82	0.20	316	950	770	2980	74.6
LG10A		75	98.3	54.7	0.78	0.20	641	1390	2120	2850	82.0
LG10B		100	97.7	58.3	0.91	0.23	319	1360	1030	2740	83.8
LG12A	WV	60	99.2	59.2	0.98	0.17	483	740	780	2740	76.7
LG12B		75	99.6	59.0	1.24	0.14	942	1000	1250	2650	81.6
LG11		100	92.7	56.5	1.12	0.15	365	1760	840	2770	76.8
LG17	PG	60	97.0	64.6	0.80	0.18	338	750	640	2880	82.8
LG16		75	95.6	63.6	1.23	0.22	220	1030	500	2850	79.3
LG14		100	98.8	54.1	1.17	0.15	404	1200	1040	2650	75.8
	Gas										
LG13	G1	0	98.2	58.3	1.29	0.04	331	960	1200	2920	80.3
LG14G	G2	0	97.8	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
LG15A	G3	0	84.8	59.8	0.94	0.06	181	750	860	2900	82.0
LG15B	G4	0	98.1	63.3	2.05	0.04	329	950	1270	3300	87.6

Table 13. Chemical analysis of dust collected from the cyclone

Run	Lignin	% Gas Replaced	wt % Ca	Na	Si	S	Fe	mg/kg Al	Mg	Mn
LG9	IR	60	23.3	2.88	1.70	2.2	20.99	3125	3225	2431
LG10A		75	20.4	3.43	1.47	1.9	22.22	2449	2993	2622
LG10B		100	20.4	3.43	1.47	1.9	22.22	2449	2993	2622
LG12A	WV	60	39.7	2.30	3.45	1.4	0.38	10570	6602	1814
LG12B		75	39.7	2.30	3.45	1.4	0.38	10570	6602	1814
LG11		100	28.4	0.47	3.53	1.5	0.60	7616	3441	204
LG17	PG	60	38.3	1.79	2.89	0.74	3.83	3350	2725	334
LG16		75	44.6	0.62	1.91	0.37	1.16	2950	2807	216
LG14		100	37.5	1.27	3.29	2.1	1.70	5105	3431	464
	Gas									
LG13	G1	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
LG14G	G2	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
LG15A	G3	0	42.5	0.35	1.57	0.44	0.27	2882	2662	181
LG15B	G4	0	42.5	0.35	1.57	0.44	0.27	2882	2662	181

The rates at which the major elements of concern entered and left the kiln are shown in Figures 37 and 38. The total flowrates given in these figures are for limestone, lime, CO_2 from calcination and the dust stream is the summation of the elemental rates. Since the cyclone on the flue gas exit was not able to capture all the material leaving the kiln, the dust stream was calculated by difference in order that the elements would balance. Figure 37 is a balance for a natural gas experiment. Sulphur was not determined in the original limestone, however the sulphur present in the lime was considered to originate in the limestone. Figures 37 and 38 show that with 100% lignin firing the amount of sulphur increased in the lime and dust streams. Since the product lime stream

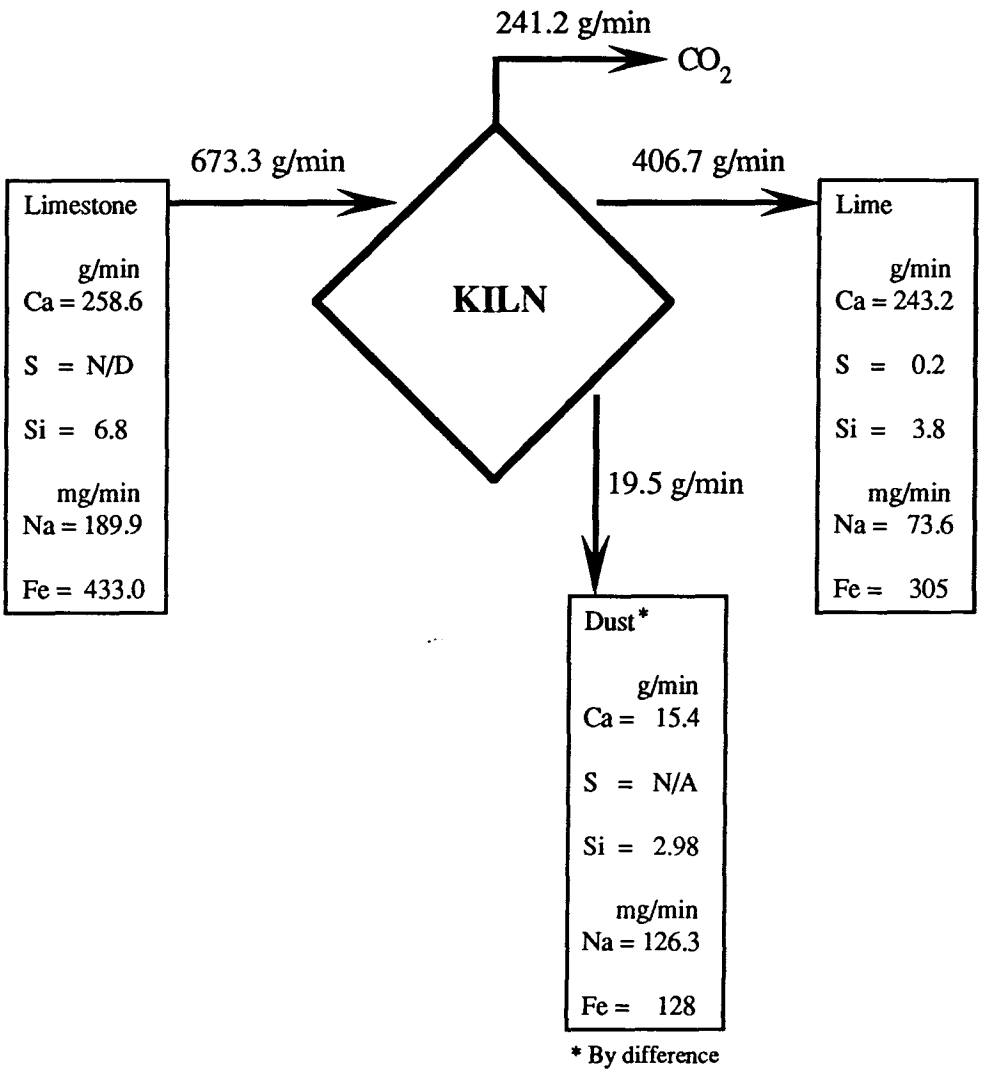


Figure 37. Elemental balance for natural gas firing (LG15A)

contained less sodium than the feed limestone stream, it suggests that the majority of sodium added by the lignin fuel will be in the dust stream. Complete elemental balances for all runs can be found in Appendix F.

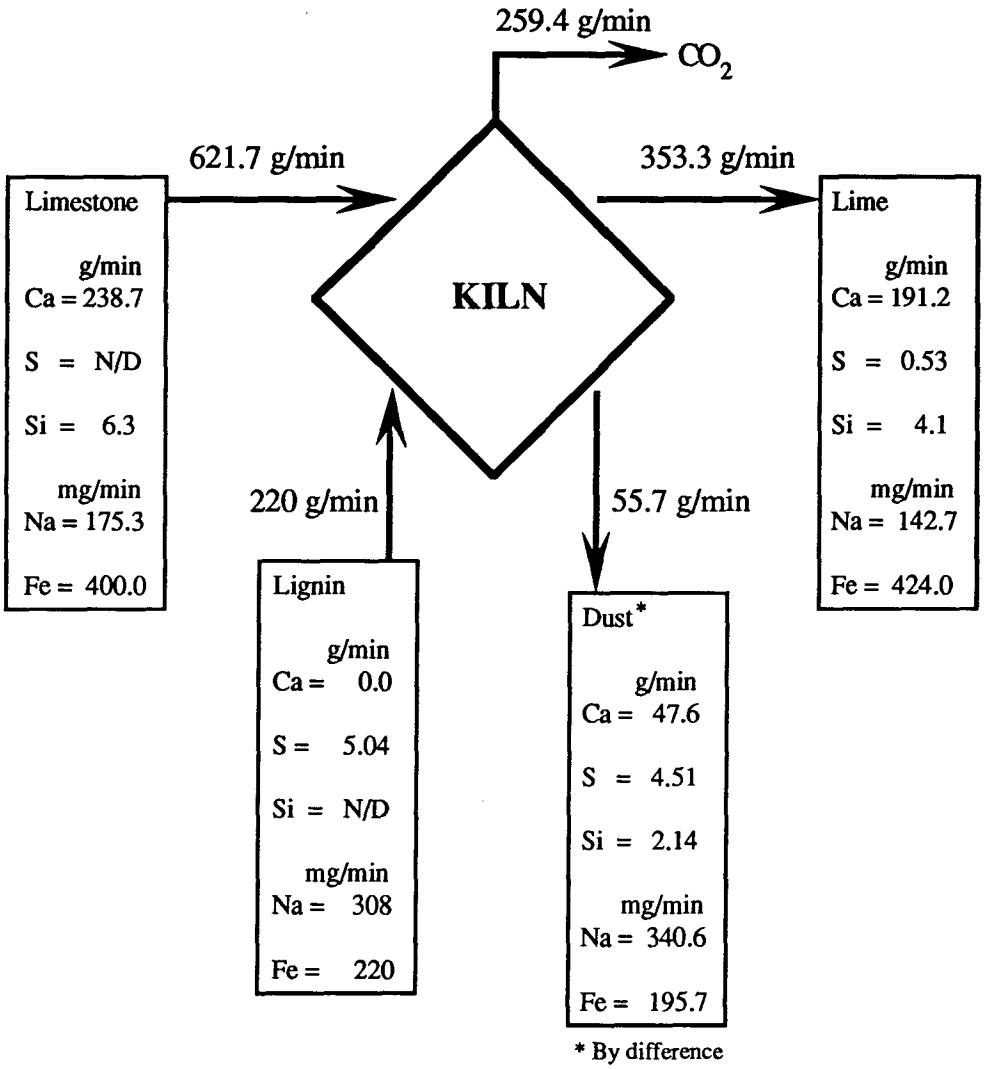


Figure 38. Elemental balance for 100% lignin PG burning (LG14)

Table 14 shows a comparison of the calculated dust composition of the major elements verses the chemical analysis for the natural gas run (LG15A) and the 100% lignin fired run (LG14). The calcium in the dust was assumed to be in the form of calcium carbonate. The calculated value for the percent silica in the dust is very high

when compared to that which was found by analysis for the natural gas run. The reported values by chemical analysis for silica, sodium and iron in the 100% lignin fired run were found to be higher than those calculated. The other elements for both trials seem to be in good agreement for the calculated values verses the chemical analysis. Similar tabulated values of dust composition for all other runs can be found in Appendix F.

Table 14. Dust composition collected and calculated for runs LG15A & LG14

			wt%		
Trial	$CaCO_3$	S	Si	Na	Fe
LG15A					
Found	38.0	0.4	1.6	0.35	0.27
Calculated	36.2	N/A	7.0	0.27	0.30
LG14					
Found	37.5	2.1	3.3	1.27	1.70
Calculated	37.4	3.6	1.7	0.27	0.15

Figures 39 and 40 were generated from all experimental trials involving lignin as a fuel. The original sulphur content in the limestone feed was found from the natural gas runs. Figure 39 shows that as the amount of organic sulphur in the lignin increased the amount of total sulphur found on the lime increased. There are however two points which seem to be questionable and do not follow this trend. Sulphur addition to the lime from sulphate in the lignin fuel was found to remain constant (≈0.15 wt%) at all levels of firing. Figure 40 shows that increasing amounts of sodium in the lignin fuel had no correlation with the resulting sodium on the lime, but seem to remain constant (at 0.008 wt%) at input levels above 1000 mg/min from the lignin fuel. Since the limestone feedrates were essentially constant in the experiments, increases in sulphur and sodium inputs arose from the lignin. These two elements may have left the kiln as sodium sulphate and/or calcium sulphate as dust in the flue gas. The cyclone was the only equipment used to remove dust from the flue gas, hence those particles with small diameters would not have been collected and were discharged from the system. The pilot–plant kiln has a short

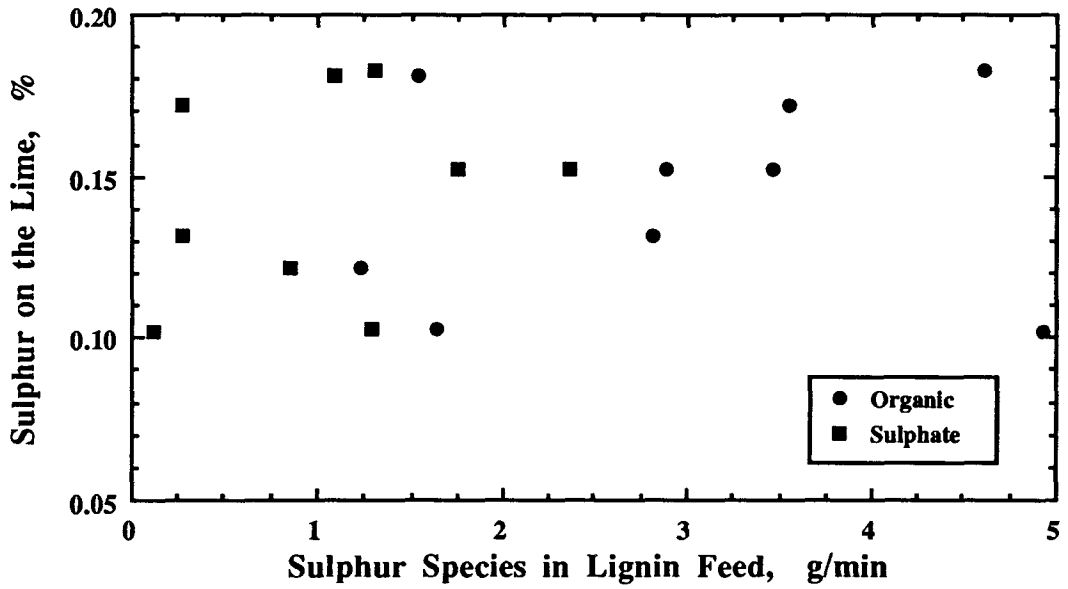


Figure 39. Sulphur found on the lime versus input from lignin

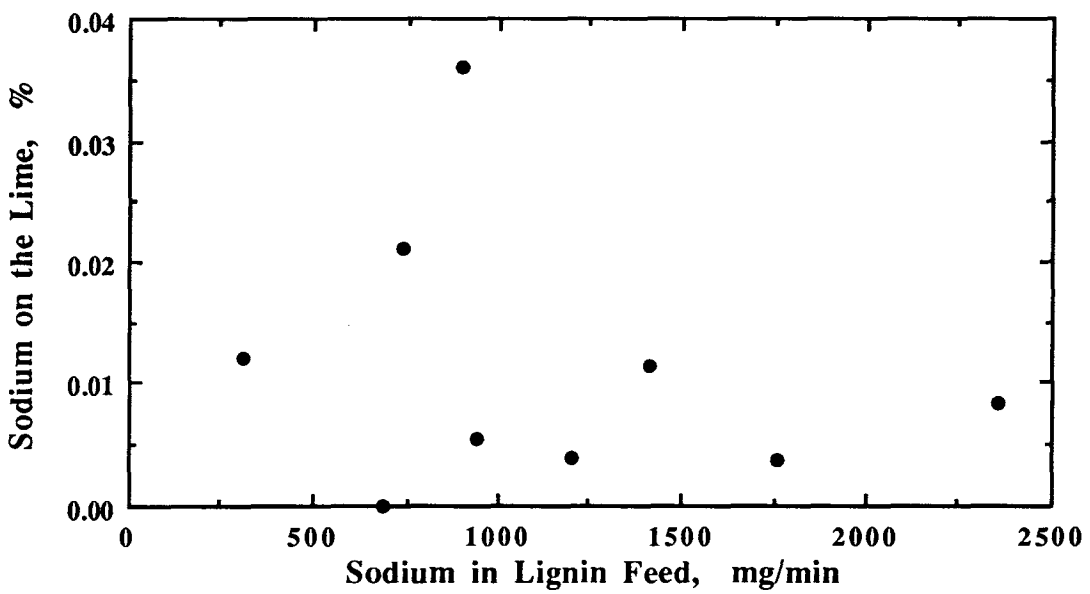


Figure 40. Sodium found on the lime versus input from lignin

L/D ratio (13.5:1), no chain section and used dry limestone as feed material. Wet lime mud and a chain section in a kiln would capture more dust from the flue gas and this dust would exit the kiln with the lime. A chain section would also increase the residence time of the sodium and sulphur and perhaps provide more time for these elements to react with the limestone or lime. A kiln with a wet scrubber or an electrostatic precipitator on the exit flue gas would return all the captured material back to the kiln with the wet lime mud. In any event, all the sodium and sulphur entering the kiln with the lignin as a fuel will end up in the lime. At a firing rate of 218 g/min of powdered lignin having 1.08 wt% Na, the highest level at which sodium entered the kiln with the lignin fuel would produce levels of 0.52% (as Na_2O) if it all left in the lime. This is within the recommended limit of 0.2% to 0.7% [60]. The formation of rings and balls should not be expected from any of the lignin used in the experiments, provided that the other alkali soluble materials in the lime mud are low. The limit of sulphur is not really known, but the presence of sulphur will decrease the availability of CaO.

Energy Balances

The collected temperature data, along with other operating parameters from the kiln was used in a program to calculate the local heat transfer rates. A description of the program written in Fortran code can be found elsewhere [54]. The local heat transfer rates within the kiln for two runs are shown in Figures 41 and 42. For each graph QSS, QSOL and QFBG represent the rate of energy lost by the shell, gained by the solids bed and lost by the freeboard gas, respectively. Figure 41 shows results for a gas fired run (LG15A) which corresponds to a lignin fired run (LG14) shown in Figure 42, having an energy input of 8.5 and 9.2 MJ/kg of $CaCO_3$, respectively. By comparing the two Figures 41 and 42 shell energy losses are about the same whether the kiln was fired with 100% lignin or 100% natural gas. The sharp dip in the net heat transferred for the natural gas fired run by the flue gas occurs at the onset of calcination and may be an anomaly due to the differentiation of the temperature data. This dip bottomed out when the kiln was fired by a lignin fuel, as shown in Figure 42. The rate of energy gained by the solids bed is about the same at distances ≥2.2 m, but is dramatically different between the two runs in the

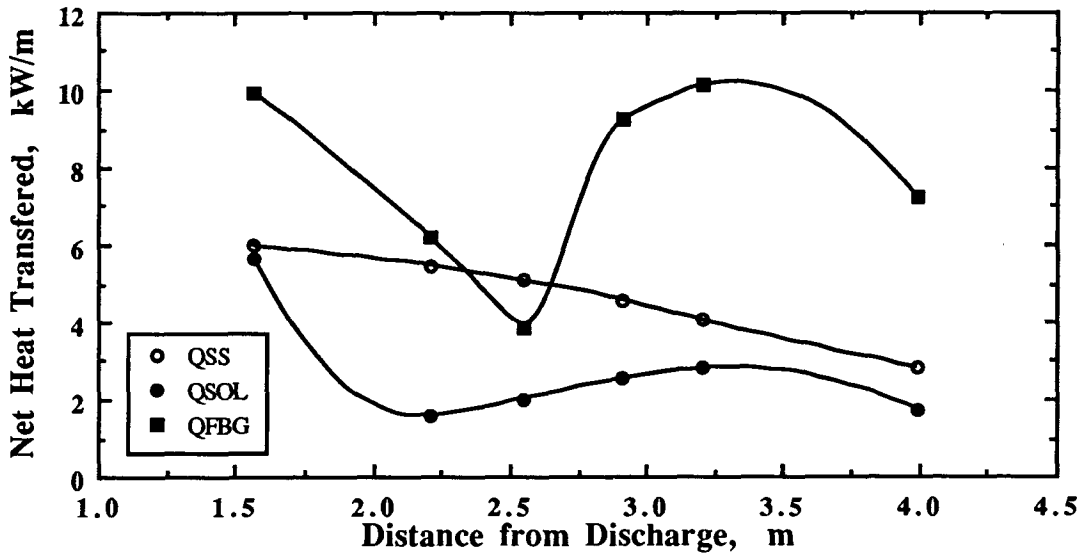


Figure 41. Net heat transfer rates for natural gas (LG15A)

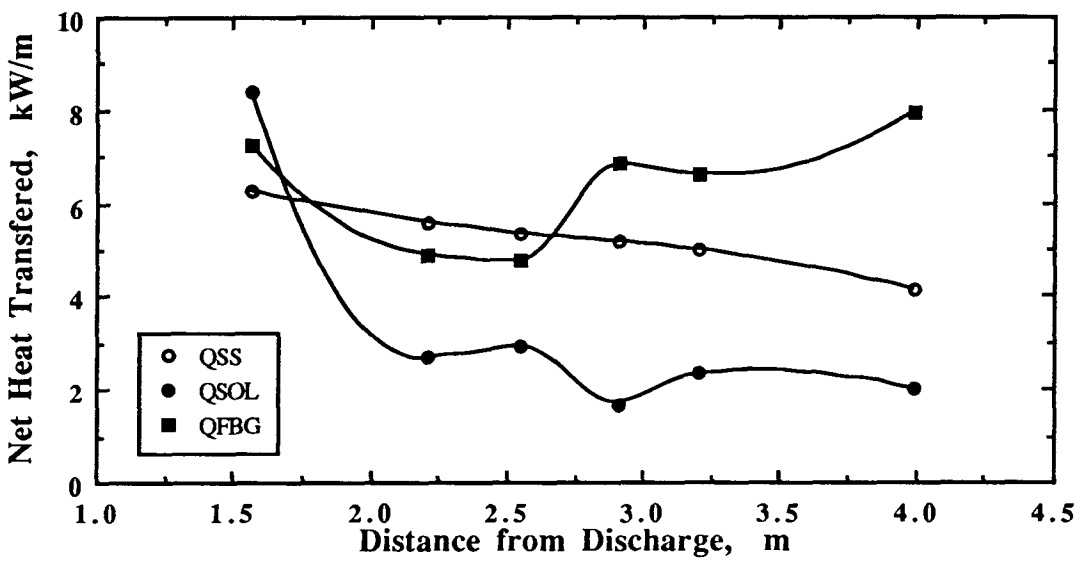


Figure 42. Net heat transfer rates for 100% lignin WV (LG14)

flame region. Substantially more energy appears to be gained by solids bed near the discharge end when the kiln was fueled by lignin, which was also seen in the axial calcination profiles (Fig. 25). However, the points at 2.2 and 2.6 m in Figure 42 are in some doubt, since the shell lost more energy than that apparently lost by the freeboard gas and gained by solids. For those runs which had complete sets of temperature data similar results were found.

The results obtained for global energy balances for all runs are summarized in Table 15. The energy loss due to the discharged of lime, flue gas, heat of calcination and shell as a percentage the total input are also reported. Two energy balances are reported in the table, since the molar flow of the flue gas, using the fuel composition, can be calculated from the supplied air or it may found from the flue gas composition. The second method includes infiltration air that leaked in through the seals and lime discharge chute. The net input of energy by the fuels was found to have a range of 5.14 to 5.48 MJ/min. Approximately 5% of the input energy exited with the lime discharge and about 19% was required for the calcination of the limestone for all runs. For the two different methods of calculation (supplied air and flue gas composition) energy loss by the flue gas and overall net loss are about the same. As expected those runs (LG9,10A,10B) with a slightly moist lignin fuel and the highest freeboard gas velocity had the highest energy loss in the exiting flue gas and lowest overall net losses. Heat loss through the shell was found from the following:

$$\text{Energy Lost} = \text{Energy Input} - \text{Energy Output} - \text{Energy consumed by Calcination}$$

$$\text{Energy Input} = \text{Energy supplied by Fuels} + \text{Energy in with Limestone Fed}$$

$$\text{Energy Output} = \text{Energy out with Lime and Flue Gas}$$

The shell energy loss is about the same whether the kiln was fired by natural gas, dry powdered lignin or a combination of the two fuels. Energy balances for the all runs can be found in Appendix G, with an example calculation provided.

Table 15. Summary of simple energy balances for all runs

Experiment	LG9*	LG10A	LG10B	LG12A	LG12B	LG11	LG17*	LG16*	LG14	LG13	LG14G	LG15A	LG15B
Limestone, MJ/min	0.514	0.508	0.476	0.422	0.437	0.450	0.465	0.491	0.470	0.390	0.423	0.423	0.450
Fuel, MJ/min	5.433	5.279	5.263	5.220	5.221	5.250	5.296	5.391	5.484	5.141	5.141	5.141	5.524
Total IN, MJ/min	5.948	5.787	5.739	5.643	5.658	5.701	5.761	5.881	5.954	5.531	5.563	5.564	5.974
Lime, MJ/min	0.268	0.305	0.254	0.274	0.299	0.253	0.317	0.315	0.294	0.287	0.313	0.404	0.345
	4.51%	5.28%	4.42%	4.86%	5.29%	4.43%	5.50%	5.36%	4.94%	5.19%	5.63%	7.26%	5.77%
Calcination, MJ/min	1.143	1.141	1.056	1.034	1.042	1.070	1.207	1.180	1.094	0.954	1.093	1.014	1.147
	19.22%	19.72%	18.41%	18.32%	18.41%	18.76%	20.95%	20.07%	18.37%	17.26%	19.65%	18.23%	19.20%
by Supplied Air													
Flue Gas, MJ/min	2.130	2.007	2.071	1.603	1.658	1.697	1.541	1.662	1.440	1.416	1.406	1.303	1.543
	35.81%	34.68%	36.09%	28.40%	29.30%	29.77%	26.75%	28.27%	24.19%	25.61%	25.26%	23.41%	25.84%
Total OUT, MJ/min	3.541	3.454	3.381	2.911	2.999	3.020	3.065	3.158	2.828	2.658	2.812	2.721	3.035
Loss, MJ/min	2.407	2.333	2.358	2.732	2.659	2.681	2.697	2.724	3.126	2.873	2.751	2.843	2.939
	40.47%	40.32%	41.08%	48.42%	47.00%	47.03%	46.80%	46.31%	52.50%	51.94%	49.45%	51.10%	49.19%
by GC Analyses													
Flue Gas, MJ/min	2.163	2.054	2.134	1.617	1.673	1.780	1.729	1.821	1.648	1.574	1.542	1.453	1.724
	36.37%	35.49%	37.17%	28.65%	29.57%	31.22%	30.01%	30.97%	27.68%	28.46%	27.72%	26.12%	28.86%
Total OUT, MJ/min	3.574	3.500	3.444	2.925	3.014	3.102	3.253	3.317	3.036	2.815	2.949	2.872	3.216
Loss, MJ/min	2.374	2.287	2.295	2.718	2.644	2.598	2.509	2.565	2.918	2.715	2.614	2.692	2.758
	39.91%	39.51%	39.99%	48.17%	46.73%	45.58%	43.54%	43.61%	49.01%	49.09%	46.99%	48.39%	46.17%

* estimated values used, see Appendix G

Conclusions

In order to access the suitability of lignin as a potential fuel for the lime kiln, a series of trials were carried out using a 0.41 m ID by 5.5 m pilot rotary kiln. Lignin from three industrial sources, Irving, Prince George and Westvaco were used during the work. The source lignins were obtained both by carbon dioxide (Irving, Westvaco) and sulphuric acid precipitation (Prince George). The lignins were fired as solid powders in conjunction with natural gas at various levels of gas replacement up to 100%. Baseline conditions were in each case established using natural gas as the sole fuel.

Once an appropriate feed system and burner configuration were developed, all the lignins were found to burn successfully in the pilot kiln. The lignin flames were longer and brighter than that of natural gas, which considerably alter the axial temperature profiles within the kiln, both for the bed and freeboard gas. The flame length produced by the powdered lignin was found to depend primarily upon the lignin particle size.

At equal specific energy inputs per unit mass of limestone (MJ/kg $CaCO_3$), lignin was found to result in a higher level of calcination than for natural gas. Gas and solids temperatures were also higher at a given location in the kiln, which was due to the higher emissivity of the lignin flame compared to that of natural gas. In the flame region, the lignin fuel significantly improved heat transfer to the bed relative to natural gas. This was reflected in the axial calcination profiles, in which calcination commenced somewhat earlier with lignin firing. No discernible differences were found between the carbon dioxide and the acid precipitated lignins. These results suggest that the throughput of a natural gas fired rotary kiln could be increased if lignin was used in conjunction with natural gas at high levels of replacement or as the sole fuel, the nature of the pilot kiln tests did not allow the benefits for a commercial scale kiln to be quantified.

The limes produced with lignin as fuel were found to be as reactive in slaking as those produced by gas firing. Lignin IR produced the fastest slaking limes and also had the highest surface area of the limes firing with lignin,

which could have been due to slight moisture content. The surface area of the product limes was increased 2 to 3 times when the kiln was fired using lignin as the sole fuel. The levels of sodium, sulphur and other inert elements found in the lignins did not effect kiln operation or the quality of lime (reactivity and maximum temperature achieved). The sodium and sulphur added by the lignin fuel was presumed to leave the kiln in the dust stream. With dust recycling all sodium and sulphur entering the kiln with the lignin as a fuel will be discharged in the lime.

The pilot kiln work suggests that lignin would be a suitable fuel for the lime kiln, and that lime kiln productivity might be increased relative to natural gas firing. Although some fraction of the trace elements in the lignin ash will inevitably appear in the product lime, they do not appear to inhibit the reactivity of the product. In summary, full scale trials will be necessary to confirm the results and to identify any potential long–term effects, on white liquor quality, the lime cycle and the life of the kiln refractory.

Recommendations for Future Work

It is evident that impurities in the lignin fuel will contaminate the lime in a kiln with dust recycle. Research is therefore needed on the comparison of sulphuric acid versus carbon dioxide precipitation of lignin and its' subsequent washing to yield lignins with low concentrations of sodium and sulphur. A study of the effect of carbon dioxide from flue gas on precipitation of lignin would also be useful.

The powdered lignin feed system for the pilot kiln produced a pulsing flame. The screw feeder needs to be redesigned (made smaller) or a different feed system developed, such that this problem may be eliminated. A proper type of burner should be investigated to maximize the full heating potential of powdered lignin. A burner that would perform improved mixing of both combustion air and powdered lignin might give a better flame than the one accomplished in the pilot kiln [11]. The length of the present kiln should be extended to incorporate a chain section, and a dust collection and recycle system to study long term effects of lignin burning on lime mud. An extension of this research project should be carried out to develop methods for firing a lignin–water–fuel oil slurry to eliminate the need and cost of drying lignin.

Computer simulation of the lime cycle might help to determine the fate of the inert compounds formed in the lime kiln.

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Appendix A

Refractory Composition and Thermal Conductivity

Refractory Composition

				wt %			
Refractory	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	CaO	MgO	Alkaliner
Plicast LWI28†	46.68	43.93	0.97	0.98	5.52	0.26	1.08
Claycast 60ES††	60	33	—	—	—	—	—

† Manufactured by Plibrico Co.

†† Manufactured by Clayburn Refractories Ltd. The other 7% is unknown.

Thermal Conductivity, (W/m °C)

			°C			
Refractory	260	538	815	1093	1371	Max T°C
Plicast LWI28‡	0.30	0.33	0.35	0.42	—	1450
Claycast 60ES‡‡	0.98	1.04	1.10	1.14	1.18	1650

‡ $k = 0.892 * (1.000 + 2.018 * 10^{-4} * T (K))$ $R^2 = 0.989$

‡‡ $k = 0.22 * (1.000 + 6.227 * 10^{-4} * T (K))$ $R^2 = 0.926$

Appendix B

Calibration Charts

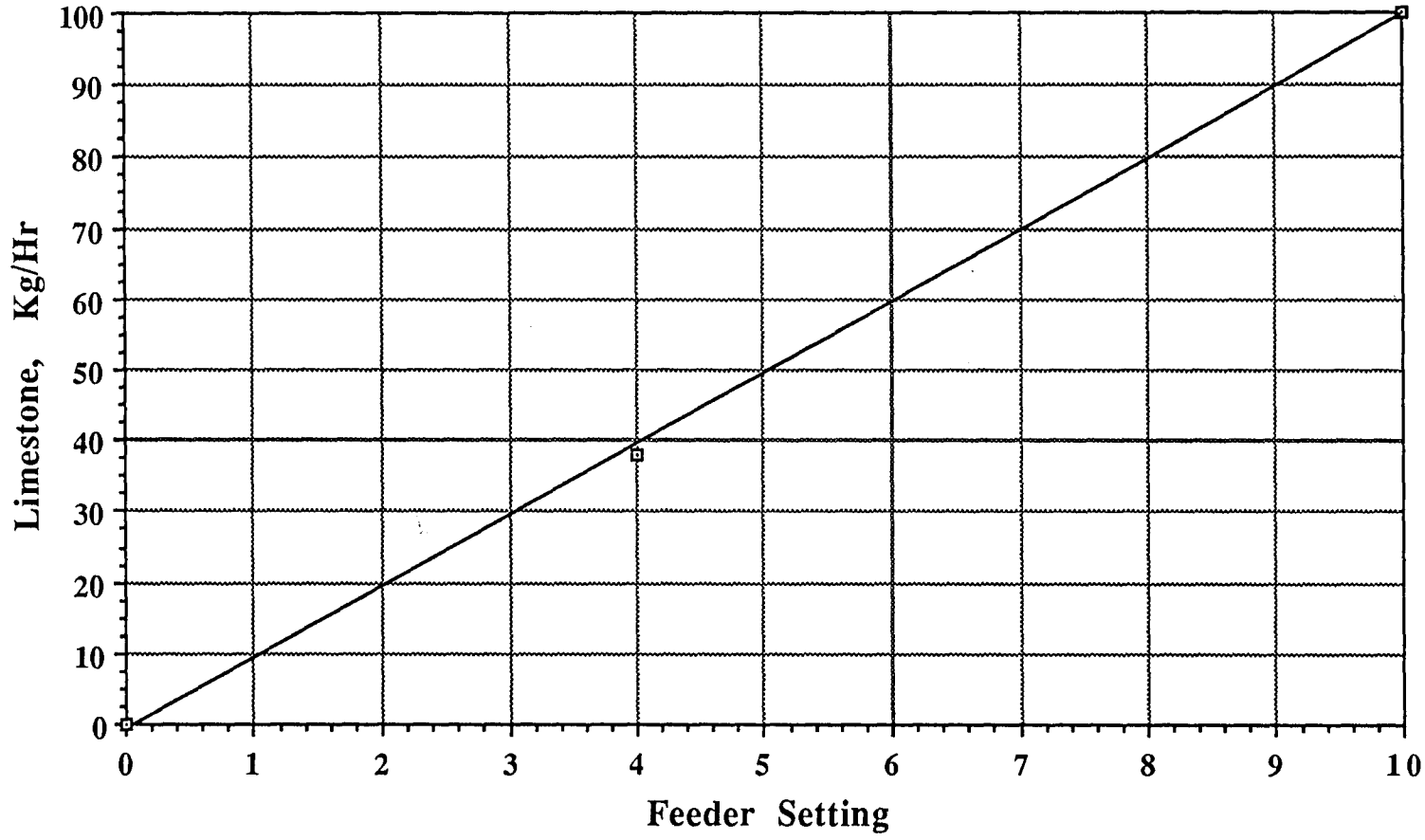


Figure B–1. Conveyor belt feeder calibration for limestone

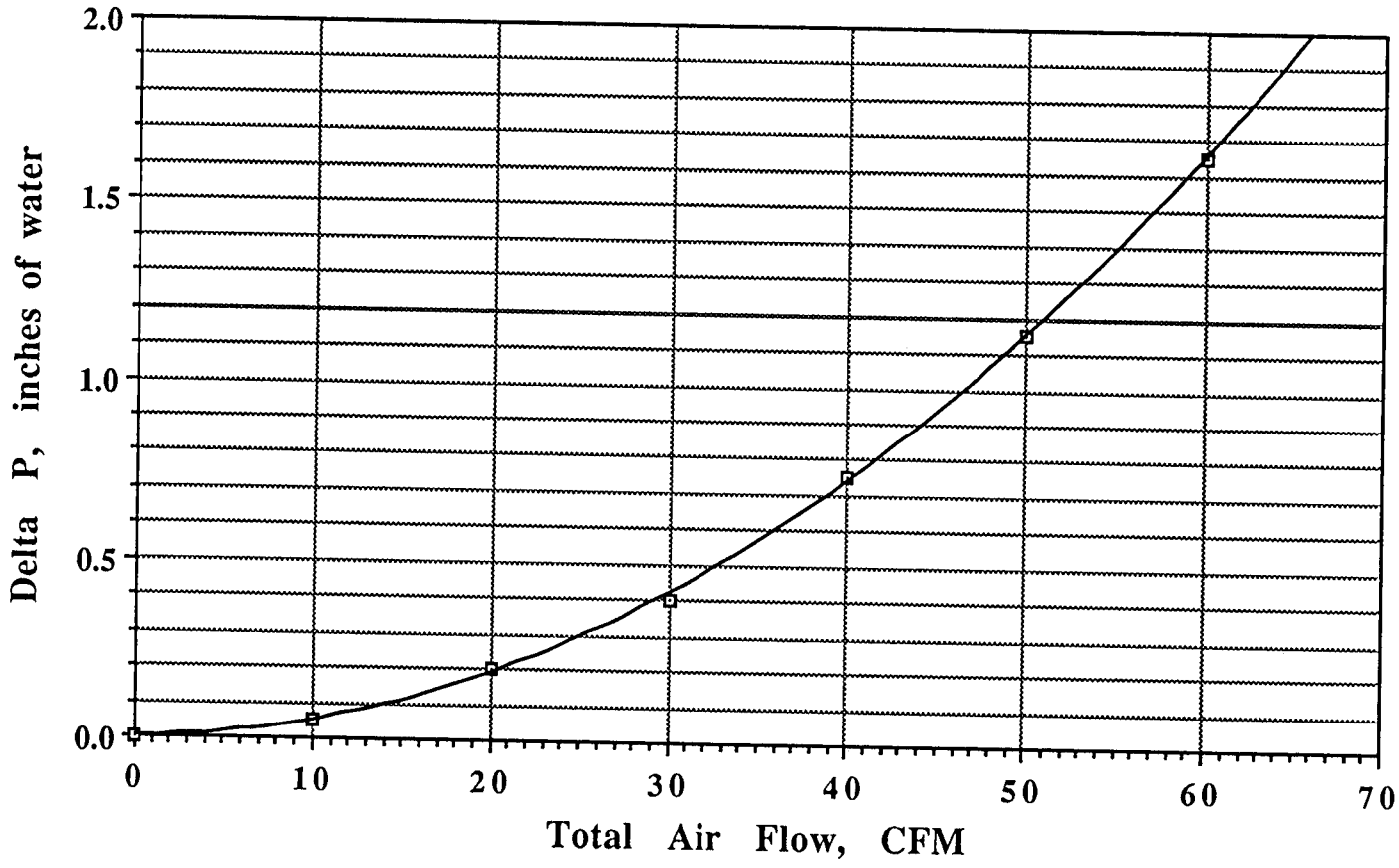


Figure B–2. Orifice plate calibration for total air flow

Appendix C

Calcination Results of Limestone Feed

Limestone	# 1	# 2	# 3	# 4	# 5
Date	13/Oct/89	22/Oct/89	22/Oct/89	22/Oct/89	22/Oct/89
Before Firing, g	30.3096	27.3167	24.6708	24.8741	25.2667
After Firing, g	22.2671	20.0647	18.3084	18.5973	18.9368
Empty Crucible, g	11.5553	10.4888	9.8948	10.2082	10.4420
Wt of $CaCO_3$, g	18.7543	16.8279	14.7760	14.6659	14.8247
Wt Loss by $CaCO_3$, g	8.0425	7.2520	6.3624	6.2768	6.3299
% Calcination	97.46	97.94	97.86	97.27	97.04

Limestone	# 6	# 7	# 8	# 9	# 10
Date	22/Oct/89	20/Feb/90	20/Feb/90	15/Mar/90	16/Mar/90
Before Firing, g	23.2220	26.8457	27.4940	28.9997	28.5065
After Firing, g	17.5497	19.7376	19.9276	20.9879	20.7330
Empty Crucible, g	10.0075	10.4444	10.0100	10.4949	10.4958
Wt of $CaCO_3$, g	13.2145	16.4013	17.4840	18.5048	18.0107
Wt Loss by $CaCO_3$, g	5.6723	7.1081	7.5664	8.0118	7.7735
% Calcination	97.56	98.50	98.35	98.40	98.09

Limestone	# 11	# 12	# 13	# 14	# 15
Date	17/Mar/90	19/Mar/90	20/Mar/90	21/Mar/90	23/Mar/90
Before Firing, g	29.4208	28.9511	27.8464	29.0938	27.9384
After Firing, g	21.2471	20.9772	20.4090	21.0802	20.4581
Empty Crucible, g	10.4986	10.5036	10.5040	10.5086	10.5070
Wt of $CaCO_3$, g	18.9222	18.4475	17.3424	18.5852	17.4314
Wt Loss by $CaCO_3$, g	8.1737	7.9739	7.4374	8.0136	7.4803
% Calcination	98.17	98.24	97.47	98.00	97.53

Limestone	# 16	# 17	# 18	# 19	# 20
Date	24/Mar/90	25/Mar/90	26/Mar/90	27/Mar/90	28/Mar/90
Before Firing, g	29.3576	29.1990	28.2172	29.9685	29.1140
After Firing, g	21.2143	21.1405	20.5941	21.5937	21.0819
Empty Crucible, g	10.5138	10.5143	10.5150	10.5185	10.5209
Wt of $CaCO_3$, g	18.8438	18.6847	17.7022	19.4500	18.5931
Wt Loss by $CaCO_3$, g	8.1433	8.0585	7.6231	8.3748	8.0321
% Calcination	98.22	98.02	97.87	97.86	98.18

Limestone	# 21	# 22	# 23	# 24	# 25
Date	29/Mar/90	30/Mar/90	31/Mar/90	1/Apr/90	10/Apr/90
Before Firing, g	28.4322	29.4117	30.3567	30.5787	29.1542
After Firing, g	20.7483	21.2605	21.7921	21.8988	21.1270
Empty Crucible, g	10.5227	10.5245	10.5265	10.5287	10.5322
Wt of $CaCO_3$, g	17.9095	18.8872	19.8302	20.0500	18.6220
Wt Loss by $CaCO_3$, g	7.6839	8.1512	8.5646	8.6799	8.0272
% Calcination	97.51	98.08	98.16	98.39	97.97

Limestone	# 26	# 27	# 28	# 29	# 30
Date	11/Apr/90	12/Apr/90	3/Jun/90	4/Jun/90	5/Jun/90
Before Firing, g	28.8249	28.6348	29.4055	29.3821	29.5828
After Firing, g	20.9188	20.8138	21.2638	21.2664	21.3330
Empty Crucible, g	10.5340	10.5370	10.5372	10.5428	10.5457
Wt of $CaCO_3$, g	18.2909	18.0978	18.8683	18.8393	19.0371
Wt Loss by $CaCO_3$, g	7.9061	7.8210	8.1417	8.1157	8.2498
% Calcination	98.24	98.22	98.07	97.91	98.49

Limestone	# 31	# 32	# 33	# 34	# 35
Date	6/Jun/90	7/Jun/90	8/Jun/90	16/Jun/90	17/Jun/90
Before Firing, g	29.3619	28.6692	29.3665	28.2046	28.4858
After Firing, g	21.3028	20.8729	21.2600	20.5521	20.6814
Empty Crucible, g	10.5472	10.5522	10.5525	10.5529	10.5549
Wt of $CaCO_3$, g	18.8147	18.1170	18.8140	17.6517	17.9309
Wt Loss by $CaCO_3$, g	8.0591	7.7963	8.1065	7.6525	7.8044
% Calcination	97.35	97.80	97.93	98.53	98.92

Average of #1 to 34 for experimental runs LG1 to LG13 = 97.95%

Limestone	# 36	# 37	# 38	# 39	# 40
Date	18/Jun/90	19/Jun/90	24/Jun/90	25/Jun/90	26/Jun/90
Before Firing, g	28.2881	28.5696	27.8919	27.3934	27.0131
After Firing, g	20.5616	20.7300	20.3687	20.0624	19.8664
Empty Crucible, g	10.5564	10.5564	10.5600	10.5621	10.5642
Wt of $CaCO_3$, g	17.7317	18.0132	17.3319	16.8313	16.4489
Wt Loss by $CaCO_3$, g	7.7265	7.8396	7.5232	7.3310	7.1467
% Calcination	99.03	98.91	98.65	98.99	98.75

Limestone	# 41	# 42	# 43	# 44
Date	27/Jun/90	28/Jun/90	29/Jun/90	30/Jun/90
Before Firing, g	29.9617	29.1080	28.2710	28.2006
After Firing, g	21.5086	21.0320	20.5537	20.5163
Empty Crucible, g	10.5659	10.5671	10.5692	10.5709
Wt of $CaCO_3$, g	19.3958	18.5409	17.7018	17.6297
Wt Loss by $CaCO_3$, g	8.4531	8.0760	7.7173	7.6843
% Calcination	99.05	98.99	99.08	99.06

Average of #35 to #44 for experimental runs LG14 to LG18 = 98.96%

Appendix D

Page

Run LG12

Run LG13

Run LG14

Page

Run LG15

Run LG16

Run LG17

Note: The tables containing temperature data within this appendix include all values recorded during the experimental runs, only the very obvious errors have been eliminated. All recorded data is availible on a high density disk (1.2MB) in spreadsheet format (Lotus 123).

Run LG9

Table of Events

Action Requested by Operator	Time
3/13/90	11:13:15.83
Kiln speed (rpm) : 1.5	11:13:20.06
Lignin = 145 g/min Gas = 2.2 CFM	10:30:00
Read Bed Temperatures	11:15:44.29
Read Hot Face Heat Flux Temperatures	11:17:15.30
Read Colder Heat Flux Temperatures	11:18:39.67
Suction T/C, Pair : 1	11:19:18.06
Suction T/C, Pair : 2	11:21:22.25
Suction T/C, Pair : 3	11:23:17.26
Suction T/C, Pair : 4	11:25:11.62
Suction T/C, Pair : 5	11:27:09.93
Read Bed Temperatures	11:35:27.06
Read Hot Face Heat Flux Temperatures	11:37:38.71
Read Colder Heat Flux Temperatures	11:39:03.08

Cyclic Bed Temperature Readings

11:15:44.29	1	2	3	4	5	6	7	8	9	10
0	996.22	1050.95	1056.12	976.91	918.05	876.33	853.58	814.74	727.57	652.31
36	992.72	1046.64	1056.12	981.31	920.79	879.03	856.02	817.40	729.71	655.14
72	993.60	1047.50	1056.12	983.95	922.78	881.24	857.73	819.33	731.14	657.50
108	997.97	1052.68	1057.84	988.34	924.52	883.70	858.70	820.54	732.09	659.62
144	1004.09	1062.14	1059.56	990.09	925.52	885.67	858.95	820.30	731.61	660.57
180	1007.59	1069.87	1063.00	992.72	925.27	885.67	856.99	816.43	728.52	659.15
216	1010.20	1075.86	1065.58	991.84	923.52	884.44	854.80	812.33	724.96	655.85
252	1010.20	1072.44	1066.43	982.19	919.79	877.80	849.92	799.31	720.92	649.24
288	1008.46	1059.56	1063.00	976.03	917.31	875.35	849.92	805.81	723.06	648.53
324	999.72	1054.40	1061.28	978.67	918.30	877.31	852.36	812.08	726.14	650.42
360	994.47	1051.81	1060.42	982.19	920.54	881.24	854.80	815.95	728.52	653.02
396	990.97	1047.50	1059.56	984.82	923.03	884.93	856.99	818.13	730.42	655.85
432	993.60	1049.23	1059.56	988.34	925.02	887.64	858.95	820.79	732.09	658.44
468	997.97	1056.12	1061.28	990.97	926.51	889.61	859.68	821.03	732.80	660.33
504	1004.09	1063.86	1063.86	993.60	926.26	889.61	858.46	819.09	731.85	660.80
540	1008.46	1070.72	1066.43	994.47	925.02	888.13	856.02	814.74	728.52	658.68
576	1013.69	1076.72	1068.15	994.47	923.52	885.91	853.82	808.95	724.96	654.67
612	1012.82	1074.15	1067.29	982.19	919.30	877.80	849.19	798.83	721.87	649.01
648	1013.69	1065.58	1065.58	979.55	917.31	874.86	849.92	806.54	724.24	649.24
684	1012.82	1066.43	1063.86	980.43	918.05	875.84	852.11	811.60	727.10	651.60
Minimum	990.97	1046.64	1056.12	9976.03	917.31	874.86	849.19	798.83	720.92	648.53
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

11:35:27.06	1	2	3	4	5	6	7	8	9	10
0	924.66	1032.82	1075.88	1010.20	942.61	903.56	874.26	834.50	744.15	669.46
36	922.04	1032.82	1076.73	1012.81	944.36	905.29	875.48	835.47	744.86	671.59
72	915.92	1031.09	1077.59	1015.43	945.36	906.28	875.48	834.50	744.15	672.53
108	909.78	1026.73	1078.45	1016.30	944.86	905.29	873.28	829.89	741.76	671.12
144	N/A	N/A	N/A	N/A	N/A	N/A	873.28	829.89	741.76	671.12
180	907.15	1021.52	1079.30	1008.46	938.61	896.39	864.95	813.20	733.67	661.20
216	911.54	1017.17	1077.59	1000.59	936.11	892.45	865.19	819.48	735.34	660.02
252	911.54	1018.91	1076.73	1001.47	937.11	893.68	867.40	825.53	738.19	661.91
288	N/A	N/A	N/A	N/A	N/A	N/A	867.40	825.53	738.19	661.91
324	920.29	1028.46	1075.88	1006.71	941.11	899.85	872.30	832.56	743.19	667.57
360	N/A	N/A	N/A	N/A	N/A	N/A	872.30	832.56	743.19	667.57
396	918.54	1030.22	1074.16	1011.07	943.61	905.54	874.99	835.47	745.58	672.53
432	910.66	1025.86	1074.16	1011.94	943.11	906.28	874.01	833.53	744.62	673.01
468	901.88	1018.04	1073.31	1011.07	940.86	904.55	871.56	829.40	740.81	670.65
504	891.30	1010.20	1070.74	1009.33	937.61	902.07	868.62	823.83	736.53	666.63
540	901.00	1006.71	1067.30	998.84	932.62	894.17	863.24	812.47	732.96	660.02
576	901.00	990.96	1058.71	990.08	927.88	889.25	860.55	814.40	732.96	658.60
612	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
648	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
684	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum	891.30	990.96	1058.71	990.08	927.88	889.25	860.55	812.47	732.96	665.60
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

11:17:15.30	1	2	3	4	5	6	7	8	9	10
0	N/A	1048.42	925.58	800.80	N/A	N/A	600.28	575.55	430.24	N/A
36	N/A	1051.00	926.46	800.56	N/A	N/A	600.28	576.02	430.95	N/A
72	N/A	1055.31	929.08	800.32	N/A	N/A	600.28	576.25	431.43	N/A
108	N/A	1043.24	926.46	800.56	N/A	N/A	599.81	576.25	429.52	N/A
144	N/A	1032.00	920.34	802.25	N/A	N/A	599.34	575.55	426.18	N/A
180	N/A	1032.00	917.72	803.93	N/A	N/A	599.81	575.07	425.47	N/A
216	N/A	1043.24	920.34	803.69	N/A	N/A	600.04	574.84	426.66	N/A
252	N/A	1044.97	922.09	802.73	N/A	N/A	600.51	575.07	427.61	N/A
288	N/A	1045.83	923.84	801.76	N/A	N/A	600.51	575.07	428.81	N/A
324	N/A	1046.69	924.71	801.28	N/A	N/A	600.75	575.55	429.76	N/A
360	N/A	1050.14	926.46	800.80	N/A	N/A	600.75	576.02	430.71	N/A
396	N/A	1054.45	929.08	800.56	N/A	N/A	600.75	576.25	431.43	N/A
432	N/A	1056.17	929.08	800.56	N/A	N/A	600.51	576.49	431.90	N/A
468	N/A	1041.51	924.71	800.80	N/A	N/A	600.04	576.49	429.28	N/A
504	N/A	1032.00	919.47	802.73	N/A	N/A	599.57	575.78	426.42	N/A
540	N/A	1037.19	917.72	803.93	N/A	N/A	600.04	575.31	426.42	N/A
576	N/A	1045.83	920.34	803.45	N/A	N/A	600.51	575.31	427.38	N/A
612	N/A	1047.55	922.09	802.73	N/A	N/A	600.75	575.31	428.33	N/A
648	N/A	1046.69	922.96	802.01	N/A	N/A	600.75	575.55	429.52	N/A
684	N/A	1047.55	924.71	801.28	N/A	N/A	600.98	576.02	430.47	N/A
Average	N/A	1045.09	923.66	801.84	N/A	N/A	600.31	575.69	428.93	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

11:37:38.71	1	2	3	4	5	6	7	8	9	10
0	N/A	903.74	884.33	819.34	N/A	N/A	606.61	578.12	434.02	N/A
36	N/A	909.88	882.56	819.10	N/A	N/A	606.14	577.64	430.44	N/A
72	N/A	915.14	881.68	818.13	N/A	N/A	605.91	576.94	427.82	N/A
108	N/A	909.88	879.90	817.16	N/A	N/A	605.67	576.47	427.58	N/A
144	N/A	901.10	877.24	816.92	N/A	N/A	605.44	575.76	428.06	N/A
180	N/A	898.46	875.47	816.68	N/A	N/A	604.97	575.29	428.53	N/A
216	N/A	895.81	873.69	816.19	N/A	N/A	604.73	574.82	429.01	N/A
252	N/A	890.52	871.02	815.71	N/A	N/A	604.50	574.58	429.49	N/A
288	N/A	885.22	869.25	815.23	N/A	N/A	604.02	573.87	429.73	N/A
324	N/A	879.90	866.58	814.99	N/A	N/A	603.79	573.64	429.96	N/A
360	N/A	875.47	864.79	814.75	N/A	N/A	603.32	573.17	429.73	N/A
396	N/A	886.10	863.90	814.26	N/A	N/A	603.32	572.70	426.15	N/A
432	N/A	890.52	863.90	813.05	N/A	N/A	603.08	571.99	423.29	N/A
468	N/A	881.68	862.12	811.85	N/A	N/A	602.61	571.52	423.29	N/A
504	N/A	876.36	860.33	811.61	N/A	N/A	602.14	571.05	423.76	N/A
540	N/A	874.58	858.55	811.12	N/A	N/A	601.90	570.34	424.00	N/A
576	N/A	871.02	856.76	810.64	N/A	N/A	601.43	569.87	424.48	N/A
612	N/A	866.58	854.97	809.92	N/A	N/A	601.20	569.40	424.72	N/A
648	N/A	863.01	853.18	809.43	N/A	N/A	600.73	568.69	424.96	N/A
684	N/A	856.76	851.39	809.19	N/A	N/A	600.26	568.22	425.20	N/A
Average	N/A	886.59	867.58	814.26	N/A	N/A	603.59	573.20	427.21	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

Interior Wall Probe Temperature Readings

11:18:39.67	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	316.51	753.74	1025.91
1.568	N/A	601.89	867.44
2.064	307.17	N/A	822.05
2.375	N/A	587.32	N/A
2.724	292.12	528.63	N/A
3.048	213.76	470.66	647.88
4.070	197.82	389.85	590.39
4.585	174.48	300.62	509.26
5.213	152.35	270.95	396.79

11:39:03.08	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	319.70	758.38	891.40
1.568	N/A	605.79	849.60
2.064	311.24	N/A	814.26
2.375	N/A	592.48	N/A
2.724	298.38	535.21	N/A
3.048	214.93	478.46	655.87
4.070	204.63	399.39	593.90
4.585	180.32	309.30	515.85
5.213	156.71	278.45	402.74

NOTE: This set of data was used for steady state calculations.

Suction Pyrometer Temperature Readings of Flue Gas

	11:19:18.06		11:21:22.25		11:23:17.26		11:25:11.62		11:27:09.93	
	1	2	3	4	5	6	7	8	9	10
0	1114.34	1164.94	1136.45	1020.92	935.36	N/A	N/A	N/A	N/A	N/A
36	1138.01	1169.97	1146.57	1020.92	940.36	N/A	N/A	N/A	N/A	N/A
72	1145.59	1169.14	1154.98	1029.62	944.11	N/A	N/A	N/A	N/A	N/A
108	1110.95	1154.85	1147.41	1026.99	948.12	N/A	N/A	N/A	783.03	N/A
144	1058.84	1138.85	1157.51	1036.55	951.63	N/A	N/A	N/A	788.55	N/A
180	1018.18	1121.11	1146.57	1033.08	956.91	N/A	N/A	N/A	793.12	N/A
216	1014.70	1124.49	1149.93	1040.00	962.19	N/A	N/A	N/A	795.04	N/A
252	1044.19	1125.34	1156.67	1045.19	964.97	N/A	N/A	N/A	795.77	N/A
288	1061.42	1147.28	1164.23	1041.73	966.98	N/A	N/A	N/A	792.64	N/A
324	1093.09	1165.78	1170.94	1044.32	968.25	N/A	N/A	N/A	790.72	N/A
360	1121.11	1175.01	1169.27	1043.46	969.25	N/A	N/A	N/A	789.76	N/A
396	1143.91	1177.52	1164.23	1042.60	969.76	N/A	N/A	N/A	789.03	N/A
432	1133.79	1168.30	1155.82	1038.28	971.78	N/A	N/A	N/A	794.08	N/A
468	1099.05	1155.69	1149.09	1043.46	973.55	N/A	N/A	N/A	796.97	N/A
504	1042.47	1140.54	1152.46	1043.46	975.83	N/A	N/A	N/A	801.06	N/A
540	1019.92	1129.57	1162.55	1049.50	977.34	N/A	N/A	N/A	804.43	N/A
576	1027.73	1125.34	1171.78	1051.22	977.34	N/A	N/A	N/A	803.47	N/A
612	1051.95	1126.18	1169.27	1048.64	976.08	N/A	N/A	N/A	802.99	N/A
648	1070.86	1152.33	1162.55	1048.64	974.81	N/A	N/A	N/A	797.69	N/A
684	1099.90	1169.97	1169.27	1047.77	973.30	N/A	N/A	N/A	796.49	N/A
Average	1080.50	1150.11	1157.88	1039.82	963.90	N/A	N/A	N/A	794.99	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Shell Temperature Readings

Time	Position, metres				
	0.146	0.921	1.492	2.210	5.354
7:57	137	103	88	72	52
9:10	187	152	127	106	66
10:17	209	182	157	140	83
10:39	216	188	166	151	90

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
8:47	2	80.8	6.2	13.0
8:52	2	74.1	3.3	22.6
8:51	2	82.2	4.4	13.4
N/A	2	81.1	4.0	14.9
9:10	2	81.1	1.1	17.8
9:40	2	79.5	5.7	14.8
9:50	7	75.3	3.4	21.3
10:27	2	78.4	8.9	12.7
10:52	2	79.1	8.3	12.6
11:04	7	81.9	5.1	13.0

Axial Calcination Results

Lignin = 180 g/m	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3
Sample Code	LPA	LPA	L#1A	L#1A	L#2A	L#2A	L#3A	L#3A
Date	26/Mar/90	26/Mar/90	26/Mar/90	26/Mar/90	26/Mar/90	26/Mar/90	26/Mar/90	26/Mar/90
Before Firing, g	20.9786	20.0579	20.5460	20.8509	23.9568	24.1926	27.5736	25.5930
After Firing, g	20.8534	19.9445	20.4877	20.7969	20.7289	20.7789	21.2049	19.6642
Empty Crucible, g	9.9232	10.2387	10.4723	10.0361	10.9423	10.0557	11.0206	10.0230
Wt of Sample Before, g	11.0554	9.8192	10.0737	10.8148	13.0145	14.1369	16.5530	15.5700
Wt Loss by $CaCO_3$, g	0.1252	0.1134	0.0583	0.0540	3.2279	3.4137	6.3687	5.9288
% Calcination	97.37	97.32	98.66	98.84	42.45	43.97	10.73	11.65
Average =	97.35%		98.75%		43.21%		11.19%	

Lignin = 180 g/m	Port #4	Port #4	Port #5	Port #5
Sample Code	L#4A	L#4A	L#5A	L#5A
Date	26/Mar/90	26/Mar/90	27/Mar/90	27/Mar/90
Before Firing, g	26.9379	28.2629	26.8597	26.7422
After Firing, g	20.1154	20.8642	19.5650	19.6306
Empty Crucible, g	10.7268	10.5694	9.9272	10.2429
Wt of Sample Before, g	16.2111	17.6935	16.9325	16.4993
Wt Loss by $CaCO_3$, g	6.8225	7.3987	7.2947	7.1116
% Calcination	2.35	2.98	0.04	-0.01
Average =	2.66%		0.02%	

Lignin = 145 g/m	Product	Product
Sample Code	LPB	LPB
Date	27/Mar/90	27/Mar/90
Before Firing, g	20.9257	20.5367
After Firing, g	20.8611	20.4757
Empty Crucible, g	10.4753	10.0393
Wt of Sample Before, g	10.4504	10.4974
Wt Loss by $CaCO_3$, g	0.0646	0.0610
% Calcination	98.57	98.65
		98.61%

Lignin = 145 g/m	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3	Port #4	Port #4
Sample Code	L#1B	L#1B	L#2B	L#2B	L#3B	L#3B	L#4B	L#4B
Date	27/Mar/90	27/Mar/90	27/Mar/90	27/Mar/90	27/Mar/90	31/Mar/90	28/Mar/90	28/Mar/90
Before Firing, g	22.1239	20.4275	25.4042	25.1964	25.8878	26.4281	27.9586	26.1981
After Firing, g	21.4329	19.8168	20.8530	20.3326	19.9834	20.4648	20.3161	19.4765
Empty Crucible, g	10.9452	10.0595	11.0250	10.0279	10.5753	10.9609	9.9291	10.2443
Wt of Sample Before, g	11.1787	10.3680	14.3792	15.1685	15.3125	15.4672	18.0295	15.9538
Wt Loss by $CaCO_3$, g	0.6910	0.6107	4.5512	4.8638	5.9044	5.9633	7.6425	6.7216
% Calcination	85.66	86.33	26.56	25.60	10.53	10.54	1.65	2.24

Average = 86.00% 26.08% 10.54% 1.94%

Lignin = 145 g/m	Port #5	Port #5	Port #6	Port #6
Sample Code	L#5B	L#5B	L#6B	L#6B
Date	28/Mar/90	28/Mar/90	28/Mar/90	28/Mar/90
Before Firing, g	27.4736	26.6750	29.4479	27.8624
After Firing, g	20.1628	19.5045	21.4350	20.1509
Empty Crucible, g	10.4778	10.0435	10.9471	10.0624
Wt of Sample Before, g	16.9958	16.6315	18.5008	17.8000
Wt Loss by $CaCO_3$, g	7.3108	7.1705	8.0129	7.7115
% Calcination	0.19	-0.04	-0.49	-0.52

Average = 0.10% 0.00%

Natural Gas = 5.4 CFM	Product	Product	Product
Sample Code	GP	GP	GP
Date	25/Mar/90	25/Mar/90	31/Mar/90
Before Firing, g	24.7015	24.1938	25.3791
After Firing, g	21.3024	20.5060	21.3735
Empty Crucible, g	10.7241	10.5671	9.9385
Wt of Sample Before, g	13.9774	13.6267	15.4406
Wt Loss by $CaCO_3$, g	3.3991	3.6878	4.0056
% Calcination	43.57	37.21	39.81

40.20%

Run LG10

Table of Events

Action Requested by Operator	Time
3/15/90	10:18:41.66
Kiln speed (rpm) : 1.5	10:18:45.67
Gas = 5.4 CFM	9:30:00
Read Bed Temperatures	11:42:12.79
Read Hot Face Heat Flux Temperatures	11:43:43.36
Read Colder Heat Flux Temperatures	11:45:07.40
Suction T/C, Pair : 1	11:45:39.81
Suction T/C, Pair : 1	11:47:10.27
Suction T/C, Pair : 2	11:51:32.37
Suction T/C, Pair : 3	11:53:02.07
Suction T/C, Pair : 4	11:54:34.12
Suction T/C, Pair : 5	11:56:18.09
Lignin = 180 g/min Gas = 1.4 CFM	12:10:00
Read Bed Temperatures	12:43:48.07
Read Hot Face Heat Flux Temperatures	12:45:25.29
Read Colder Heat Flux Temperatures	12:46:49.32
Suction T/C, Pair : 1	12:48:09.18
Suction T/C, Pair : 2	12:49:44.48
Suction T/C, Pair : 3	12:51:14.34
Read Hot Face Heat Flux Temperatures	12:52:54.52
Read Colder Heat Flux Temperatures	12:54:18.39
Read Bed Temperatures	13:10:36.23
Read Hot Face Heat Flux Temperatures	13:12:08.45
Read Colder Heat Flux Temperatures	13:13:32.49
Suction T/C, Pair : 1	13:48:25.48
Suction T/C, Pair : 2	13:49:51.16
Suction T/C, Pair : 3	13:52:56.76
Suction T/C, Pair : 4	13:54:21.01

Lignin = 240 g/min Gas = 0.0 CFM	13:56:00
Read Bed Temperatures	14:19:09.82
Read Hot Face Heat Flux Temperatures	14:21:04.18
Read Colder Heat Flux Temperatures	14:22:28.32
Suction T/C, Pair : 1	14:22:55.07
Suction T/C, Pair : 2	14:24:19.22
Suction T/C, Pair : 3	14:26:00.01
Read Hot Face Heat Flux Temperatures	14:27:24.43
Read Colder Heat Flux Temperatures	14:28:48.35
Suction T/C, Pair : 4	14:30:41.99
Suction T/C, Pair : 5	14:32:12.35
Read Bed Temperatures	14:44:14.67
Read Hot Face Heat Flux Temperatures	14:45:45.41
Read Colder Heat Flux Temperatures	14:47:09.55
Suction T/C, Pair : 1	14:47:54.92
Suction T/C, Pair : 2	14:49:20.22
Suction T/C, Pair : 3	14:51:14.25
Suction T/C, Pair : 4	14:52:40.92
Suction T/C, Pair : 5	14:54:11.05

Cyclic Bed Temperature Readings

11:42:12.79	1	2	3	4	5	6	7	8	9	10
0	964.48	1052.58	1078.33	991.76	926.30	879.05	835.58	767.63	665.74	582.31
36	956.52	1029.26	1067.19	992.64	921.82	874.14	836.31	779.12	670.47	582.07
72	957.41	1028.39	1062.90	1005.75	931.78	876.35	841.66	789.69	677.56	585.84
108	958.29	1033.59	1064.62	1017.95	942.78	882.49	847.01	797.38	683.47	591.02
144	968.90	1043.96	1069.76	1029.26	950.81	887.66	850.42	801.72	687.25	595.97
180	974.19	1054.30	1078.33	1040.50	958.60	892.84	854.57	806.30	691.04	600.92
216	985.62	1062.90	1083.46	1046.54	962.38	896.04	856.28	807.26	692.22	604.68
252	996.14	1067.19	1086.02	1047.41	960.36	896.29	855.06	804.13	689.85	605.16
288	1003.13	1072.33	1086.02	1041.37	955.08	894.56	852.13	796.66	682.29	600.92
324	993.51	1069.76	1085.16	1033.59	947.29	891.11	848.23	790.41	675.19	595.03
360	968.02	1056.88	1080.89	999.64	931.04	880.53	837.52	768.58	666.22	583.25
396	955.64	1030.99	1068.91	989.13	920.57	873.90	837.52	776.49	669.76	581.84
432	954.75	1026.63	1064.62	1001.39	928.54	874.63	841.66	787.52	676.38	584.90
468	953.87	1028.39	1066.33	1016.21	940.03	879.30	846.04	795.22	682.05	589.61
504	960.95	1040.50	1069.76	1026.63	949.55	885.45	849.69	800.03	686.78	594.79
540	969.78	1050.85	1077.47	1035.32	957.59	891.11	853.35	804.61	690.33	599.74
576	982.11	1062.90	1083.46	1044.82	963.38	895.80	855.79	806.54	691.98	603.98
612	993.51	1068.05	1086.87	1045.68	964.39	897.77	856.03	805.33	691.27	605.86
648	1002.26	1073.19	1086.87	1043.09	959.61	896.29	852.37	797.38	685.36	603.27
684	997.89	1073.19	1087.72	1037.05	950.81	892.84	848.96	791.85	679.92	597.85
Minimum	953.87	1026.63	1062.90	989.13	920.57	873.90	835.58	767.63	665.74	581.84
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

12:43:48.07	1	2	3	4	5	6	7	8	9	10
0	955.38	1047.22	1059.28	989.78	932.44	895.24	872.87	834.58	741.86	658.70
36	951.83	1039.44	1060.14	997.66	938.43	899.68	876.05	838.47	744.95	662.48
72	951.83	1035.98	1060.14	1004.66	942.93	903.14	878.51	841.38	747.10	665.78
108	955.38	1036.85	1061.86	1008.15	946.18	905.61	880.22	843.57	748.29	668.38
144	961.58	1042.90	1064.44	1011.64	947.94	906.85	880.72	843.33	748.29	670.03
180	967.77	1051.53	1067.87	1014.26	947.69	906.85	879.73	840.41	745.67	669.33
216	970.42	1058.42	1070.45	1013.38	945.18	905.61	877.77	837.50	742.10	665.78
252	969.53	1061.00	1069.59	997.66	937.93	899.19	873.11	824.65	735.91	656.58
288	968.65	1055.84	1062.72	973.94	924.96	890.80	868.70	823.92	734.72	652.57
324	962.46	1051.53	1058.42	980.99	925.96	887.85	869.44	829.97	737.81	654.22
360	955.38	1047.22	1057.56	988.90	931.44	889.57	871.88	833.85	741.14	657.29
396	951.83	1040.31	1058.42	995.91	936.93	893.02	874.58	837.50	743.29	660.59
432	948.28	1033.39	1057.56	1000.29	941.18	895.73	876.54	839.92	745.19	663.90
468	950.95	1033.39	1059.28	1005.53	944.43	898.20	878.75	843.08	746.86	666.73
504	957.15	1038.58	1061.86	1009.90	946.44	899.93	879.49	843.57	747.34	668.62
540	N/A	N/A	N/A	N/A	N/A	N/A	879.49	843.57	747.34	668.62
576	966.00	1055.84	1068.73	1013.38	944.18	899.43	876.54	837.98	742.57	666.73
612	967.77	1060.14	1068.73	1006.41	939.18	896.22	873.11	829.25	736.86	659.65
648	967.77	1057.56	1064.44	975.71	924.96	888.34	867.72	821.98	733.53	653.51
684	964.23	1052.39	1059.28	980.11	922.72	884.89	867.23	828.04	736.38	654.22
Minimum	948.28	1033.39	1057.56	973.94	922.72	884.89	867.23	821.98	733.53	652.57
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

13:10:36.23	1	2	3	4	5	6	7	8	9	10
0	953.56	1032.50	1060.98	1008.12	942.02	893.86	870.03	833.72	742.22	666.15
36	957.99	1040.29	1064.42	1010.74	943.52	895.34	870.28	832.03	741.03	666.86
72	962.42	1050.65	1067.86	1011.61	941.52	894.84	868.56	828.63	738.17	664.97
108	963.30	1054.96	1069.57	1008.99	938.27	893.37	866.36	822.82	734.13	660.25
144	965.07	1051.51	1068.71	983.59	927.05	885.98	859.76	807.85	727.95	651.05
180	962.42	1037.69	1061.84	977.43	920.33	881.56	859.52	815.81	730.09	650.34
216	955.33	1035.96	1058.40	984.47	924.31	882.29	861.72	822.82	733.65	652.94
252	949.12	1030.74	1058.40	989.74	929.79	886.47	864.89	827.18	736.75	656.48
288	946.46	1025.53	1058.40	995.88	934.77	891.39	867.83	830.57	739.36	660.01
324	948.23	1025.53	1060.12	1002.00	939.52	895.34	870.77	833.48	741.27	663.08
360	950.90	1029.87	1061.84	1006.37	942.52	898.05	872.48	834.45	742.46	665.68
396	955.33	1035.96	1064.42	1009.87	944.02	899.28	872.72	833.72	741.75	667.10
432	957.99	1044.61	1067.86	1012.48	943.52	899.04	871.50	830.33	739.13	665.68
468	958.88	1050.65	1069.57	1010.74	940.77	897.56	869.05	825.97	735.80	662.37
504	960.65	1053.23	1069.57	991.49	931.78	890.16	862.69	808.82	729.14	652.70
540	961.53	1040.29	1063.56	977.43	921.58	883.52	860.25	814.12	729.38	650.81
576	956.22	1038.56	1059.26	983.59	923.32	882.78	861.72	821.61	732.94	652.70
612	950.01	1034.23	1058.40	989.74	928.29	886.23	864.40	826.45	736.03	655.77
648	946.46	1029.87	1058.40	995.00	933.03	890.66	867.58	830.33	738.89	659.54
684	946.46	1027.27	1059.26	1000.25	937.27	894.60	869.79	832.27	741.03	662.61
Minimum	946.46	1025.53	1058.40	977.43	920.33	881.56	859.52	807.85	727.95	650.34
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

14:19:09.82	1	2	3	4	5	6	7	8	9	10
0	873.45	1017.10	1092.96	1030.14	960.82	918.61	891.67	852.01	756.38	676.42
36	874.33	1018.84	1093.82	1033.63	964.09	921.84	893.64	853.96	757.81	679.25
72	868.99	1017.10	1094.67	1035.36	965.85	923.33	894.13	853.47	758.05	681.14
108	864.54	1011.87	1094.67	1037.09	965.10	923.08	892.41	849.57	756.14	680.43
144	860.07	1007.50	1095.52	1037.96	962.83	921.34	889.95	846.17	753.04	677.60
180	854.70	1005.75	1096.38	1031.87	957.55	916.13	885.77	831.85	747.79	669.33
216	852.91	1003.13	1093.82	1012.74	947.02	907.71	880.61	830.88	746.13	665.08
252	851.12	1000.50	1090.40	1013.61	946.02	905.73	880.86	838.15	748.75	666.50
288	856.49	1004.88	1092.11	1019.71	950.28	908.95	883.31	843.74	751.85	669.57
324	864.54	1010.12	1092.11	1024.93	955.79	913.16	886.01	848.11	754.47	672.87
360	872.56	1015.35	1092.11	1030.14	960.32	917.12	888.47	851.28	756.62	676.42
396	873.45	1017.10	1092.96	1033.63	963.34	919.60	890.19	853.71	758.29	679.49
432	868.99	1015.35	1092.96	1036.23	965.35	921.34	891.18	854.44	758.76	681.38
468	861.86	1009.25	1093.82	1037.09	965.10	921.84	890.69	852.01	758.05	681.85
504	860.07	1003.13	1093.82	1037.09	962.83	920.60	888.96	847.87	754.47	679.49
540	854.70	1004.00	1096.38	1035.36	958.56	917.12	886.01	837.67	749.94	673.35
576	852.91	1004.00	1094.67	1014.48	947.52	908.20	880.61	831.12	746.84	666.97
612	849.32	999.63	1092.11	1013.61	945.27	905.48	881.10	839.12	748.75	667.68
648	855.60	1004.88	1092.11	1019.71	949.53	907.96	883.56	844.71	751.85	670.28
684	866.32	1011.87	1092.96	1026.66	955.04	912.16	886.50	848.60	754.23	673.11
Minimum	849.32	999.63	1090.40	1012.74	945.27	905.48	880.61	830.88	746.13	665.08
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

14:44:14.67	1	2	3	4	5	6	7	8	9	10
0	909.25	1051.37	1107.89	1030.59	957.00	916.33	889.17	850.75	755.16	673.56
36	911.01	1052.23	1107.89	1033.19	960.26	919.31	891.14	852.95	757.07	676.63
72	909.25	1051.37	1108.74	1035.81	962.28	921.05	891.63	852.95	757.54	678.52
108	903.10	1046.19	1109.59	1038.41	962.53	921.05	890.64	850.51	755.87	677.81
144	898.69	1041.01	1110.44	1039.28	960.52	919.80	888.43	845.89	752.53	674.27
180	894.28	1041.01	1112.14	1038.41	957.25	917.08	885.48	839.57	748.96	669.31
216	898.69	1041.87	1111.29	1023.64	948.72	908.41	880.32	829.63	745.39	662.46
252	N/A	1041.01	1107.89	1017.55	944.22	904.95	879.59	837.14	747.29	662.70
288	898.69	1044.46	1107.04	1019.29	946.22	907.17	881.31	842.97	750.39	665.53
324	903.10	1047.92	1107.89	1021.90	950.48	911.62	884.50	846.86	753.25	668.60
360	909.25	1051.37	1108.74	1026.25	954.99	915.59	887.69	850.02	755.64	672.38
396	914.52	1053.96	1108.74	1031.45	958.76	918.56	889.91	851.73	757.07	675.45
432	912.77	1052.23	1109.59	1034.08	961.02	920.55	891.14	852.46	757.78	677.58
468	907.50	1048.78	1110.44	1037.54	961.77	920.80	890.40	849.78	756.35	677.58
504	901.34	1043.60	1111.29	1038.41	960.26	919.56	888.18	845.64	752.77	674.51
540	896.05	1041.87	1112.14	1038.41	957.50	917.32	885.23	841.27	749.44	670.02
576	899.57	1043.60	1112.14	1026.25	950.23	909.15	880.08	829.15	745.15	662.46
612	899.57	1043.60	1109.59	1018.42	944.72	904.20	878.61	834.96	746.34	661.76
648	897.81	1047.06	1107.89	1019.29	946.47	903.96	881.06	840.79	749.20	664.12
684	903.10	1051.37	1109.59	1023.64	950.48	907.42	884.25	844.92	752.06	667.66
Minimum	894.28	1041.01	1107.04	1017.55	944.22	903.96	878.61	829.15	745.15	661.76
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

11:43:43.36	1	2	3	4	5	6	7	8	9	10
0	N/A	999.72	934.40	792.65	N/A	N/A	554.11	511.64	365.87	N/A
36	N/A	1005.83	937.96	791.45	N/A	N/A	554.35	511.64	366.84	N/A
72	N/A	1011.06	940.63	790.25	N/A	N/A	554.59	512.11	368.04	N/A
108	N/A	1014.55	942.41	789.29	N/A	N/A	554.82	512.58	369.00	N/A
144	N/A	1015.42	944.19	788.81	N/A	N/A	554.82	513.29	370.20	N/A
180	N/A	1015.42	945.07	788.33	N/A	N/A	554.82	513.76	370.92	N/A
216	N/A	1013.68	945.07	788.33	N/A	N/A	554.59	514.23	371.16	N/A
252	N/A	996.22	941.52	788.81	N/A	N/A	554.11	514.00	369.24	N/A
288	N/A	982.19	934.40	790.97	N/A	N/A	553.64	513.29	366.11	N/A
324	N/A	979.55	929.94	793.13	N/A	N/A	553.88	512.34	364.91	N/A
360	N/A	997.09	933.50	793.13	N/A	N/A	554.35	512.11	366.11	N/A
396	N/A	1003.21	937.96	791.93	N/A	N/A	554.82	512.34	367.32	N/A
432	N/A	1012.81	940.63	790.97	N/A	N/A	554.82	512.58	368.28	N/A
468	N/A	1015.42	943.30	790.01	N/A	N/A	555.06	513.05	369.48	N/A
504	N/A	1017.16	944.19	789.29	N/A	N/A	555.06	513.53	370.44	N/A
540	N/A	1017.16	945.96	789.05	N/A	N/A	555.06	514.23	371.16	N/A
576	N/A	1014.55	945.07	788.81	N/A	N/A	554.82	514.47	371.64	N/A
612	N/A	1011.94	944.19	789.05	N/A	N/A	554.35	514.47	370.20	N/A
648	N/A	990.96	936.18	790.73	N/A	N/A	553.88	513.76	366.60	N/A
684	N/A	984.82	929.94	793.13	N/A	N/A	553.88	512.82	364.67	N/A
Average	N/A	1004.94	939.82	790.40	N/A	N/A	554.49	513.11	368.41	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

12:45:25.29	1	2	3	4	5	6	7	8	9	10
0	N/A	1038.63	944.78	808.27	N/A	N/A	612.79	581.46	428.82	N/A
36	N/A	1043.82	945.67	807.78	N/A	N/A	612.55	581.70	429.53	N/A
72	N/A	1044.68	946.56	807.54	N/A	N/A	612.55	581.93	429.29	N/A
108	N/A	1031.71	941.22	808.27	N/A	N/A	612.08	581.70	426.19	N/A
144	N/A	1025.61	934.98	810.20	N/A	N/A	611.61	580.99	423.09	N/A
180	N/A	1028.21	933.20	811.64	N/A	N/A	612.08	580.28	423.09	N/A
216	N/A	1033.44	936.77	811.16	N/A	N/A	612.32	580.28	424.05	N/A
252	N/A	1031.71	939.44	809.95	N/A	N/A	612.55	580.28	425.24	N/A
288	N/A	1031.71	940.33	808.75	N/A	N/A	612.55	580.52	426.43	N/A
324	N/A	1035.17	942.11	808.27	N/A	N/A	612.55	580.99	427.38	N/A
360	N/A	1038.63	943.00	807.54	N/A	N/A	612.55	581.23	428.10	N/A
396	N/A	1042.09	944.78	807.06	N/A	N/A	612.55	581.46	428.82	N/A
432	N/A	1042.95	945.67	806.82	N/A	N/A	612.55	581.70	429.29	N/A
468	N/A	1033.44	941.22	807.06	N/A	N/A	612.08	581.70	426.43	N/A
504	N/A	1027.35	935.87	808.75	N/A	N/A	611.61	580.99	423.09	N/A
540	N/A	1026.48	932.31	810.44	N/A	N/A	611.85	580.28	422.38	N/A
576	N/A	1032.57	934.98	810.20	N/A	N/A	612.32	580.05	423.57	N/A
612	N/A	1032.57	937.66	809.23	N/A	N/A	612.32	580.05	424.76	N/A
648	N/A	1031.71	939.44	808.27	N/A	N/A	612.55	580.05	425.72	N/A
684	N/A	1032.57	941.22	807.30	N/A	N/A	612.55	580.52	426.67	N/A
Average	N/A	1034.25	940.06	808.72	N/A	N/A	612.33	580.91	426.10	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

12:52:54.52	1	2	3	4	5	6	7	8	9	10
0	N/A	1038.83	939.64	801.24	N/A	N/A	611.81	577.89	425.92	N/A
36	N/A	1040.56	940.53	800.76	N/A	N/A	611.81	578.13	426.63	N/A
72	N/A	1042.29	941.42	800.52	N/A	N/A	611.81	578.36	426.87	N/A
108	N/A	1029.28	936.97	800.76	N/A	N/A	611.10	577.89	423.77	N/A
144	N/A	1023.21	930.72	802.68	N/A	N/A	610.63	577.19	420.43	N/A
180	N/A	1024.94	926.35	804.13	N/A	N/A	611.10	576.48	420.19	N/A
216	N/A	1031.04	931.61	803.89	N/A	N/A	611.34	576.24	421.14	N/A
252	N/A	1031.04	934.29	802.92	N/A	N/A	611.57	576.24	422.34	N/A
288	N/A	1029.28	936.07	801.96	N/A	N/A	611.57	576.48	423.29	N/A
324	N/A	1032.77	937.86	801.24	N/A	N/A	611.57	576.95	424.48	N/A
360	N/A	1035.37	938.75	800.52	N/A	N/A	611.57	577.42	425.44	N/A
396	N/A	1038.83	939.64	800.27	N/A	N/A	611.57	577.66	426.15	N/A
432	N/A	1042.29	940.53	800.03	N/A	N/A	611.57	578.13	426.63	N/A
468	N/A	1032.77	938.75	800.03	N/A	N/A	611.10	577.89	424.48	N/A
504	N/A	1024.07	931.61	801.72	N/A	N/A	610.63	577.42	421.14	N/A
540	N/A	1021.47	925.48	803.65	N/A	N/A	610.87	576.48	419.95	N/A
576	N/A	1030.15	928.10	803.65	N/A	N/A	611.34	576.48	420.90	N/A
612	N/A	1031.91	933.40	802.68	N/A	N/A	611.34	576.48	422.10	N/A
648	N/A	1030.15	935.18	801.72	N/A	N/A	611.57	576.48	423.05	N/A
684	N/A	1031.91	936.97	801.00	N/A	N/A	611.57	576.95	424.01	N/A
Average	N/A	1032.11	935.19	801.77	N/A	N/A	611.37	577.16	423.45	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

13:12:08.45	1	2	3	4	5	6	7	8	9	10
0	N/A	1041.25	941.22	795.43	N/A	N/A	614.38	582.12	432.33	N/A
36	N/A	1023.03	934.09	796.63	N/A	N/A	613.68	581.41	428.99	N/A
72	N/A	1016.94	926.17	798.80	N/A	N/A	613.44	580.47	426.61	N/A
108	N/A	1023.90	926.17	799.76	N/A	N/A	613.91	580.00	427.08	N/A
144	N/A	1028.24	928.79	799.28	N/A	N/A	614.15	580.00	428.04	N/A
180	N/A	1029.10	933.20	798.08	N/A	N/A	614.15	580.23	429.23	N/A
216	N/A	1029.97	934.98	797.35	N/A	N/A	614.38	580.47	430.18	N/A
252	N/A	1032.60	936.76	796.63	N/A	N/A	614.38	580.94	431.37	N/A
288	N/A	1035.19	937.66	795.91	N/A	N/A	614.38	581.17	432.09	N/A
324	N/A	1039.52	939.44	795.67	N/A	N/A	614.38	581.65	432.80	N/A
360	N/A	1041.25	940.33	795.43	N/A	N/A	614.38	581.88	432.80	N/A
396	N/A	1025.63	934.98	796.39	N/A	N/A	613.91	581.65	429.71	N/A
432	N/A	1018.68	927.04	798.32	N/A	N/A	613.68	580.94	426.37	N/A
468	N/A	1021.29	925.29	799.76	N/A	N/A	613.91	580.23	426.37	N/A
504	N/A	1027.37	928.79	799.28	N/A	N/A	614.38	580.23	427.56	N/A
540	N/A	1028.24	933.20	798.08	N/A	N/A	614.38	580.23	428.51	N/A
576	N/A	1029.10	934.98	797.11	N/A	N/A	614.62	580.70	429.71	N/A
612	N/A	1031.73	936.76	796.39	N/A	N/A	614.62	581.17	430.90	N/A
648	N/A	1034.33	938.55	795.91	N/A	N/A	614.62	581.41	431.61	N/A
684	N/A	1037.79	939.44	795.43	N/A	N/A	614.62	581.88	432.57	N/A
Average	N/A	1029.76	933.89	797.28	N/A	N/A	614.22	580.94	429.74	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

14:21:04.18	1	2	3	4	5	6	7	8	9	10
0	N/A	1031.11	962.76	802.97	N/A	N/A	628.88	594.96	436.96	N/A
36	N/A	1031.98	964.53	801.53	N/A	N/A	628.64	594.73	437.91	N/A
72	N/A	1032.85	966.30	800.57	N/A	N/A	628.88	595.20	439.10	N/A
108	N/A	1032.85	968.07	799.61	N/A	N/A	628.88	595.67	440.30	N/A
144	N/A	1033.74	969.83	799.12	N/A	N/A	628.88	595.90	441.25	N/A
180	N/A	1031.98	970.72	798.88	N/A	N/A	629.12	596.37	442.20	N/A
216	N/A	1032.85	971.60	798.64	N/A	N/A	628.88	596.61	442.20	N/A
252	N/A	1024.17	965.41	800.09	N/A	N/A	628.41	596.14	438.87	N/A
288	N/A	1018.95	958.33	802.97	N/A	N/A	628.17	595.20	436.24	N/A
324	N/A	1024.17	957.44	804.42	N/A	N/A	628.88	594.73	436.72	N/A
360	N/A	1031.98	961.87	803.94	N/A	N/A	629.35	594.96	437.91	N/A
396	N/A	1033.74	965.41	802.49	N/A	N/A	629.12	594.73	438.87	N/A
432	N/A	1033.74	967.18	801.29	N/A	N/A	629.35	595.20	440.06	N/A
468	N/A	1033.74	968.95	800.33	N/A	N/A	629.59	595.67	441.01	N/A
504	N/A	1033.74	970.72	799.61	N/A	N/A	629.59	596.14	441.96	N/A
540	N/A	1032.85	971.60	799.36	N/A	N/A	629.35	596.37	442.68	N/A
576	N/A	1032.85	972.48	799.36	N/A	N/A	629.35	596.61	442.91	N/A
612	N/A	1025.91	968.07	800.33	N/A	N/A	629.12	596.85	439.34	N/A
648	N/A	1019.82	960.10	803.22	N/A	N/A	628.88	595.90	436.24	N/A
684	N/A	1022.43	958.33	805.38	N/A	N/A	629.35	595.43	436.48	N/A
Average	N/A	1029.77	965.99	801.21	N/A	N/A	629.03	595.67	439.46	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

14:27:24.43	1	2	3	4	5	6	7	8	9	10
0	N/A	1037.26	969.89	803.03	N/A	N/A	632.24	598.32	444.40	N/A
36	N/A	1036.40	970.78	802.55	N/A	N/A	631.77	598.32	444.64	N/A
72	N/A	1035.53	971.66	802.07	N/A	N/A	631.77	598.55	445.12	N/A
108	N/A	1033.80	969.89	802.55	N/A	N/A	631.53	598.79	443.69	N/A
144	N/A	1025.97	962.82	804.72	N/A	N/A	631.06	598.08	440.12	N/A
180	N/A	1021.62	957.50	807.13	N/A	N/A	631.30	597.38	438.69	N/A
216	N/A	1032.04	961.05	807.61	N/A	N/A	631.77	597.14	439.64	N/A
252	N/A	1037.26	965.47	806.65	N/A	N/A	632.00	597.38	440.83	N/A
288	N/A	1038.13	966.36	804.96	N/A	N/A	632.00	597.14	441.55	N/A
324	N/A	1037.26	969.01	803.76	N/A	N/A	632.00	597.61	442.74	N/A
360	N/A	1037.26	970.78	802.79	N/A	N/A	632.00	598.08	443.69	N/A
396	N/A	1038.13	972.54	802.31	N/A	N/A	632.00	598.32	444.40	N/A
432	N/A	1038.13	973.43	801.83	N/A	N/A	632.00	598.79	445.12	N/A
468	N/A	1037.26	973.43	801.83	N/A	N/A	631.77	599.03	443.93	N/A
504	N/A	1028.57	965.47	803.76	N/A	N/A	631.30	598.32	440.36	N/A
540	N/A	1024.23	958.39	806.65	N/A	N/A	631.30	597.61	438.45	N/A
576	N/A	1032.04	960.16	807.37	N/A	N/A	631.77	597.14	439.16	N/A
612	N/A	1036.40	964.59	806.41	N/A	N/A	632.24	597.14	440.59	N/A
648	N/A	1037.26	966.36	804.96	N/A	N/A	632.00	597.14	441.55	N/A
684	N/A	1038.99	969.01	803.76	N/A	N/A	632.24	597.61	442.74	N/A
Average	N/A	1034.18	966.93	804.33	N/A	N/A	631.80	597.89	442.07	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

14:45:45.41	1	2	3	4	5	6	7	8	9	10
0	N/A	1058.32	977.28	807.46	N/A	N/A	635.40	598.88	445.21	N/A
36	N/A	1058.32	978.17	807.22	N/A	N/A	635.16	599.12	445.69	N/A
72	N/A	1058.32	979.05	807.22	N/A	N/A	635.16	599.59	445.45	N/A
108	N/A	1054.01	972.87	807.94	N/A	N/A	634.45	599.12	442.35	N/A
144	N/A	1050.56	965.80	810.83	N/A	N/A	634.22	598.41	439.49	N/A
180	N/A	1051.42	964.92	812.52	N/A	N/A	634.69	597.71	439.73	N/A
216	N/A	1057.46	969.34	811.80	N/A	N/A	635.16	598.18	441.16	N/A
252	N/A	1060.04	971.99	810.83	N/A	N/A	635.16	597.94	441.88	N/A
288	N/A	1058.32	972.87	809.39	N/A	N/A	635.16	598.18	443.07	N/A
324	N/A	1058.32	975.52	808.42	N/A	N/A	635.40	598.65	444.02	N/A
360	N/A	1057.46	976.40	807.70	N/A	N/A	635.40	599.12	444.97	N/A
396	N/A	1058.32	977.28	807.22	N/A	N/A	635.16	599.36	445.69	N/A
432	N/A	1058.32	979.05	807.22	N/A	N/A	635.16	599.59	445.92	N/A
468	N/A	1056.59	975.52	807.94	N/A	N/A	634.93	599.36	441.88	N/A
504	N/A	1052.28	967.57	810.59	N/A	N/A	634.69	598.65	438.78	N/A
540	N/A	1052.28	964.92	812.76	N/A	N/A	634.93	597.94	439.02	N/A
576	N/A	1058.32	968.46	812.28	N/A	N/A	635.16	597.71	440.21	N/A
612	N/A	1060.04	971.11	810.83	N/A	N/A	635.16	597.71	441.16	N/A
648	N/A	1060.04	972.87	809.39	N/A	N/A	635.40	597.94	442.35	N/A
684	N/A	1060.04	975.52	808.42	N/A	N/A	635.40	598.41	443.54	N/A
Average	N/A	1056.94	972.83	809.40	N/A	N/A	635.07	598.58	442.58	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

Interior Wall Probe Temperature Readings

11:45:07.40	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	312.17	732.26	978.67
1.568	296.20	598.98	877.17
2.064	N/A	N/A	818.45
2.375	N/A	568.96	N/A
2.724	N/A	519.20	N/A
3.048	211.36	457.86	620.78
4.070	191.49	366.84	544.92
4.585	165.69	278.30	456.20
5.213	147.98	247.09	345.65

12:46:49.32	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	320.22	757.97	1016.05
1.568	308.85	623.13	889.27
2.064	317.82	N/A	837.06
2.375	N/A	604.78	N/A
2.724	N/A	548.47	N/A
3.048	224.76	487.27	647.19
4.070	206.13	394.40	603.13
4.585	177.89	299.63	512.35
5.213	154.77	267.52	395.12

12:54:18.39	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	320.42	755.38	1013.63
1.568	312.47	624.31	882.40
2.064	319.47	N/A	832.16
2.375	N/A	605.92	N/A
2.724	N/A	551.03	N/A
3.048	228.14	491.02	647.16
4.070	207.80	399.87	602.62
4.585	179.56	303.96	512.79
5.213	156.20	271.62	395.08

13:13:32.49	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	324.50	756.07	1009.09
1.568	315.43	621.06	879.54
2.064	322.82	N/A	832.13
2.375	N/A	605.91	N/A
2.724	N/A	553.13	N/A
3.048	232.26	496.45	644.55
4.070	214.13	409.17	605.20
4.585	185.41	312.89	517.02
5.213	161.08	278.40	399.60

NOTE: This set of data was used for steady state calculations.

14:22:28.32	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	328.78	744.09	1009.36
1.568	321.98	622.08	900.11
2.064	326.04	N/A	847.98
2.375	N/A	608.15	N/A
2.724	N/A	558.44	N/A
3.048	247.23	505.79	650.57
4.070	227.90	425.51	619.69
4.585	199.21	329.43	530.61
5.213	171.20	290.14	408.55

14:28:48.35	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	325.44	745.08	1015.52
1.568	318.64	624.12	902.82
2.064	325.62	N/A	849.74
2.375	N/A	610.09	N/A
2.724	N/A	559.92	N/A
3.048	245.58	507.27	652.98
4.070	228.45	427.01	622.58
4.585	199.76	330.70	533.73
5.213	171.51	291.66	411.72

14:47:09.55	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	324.64	754.75	1037.59
1.568	321.24	632.32	911.06
2.064	326.91	N/A	855.92
2.375	N/A	615.37	N/A
2.724	N/A	564.96	N/A
3.048	249.33	512.80	658.74
4.070	231.48	432.58	626.44
4.585	202.30	335.86	537.37
5.213	173.31	295.64	414.44

NOTE: This set of data was used for steady state calculations.

Suction Pyrometer Temperature Readings by Flue Gas

	11:47:10.27		11:51:32.37		11:53:02.07		11:54:34.12		11:56:18.09	
	1	2	3	4	5	6	7	8	9	10
0	1156.49	1232.52	1154.98	1033.11	940.26	N/A	N/A	N/A	687.86	629.09
36	1179.98	1188.35	1157.51	1037.44	944.77	N/A	N/A	N/A	688.81	625.08
72	1182.49	1169.92	1175.13	1044.35	950.03	N/A	N/A	N/A	690.94	631.45
108	1179.14	1159.01	1177.65	1044.35	955.56	N/A	N/A	N/A	695.20	636.16
144	1184.17	1169.92	1188.53	1048.66	961.34	N/A	N/A	N/A	698.51	642.52
180	1190.86	1172.44	1195.22	1053.83	967.65	N/A	N/A	N/A	707.04	654.55
216	1210.06	1174.12	1210.24	1059.85	971.18	N/A	N/A	N/A	710.36	663.05
252	1207.56	1211.72	1217.73	1065.86	971.18	N/A	N/A	N/A	715.58	667.77
288	1188.35	1206.72	1210.24	1065.86	968.91	N/A	N/A	N/A	719.38	673.44
324	1161.53	1215.05	1212.74	1067.58	967.65	N/A	N/A	N/A	715.35	667.54
360	1154.80	1228.36	1206.07	1066.72	965.88	N/A	N/A	N/A	712.02	655.73
396	1176.63	1188.35	1201.90	1068.44	965.88	N/A	N/A	N/A	704.44	649.60
432	1177.47	1177.47	1207.74	1068.44	968.91	N/A	N/A	N/A	697.57	643.94
468	1178.31	1161.53	1193.55	1066.72	972.70	N/A	N/A	N/A	695.91	645.12
504	1185.00	1159.85	1188.53	1070.15	977.51	N/A	N/A	N/A	700.65	651.96
540	1189.19	1179.98	1196.05	1072.72	979.79	N/A	N/A	N/A	704.44	659.51
576	1213.39	1149.76	1207.74	1079.57	979.53	N/A	N/A	N/A	710.84	668.72
612	1214.22	1203.39	1222.72	1084.70	978.27	N/A	N/A	N/A	717.01	675.57
648	1190.86	1192.53	1226.88	1085.55	975.48	N/A	N/A	N/A	721.99	678.40
684	1167.41	1199.21	1216.90	1080.43	973.46	N/A	N/A	N/A	719.62	673.20
Average	1184.40	1187.01	1198.40	1063.22	966.80	N/A	N/A	N/A	705.68	654.62
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

	12:48:09.18		12:49:44.48		12:51:14.34	
	1	2	3	4	5	6
0	1005.68	1144.52	1122.61	1023.16	933.44	N/A
36	1017.02	1152.10	1124.30	1027.50	936.43	N/A
72	1036.14	1153.78	1136.13	1030.99	939.93	N/A
108	1040.46	1142.83	1132.76	1037.05	941.68	N/A
144	1037.00	1141.99	1145.41	1039.65	942.93	N/A
180	993.43	1112.40	1148.78	1043.10	943.93	N/A
216	957.30	1090.27	1151.30	1044.83	947.94	N/A
252	940.43	1093.69	1152.15	1047.42	954.21	N/A
288	956.42	1114.09	1158.04	1049.14	956.97	N/A
324	968.80	1126.79	1157.19	1046.56	960.24	N/A
360	991.68	1140.30	1147.94	1043.97	963.26	N/A
396	1004.81	1152.10	1142.04	1039.65	966.79	N/A
432	1029.18	1155.46	1144.57	1042.24	970.32	N/A
468	1040.46	1147.89	1140.35	1046.56	972.85	N/A
504	1029.18	1139.46	1141.19	1046.56	973.86	N/A
540	996.06	1110.70	1150.46	1049.14	973.61	N/A
576	959.07	1104.75	1152.99	1050.01	973.86	N/A
612	940.43	1104.75	1149.62	1050.01	974.87	N/A
648	944.88	1121.72	1158.88	1050.01	975.63	N/A
684	958.19	1120.87	1152.15	1046.56	975.88	N/A
Average	992.33	1128.52	1145.44	1042.70	958.93	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553

	13:48:25.48		13:49:51.16		13:52:56.76		13:54:21.01	
	1	2	3	4	5	6	7	8
0	969.85	1079.38	1135.48	1035.47	948.12	N/A	N/A	N/A
36	942.36	1067.38	1138.86	1042.39	950.38	N/A	N/A	N/A
72	929.05	1068.24	1144.76	1046.71	952.13	N/A	N/A	N/A
108	941.47	1093.06	1153.18	1051.89	953.89	N/A	N/A	N/A
144	966.31	1125.34	1155.71	1053.61	955.65	N/A	N/A	N/A
180	997.99	1148.97	1155.71	1050.16	957.66	N/A	N/A	N/A
216	1014.59	1156.55	1155.71	1049.30	959.67	N/A	N/A	N/A
252	1056.20	1168.32	1160.76	1050.16	960.42	N/A	N/A	N/A
288	1063.08	1180.06	1154.03	1050.16	959.92	N/A	N/A	N/A
324	1044.12	1151.50	1151.50	1052.75	958.66	N/A	N/A	N/A
360	1008.49	1127.87	1150.66	1057.92	957.91	N/A	N/A	N/A
396	966.31	1113.48	1154.87	1057.06	959.42	N/A	N/A	N/A
432	958.35	1114.33	1152.34	1057.92	960.17	N/A	N/A	N/A
468	967.20	1127.87	1158.23	1059.64	962.69	N/A	N/A	N/A
504	979.55	1138.86	1155.71	1056.20	964.20	N/A	N/A	N/A
540	1000.62	1159.92	1159.07	1055.33	964.95	N/A	N/A	N/A
576	1029.38	1167.48	1148.13	1051.89	966.46	N/A	N/A	N/A
612	1045.85	1168.32	1152.34	1051.02	967.22	N/A	N/A	N/A
648	1051.89	1127.03	1138.86	1045.85	966.21	N/A	N/A	N/A
684	1046.71	1110.93	1138.86	1044.12	962.43	N/A	N/A	N/A
Average	998.97	1129.74	1150.74	1050.98	959.41	N/A	N/A	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270

NOTE: This set of data was used for steady state calculations.

	14:22:55.07		14:24:19.22		14:26:00.01		14:30:41.99		14:32:12.35	
	1	2	3	4	5	6	7	8	9	10
0	853.98	1088.01	1167.57	1069.17	994.61	N/A	N/A	N/A	778.65	713.61
36	840.50	1099.10	1173.45	1073.46	995.89	N/A	N/A	N/A	784.16	715.98
72	833.29	1093.99	1175.96	1081.17	996.14	N/A	N/A	N/A	788.00	716.46
108	837.80	1100.81	1175.96	1084.59	998.69	N/A	N/A	N/A	793.52	723.34
144	834.19	1083.74	1179.32	1090.57	1002.51	N/A	N/A	N/A	800.02	732.84
180	828.77	1083.74	1182.67	1093.13	1006.33	N/A	N/A	N/A	805.31	742.36
216	821.52	1065.73	1186.86	1093.99	1010.42	N/A	N/A	N/A	810.37	749.98
252	806.06	1063.15	1186.86	1095.69	1013.49	N/A	N/A	N/A	813.75	756.66
288	797.83	1076.89	1187.69	1094.84	1016.30	N/A	N/A	N/A	814.71	757.37
324	798.74	1084.59	1184.34	1093.13	1019.12	N/A	N/A	N/A	815.20	757.14
360	799.66	1100.81	1186.86	1091.43	1019.63	N/A	N/A	N/A	810.85	749.27
396	793.25	1105.91	1186.02	1093.99	1018.61	N/A	N/A	N/A	809.41	742.84
432	808.79	1111.86	1189.37	1098.25	1016.81	N/A	N/A	N/A	807.72	743.31
468	808.79	1105.91	1183.51	1099.95	1014.51	N/A	N/A	N/A	808.20	743.31
504	821.52	1099.10	1186.02	1104.21	1015.53	N/A	N/A	N/A	810.61	747.84
540	815.17	1082.03	1186.02	1105.91	1016.30	N/A	N/A	N/A	815.68	753.56
576	802.40	1070.88	1191.04	1105.91	1017.84	N/A	N/A	N/A	822.20	758.57
612	789.58	1049.37	1194.39	1108.46	1019.63	N/A	N/A	N/A	824.38	762.15
648	799.66	1070.03	1191.04	1103.36	1021.94	N/A	N/A	N/A	824.62	764.06
684	824.24	1058.85	1192.71	1103.36	1023.74	N/A	N/A	N/A	824.14	762.39
Average	815.79	1084.72	1184.38	1094.23	1011.90	N/A	N/A	N/A	808.08	744.65
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

	14:47:54.92		14:49:20.22		14:51:14.25		14:52:40.92		14:54:11.05	
	1	2	3	4	5	6	7	8	9	10
0	853.47	1129.19	1179.77	1079.05	970.30	N/A	N/A	N/A	N/A	N/A
36	850.78	1143.55	1184.79	1080.76	975.30	N/A	N/A	N/A	N/A	N/A
72	846.29	1145.24	1189.82	1085.04	980.36	N/A	N/A	N/A	804.74	734.42
108	846.29	1149.45	1189.82	1089.32	986.43	N/A	N/A	N/A	808.11	740.37
144	857.95	1148.61	1186.47	1089.32	991.25	N/A	N/A	N/A	809.07	741.56
180	856.16	1127.50	1188.98	1094.44	996.84	N/A	N/A	N/A	807.15	739.18
216	854.37	1120.73	1192.33	1097.00	1000.66	N/A	N/A	N/A	804.74	733.71
252	850.78	1114.80	1190.65	1097.00	1002.45	N/A	N/A	N/A	802.33	731.09
288	836.39	1114.80	1199.02	1102.11	1003.98	N/A	N/A	N/A	802.57	731.33
324	824.63	1099.49	1195.67	1100.40	1003.21	N/A	N/A	N/A	804.02	733.00
360	830.06	1128.35	1198.18	1100.40	1001.68	N/A	N/A	N/A	807.87	737.75
396	830.06	1144.39	1198.18	1097.00	1001.94	N/A	N/A	N/A	813.41	745.13
432	833.68	1149.45	1199.85	1101.26	1002.96	N/A	N/A	N/A	816.79	750.13
468	826.44	1147.77	1199.85	1103.81	1005.51	N/A	N/A	N/A	818.00	751.56
504	839.09	1156.19	1197.35	1103.81	1008.06	N/A	N/A	N/A	819.21	751.80
540	848.98	1139.33	1194.00	1105.51	1010.87	N/A	N/A	N/A	814.86	748.23
576	848.98	1130.04	1195.67	1105.51	1013.43	N/A	N/A	N/A	811.49	742.99
612	838.19	1113.95	1196.51	1108.06	1013.68	N/A	N/A	N/A	809.80	739.65
648	848.98	1112.25	1199.02	1110.61	1014.19	N/A	N/A	N/A	810.76	737.51
684	873.12	1104.60	1200.69	1107.21	1012.91	N/A	N/A	N/A	810.52	739.18
Average	844.73	1130.98	1193.83	1097.88	999.81	N/A	N/A	N/A	809.75	740.48
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Shell Temperature Readings

Time	Position, metres				
	0.146	0.921	1.492	2.210	5.354
11:42	226	195	174	158	94
13:10	233	203	188	170	104
14:35	230	203	190	173	117
14:58	227	202	190	174	120

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
11:31	2	81.9	6.6	11.5
11:42	2	79.1	4.5	16.4
N/A	7	74.6	0.4	25.0
13:14	7	81.5	5.8	12.7
13:20	7	75.1	4.2	20.7
13:33	7	72.6	4.9	22.5
13:48	3	76.2	3.5	20.3
14:17	3	77.7	5.2	17.1
14:21	3	76.2	4.8	19.0
14:29	3	73.6	4.0	22.4
14:32	7	76.4	3.9	19.7
14:43	8	77.3	4.6	18.1
14:46	1	75.8	13.5	10.7

Axial Calcination Results

Lignin = 180 g/m	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #5	Port #5
Sample Code	LPA	LPA	L#1A	L#1A	L#2A	L#2A	L#5A	L#5A
Date	21/Mar/90	21/Mar/90	26/Mar/90	30/Mar/90	26/Mar/90	30/Mar/90	26/Mar/90	26/Mar/90
Before Firing, g	20.3541	20.1428	22.4970	24.2226	25.3694	25.9186	28.2843	27.2989
After Firing, g	20.2792	20.0722	20.1330	21.7485	20.1724	20.7400	20.8054	19.8580
Empty Crucible, g	9.9145	10.2287	9.9221	10.9577	10.4707	11.0351	10.9378	10.0528
Wt of Sample Before, g	10.4396	9.9141	12.5749	13.2649	14.8987	14.8835	17.3465	17.2461
Wt Loss by $CaCO_3$, g	0.0749	0.0706	2.3640	2.4741	5.1970	5.1786	7.4789	7.4409
% Calcination	98.34	98.35	56.38	56.72	19.06	19.27	-0.04	-0.11

Average = 98.34% 56.55% 19.17% 0.00%

Lignin = 240 g/m	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3
Sample Code	LPB	LPB	L#1B	L#1B	L#2B	L#2B	L#3B	L#3B
Date	21/Mar/90	21/Mar/90	23/Mar/90	23/Mar/90	23/Mar/90	23/Mar/90	23/Mar/90	30/Mar/90
Before Firing, g	22.0795	21.4950	20.7177	20.5031	24.1325	25.0543	28.1608	25.1348
After Firing, g	21.9650	21.3780	20.6976	20.4663	21.7589	22.3240	21.9612	19.7873
Empty Crucible, g	10.4644	10.0285	9.9145	10.2294	10.4653	10.0286	10.9300	10.0478
Wt of Sample Before, g	11.6151	11.4665	10.8032	10.2737	13.6672	15.0257	17.2308	15.0870
Wt Loss by $CaCO_3$, g	0.1145	0.1170	0.0201	0.0368	2.3736	2.7303	6.1996	5.3475
% Calcination	97.71	97.63	99.57	99.17	59.70	57.84	16.52	17.76

Average = 97.67% 99.37% 58.77% 17.14%

Lignin = 240 g/m	Port #4	Port #4	Port #5	Port #5	Port #6	Port #6	Port #7	Port #7
Sample Code	L#4B	L#4B	L#5B	L#5B	L#6B	L#6B	L#7B	L#7B
Date	23/Mar/90	23/Mar/90	23/Mar/90	23/Mar/90	24/Mar/90	24/Mar/90	24/Mar/90	24/Mar/90
Before Firing, g	28.2467	26.0602	28.8253	29.4430	29.8343	26.4227	28.3885	28.5531
After Firing, g	21.3812	19.5978	21.1633	21.4470	21.2792	19.4471	20.6146	20.5337
Empty Crucible, g	11.0067	10.0121	10.7155	10.5588	9.9191	10.2327	10.4685	10.0336
Wt of Sample Before, g	17.2400	16.0481	18.1098	18.8842	19.9152	16.1900	17.9200	18.5195
Wt Loss by $CaCO_3$, g	6.8655	6.4624	7.6620	7.9960	8.5551	6.9756	7.7739	8.0194
% Calcination	7.60	6.57	1.83	1.76	0.33	0.03	-0.66	-0.47
Average =	7.08%		1.79%		0.18%		0.00%	

Run LG11

Table of Events

Event Requested by Operator	Time
5/29/90	11:58:03.33
Kiln speed (rpm) : 1.5	11:58:07.51
Gas = 5.4 CFM	10:30:00
Read Bed Temperatures	11:58:44.25
Read Hot Face Heat Flux Temperatures	12:00:21.41
Read Colder Heat Flux Temperatures	12:01:46.27
Read Hot Face Heat Flux Temperatures	12:02:41.04
Read Colder Heat Flux Temperatures	12:04:05.90
Read Shell Temperatures	12:04:41.98
Suction T/C, Pair : 1	12:10:41.03
Suction T/C, Pair : 2	12:12:12.86
Suction T/C, Pair : 3	12:13:49.42
Suction T/C, Pair : 4	12:15:17.63
Suction T/C, Pair : 5	12:16:50.62
Lignin = 218 g/min Gas = 0.0 CFM	13:20:00
Read Bed Temperatures	13:28:59.74
Read Shell Temperatures	13:30:36.02
Read Hot Face Heat Flux Temperatures	13:31:00.41
Read Colder Heat Flux Temperatures	13:32:25.22
Read Hot Face Heat Flux Temperatures	13:32:46.80
Read Colder Heat Flux Temperatures	13:34:11.77
Suction T/C, Pair : 1	14:03:54.65
Suction T/C, Pair : 2	14:05:28.47
Suction T/C, Pair : 3	14:07:00.19
Suction T/C, Pair : 4	14:08:38.01
Suction T/C, Pair : 5	14:10:13.04

Cyclic Bed Temperature Readings

11:58:44.25	1	2	3	4	5	6	7	8	9	10
0	993.97	1103.56	1122.22	1015.81	922.53	875.62	823.73	768.64	683.08	609.96
36	993.09	1104.41	1126.45	1020.16	918.06	873.66	819.86	767.20	673.62	603.60
72	1006.22	1105.26	1134.90	1019.29	908.89	866.80	812.61	763.14	658.04	592.53
108	995.72	1104.41	1130.68	1012.32	902.21	860.69	807.54	756.69	646.25	582.40
144	959.62	1014.94	1088.23	970.23	876.84	840.22	790.70	744.76	637.29	570.15
180	926.78	971.11	1058.23	948.98	871.94	831.24	788.29	734.29	638.94	570.39
216	935.63	1011.45	1089.93	968.46	889.63	841.19	798.15	738.33	650.02	577.92
252	956.96	1040.12	1108.66	987.83	902.45	848.25	806.34	745.48	661.11	586.40
288	975.52	1057.37	1112.06	1000.10	913.60	856.29	813.33	752.87	670.79	594.65
324	986.95	1073.69	1115.45	1009.71	921.79	864.84	819.13	759.32	677.64	601.71
360	994.85	1089.08	1124.76	1014.94	923.53	870.22	822.28	764.57	682.13	606.66
396	993.09	1095.90	1126.45	1016.68	922.29	873.41	823.49	768.16	684.26	610.19
432	991.34	1101.01	1128.14	1017.55	919.30	874.39	822.76	768.88	680.95	608.78
468	988.71	1101.86	1124.76	1015.81	914.34	871.69	819.38	767.20	669.14	600.30
504	981.68	1100.16	1121.38	1011.45	905.42	865.09	812.37	761.47	653.79	587.82
540	948.09	1083.10	1117.14	998.35	894.31	858.49	806.10	755.73	644.83	579.81
576	924.16	980.80	1059.95	954.30	872.43	833.66	787.33	740.24	635.87	569.91
612	908.41	983.44	1059.95	949.87	878.81	836.82	793.58	737.14	642.95	573.68
648	922.42	1018.42	1085.67	973.75	894.80	846.06	803.45	742.86	654.74	582.40
684	950.76	1047.89	1102.71	990.46	904.68	853.12	810.44	749.77	664.89	591.11
Minimum	908.41	971.11	1058.23	948.98	871.94	831.24	787.33	734.29	635.87	569.91
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

13:28:59.74	1	2	3	4	5	6	7	8	9	10
0	874.93	1009.81	1114.75	994.94	917.18	898.87	861.07	810.36	705.04	625.71
36	890.00	1048.88	1113.06	1006.32	937.59	910.49	869.63	813.25	715.00	634.42
72	923.39	1078.11	1118.99	1023.75	958.63	925.63	879.43	819.05	724.49	644.09
108	948.17	1094.34	1128.30	1038.51	972.24	937.34	887.54	824.85	732.57	651.87
144	957.93	1098.60	1138.44	1051.47	978.30	944.34	893.20	829.70	738.99	659.65
180	950.83	1096.05	1146.03	1061.80	984.13	950.10	897.64	833.33	742.80	664.85
216	933.92	1092.64	1153.61	1072.11	986.41	954.11	899.61	836.49	743.99	667.68
252	911.14	1095.20	1162.02	1076.39	983.62	953.36	899.36	837.94	742.33	667.68
288	904.11	1101.16	1167.06	1077.25	977.04	945.59	894.68	836.49	736.14	660.60
324	903.23	1108.81	1167.06	1072.11	966.69	935.84	887.29	832.12	723.07	648.33
360	890.88	1108.81	1162.86	1063.52	958.13	928.86	881.64	827.27	714.29	639.37
396	885.58	1035.05	1134.22	1010.69	924.38	902.82	860.34	815.67	704.81	624.29
432	885.58	1022.01	1112.21	999.32	923.89	902.08	864.00	810.60	710.73	629.00
468	910.26	1061.80	1115.60	1015.92	947.09	914.70	872.07	814.94	720.46	638.19
504	939.27	1084.10	1122.38	1031.56	964.92	929.11	881.15	820.98	728.77	647.15
540	957.93	1096.90	1128.30	1045.43	972.99	938.84	888.52	826.06	735.66	654.94
576	962.35	1099.46	1140.12	1055.78	978.56	944.34	893.69	830.67	740.42	661.54
612	951.72	1096.05	1147.71	1066.10	983.62	949.85	897.39	833.82	742.80	665.56
648	933.02	1094.34	1154.45	1073.82	985.14	952.11	899.12	836.49	742.57	667.68
684	907.62	1092.64	1160.34	1077.25	980.83	950.10	897.39	837.21	738.76	664.61
Minimum	874.93	1009.81	1112.21	994.94	917.18	898.87	860.34	810.36	704.81	624.29
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

12:00:21.41	1	2	3	4	5	6	7	8	9	10
0	N/A	988.76	918.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	990.51	918.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
72	N/A	986.12	916.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	N/A	972.92	910.21	N/A	N/A	N/A	N/A	N/A	N/A	N/A
144	N/A	965.86	905.82	N/A	N/A	N/A	N/A	N/A	N/A	N/A
180	N/A	970.28	906.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216	N/A	977.33	910.21	N/A	N/A	N/A	N/A	N/A	N/A	N/A
252	N/A	980.85	911.97	N/A	N/A	N/A	N/A	N/A	N/A	N/A
288	N/A	983.49	913.72	N/A	N/A	N/A	N/A	N/A	N/A	N/A
324	N/A	985.25	915.47	N/A	N/A	N/A	N/A	N/A	N/A	N/A
360	N/A	987.00	917.22	N/A	N/A	N/A	N/A	N/A	N/A	N/A
396	N/A	990.51	918.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
432	N/A	991.39	918.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
468	N/A	993.14	918.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
504	N/A	980.85	914.60	N/A	N/A	N/A	N/A	N/A	N/A	N/A
540	N/A	972.04	909.34	N/A	N/A	N/A	N/A	N/A	N/A	N/A
576	N/A	965.86	905.82	N/A	N/A	N/A	N/A	N/A	N/A	N/A
612	N/A	974.69	909.34	N/A	N/A	N/A	N/A	N/A	N/A	N/A
648	N/A	980.85	911.97	N/A	N/A	N/A	N/A	N/A	N/A	N/A
684	N/A	983.49	914.60	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	N/A	981.06	913.19	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

12:02:41.04	1	2	3	4	5	6	7	8	9	10
0	N/A	991.44	919.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	994.07	920.77	N/A	N/A	N/A	N/A	N/A	N/A	N/A
72	N/A	989.69	918.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	N/A	978.26	912.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A
144	N/A	971.21	907.63	N/A	N/A	N/A	N/A	N/A	N/A	N/A
180	N/A	975.62	908.51	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216	N/A	981.78	912.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A
252	N/A	986.17	914.65	N/A	N/A	N/A	N/A	N/A	N/A	N/A
288	N/A	988.81	916.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A
324	N/A	990.56	918.15	N/A	N/A	N/A	N/A	N/A	N/A	N/A
360	N/A	991.44	919.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A
396	N/A	994.07	919.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A
432	N/A	994.95	920.77	N/A	N/A	N/A	N/A	N/A	N/A	N/A
468	N/A	995.82	920.77	N/A	N/A	N/A	N/A	N/A	N/A	N/A
504	N/A	985.30	916.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A
540	N/A	976.50	910.26	N/A	N/A	N/A	N/A	N/A	N/A	N/A
576	N/A	971.21	907.63	N/A	N/A	N/A	N/A	N/A	N/A	N/A
612	N/A	980.02	910.26	N/A	N/A	N/A	N/A	N/A	N/A	N/A
648	N/A	985.30	913.77	N/A	N/A	N/A	N/A	N/A	N/A	N/A
684	N/A	987.05	916.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	N/A	985.46	915.17	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

13:31:00.41	1	2	3	4	5	6	7	8	9	10
0	N/A	1035.05	964.12	N/A	N/A	N/A	N/A	538.76	401.52	N/A
36	N/A	1037.65	965.01	N/A	N/A	N/A	N/A	539.23	402.00	N/A
72	N/A	1039.38	965.01	N/A	N/A	N/A	N/A	539.46	402.48	N/A
108	N/A	1035.05	963.24	N/A	N/A	N/A	N/A	539.46	401.04	N/A
144	N/A	1025.48	954.38	N/A	N/A	N/A	N/A	539.23	398.65	N/A
180	N/A	1019.40	947.28	N/A	N/A	N/A	N/A	538.52	396.73	N/A
216	N/A	1022.01	949.05	N/A	N/A	N/A	N/A	538.05	396.73	N/A
252	N/A	1027.22	952.61	N/A	N/A	N/A	N/A	537.81	397.45	N/A
288	N/A	1030.69	956.15	N/A	N/A	N/A	N/A	537.81	398.41	N/A
324	N/A	1033.32	959.70	N/A	N/A	N/A	N/A	538.05	399.13	N/A
360	N/A	1034.18	961.47	N/A	N/A	N/A	N/A	538.52	400.08	N/A
396	N/A	1035.91	963.24	N/A	N/A	N/A	N/A	538.76	400.80	N/A
432	N/A	1037.65	965.01	N/A	N/A	N/A	N/A	539.23	401.52	N/A
468	N/A	1039.38	965.89	N/A	N/A	N/A	N/A	539.70	402.00	N/A
504	N/A	1040.24	965.89	N/A	N/A	N/A	N/A	539.70	402.24	N/A
540	N/A	1033.32	960.58	N/A	N/A	N/A	N/A	539.70	399.13	N/A
576	N/A	1025.48	952.61	N/A	N/A	N/A	N/A	539.23	396.73	N/A
612	N/A	1020.27	947.28	N/A	N/A	N/A	N/A	538.76	396.01	N/A
648	N/A	1026.35	950.83	N/A	N/A	N/A	N/A	538.28	396.73	N/A
684	N/A	1030.69	954.38	N/A	N/A	N/A	N/A	538.05	397.45	N/A
Average	N/A	1031.44	958.19	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

13:32:46.80	1	2	3	4	5	6	7	8	9	10
0	N/A	1033.37	960.63	N/A	N/A	N/A	N/A	539.99	401.09	N/A
36	N/A	1024.67	952.66	N/A	N/A	N/A	N/A	539.51	398.94	N/A
72	N/A	1019.45	947.33	N/A	N/A	N/A	N/A	538.81	397.50	N/A
108	N/A	1024.67	949.99	N/A	N/A	N/A	N/A	538.33	397.98	N/A
144	N/A	1029.01	954.43	N/A	N/A	N/A	N/A	538.10	398.70	N/A
180	N/A	1031.61	957.09	N/A	N/A	N/A	N/A	538.33	399.41	N/A
216	N/A	1033.37	960.63	N/A	N/A	N/A	N/A	538.57	400.13	N/A
252	N/A	1035.10	962.40	N/A	N/A	N/A	N/A	538.81	400.85	N/A
288	N/A	1035.96	963.29	N/A	N/A	N/A	N/A	539.28	401.57	N/A
324	N/A	1037.70	965.06	N/A	N/A	N/A	N/A	539.51	402.29	N/A
360	N/A	1040.29	965.06	N/A	N/A	N/A	N/A	539.75	402.77	N/A
396	N/A	1041.16	965.06	N/A	N/A	N/A	N/A	539.99	402.53	N/A
432	N/A	1029.87	957.09	N/A	N/A	N/A	N/A	539.75	400.37	N/A
468	N/A	1023.80	949.99	N/A	N/A	N/A	N/A	539.28	398.22	N/A
504	N/A	1022.06	947.33	N/A	N/A	N/A	N/A	538.57	397.50	N/A
540	N/A	1027.27	951.77	N/A	N/A	N/A	N/A	538.33	397.98	N/A
576	N/A	1030.74	955.32	N/A	N/A	N/A	N/A	538.10	398.70	N/A
612	N/A	1033.37	957.98	N/A	N/A	N/A	N/A	538.33	399.41	N/A
648	N/A	1035.10	959.75	N/A	N/A	N/A	N/A	538.57	400.37	N/A
684	N/A	1035.96	961.52	N/A	N/A	N/A	N/A	539.04	401.09	N/A
Average	N/A	1031.22	957.22	N/A	N/A	N/A	N/A	538.95	399.87	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

Interior Wall Probe Temperature Readings

12:01:46.27	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	339.21	627.86	N/A
1.568	285.75	570.09	849.93
2.064	281.70	N/A	N/A
2.375	N/A	543.80	N/A
2.724	N/A	487.55	N/A
3.048	193.91	429.10	590.22
4.070	185.07	347.83	510.03
4.585	162.46	269.04	431.25
5.213	154.58	252.20	341.56

12:04:05.90	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	341.50	630.85	N/A
1.568	285.80	572.16	851.77
2.064	281.99	N/A	N/A
2.375	N/A	545.03	N/A
2.724	N/A	488.79	N/A
3.048	194.45	430.11	591.92
4.070	185.61	348.60	511.03
4.585	162.75	269.57	432.25
5.213	154.63	252.50	342.09

13:32:25.22	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	362.25	660.90	N/A
1.568	305.90	610.90	893.53
2.064	304.15	N/A	N/A
2.375	N/A	585.43	N/A
2.724	N/A	535.45	N/A
3.048	213.63	474.42	640.79
4.070	203.81	387.86	563.04
4.585	177.78	298.81	483.19
5.213	161.55	272.30	378.50

13:34:11.77	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	362.30	662.88	N/A
1.568	305.95	611.94	894.47
2.064	304.20	N/A	N/A
2.375	N/A	586.18	N/A
2.724	N/A	536.45	N/A
3.048	216.37	475.18	641.78
4.070	204.35	388.39	563.09
4.585	178.07	299.35	483.72
5.213	161.85	272.59	378.55

NOTE: This set of data was used for steady state calculations.

Suction Pyrometer Temperature Readings by Flue Gas

	12:10:41.03		12:12:12.86		12:13:49.42		12:15:17.63		12:16:50.62	
	1	2	3	4	5	6	7	8	9	10
0	1043.82	1190.59	1124.15	1023.01	919.35	893.61	835.41	763.19	680.58	593.10
36	1038.63	1178.03	1136.83	1029.08	923.32	900.77	843.67	769.41	686.02	592.63
72	1048.13	1179.71	1144.42	1034.30	926.31	906.70	849.02	775.87	687.20	592.40
108	1052.44	1186.41	1150.31	1039.49	929.05	912.40	852.44	782.10	686.02	592.87
144	1060.19	1191.43	1152.84	1044.68	930.79	914.38	855.61	787.38	691.22	593.81
180	1069.64	1203.12	1152.84	1046.41	931.79	915.13	857.31	791.71	694.53	594.99
216	1083.34	1216.46	1160.41	1049.86	931.79	912.65	855.12	793.63	699.03	596.17
252	1093.59	1215.63	1160.41	1053.30	931.54	909.92	850.49	792.67	698.09	596.87
288	1101.25	1219.79	1162.09	1055.03	930.79	906.21	846.35	787.86	701.64	597.11
324	1112.30	1221.46	1170.49	1053.30	930.29	904.72	841.48	783.54	695.95	596.64
360	1108.05	1226.45	1168.81	1047.27	931.04	908.19	843.67	780.18	691.22	595.69
396	1098.70	1225.61	1166.29	1042.09	932.79	913.89	845.37	778.99	682.71	594.52
432	1079.07	1214.80	1170.49	1044.68	934.53	916.61	848.05	781.14	682.23	593.57
468	1076.50	1201.45	1168.81	1048.13	936.28	920.59	852.68	784.98	691.93	593.10
504	1075.64	1200.62	1166.29	1051.58	937.28	923.57	857.31	789.78	688.15	593.10
540	1077.35	1203.12	1167.13	1054.17	937.78	924.07	860.98	794.59	690.51	593.81
576	1075.64	1198.11	1166.29	1055.89	937.78	923.07	861.95	797.96	698.09	594.99
612	1090.17	1207.29	1166.29	1056.75	937.03	921.08	861.22	800.36	697.14	596.17
648	1093.59	1210.63	1167.97	1057.61	936.78	918.10	858.53	800.85	697.38	597.34
684	1110.60	1219.79	1166.29	1056.75	934.53	911.90	854.14	798.68	695.48	597.81
Average	1079.43	1205.53	1159.47	1047.17	932.04	912.88	851.54	786.74	691.76	594.83
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

	14:03:54.65		14:05:28.47		14:07:00.19		14:08:38.01		14:10:13.04	
	1	2	3	4	5	6	7	8	9	10
0	915.44	1127.41	1218.92	1137.60	N/A	N/A	N/A	859.59	789.00	676.73
36	888.15	1123.18	1233.06	1144.35	N/A	N/A	N/A	865.94	N/A	675.55
72	865.05	1128.25	1239.72	1144.35	N/A	N/A	N/A	873.03	784.44	674.84
108	857.01	1140.92	1236.39	1138.44	N/A	N/A	941.55	881.13	790.92	674.37
144	899.62	1161.14	1242.22	1135.91	N/A	N/A	949.06	888.99	796.69	674.84
180	909.30	1173.73	1246.37	1139.29	N/A	N/A	954.82	896.62	798.37	675.55
216	948.08	1175.41	1242.22	1145.19	N/A	N/A	957.33	902.79	791.16	676.97
252	967.58	1180.44	1246.37	1150.25	N/A	N/A	959.09	906.50	807.52	678.15
288	982.57	1176.25	1250.53	1155.30	N/A	N/A	957.84	908.73	805.59	679.09
324	986.09	1174.57	1254.68	1158.66	N/A	N/A	953.57	907.74	798.37	679.33
360	958.73	1158.61	1256.34	1160.35	N/A	N/A	944.55	903.29	795.01	678.86
396	926.81	1158.61	1260.49	1162.03	N/A	N/A	941.55	899.83	791.64	677.67
432	889.92	1160.30	1262.15	1162.87	N/A	N/A	941.30	896.87	780.85	676.49
468	876.62	1149.35	1258.83	1162.87	N/A	N/A	945.30	895.88	781.33	675.31
504	856.11	1145.98	1254.68	1156.14	N/A	N/A	950.81	899.09	791.40	674.60
540	882.83	1166.18	1251.36	1148.56	N/A	N/A	955.07	903.78	794.05	674.60
576	906.67	1176.25	1249.70	1147.72	N/A	N/A	957.84	908.73	798.13	675.31
612	937.39	1181.28	1251.36	1148.56	N/A	N/A	959.59	912.69	802.95	676.26
648	961.38	1182.12	1248.04	1151.93	N/A	N/A	961.10	916.16	803.91	677.67
684	982.57	1186.31	1252.19	1154.46	N/A	N/A	960.85	918.14	805.59	678.86
Average	919.90	1161.32	1247.78	1150.24	N/A	N/A	952.42	897.28	795.10	676.55
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Shell Temperature Readings

Time	Position, metres				
	0.146	0.921	1.492	2.210	5.354
12:04:05.90	254.75	168.70	161.33	142.14	90.73
13:28:59.74	267.91	179.50	175.57	161.30	102.01

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
12:56	5	82.9	2.1	15.0
13:50	5	77.9	6.5	15.6
14:00	5	74.2	5.0	20.8
14:05	5	75.4	3.7	20.9
14:11	5	72.0	1.2	26.8
14:18	5	72.8	3.0	24.2
14:25	5	72.5	2.7	24.8

Axial Calcination Results

Natural Gas = 5.4 CFM	Product	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3
Sample Code	GP	GP	GP	G#1	G#1	G#2	G#2	G#3	G#3
Date	3/Jun/90	3/Jun/90	7/Jun/90	3/Jun/90	6/Jun/90	3/Jun/90	3/Jun/90	3/Jun/90	3/Jun/90
Before Firing, g	24.6943	23.7996	24.5387	24.8338	24.7918	27.4482	27.6574	27.5341	28.5393
After Firing, g	23.5986	22.7832	23.4216	22.0343	22.2698	22.0987	22.0417	21.3317	21.8565
Empty Crucible, g	12.5313	11.8686	11.6270	12.3096	12.4639	11.9972	11.6064	12.0411	11.9087
Wt of Sample Before, g	12.1630	11.9310	12.9117	12.5242	12.3279	15.4510	16.0510	15.4930	16.6306
Wt Loss by $CaCO_3$, g	1.0957	1.0164	1.1171	2.7995	2.5220	5.3495	5.6157	6.2024	6.6828
% Calcination	79.10	80.23	79.93	48.14	52.53	19.67	18.82	7.11	6.76

Average = 79.75% 50.34% 19.24% 6.94%

Lignin = 218 g/m	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3
Sample Code	LP	LP	L#1	L#1	L#2	L#2	L#3	L#3
Date	3/Jun/90	3/Jun/90	3/Jun/90	3/Jun/90	4/Jun/90	4/Jun/90	4/Jun/90	7/Jun/90
Before Firing, g	23.1423	23.0835	22.3594	22.1656	24.0010	22.8294	27.1641	25.9555
After Firing, g	23.0861	23.0160	22.3298	22.1411	22.9614	22.3641	22.1550	21.2875
Empty Crucible, g	12.4412	11.7458	11.8856	11.6698	12.5383	11.8777	12.2205	11.8948
Wt of Sample Before, g	10.7011	11.3377	10.4738	10.4958	11.4627	10.9517	14.9436	14.0607
Wt Loss by $CaCO_3$, g	0.0562	0.0675	0.0296	0.0245	1.0396	0.4653	5.0091	4.6680
% Calcination	98.78	98.62	99.34	99.46	78.96	90.14	22.23	22.97

Average = 98.70% 99.40% 84.55% 22.60%

Lignin = 218 g/m	Port #4	Port #4	Port #5	Port #5
Sample Code	L#4	L#4	L#5	L#5
Date	4/Jun/90	4/Jun/90	4/Jun/90	4/Jun/90
Before Firing, g	28.0475	27.9036	27.4930	29.2116
After Firing, g	21.2744	21.3795	21.0612	21.8314
Empty Crucible, g	11.6143	12.1576	12.5192	12.0465
Wt of Sample Before, g	16.4332	15.7460	14.9738	17.1651
Wt Loss by $CaCO_3$, g	6.7731	6.5241	6.4318	7.3802
% Calcination	4.37	3.86	0.34	0.24

Average = 4.12% 0.29%

Run LG12

Table of Events

Action Requested by Operator	Time
5/31/90	08:33:49.56
Kiln speed (rpm) : 1.5	08:33:54.34
Lignin = 131 g/min Gas = 2.2 CFM	8:30:00
Read Bed Temperatures	09:48:45.66
Read Bed Temperatures	09:50:50.06
Read Hot Face Heat Flux Temperatures	09:53:31.54
Read Colder Heat Flux Temperatures	09:54:56.46
Read Shell Temperatures	10:02:10.53
Suction T/C, Pair : 0	10:02:40.91
Read Bed Temperatures	12:05:34.38
Read Hot Face Heat Flux Temperatures	12:07:15.94
Read Colder Heat Flux Temperatures	12:08:40.85
Suction T/C, Pair : 1	12:11:08.49
Suction T/C, Pair : 2	12:13:06.31
Suction T/C, Pair : 3	12:14:35.40
Suction T/C, Pair : 4	12:16:06.68
Suction T/C, Pair : 5	12:17:50.71
Read Bed Temperatures	12:19:22.33
Read Bed Temperatures	12:21:30.74
Read Hot Face Heat Flux Temperatures	12:30:07.70
Read Colder Heat Flux Temperatures	12:31:32.51
Read Shell Temperatures	12:32:35.89
Lignin = 163 g/min Gas = 1.4 CFM	12:35:00
Read Bed Temperatures	13:38:21.79
Read Hot Face Heat Flux Temperatures	13:39:57.75
Read Colder Heat Flux Temperatures	13:41:22.72
Read Shell Temperatures	13:42:02.81
Suction T/C, Pair : 1	13:42:33.19
Suction T/C, Pair : 2	13:44:24.91
Suction T/C, Pair : 3	13:45:52.62
Suction T/C, Pair : 4	13:47:18.85
Suction T/C, Pair : 5	13:48:49.48

Cyclic Bed Temperature Readings

09:48:45.66	1	2	3	4	5	6	7	8	9	10
0	992.10	1078.63	1111.83	1001.72	895.87	846.33	791.88	724.01	625.65	557.81
36	1001.72	1092.28	1116.06	1008.70	902.30	852.67	796.70	729.48	631.78	564.88
72	1008.70	1100.79	1119.45	1016.54	907.99	858.29	799.59	734.48	636.03	570.06
108	1006.96	1099.94	1117.76	1018.28	910.22	861.22	801.27	738.05	636.26	572.42
144	999.98	1099.09	1112.67	1018.28	909.73	860.24	800.07	739.72	628.95	568.18
180	993.85	1099.94	1109.28	1016.54	905.76	855.11	793.81	736.14	615.29	555.45
216	993.85	1098.24	1110.13	1011.32	900.32	849.50	786.11	729.24	606.57	545.79
252	969.25	1013.93	1092.28	964.84	878.13	823.02	769.81	715.22	603.51	539.18
288	964.84	1025.22	1095.69	970.13	878.63	830.04	777.71	712.38	610.58	543.67
324	979.82	1059.77	1106.74	987.72	888.72	837.57	784.91	717.12	619.29	551.45
360	993.85	1081.19	1117.76	1001.72	898.09	845.36	791.64	723.06	626.83	558.99
396	1004.34	1091.43	1122.83	1012.19	904.52	851.21	796.46	728.53	632.49	565.35
432	1005.22	1097.39	1121.98	1020.01	910.72	858.78	801.03	734.00	636.03	570.06
468	1001.72	1096.54	1123.67	1021.75	913.45	860.98	802.72	737.81	637.44	571.95
504	997.35	1097.39	1119.45	1019.15	913.45	860.00	801.51	739.95	631.31	567.94
540	997.35	1100.79	1118.60	1016.54	908.49	853.89	793.33	735.67	615.76	555.69
576	993.85	1098.24	1117.76	1013.06	903.04	848.04	785.39	728.77	605.87	546.73
612	967.49	1026.09	1098.24	966.61	880.35	822.77	768.37	715.70	603.04	539.42
648	958.65	1027.85	1099.09	968.37	878.38	830.04	776.27	711.43	608.93	542.49
684	978.94	1061.49	1110.98	987.72	886.25	838.54	784.43	716.41	618.12	550.50
Minimum	958.65	1013.93	1092.28	964.84	878.13	822.77	768.37	711.43	603.04	539.18
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

09:50:50.06	1	2	3	4	5	6	7	8	9	10
0	989.55	1085.54	1124.60	1014.88	903.37	853.24	798.46	731.46	632.57	565.90
36	992.18	1094.07	1122.91	1022.70	909.81	860.08	802.32	736.22	637.28	571.09
72	994.81	1095.77	1121.22	1024.43	911.79	863.50	804.25	740.27	638.70	573.21
108	989.55	1094.92	1116.99	1023.57	913.03	863.99	803.76	741.94	632.57	568.73
144	991.31	1094.92	1112.75	1019.23	908.07	859.10	798.94	740.03	618.67	557.18
180	978.14	1089.81	1109.36	1012.27	902.87	852.51	791.96	735.27	609.24	549.17
216	956.08	1014.88	1093.21	968.45	881.41	825.52	772.52	721.24	605.24	541.15
252	943.66	1018.36	1093.21	969.33	879.20	831.58	779.71	714.83	611.13	544.22
288	968.45	1054.69	1111.91	991.31	889.78	842.03	788.60	719.10	620.08	551.29
324	986.05	1076.14	1122.06	1006.17	898.91	849.34	794.61	725.28	627.86	559.07
360	998.31	1087.25	1125.44	1014.88	906.09	856.17	799.18	730.99	633.98	565.90
396	1001.80	1093.21	1124.60	1024.43	912.54	862.28	803.76	736.46	638.46	571.32
432	997.43	1094.07	1121.22	1024.43	914.77	866.93	806.66	740.99	640.11	574.15
468	993.06	1094.07	1114.45	1024.43	915.02	865.71	804.00	742.89	634.69	569.91
504	993.93	1097.47	1113.60	1019.23	911.54	861.30	797.98	740.99	622.20	559.30
540	989.55	1095.77	1112.75	1014.01	906.34	855.68	791.72	735.27	610.89	549.64
576	968.45	1020.96	1096.62	972.86	884.12	829.88	772.76	721.72	605.24	541.15
612	956.08	1016.62	1094.92	969.33	881.66	832.79	779.47	715.07	610.89	544.22
648	974.62	1052.11	1111.91	990.43	892.49	841.30	788.12	718.87	619.14	550.82
684	993.06	1077.00	1122.91	1007.04	902.38	848.36	794.61	724.57	625.97	557.65
Minimum	943.66	1014.88	1093.21	968.45	879.20	825.52	772.52	714.83	605.24	541.15
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

12:05:34.38	1	2	3	4	5	6	7	8	9	10
0	956.56	1096.38	1150.55	1049.23	949.73	910.36	864.83	814.54	691.60	610.20
36	959.21	1069.02	1127.77	1018.90	933.97	898.24	862.88	807.78	694.20	611.38
72	961.87	1075.88	1124.39	1033.68	942.22	906.89	867.52	808.27	701.07	619.62
108	976.00	1086.15	1129.46	1049.23	952.99	917.80	872.66	810.92	707.46	628.11
144	993.57	1097.23	1133.69	1060.43	962.55	930.98	880.02	814.06	713.15	635.41
180	1005.82	1104.89	1138.75	1070.74	969.61	938.72	885.43	817.68	717.43	641.30
216	1013.67	1109.14	1142.13	1075.88	973.65	942.97	888.63	820.34	719.56	645.31
252	1014.55	1112.54	1144.66	1078.45	975.92	945.47	891.34	822.52	719.09	645.31
288	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	645.31
324	985.68	1110.84	1149.71	1084.44	971.37	933.48	883.46	822.27	702.49	625.75
360	N/A	1104.89	1151.39	1068.16	957.77	920.78	872.66	819.13	695.38	614.91
396	957.44	1067.31	1132.00	1021.51	935.47	898.24	863.61	811.16	693.96	611.61
432	951.24	1068.16	1122.70	1031.08	939.47	904.91	868.01	809.47	700.12	619.15
468	962.75	1076.74	1124.39	1045.78	950.99	916.06	873.65	811.64	706.99	627.40
504	982.16	1086.15	1129.46	1059.57	961.54	928.99	880.51	814.54	712.92	634.94
540	997.95	1095.53	1136.22	1067.31	967.59	935.47	883.95	817.44	716.71	640.60
576	1008.44	1104.89	1140.44	1072.45	971.37	940.22	887.15	819.86	719.32	645.08
612	1010.19	1109.99	1144.66	1077.59	974.66	941.97	888.63	821.55	719.32	646.25
648	1006.70	1115.93	1150.55	1082.73	975.67	940.47	886.91	822.03	714.10	640.60
684	982.16	1118.47	1153.08	1087.00	973.39	934.97	882.48	820.82	701.54	628.34
Minimum	951.24	1067.31	1122.70	1018.90	933.97	898.24	862.88	807.78	691.60	610.20
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

12:19:22.33	1	2	3	4	5	6	7	8	9	10
0	955.92	1088.10	1127.18	1025.23	938.72	902.20	869.49	813.34	700.37	617.52
36	962.12	1094.93	1129.71	1042.58	948.98	914.08	875.86	815.03	707.24	625.76
72	981.53	1101.74	1133.94	1054.66	956.76	925.50	881.99	817.93	713.64	634.01
108	993.82	1109.39	1139.85	1065.84	965.06	937.47	888.88	821.07	718.39	641.08
144	1005.20	1115.33	1143.22	1071.85	970.11	943.72	892.82	824.22	721.71	646.27
180	1013.92	1118.72	1146.59	1079.56	975.16	949.48	897.26	827.12	723.85	649.33
216	1008.69	1119.57	1149.96	1083.83	977.18	948.98	896.27	829.30	721.47	647.68
252	989.44	1121.26	1153.33	1087.25	976.68	944.47	891.83	829.55	712.46	638.02
288	963.89	1110.24	1154.17	1085.54	972.38	936.97	887.16	827.61	702.98	627.41
324	945.27	1093.22	1149.12	1044.31	950.73	913.09	870.47	822.52	698.48	613.98
360	947.93	1080.41	1128.02	1021.76	936.97	902.20	869.49	815.76	701.55	616.10
396	952.37	1082.12	1125.49	1037.39	943.47	910.61	874.88	816.00	708.19	624.35
432	968.31	1091.52	1131.41	1053.79	954.25	922.52	881.01	818.17	713.40	632.13
468	990.32	1100.89	1137.32	1064.98	960.28	931.48	886.91	821.31	718.86	639.90
504	1003.45	1107.69	1141.53	1074.42	968.34	940.97	892.33	824.46	722.19	645.33
540	1007.82	1114.48	1146.59	1080.41	974.15	947.23	896.02	827.36	723.61	648.63
576	1004.33	1117.02	1149.96	1083.83	976.42	949.23	897.01	829.30	722.66	648.16
612	996.45	1114.48	1152.49	1088.10	977.69	946.47	893.80	830.03	713.64	639.43
648	980.65	1111.09	1155.01	1091.52	974.65	938.72	889.12	828.33	701.55	626.94
684	959.46	1105.14	1155.01	1065.84	958.27	922.02	876.10	824.94	696.58	614.69
Minimum	945.27	1080.41	1125.49	1021.76	936.97	902.20	869.49	813.34	696.58	613.98
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

12:21:30.74	1	2	3	4	5	6	7	8	9	10
0	984.22	1091.57	1131.46	1046.08	949.28	915.86	875.66	817.98	710.13	627.93
36	998.25	1100.09	1136.52	1059.87	958.82	927.30	881.31	820.64	715.59	635.71
72	1010.49	1108.59	1141.58	1071.04	968.64	939.02	888.19	824.03	720.34	642.55
108	1016.59	1113.68	1145.80	1077.04	972.93	945.02	891.88	826.93	722.95	647.50
144	1017.46	1118.77	1150.01	1082.17	976.22	947.03	894.35	829.11	723.19	649.38
180	1010.49	1119.62	1154.22	1087.30	976.22	945.27	893.61	830.32	719.86	644.67
216	988.61	1122.16	1155.90	1090.71	975.71	939.77	889.42	829.84	709.90	633.59
252	964.82	1120.46	1158.43	1091.57	970.16	932.53	884.25	827.66	703.26	623.69
288	954.20	1096.68	1147.48	1035.71	944.52	904.72	867.82	820.88	698.29	611.91
324	956.86	1084.74	1128.07	1027.89	936.52	902.00	870.27	815.81	703.26	617.57
360	963.05	1094.13	1128.92	1043.49	947.28	913.88	876.15	817.01	709.42	626.05
396	978.94	1103.49	1133.99	1059.01	958.57	926.55	883.03	819.91	714.88	633.83
432	993.00	1111.14	1140.74	1071.04	968.39	937.52	889.17	823.06	719.62	640.66
468	1007.87	1117.07	1144.96	1078.75	973.19	943.02	893.12	825.96	722.71	646.08
504	1015.72	1121.31	1147.48	1084.74	976.98	947.53	896.57	828.63	724.37	649.15
540	1010.49	1124.69	1153.38	1087.30	978.24	946.52	895.33	830.08	722.24	647.50
576	994.75	1121.31	1156.74	1091.57	978.24	943.77	891.64	830.08	712.98	636.18
612	965.71	1108.59	1156.74	1092.42	974.70	937.27	887.70	828.38	705.63	626.52
648	952.42	1094.13	1154.22	1049.53	952.79	913.63	871.00	823.78	699.95	612.86
684	960.40	1078.75	1132.30	1020.94	936.77	900.02	869.05	816.53	702.55	615.45
Minimum	952.42	1078.75	1128.07	1020.94	936.52	900.02	867.82	815.81	698.29	611.91
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

13:38:21.79	1	2	3	4	5	6	7	8	9	10
0	1016.45	1173.46	1191.06	1064.05	955.65	919.45	881.43	844.79	717.43	627.41
36	1026.01	1162.55	1164.23	1035.58	941.37	906.56	878.49	837.26	718.61	628.59
72	1032.98	1166.75	1160.03	1051.13	947.87	916.72	884.38	837.26	722.17	636.13
108	1039.91	1174.30	1167.59	1065.77	957.66	930.64	892.25	839.20	725.50	643.91
144	1048.55	1180.17	1173.46	1076.92	966.46	942.12	898.66	841.87	728.35	650.51
180	1055.44	1183.52	1178.50	1085.48	973.02	949.88	903.85	845.03	731.20	656.17
216	1060.61	1186.87	1181.85	1093.17	977.57	952.64	905.08	847.71	732.15	659.71
252	1064.05	1187.71	1186.04	1098.28	979.84	953.14	904.59	849.41	731.44	659.71
288	1053.72	1189.38	1190.22	1103.39	981.62	950.88	902.36	850.38	728.82	654.99
324	1040.77	1191.89	1196.08	1105.09	978.58	945.37	897.67	849.65	723.84	644.15
360	1020.80	1194.40	1200.25	1088.05	967.47	931.64	887.82	847.46	720.51	634.01
396	1035.58	1175.98	1175.98	1041.64	946.62	906.56	876.77	839.20	717.19	628.83
432	1041.64	1176.82	1159.18	1045.09	946.87	912.51	880.70	837.02	718.61	634.72
468	1062.33	1185.20	1158.34	1057.17	956.15	924.67	886.35	837.99	722.65	642.03
504	1070.92	1186.87	1162.55	1066.63	963.44	934.88	892.01	839.69	725.50	647.92
540	1070.92	1189.38	1170.11	1077.78	970.50	944.62	897.92	842.36	728.11	652.87
576	1070.92	1191.89	1175.14	1084.63	977.06	952.89	903.60	845.03	730.73	657.12
612	N/A	N/A	N/A	N/A	N/A	N/A	903.60	845.03	730.73	657.12
648	1058.03	1193.57	1184.36	1096.58	983.64	955.65	904.09	849.65	730.01	657.83
684	1044.23	1192.73	1188.55	1100.84	982.12	950.13	900.14	850.14	725.26	647.68
Minimum	1016.45	1162.55	1158.34	1035.58	941.37	906.56	876.77	837.02	717.19	627.41
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

09:53:31.54	1	2	3	4	5	6	7	8	9	10
0	N/A	985.33	915.54	N/A	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	986.21	918.16	N/A	N/A	N/A	N/A	N/A	N/A	N/A
72	N/A	986.21	919.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	N/A	987.08	919.91	N/A	N/A	N/A	N/A	N/A	N/A	N/A
144	N/A	987.96	919.91	N/A	N/A	N/A	N/A	N/A	N/A	N/A
180	N/A	983.57	918.16	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216	N/A	973.90	912.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A
252	N/A	969.49	907.66	N/A	N/A	N/A	N/A	N/A	N/A	N/A
288	N/A	977.42	911.17	N/A	N/A	N/A	N/A	N/A	N/A	N/A
324	N/A	982.69	913.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A
360	N/A	984.45	915.54	N/A	N/A	N/A	N/A	N/A	N/A	N/A
396	N/A	986.21	917.29	N/A	N/A	N/A	N/A	N/A	N/A	N/A
432	N/A	986.21	919.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A
468	N/A	987.08	919.91	N/A	N/A	N/A	N/A	N/A	N/A	N/A
504	N/A	987.08	919.91	N/A	N/A	N/A	N/A	N/A	N/A	N/A
540	N/A	982.69	918.16	N/A	N/A	N/A	N/A	N/A	N/A	N/A
576	N/A	973.90	912.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A
612	N/A	968.61	907.66	N/A	N/A	N/A	N/A	N/A	N/A	N/A
648	N/A	976.54	911.17	N/A	N/A	N/A	N/A	N/A	N/A	N/A
684	N/A	980.94	913.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	N/A	981.68	915.50	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

12:07:15.94	1	2	3	4	5	6	7	8	9	10
0	N/A	1031.08	969.82	N/A	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	1031.95	971.59	N/A	N/A	N/A	N/A	N/A	N/A	N/A
72	N/A	1034.54	973.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	N/A	1035.41	974.23	N/A	N/A	N/A	N/A	N/A	N/A	N/A
144	N/A	1035.41	976.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A
180	N/A	1029.32	971.59	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216	N/A	1022.38	961.87	N/A	N/A	N/A	N/A	N/A	N/A	N/A
252	N/A	1019.77	957.44	N/A	N/A	N/A	N/A	N/A	N/A	N/A
288	N/A	1025.85	961.87	N/A	N/A	N/A	N/A	N/A	N/A	N/A
324	N/A	1028.45	965.41	N/A	N/A	N/A	N/A	N/A	N/A	N/A
360	N/A	1031.08	968.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A
396	N/A	1032.81	970.71	N/A	N/A	N/A	N/A	N/A	N/A	N/A
432	N/A	1034.54	972.47	N/A	N/A	N/A	N/A	N/A	N/A	N/A
468	N/A	1035.41	973.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
504	N/A	1036.28	974.23	N/A	N/A	N/A	N/A	N/A	N/A	N/A
540	N/A	1033.68	973.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A
576	N/A	1026.72	963.64	N/A	N/A	N/A	N/A	N/A	N/A	N/A
612	N/A	1021.51	956.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A
648	N/A	1024.98	960.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
684	N/A	1028.45	964.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	N/A	1029.98	968.01	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

12:30:07.70	1	2	3	4	5	6	7	8	9	10
0	N/A	1057.49	975.62	N/A	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	1058.35	975.62	N/A	N/A	N/A	N/A	N/A	N/A	N/A
72	N/A	1049.73	966.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	N/A	1045.42	958.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A
144	N/A	1048.01	959.71	N/A	N/A	N/A	N/A	N/A	N/A	N/A
180	N/A	1052.32	964.14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216	N/A	1054.04	966.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A
252	N/A	1054.91	969.44	N/A	N/A	N/A	N/A	N/A	N/A	N/A
288	N/A	1055.77	971.21	N/A	N/A	N/A	N/A	N/A	N/A	N/A
324	N/A	1055.77	972.09	N/A	N/A	N/A	N/A	N/A	N/A	N/A
360	N/A	1057.49	973.85	N/A	N/A	N/A	N/A	N/A	N/A	N/A
396	N/A	1058.35	973.85	N/A	N/A	N/A	N/A	N/A	N/A	N/A
432	N/A	1052.32	966.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A
468	N/A	1048.01	958.83	N/A	N/A	N/A	N/A	N/A	N/A	N/A
504	N/A	1047.15	957.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A
540	N/A	1052.32	961.48	N/A	N/A	N/A	N/A	N/A	N/A	N/A
576	N/A	1054.04	964.14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
612	N/A	1055.77	966.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A
648	N/A	1056.63	968.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A
684	N/A	1057.49	970.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	N/A	1053.57	967.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

13:39:57.75	1	2	3	4	5	6	7	8	9	10
0	N/A	1100.84	973.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A
36	N/A	1102.54	976.13	N/A	N/A	N/A	N/A	N/A	N/A	N/A
72	N/A	1103.39	978.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	N/A	1102.54	980.54	N/A	N/A	N/A	N/A	N/A	N/A	N/A
144	N/A	1101.69	982.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A
180	N/A	1099.99	984.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A
216	N/A	1100.84	985.82	N/A	N/A	N/A	N/A	N/A	N/A	N/A
252	N/A	1095.73	977.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A
288	N/A	1092.31	968.19	N/A	N/A	N/A	N/A	N/A	N/A	N/A
324	N/A	N/A	968.19	N/A	N/A	N/A	N/A	N/A	N/A	N/A
360	N/A	1099.13	970.84	N/A	N/A	N/A	N/A	N/A	N/A	N/A
396	N/A	1100.84	973.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A
432	N/A	1101.69	976.13	N/A	N/A	N/A	N/A	N/A	N/A	N/A
468	N/A	1103.39	978.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A
504	N/A	1104.24	980.54	N/A	N/A	N/A	N/A	N/A	N/A	N/A
540	N/A	1105.94	981.42	N/A	N/A	N/A	N/A	N/A	N/A	N/A
576	N/A	1106.79	983.18	N/A	N/A	N/A	N/A	N/A	N/A	N/A
612	N/A	1105.09	977.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A
648	N/A	1099.99	969.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A
684	N/A	1096.58	964.65	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	N/A	1101.24	976.53	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

Interior Wall Probe Temperature Readings

09:54:56.46	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	329.03	629.34	N/A
1.568	271.93	557.56	850.08
2.064	263.90	N/A	N/A
2.375	N/A	508.49	N/A
2.724	N/A	450.43	N/A
3.048	170.34	383.11	555.69
4.070	162.47	307.41	465.16
4.585	150.91	247.06	397.96
5.213	137.87	235.82	314.92

12:08:40.85	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	366.43	673.06	N/A
1.568	312.51	620.41	903.62
2.064	307.39	N/A	N/A
2.375	N/A	581.23	N/A
2.724	N/A	538.33	N/A
3.048	207.84	471.15	633.76
4.070	198.03	378.09	550.36
4.585	173.71	289.91	470.20
5.213	149.36	253.37	356.45

12:31:32.51	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	370.26	682.21	N/A
1.568	318.69	628.79	906.75
2.064	312.50	N/A	N/A
2.375	N/A	589.27	N/A
2.724	N/A	548.74	N/A
3.048	216.19	481.85	640.15
4.070	203.68	387.95	558.17
4.585	178.14	296.97	476.87
5.213	153.79	258.50	361.05

NOTE: This set of data was used for steady state calculations.

13:41:22.72	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	389.30	716.98	N/A
1.568	332.53	642.93	N/A
2.064	322.38	N/A	575.83
2.375	N/A	604.33	N/A
2.724	N/A	568.52	N/A
3.048	231.06	504.80	504.80
4.070	219.30	410.18	219.30
4.585	190.35	313.17	313.17
5.213	167.25	272.10	272.10

NOTE: This set of data was used for steady state calculations.

Suction Pyrometer Temperature Readings of Flue Gas

	12:11:08.49		12:13:06.31		12:14:35.40		12:16:06.68		12:17:50.71	
	1	2	3	4	5	6	7	8	9	10
0	1015.52	1129.56	1180.89	1098.19	N/A	N/A	932.63	864.25	748.07	633.02
36	1041.56	1147.28	1190.09	1102.44	N/A	N/A	934.12	868.65	741.16	632.08
72	1072.55	1164.95	1193.44	1106.69	998.92	N/A	935.37	872.08	747.83	631.13
108	1087.10	1166.63	1199.29	1110.94	1001.47	N/A	928.39	872.57	756.65	630.66
144	1108.39	1181.72	1205.97	1115.18	1003.76	N/A	922.42	869.63	758.56	630.66
180	1093.93	1180.05	1213.47	1120.26	1004.53	N/A	923.91	867.67	763.10	631.37
216	1063.11	1175.02	1217.63	1122.80	1001.98	N/A	927.15	867.18	766.93	632.08
252	1047.61	1149.81	1220.96	1124.49	1000.19	N/A	929.14	867.67	769.56	632.78
288	1039.83	1149.81	1225.12	1128.72	1000.45	N/A	931.88	870.12	768.84	633.49
324	1007.67	1154.86	1229.28	1129.56	1001.47	N/A	936.12	874.04	765.97	633.73
360	1010.29	1166.63	1232.61	1127.87	1003.51	N/A	937.37	876.74	759.76	633.25
396	1024.21	1167.47	1227.62	1125.34	1005.80	N/A	940.62	879.93	752.84	632.55
432	1075.12	1176.70	1229.28	1125.34	1007.59	N/A	938.37	881.65	748.54	631.60
468	1090.51	1186.75	1227.62	1127.87	1008.62	N/A	939.12	881.89	753.31	631.13
504	1110.94	1201.79	1227.62	1129.56	1008.87	N/A	932.13	880.17	760.95	630.90
540	1109.24	1190.93	1225.12	1131.26	1007.59	N/A	929.14	876.25	770.52	631.37
576	1085.39	1181.72	1227.62	1133.79	1007.08	N/A	930.14	874.78	769.08	632.08
612	1069.12	1178.37	1233.44	1135.48	1004.78	N/A	931.88	874.78	773.39	633.02
648	1022.48	1172.50	1230.94	1135.48	1003.51	N/A	935.87	876.74	771.71	633.73
684	1019.00	1172.50	1238.43	1130.41	999.43	N/A	937.62	879.44	764.78	634.20
Average	1059.68	1169.75	1218.82	1123.08	1002.82	N/A	932.67	873.81	760.58	632.24
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

	13:42:33.19		13:44:24.91		13:45:52.62		13:47:18.85		13:48:49.48	
	1	2	3	4	5	6	7	8	9	10
0	1068.46	1218.71	1205.37	1102.65	993.70	N/A	922.89	863.28	765.01	651.19
36	1092.42	1227.86	1217.05	1107.75	996.50	N/A	923.63	867.92	772.66	650.72
72	1112.85	1242.01	1222.04	1108.60	995.99	N/A	928.61	873.79	777.93	650.72
108	1119.63	1247.00	1229.53	1109.45	999.30	N/A	932.59	880.66	785.12	651.19
144	1120.48	1249.49	1237.01	1109.45	1003.38	N/A	935.34	885.33	787.52	651.67
180	1123.02	1263.60	1237.85	1111.15	1004.65	N/A	939.58	889.51	784.88	652.37
216	1121.33	1266.09	1230.36	1111.15	1004.91	N/A	940.08	893.20	786.32	652.61
252	1135.70	1268.58	1240.34	1118.78	1008.23	N/A	942.08	895.66	783.68	652.61
288	1120.48	1251.98	1236.18	1123.02	1009.25	N/A	938.33	896.40	782.72	652.14
324	1104.35	1263.60	1233.68	1125.56	1008.99	N/A	933.34	893.94	777.93	651.19
360	1108.60	1255.30	1236.18	1130.63	1008.48	N/A	932.84	892.46	778.41	650.25
396	1099.24	1245.33	1241.17	1133.17	1007.46	N/A	931.85	892.22	781.05	649.78
432	1109.45	1247.00	1251.98	1134.01	1009.50	N/A	932.59	893.45	786.32	649.78
468	1117.94	1245.33	1258.62	1134.01	1010.53	N/A	934.84	896.90	788.00	650.25
504	1117.94	1242.01	1259.45	1134.01	1013.34	N/A	936.33	900.35	788.72	650.96
540	1119.63	1233.68	1254.47	1133.17	1016.15	N/A	938.83	904.06	790.16	651.90
576	1104.35	1239.51	1239.51	1134.86	1017.69	N/A	937.83	905.79	792.08	652.61
612	1083.88	1233.68	1234.52	1134.86	1019.23	N/A	938.58	906.77	785.84	652.85
648	1070.17	1221.21	1225.37	1134.01	1018.46	N/A	937.33	906.77	783.20	652.61
684	1071.03	1238.68	1213.71	1134.01	1016.15	N/A	932.84	903.81	776.26	651.67
Average	1106.05	1245.03	1235.22	1123.22	1008.09	N/A	934.52	892.11	782.69	651.45
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Shell Temperature Readings

Time	Position, metres				
	0.146	0.921	1.492	2.210	5.354
09:54:56.46	250.65	168.78	149.84	120.07	89.57
12:31:32.51	269.77	191.95	179.42	155.56	99.23
13:41:22.72	282.38	204.64	188.43	171.97	112.19

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
9:43	5	83.7	2.3	14.0
11:18	5	79.8	3.8	16.4
11:22	5	80.4	3.0	16.6
11:27	5	80.9	2.2	16.9
12:49	5	79.7	1.9	18.4
13:08	5	80.0	2.0	18.0
13:30	5	80.9	2.0	17.1

Axial Calcination Results

Lignin = 131 g/m	Product	Product	Port #1	Port #1	Port #1	Port #1	Port #2	Port #2
Sample Code	LPA	LPA	L#1A	L#1A	L#1A	L#1A	L#2A	L#2A
Date	4/Jun/90	4/Jun/90	5/Jun/90	5/Jun/90	7/Jun/90	7/Jun/90	5/Jun/90	7/Jun/90
Before Firing, g	22.9786	22.7028	23.9742	22.3371	23.5716	22.7901	25.0347	24.2484
After Firing, g	22.9375	22.6647	23.9157	22.2919	23.5003	22.7259	22.9607	22.2342
Empty Crucible, g	11.8945	11.6788	12.5445	11.8838	12.4663	11.7713	12.1463	11.6949
Wt of Sample Before, g	11.0841	11.0240	11.4297	10.4533	11.1053	11.0188	12.8884	12.5535
Wt Loss by $CaCO_3$, g	0.0411	0.0381	0.0585	0.0452	0.0713	0.0642	2.0740	2.0142
% Calcination	99.14	99.20	98.81	99.00	98.51	98.65	62.66	62.77

Average = 99.17% 98.74% 62.72%

Lignin = 131 g/m	Port #3	Port #3	Port #3	Port #4	Port #4
Sample Code	L#3A	L#3A	L#3A	L#4A	L#4A
Date	5/Jun/90	8/Jun/90	8/Jun/90	5/Jun/90	5/Jun/90
Before Firing, g	28.1623	24.6959	25.5854	29.1634	29.8142
After Firing, g	22.2800	20.2683	20.6348	21.9533	22.5498
Empty Crucible, g	11.6182	12.5594	11.8972	12.0523	12.5255
Wt of Sample Before, g	16.5441	12.1365	13.6882	17.1111	17.2887
Wt Loss by $CaCO_3$, g	5.8823	4.4276	4.9506	7.2101	7.2644
% Calcination	17.50	15.35	16.08	2.23	2.51

Average = 16.31% 2.37%

Lignin = 163 g/m	Product	Product	Port #1	Port #1	Port #2	Port #2
Sample Code	LPB	LPB	L#1B	L#1B	L#2B	L#2B
Date	5/Jun/90	5/Jun/90	5/Jun/90	5/Jun/90	6/Jun/90	6/Jun/90
Before Firing, g	23.3786	22.6664	22.7791	22.7349	24.9443	23.3951
After Firing, g	23.3618	22.6484	22.7312	22.6823	23.7670	22.0138
Empty Crucible, g	12.4546	11.7584	11.9012	11.6852	12.5514	11.8903
Wt of Sample Before, g	10.9240	10.9080	10.8779	11.0497	12.3929	11.5048
Wt Loss by $CaCO_3$, g	0.0168	0.0180	0.0479	0.0526	1.1773	1.3813
% Calcination	99.64	99.62	98.98	98.90	77.96	72.14
Average =	99.63%		98.94%		75.05%	

Lignin = 163 g/m	Port #3	Port #3	Port #3	Port #3	Port #4	Port #4	Port #4	Port #5	Port #5
Sample Code	L#3B	L#3B	L#3B	L#3B	L#4B	L#4B	L#4B	L#5B	L#5B
Date	6/Jun/90	6/Jun/90	8/Jun/90	8/Jun/90	6/Jun/90	8/Jun/90	8/Jun/90	6/Jun/90	6/Jun/90
Before Firing, g	29.7975	26.2465	28.2731	26.9965	28.2364	29.0384	28.8815	27.9212	27.8051
After Firing, g	23.2228	21.4515	22.2990	21.5064	21.3470	22.1629	21.8545	21.3087	21.0395
Empty Crucible, g	12.1535	12.2290	12.0237	11.6333	11.6231	12.5420	12.0645	12.5336	12.0576
Wt of Sample Before, g	17.6440	14.0175	16.2494	15.3632	16.6133	16.4964	16.8170	15.3876	15.7475
Wt Loss by $CaCO_3$, g	6.5747	4.7950	5.9741	5.4901	6.8894	6.8755	7.0270	6.6125	6.7656
% Calcination	13.54	20.63	14.70	17.08	3.78	3.29	3.05	0.29	0.32
Average =		16.49%				3.37%		0.30%	

Natural Gas = 5.4 CFM	Product	Product	Product	Product
Sample Code	GP	GP	GP	GP
Date	4/Jun/90	4/Jun/90	7/Jun/90	7/Jun/90
Before Firing, g	23.8206	23.0674	23.2964	23.3835
After Firing, g	23.0650	22.5139	22.8724	22.9694
Empty Crucible, g	12.4518	11.7562	12.5377	12.0606
Wt of Sample Before, g	11.3688	11.3112	10.7587	11.3229
Wt Loss by $CaCO_3$, g	0.7556	0.5535	0.4240	0.4141
% Calcination	84.58	88.65	90.86	91.51

Average = 88.90%

Run LG13

Table of Events

Action Requested by Operator	Time
6/12/90	07:30:24.16
Kiln speed (rpm) : 1.5	07:30:31.36
Gas = 5.4 CFM	9:40:00
Read Bed Temperatures	11:09:52.82
Read Hot Face Heat Flux Temperatures	11:13:24.45
Read Colder Heat Flux Temperatures	11:14:49.37
Read Shell Temperatures	11:15:32.70
Read Shell Temperatures	11:15:50.00
Suction T/C, Pair : 1	11:16:17.36
Suction T/C, Pair : 2	11:18:10.50
Suction T/C, Pair : 3	11:19:36.85
Suction T/C, Pair : 4	11:21:02.69
Suction T/C, Pair : 5	11:22:51.17

Cyclic Bed Temperature Readings

11:09:52.82	1	2	3	4	5	6	7	8	9	10
0	1084.15	1130.87	1121.57	1057.56	943.18	910.81	863.07	827.31	696.04	627.11
36	1054.12	1135.09	1127.48	1058.42	939.93	904.13	858.68	821.50	686.81	616.74
72	1025.56	1112.25	1113.94	1039.44	930.44	891.29	849.17	811.84	682.32	610.38
108	1022.96	1066.16	1071.31	N/A	N/A	N/A	N/A	N/A	N/A	610.38
144	1035.98	1080.73	1082.44	1023.82	918.25	883.17	847.95	802.67	688.23	615.56
180	1048.08	1096.09	1096.09	1035.98	924.96	890.31	852.09	808.70	693.67	621.93
216	1054.98	1105.45	1106.30	1042.04	930.44	897.95	855.99	814.97	698.17	628.76
252	1061.86	1110.55	1110.55	1049.81	935.93	905.36	860.39	821.02	701.25	633.47
288	1073.02	1118.18	1112.25	1052.39	940.18	910.81	863.56	825.86	703.62	637.01
324	1090.12	1124.10	1113.09	1054.98	942.93	913.29	864.79	828.52	703.38	637.48
360	1094.39	1127.48	1115.64	1056.70	943.68	912.05	863.32	826.83	697.46	629.94
396	1075.59	1130.02	1122.41	1058.42	942.18	907.59	859.90	821.26	689.18	618.39
432	1042.90	1128.33	1126.64	1052.39	936.43	899.68	853.07	814.01	683.50	611.32
468	1033.39	1071.31	1073.02	1014.26	922.23	882.44	844.06	800.75	682.79	607.56
504	1039.44	1074.73	1077.30	1018.61	919.00	883.17	847.22	800.27	687.29	613.44
540	1049.81	1092.68	1096.09	1031.66	923.72	890.31	851.85	806.53	692.73	620.51
576	1057.56	1103.75	1109.70	1041.17	930.19	899.43	855.75	813.52	696.99	626.87
612	1062.72	1108.85	1116.48	1047.22	935.93	907.10	860.14	819.57	700.54	632.29
648	1070.45	1113.94	1116.48	1050.67	N/A	N/A	N/A	N/A	N/A	632.29
684	1086.71	1120.72	1116.48	1051.53	941.93	914.03	865.28	827.31	703.38	637.48
Minimum	1022.96	1066.16	1071.31	1014.26	918.25	882.44	844.06	800.27	682.32	607.56
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

11:13:24.45	1	2	3	4	5	6	7	8	9	10
0	N/A	1012.71	944.04	912.50	885.83	835.51	N/A	N/A	525.49	392.16
36	N/A	1005.73	936.02	908.29	883.13	832.84	N/A	N/A	525.02	389.52
72	N/A	999.61	931.56	904.82	881.16	832.11	N/A	N/A	524.55	388.08
108	N/A	1006.61	935.13	906.55	881.90	833.57	N/A	N/A	524.31	388.08
144	N/A	1010.97	938.70	908.53	883.13	835.03	N/A	N/A	524.08	388.80
180	N/A	1012.71	940.48	910.52	884.36	836.00	N/A	N/A	N/A	388.80
216	N/A	1014.46	942.26	911.75	885.34	836.72	N/A	N/A	524.55	390.00
252	N/A	1015.33	944.04	912.75	886.32	837.45	N/A	N/A	524.79	390.72
288	N/A	1016.20	944.04	913.24	886.57	837.45	N/A	N/A	525.02	391.44
324	N/A	1017.94	945.82	913.49	886.82	837.21	N/A	N/A	525.49	391.92
360	N/A	1015.33	N/A	N/A	N/A	N/A	N/A	N/A	525.49	391.92
396	N/A	1008.35	939.59	909.28	884.11	833.81	N/A	N/A	525.26	389.76
432	N/A	1001.36	932.46	905.32	881.65	831.87	N/A	N/A	524.79	388.08
468	N/A	1005.73	934.24	905.81	881.41	833.33	N/A	N/A	524.08	388.08
504	N/A	1010.97	937.81	908.04	882.64	834.78	N/A	N/A	524.31	389.04
540	N/A	1013.58	940.48	909.77	883.86	835.75	N/A	N/A	524.08	389.52
576	N/A	1014.46	942.26	911.51	885.09	836.72	N/A	N/A	524.55	390.24
612	N/A	1015.33	944.04	912.50	885.83	837.21	N/A	N/A	524.79	390.96
648	N/A	1016.20	944.93	913.24	886.57	837.45	N/A	N/A	525.26	391.44
684	N/A	1017.07	945.82	913.49	886.82	837.21	N/A	N/A	525.49	392.16
Average	N/A	1011.53	940.20	910.07	884.34	835.37	N/A	N/A	524.81	390.04
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

Interior Wall Probe Temperature Readings

11:14:49.37	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	365.23	676.82	N/A
1.568	311.28	609.44	880.57
2.064	N/A	618.59	868.41
2.375	N/A	N/A	845.72
2.724	N/A	588.68	788.44
3.048	N/A	N/A	735.16
4.070	213.15	393.35	551.92
4.585	192.04	310.45	479.13
5.213	176.07	284.72	374.40

NOTE: This set of data was used for steady state calculations.

Suction Pyrometer Temperature Readings of Flue Gas

	11:16:17.36		11:18:10.50		11:19:36.85		11:21:02.69		11:22:51.17	
	1	2	3	4	5	6	7	8	9	10
0	N/A	1165.74	1189.21	1096.43	N/A	N/A	N/A	N/A	732.83	617.94
36	1135.43	1162.38	1195.06	1098.14	N/A	N/A	N/A	N/A	730.69	618.17
72	1141.33	1167.42	1198.40	1097.28	N/A	N/A	892.77	846.25	727.60	617.70
108	1140.49	1164.06	1190.88	1098.14	974.05	945.37	898.19	854.29	727.60	617.70
144	1159.86	1172.45	1182.51	1100.69	976.32	949.88	901.16	860.63	718.10	616.05
180	1185.02	1184.19	1175.81	1101.54	978.60	951.64	900.66	861.37	727.12	615.58
216	1205.08	1204.25	1168.26	1103.24	978.35	952.89	896.47	858.92	735.21	615.58
252	1181.67	1210.09	1166.58	1106.64	979.87	952.39	894.00	854.53	736.40	615.58
288	1143.02	1242.54	1180.84	1107.49	978.85	947.63	890.55	850.15	737.35	616.05
324	1135.43	1235.89	1198.40	1110.04	976.83	944.62	888.58	846.25	740.92	617.00
360	1159.86	1225.07	1195.90	1111.74	976.32	942.87	893.75	848.68	734.73	617.70
396	1164.06	1188.37	1200.07	1110.89	980.88	945.87	895.48	852.58	737.59	617.94
432	1164.06	1185.02	1198.40	1111.74	982.15	948.38	900.42	857.95	737.59	617.70
468	1168.26	1179.16	1201.74	1108.34	980.88	952.14	903.63	862.83	726.89	617.00
504	1172.45	1165.74	1191.72	1110.89	981.64	955.40	905.11	866.50	719.76	616.29
540	1180.84	1172.45	1178.32	1109.19	980.63	957.67	904.12	867.23	722.85	615.58
576	1207.58	1188.37	1172.45	1108.34	983.16	957.92	902.15	866.25	731.64	615.35
612	1190.88	1204.25	1173.29	1110.89	982.65	957.67	895.48	858.92	736.87	615.58
648	1156.49	N/A	1177.48	1110.04	982.15	954.40	892.03	850.88	736.87	615.58
684	1141.33	1205.08	1153.97	1100.69	980.63	951.39	892.28	849.17	739.01	616.53
Average	1164.90	1190.66	1184.47	1105.62	979.64	951.07	897.05	856.30	731.88	616.63
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Shell Temperature Readings

Time	Position, metres				
	0.146	0.921	1.492	2.210	5.354
11:14:49.37	268.25	184.76	175.43	155.75	116.63
11:15:32.70	268.74	184.03	175.43	151.08	114.91

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
11:12	5	81.6	2.1	16.3
11:38	5	81.5	2.1	16.4

Axial Calcination Results

Natural Gas = 5.4 CFM	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3
Sample Code	GP	GP	G#1	G#1	G#2	G#2	G#3	G#3
Date	16/Jun/90	16/Jun/90	24/Jun/90	24/Jun/90	16/Jun/90	16/Jun/90	16/Jun/90	16/Jun/90
Before Firing, g	24.2610	23.2548	20.2842	20.5181	25.9911	26.1741	26.5307	27.8397
After Firing, g	24.1660	23.1722	19.3582	19.8418	21.9450	22.5271	21.0885	21.6473
Empty Crucible, g	12.5591	11.8981	9.9512	10.2624	12.0268	11.6350	12.5436	12.0667
Wt of Sample Before, g	11.7019	11.3567	10.3330	10.2557	13.9643	14.5391	13.9871	15.7730
Wt Loss by $CaCO_3$, g	0.0950	0.0826	0.9260	0.6763	4.0461	3.6470	5.4422	6.1924
% Calcination	98.12	98.31	79.21	84.70	32.77	41.80	9.72	8.91
Average =	98.21%		81.95%		37.29%		9.32%	

Natural Gas = 5.4 CFM	Port #4	Port #4	Port #5	Port #5
Sample Code	G#4	G#4	G#5	G#5
Date	16/Jun/90	16/Jun/90	16/Jun/90	16/Jun/90
Before Firing, g	28.8340	28.6314	29.2519	28.5556
After Firing, g	21.8096	21.4110	21.7222	21.2690
Empty Crucible, g	12.4691	11.7743	11.9127	11.6972
Wt of Sample Before, g	16.3649	16.8571	17.3392	16.8584
Wt Loss by $CaCO_3$, g	7.0244	7.2204	7.5297	7.2866
% Calcination	0.41	0.62	-0.76	-0.29
Average =	0.51%		0.00%	

Run LG14

Table of Events

Action Requested by Operator	Time
6/14/90	10:06:54.88
Kiln speed (rpm) : 1.5	10:06:59.83
Gas = 5.4 CFM	9:10:00
Read Bed Temperatures	10:56:19.65
Read Shell Temperatures	10:57:56.54
Read Hot Face Heat Flux Temperatures	10:58:05.66
Read Colder Heat Flux Temperatures	10:59:30.57
Suction T/C, Pair : 1	11:01:56.51
Suction T/C, Pair : 2	11:03:31.59
Suction T/C, Pair : 3	11:05:15.12
Suction T/C, Pair : 4	11:06:41.85
Suction T/C, Pair : 5	11:08:06.65
Lignin = 220 g/min Gas = 0.0 CFM	11:20:00
Read Bed Temperatures	12:46:21.37
Read Hot Face Heat Flux Temperatures	12:48:06.44
Read Colder Heat Flux Temperatures	12:49:31.41
Read Bed Temperatures	13:03:02.49
Read Hot Face Heat Flux Temperatures	13:04:34.60
Read Colder Heat Flux Temperatures	13:05:59.46
Read Shell Temperatures	13:06:39.78
Suction T/C, Pair : 1	13:07:00.81
Suction T/C, Pair : 2	13:08:31.06
Suction T/C, Pair : 3	13:09:59.27
Suction T/C, Pair : 4	13:11:50.27
Suction T/C, Pair : 5	13:13:14.80

Cyclic Bed Temperature Readings

10:56:19.65	1	2	3	4	5	6	7	8	9	10
0	1051.71	1101.39	1109.89	1044.81	929.74	901.71	851.91	813.60	695.42	618.96
36	1066.34	1109.89	1109.04	1044.81	931.73	903.44	852.89	815.77	691.87	618.25
72	1070.63	1108.19	1108.19	1045.67	932.48	901.95	851.18	812.88	679.11	610.72
108	1067.20	1109.89	1109.04	1043.94	930.24	896.52	847.53	804.44	666.59	598.94
144	1047.40	1086.90	1105.64	1030.94	923.27	887.16	839.99	794.81	660.21	590.70
180	1013.55	N/A	1036.16	988.18	910.36	869.50	830.05	779.69	658.33	588.34
216	1015.30	1042.21	1059.46	999.58	908.38	871.45	834.17	781.36	667.06	593.52
252	1032.70	1074.92	1088.60	1017.04	913.83	877.58	838.29	788.80	680.29	600.35
288	1043.08	1092.87	1107.34	1031.83	920.78	886.43	843.15	798.18	689.98	607.42
324	1049.12	1097.98	1111.59	1038.76	926.00	893.07	846.80	805.40	695.42	613.54
360	1059.46	1103.09	1113.29	1043.08	929.99	898.00	849.48	810.94	696.61	617.55
396	1076.63	1107.34	1111.59	1044.81	931.73	900.47	850.94	814.08	693.29	618.49
432	1086.04	1110.74	1109.89	1046.53	931.73	899.24	850.21	812.63	679.11	611.66
468	1075.77	1114.98	1110.74	1044.81	930.24	895.29	847.29	806.60	666.12	600.12
504	1044.81	1107.34	1115.83	1041.35	925.51	889.38	841.94	798.66	660.69	593.29
540	1016.17	1013.55	1046.53	993.45	911.85	870.48	830.05	781.84	652.43	587.40
576	N/A	1031.83	1055.16	995.20	907.39	870.97	833.44	780.17	657.62	591.17
612	1016.17	1062.04	1085.19	1014.42	912.84	878.07	837.81	787.84	670.60	598.47
648	1030.07	1085.19	1107.34	1029.20	919.79	885.93	842.91	796.49	681.71	606.01
684	1036.16	1092.02	1112.44	1038.76	926.25	894.55	847.53	805.16	687.85	611.89
Minimum	1013.55	1013.55	1036.16	988.18	907.39	869.50	830.05	779.69	652.43	587.40
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

12:46:21.37	1	2	3	4	5	6	7	8	9	10
0	990.62	1099.62	1123.41	1067.09	955.93	931.69	889.63	850.50	737.81	663.22
36	978.29	1095.35	1125.95	1073.96	957.93	931.19	888.40	849.04	732.10	657.33
72	971.23	1101.32	1136.10	1079.96	957.68	925.97	885.45	844.67	723.79	647.19
108	965.04	1125.95	1142.85	1070.53	952.17	919.26	880.79	838.11	717.86	640.35
144	988.86	1060.21	1073.10	1014.26	937.17	902.19	871.97	826.97	715.01	636.58
180	996.76	1092.79	1091.94	1020.36	931.94	899.97	871.97	827.46	719.52	641.53
216	1000.27	1114.93	1120.87	1039.48	935.67	905.90	874.67	833.27	724.50	648.13
252	1002.02	1117.48	1131.02	1049.00	940.91	913.81	877.85	838.36	731.63	653.55
288	1002.02	1115.78	1131.87	1057.62	945.41	919.76	880.79	842.24	735.19	657.80
324	1002.89	1113.23	1128.49	1061.07	949.41	924.23	883.49	845.64	737.33	661.10
360	998.51	1108.13	1125.95	1066.23	953.42	928.70	885.95	848.07	735.90	661.81
396	982.70	1101.32	1125.10	1072.25	956.18	929.94	886.44	847.58	732.81	657.80
432	966.81	1097.91	1133.56	1077.39	957.43	928.45	884.96	844.91	724.74	648.13
468	953.51	1114.93	1144.54	1077.39	954.92	923.23	882.26	840.06	718.57	640.59
504	963.27	1072.25	1090.23	1024.71	940.16	905.90	872.95	829.63	712.17	635.64
540	973.00	1084.25	1083.39	1017.74	931.94	898.99	871.24	826.49	714.54	638.94
576	979.17	1107.28	1116.63	1040.35	935.17	903.43	873.20	830.12	718.81	644.12
612	983.58	1108.98	1127.64	1055.04	942.16	912.33	876.87	835.20	725.93	649.07
648	987.98	1108.13	1130.18	1063.65	948.16	919.02	880.06	839.81	730.91	653.55
684	992.37	1107.28	1129.33	1067.09	952.67	924.97	883.00	843.70	734.48	657.33
Minimum	953.51	1060.21	1073.10	1014.26	931.94	898.99	871.24	826.49	712.17	635.64
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

13:03:02.49	1	2	3	4	5	6	7	8	9	10
0	979.67	1085.60	1111.18	1036.52	948.91	916.54	885.71	840.80	722.39	637.79
36	991.12	1079.61	1084.75	1017.37	938.67	907.63	883.75	837.16	728.09	640.14
72	995.51	1098.41	1111.18	1034.76	943.16	915.30	887.67	843.23	735.45	648.16
108	1002.52	1115.43	1127.30	1047.77	949.91	926.22	892.84	850.76	742.35	656.18
144	1012.14	1125.60	1138.29	1060.71	956.18	935.67	897.76	857.58	747.83	663.25
180	1012.14	1129.83	1145.04	1069.31	961.95	942.66	901.71	862.94	750.21	668.68
216	1005.14	1128.99	1149.25	1077.04	965.97	946.91	904.67	867.09	750.45	671.51
252	990.24	1126.45	1153.47	1079.61	968.49	948.41	905.66	868.80	748.30	670.10
288	981.44	1122.21	1156.83	1084.75	969.25	946.16	903.43	866.12	737.36	661.13
324	971.73	1121.37	1158.52	1081.32	966.73	939.41	898.50	858.55	729.04	651.46
360	969.08	1103.53	1135.75	1054.67	955.92	925.47	889.89	847.84	724.29	640.62
396	984.08	1074.46	1080.46	1016.50	941.41	909.61	883.01	837.40	728.09	639.20
432	996.38	1099.27	1106.93	1032.16	941.91	914.81	885.71	841.53	735.69	646.04
468	1004.27	1115.43	1124.76	1046.90	949.41	926.71	891.12	849.06	741.87	653.82
504	1017.37	1128.14	1135.75	1059.85	955.92	935.92	896.04	855.63	747.11	660.66
540	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	660.66
576	N/A	1140.82	1153.47	1077.04	965.47	946.41	902.69	864.65	750.21	670.10
612	1012.14	1143.35	1161.88	1081.32	967.99	947.41	903.93	866.36	747.59	670.57
648	1001.64	1149.25	1168.61	1082.18	967.99	943.41	901.21	863.92	741.16	663.02
684	996.38	1149.25	1169.45	1079.61	965.47	936.67	897.27	856.85	733.08	652.87
Minimum	969.08	1074.46	1080.46	1016.50	938.67	907.63	883.01	837.16	722.39	637.79
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

10:58:05.66	1	2	3	4	5	6	7	8	9	10
0	N/A	992.67	920.25	893.91	861.04	818.53	N/A	N/A	499.72	366.21
36	N/A	997.93	923.75	895.88	861.77	820.22	N/A	N/A	499.49	366.45
72	N/A	1000.55	926.37	897.61	862.75	821.43	N/A	N/A	499.72	367.41
108	N/A	1001.43	928.11	898.84	863.73	822.40	N/A	N/A	499.72	367.89
144	N/A	1002.30	931.61	900.08	864.46	822.88	N/A	N/A	499.96	368.61
180	N/A	1003.18	933.40	900.82	865.19	823.37	N/A	N/A	500.43	369.33
216	N/A	1004.05	933.40	901.31	865.44	823.37	N/A	N/A	500.91	370.06
252	N/A	1004.05	934.29	901.31	865.68	822.88	N/A	N/A	501.14	370.54
288	N/A	998.80	928.99	899.59	864.46	820.95	N/A	N/A	501.14	369.33
324	N/A	991.79	923.75	895.88	862.26	818.05	N/A	N/A	500.67	367.17
360	N/A	989.16	920.25	893.67	860.79	818.05	N/A	N/A	499.96	366.45
396	N/A	997.05	923.75	895.64	861.53	819.98	N/A	N/A	499.72	366.69
432	N/A	1001.43	926.37	897.36	862.75	821.43	N/A	N/A	499.72	367.41
468	N/A	1002.30	928.11	898.84	863.73	822.40	N/A	N/A	499.96	368.13
504	N/A	1003.18	932.50	900.33	864.70	823.37	N/A	N/A	500.20	368.85
540	N/A	1004.93	933.40	901.56	865.44	824.09	N/A	N/A	500.67	369.57
576	N/A	1005.80	935.18	902.05	865.93	824.09	N/A	N/A	500.91	370.06
612	N/A	1006.67	935.18	902.05	866.17	823.61	N/A	N/A	501.38	370.78
648	N/A	1003.18	933.40	901.07	865.19	822.16	N/A	N/A	501.38	370.06
684	N/A	994.42	925.49	897.12	863.24	819.25	N/A	N/A	500.91	367.65
Average	N/A	1000.24	928.88	898.75	863.81	821.62	N/A	N/A	500.39	368.43
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

12:48:06.44	1	2	3	4	5	6	7	8	9	10
0	N/A	1045.60	961.56	921.06	886.74	859.33	N/A	574.69	542.86	402.76
36	N/A	1049.92	965.10	923.05	887.48	860.06	N/A	574.69	542.86	403.47
72	N/A	1051.65	966.87	924.54	888.46	860.80	N/A	574.69	542.86	404.19
108	N/A	1052.51	968.64	925.53	888.95	861.53	N/A	574.69	542.86	404.91
144	N/A	1051.65	970.41	926.27	889.45	861.77	N/A	574.69	543.09	405.39
180	N/A	1051.65	971.29	926.52	889.69	861.77	N/A	574.69	543.33	406.11
216	N/A	1053.37	972.17	926.52	889.45	861.53	N/A	574.69	543.57	406.59
252	N/A	1056.82	971.29	926.03	889.20	861.04	N/A	574.69	543.57	406.35
288	N/A	1047.33	963.33	922.05	886.99	858.36	N/A	574.45	543.33	403.95
324	N/A	1042.14	955.35	917.84	884.78	856.65	N/A	574.45	542.86	401.56
360	N/A	1047.33	955.35	917.84	884.53	857.38	N/A	574.69	542.39	401.56
396	N/A	1054.23	958.90	919.57	885.27	858.11	N/A	574.69	542.15	402.04
432	N/A	1055.96	961.56	921.06	886.01	858.60	N/A	574.69	542.15	402.76
468	N/A	1055.96	964.21	922.30	886.50	859.33	N/A	574.69	542.15	403.47
504	N/A	1056.82	965.98	923.05	886.99	859.58	N/A	574.69	542.39	404.19
540	N/A	1055.96	966.87	923.54	887.48	860.06	N/A	574.69	542.62	404.91
576	N/A	1057.68	967.75	923.79	887.73	860.06	N/A	574.69	542.86	405.63
612	N/A	1060.27	967.75	923.54	887.73	859.82	N/A	574.45	542.86	405.87
648	N/A	1052.51	961.56	920.81	886.25	857.63	N/A	574.45	542.86	403.95
684	N/A	1046.46	953.57	916.60	884.04	855.68	N/A	574.45	542.39	401.56
Average	N/A	1052.29	964.48	922.58	887.19	859.45	N/A	574.63	542.80	404.06
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

13:04:34.60	1	2	3	4	5	6	7	8	9	10
0	N/A	1071.96	967.38	925.54	892.17	866.92	N/A	N/A	543.13	400.39
36	N/A	1075.39	970.92	927.53	893.40	868.14	N/A	N/A	543.13	401.11
72	N/A	1077.96	973.57	929.02	N/A	N/A	N/A	N/A	N/A	401.11
108	N/A	1080.53	976.22	930.27	895.12	869.61	N/A	N/A	543.60	402.79
144	N/A	1082.25	977.98	931.26	895.62	869.85	N/A	N/A	543.84	403.74
180	N/A	1083.10	978.86	932.01	896.11	869.85	N/A	N/A	544.08	404.46
216	N/A	1083.96	980.63	932.26	896.11	869.12	N/A	N/A	544.31	404.94
252	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	544.31	404.94
288	N/A	1070.24	970.03	926.29	892.66	864.97	N/A	N/A	544.08	401.11
324	N/A	1064.22	963.84	922.56	890.69	864.48	N/A	N/A	543.60	399.91
360	N/A	1071.10	966.49	924.55	891.43	866.19	N/A	N/A	543.13	400.15
396	N/A	1075.39	970.03	926.78	892.91	867.41	N/A	N/A	543.13	400.87
432	N/A	1077.96	973.57	928.77	893.89	868.39	N/A	N/A	543.13	401.83
468	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	543.13	401.83
504	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	543.13	401.83
540	N/A	1082.25	979.74	932.01	895.86	869.85	N/A	N/A	544.08	404.46
576	N/A	1083.10	980.63	932.51	896.11	869.36	N/A	N/A	544.31	404.94
612	N/A	1084.82	980.63	932.26	895.86	868.63	N/A	N/A	544.31	404.94
648	N/A	1072.82	971.80	927.53	893.40	865.70	N/A	N/A	544.08	402.79
684	N/A	1067.66	963.84	923.06	890.94	863.99	N/A	N/A	543.84	400.87
Average	N/A	1076.75	973.30	928.48	893.89	867.65	N/A	N/A	543.70	402.45
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

Interior Wall Probe Temperature Readings

10:59:30.57	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	350.57	652.61	N/A
1.568	N/A	596.46	870.86
2.064	343.56	592.68	854.69
2.375	N/A	575.96	804.05
2.724	315.27	564.17	771.88
3.048	N/A	N/A	715.43
4.070	208.94	380.38	533.75
4.585	188.07	300.24	461.08
5.213	163.24	263.98	351.76

NOTE: This set of data was used for steady state calculations.

12:49:31.41	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	376.97	689.59	N/A
1.568	N/A	628.37	904.22
2.064	367.71	624.15	882.57
2.375	N/A	N/A	832.84
2.724	346.75	610.02	815.68
3.048	N/A	N/A	762.65
4.070	227.06	412.09	577.28
4.585	198.12	317.97	501.27
5.213	168.13	275.93	383.33

13:05:59.46	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	378.59	695.85	N/A
1.568	N/A	632.81	910.01
2.064	370.63	628.20	887.50
2.375	N/A	N/A	834.81
2.724	349.19	612.88	821.02
3.048	N/A	N/A	768.17
4.070	229.53	418.10	583.21
4.585	200.10	322.35	504.62
5.213	169.87	279.12	382.64

NOTE: This set of data was used for steady state calculations.

Suction Pyrometer Temperature Readings of Flue Gas

	11:01:56.51		11:03:31.59		11:05:15.12		11:06:41.85		11:08:06.65	
	1	2	3	4	5	6	7	8	9	10
0	1170.06	1247.66	1171.84	1066.70	938.38	910.03	860.19	789.99	705.42	596.40
36	1150.72	1255.96	1165.96	1070.13	941.88	913.75	865.32	795.52	694.29	595.46
72	1138.92	1244.33	1158.39	1075.28	942.88	914.24	869.23	802.26	699.73	594.98
108	1154.09	1233.52	1155.87	1077.85	945.13	914.24	874.87	811.41	707.31	594.51
144	1152.40	1226.03	1157.55	1081.27	947.89	917.72	882.96	821.32	710.39	594.75
180	1147.35	1216.05	1157.55	1082.98	951.14	921.94	887.14	829.06	713.00	594.75
216	1149.88	1211.88	1171.00	1085.55	952.90	927.66	891.08	835.12	717.98	595.46
252	1169.22	1223.54	1186.92	1090.67	953.65	930.15	891.08	837.06	718.22	595.93
288	1177.61	1226.86	1194.45	1090.67	953.90	932.39	887.63	836.58	715.85	596.40
324	1185.15	1228.53	1192.78	1091.52	953.40	932.14	883.21	831.73	706.84	596.87
360	1172.57	1232.68	1199.46	1093.23	951.90	928.90	879.03	825.91	712.29	596.63
396	1150.72	1243.50	1191.94	1094.94	951.39	927.16	878.05	822.77	702.57	595.93
432	1143.98	1251.81	1173.51	1093.23	950.14	925.42	879.03	823.25	704.23	595.46
468	1149.04	1250.15	1164.28	1094.08	951.14	926.16	882.47	825.19	704.47	594.98
504	1154.09	1234.35	1160.92	1094.08	952.15	927.16	888.86	830.52	713.95	594.98
540	1150.72	1222.71	1159.24	1099.20	954.15	930.15	894.53	835.85	716.32	595.22
576	1154.09	1217.71	1168.48	1099.20	956.16	932.89	896.25	839.25	717.51	595.69
612	1169.22	1219.38	1181.90	1100.05	956.41	934.64	896.99	841.43	721.78	596.40
648	1173.41	1220.21	1190.27	1101.75	955.41	936.13	893.54	840.95	721.31	596.87
684	1186.82	1232.68	1192.78	1100.90	955.41	935.88	886.16	838.03	717.27	597.34
Average	1160.00	1231.98	1174.75	1089.16	950.77	925.94	883.38	825.66	711.04	595.75
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

	13:07:00.81		13:08:31.06		13:09:59.27		13:11:50.27		13:13:14.80	
	1	2	3	4	5	6	7	8	9	10
0	1058.25	1213.10	1178.87	1084.08	998.03	948.10	903.94	849.07	770.10	650.13
36	1073.73	1196.40	1176.36	1085.79	1000.83	955.36	909.62	853.45	768.66	649.66
72	1060.84	1197.24	1184.74	1090.07	1001.85	960.88	915.07	858.33	766.99	648.95
108	1063.42	1190.54	1189.77	1092.63	1002.36	965.16	918.78	864.18	769.14	648.71
144	1070.30	1197.24	1193.11	1095.19	1006.44	967.93	922.50	870.04	771.77	648.48
180	1071.16	1199.75	1198.97	1097.75	1002.61	969.94	925.48	875.43	778.71	648.95
216	1084.88	1206.43	1203.15	1100.31	998.54	968.68	928.96	880.33	783.98	649.42
252	1086.59	1216.44	1201.48	1102.86	998.80	967.93	929.46	883.51	781.10	650.13
288	1086.59	1239.74	1206.49	1102.86	1003.89	967.42	927.72	884.01	780.86	650.84
324	1108.76	1243.90	1202.31	1103.72	1005.16	967.67	926.48	882.78	776.79	651.07
360	1133.34	1247.23	1201.48	1104.57	1006.44	968.93	922.75	880.57	777.27	650.84
396	1126.58	1236.41	1207.32	1104.57	1009.24	970.95	921.02	879.35	769.86	650.36
432	1117.26	1225.60	1211.50	1106.27	1008.22	973.97	923.75	879.10	772.73	649.42
468	1107.91	1225.60	1211.50	1107.12	1008.22	976.24	926.23	880.57	773.20	648.71
504	1096.84	1210.60	1214.00	1108.82	1011.28	977.00	929.46	883.27	775.60	648.48
540	1098.54	1208.93	1215.67	1109.67	1008.48	977.25	931.70	885.97	783.02	648.71
576	1102.80	1217.27	1216.50	1112.22	1005.42	975.99	933.94	888.43	784.22	649.19
612	1098.54	1216.44	1214.00	1113.07	1005.42	974.23	934.19	889.90	784.94	649.66
648	1101.10	1230.59	1209.83	1112.22	1005.16	972.71	932.95	890.64	782.30	650.36
684	1117.26	1247.23	1208.99	1113.07	1006.44	972.46	926.73	887.20	783.74	650.84
Average	1093.23	1218.33	1202.30	1102.34	1004.64	968.94	924.54	877.31	776.75	649.65
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Shell Temperature Readings

Time	Position, metres				
	0.146	0.921	1.492	2.210	5.354
10:56:19.65	251.72	186.79	171.31	148.68	116.94
13:05:59.46	266.99	204.58	186.40	150.99	125.40

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
10:54	5	86.1	2.0	11.9
12:13	5	76.9	2.0	21.1
12:55	5	78.9	1.2	19.9
13:03	5	76.6	2.7	20.7

Axial Calcination Results

Natural Gas = 5.4 CFM	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3
Sample Code	GP	GP	G#1	G#1	G#2	G#2	G#3	G#3
Date	17/Jun/90	17/Jun/90	17/Jun/90	24/Jun/90	17/Jun/90	24/Jun/90	17/Jun/90	17/Jun/90
Before Firing, g	23.2346	23.3147	24.4693	20.9483	27.2537	25.6326	27.0581	28.1154
After Firing, g	23.1308	23.2118	23.1051	19.5445	22.7242	21.3752	21.1209	21.6785
Empty Crucible, g	12.5641	11.9020	12.1685	10.0846	12.0325	11.7832	12.5481	12.0709
Wt of Sample Before, g	10.6705	11.4127	12.3008	10.8637	15.2212	13.8494	14.5100	16.0445
Wt Loss by $CaCO_3$, g	0.1038	0.1029	1.3642	1.4038	4.5295	4.2574	5.9372	6.4369
% Calcination	97.77	97.93	74.53	70.32	31.66	29.40	6.03	7.86
Average =	98.85%		72.43%		30.53%		6.95%	

Natural Gas = 5.4 CFM	Port #4	Port #4	Port #5	Port #5
Sample Code	G#4	G#4	G#5	G#5
Date	17/Jun/90	17/Jun/90	17/Jun/90	17/Jun/90
Before Firing, g	27.6793	27.6238	28.3785	28.6103
After Firing, g	21.1469	20.8046	21.2296	21.2701
Empty Crucible, g	12.4738	11.7777	11.9162	11.7008
Wt of Sample Before, g	15.2055	15.8461	16.4623	16.9095
Wt Loss by $CaCO_3$, g	6.5324	6.8192	7.1489	7.3402
% Calcination	1.34	1.17	0.27	0.31
Average =	1.25%		0.29%	

Lignin = 220 g/m	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3	Port #3
Sample Code	LP	LP	L#1	L#1	L#2	L#2	L#3	L#3	L#3
Date	18/Jun/90	18/Jun/90	18/Jun/90	18/Jun/90	24/Jun/90	24/Jun/90	18/Jun/90	24/Jun/90	24/Jun/90
Before Firing, g	23.8372	23.6659	23.7255	23.6882	24.6827	24.6416	27.0640	27.1961	27.6514
After Firing, g	23.7752	23.6053	23.6663	23.6290	22.5978	22.4045	21.6988	21.8855	22.0379
Empty Crucible, g	12.5691	11.9194	12.1751	12.2482	12.0421	11.6485	12.0743	12.5574	12.0793
Wt of Sample Before, g	11.2681	11.7465	11.5504	11.4400	12.6406	12.9931	14.9897	14.6387	15.5721
Wt Loss by $CaCO_3$, g	0.0620	0.0606	0.0592	0.0592	2.0849	2.2371	5.3652	5.3106	5.6135
% Calcination	98.74	98.82	98.82	98.81	62.12	60.46	17.80	16.69	17.21

Average = 98.78% 98.82% 61.29% 17.23%

Lignin = 220 g/m	Port #4	Port #4	Port #5	Port #5
Sample Code	L#4	L#4	L#5	L#5
Date	19/Jun/90	19/Jun/90	19/Jun/90	19/Jun/90
Before Firing, g	27.5815	27.7414	27.9539	27.8098
After Firing, g	21.2003	21.1112	21.1273	20.8694
Empty Crucible, g	12.1748	11.7805	12.0379	11.6463
Wt of Sample Before, g	15.4067	15.9609	15.9160	16.1635
Wt Loss by $CaCO_3$, g	6.3812	6.6302	6.8266	6.9404
% Calcination	4.88	4.60	1.50	1.39

Average = 4.74% 1.44%

Run LG15

Table of Events

Action Requested by Operator	Time
6/20/90	13:41:15.63
Kiln speed (rpm) : 1.5	13:41:19.92
Gas = 5.4 CFM	12:09:00
Read Bed Temperatures	14:02:37.15
Read Hot Face Heat Flux Temperatures	14:04:28.43
Read Colder Heat Flux Temperatures	14:05:52.14
Read Shell Temperatures	14:06:32.07
Suction T/C, Pair : 1	14:08:39.55
Suction T/C, Pair : 2	14:10:07.16
Suction T/C, Pair : 3	14:11:58.77
Suction T/C, Pair : 4	14:13:49.66
Suction T/C, Pair : 5	14:15:16.50
Gas = 5.8 CFM	14:32:00
Read Bed Temperatures	14:39:21.53
Read Bed Temperatures	14:54:07.26
Read Hot Face Heat Flux Temperatures	14:56:47.48
Read Colder Heat Flux Temperatures	14:58:11.19
Read Shell Temperatures	14:58:39.42
Suction T/C, Pair : 1	14:59:30.99
Suction T/C, Pair : 2	15:01:02.66
Suction T/C, Pair : 3	15:02:30.65
Suction T/C, Pair : 4	15:04:23.75
Suction T/C, Pair : 5	15:05:51.68

Cyclic Bed Temperature Readings

14:02:37.15	1	2	3	4	5	6	7	8	9	10
0	1075.59	1119.04	1103.76	1024.67	907.57	870.66	814.75	774.13	643.20	582.42
36	1064.43	1117.35	1103.76	1020.32	905.34	865.52	810.89	765.28	629.05	567.34
72	1035.10	1108.86	1100.36	1009.86	900.90	858.44	804.38	752.86	619.16	559.09
108	1003.75	1011.61	1034.23	965.94	890.05	839.69	791.15	735.48	613.74	553.90
144	983.58	1018.58	1032.50	969.48	886.36	841.15	793.80	735.24	621.28	561.44
180	994.12	1045.48	1054.10	987.10	890.29	849.17	800.05	745.71	630.23	571.81
216	1009.86	1069.58	1073.02	1002.00	896.21	857.22	806.07	757.16	641.55	581.71
252	1016.84	1084.15	1091.83	1015.09	901.88	864.78	811.61	767.19	649.33	589.48
288	1031.61	1098.65	1099.51	1022.93	906.58	871.15	815.72	774.85	653.81	594.43
324	1061.85	1114.80	1102.06	1025.53	909.05	873.84	817.65	778.20	651.92	593.49
360	1076.44	1118.19	1103.76	1027.27	909.30	872.61	816.68	776.52	639.42	582.89
396	1065.29	1119.89	1104.61	1022.06	906.58	866.99	812.58	767.19	627.64	566.87
432	1042.02	1110.56	1098.65	1010.74	901.39	858.68	805.11	755.49	619.16	557.91
468	1001.12	1011.61	1029.01	965.94	890.05	839.93	792.84	737.38	615.63	555.32
504	987.10	1029.87	1036.83	972.13	886.85	842.61	796.20	737.62	621.51	563.09
540	997.62	1058.41	1058.41	987.97	891.03	850.39	801.73	747.86	633.30	574.17
576	1011.61	1082.44	1079.87	1005.50	897.69	859.17	808.00	759.54	645.08	584.77
612	1023.80	1095.25	1098.65	1016.84	903.37	866.01	812.82	768.39	651.21	591.37
648	1042.02	1109.71	1106.31	1022.06	906.83	870.66	816.20	774.61	654.04	595.13
684	1065.29	1121.58	1108.01	1024.67	908.81	872.12	817.17	777.00	651.92	594.43
Minimum	983.58	1011.61	1029.01	965.94	886.36	839.93	791.15	735.24	613.74	553.90
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

14:39:21.53	1	2	3	4	5	6	7	8	9	10
0	1021.03	1075.45	1072.02	1000.95	906.92	872.48	828.42	776.19	664.59	597.19
36	1033.19	1099.38	1095.12	1017.55	913.11	882.53	833.99	786.25	678.52	608.02
72	1050.51	1121.47	1113.84	1027.98	918.56	890.64	838.60	795.62	686.32	615.09
108	1066.01	1132.46	1124.01	1038.41	923.78	897.29	842.97	803.07	689.39	619.33
144	N/A	N/A	N/A	N/A	N/A	N/A	842.97	803.07	689.39	619.33
180	1103.64	1142.60	1123.16	1041.01	926.76	898.28	844.92	805.72	677.34	610.37
216	1098.53	1144.28	1124.01	1036.68	925.02	892.86	841.76	798.02	661.28	595.77
252	1084.02	1136.69	1121.47	1028.85	921.05	885.23	836.17	787.69	650.67	586.82
288	1048.78	1035.81	1053.96	982.52	909.64	867.10	823.10	770.68	644.54	580.93
324	1021.03	1037.54	1050.51	982.52	903.71	865.88	824.55	768.53	653.74	588.47
360	1024.51	1069.45	1075.45	1001.83	906.92	873.46	829.63	777.15	667.89	599.07
396	1041.01	1098.53	1095.97	1016.67	913.11	882.78	835.20	787.69	680.88	608.96
432	1054.82	1119.77	1112.14	1029.72	919.31	891.63	840.30	797.06	687.50	615.79
468	1066.87	1134.16	1121.47	1036.68	923.78	897.05	843.94	803.55	689.87	620.03
504	1090.00	1143.44	1125.70	1041.87	927.01	900.01	846.13	806.93	686.79	618.85
540	1102.79	1145.13	1122.32	1040.14	927.26	897.79	845.40	805.96	675.45	608.73
576	1096.83	1145.97	1122.32	1038.41	925.27	892.37	842.00	799.22	662.46	593.18
612	1087.44	1135.00	1116.38	1029.72	921.54	886.22	836.42	789.85	652.79	583.52
648	1050.51	1032.32	1047.92	982.52	909.89	867.59	823.10	772.60	646.19	580.70
684	1022.77	1038.41	1049.65	984.28	904.20	866.61	825.27	771.40	656.33	588.71
Minimum	1021.03	1032.32	1047.92	982.52	903.71	865.88	823.10	768.53	644.54	580.70
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

14:54:07.26	1	2	3	4	5	6	7	8	9	10
0	1067.55	1141.59	1123.00	1041.69	926.20	900.69	850.22	809.29	693.39	628.02
36	1083.84	1144.12	1128.92	1046.87	930.68	905.38	853.14	814.12	694.33	630.61
72	1100.91	1150.02	1128.92	1049.46	932.92	906.61	854.60	815.81	690.31	626.37
108	1111.97	1152.55	1124.69	1048.60	932.42	903.65	853.14	812.67	678.26	612.23
144	1100.06	1157.60	1128.92	1044.28	929.68	897.48	849.49	804.72	666.21	599.28
180	1087.26	1071.84	1104.32	1014.74	921.73	885.18	839.52	792.93	659.13	590.80
216	1041.69	1041.69	1045.14	982.32	911.07	872.18	832.73	779.74	660.31	594.10
252	1035.63	1095.80	1067.55	1002.51	910.32	877.08	836.85	784.29	667.87	603.99
288	1040.82	1112.82	1090.68	1020.84	916.02	886.16	841.47	793.65	678.96	613.88
324	1055.50	1134.84	1111.12	1033.87	921.97	894.28	846.32	802.79	687.47	622.13
360	1072.70	1142.43	1124.69	1043.42	926.94	900.93	850.46	809.78	692.20	627.54
396	1083.84	1149.18	1130.61	1049.46	931.42	905.38	853.38	814.36	693.15	628.96
432	1103.47	1154.23	1130.61	1050.33	933.42	906.12	854.11	815.32	689.36	624.95
468	1101.77	1157.60	1128.07	1046.87	932.92	902.41	852.65	811.95	678.96	610.58
504	1093.24	1159.28	1129.76	1043.42	929.93	896.74	849.24	803.75	666.68	598.57
540	1083.84	1067.55	1100.06	1011.25	921.73	884.19	839.04	791.73	658.19	590.56
576	1041.69	1042.55	1045.14	981.44	911.31	871.94	832.98	779.50	662.67	594.10
612	1035.63	1095.80	1068.41	1000.76	911.07	875.85	836.61	784.29	671.88	604.22
648	1043.42	1113.67	1090.68	1016.48	915.77	883.70	841.22	793.17	680.62	614.35
684	1051.19	1127.23	1111.12	1032.13	922.72	893.05	846.81	803.03	688.42	622.36
Minimum	1035.63	1041.69	1045.14	981.44	910.32	871.94	832.73	779.50	658.19	590.56
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

14:04:28.43	1	2	3	4	5	6	7	8	9	10
0	N/A	982.76	914.75	874.88	835.14	784.25	N/A	491.83	448.40	341.30
36	N/A	984.52	916.51	875.86	835.87	784.73	N/A	491.83	448.64	342.02
72	N/A	986.28	917.38	876.11	836.11	784.73	N/A	491.83	449.11	342.50
108	N/A	987.16	917.38	876.11	836.11	784.25	N/A	491.83	449.11	342.99
144	N/A	979.24	913.88	874.64	835.14	782.33	N/A	491.60	448.88	341.78
180	N/A	967.77	908.61	871.70	832.96	779.46	N/A	491.36	448.40	340.09
216	N/A	964.23	905.98	870.23	832.23	779.22	N/A	491.36	447.92	339.61
252	N/A	973.07	909.49	871.70	832.96	781.14	N/A	491.60	447.69	339.85
288	N/A	978.36	912.12	873.16	833.93	782.57	N/A	491.83	447.69	340.33
324	N/A	981.88	913.88	874.39	834.65	783.77	N/A	492.07	448.16	341.05
360	N/A	983.64	914.75	875.37	835.62	784.49	N/A	492.07	448.40	341.78
396	N/A	984.52	915.63	875.86	836.11	784.97	N/A	492.07	448.88	342.50
432	N/A	986.28	915.63	876.35	836.35	784.97	N/A	492.07	449.11	342.99
468	N/A	988.03	916.51	876.35	836.60	784.73	N/A	492.31	449.59	343.47
504	N/A	977.48	913.00	874.64	835.38	782.57	N/A	491.60	448.88	341.30
540	N/A	966.00	907.73	871.70	833.44	779.70	N/A	491.36	448.40	339.61
576	N/A	965.12	905.98	870.47	832.47	779.94	N/A	491.60	447.92	339.12
612	N/A	973.07	908.61	871.70	833.44	781.85	N/A	492.07	447.92	339.61
648	N/A	978.36	912.12	873.41	834.41	783.29	N/A	492.31	448.16	340.09
684	N/A	981.88	913.88	874.88	835.38	784.49	N/A	492.54	448.64	340.81
Average	N/A	978.48	912.69	873.97	834.72	782.87	N/A	491.86	448.49	341.14
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

14:56:47.48	1	2	3	4	5	6	7	8	9	10
0	N/A	1024.44	938.13	897.60	864.72	819.31	N/A	N/A	498.41	367.23
36	N/A	1026.18	939.91	898.83	865.70	820.03	N/A	N/A	498.89	367.96
72	N/A	1027.91	940.81	899.33	866.19	820.27	N/A	N/A	499.12	368.68
108	N/A	1027.91	940.81	899.57	866.19	820.03	N/A	N/A	499.60	369.40
144	N/A	1028.78	940.81	899.33	865.94	819.31	N/A	N/A	499.83	369.16
180	N/A	1013.12	934.56	895.88	863.99	816.41	N/A	N/A	499.60	367.23
216	N/A	1004.38	927.57	892.92	862.28	814.72	N/A	N/A	499.12	365.55
252	N/A	1011.37	928.44	893.17	862.28	816.17	N/A	N/A	498.65	365.55
288	N/A	1017.47	931.94	894.89	863.01	817.86	N/A	N/A	498.41	366.03
324	N/A	1021.83	936.35	896.37	864.23	818.82	N/A	N/A	498.65	366.99
360	N/A	1024.44	939.02	897.85	865.21	819.79	N/A	N/A	498.89	367.71
396	N/A	1026.18	939.91	898.83	865.94	820.27	N/A	N/A	499.12	368.44
432	N/A	1027.91	940.81	899.57	866.43	820.51	N/A	N/A	499.60	369.16
468	N/A	1028.78	941.70	899.57	866.43	820.27	N/A	N/A	500.07	369.64
504	N/A	1028.78	941.70	899.33	866.19	819.55	N/A	N/A	500.07	368.68
540	N/A	1014.86	934.56	895.88	863.99	816.65	N/A	N/A	499.83	366.75
576	N/A	1007.88	927.57	892.67	862.28	814.72	N/A	N/A	499.36	365.31
612	N/A	1013.99	928.44	893.17	862.04	816.65	N/A	N/A	498.89	365.55
648	N/A	1020.96	931.94	894.89	863.01	818.10	N/A	N/A	498.89	366.27
684	N/A	1024.44	937.24	896.62	863.99	819.31	N/A	N/A	498.89	366.27
Average	N/A	1021.08	936.11	896.81	864.50	818.44	N/A	N/A	499.20	367.38
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

Interior Wall Probe Temperature Readings

14:05:52.14	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	337.74	634.68	N/A
1.568	N/A	573.01	850.94
2.064	319.05	560.09	828.84
2.375	N/A	N/A	778.26
2.724	287.50	520.21	731.73
3.048	N/A	N/A	669.68
4.070	186.49	337.91	487.57
4.585	165.35	262.66	418.13
5.213	148.87	234.56	322.92

NOTE: This set of data was used for steady state calculations.

14:58:11.19	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	356.88	663.33	N/A
1.568	N/A	602.40	874.70
2.064	339.99	588.56	853.01
2.375	N/A	N/A	808.45
2.724	308.77	553.92	767.42
3.048	N/A	N/A	709.61
4.070	200.60	362.90	522.77
4.585	175.78	280.09	447.86
5.213	157.58	249.84	347.24

NOTE: This set of data was used for steady state calculations.

Suction Pyrometer Temperature Readings of Flue Gas

	14:08:39.55		14:10:07.16		14:11:58.77		14:13:49.66		14:15:16.50	
	1	2	3	4	5	6	7	8	9	10
0	1099.72	1196.64	1157.34	1050.97	904.72	876.91	841.82	780.31	667.03	569.70
36	1099.72	1188.28	1161.55	1053.56	914.87	880.59	836.97	773.84	668.21	568.99
72	1100.57	1194.97	1163.23	1057.87	922.07	884.76	841.82	771.45	665.85	568.05
108	1111.62	1208.33	1164.07	1061.31	927.54	890.17	845.47	770.97	672.93	567.58
144	1115.86	1181.58	1157.34	1063.89	931.78	895.34	851.31	776.95	677.89	567.58
180	1125.18	1213.33	1163.23	1065.61	931.78	899.54	859.60	784.62	683.80	567.82
216	1141.23	1216.67	1168.27	1066.47	933.27	902.25	865.46	792.30	684.27	568.52
252	1156.39	1224.16	1167.43	1068.19	931.28	903.24	867.90	798.55	686.17	569.47
288	1174.87	1220.83	1165.75	1069.90	931.53	902.50	867.42	802.16	689.24	570.17
324	1173.19	1227.48	1186.71	1072.48	933.27	900.28	863.99	802.65	687.82	570.41
360	1163.12	1231.64	1192.57	1073.34	933.27	900.03	857.16	795.19	685.46	570.17
396	1147.97	1245.78	1197.59	1075.05	938.76	900.03	849.60	788.46	671.28	569.23
432	1142.91	1232.47	1176.66	1075.05	941.76	902.50	847.17	781.51	671.99	568.52
468	1151.34	1233.30	1175.82	1075.91	943.76	905.71	852.77	781.51	683.33	568.05
504	1150.50	1218.33	1168.27	1075.91	943.51	908.68	856.91	785.82	684.27	568.05
540	1155.55	1224.99	1161.55	1076.76	940.51	910.66	863.99	791.58	690.19	568.52
576	1164.80	1229.15	1164.91	1076.76	939.51	912.15	869.62	797.83	692.55	568.99
612	1179.06	1234.14	1173.30	1078.48	938.26	911.90	871.33	802.89	691.13	569.94
648	1187.44	1227.48	1171.63	1081.05	937.51	909.42	870.35	805.54	690.19	570.64
684	1163.96	1204.99	1165.75	1081.05	935.52	907.94	866.19	803.61	685.93	570.88
Average	1145.25	1217.73	1170.15	1069.98	932.72	900.23	857.34	789.39	681.48	569.07
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

	14:59:30.99		15:01:02.66		15:02:30.65		15:04:23.75		15:05:51.68	
	1	2	3	4	5	6	7	8	9	10
0	1169.61	1204.78	1183.09	1068.71	955.77	907.46	867.45	798.87	714.04	608.05
36	1181.35	1218.96	1193.14	1074.72	962.05	914.14	876.02	805.85	720.21	607.82
72	1189.73	1228.94	1205.67	1079.00	960.29	920.34	883.87	813.32	722.58	608.05
108	1187.22	1237.26	1211.51	1081.57	958.03	924.56	890.50	821.29	729.47	608.52
144	1169.61	1232.27	1209.01	1082.43	962.30	927.79	894.69	828.78	729.95	609.23
180	1166.25	1233.93	1205.67	1085.00	965.07	929.78	896.66	834.35	731.85	610.17
216	1177.16	1252.23	1202.33	1086.71	966.07	929.78	896.91	838.23	729.47	610.64
252	1183.03	1245.58	1201.50	1088.42	966.33	928.54	893.70	838.96	725.67	610.64
288	1185.54	1251.40	1205.67	1090.13	968.34	927.79	887.80	836.54	718.08	610.17
324	1200.60	1257.21	1204.00	1093.54	966.33	927.79	886.32	833.14	719.97	609.47
360	1212.29	1261.36	1202.33	1095.25	969.10	929.03	886.32	830.48	721.87	608.76
396	1224.78	1258.87	1198.99	1097.81	968.84	931.28	890.75	831.21	726.86	608.52
432	1227.28	1266.34	1208.18	1098.66	966.83	934.02	894.93	834.60	734.94	608.76
468	1209.79	1280.42	1231.50	1097.81	969.60	936.26	898.14	838.96	739.22	609.23
504	1195.59	1262.19	1226.51	1097.81	968.09	938.75	902.08	843.09	735.89	610.17
540	1187.22	1248.91	1209.01	1100.36	970.36	939.00	903.81	846.01	735.89	610.88
576	1203.11	1263.85	1209.85	1100.36	964.82	937.26	903.07	847.71	729.00	611.35
612	1200.60	1258.87	1213.18	1102.92	969.10	935.26	900.60	846.98	732.32	611.35
648	1203.94	1262.19	1209.85	1102.92	971.11	934.02	893.95	843.58	729.23	610.64
684	1217.29	1262.19	1205.67	1094.39	970.86	933.77	889.77	838.48	722.35	609.94
Average	1194.60	1249.39	1206.83	1090.92	965.96	929.33	891.87	832.52	727.44	609.62
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Shell Temperature Readings

Time	Position, metres				
	0.146	0.921	1.492	2.210	5.354
14:05:52.14	254.95	183.40	161.02	145.77	105.18
14:58:11.19	264.55	194.03	172.89	154.20	111.64

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
14:21	5	81.4	2.1	16.5
14:31	5	82.3	2.4	15.3
14:50	5	80.0	2.4	17.6

Axial Calcination Results

Natural Gas = 5.4 CFM	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #2
Sample Code	GPA	GPA	G#1A	G#1A	G#2A	G#2A	G#2A
Date	28/Jun/90	28/Jun/90	26/Jun/90	28/Jun/90	26/Jun/90	28/Jun/90	28/Jun/90
Before Firing, g	24.9552	25.9124	24.7974	26.7740	25.7606	26.9211	25.3635
After Firing, g	24.1051	25.0391	20.8359	22.7946	20.5636	22.0128	21.1630
Empty Crucible, g	12.1914	12.6081	10.0667	11.6649	10.0921	12.5754	12.0947
Wt of Sample Before, g	12.7638	13.3043	14.7307	15.1091	15.6685	14.3457	13.2688
Wt Loss by $CaCO_3$, g	0.8501	0.8733	3.9615	3.9794	5.1970	4.9083	4.2005
% Calcination	84.70	84.93	38.24	39.51	23.83	21.42	27.30

Average = 84.81% 38.88% 24.18%

Natural Gas = 5.4 CFM	Port #3	Port #3	Port #4	Port #4
Sample Code	G#3A	G#3A	G#4A	G#4A
Date	26/Jun/90	26/Jun/90	26/Jun/90	26/Jun/90
Before Firing, g	28.5474	28.3497	28.3109	28.5262
After Firing, g	21.8112	21.5873	21.2836	21.2312
Empty Crucible, g	12.1860	11.7885	12.0481	11.6567
Wt of Sample Before, g	16.3614	16.5612	16.2628	16.8695
Wt Loss by $CaCO_3$, g	6.7362	6.7624	7.0273	7.2950
% Calcination	5.45	6.22	0.76	0.69

Average = 5.84% 0.73%

Natural Gas = 5.8 CFM	Product	Product	Port #1	Port #1	Port #2	Port #2	Port #3	Port #3
Sample Code	GPB	GPB	G#1B	G#1B	G#2B	G#2B	G#3B	G#3B
Date	26/Jun/90	26/Jun/90	27/Jun/90	27/Jun/90	27/Jun/90	29/Jun/90	29/Jun/90	29/Jun/90
Before Firing, g	23.5073	23.8729	24.0578	23.8286	26.8904	26.6579	26.0144	26.0932
After Firing, g	23.4277	23.7635	21.9629	21.5952	22.9277	22.7431	19.9842	20.5024
Empty Crucible, g	12.5667	12.0869	11.3795	10.5863	12.6033	12.0341	11.1490	12.3248
Wt of Sample Before, g	10.9406	11.7860	12.6783	13.2423	14.2871	14.6238	14.8654	13.7684
Wt Loss by $CaCO_3$, g	0.0796	0.1094	2.0949	2.2334	3.9627	3.9148	6.0302	5.5908
% Calcination	98.33	97.87	62.05	61.27	36.30	38.52	6.84	6.74
Average =	98.10%		61.66%		37.41%		6.79%	

Natural Gas = 5.8 CFM	Port #4	Port #4
Sample Code	G#4B	G#4B
Date	27/Jun/90	27/Jun/90
Before Firing, g	28.5960	27.2115
After Firing, g	21.6861	20.7145
Empty Crucible, g	12.5721	12.0913
Wt of Sample Before, g	16.0239	15.1202
Wt Loss by $CaCO_3$, g	6.9099	6.4970
% Calcination	0.97	1.32
Average =	1.14%	

Run LG16

Table of Events

Action Requested by Operator	Time
6/21/90	09:40:21.00
Kiln speed (rpm) : 1.5	09:40:26.11
Gas = 5.6 CFM	9:10:00
Read Bed Temperatures	09:40:56.59
Read Bed Temperatures	10:20:55.46
Read Bed Temperatures	11:09:56.50
Read Bed Temperatures	12:04:47.53
Read Bed Temperatures	12:55:31.66
Read Bed Temperatures	13:08:27.71
Read Shell Temperatures	13:10:18.27
Read Hot Face Heat Flux Temperatures	13:10:25.30
Read Colder Heat Flux Temperatures	13:11:49.45
Suction T/C, Pair : 1	13:22:16.09
Suction T/C, Pair : 2	13:23:44.69
Suction T/C, Pair : 3	13:25:09.88
Suction T/C, Pair : 4	13:26:33.58
Suction T/C, Pair : 5	13:28:25.63
Lignin = 165 g/min Gas = 1.4 CFM	13:39:00
Read Bed Temperatures	13:40:15.93
Read Bed Temperatures	14:02:04.97
Read Bed Temperatures	14:05:39.89
Read Shell Temperatures	14:24:30.59
Read Hot Face Heat Flux Temperatures	14:24:36.74
Read Colder Heat Flux Temperatures	14:26:00.88
Suction T/C, Pair : 1	14:27:11.68
Suction T/C, Pair : 2	14:31:48.62
Suction T/C, Pair : 3	14:33:14.85
Suction T/C, Pair : 4	14:34:43.72
Suction T/C, Pair : 5	14:36:31.98
Read Bed Temperatures	14:38:40.61

Cyclic Bed Temperature Readings

09:40:56.59	1	2	3	4	5	6	7	8	9	10
0	1049.20	1116.72	1081.83	989.17	880.11	846.61	802.06	760.33	664.70	609.54
36	1056.09	1141.23	1103.14	1000.55	885.51	853.68	806.64	768.22	669.42	614.25
72	1068.12	1154.70	1121.80	1011.03	890.68	860.27	810.74	775.40	672.97	618.49
108	1091.22	1175.70	1131.95	1014.52	894.13	864.18	813.16	779.24	673.44	620.61
144	1115.87	1175.70	1131.10	1013.65	895.12	865.15	813.64	780.19	671.79	619.67
180	1115.03	1173.18	1125.18	1008.42	893.89	862.22	811.71	778.04	665.17	610.24
216	1109.09	1166.47	1117.57	1003.18	891.42	857.82	807.85	771.57	656.44	601.76
252	1099.74	1086.95	1094.63	982.14	886.01	848.31	800.14	761.52	650.78	594.23
288	N/A	N/A	1042.29	952.11	876.91	835.67	793.88	750.78	652.90	596.11
324	1051.78	1093.78	1058.67	972.45	876.18	840.29	797.01	753.41	659.27	601.76
360	1039.70	1115.87	1080.12	990.04	880.11	846.61	801.82	760.57	665.41	608.36
396	1053.51	1135.32	1107.39	1003.18	885.27	853.19	806.40	767.98	669.90	614.25
432	1070.70	1157.23	1124.34	1011.90	890.19	859.53	810.26	774.68	673.44	618.72
468	1097.19	1170.66	1131.95	1016.26	893.39	863.69	812.91	779.24	673.68	619.90
504	1115.03	1170.66	1133.64	1013.65	894.87	864.67	813.64	780.43	671.55	618.96
540	1115.03	1172.34	1126.03	1010.16	894.87	863.20	812.19	777.80	663.76	610.01
576	1111.64	1158.91	1113.33	1004.92	892.41	857.82	808.57	770.13	653.37	598.00
612	1096.33	1078.41	1086.95	981.26	886.50	848.31	800.62	760.57	648.89	592.11
648	1069.84	1059.53	1037.97	954.77	877.65	836.40	794.84	751.02	651.96	595.17
684	1049.20	1092.93	1055.23	971.57	876.91	841.50	798.45	754.36	658.80	601.06
Minimum	1039.70	1059.53	1037.97	952.11	876.18	835.67	793.88	750.78	648.89	592.11
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

10:20:55.46	1	2	3	4	5	6	7	8	9	10
0	1052.38	1151.97	1141.02	1031.61	911.53	879.73	829.02	790.67	675.05	610.91
36	1080.73	1157.86	1144.39	1035.10	914.26	881.93	830.23	793.32	673.63	609.50
72	1076.44	1151.97	1139.33	1031.61	914.50	882.43	830.72	792.60	665.61	597.49
108	1060.13	1131.73	1123.28	1023.80	913.51	879.23	828.54	787.79	655.69	586.18
144	1035.96	1045.48	1098.65	999.37	907.07	869.43	820.31	777.96	646.50	575.58
180	1000.25	1008.99	1040.29	962.40	896.45	854.05	811.13	762.17	648.85	578.88
216	986.22	1051.52	1052.38	976.54	894.24	856.73	814.03	763.84	657.58	587.60
252	986.22	1076.44	1074.73	994.12	898.43	863.07	817.89	770.54	664.42	594.66
288	997.62	1115.65	1102.06	1011.61	904.11	869.68	822.24	778.68	670.80	602.91
324	1023.80	1144.39	1128.35	1024.67	908.81	876.05	826.11	785.39	674.34	608.56
360	1057.55	1159.55	1143.55	1031.61	912.52	880.95	829.26	790.91	675.76	611.15
396	1085.00	1162.07	1147.76	1033.37	914.75	882.92	830.23	793.56	673.63	610.44
432	N/A	N/A	N/A	N/A	N/A	N/A	830.23	793.56	673.63	610.44
468	1066.15	1135.96	1124.97	1023.80	912.77	878.25	826.84	786.11	656.40	587.60
504	1040.29	1053.24	1094.39	996.75	906.08	868.45	817.89	776.04	646.97	577.23
540	1002.00	1019.45	1043.75	962.40	895.71	853.80	810.41	760.98	647.20	580.53
576	987.97	1061.85	1055.83	980.06	893.25	856.24	814.03	763.84	653.81	589.48
612	989.73	1089.27	1077.30	997.62	896.95	862.59	818.37	771.26	661.36	596.78
648	1005.50	1125.81	1105.46	1013.35	901.64	868.70	822.48	778.44	667.49	603.14
684	1029.01	1145.23	1130.88	1026.40	905.84	873.35	825.63	784.91	671.51	608.32
Minimum	986.22	1008.99	1040.29	962.40	893.25	853.80	810.41	760.98	646.50	575.58
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

11:09:56.50	1	2	3	4	5	6	7	8	9	10
0	979.10	1132.60	1110.57	1021.14	915.33	884.00	841.04	801.65	691.32	619.83
36	999.31	1156.22	1139.36	1038.52	920.54	890.89	845.17	808.87	696.05	625.25
72	1026.36	1165.47	1155.37	1045.44	924.76	895.32	847.35	812.73	697.47	628.08
108	1052.35	1167.99	1157.90	1048.04	926.75	896.80	848.08	814.17	694.87	626.67
144	1054.94	1157.06	1149.48	1042.85	926.75	896.06	847.84	813.21	689.66	616.77
180	1044.58	1136.83	1135.98	1035.93	924.76	893.10	845.90	808.87	681.86	605.00
216	1025.49	1054.94	1102.07	1002.81	917.06	882.53	837.40	798.52	669.11	590.63
252	979.10	1016.78	1041.12	969.39	906.17	868.57	830.37	783.64	669.11	596.52
288	960.54	1057.52	1057.52	987.02	903.95	870.52	833.28	787.23	677.85	605.94
324	964.08	1085.00	1083.29	1006.31	908.40	877.38	836.67	793.95	684.46	613.71
360	976.45	1126.68	1109.72	1022.01	913.59	884.25	840.07	800.93	691.08	621.01
396	996.68	1155.37	1135.14	1035.06	918.30	891.13	843.71	806.94	695.81	626.67
432	1022.01	1177.22	1152.01	1041.12	921.28	894.33	845.90	810.80	697.23	629.26
468	1045.44	1168.83	1153.69	1043.71	923.52	897.53	847.84	813.45	695.58	626.90
504	1048.04	1156.22	1148.64	1042.85	924.51	897.29	847.84	812.25	686.35	616.30
540	1040.26	1140.20	1132.60	1033.30	922.52	892.12	844.92	806.46	678.08	603.82
576	1024.62	1060.97	1102.07	1001.93	915.58	882.04	836.67	796.60	668.64	590.63
612	972.92	1023.75	1041.99	968.50	904.69	868.08	829.64	782.68	669.11	595.81
648	953.44	1066.13	1057.52	986.14	903.46	869.55	832.79	786.03	674.78	605.23
684	960.54	1091.83	1083.29	1004.56	908.15	875.66	836.67	793.47	685.17	613.71
Minimum	953.44	1016.78	1041.12	968.50	903.46	868.08	829.64	782.68	668.64	590.63
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

12:04:47.53	1	2	3	4	5	6	7	8	9	10
0	N/A	1192.36	1163.83	1051.47	905.53	860.15	826.89	712.83	644.79	N/A
36	N/A	1194.87	1169.72	1054.06	909.48	862.35	830.28	711.64	642.90	N/A
72	N/A	1187.34	1165.52	1054.92	910.23	862.10	829.55	706.43	633.71	N/A
108	N/A	1171.40	1157.10	1046.29	912.05	865.53	819.42	704.23	626.73	N/A
144	N/A	1081.57	1126.71	1017.61	896.16	853.09	815.78	687.03	604.50	N/A
180	N/A	1058.37	1050.61	979.90	879.71	843.36	797.97	682.31	605.92	N/A
216	N/A	1099.52	1062.68	990.47	880.23	837.01	804.34	688.45	619.87	N/A
252	N/A	1135.17	1096.96	1011.50	884.12	847.98	806.86	699.57	625.70	N/A
288	N/A	1153.73	1125.02	1028.06	899.63	852.47	812.11	704.82	635.96	N/A
324	N/A	1175.60	1152.05	1041.96	899.86	856.01	821.57	710.22	639.60	N/A
360	N/A	1187.34	1163.83	1050.61	905.53	858.93	826.65	712.36	642.90	N/A
396	N/A	1191.52	1168.04	1054.92	908.50	861.13	829.55	711.64	641.49	N/A
432	N/A	1188.17	1163.83	1054.06	908.25	861.13	829.31	705.25	630.18	N/A
468	N/A	1169.72	1152.89	1045.42	903.06	857.96	822.54	694.13	617.46	N/A
504	N/A	1091.84	1119.93	1015.87	894.44	851.63	813.85	684.20	601.68	N/A
540	N/A	1059.23	1047.15	979.02	878.97	842.64	796.52	679.94	601.68	N/A
576	N/A	1098.67	1062.68	992.23	877.25	844.09	797.97	686.80	613.69	N/A
612	N/A	1125.02	1089.28	1009.75	884.18	844.12	807.49	695.42	623.89	N/A
648	N/A	1157.10	1124.17	1030.66	893.46	852.36	814.57	703.59	632.53	N/A
684	N/A	1180.63	1147.83	1045.42	901.09	856.25	821.33	708.56	637.48	N/A
Minimum	N/A	1058.37	1047.15	979.02	877.25	837.01	796.52	679.94	601.68	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

12:55:31.66	1	2	3	4	5	6	7	8	9	10
0	N/A	1180.11	1159.10	1050.04	911.22	867.43	821.07	719.02	650.39	N/A
36	N/A	1181.79	1164.99	1056.08	914.46	870.64	822.77	721.19	648.49	N/A
72	N/A	1177.60	1160.79	1051.77	914.46	869.90	822.53	710.23	641.15	N/A
108	N/A	1160.79	1148.99	1044.85	905.21	860.58	825.63	698.60	625.45	N/A
144	N/A	1074.16	1106.65	1011.79	896.34	854.00	817.42	688.67	607.78	N/A
180	N/A	1045.72	1041.39	977.53	881.11	845.01	799.61	687.25	609.67	N/A
216	N/A	1082.73	1057.81	990.75	876.21	846.47	801.77	694.81	620.27	N/A
252	N/A	1106.65	1087.02	1011.79	881.60	850.35	810.43	703.33	628.75	N/A
288	N/A	1146.46	1116.00	1029.22	890.68	854.73	818.87	711.86	637.23	N/A
324	N/A	1172.56	N/A	N/A	900.03	859.12	826.36	717.78	643.83	N/A
360	N/A	1190.17	1164.15	1053.49	906.69	862.29	830.71	719.68	647.13	N/A
396	N/A	1196.03	1170.04	1054.36	909.16	863.99	832.65	719.44	647.60	N/A
432	N/A	1172.56	1162.47	1052.63	910.64	864.73	832.89	713.52	639.35	N/A
468	N/A	1156.58	1146.46	1043.98	907.68	863.02	829.02	705.46	629.45	N/A
504	N/A	1078.45	1106.65	1011.79	898.80	856.92	821.04	691.50	611.55	N/A
540	N/A	1042.25	1039.66	977.53	882.58	847.44	801.29	687.48	613.67	N/A
576	N/A	1078.45	1053.49	989.87	879.64	848.17	803.21	698.60	623.09	N/A
612	N/A	1098.12	1079.31	1006.54	895.10	847.00	811.33	701.15	637.59	N/A
648	N/A	1139.71	1107.50	1022.26	899.80	854.62	814.73	708.15	643.75	N/A
684	N/A	1170.04	1136.33	1036.16	904.02	860.77	817.90	723.94	648.97	N/A
Minimum	N/A	1042.25	1039.66	977.53	876.21	845.01	799.61	687.25	607.78	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

13:08:27.71	1	2	3	4	5	6	7	8	9	10
0	N/A	1108.63	1137.45	1038.18	924.01	900.62	863.74	807.93	687.96	N/A
36	N/A	1067.56	1067.56	990.15	919.83	888.26	850.15	806.38	688.00	N/A
72	N/A	1077.87	1050.32	983.11	899.92	888.20	841.33	806.99	687.01	N/A
108	N/A	1096.70	1075.30	1002.44	914.39	883.84	850.88	808.30	706.22	N/A
144	N/A	1134.92	1107.78	1022.54	919.34	891.45	854.28	815.53	713.80	N/A
180	N/A	1165.27	1138.30	1038.18	924.55	898.83	857.69	822.53	718.77	N/A
216	N/A	1180.39	1162.75	1051.18	929.02	904.50	860.86	828.09	721.38	N/A
252	N/A	1185.42	1171.16	1058.09	932.99	908.45	863.54	831.72	720.91	N/A
288	N/A	1181.23	1167.80	1058.09	934.49	909.94	864.03	832.68	715.69	N/A
324	N/A	1170.32	1159.38	1052.91	933.49	907.71	862.81	829.78	707.64	N/A
360	N/A	1113.73	1140.84	1039.94	922.78	899.88	863.98	809.59	690.31	N/A
396	N/A	1058.09	1063.26	987.51	907.28	889.66	847.10	798.24	678.30	N/A
432	N/A	1070.14	1052.05	983.11	899.67	887.72	841.09	806.99	687.48	N/A
468	N/A	1091.57	1077.01	1003.32	913.89	884.09	850.39	807.10	705.03	N/A
504	N/A	1135.76	1107.78	1022.54	919.34	892.93	854.28	815.53	711.90	N/A
540	N/A	1164.43	1137.45	1037.31	924.30	899.33	857.20	822.05	715.93	N/A
576	N/A	1179.55	1161.91	1051.18	929.26	905.74	861.10	827.85	718.54	N/A
612	N/A	1180.39	1169.48	1056.36	932.99	909.94	863.79	831.72	718.77	N/A
648	N/A	1179.55	1168.64	1058.09	934.99	911.17	864.76	832.68	713.80	N/A
684	N/A	1167.80	1160.23	1053.77	934.24	909.19	864.03	830.26	704.79	N/A
Minimum	N/A	1058.09	1050.32	983.11	899.67	883.84	841.09	798.24	678.30	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

13:40:15.93	1	2	3	4	5	6	7	8	9	10
0	N/A	1032.75	1072.51	1031.02	941.12	923.46	883.76	850.80	740.79	668.34
36	N/A	1032.75	1075.09	1032.75	943.86	926.93	886.21	853.96	740.56	671.17
72	N/A	1037.96	1074.23	1033.62	945.36	927.93	887.44	855.42	737.47	667.40
108	N/A	1039.72	1075.95	1030.15	944.61	925.94	886.70	854.45	731.76	659.61
144	N/A	1027.54	1076.80	1028.41	941.37	920.73	883.27	849.10	722.74	647.35
180	N/A	980.23	1023.19	982.87	929.42	902.69	871.76	829.22	709.47	627.79
216	N/A	993.44	1009.22	974.93	921.48	893.82	868.10	822.70	718.24	639.57
252	N/A	1027.54	1042.32	997.83	924.20	899.98	871.27	830.19	726.54	648.29
288	N/A	1033.62	1060.46	1013.59	930.16	909.60	875.67	837.21	734.14	657.25
324	N/A	1030.15	1069.93	1021.44	935.64	916.77	879.34	842.54	736.51	663.62
360	N/A	1031.89	1073.37	1027.54	939.12	921.48	882.78	847.88	739.37	667.87
396	N/A	1033.62	1073.37	1031.02	942.37	925.44	885.72	852.99	740.56	670.23
432	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	670.23
468	N/A	1042.32	1075.09	1032.75	944.86	925.44	886.70	853.23	731.29	656.31
504	N/A	1034.49	1076.80	1029.28	942.37	919.99	883.02	847.88	723.46	646.17
540	N/A	984.64	1024.93	983.76	930.16	902.93	871.52	829.22	708.52	624.97
576	N/A	999.58	1007.47	974.93	921.72	893.33	867.12	822.70	716.58	633.92
612	N/A	N/A	N/A	N/A	N/A	N/A	867.12	822.70	716.58	633.92
648	N/A	1032.75	1057.01	1013.59	929.67	907.13	873.96	836.72	734.38	652.77
684	N/A	1029.28	1068.21	1021.44	934.14	914.29	878.12	849.37	N/A	652.77
Minimum	N/A	980.23	1007.47	974.93	921.48	893.33	867.12	822.70	708.52	624.97
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

14:02:04.97	1	2	3	4	5	6	7	8	9	10
0	N/A	1020.37	1038.63	998.50	894.00	862.67	814.92	711.32	629.88	N/A
36	N/A	1033.42	1062.85	1015.13	902.62	867.06	824.33	717.72	640.24	N/A
72	N/A	1040.39	1076.62	1025.60	910.02	870.72	831.58	721.04	646.84	N/A
108	N/A	1042.12	1081.76	1031.69	935.06	876.45	834.63	727.15	654.13	N/A
144	N/A	1041.26	1083.48	1036.90	939.30	880.66	837.81	731.76	656.02	N/A
180	N/A	1050.77	1085.19	1039.50	922.64	879.77	843.94	724.84	654.15	N/A
216	N/A	1054.23	1086.90	1039.50	922.15	879.77	842.97	719.38	644.72	N/A
252	N/A	1056.82	1090.33	1039.50	918.92	877.57	838.36	712.27	632.00	N/A
288	N/A	997.62	1057.68	1002.88	906.81	868.77	827.23	701.38	607.73	N/A
324	N/A	980.90	1015.13	980.02	892.04	861.45	811.79	702.33	616.92	N/A
360	N/A	1025.60	1041.26	998.50	894.25	863.15	816.85	709.19	629.17	N/A
396	N/A	1042.12	1067.16	1015.13	902.86	866.81	824.57	715.35	639.30	N/A
432	N/A	1042.99	1080.91	1026.47	910.76	871.21	831.83	719.86	647.31	N/A
468	N/A	1044.72	1086.05	1032.56	917.93	875.61	837.64	723.18	652.26	N/A
504	N/A	1046.45	1088.62	1036.90	939.79	883.14	839.28	732.73	655.31	N/A
540	N/A	1052.50	1088.62	1038.63	942.29	884.87	840.99	734.67	654.84	N/A
576	N/A	1055.09	1091.18	1040.39	942.54	883.14	840.26	732.97	649.14	N/A
612	N/A	1056.82	1092.04	1039.50	941.29	878.18	837.08	727.15	642.04	N/A
648	N/A	1003.76	1058.54	1004.64	905.82	868.52	825.78	700.67	605.62	N/A
684	N/A	985.31	1014.26	980.90	902.15	851.54	820.47	700.35	630.67	N/A
Minimum	N/A	980.90	1014.26	980.02	892.02	851.54	811.79	700.67	605.62	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

14:05:39.89	1	2	3	4	5	6	7	8	9	10
0	N/A	1043.93	1082.70	1031.77	914.89	878.26	835.44	729.41	652.78	N/A
36	N/A	1049.13	1085.27	1036.11	917.63	880.99	837.65	731.84	653.26	N/A
72	N/A	1055.17	1089.55	1039.58	921.48	878.14	841.59	718.75	642.68	N/A
108	N/A	1059.49	1091.26	1041.34	918.26	875.93	836.75	711.40	629.01	N/A
144	N/A	1013.47	1078.41	1021.32	911.09	870.56	829.49	702.88	611.82	N/A
180	N/A	984.51	1023.94	988.03	904.46	855.07	821.04	701.15	614.84	N/A
216	N/A	1017.83	1028.29	994.19	892.12	861.77	812.35	700.51	623.36	N/A
252	N/A	1033.50	1050.85	1006.47	899.25	864.94	820.55	708.80	634.43	N/A
288	N/A	1037.84	1067.24	1016.96	905.90	868.36	827.55	714.96	643.39	N/A
324	N/A	1042.20	1075.84	1025.68	911.16	872.32	832.51	723.36	649.46	N/A
360	N/A	1049.13	1083.56	1033.50	916.78	875.69	838.20	722.07	653.76	N/A
396	N/A	1051.72	1087.84	1037.84	919.75	877.65	840.38	721.83	653.52	N/A
432	N/A	1060.35	1092.12	1040.47	920.49	877.89	840.38	716.62	642.92	N/A
468	N/A	1059.49	1094.68	1041.34	917.02	875.44	835.54	708.09	631.13	N/A
504	N/A	1017.83	1081.84	1021.32	909.85	870.31	828.76	700.51	611.82	N/A
540	N/A	989.79	1026.55	986.27	903.47	854.08	820.80	700.67	616.26	N/A
576	N/A	1015.21	1029.16	989.79	889.66	860.31	810.91	705.01	623.60	N/A
612	N/A	1032.64	1050.85	1005.59	897.28	863.97	819.83	712.35	634.67	N/A
648	N/A	1039.58	1068.10	1016.96	906.40	868.85	828.28	718.75	644.80	N/A
684	N/A	1043.07	1076.70	1024.81	910.42	873.56	833.73	725.05	652.07	N/A
Minimum	N/A	984.51	1023.94	986.27	889.66	854.08	810.97	700.51	611.82	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

14:38:40.61	1	2	3	4	5	6	7	8	9	10
0	N/A	1008.99	1029.06	986.16	889.20	860.35	808.79	694.43	614.00	N/A
36	N/A	1036.88	1049.03	1002.86	890.92	862.05	814.33	703.18	627.43	N/A
72	N/A	1047.30	1068.87	1015.98	900.02	865.96	823.01	710.28	637.79	N/A
108	N/A	1053.35	1081.76	1026.45	908.40	870.35	830.02	715.73	646.28	N/A
144	N/A	1056.81	1086.90	1031.67	911.68	874.58	834.26	725.34	649.76	N/A
180	N/A	1059.39	1090.32	1036.88	919.28	877.19	839.21	721.18	655.00	N/A
216	N/A	1063.70	1092.89	1040.35	921.51	878.66	840.67	719.76	651.46	N/A
252	N/A	1068.01	1096.31	1043.84	919.77	877.19	837.76	714.07	635.91	N/A
288	N/A	1070.59	1098.87	1043.84	915.07	874.01	831.71	706.25	626.49	N/A
324	N/A	1035.14	1071.45	1008.99	902.24	865.47	820.11	695.84	604.58	N/A
360	N/A	1012.49	1030.80	986.16	889.45	859.62	808.07	697.74	616.12	N/A
396	N/A	1037.75	1048.17	1004.61	892.64	862.54	815.53	705.54	629.78	N/A
432	N/A	1047.30	1067.15	1017.73	901.50	866.93	824.70	711.46	639.91	N/A
468	N/A	1053.35	1080.90	1028.19	909.88	871.57	832.19	716.20	647.69	N/A
504	N/A	1054.22	1088.61	1036.01	911.93	876.31	835.73	727.52	649.76	N/A
540	N/A	1056.81	1092.03	1040.35	915.66	880.77	838.66	731.64	651.89	N/A
576	N/A	1062.84	1093.74	1044.70	918.40	882.75	840.38	732.85	650.71	N/A
612	N/A	1067.15	1095.45	1047.30	919.65	881.51	839.40	729.94	645.49	N/A
648	N/A	1068.01	1098.01	1048.17	918.15	876.56	836.21	722.92	639.33	N/A
684	N/A	1030.80	1070.59	1009.86	903.47	867.66	821.56	700.10	607.41	N/A
Minimum	N/A	1008.99	1029.06	986.16	889.20	859.62	808.07	694.43	604.58	N/A
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

13:10:25.30	1	2	3	4	5	6	7	8	9	10
0	N/A	1036.44	950.34	905.98	868.67	837.53	N/A	N/A	527.20	380.08
36	N/A	1026.02	945.89	904.26	867.93	835.59	N/A	N/A	527.20	378.88
72	N/A	1017.31	939.64	900.31	865.74	833.41	N/A	N/A	526.96	376.71
108	N/A	1012.94	934.38	898.10	864.52	833.41	N/A	N/A	526.25	375.75
144	N/A	1019.05	939.64	899.82	865.25	834.62	N/A	N/A	525.78	375.99
180	N/A	1025.15	943.21	901.54	865.98	835.59	N/A	N/A	525.78	376.71
216	N/A	1031.24	945.89	903.27	866.96	836.32	N/A	N/A	526.02	377.44
252	N/A	1034.71	948.56	904.75	867.69	837.29	N/A	N/A	526.25	378.16
288	N/A	1036.44	949.45	905.74	868.42	837.77	N/A	N/A	526.49	378.88
324	N/A	1037.31	951.23	906.23	868.91	837.77	N/A	N/A	526.96	379.60
360	N/A	1036.44	951.23	906.48	868.91	837.53	N/A	N/A	527.20	380.08
396	N/A	1027.76	946.78	905.00	868.18	836.07	N/A	N/A	527.20	379.12
432	N/A	1018.18	939.64	901.05	865.98	833.65	N/A	N/A	526.72	376.96
468	N/A	1013.81	934.38	898.59	864.76	833.41	N/A	N/A	526.02	375.99
504	N/A	1019.92	939.64	900.07	865.25	834.86	N/A	N/A	525.78	376.23
540	N/A	1026.02	943.21	902.04	866.23	835.83	N/A	N/A	525.54	376.96
576	N/A	1032.10	946.78	903.76	867.20	836.56	N/A	N/A	525.78	377.68
612	N/A	1035.58	948.56	905.00	867.93	837.29	N/A	N/A	526.02	378.40
648	N/A	1037.31	950.34	905.98	868.67	837.53	N/A	N/A	526.25	379.12
684	N/A	1037.31	950.34	906.48	868.91	837.77	N/A	N/A	526.72	379.84
Average	N/A	1028.05	944.96	903.22	867.10	835.99	N/A	N/A	526.41	377.93
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

14:24:36.74	1	2	3	4	5	6	7	8	9	10
0	N/A	988.49	945.07	910.07	877.62	849.34	N/A	N/A	535.67	385.06
36	N/A	981.44	937.11	906.12	875.42	847.15	N/A	N/A	535.20	382.66
72	N/A	978.79	933.62	903.90	874.19	847.39	N/A	N/A	534.49	381.70
108	N/A	984.97	937.11	905.62	875.17	848.85	N/A	N/A	534.02	382.18
144	N/A	989.37	942.40	907.35	875.90	850.06	N/A	N/A	534.02	383.14
180	N/A	992.01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	383.14
216	N/A	993.77	945.96	910.07	877.62	851.52	N/A	N/A	534.49	384.82
252	N/A	994.65	947.75	910.81	878.11	851.52	N/A	N/A	534.73	385.54
288	N/A	995.53	948.64	911.55	878.60	851.52	N/A	N/A	535.20	386.26
324	N/A	997.28	949.53	911.80	878.60	851.04	N/A	N/A	535.43	386.74
360	N/A	990.25	945.07	909.57	877.37	849.09	N/A	N/A	535.43	384.82
396	N/A	983.20	937.11	905.62	875.17	846.91	N/A	N/A	534.96	382.42
432	N/A	980.56	933.62	903.40	874.19	847.15	N/A	N/A	534.25	381.46
468	N/A	986.73	937.11	905.13	874.93	848.85	N/A	N/A	534.02	382.18
504	N/A	990.25	942.40	906.86	875.90	850.06	N/A	N/A	533.78	382.90
540	N/A	992.01	N/A	N/A	N/A	N/A	N/A	N/A	533.78	382.90
576	N/A	992.89	946.86	909.82	877.62	851.52	N/A	N/A	534.25	384.58
612	N/A	993.77	947.75	910.81	878.11	851.77	N/A	N/A	534.73	385.30
648	N/A	994.65	948.64	911.55	878.60	851.77	N/A	N/A	534.96	386.02
684	N/A	996.40	950.42	911.80	878.60	851.28	N/A	N/A	535.43	386.50
Average	N/A	989.85	943.12	908.44	876.76	849.82	N/A	N/A	534.68	384.02
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

NOTE: This set of data was used for steady state calculations.

Interior Wall Probe Temperature Readings

13:11:49.45	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	379.96	692.58	N/A
1.568	N/A	625.44	887.77
2.064	359.62	611.36	862.57
2.375	N/A	589.46	812.64
2.724	335.00	N/A	789.56
3.048	N/A	N/A	738.72
4.070	225.88	406.46	560.94
4.585	195.95	312.71	480.33
5.213	168.42	270.63	361.31

NOTE: This set of data was used for steady state calculations.

14:26:00.88	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	378.50	680.01	N/A
1.568	N/A	629.27	887.85
2.064	366.06	617.93	868.09
2.375	N/A	599.32	822.22
2.724	344.11	N/A	803.67
3.048	N/A	N/A	754.38
4.070	234.36	419.57	573.41
4.585	201.49	320.88	489.07
5.213	174.70	275.42	366.78

NOTE: This set of data was used for steady state calculations.

Suction Pyrometer Temperature Readings of Flue Gas

	13:22:16.09		13:23:44.69		13:25:09.88		13:26:33.58		13:28:25.63	
	1	2	3	4	5	6	7	8	9	10
0	1137.67	1203.22	1136.05	1072.15	N/A	908.00	883.96	821.68	735.75	618.79
36	1152.02	1204.89	1132.67	1071.29	N/A	913.19	890.58	828.93	735.51	618.55
72	1152.02	1188.16	1143.66	1069.57	N/A	917.40	897.47	836.68	739.55	617.84
108	1149.49	1189.83	1163.04	1074.73	N/A	922.60	901.17	843.47	735.99	617.14
144	1142.75	1192.35	1180.68	1078.16	N/A	927.82	905.36	849.54	735.04	616.67
180	1124.14	1189.83	1186.55	1085.87	N/A	931.79	906.59	852.94	743.60	616.67
216	1129.22	1209.07	1181.52	1088.44	N/A	934.78	906.84	854.64	748.59	616.90
252	1161.29	1254.03	1183.20	1091.01	N/A	937.02	902.15	853.91	752.40	617.61
288	1172.22	1262.33	1174.81	1093.57	N/A	936.52	899.69	851.97	747.88	618.55
324	1176.42	1253.20	1167.25	1094.43	N/A	936.27	900.43	850.51	749.78	619.02
360	1184.81	1238.22	1167.25	1094.43	N/A	935.77	903.14	850.99	748.12	619.26
396	1189.83	1229.91	1161.36	1089.30	N/A	935.03	907.33	853.67	746.45	619.02
432	1188.16	1227.41	1152.94	1082.45	N/A	936.52	910.05	856.83	741.69	618.32
468	1176.42	1236.56	1189.90	1083.30	N/A	939.01	913.01	860.24	741.93	617.61
504	1164.65	1211.57	1202.46	1086.73	N/A	941.76	913.76	862.93	745.26	616.90
540	1150.34	1213.24	1199.95	1091.01	N/A	944.00	914.50	864.88	747.64	616.67
576	1147.81	1219.91	1193.25	1095.28	N/A	945.50	913.26	865.12	751.93	616.90
612	1179.77	1266.48	1187.39	1096.13	N/A	946.00	907.58	862.68	757.88	617.61
648	1189.00	1265.65	1179.84	1097.84	N/A	945.50	903.88	859.03	756.69	618.32
684	1191.51	1252.36	1176.49	1096.99	N/A	943.75	903.14	855.86	755.74	618.79
Average	1162.98	1225.41	1173.01	1086.63	N/A	933.91	904.19	851.82	745.87	617.86
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

	14:27:11.68		14:31:48.62		14:33:14.85		14:34:43.72		14:36:31.98	
	1	2	3	4	5	6	7	8	9	10
0	1019.25	1106.31	1124.24	1058.38	948.06	911.54	895.03	828.74	745.81	622.41
36	1026.22	1110.57	1122.55	1062.69	945.31	914.51	898.72	833.57	743.19	621.47
72	1031.44	1113.12	1114.05	1059.24	952.56	917.48	901.92	837.45	737.25	620.29
108	1016.63	1108.02	1114.90	1056.66	957.07	920.70	905.62	841.32	742.24	619.82
144	1014.88	1109.72	1119.15	1059.24	954.81	924.17	905.86	844.23	746.76	619.82
180	1011.38	1113.97	1127.63	1064.42	952.56	927.39	906.60	846.42	752.24	620.53
216	1014.88	1120.77	1131.02	1070.44	960.83	930.37	906.36	847.39	752.95	621.70
252	1013.13	1113.97	1133.56	1072.16	956.56	931.86	906.36	847.63	756.05	622.65
288	1019.25	1122.47	1134.40	1076.46	953.81	932.36	906.60	847.39	756.76	623.59
324	1025.35	1130.94	1133.56	1078.17	958.82	932.36	903.64	846.42	756.53	624.06
360	1032.31	1131.79	1131.02	1076.46	960.83	932.61	904.14	846.90	756.29	623.82
396	1038.38	1141.93	1127.63	1074.74	958.82	932.11	905.12	847.63	746.52	623.35
432	1039.25	1136.01	1116.60	1067.86	963.08	932.36	906.11	849.09	748.90	622.65
468	1024.48	1130.94	1119.15	1065.28	953.06	933.85	907.84	850.55	747.00	622.18
504	1020.99	1130.94	1120.85	1067.00	954.56	935.59	908.83	852.01	752.00	622.18
540	1017.50	1126.70	1126.78	1069.58	964.84	937.58	906.85	852.25	758.43	622.65
576	1019.25	1126.70	1130.17	1071.30	957.82	939.33	903.64	851.28	758.19	623.59
612	1022.73	1130.94	1131.02	1073.02	964.09	940.32	901.43	849.58	756.29	624.53
648	1026.22	1133.48	1131.87	1072.16	958.07	940.57	901.43	848.12	762.49	625.47
684	1033.18	1116.52	1117.45	1072.16	961.08	938.83	899.95	846.42	758.67	625.94
Average	1023.33	1122.79	1125.38	1068.37	956.83	930.29	904.10	845.72	751.73	622.64
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Shell Temperature Readings

Time	Position, metres				
	0.146	0.921	1.492	2.210	5.354
13:08:27.71	271.61	203.56	184.15	156.36	121.42
14:05:39.89	273.22	206.16	188.47	164.13	125.99

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
13:15	5	82.4	3.4	14.2
13:20	5	81.7	2.2	16.1
13:43	5	76.1	5.9	18.0
13:53	5	76.1	4.2	19.7
13:57	5	75.4	2.3	22.3

Axial Calcination Results

Natural Gas = 5.6 CFM	Product	Product
Sample Code	GP	GP
Date	25/Jun/90	25/Jun/90
Before Firing, g	22.2855	21.9728
After Firing, g	22.2077	21.8949
Empty Crucible, g	9.9545	10.2683
Wt of Sample Before, g	12.3310	11.7045
Wt Loss by $CaCO_3$, g	0.0778	0.0779
% Calcination	98.55	98.47

Average = 98.51%

Lignin = 165 g/m	Product	Product	Port #1	Port #1
Sample Code	LP	LP	L#1	L#1
Date	25/Jun/90	25/Jun/90	28/Jun/90	28/Jun/90
Before Firing, g	20.8824	21.5706	22.4253	23.8049
After Firing, g	20.6657	21.3674	20.4204	22.1204
Empty Crucible, g	10.5001	10.0641	10.4130	11.7836
Wt of Sample Before, g	10.3823	11.5065	12.0123	12.0213
Wt Loss by $CaCO_3$, g	0.2167	0.2032	2.0049	1.6845
% Calcination	95.21	95.94	61.67	67.82

Average = 95.58% 64.74%

Lignin = 165 g/m	Port #2	Port #2	Port #3	Port #3	Port #4	Port #4
Sample Code	L#2	L#2	L#3	L#3	L#4	L#4
Date	25/Jun/90	28/Jun/90	25/Jun/90	25/Jun/90	25/Jun/90	25/Jun/90
Before Firing, g	24.7378	25.4935	27.2490	27.4466	29.7319	28.1727
After Firing, g	21.1773	21.4054	21.4059	21.3925	22.5711	21.4066
Empty Crucible, g	12.1847	11.1864	12.0454	11.6540	12.5625	12.0844
Wt of Sample Before, g	12.5531	14.3071	15.2036	15.7926	17.1694	16.0883
Wt Loss by $CaCO_3$, g	3.5605	4.0881	5.8431	6.0541	7.1608	6.7661
% Calcination	34.86	34.38	11.74	11.96	4.22	3.41

Average = 34.62% 11.85% 3.82%

Run LG17

Table of Events

Action Requested by Operator	Time
6/26/90	12:01:06.18
Kiln speed (rpm) : 1.5	12:01:07.83
Gas = 5.4 CFM	11:20:00
Read Bed Temperatures	12:13:10.48
Lignin = 132 g/min Gas = 2.2 CFM	12:17:00
Read Bed Temperatures	12:36:50.91
Read Bed Temperatures	13:24:03.75
Read Bed Temperatures	13:53:27.35
Read Bed Temperatures	13:59:01.13
Read Bed Temperatures	14:09:10.64
Read Shell Temperatures	14:11:04.89
Read Hot Face Heat Flux Temperatures	14:11:10.60
Read Colder Heat Flux Temperatures	14:12:35.57
Read Bed Temperatures	14:13:26.04
Read Bed Temperatures	14:35:34.36

Cyclic Bed Temperature Readings

12:13:10.48	1	2	3	4	5	6	7	8	9	10
0	1035.00	1108.89	1097.82	1017.61	908.74	881.18	838.75	794.84	686.32	607.80
36	1040.23	1112.29	1109.74	N/A	N/A	N/A	N/A	N/A	N/A	607.80
72	1048.88	1119.93	1113.14	1034.14	916.66	891.49	845.31	806.86	694.13	618.87
108	1060.96	1127.56	1112.29	1035.00	918.64	893.70	847.49	809.99	691.53	617.22
144	1066.98	1130.10	1111.44	1035.00	918.89	893.46	847.74	807.83	678.53	604.74
180	1058.37	1121.63	1108.04	1029.80	916.66	889.52	845.55	803.25	668.37	592.26
216	1034.14	1091.84	1105.49	1016.74	911.46	882.16	839.97	795.32	658.70	577.89
252	1008.00	1040.23	1050.61	977.26	902.32	869.18	830.76	778.06	651.86	578.36
288	1008.88	1073.00	1049.74	980.78	898.87	866.98	831.00	779.02	658.23	588.25
324	1023.71	1099.52	1075.57	1000.12	902.32	872.85	834.63	786.92	666.25	598.62
360	1035.00	1107.19	1095.26	1012.37	907.01	879.46	838.51	794.84	674.28	607.57
396	1040.23	1113.99	1108.04	1023.71	N/A	N/A	N/A	N/A	N/A	607.57
432	1045.42	1121.63	1114.84	1029.80	915.67	890.75	845.79	807.59	683.96	618.87
468	1060.09	1129.25	1112.29	1030.66	917.90	893.21	847.74	809.99	683.72	618.40
504	1068.70	1130.94	1109.74	1031.53	918.64	893.21	848.22	809.75	676.40	607.57
540	1061.82	1123.32	1105.49	1027.19	916.66	889.28	846.28	803.74	666.49	592.73
576	1037.63	1096.96	1101.23	1017.61	911.71	882.65	840.94	796.52	658.70	578.59
612	1007.13	1035.87	1049.74	976.37	903.06	869.67	831.00	778.54	653.04	576.47
648	1001.88	1059.23	1047.15	979.90	899.12	866.49	830.76	778.06	660.35	586.37
684	1018.48	1094.40	1072.14	1000.12	901.83	872.60	834.15	786.21	669.32	598.38
Minimum	1001.88	1035.87	1047.15	976.37	898.87	866.98	830.76	778.06	651.86	576.47
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

12:36:50.91	1	2	3	4	5	6	7	8	9	10
0	952.79	1063.01	1098.15	1044.02	935.37	913.03	865.85	827.46	698.95	632.39
36	953.68	1065.59	1097.29	1044.02	936.87	913.28	866.82	826.74	693.04	622.26
72	954.56	1066.45	1097.29	1042.29	935.87	910.80	865.85	822.39	683.11	607.42
108	937.64	1043.16	1093.03	1029.26	929.40	902.41	859.99	813.46	674.84	589.76
144	917.52	997.82	1045.75	987.28	916.99	886.41	849.04	793.97	670.36	589.29
180	911.38	1012.70	1039.69	995.19	914.02	883.71	848.55	794.93	676.73	600.59
216	920.15	1031.86	1059.56	1011.83	918.48	890.83	852.20	803.58	686.42	612.14
252	930.65	1040.56	1076.76	1024.91	923.68	898.71	856.09	811.53	693.04	620.85
288	940.32	1049.21	1087.04	1032.73	904.63	859.75	818.28	697.06	627.92	620.85
324	945.67	1056.11	1091.32	1037.07	931.88	909.07	863.41	823.11	699.66	632.39
360	950.12	1060.42	1093.88	1040.56	935.37	912.29	866.09	826.01	700.13	632.63
396	954.56	1063.87	1094.73	1040.56	936.87	912.78	867.07	826.01	693.27	622.97
432	956.34	1063.87	1095.59	1040.56	936.37	909.32	865.12	821.42	683.82	607.66
468	1047.48	1030.99	N/A	N/A	N/A	N/A	N/A	N/A	683.82	607.66
504	918.40	999.58	1045.75	988.16	918.48	887.15	849.28	794.93	667.76	588.82
540	914.89	1011.83	1037.96	993.43	914.27	882.98	848.31	795.17	673.43	601.07
576	920.15	1030.13	1058.70	1007.46	918.48	890.10	851.96	803.34	684.05	611.90
612	930.65	1041.42	1075.04	1021.43	923.68	897.72	855.85	811.05	692.09	621.32
648	938.53	1050.94	1085.33	1030.99	928.65	903.89	859.75	817.56	697.06	628.39
684	942.99	1056.98	1090.46	1037.07	933.13	909.32	863.65	823.11	700.61	632.39
Minimum	911.38	997.82	1037.96	987.28	904.63	859.75	818.28	697.06	627.92	588.82
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

13:24:03.75	1	2	3	4	5	6	7	8	9	10
0	943.47	1049.69	1073.81	1022.78	922.18	899.44	862.18	819.73	694.70	624.39
36	951.49	1056.59	1086.67	1034.95	927.39	907.33	866.57	826.25	699.43	632.64
72	961.26	1061.77	1094.36	1043.64	932.61	913.76	870.72	830.84	702.74	637.82
108	964.80	1066.07	1097.77	1047.96	937.10	918.96	874.39	834.96	705.35	641.36
144	969.23	1068.65	1098.63	1049.69	939.34	920.69	876.84	836.90	705.35	635.94
180	972.77	1070.37	1097.77	1050.55	939.84	919.70	877.09	700.38	N/A	635.94
216	972.77	1072.09	1096.92	1047.96	938.59	915.98	874.88	700.38	N/A	635.94
252	953.27	1041.90	1087.52	1019.29	928.14	904.12	868.04	817.07	687.37	589.30
288	941.69	1014.93	1050.55	993.04	916.73	890.09	858.77	805.27	685.48	599.66
324	943.47	1038.44	1057.46	1007.94	917.47	892.30	859.01	811.05	689.50	612.62
360	946.15	1048.82	1072.95	1021.91	923.17	900.67	862.18	819.24	694.70	623.69
396	952.38	1057.46	1084.95	1034.95	928.39	907.58	865.84	825.04	698.96	631.46
432	958.60	1062.63	1092.65	1041.04	933.61	913.76	869.50	830.60	702.51	637.35
468	963.92	1066.93	1095.21	1045.37	938.34	918.71	873.41	834.96	704.88	640.18
504	968.34	1069.51	1096.07	1048.82	941.09	921.44	876.11	836.90	704.64	634.76
540	N/A	N/A	N/A	N/A	919.95	N/A	N/A	N/A	N/A	634.76
576	971.00	1072.95	1097.77	1051.42	939.09	915.49	873.90	N/A	N/A	634.76
612	950.60	1041.04	1089.23	1021.91	928.88	903.63	867.30	817.55	686.66	589.30
648	938.12	1014.93	1051.42	996.55	917.72	889.35	858.28	805.51	685.01	598.25
684	943.47	1039.31	1057.46	1010.56	918.71	891.56	859.01	810.80	688.55	610.97
Minimum	938.12	1014.93	1050.55	993.04	916.73	889.35	858.28	700.38	620.86	589.30
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

13:53:27.35	1	2	3	4	5	6	7	8	9	10
0	934.03	1036.96	1065.49	1016.08	912.80	883.00	840.57	794.01	668.52	601.83
36	941.08	1044.78	1078.38	1028.28	918.00	891.10	844.21	800.50	674.19	610.54
72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	610.54
108	953.55	1056.87	1088.66	1042.18	928.91	904.40	852.23	810.36	681.51	620.43
144	957.99	1058.60	1089.51	1043.92	932.40	908.60	856.12	813.49	682.69	618.55
180	956.21	1060.32	1091.22	1043.05	933.89	909.34	859.05	813.98	678.67	607.48
216	956.21	1062.05	1091.22	1043.05	932.89	906.87	859.78	810.84	672.53	607.48
252	935.78	1040.45	1086.95	1021.31	925.19	896.76	856.12	803.62	665.69	571.44
288	921.79	1007.34	1049.10	988.04	913.05	880.80	843.73	788.97	662.39	578.27
324	924.42	1024.80	1049.10	1002.09	910.57	878.59	841.30	790.17	666.40	591.23
360	933.16	1036.09	1064.63	1017.83	914.78	885.21	842.51	795.45	672.06	603.00
396	943.75	1045.65	1078.38	1030.02	920.72	893.81	845.91	801.46	677.02	611.48
432	949.99	1086.09	N/A	N/A	N/A	N/A	N/A	N/A	677.02	611.48
468	957.10	1056.87	1089.51	1043.92	928.91	905.14	853.20	810.12	683.16	619.96
504	957.99	1058.60	1091.22	1048.24	931.15	907.86	856.37	812.77	684.11	618.31
540	959.76	1060.32	1092.93	1047.38	932.40	908.35	858.56	813.25	680.80	607.01
576	964.20	1062.05	1092.93	1049.10	931.15	906.13	858.80	810.12	680.80	607.01
612	944.65	1040.45	1090.37	1027.41	923.20	896.51	855.39	803.38	668.76	573.09
648	928.79	1006.47	1051.70	991.56	911.81	880.80	843.48	788.97	663.80	578.51
684	927.92	1023.93	1050.83	1002.97	909.83	879.08	840.81	789.93	667.10	590.76
Minimum	921.79	1006.47	1049.10	988.04	909.83	878.59	840.57	788.97	662.39	571.44
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

13:59:01.13	1	2	3	4	5	6	7	8	9	10
0	963.31	1060.32	1090.37	1040.45	926.18	901.19	852.23	808.20	681.74	621.61
36	965.97	1062.91	1092.08	1043.05	928.42	903.41	854.66	809.88	681.51	615.49
72	N/A	N/A	N/A	N/A	N/A	N/A	854.66	809.88	681.51	615.49
108	967.74	1063.77	1094.64	1046.51	N/A	N/A	N/A	N/A	681.51	615.49
144	940.19	1025.67	1076.66	1007.34	916.51	886.44	849.31	794.01	665.22	574.26
180	926.17	1009.97	1046.51	994.19	908.10	875.90	839.60	787.06	665.22	585.57
216	934.90	1030.89	1056.01	1009.97	909.59	878.59	839.60	790.41	668.52	596.41
252	946.43	1041.32	1071.51	1023.93	915.03	886.93	841.78	796.17	673.01	605.83
288	953.55	1049.10	1083.52	1034.36	919.48	893.32	844.70	800.74	677.02	605.83
324	958.88	1054.29	1088.66	1040.45	924.20	898.98	847.85	805.07	680.09	619.02
360	966.85	1057.74	1091.22	1043.05	927.42	902.67	851.50	808.20	682.22	621.61
396	968.62	1059.46	1093.79	1046.51	930.16	904.89	853.93	809.88	681.51	617.13
432	967.74	1062.05	1095.49	1049.10	932.15	905.88	856.37	809.40	676.55	603.00
468	967.74	1063.77	1097.20	1046.51	N/A	N/A	N/A	809.40	676.55	603.00
504	941.08	1023.93	1078.38	1007.34	919.48	889.14	850.77	795.69	664.27	575.91
540	925.29	1008.22	1048.24	994.19	910.33	877.86	840.81	787.78	664.51	587.93
576	931.41	1027.41	1056.87	1012.59	913.05	881.78	841.30	792.09	669.46	599.47
612	941.08	1039.59	1070.65	1026.54	918.25	889.63	843.97	797.85	674.89	608.89
648	947.32	1048.24	1082.66	1035.23	923.45	897.75	847.85	803.38	679.38	608.89
684	952.66	1053.42	1087.80	1040.45	928.17	904.40	851.99	807.95	682.92	622.08
Minimum	925.29	1008.22	1046.51	994.19	908.10	875.90	839.60	787.06	664.27	574.26
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

14:09:10.64	1	2	3	4	5	6	7	8	9	10
0	964.34	1060.46	1091.36	1046.65	933.53	908.49	861.38	812.19	677.16	603.14
36	960.79	1060.46	N/A	N/A	N/A	N/A	N/A	812.19	677.16	603.14
72	934.17	1022.33	1071.65	1003.98	919.13	890.51	854.32	797.27	665.36	578.17
108	924.56	1010.98	1048.38	996.97	911.70	880.20	844.11	791.99	666.06	588.30
144	931.55	1030.16	1058.74	1015.35	914.42	883.88	844.35	795.83	671.49	600.55
180	939.43	1039.73	1072.51	1026.68	918.88	891.73	846.05	800.40	676.69	610.21
216	948.35	1046.65	1081.09	1035.37	924.09	899.12	849.70	N/A	676.69	610.21
252	955.46	1052.70	1087.09	1041.46	928.56	905.03	853.34	808.34	684.25	623.16
288	962.56	1054.43	1089.65	1044.92	932.29	908.74	856.99	810.98	686.14	624.11
324	966.11	1057.88	1091.36	1049.24	935.03	911.21	859.19	812.91	684.48	617.75
360	967.88	1060.46	1092.22	1050.11	935.27	910.71	862.11	812.43	676.92	604.32
396	965.22	1059.60	1091.36	1046.65	935.27	910.71	862.11	812.43	676.92	604.32
432	938.54	1023.20	1072.51	1003.98	920.62	891.24	856.26	798.47	666.30	579.82
468	927.18	1048.38	N/A	N/A	N/A	N/A	N/A	N/A	590.90	579.82
504	939.43	1029.29	1057.88	1013.60	915.66	884.86	844.84	796.31	673.85	603.14
540	943.00	1037.97	1070.79	1026.68	920.62	893.70	846.78	802.08	678.81	613.27
576	949.24	1045.79	1080.23	1035.37	924.83	900.84	850.67	806.89	682.59	613.27
612	955.46	1050.97	1086.23	1041.46	928.56	905.53	854.56	810.26	685.19	624.81
648	958.13	1054.43	1087.94	1043.19	932.04	909.48	857.97	813.15	687.08	627.17
684	959.02	1055.29	1088.80	1044.92	934.03	911.21	861.38	814.84	686.14	620.10
Average	924.56	1010.98	1048.38	996.97	911.70	880.20	844.11	791.99	665.36	578.17
Distance, m	0.146	0.464	0.921	1.492	2.210	2.553	2.915	3.270	3.994	4.521

NOTE: This set of data was used for steady state calculations.

Cyclic Hot Face Wall Probe Temperature Readings

14:11:10.60	1	2	3	4	5	6	7	8	9	10
0	N/A	1004.86	951.91	911.46	867.72	837.32	N/A	N/A	508.55	N/A
36	N/A	1003.98	951.91	N/A	N/A	N/A	N/A	N/A	508.55	N/A
72	N/A	993.46	944.79	906.76	865.53	833.68	N/A	N/A	509.02	364.96
108	N/A	986.42	938.54	902.81	863.58	831.99	N/A	N/A	508.31	363.27
144	N/A	990.82	940.33	903.80	863.82	833.68	N/A	N/A	507.84	363.27
180	N/A	996.97	943.89	906.02	864.80	835.14	N/A	N/A	507.84	363.75
216	N/A	999.60	946.57	907.75	865.53	836.11	N/A	N/A	507.60	363.75
252	N/A	1001.35	948.35	909.23	866.50	836.83	N/A	N/A	507.84	364.96
288	N/A	1003.11	950.13	910.22	866.99	837.32	N/A	N/A	508.31	365.68
324	N/A	1003.98	951.91	911.21	867.72	837.56	N/A	N/A	508.78	366.40
360	N/A	1004.86	952.80	911.70	867.72	N/A	N/A	N/A	N/A	366.40
396	N/A	1003.98	951.91	911.46	867.72	N/A	N/A	N/A	N/A	366.40
432	N/A	992.58	944.79	907.26	865.53	833.44	N/A	N/A	509.26	366.40
468	N/A	986.42	938.54	903.31	863.58	831.75	N/A	N/A	508.78	363.75
504	N/A	990.82	939.43	903.80	863.58	833.68	N/A	N/A	508.07	363.75
540	N/A	996.97	943.89	906.02	864.55	835.14	N/A	N/A	508.07	364.23
576	N/A	999.60	946.57	907.75	865.28	836.35	N/A	N/A	507.84	364.23
612	N/A	1000.48	948.35	909.73	866.50	837.56	N/A	N/A	508.07	365.20
648	N/A	1001.35	950.13	910.96	867.48	838.29	N/A	N/A	508.55	365.92
684	N/A	1002.23	951.91	911.70	867.97	838.53	N/A	N/A	508.78	366.64
Average	N/A	998.19	946.83	908.05	865.90	835.55	N/A	N/A	508.34	364.94
Distance, m	0.616	1.010	1.568	2.064	2.375	2.724	3.048	4.070	4.585	5.213

Interior Wall Probe Temperature Readings

14:12:35.57	Radius, m		
Position	0.2506	0.2318	0.2130
0.616	N/A	N/A	N/A
1.010	384.17	688.53	N/A
1.568	N/A	630.16	890.22
2.064	361.82	614.92	866.99
2.375	N/A	580.53	N/A
2.724	N/A	N/A	790.79
3.048	N/A	N/A	738.98
4.070	N/A	N/A	550.36
4.585	N/A	317.11	470.62
5.213	N/A	267.74	350.01

Suction Pyrometer Temperature Readings of Flue Gas

This data was lost to the computer.

Shell Temperature Readings

This data was lost to the computer.

Flue Gas Analysis

Time	Port	N_2	O_2	CO_2
12:38	5	75.1	2.7	22.2
12:46	5	77.6	2.6	19.8
12:50	5	75.2	1.7	23.1
12:54	5	78.3	1.5	20.2
12:59	5	74.9	1.7	23.4
13:26	5	76.1	2.4	21.5
13:55	5	74.0	2.2	23.8

Axial Calcination Results

Natural Gas = 5.4 CFM	Product	Product
Sample Code	GP	GP
Date	27/Jun/90	27/Jun/90
Before Firing, g	21.3731	22.5059
After Firing, g	21.3037	22.3912
Empty Crucible, g	10.4086	11.7910
Wt of Sample Before, g	10.9645	10.7149
Wt Loss by $CaCO_3$, g	0.0694	0.1147
% Calcination	98.55	97.54

Average = 98.04%

Lignin = 132 g/m	Product	Product	Port #1	Port #1
Sample Code	LP	LP	L#1	L#1
Date	27/Jun/90	27/Jun/90	30/Jun/90	30/Jun/90
Before Firing, g	22.5754	23.4529	23.8047	21.9730
After Firing, g	22.4063	23.3278	21.6156	19.9854
Empty Crucible, g	11.1783	12.0220	11.3931	10.6012
Wt of Sample Before, g	11.3971	11.4309	12.4116	11.3718
Wt Loss by $CaCO_3$, g	0.1691	0.1251	2.1891	1.9876
% Calcination	96.59	97.49	59.49	59.86

Average = 97.04% 59.68%

Lignin = 132 g/m	Port #2	Port #2	Port #3	Port #3	Port #3	Port #3	Port #4	Port #4	Port #5	Port #5
Sample Code	L#2	L#2	L#3	L#3	L#3	L#3	L#4	L#4	L#5	L#5
Date	27/Jun/90	27/Jun/90	27/Jun/90	27/Jun/90	30/Jun/90	30/Jun/90	27/Jun/90	27/Jun/90	28/Jun/90	28/Jun/90
Before Firing, g	23.5239	22.5660	26.8818	25.7489	25.8480	26.2792	26.5337	25.8418	28.0523	28.9566
After Firing, g	19.9058	19.3174	20.7256	19.9813	20.7661	21.1439	19.9728	19.1737	20.8625	21.0204
Empty Crucible, g	9.9582	10.2720	10.5041	10.0690	12.1949	12.6168	10.9828	10.0932	11.3850	10.5921
Wt of Sample Before, g	13.5657	12.2940	16.3777	15.6799	13.6531	13.6624	15.5509	15.7486	16.6673	18.3645
Wt Loss by $CaCO_3$, g	3.6181	3.2486	6.1562	5.7676	5.0819	5.1353	6.5609	6.6681	7.1898	7.9362
% Calcination	38.75	39.31	13.67	15.52	14.52	13.68	3.11	2.76	0.93	0.75

Average = 39.03% 14.35% 2.93% 0.84%

Appendix E

Other Graphs, Temperature, Calcination & Slaking Profiles

Page

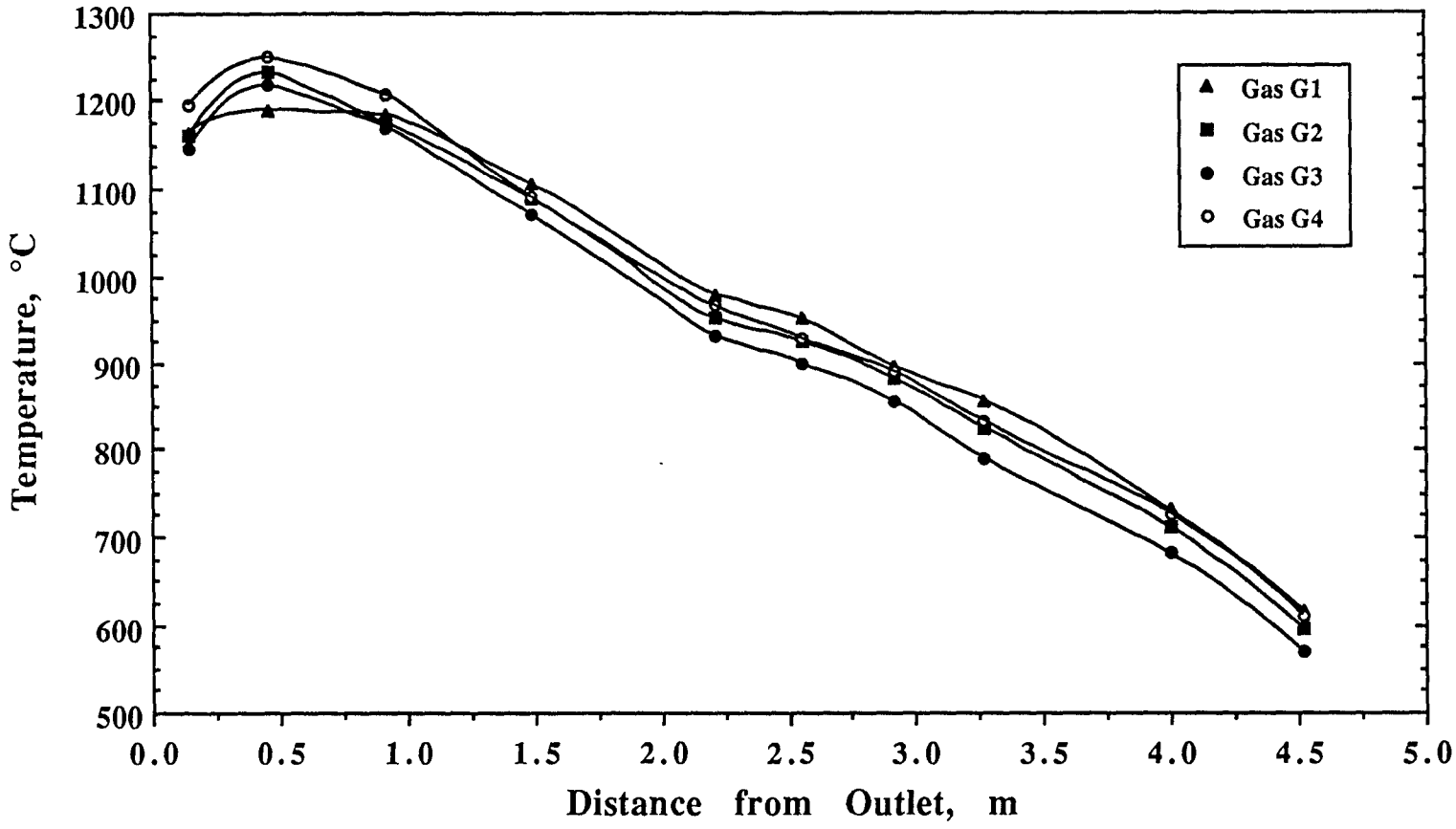


Figure E–1. Axial gas temperature profiles for tests with natural gas

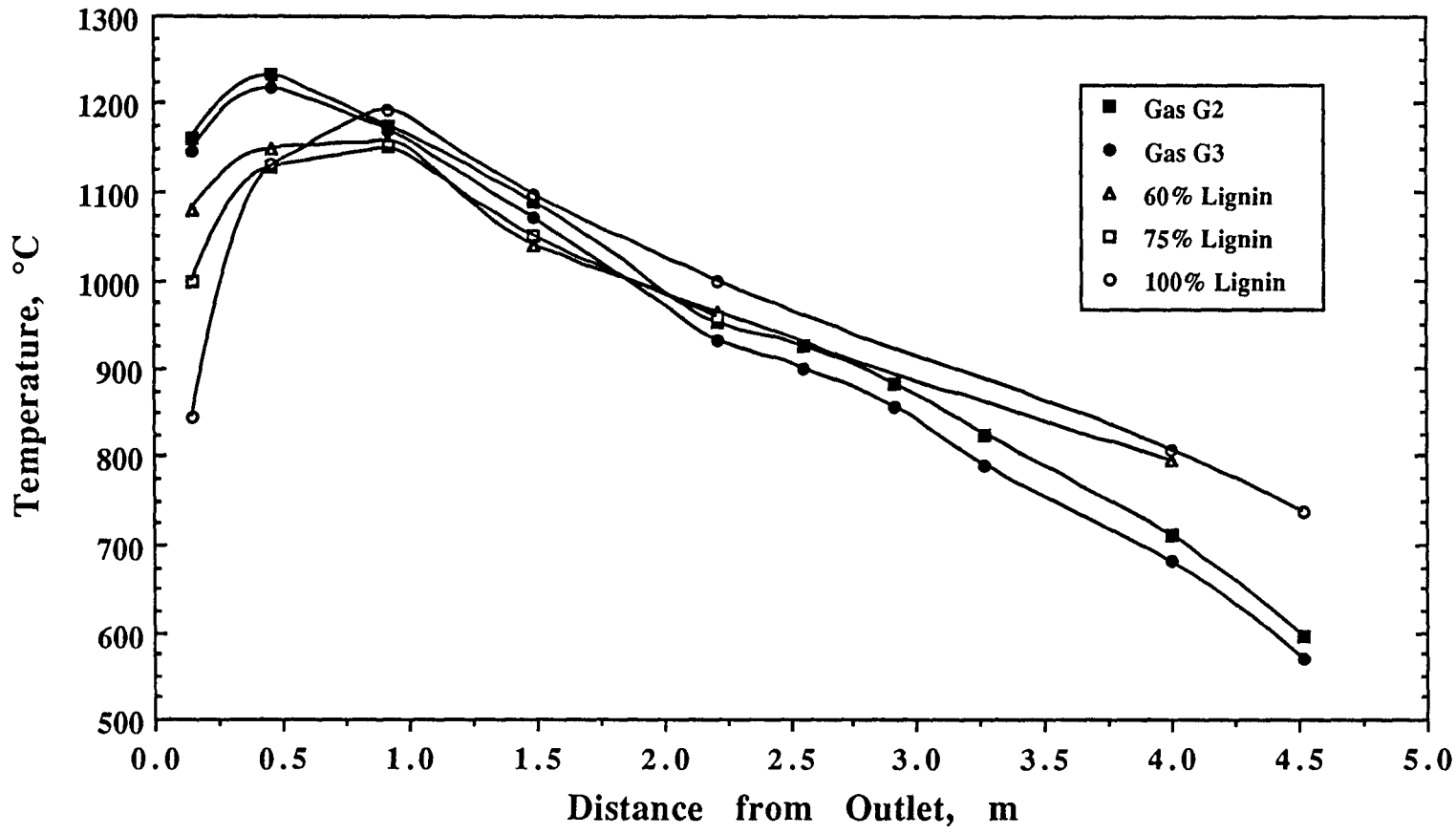


Figure E–2. Axial gas temperature profiles for tests with lignin IR

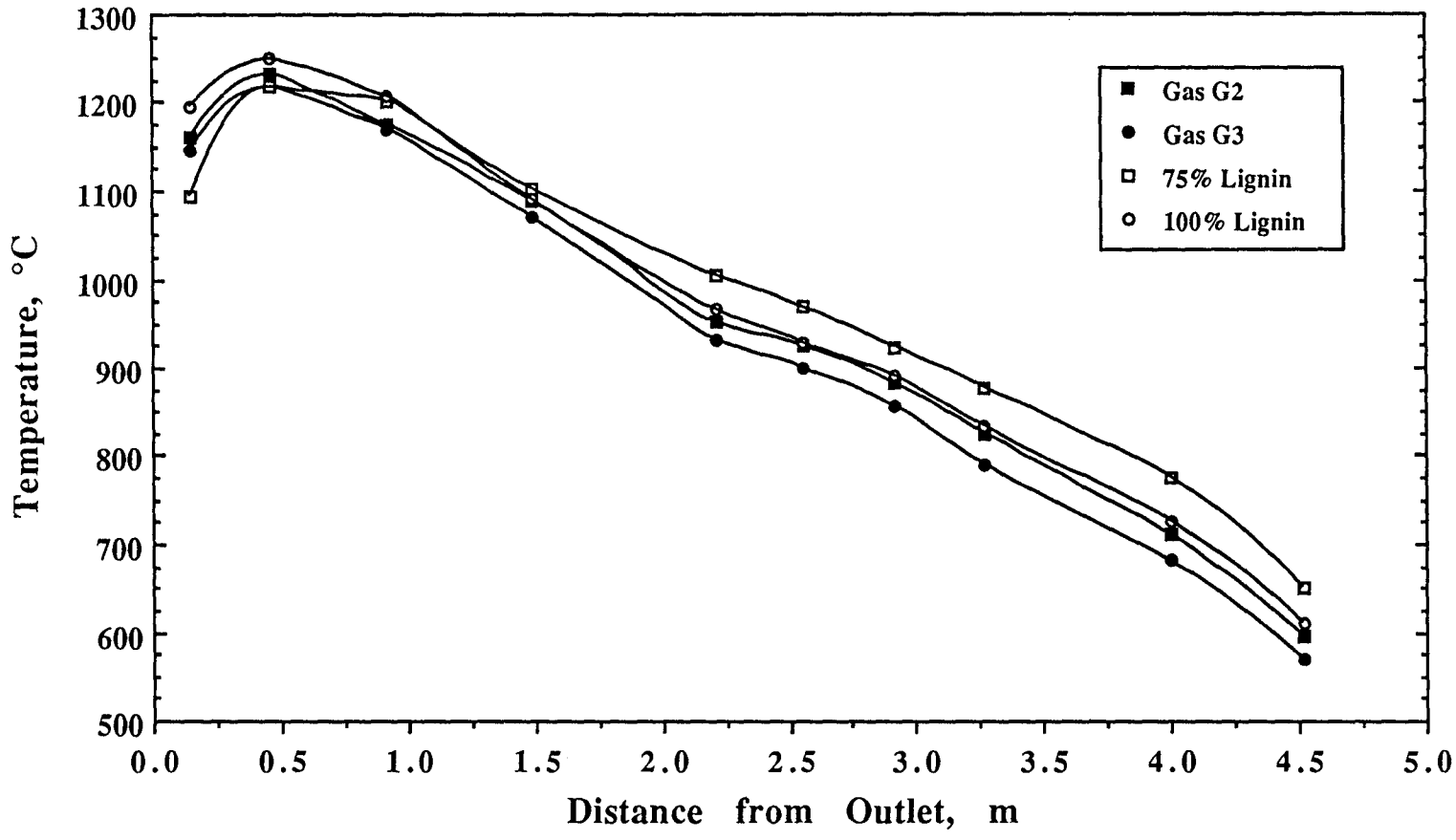


Figure E–3. Axial gas temperature profiles for tests with lignin PG

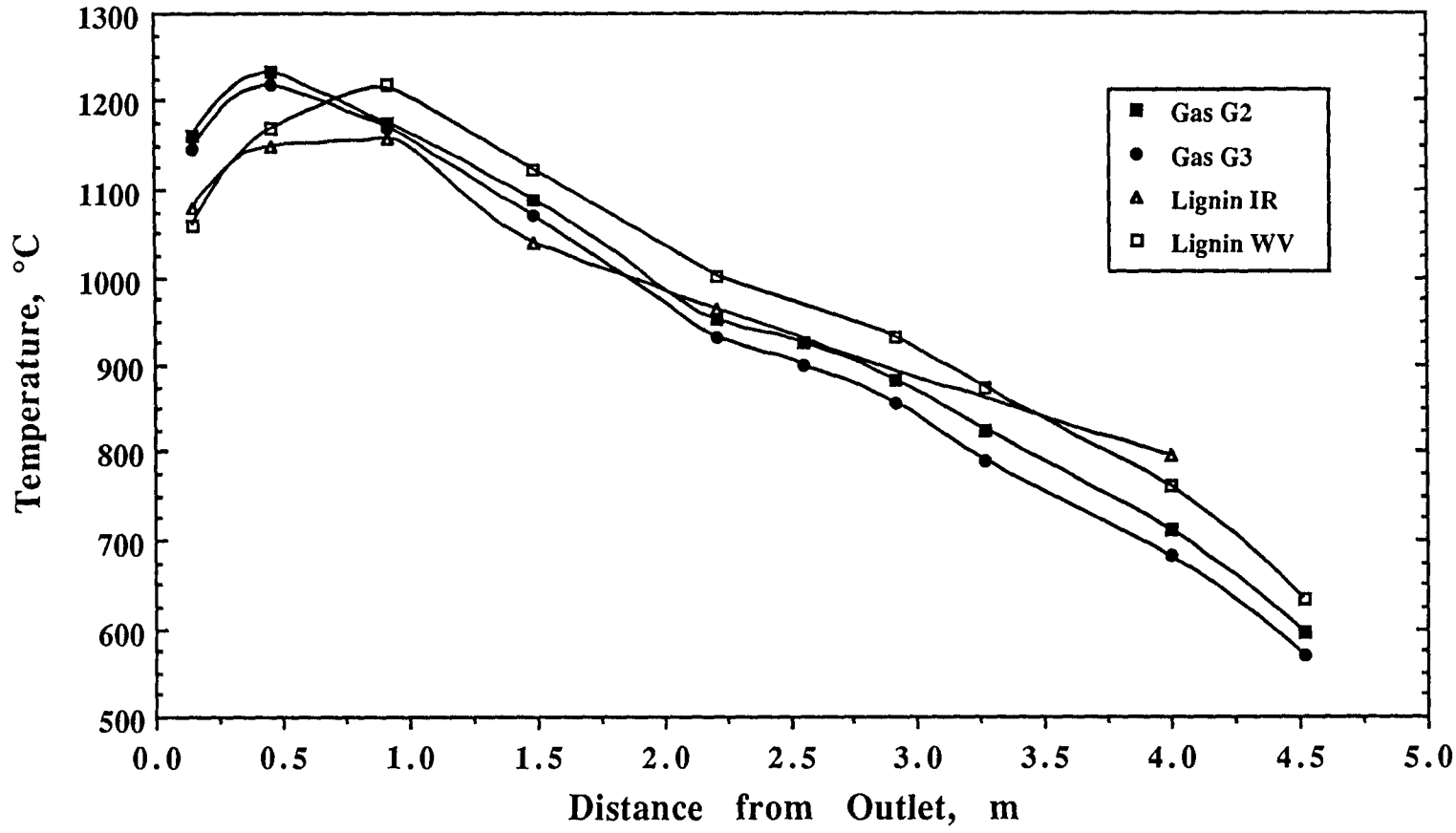


Figure E–4. Axial gas temperature profiles for tests with natural gas firing versus 60% lignin burning

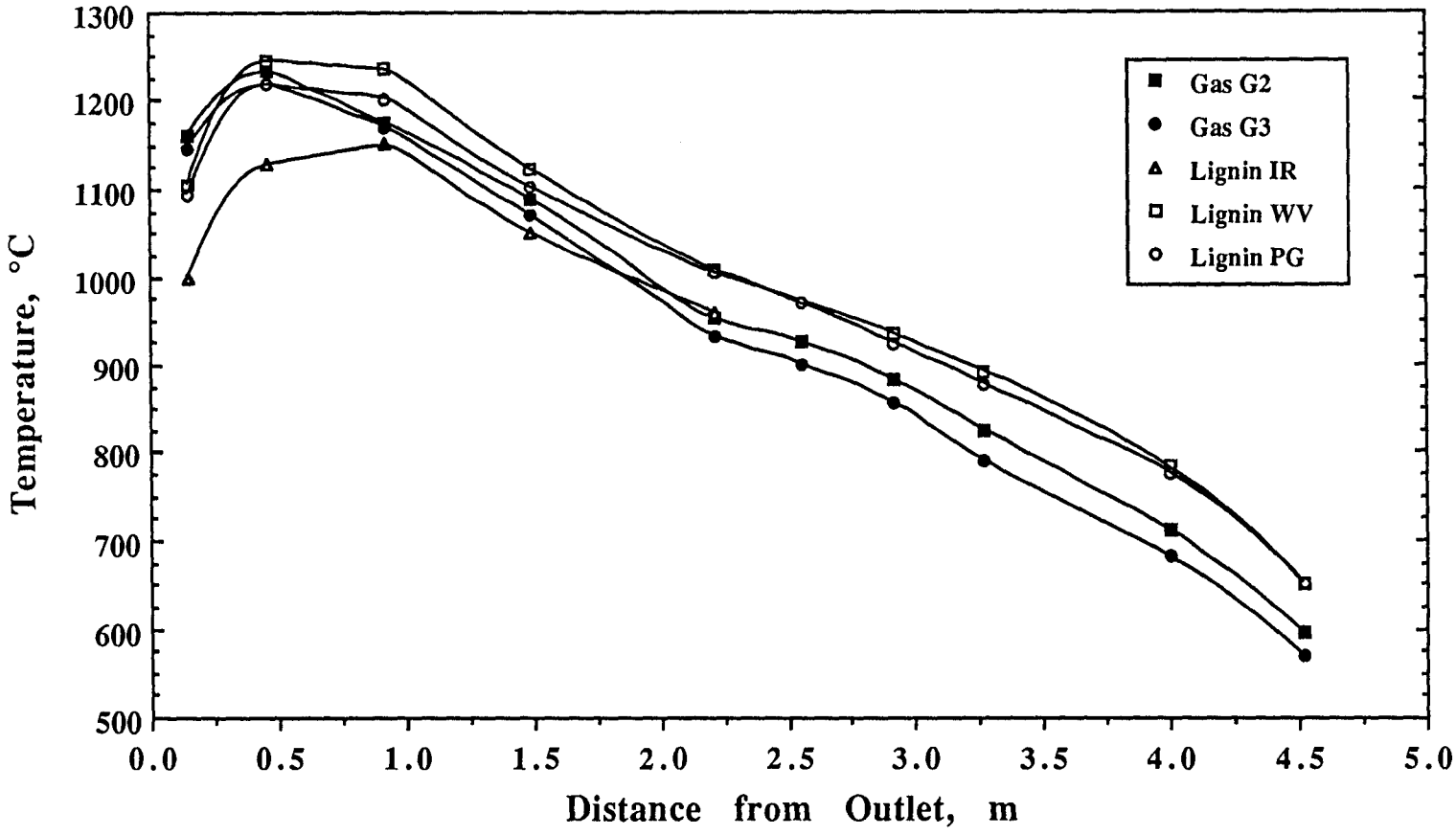


Figure E–5. Axial gas temperature profiles for tests with natural gas firing versus 75% lignin burning

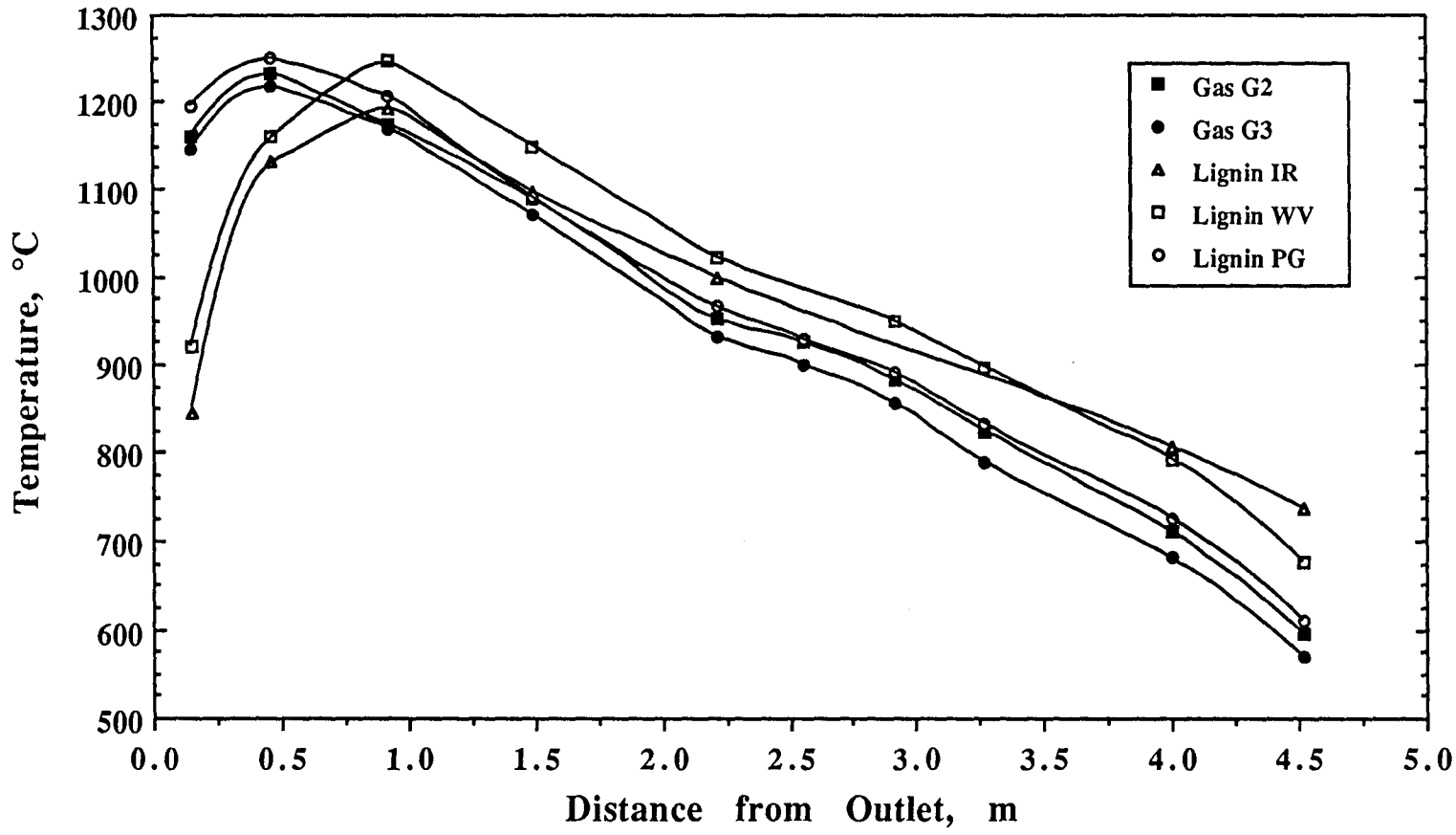


Figure E–6. Axial gas temperature profiles for tests with natural gas firing versus 100% lignin burning

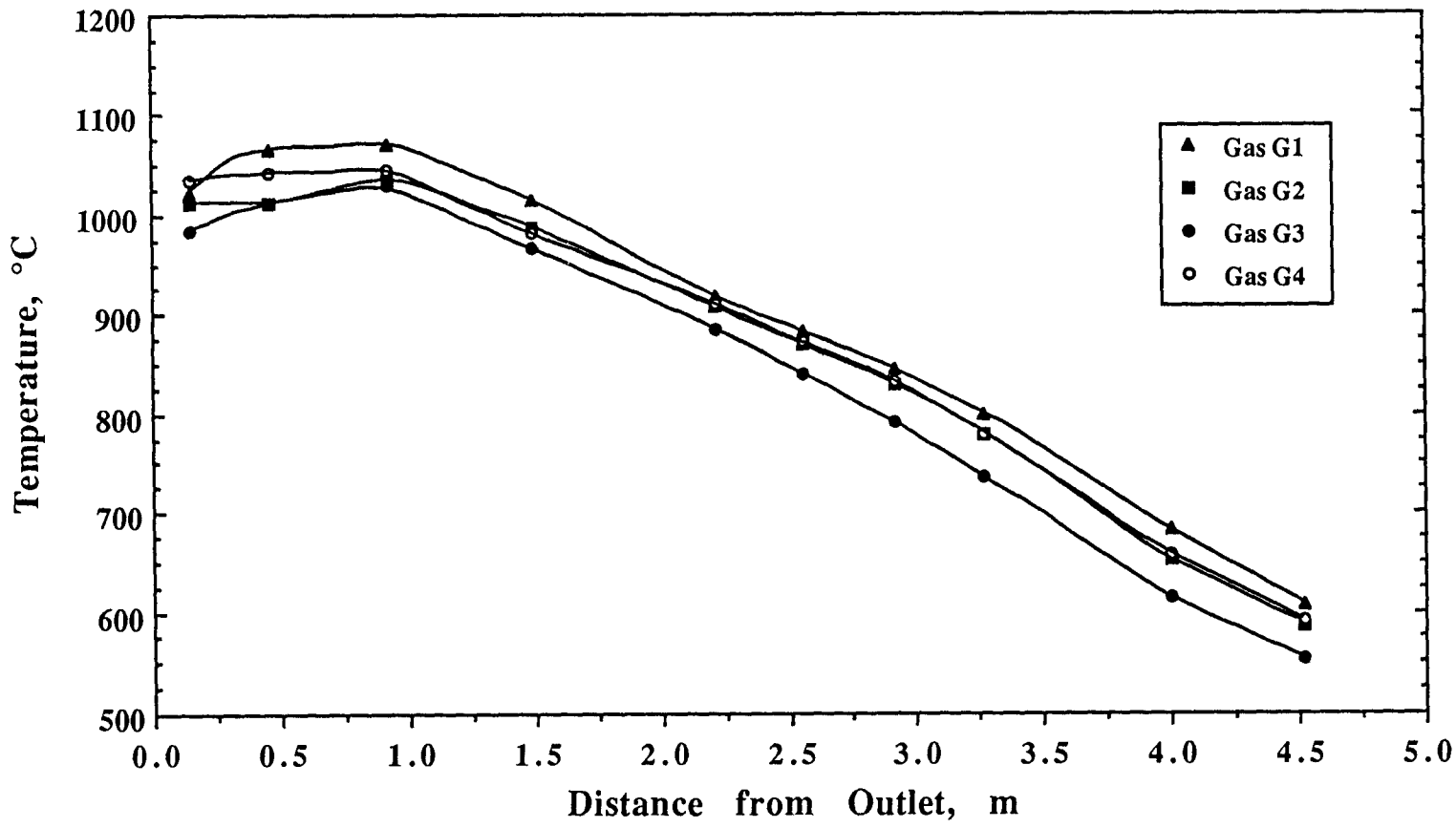


Figure E–7. Axial bed temperature profiles for tests with natural gas

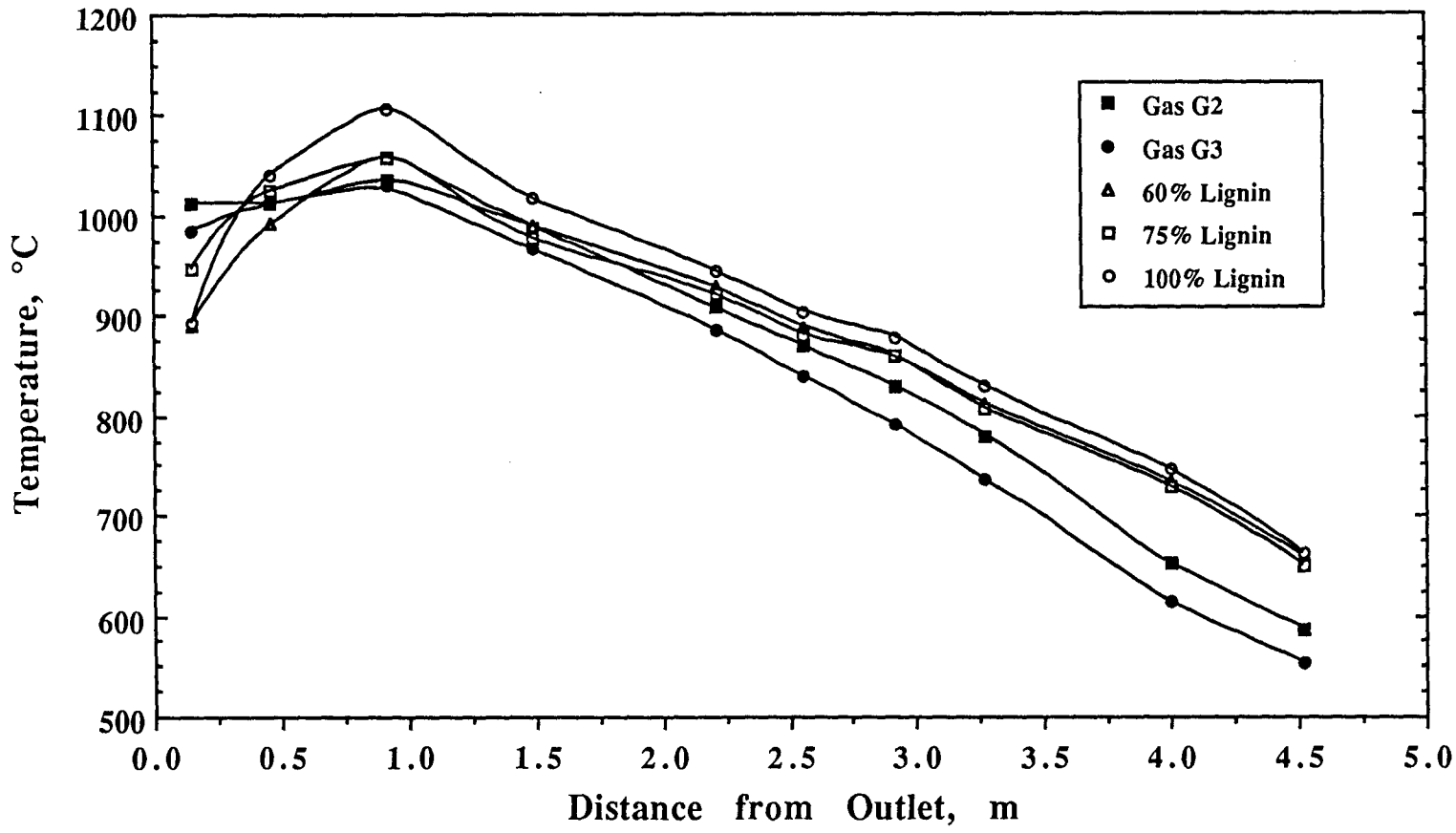


Figure E–8. Axial bed temperature profiles for tests with lignin IR

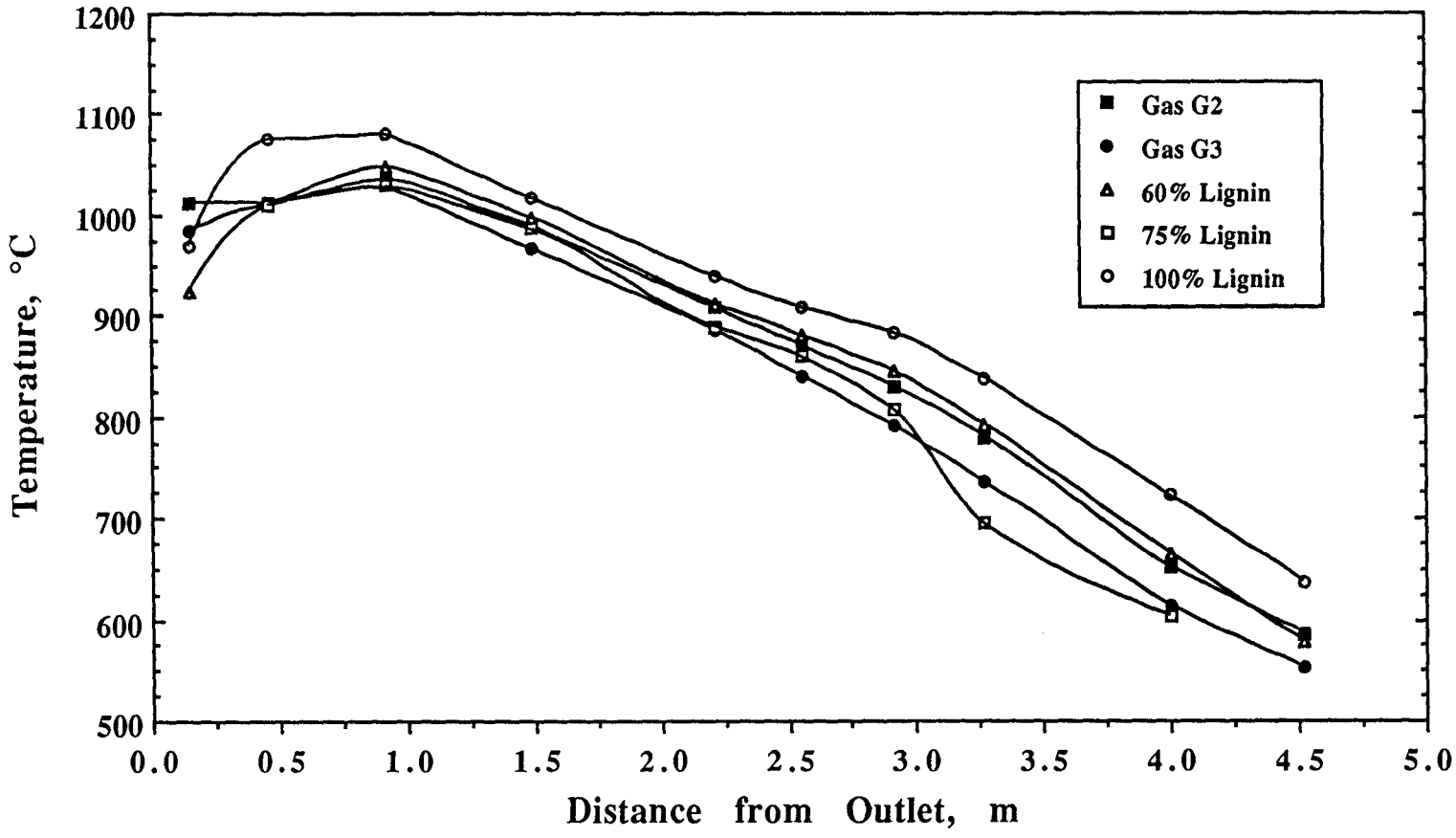


Figure E–9. Axial bed temperature profiles for tests with lignin PG

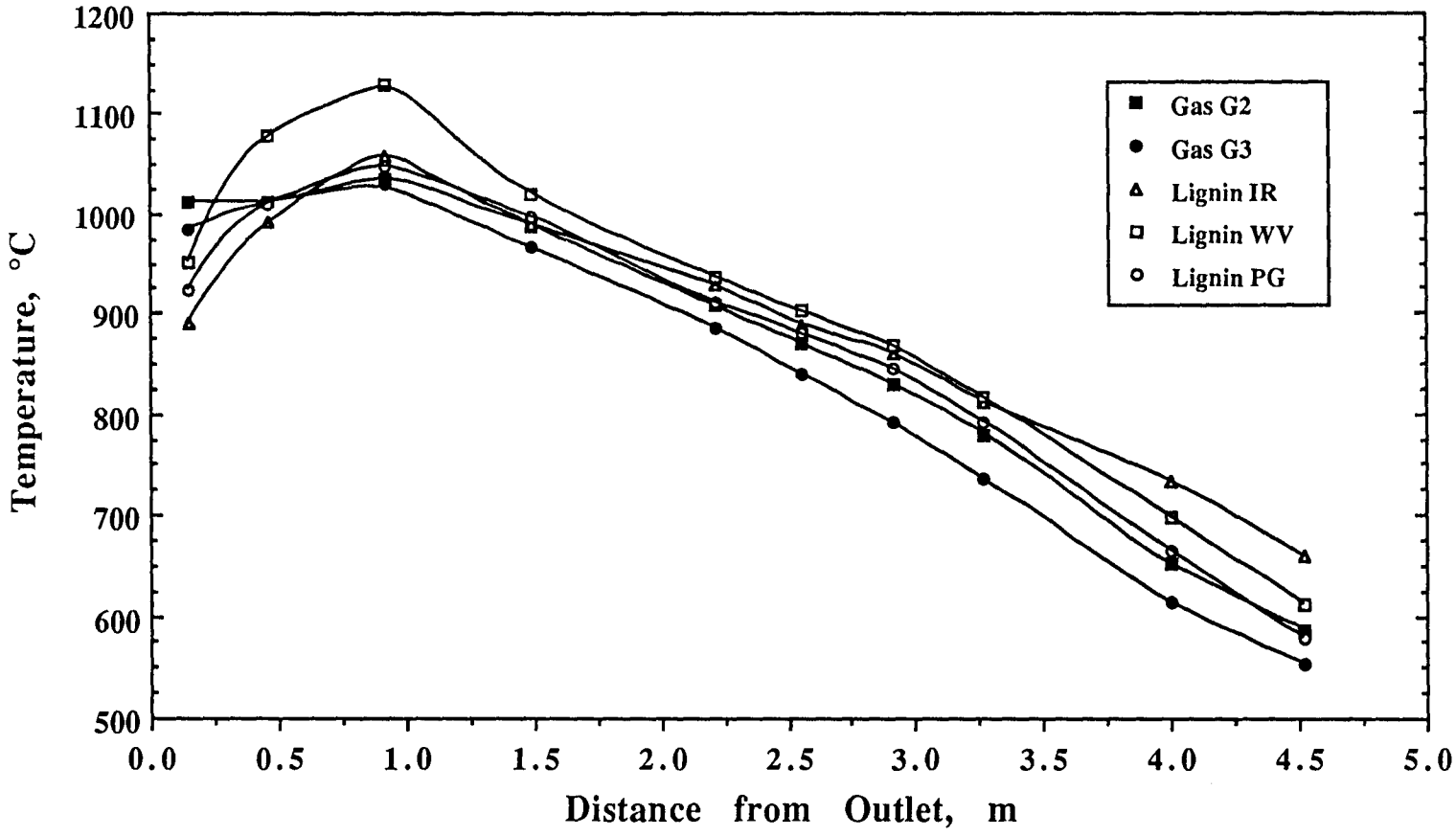


Figure E–10. Axial bed temperature profiles for tests with natural gas firing versus 60% lignin burning

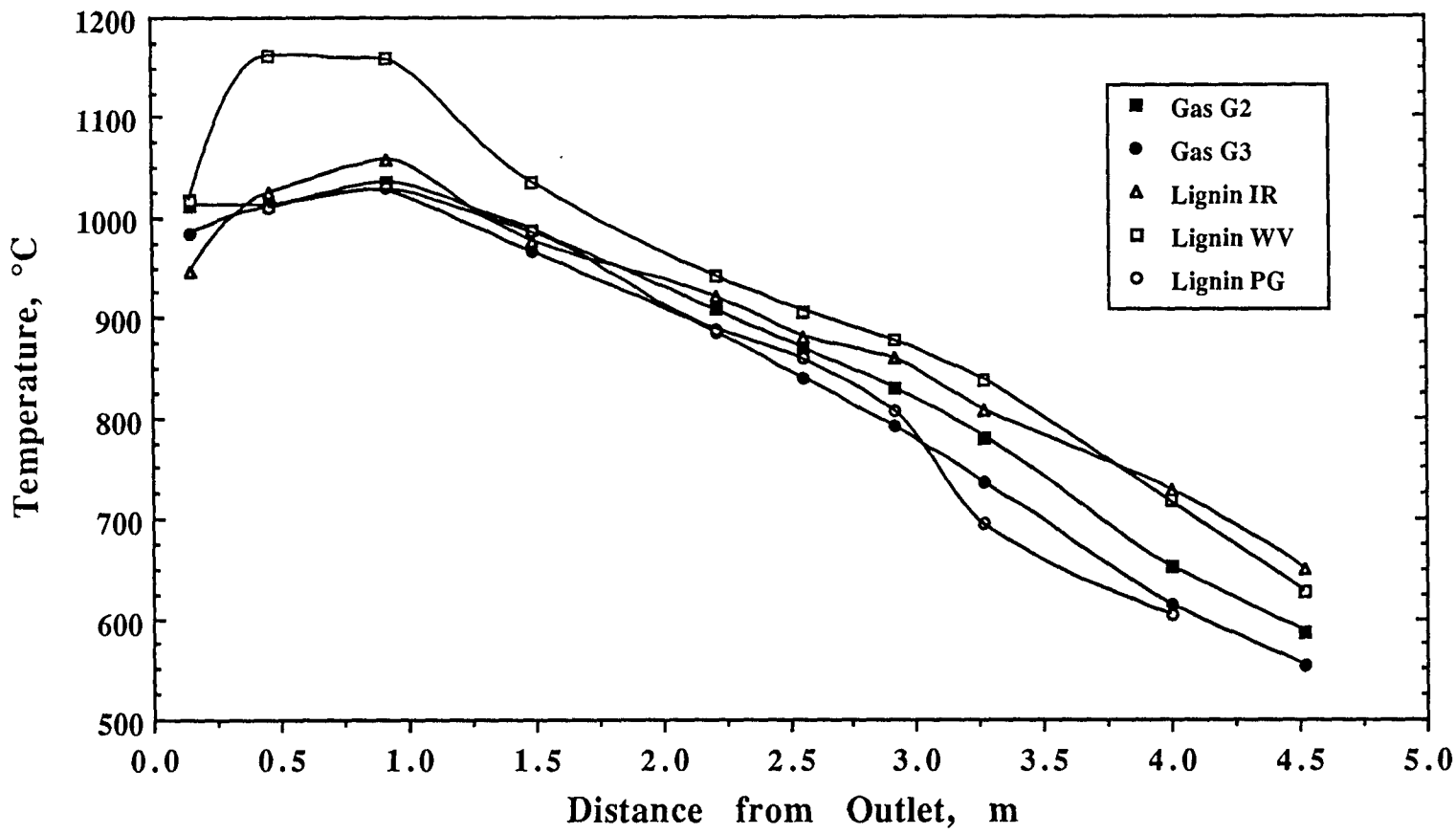


Figure E–11. Axial bed temperature profiles for tests with natural gas firing versus 75% lignin burning

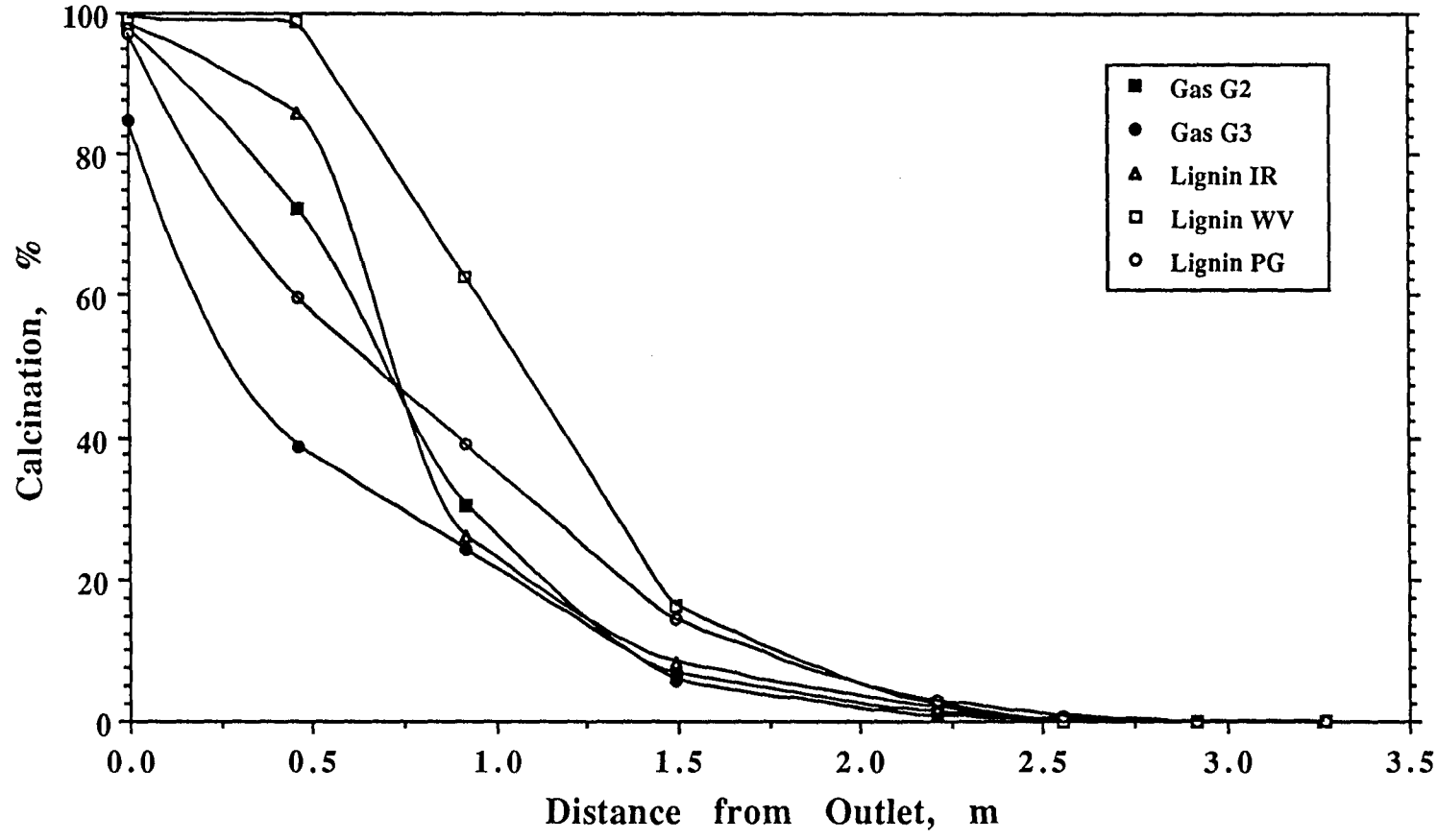


Figure E–12. Axial calcination profiles for tests with natural gas firing versus 60% lignin burning

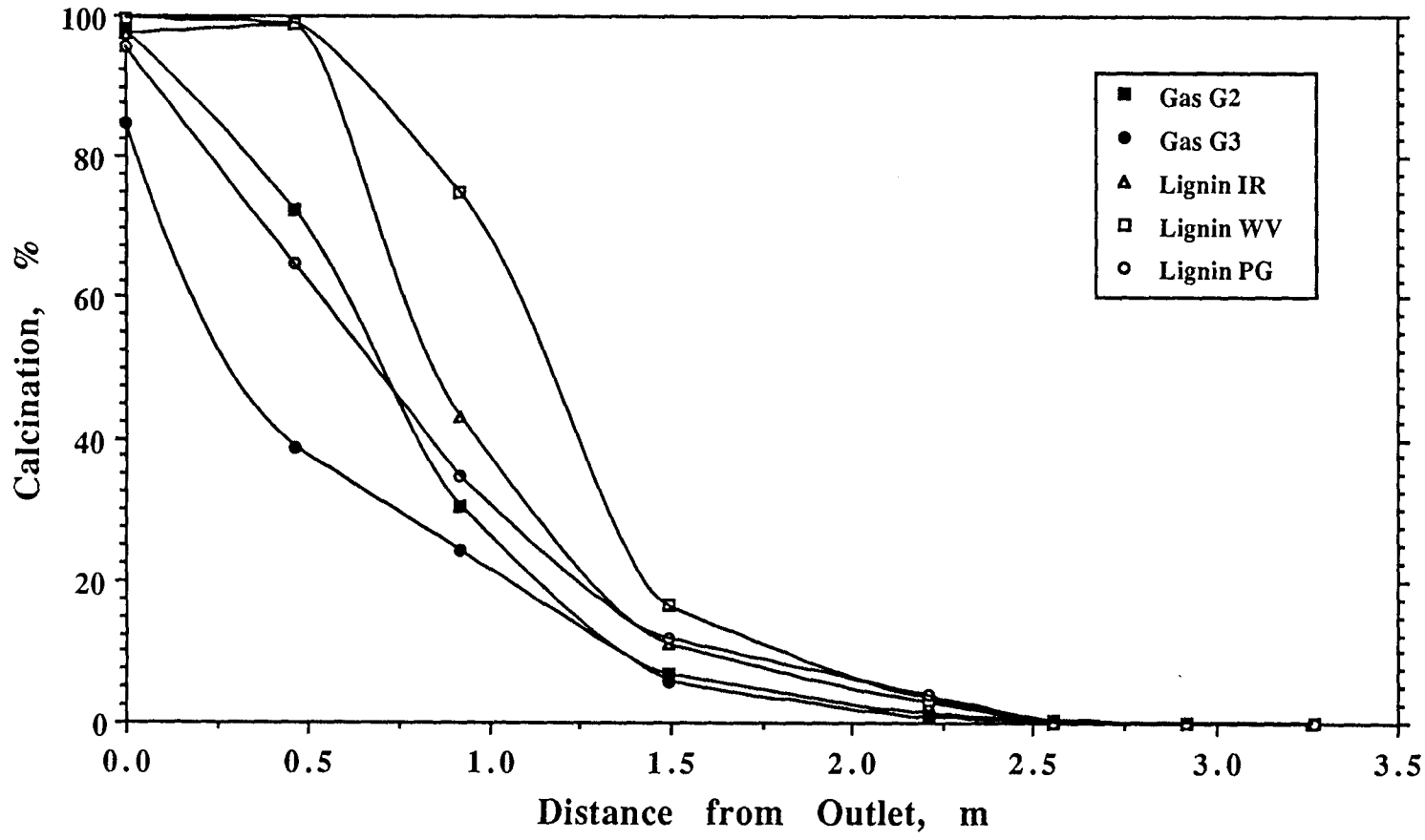


Figure E–13. Axial calcination profiles for tests with natural gas firing versus 75% lignin burning

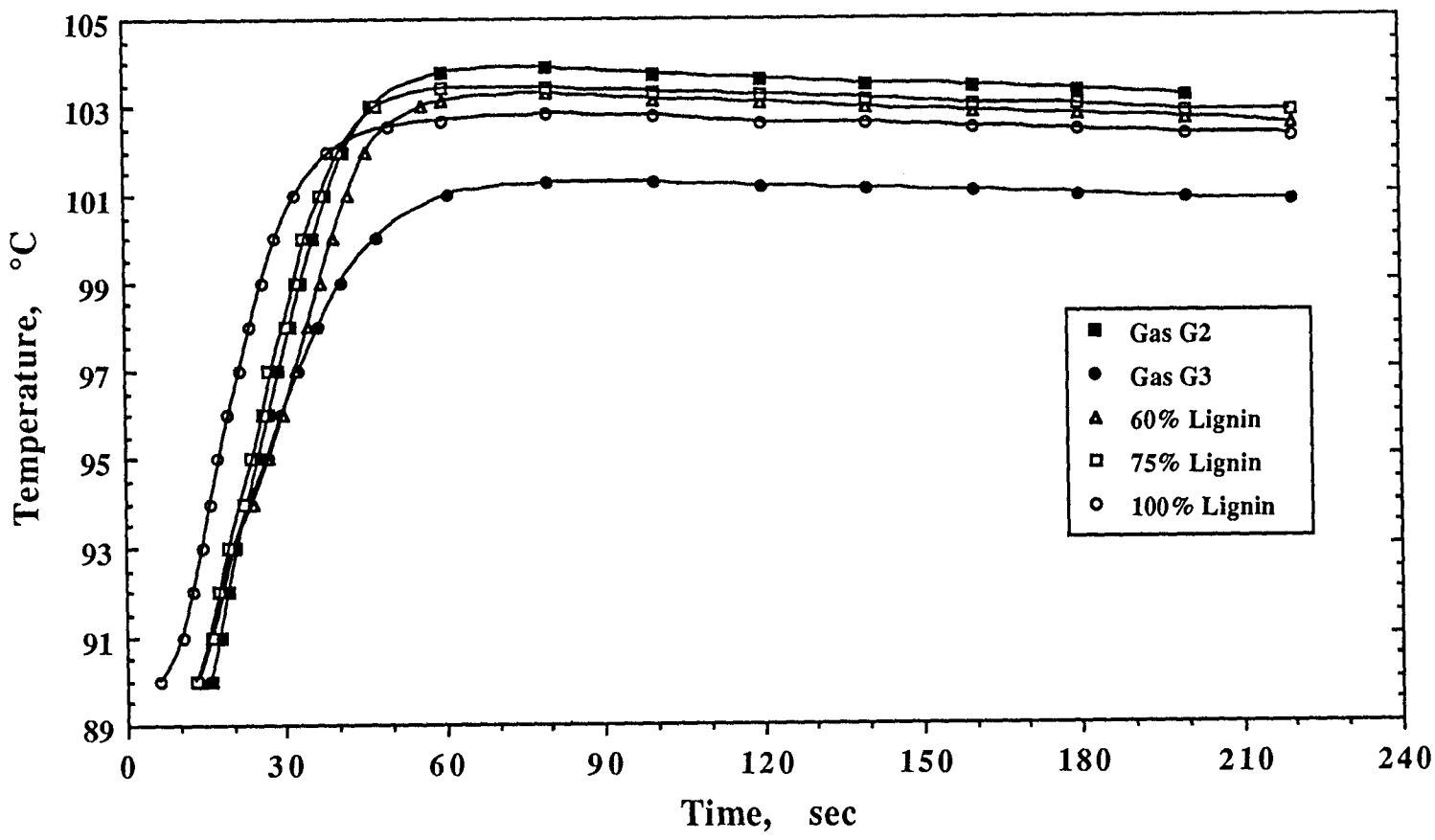


Figure E–14. Slaking temperature rise curves for tests with lignin IR

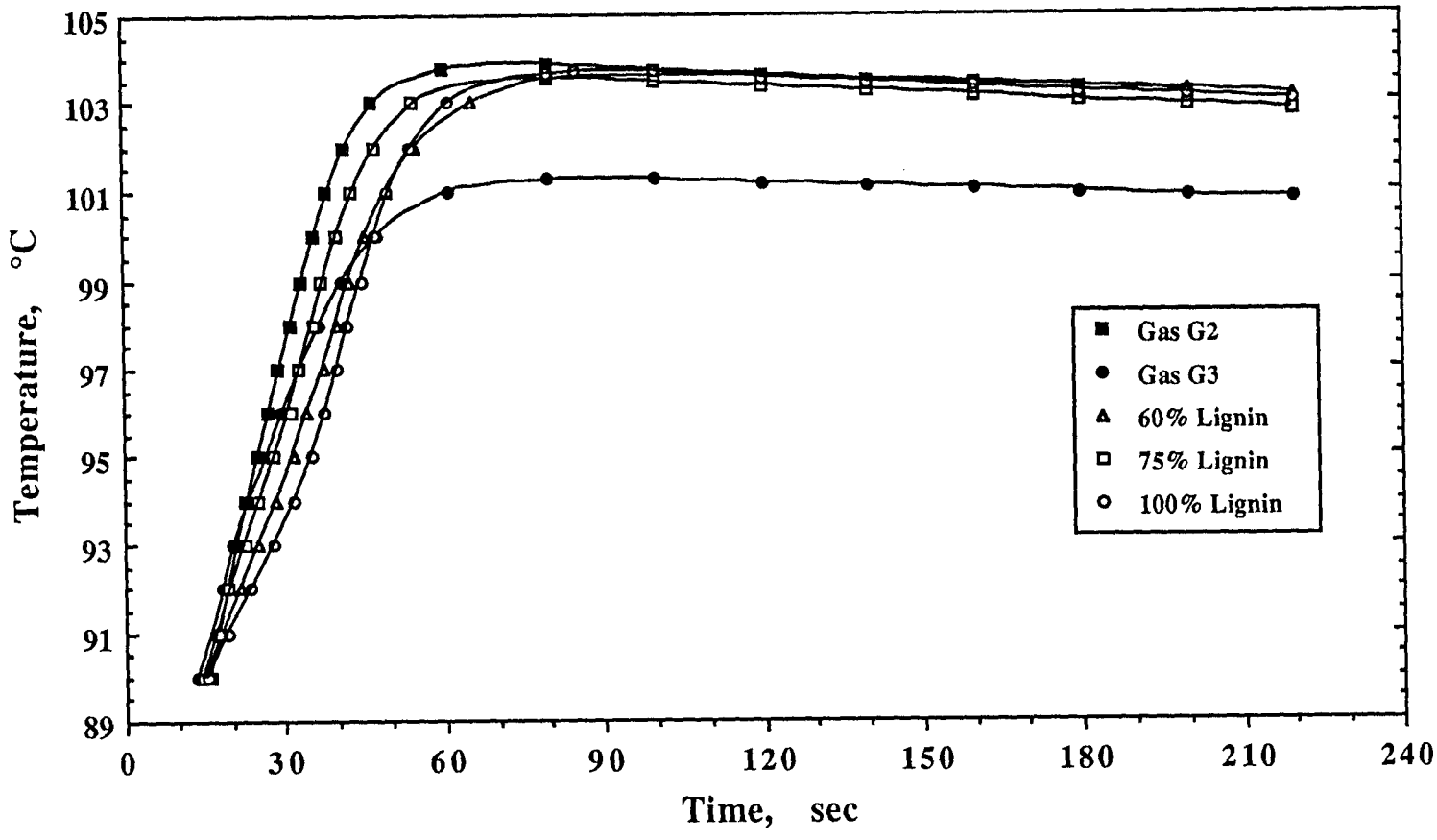


Figure E–15. Slaking temperature rise curves for tests with lignin PG

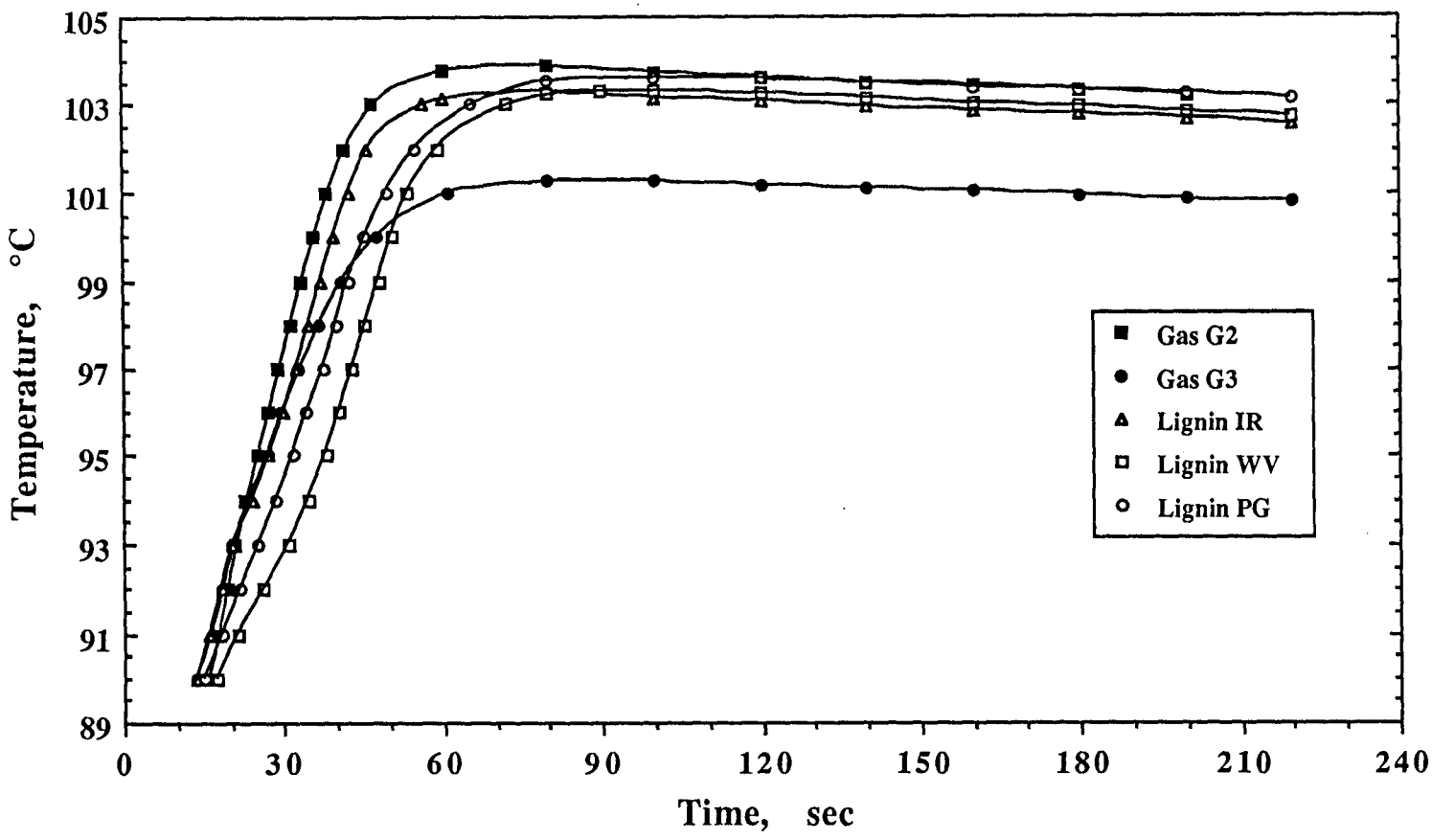


Figure E–16. Slaking temperature rise curves for tests with natural gas firing versus 60% lignin burning

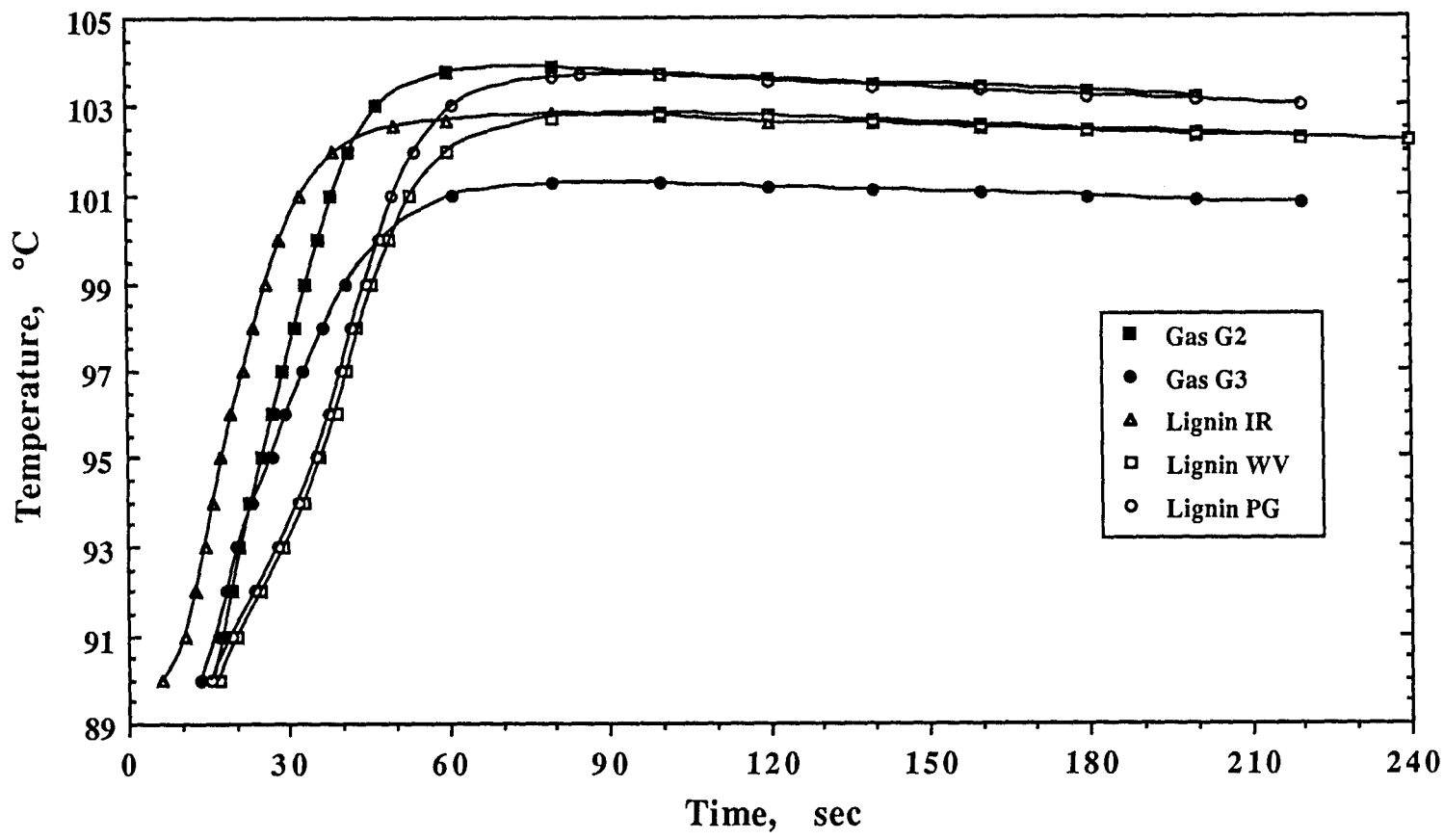


Figure E–17. Slaking temperature rise curves for tests with natural gas firing versus 100% lignin burning

Appendix F

Elemental Balances for Experimental Runs

Elemental Balance for LG9

Limestone =	39.3	kg/Hr	655.0	g/min	**Lignin =**	145	g/min			**Total Input**				
Ca =	38.4	%	251.5	g/min						Ca =	251.5	g/min	38.07	%
S =	Assumed to be ZERO				S =	3.2	%	4.64	g/min	S =	4.64	g/min	0.70	%
SO_4 =	Assumed to be ZERO				SO_4 =	1.21	%	1.75	g/min	SO_4 =	1.75	g/min	0.27	%
org S =	Assumed to be ZERO				org S =	1.99	%	2.89	g/min	org S =	2.89	g/min	0.44	%
Si =	1.01	%	6.6	g/min	Si =	Assumed to be ZERO				Si =	6.62	g/min	1.00	%
Na =	282	mg/kg	184.7	mg/min	Na =	0.51	%	0.74	g/min	Na =	0.92	g/min	0.14	%
Fe =	643	mg/kg	421.2	mg/min	Fe =	0.13	%	0.19	g/min	Fe =	0.61	g/min	0.09	%
Al =	830	mg/kg	543.7	mg/min	Al =	130	mg/kg	18.9	mg/min	Al =	562.5	mg/min	851.5	mg/kg
Mg =	2730	mg/kg	1788.2	mg/min	Mg =	132	mg/kg	19.1	mg/min	Mg =	1807.3	mg/min	2735.7	mg/kg
Mn =	57.1	mg/kg	37.4	mg/min	Mn =	182	mg/kg	26.4	mg/min	Mn =	63.8	mg/min	96.6	mg/kg

Lime =	22.5	kg/Hr	375.0	g/min
Ca =	57.4	%	215.3	g/min
S =	0.2	%	0.75	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	0.82	%	3.08	g/min
Na =	316	mg/kg	118.5	mg/min
Fe =	950	mg/kg	356.3	mg/min
Al =	770	mg/kg	288.8	mg/min
Mg =	2980	mg/kg	1117.5	mg/min
Mn =	74.6	mg/kg	28.0	mg/min

Dust		
Ca =	23.3	%
S =	2.2	%
SO_4 =	N/A	
org S =	N/A	
Si =	1.7	%
Na =	2.88	%
Fe =	20.99	%
Al =	3125	mg/kg
Mg =	3225	mg/kg
Mn =	2431	mg/kg

Amount Required for Balance			
36.27	g/min	36.21	%
3.89	g/min	3.88	%
3.54	g/min	3.53	%
0.81	g/min	0.80	%
0.25	g/min	0.25	%
273.8	mg/min	2733.0	mg/kg
689.8	mg/min	6886.6	mg/kg
35.8	mg/min	357.6	mg/kg

Element / Input	%
Ca =	85.58
S =	16.16
SO_4 =	N/A
org S =	N/A
Si =	46.48
Na =	12.82
Fe =	58.43
Al =	51.33
Mg =	61.83
Mn =	43.85

Elemental Balance for LG10A

Limestone =	39.3	kg/Hr	655.0	g/min	**Lignin =**	180	g/min			**Total Input**				
Ca =	38.4	%	251.5	g/min						Ca =	251.5	g/min	37.99	%
S =	Assumed to be ZERO				S =	3.23	%	5.8	g/min	S =	5.81	g/min	0.88	%
SO_4 =	Assumed to be ZERO				SO_4 =	1.31	%	2.36	g/min	SO_4 =	2.36	g/min	0.36	%
org S =	Assumed to be ZERO				org S =	1.92	%	3.46	g/min	org S =	3.46	g/min	0.52	%
Si =	1.01	%	6.6	g/min	Si =	Assumed to be ZERO				Si =	6.62	g/min	1.00	%
Na =	282	mg/kg	184.7	mg/min	Na =	0.5	%	0.9	g/min	Na =	1.08	g/min	0.16	%
Fe =	643	mg/kg	421.2	mg/min	Fe =	0.15	%	0.3	g/min	Fe =	0.69	g/min	0.10	%
Al =	830	mg/kg	543.7	mg/min	Al =	130	mg/kg	23.4	mg/min	Al =	567.1	mg/min	856.5	mg/kg
Mg =	2730	mg/kg	1788.2	mg/min	Mg =	121	mg/kg	21.8	mg/min	Mg =	1809.9	mg/min	2733.8	mg/kg
Mn =	57.1	mg/kg	37.4	mg/min	Mn =	172	mg/kg	31.0	mg/min	Mn =	68.4	mg/min	103.3	mg/kg

Lime =	22.5	kg/Hr	375.0	g/min
Ca =	54.7	%	205.1	g/min
S =	0.2	%	0.8	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	0.78	%	2.9	g/min
Na =	641	mg/kg	240.4	mg/min
Fe =	1390	mg/kg	521.3	mg/min
Al =	2120	mg/kg	795.0	mg/min
Mg =	2850	mg/kg	1068.8	mg/min
Mn =	82	mg/kg	30.8	mg/min

Dust		
Ca =	20.4	%
S =	1.9	%
SO_4 =	N/A	
org S =	N/A	
Si =	1.47	%
Na =	3.43	%
Fe =	22.22	%
Al =	2449	mg/kg
Mg =	2993	mg/kg
Mn =	2622	mg/kg

Amount Required for Balance			
46.40	g/min	36.67	%
5.06	g/min	4.00	%
3.69	g/min	2.92	%
0.84	g/min	0.67	%
0.17	g/min	0.13	%
-228.0	mg/min	0.0	mg/kg
741.2	mg/min	5857.5	mg/kg
37.6	mg/min	297.2	mg/kg

Element / Input	%
Ca =	81.55
S =	12.90
SO_4 =	N/A
org S =	N/A
Si =	44.21
Na =	22.16
Fe =	75.42
Al =	140.20
Mg =	59.05
Mn =	44.98

Elemental Balance for LG10B

Limestone =	36.0	kg/Hr	600.0	g/min	**Lignin =**	240	g/min			**Total Input**				
Ca =	38.4	%	230.4	g/min						Ca =	230.4	g/min	37.81	%
S =	Assumed to be ZERO				S =	3.23	%	7.8	g/min	S =	7.75	g/min	1.27	%
SO_4 =	Assumed to be ZERO				SO_4 =	1.31	%	3.14	g/min	SO_4 =	3.14	g/min	0.52	%
org S =	Assumed to be ZERO				org S =	1.92	%	4.61	g/min	org S =	4.61	g/min	0.76	%
Si =	1.01	%	6.1	g/min	Si =	Assumed to be ZERO				Si =	6.06	g/min	0.99	%
Na =	282	mg/kg	169.2	mg/min	Na =	0.5	%	1.2	g/min	Na =	1.37	g/min	0.22	%
Fe =	643	mg/kg	385.8	mg/min	Fe =	0.15	%	0.4	g/min	Fe =	0.75	g/min	0.12	%
Al =	830	mg/kg	498.0	mg/min	Al =	130	mg/kg	31.2	mg/min	Al =	529.2	mg/min	868.4	mg/kg
Mg =	2730	mg/kg	1638.0	mg/min	Mg =	121	mg/kg	29.0	mg/min	Mg =	1667.0	mg/min	2735.5	mg/kg
Mn =	57.1	mg/kg	34.3	mg/min	Mn =	172	mg/kg	41.3	mg/min	Mn =	75.5	mg/min	124.0	mg/kg

Lime =	20.7	kg/Hr	345.0	g/min
Ca =	58.3	%	201.1	g/min
S =	0.23	%	0.8	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	0.91	%	3.1	g/min
Na =	319	mg/kg	110.1	mg/min
Fe =	1360	mg/kg	469.2	mg/min
Al =	1030	mg/kg	355.4	mg/min
Mg =	2740	mg/kg	945.3	mg/min
Mn =	83.8	mg/kg	28.9	mg/min

Dust		
Ca =	20.4	%
S =	1.9	%
SO_4 =	N/A	
org S =	N/A	
Si =	1.47	%
Na =	3.43	%
Fe =	22.22	%
Al =	2449	mg/kg
Mg =	2993	mg/kg
Mn =	2622	mg/kg

Amount Required for Balance			
29.27	g/min	34.22	%
6.96	g/min	8.14	%
2.92	g/min	3.42	%
1.26	g/min	1.47	%
0.28	g/min	0.32	%
173.9	mg/min	2032.9	mg/kg
721.7	mg/min	8439.5	mg/kg
46.6	mg/min	545.2	mg/kg

Element / Input	%
Ca =	87.30
S =	10.24
SO_4 =	N/A
org S =	N/A
Si =	51.81
Na =	8.04
Fe =	62.91
Al =	67.15
Mg =	56.71
Mn =	38.27

Elemental Balance for LG11

Limestone =	36.6	kg/Hr	610.0	g/min	**Lignin =**	218	g/min			**Total Input**				
Ca =	38.4	%	234.2	g/min						Ca =	234.2	g/min	38.06	%
S =	Assumed to be ZERO				S =	1.34	%	2.92	g/min	S =	2.92	g/min	0.47	%
SO_4 =	Assumed to be ZERO				SO_4 =	0.59	%	1.29	g/min	SO_4 =	1.29	g/min	0.21	%
org S =	Assumed to be ZERO				org S =	0.75	%	1.64	g/min	org S =	1.64	g/min	0.27	%
Si =	1.01	%	6.2	g/min	Si =	Assumed to be ZERO				Si =	6.16	g/min	1.00	%
Na =	282	mg/kg	172.0	mg/min	Na =	1.08	%	2.35	g/min	Na =	2.53	g/min	0.41	%
Fe =	643	mg/kg	392.2	mg/min	Fe =	0.01	%	0.02	g/min	Fe =	0.41	g/min	0.07	%
Al =	830	mg/kg	506.3	mg/min	Al =	340	mg/kg	74.1	mg/min	Al =	580.4	mg/min	943.1	mg/kg
Mg =	2730	mg/kg	1665.3	mg/min	Mg =	105	mg/kg	22.9	mg/min	Mg =	1688.2	mg/min	2743.2	mg/kg
Mn =	57.1	mg/kg	34.8	mg/min	Mn =	60.3	mg/kg	13.1	mg/min	Mn =	48.0	mg/min	78.0	mg/kg

Lime =	21.0	kg/Hr	350.0	g/min
Ca =	56.5	%	197.8	g/min
S =	0.15	%	0.53	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	1.12	%	3.92	g/min
Na =	365	mg/kg	127.8	mg/min
Fe =	1760	mg/kg	616.0	mg/min
Al =	840	mg/kg	294.0	mg/min
Mg =	2770	mg/kg	969.5	mg/min
Mn =	76.8	mg/kg	26.9	mg/min

Dust		
Ca =	28.40	%
S =	1.50	%
SO_4 =	N/A	
org S =	N/A	
Si =	3.53	%
Na =	0.47	%
Fe =	0.60	%
Al =	7616	mg/kg
Mg =	3441	mg/kg
Mn =	204	mg/kg

Amount Required for Balance			
36.49	g/min	36.75	%
2.40	g/min	2.41	%
2.24	g/min	2.26	%
2.40	g/min	2.42	%
-0.20	g/min	0.00	%
286.4	mg/min	2884.8	mg/kg
718.7	mg/min	7238.5	mg/kg
21.1	mg/min	212.5	mg/kg

Element /	Input %
Ca =	84.42
S =	17.97
SO_4 =	N/A
org S =	N/A
Si =	63.63
Na =	5.06
Fe =	148.78
Al =	50.65
Mg =	57.43
Mn =	56.03

Elemental Balance for LG12A

Limestone =	35.3	kg/Hr	588.3	g/min	**Lignin =**	131	g/min			**Total Input**				
Ca =	38.4	%	225.9	g/min						Ca =	225.9	g/min	38.17	%
S =	Assumed to be ZERO				S =	1.6	%	2.1	g/min	S =	2.10	g/min	0.35	%
SO_4 =	Assumed to be ZERO				SO_4 =	0.66	%	0.86	g/min	SO_4 =	0.86	g/min	0.15	%
org S =	Assumed to be ZERO				org S =	0.94	%	1.23	g/min	org S =	1.23	g/min	0.21	%
Si =	1.01	%	5.9	g/min	Si =	Assumed to be ZERO				Si =	5.94	g/min	1.00	%
Na =	282	mg/kg	165.9	mg/min	Na =	1.08	%	1.4	g/min	Na =	1.58	g/min	0.27	%
Fe =	643	mg/kg	378.3	mg/min	Fe =	0.01	%	0.0	g/min	Fe =	0.39	g/min	0.07	%
Al =	830	mg/kg	488.3	mg/min	Al =	320	mg/kg	41.9	mg/min	Al =	530.2	mg/min	895.8	mg/kg
Mg =	2730	mg/kg	1606.2	mg/min	Mg =	106	mg/kg	13.9	mg/min	Mg =	1620.0	mg/min	2736.9	mg/kg
Mn =	57.1	mg/kg	33.6	mg/min	Mn =	61	mg/kg	8.0	mg/min	Mn =	41.6	mg/min	70.3	mg/kg

Lime =	20.2	kg/Hr	336.7	g/min
Ca =	59.2	%	199.3	g/min
S =	0.17	%	0.6	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	0.98	%	3.3	g/min
Na =	483	mg/kg	162.6	mg/min
Fe =	740	mg/kg	249.1	mg/min
Al =	780	mg/kg	262.6	mg/min
Mg =	2740	mg/kg	922.5	mg/min
Mn =	76.7	mg/kg	25.8	mg/min

Dust		
Ca =	39.7	%
S =	1.4	%
SO_4 =	N/A	
org S =	N/A	
Si =	3.45	%
Na =	2.3	%
Fe =	0.38	%
Al =	10570	mg/kg
Mg =	6602	mg/kg
Mn =	1814	mg/kg

Amount Required for Balance			
26.61	g/min	36.34	%
1.52	g/min	2.08	%
2.64	g/min	3.61	%
1.42	g/min	1.94	%
0.14	g/min	0.19	%
267.6	mg/min	3654.2	mg/kg
697.6	mg/min	9524.3	mg/kg
15.8	mg/min	215.2	mg/kg

Element /	Input %
Ca =	88.22
S =	27.31
SO_4 =	N/A
org S =	N/A
Si =	55.52
Na =	10.29
Fe =	63.65
Al =	49.53
Mg =	56.94
Mn =	62.10

Elemental Balance for LG12B

Limestone =	35.4	kg/Hr	590.0	g/min	**Lignin =**	163	g/min			**Total Input**				
Ca =	38.4	%	226.6	g/min						Ca =	226.6	g/min	38.11	%
S =	Assumed to be ZERO				S =	1.6	%	2.6	g/min	S =	2.61	g/min	0.44	%
SO_4 =	Assumed to be ZERO				SO_4 =	0.66	%	1.08	g/min	SO_4 =	1.08	g/min	0.18	%
org S =	Assumed to be ZERO				org S =	0.94	%	1.53	g/min	org S =	1.53	g/min	0.26	%
Si =	1.01	%	6.0	g/min	Si =	Assumed to be ZERO				Si =	5.96	g/min	1.00	%
Na =	282	mg/kg	166.4	mg/min	Na =	1.08	%	1.8	g/min	Na =	1.93	g/min	0.32	%
Fe =	643	mg/kg	379.4	mg/min	Fe =	0.01	%	0.0	g/min	Fe =	0.40	g/min	0.07	%
Al =	830	mg/kg	489.7	mg/min	Al =	320	mg/kg	52.2	mg/min	Al =	541.9	mg/min	911.5	mg/kg
Mg =	2730	mg/kg	1610.7	mg/min	Mg =	106	mg/kg	17.3	mg/min	Mg =	1628.0	mg/min	2738.6	mg/kg
Mn =	57.1	mg/kg	33.7	mg/min	Mn =	61	mg/kg	9.9	mg/min	Mn =	43.6	mg/min	73.4	mg/kg

Lime =	20.2	kg/Hr	336.7	g/min
Ca =	58.3	%	196.3	g/min
S =	0.23	%	0.8	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	0.91	%	3.1	g/min
Na =	319	mg/kg	107.4	mg/min
Fe =	1360	mg/kg	457.9	mg/min
Al =	1030	mg/kg	346.8	mg/min
Mg =	2740	mg/kg	922.5	mg/min
Mn =	83.8	mg/kg	28.2	mg/min

Dust		
Ca =	39.7	%
S =	1.4	%
SO_4 =	N/A	
org S =	N/A	
Si =	3.45	%
Na =	2.3	%
Fe =	0.38	%
Al =	10570	mg/kg
Mg =	6602	mg/kg
Mn =	1814	mg/kg

Amount Required for Balance			
30.28	g/min	36.41	%
1.83	g/min	2.20	%
2.90	g/min	3.48	%
1.82	g/min	2.19	%
-0.06	g/min	0.00	%
195.1	mg/min	2345.6	mg/kg
705.5	mg/min	8482.5	mg/kg
15.4	mg/min	185.4	mg/kg

Element / Input	%
Ca =	86.63
S =	29.69
SO_4 =	N/A
org S =	N/A
Si =	51.41
Na =	5.57
Fe =	115.72
Al =	64.00
Mg =	56.66
Mn =	64.66

Elemental Balance for LG13

Limestone =	33.2	kg/Hr	553.3	g/min	**Lignin =**	0	g/min			**Total Input**				
Ca =	38.4	%	212.5	g/min						Ca =	212.5	g/min	38.40	%
S =	Assumed to be ZERO				S =	3.2	%	0.00	g/min	S =	0.00	g/min	0.00	%
SO4 =	Assumed to be ZERO				SO4 =	0.05	%	0.00	g/min	SO4 =	0.00	g/min	0.00	%
org S =	Assumed to be ZERO				org S =	3.15	%	0.00	g/min	org S =	0.00	g/min	0.00	%
Si =	1.01	%	5.6	g/min	Si =	Assumed to be ZERO				Si =	5.59	g/min	1.01	%
Na =	282	mg/kg	156.0	mg/min	Na =	0.51	%	0.00	g/min	Na =	0.16	g/min	0.03	%
Fe =	643	mg/kg	355.8	mg/min	Fe =	0.13	%	0.00	g/min	Fe =	0.36	g/min	0.06	%
Al =	830	mg/kg	459.3	mg/min	Al =	130	mg/kg	0.0	mg/min	Al =	459.3	mg/min	830.0	mg/kg
Mg =	2730	mg/kg	1510.6	mg/min	Mg =	132	mg/kg	0.0	mg/min	Mg =	1510.6	mg/min	2730.0	mg/kg
Mn =	57.1	mg/kg	31.6	mg/min	Mn =	182	mg/kg	0.0	mg/min	Mn =	31.6	mg/min	57.1	mg/kg

Lime =	18.9	kg/Hr	315.0	g/min
Ca =	58.3	%	183.6	g/min
S =	0.04	%	0.13	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	1.29	%	4.06	g/min
Na =	331	mg/kg	104.3	mg/min
Fe =	960	mg/kg	302.4	mg/min
Al =	1200	mg/kg	378.0	mg/min
Mg =	2920	mg/kg	919.8	mg/min
Mn =	80.3	mg/kg	25.3	mg/min

Dust		
Ca =	N/D	%
S =	N/D	%
SO_4 =	N/A	
org S =	N/A	
Si =	N/D	%
Na =	N/D	%
Fe =	N/D	%
Al =	N/D	mg/kg
Mg =	N/D	mg/kg
Mn =	N/D	mg/kg

Amount Required for Balance			
28.83	g/min	38.76	%
-0.13	g/min	0.00	%
1.53	g/min	2.05	%
0.05	g/min	0.07	%
0.05	g/min	0.07	%
81.3	mg/min	1092.3	mg/kg
590.8	mg/min	7941.3	mg/kg
6.3	mg/min	84.7	mg/kg

Element / Input	%
Ca =	86.43
S =	0.00
SO_4 =	N/A
org S =	N/A
Si =	72.71
Na =	66.82
Fe =	84.99
Al =	82.31
Mg =	60.89
Mn =	80.06

Elemental Balance for LG14

Limestone =	37.3	kg/Hr	621.7	g/min	**Lignin =**	220	g/min			**Total Input**				
Ca =	38.4	%	238.7	g/min						Ca =	238.7	g/min	38.06	%
S =	Assumed to be ZERO				S =	2.29	%	5.04	g/min	S =	5.04	g/min	0.80	%
SO_4 =	Assumed to be ZERO				SO_4 =	0.05	%	0.11	g/min	SO_4 =	0.11	g/min	0.02	%
org S =	Assumed to be ZERO				org S =	2.24	%	4.93	g/min	org S =	4.93	g/min	0.79	%
Si =	1.01	%	6.3	g/min	Si =	Assumed to be ZERO				Si =	6.28	g/min	1.00	%
Na =	282	mg/kg	175.3	mg/min	Na =	0.14	%	0.31	g/min	Na =	0.48	g/min	0.08	%
Fe =	643	mg/kg	399.7	mg/min	Fe =	0.1	%	0.22	g/min	Fe =	0.62	g/min	0.10	%
Al =	830	mg/kg	516.0	mg/min	Al =	150	mg/kg	33.0	mg/min	Al =	549.0	mg/min	875.2	mg/kg
Mg =	2730	mg/kg	1697.2	mg/min	Mg =	29.7	mg/kg	6.5	mg/min	Mg =	1703.7	mg/min	2716.0	mg/kg
Mn =	57.1	mg/kg	35.5	mg/min	Mn =	16.4	mg/kg	3.6	mg/min	Mn =	39.1	mg/min	62.3	mg/kg

Lime =	21.2	kg/Hr	353.3	g/min
Ca =	54.1	%	191.2	g/min
S =	0.15	%	0.53	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	1.17	%	4.13	g/min
Na =	404	mg/kg	142.7	mg/min
Fe =	1200	mg/kg	424.0	mg/min
Al =	1040	mg/kg	367.5	mg/min
Mg =	2650	mg/kg	936.3	mg/min
Mn =	75.8	mg/kg	26.8	mg/min

Dust		
Ca =	37.5	%
S =	2.1	%
SO_4 =	N/A	
org S =	N/A	
Si =	3.29	%
Na =	1.27	%
Fe =	1.7	%
Al =	5105	mg/kg
Mg =	3431	mg/kg
Mn =	464	mg/kg

Amount Required for Balance			
47.57	g/min	37.43	%
4.51	g/min	3.55	%
2.14	g/min	1.69	%
0.34	g/min	0.27	%
0.20	g/min	0.15	%
181.5	mg/min	1428.5	mg/kg
767.4	mg/min	6038.9	mg/kg
12.3	mg/min	97.0	mg/kg

Element /	Input %
Ca =	80.07
S =	10.52
SO_4 =	N/A
org S =	N/A
Si =	65.84
Na =	29.54
Fe =	68.42
Al =	66.94
Mg =	54.96
Mn =	68.49

Elemental Balance for LG15A

Limestone =	40.4	kg/Hr	673.3	g/min	**Lignin =**	0	g/min			**Total Input**				
Ca =	38.4	%	258.6	g/min						Ca =	258.6	g/min	38.40	%
S =	Assumed to be ZERO				S =	3.23	%	0.0	g/min	S =	0.00	g/min	0.00	%
SO_4 =	Assumed to be ZERO				SO_4 =	0.05	%	0.00	g/min	SO_4 =	0.00	g/min	0.00	%
org S =	Assumed to be ZERO				org S =	3.18	%	0.00	g/min	org S =	0.00	g/min	0.00	%
Si =	1.01	%	6.8	g/min	Si =	Assumed to be ZERO				Si =	6.80	g/min	1.01	%
Na =	282	mg/kg	189.9	mg/min	Na =	0.5	%	0.0	g/min	Na =	0.19	g/min	0.03	%
Fe =	643	mg/kg	433.0	mg/min	Fe =	0.15	%	0.0	g/min	Fe =	0.43	g/min	0.06	%
Al =	830	mg/kg	558.9	mg/min	Al =	130	mg/kg	0.0	mg/min	Al =	558.9	mg/min	830.0	mg/kg
Mg =	2730	mg/kg	1838.2	mg/min	Mg =	121	mg/kg	0.0	mg/min	Mg =	1838.2	mg/min	2730.0	mg/kg
Mn =	57.1	mg/kg	38.4	mg/min	Mn =	172	mg/kg	0.0	mg/min	Mn =	38.4	mg/min	57.1	mg/kg

Lime =	24.4	kg/Hr	406.7	g/min
Ca =	59.8	%	243.2	g/min
S =	0.06	%	0.2	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	0.94	%	3.8	g/min
Na =	181	mg/kg	73.6	mg/min
Fe =	750	mg/kg	305.0	mg/min
Al =	860	mg/kg	349.7	mg/min
Mg =	2900	mg/kg	1179.3	mg/min
Mn =	82	mg/kg	33.3	mg/min

Dust		
Ca =	42.5	%
S =	0.44	%
SO_4 =	N/A	
org S =	N/A	
Si =	1.57	%
Na =	0.35	%
Fe =	0.27	%
Al =	2882	mg/kg
Mg =	2662	mg/kg
Mn =	181	mg/kg

Amount Required for Balance			
15.37	g/min	36.15	%
-0.24	g/min	0.00	%
2.98	g/min	7.00	%
0.12	g/min	0.27	%
0.13	g/min	0.30	%
209.1	mg/min	4917.5	mg/kg
658.9	mg/min	15492.3	mg/kg
5.1	mg/min	119.9	mg/kg

Element /	Input %
Ca =	94.05
S =	0.00
SO_4 =	N/A
org S =	N/A
Si =	56.21
Na =	38.76
Fe =	70.45
Al =	62.58
Mg =	64.16
Mn =	86.73

Elemental Balance for LG15B

Limestone =	39.5	kg/Hr	658.3	g/min	**Lignin** =	0	g/min			**Total Input**				
Ca =	38.4	%	252.8	g/min						Ca =	252.8	g/min	38.40	%
S =	Assumed to be ZERO				S =	3.23	%	0.0	g/min	S =	0.00	g/min	0.00	%
SO_4 =	Assumed to be ZERO				SO_4 =	0.05	%	0.00	g/min	SO_4 =	0.00	g/min	0.00	%
org S =	Assumed to be ZERO				org S =	3.18	%	0.00	g/min	org S =	0.00	g/min	0.00	%
Si =	1.01	%	6.6	g/min	Si =	Assumed to be ZERO				Si =	6.65	g/min	1.01	%
Na =	282	mg/kg	185.7	mg/min	Na =	0.5	%	0.0	g/min	Na =	0.19	g/min	0.03	%
Fe =	643	mg/kg	423.3	mg/min	Fe =	0.15	%	0.0	g/min	Fe =	0.42	g/min	0.06	%
Al =	830	mg/kg	546.4	mg/min	Al =	130	mg/kg	0.0	mg/min	Al =	546.4	mg/min	830.0	mg/kg
Mg =	2730	mg/kg	1797.3	mg/min	Mg =	121	mg/kg	0.0	mg/min	Mg =	1797.3	mg/min	2730.0	mg/kg
Mn =	57.1	mg/kg	37.6	mg/min	Mn =	172	mg/kg	0.0	mg/min	Mn =	37.6	mg/min	57.1	mg/kg

Lime =	22.5	kg/Hr	375.0	g/min
Ca =	63.3	%	237.4	g/min
S =	0.04	%	0.2	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	2.05	%	7.7	g/min
Na =	329	mg/kg	123.4	mg/min
Fe =	950	mg/kg	356.3	mg/min
Al =	1270	mg/kg	476.3	mg/min
Mg =	3300	mg/kg	1237.5	mg/min
Mn =	87.6	mg/kg	32.9	mg/min

Dust		
Ca =	42.5	%
S =	0.44	%
SO_4 =	N/A	
org S =	N/A	
Si =	1.57	%
Na =	0.35	%
Fe =	0.27	%
Al =	2882	mg/kg
Mg =	2662	mg/kg
Mn =	181	mg/kg

Amount Required for Balance			
15.43	g/min	39.22	%
-0.15	g/min	0.00	%
-1.04	g/min	0.00	%
0.06	g/min	0.16	%
0.07	g/min	0.17	%
70.2	mg/min	1784.2	mg/kg
559.8	mg/min	14233.4	mg/kg
4.7	mg/min	120.6	mg/kg

Element / Input	%
Ca =	93.90
S =	0.00
SO_4 =	N/A
org S =	N/A
Si =	115.62
Na =	66.46
Fe =	84.16
Al =	87.16
Mg =	68.86
Mn =	87.39

Elemental Balance for LG16

Limestone =	41.7	kg/Hr	695.0	g/min	**Lignin =**	165	g/min			**Total Input**				
Ca =	38.4	%	266.9	g/min						Ca =	266.9	g/min	38.13	%
S =	Assumed to be ZERO				S =	2.32	%	3.83	g/min	S =	3.83	g/min	0.55	%
SO_4 =	Assumed to be ZERO				SO_4 =	0.17	%	0.28	g/min	SO_4 =	0.28	g/min	0.04	%
org S =	Assumed to be ZERO				org S =	2.15	%	3.55	g/min	org S =	3.55	g/min	0.51	%
Si =	1.01	%	7.0	g/min	Si =	Assumed to be ZERO				Si =	7.02	g/min	1.00	%
Na =	282	mg/kg	196.0	mg/min	Na =	0.42	%	0.69	g/min	Na =	0.89	g/min	0.13	%
Fe =	643	mg/kg	446.9	mg/min	Fe =	0.19	%	0.31	g/min	Fe =	0.76	g/min	0.11	%
Al =	830	mg/kg	576.9	mg/min	Al =	160	mg/kg	26.4	mg/min	Al =	603.3	mg/min	861.9	mg/kg
Mg =	2730	mg/kg	1897.4	mg/min	Mg =	35.3	mg/kg	5.8	mg/min	Mg =	1903.2	mg/min	2719.3	mg/kg
Mn =	57.1	mg/kg	39.7	mg/min	Mn =	20.6	mg/kg	3.4	mg/min	Mn =	43.1	mg/min	61.6	mg/kg

Lime =	24.0	kg/Hr	400.0	g/min
Ca =	63.6	%	254.4	g/min
S =	0.22	%	0.88	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	1.23	%	4.92	g/min
Na =	220	mg/kg	88.0	mg/min
Fe =	1030	mg/kg	412.0	mg/min
Al =	500	mg/kg	200.0	mg/min
Mg =	2850	mg/kg	1140.0	mg/min
Mn =	79.3	mg/kg	31.7	mg/min

Dust		
Ca =	44.6	%
S =	0.37	%
SO_4 =	N/A	
org S =	N/A	
Si =	1.91	%
Na =	0.62	%
Fe =	1.16	%
Al =	2950	mg/kg
Mg =	2807	mg/kg
Mn =	216	mg/kg

Amount Required for Balance			
12.48	g/min	32.35	%
2.95	g/min	7.64	%
2.10	g/min	5.44	%
0.80	g/min	2.08	%
0.35	g/min	0.90	%
403.3	mg/min	10453.8	mg/kg
763.2	mg/min	19784.3	mg/kg
11.4	mg/min	294.6	mg/kg

Element / Input	%
Ca =	95.32
S =	22.99
SO_4 =	N/A
org S =	N/A
Si =	70.09
Na =	9.90
Fe =	54.18
Al =	33.15
Mg =	59.90
Mn =	73.62

Elemental Balance for LG17

Limestone =	42.0	kg/Hr	700.0	g/min	**Lignin =**	132	g/min			**Total Input**				
Ca =	38.4	%	268.8	g/min						Ca =	268.8	g/min	38.16	%
S =	Assumed to be ZERO				S =	2.34	%	3.09	g/min	S =	3.09	g/min	0.44	%
SO_4 =	Assumed to be ZERO				SO_4 =	0.21	%	0.28	g/min	SO_4 =	0.28	g/min	0.04	%
org S =	Assumed to be ZERO				org S =	2.13	%	2.81	g/min	org S =	2.81	g/min	0.40	%
Si =	1.01	%	7.1	g/min	Si =	Assumed to be ZERO				Si =	7.07	g/min	1.00	%
Na =	282	mg/kg	197.4	mg/min	Na =	0.71	%	0.94	g/min	Na =	1.13	g/min	0.16	%
Fe =	643	mg/kg	450.1	mg/min	Fe =	0.2	%	0.26	g/min	Fe =	0.71	g/min	0.10	%
Al =	830	mg/kg	581.0	mg/min	Al =	190	mg/kg	25.1	mg/min	Al =	606.1	mg/min	860.5	mg/kg
Mg =	2730	mg/kg	1911.0	mg/min	Mg =	42.7	mg/kg	5.6	mg/min	Mg =	1916.6	mg/min	2721.2	mg/kg
Mn =	57.1	mg/kg	40.0	mg/min	Mn =	26.3	mg/kg	3.5	mg/min	Mn =	43.4	mg/min	61.7	mg/kg

Lime =	24.0	kg/Hr	400.0	g/min
Ca =	64.6	%	258.4	g/min
S =	0.18	%	0.72	g/min
SO_4 =	N/A			
org S =	N/A			
Si =	0.8	%	3.20	g/min
Na =	338	mg/kg	135.2	mg/min
Fe =	750	mg/kg	300.0	mg/min
Al =	640	mg/kg	256.0	mg/min
Mg =	2880	mg/kg	1152.0	mg/min
Mn =	82.8	mg/kg	33.1	mg/min

Dust		
Ca =	38.3	%
S =	0.74	%
SO_4 =	N/A	
org S =	N/A	
Si =	2.89	%
Na =	1.79	%
Fe =	3.83	%
Al =	3350	mg/kg
Mg =	2725	mg/kg
Mn =	334	mg/kg

Amount Required for Balance			
10.40	g/min	29.90	%
2.37	g/min	6.81	%
3.87	g/min	11.13	%
1.00	g/min	2.87	%
0.41	g/min	1.19	%
350.1	mg/min	10066.3	mg/kg
764.6	mg/min	21986.6	mg/kg
10.3	mg/min	296.8	mg/kg

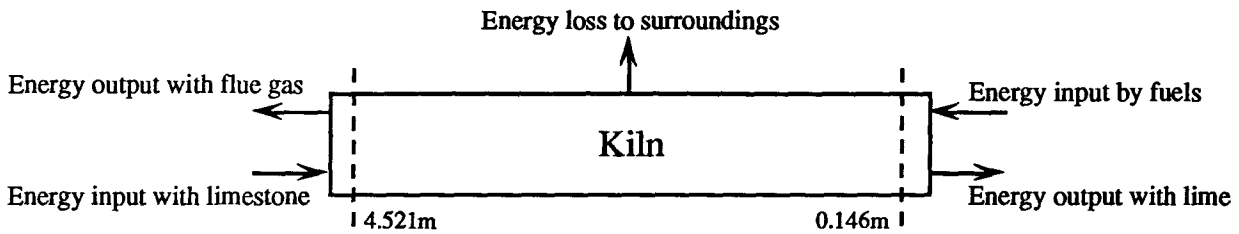
Element / Input	%
Ca =	96.13
S =	23.31
SO_4 =	N/A
org S =	N/A
Si =	45.26
Na =	11.92
Fe =	42.01
Al =	42.24
Mg =	60.11
Mn =	76.24

Appendix G

Simple Energy Balances for Experimental Runs

An Example Calculation

Simple Energy Balance about the Kiln for Run LG10A



Energy flow diagram

Energy Lost = Energy Input - Energy Output - Energy consumed by Calcination

Energy Input = Energy supplied by Fuels + Energy in with Limestone Fed

Energy Output = Energy out with Lime and Flue Gas

Assumptions

Reference temperature is 25°C.

The measurement devices for combustion air and natural gas are calibrated for 20°C.

The boundary at the cold end is at 4.521 m from the discharge end.

The boundary at the hot end for the lime is at 0.146 m from the discharge end.

The inerts are assumed to have a molecular weight of 159.7 kg/kmol.

The heat of vapourization of water is 0.044 MJ/mol @ 25°C.

The sulphur dioxide formed reacts with the lime and no SO_2 leaves in the flue gas.

Heat capacity equations were obtained from *Metallurgical Thermochemistry*, by O. Kubaschewski and C.B. Alcock, 5th Ed., Oxford, New York, Pergamon Press, 1979.

Limestone

Limestone feed rate = 39.4 kg/hr

Purity of limestone = 97.95%

Temperature of limestone = 923.5 K at 4.521 m from discharge end.

Energy entering with limestone

ΔH of $CaCO_3 = M_s \int C_p \, dT$

$= M_s * (104.59 * (T - T_{ref}) + 0.0219 * (T^2 - T_{ref}^2) - 2.6*10^6 / (T - T_{ref}) / 6*10^6$

$= 39.4 * 0.9795 * (104.59 * (923.5 - 298.2) + 0.0219 * (923.5^2 - 298.2^2) - 2.6*10^6 / (923.5 - 298.2) / 6*10^6$

= 0.502 MJ/min

ΔH of Inerts $= M_s \int C_p \, dT$

$= M_s * (106.68 * (T - T_{ref}) + 0.0178 * (T^2 - T_{ref}^2) - 2.855*10^6 / (T - T_{ref}) / 159.7 / 6*10^4$

$= 39.4 * (1 - 0.9795) * (106.68 * (923.5 - 298.2) + 0.0178 * (923.5^2 - 298.2^2) - 2.855*10^6 / (923.5 - 298.2) / 159.7 / 6*10^4$

= 0.006 MJ/min

Total = 0.502 + 0.006 = **0.508** MJ/min

Final Calcination = 98.34%

Inerts in 40 kg of limestone = 0.82 kg

Lime Output = 0.82 +(39.4 -0.82) / ((1 -0.9795) +0.9834 / 56) = 22.5 kg/hr

Temperature of Lime at Output = 1219.6 K at 0.146 m from discharge end.

Heat of Calcination = 3.2215 MJ/kg of CaO

Energy Required for Calcination = Limestone feedrate * %Purity * %Calcination * Heat of calcination

= 39.4 * 0.9795 * 0.9834 * 3.2215 * 56 / 6000 = 1.141 MJ/min

Energy Leaving with Lime

ΔH of $CaCO_3 = M_s \int C_p \, dT$

$= M_s * (104.59 * (T - T_{ref}) + 0.0219 * (T^2 - T_{ref}^2) - 2.6*10^6 / (T - T_{ref}) / 6*10^6$

$= 22.5 * 0.9795 * (1 - 0.9834) * (104.59 * (1219.6 - 298.2) + 0.0219 * (1219.6^2 - 298.2^2) - 2.6*10^6 / (1219.6 - 298.2) / 6*10^6$

= 0.008 MJ/min

ΔH of CaO = $M_s \int C_p \, dT$

$= M_s * (49.66 * (T - T_{ref}) + 0.00452 * (T^2 - T_{ref}^2) - 6.95*10^6 / (T - T_{ref}) / 6*10^8$

$= 22.5 * 0.9795 * 0.9834 * (49.66 * (1219.6 - 298.2) + 0.00452 * (1219.6^2 - 298.2^2) - 6.95*10^6 / (1219.6 - 298.2) / 6*10^8$

= 0.288 MJ/min

ΔH of Inerts = $M_s \int C_p \, dT$

$= M_s * (106.68 * (T - T_{ref}) + 0.0178 * (T^2 - T_{ref}^2) - 2.855*10^6 / (T - T_{ref}) / 159.7 / 6*10^4$

$= 39.4 * (1 - 0.9795) * (106.68 * (1219.6 - 298.2) + 0.0178 * (1219.6^2 - 298.2^2) - 2.855*10^6 / (1219.6 - 298.2) / 159.7 / 6*10^4$

= 0.010 MJ/min

Total = 0.008 + 0.288 + 0.010 = **0.305** MJ/min

Combustion Air

Temperature of Air = 293.2 K

Excess Oxygen = 4.2%

mols of air = Air flowrate * Conversion {CFM to M^3} / Gas constant / Temperature

Lance =	9.8 CFM	= 9.8 * 28.32 / (0.08206 *293.2) =	11.5 mols/min
Primary =	48.0 CFM	= 52.0 * 28.32 / (0.08206 *293.2) =	56.5 mols/min
Secondary =	5.0 CFM	= 5.0 * 28.32 / (0.08206 *293.2) =	5.9 mols/min

Total = 11.5 + 56.5 + 5.9 = 73.9 mols/min

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	59.69
Hydrogen	24.50	5.29
Oxygen	0.00	26.17
Nitrogen	1.21	0.05
Sulphur	0.00	1.92

Fuel Supplied to the Kiln

Natural Gas = 39.6 L/min

mols of Natural Gas = 39.6 / (0.08206 * 293.2) = 1.65 mols/min

Higher Heating Value = 0.03728 MJ/L

Heat of Vapourization = 44.013 MJ/kmol

Net Energy = Gas flowrate * Heating value - Heat of vapourization

= 39.6 * 0.03728 - 2 * 1.65 * 0.044 = 1.331 MJ/min

Lignin = 0.180 kg/min

Moisture = 5.19 %

Calorific Heating Value = 0.02442 MJ/kg

Net Energy = Lignin feedrate * ((100 -%Moisture) * Heating value - (%Moisture / Mw of water + (100 - %Moisture) * %Hydrogen / Mw of H_2) * Heat of vapourization)

= 0.180 * ((1 -0.0519) * 0.02442 -(0.0519 / 18.02 +(1 -0.0519) * 0.0529 / 2.016) * 44.013)

= 3.948 MJ/min

Energy Supplied by Fuels = 1.331 + 3.948 = **5.279** MJ/min

Calculation by Supplied Air

mols of Flue Gas & Composition

CO_2 = mols of natural gas + Dry lignin feedrate * %Carbon + Limestone feedrate * %Purity * %Calcination

= 1.65 +0.180 * (1 -0.0519) * 0.5969 / 12.01 +39.4 * 0.9795 * 0.9834 * 1000 / 60 / 100

= 16.453 mols/min

H_2O = 2 * mols of natural gas + mols of H in dry lignin + mols of water from wet lignin

= 2 * 1.65 +0.180 * ((1 -0.0519) * 0.0529 / 2.016 +0.0519 / 18.02) * 1000

= 8.289 mols/min

N_2 = mols of N_2 in combustion air + mols of N_2 from natural gas + mols of N_2 from dry lignin

= 0.79 * 73.9 +1.65 * 0.0121 +0.180 * (1 -0.0519) * 0.0005 / 28.02 * 1000

= 58.429 mols/min

SO_2 = mols of S from dry lignin

= 0.180 * (1 -0.0519) * 0.0192 / 32.06 * 1000

= 0.102 mols/min

O_2 = mols of O_2 in combustion air - 2 * mols of natural gas - Dry lignin feedrate * (mols of CO_2 + H_2O - O_2 + SO_2)

= 0.21 * 73.9 -2 * 1.65 -0.180 * (1 -0.0519) * (0.5969 / 12.01 +0.0529 / 4.032 -0.2617 / 32 +0.0192 / 32.06) * 1000

= 2.806 mols/min

Total = 16.453 + 58.429 + 2.806 = 77.688 mols/min

% CO_2 = 16.453 / 77.688 * 100 = 21.18%

% N_2 = 58.429 / 77.688 * 100 = 75.21%

% O_2 = 2.806 / 77.688 * 100 = 3.61%

Enthalpy of Flue Gas

Temperature of limestone = 973.2 K at 4.521 m from discharge end.

ΔH of CO_2 = $M_g \int C_p \, dT$

$= M_g * (19.936 * (T_g - T_{ref}) + 7.667*10^{-2} * (T_g^2 - T_{ref}^2) /2 - 6.91*10^{-5} * (T_g^3 - T_{ref}^3) /3 + 2.9961*10^{-8} * (T_g^4 - T_{ref}^4) /4) /10^6$

$= 16.453 * (19.936 * (973.2 - 298.2) + 7.667*10^{-2} * (973.2^2 - 298.2^2) /2 - 6.91*10^{-5} * (973.2^3 - 298.2^3) /3 + 2.9961*10^{-8} * (973.2^4 - 298.2^4) /4) /10^6$

= 0.533 MJ/min

ΔH of H_2O = $M_g \int C_p \, dT$

$= M_g * (30.245 * (T_g - T_{ref}) + 1.0604*10^{-2} * (T_g^2 - T_{ref}^2) /2) /10^6$

$= 8.289 * (30.245 * (973.2 - 298.2) + 1.0604*10^{-2} * (973.2^2 - 298.2^2) /2) /10^6$

= 0.207 MJ/min

ΔH of $N_2 = M_g \int C_p \, dT$

$= M_g * (27.88 * (T_g - T_{ref}) + 4.271*10^{-3} * (T_g^2 - T_{ref}^2) /2) /10^6$

$= 58.429 * (27.88 * (973.2 - 298.2) + 4.271*10^{-3} * (973.2^2 - 298.2^2) /2) /10^6$

$= 1.207$ MJ/min

ΔH of $O_2 = M_g \int C_p \, dT$

$= M_g * (26.615 * (T_g - T_{ref}) + 1.0878*10^{-2} * (T_g^2 - T_{ref}^2) /2 - 4.2461*10^{-6} * (T_g^3 - T_{ref}^3) /3 + 8.5186*10^{-10} * (T_g^4 - T_{ref}^4) /4) /10^6$

$= 2.806 * (26.615 * (973.2 - 298.2) + 1.0878*10^{-2} * (973.2^2 - 298.2^2) /2 - 4.2461*10^{-6} * (973.2^3 - 298.2^3) /3 + 8.5186*10^{-10} * (973.2^4 - 298.2^4) /4) /10^6$

$= 0.060$ MJ/min

Total = 0.533 + 0.207 + 1.207 + 0.060 = **2.007** MJ/min

Energy Balance

Energy In

Limestone =	0.508	MJ/min
Combustion Air =	0.000	MJ/min
Fuels =	5.279	MJ/min
Total =	**5.787**	MJ/min

Energy Out

Lime =	0.305	MJ/min
Flue Gas =	2.007	MJ/min
Calcination =	1.141	MJ/min
Total =	**3.454**	MJ/min

Energy Loss

Imput - Output =	**2.333**	MJ/min

Calculation by Excess Air, GC Analyses

$CO_2 = 44.01 * (1.65 + 0.180 * (1 - 0.0519) * 0.5969 / 12.01)$

$= 445.73$ g/min

H_2O = 18.02 * (2 * 1.65 +0.180 * (1 -0.0519) * 0.0529 / 2.016)
= 140.02 g/min

O_2 = 32.00 * (1.65 * 0.00 +0.180 * (1 -0.0519) * 0.2617 / 32)
= 44.66 g/min

N_2 = 28.02 * (1.65 * 0.0121 +0.180 * (1 -0.0519) * 0.0005 / 28.02)
= 0.6434 g/min

Amount of O_2 and N_2 required for Stochiometric Combustion

O_2 = (mols of CO_2 + mols of H_2O) * Mw of O_2 - O_2 supplied by fuel
= (445.73 / 44.01 +0.5 * 140.02 / 18.02) * 32.00 -44.66
= 403.76 g/min

N_2 = 403.76 * 28.02 / 32 * 79 / 21 + 0.6434 = 1330.63 g/min

Amount of Oxygen and Nitrogen at Excess Air

mols of gas other than O_2 = mols of CO_2 + mols of CO_2 from limestone + mols of N_2
= 445.73 / 44.01 +39.4 * 0.9795 * 0.9834 / 600 +1330.63 / 28.02
= 63.94 mols/min

O_2 = 100 /4.2 -79 / 21 -1 = 19.05 mols/min

O_2 = 63.94 * 32 / 19.05 = 107.42 g/min

N_2 = 1330.63 +107.42 * 28.02 / 32 * 79 / 21 = 1684.48 g/min

mols of Flue Gas & Composition

CO_2 = 445.73 / 44.01 +39.4 * 0.9795 * 0.9834 8 1000 / 60 / 100 = 16.453 mols/min

H_2O = 2 * 1.65 +0.180 * ((1 -0.0519) * 0.0529 / 2.016 + 0.0519 / 18.02) * 1000 = 8.289 mols/min

N_2 = 1543.17 / 28.02 = 60.117 mols/min

SO_2 = 0.180 * (1 -0.0519) * 0.0192 / 32.06 = 0.102 mols/min

O_2 = 100.35 / 32 = 3.357 mols/min

Total = 16.453 + 60.117 + 3.357 = 79.927 mols/min

% CO_2 = 16.453 / 79.927 * 100 = 20.59%

% N_2 = 60.117 / 79.927 * 100 = 75.21%

% O_2 = 3.357 / 79.927 * 100 = 4.20%

Enthalpy of Flue Gas

ΔH of $CO_2 = M_g \int C_p \, dT$

$= M_g * (19.936 * (T_g - T_{ref}) + 7.667*10^{-2} * (T_g^2 - T_{ref}^2) /2 - 6.91*10^{-5} * (T_g^3 - T_{ref}^3) /3 + 2.9961*10^{-8} * (T_g^4 - T_{ref}^4) /4) /10^6$

$= 16.453 * (19.936 * (973.2 - 298.2) + 7.667*10^{-2} * (973.2^2 - 298.2^2) /2 - 6.91*10^{-5} * (973.2^3 - 298.2^3) /3 + 2.9961*10^{-8} * (973.2^4 - 298.2^4) /4) /10^6$

= 0.533 MJ/min

ΔH of $H_2O = M_g \int C_p \, dT$

$= M_g * (30.245 * (T_g - T_{ref}) + 1.0604*10^{-2} * (T_g^2 - T_{ref}^2) /2) /10^6$

$= 8.289 * (30.245 * (973.2 - 298.2) + 1.0604*10^{-2} * (973.2^2 - 298.2^2) /2) /10^6$

= 0.207 MJ/min

ΔH of $N_2 = M_g \int C_p \, dT$

$= M_g * (27.88 * (T_g - T_{ref}) + 4.271*10^{-3} * (T_g^2 - T_{ref}^2) /2) /10^6$

$= 60.117 * (27.88 * (973.2 - 298.2) + 4.271*10^{-3} * (973.2^2 - 298.2^2) /2) /10^6$

= 1.242 MJ/min

ΔH of $O_2 = M_g \int C_p \, dT$

$= M_g * (26.615 * (T_g - T_{ref}) + 1.0878*10^{-2} * (T_g^2 - T_{ref}^2) /2 - 4.2461*10^{-6} * (T_g^3 - T_{ref}^3) /3 + 8.5186*10^{-10} * (T_g^4 - T_{ref}^4) /4) /10^6$

$= 3.357 * (26.615 * (973.2 - 298.2) + 1.0878*10^{-2} * (973.2^2 - 298.2^2) /2 - 4.2461*10^{-6} * (973.2^3 - 298.2^3) /3 + 8.5186*10^{-10} * (973.2^4 - 298.2^4) /4) /10^6$

$= 0.072$ MJ/min

Total = 0.533 + 0.207 + 1.242 + 0.072 = **2.054** MJ/min

Energy Balance

Energy In

Limestone =	0.508	MJ/min
Combustion Air =	0.000	MJ/min
Fuels =	5.279	MJ/min
Total =	**5.787**	MJ/min

Energy Out

Lime =	0.305	MJ/min
Flue Gas =	2.054	MJ/min
Calcination =	1.141	MJ/min
Total =	**3.500**	MJ/min

Energy Loss

Imput - Output =	**2.287**	MJ/min

Energy Balance for LG9

Limestone

Limestone Feed Rate =	39.3	kg/Hr
Purity of Limestone =	97.95	%
Temperature of Limestone =	931.3	K
Energy Entering with Limestone		
$CaCO_3$ =	0.508	MJ/min
Inerts =	0.006	MJ/min
Total =	**0.514**	MJ/min
Calcination =	98.75	%
Lime Output =	22.4	kg/Hr
Temperature of Lime =	1145.0	K
Energy Required for Calcination =	1.143	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.005	MJ/min
CaO =	0.254	MJ/min
Inerts =	0.009	MJ/min
Total =	**0.268**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	9.8	CFM	11.5	mols/min
Primary =	52.0	CFM	61.2	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	66.8	CFM	78.6	mols/min
Flue Gas Temperature at Exit =			980.0*	K
Measured Excess Oxygen =			5.1	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	59.72
Hydrogen	24.50	5.35
Oxygen	0.00	26.10
Nitrogen	1.21	0.11
Sulphur	0.00	1.21
Total	100.00	92.49

Fuel Supplied to the Kiln

Natural Gas =	62.3	L/min
mols of Natural Gas =	2.59	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	2.095	MJ/min
Lignin =	145.0	g/min
Moisture =	6.83	%
Calorific Heating Value =	26.06	MJ/kg
Net Energy =	3.339	MJ/min
Energy Supplied by Fuels =	**5.433**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	Dry %	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	15.643	19.15	0.0328	0.513
H_2O	9.314		0.0252	0.235
N_2	62.163	76.10	0.0209	1.297
SO_2	0.051		0.0334	
O_2	3.876	4.74	0.0218	0.084
Total	81.682			**2.130**

ENERGY BALANCE

ENERGY IN

Limestone =	0.514	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.433	MJ/min
Total =	**5.948**	MJ/min

ENERGY OUT

Lime =	0.268	MJ/min
Flue Gas =	2.130	MJ/min
Calcination =	1.143	MJ/min
Total =	**3.541**	MJ/min

ENERGY LOSS

Input - Output =	**2.407**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	Dry %	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	15.643	18.79	0.0328	0.513
H_2O	9.314		0.0252	0.235
N_2	63.364	76.11	0.0209	1.322
SO_2	0.051		0.0334	
O_2	4.246	5.10	0.0218	0.093
Total	83.253			**2.163**

ENERGY BALANCE

ENERGY IN

Limestone =	0.514	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.433	MJ/min
Total =	**5.948**	MJ/min

ENERGY OUT

Lime =	0.268	MJ/min
Flue Gas =	2.163	MJ/min
Calcination =	1.143	MJ/min
Total =	**3.574**	MJ/min

ENERGY LOSS

Input - Output =	**2.374**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1431.0	K
Flue Gas Temperature at Exit =	980.0*	K
Flue Gas Velocity at Tmax =	1.518	m/sec
Flue Gas Velocity at Exit =	1.039	m/sec
Avg Flue Gas Velocity =	1.279	m/sec

* an estimated value

Energy Balance for LG10A

Limestone

Limestone Feed Rate =	39.4	kg/Hr
Purity of Limestone =	97.95	%
Temperature of Limestone =	923.5	K
Energy Entering with Limestone		
$CaCO_3$ =	0.502	MJ/min
Inerts =	0.006	MJ/min
Total =	**0.508**	MJ/min
Calcination =	98.34	%
Lime Output =	22.5	kg/Hr
Temperature of Lime =	1219.6	K
Energy Required for Calcination =	1.141	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.008	MJ/min
CaO =	0.288	MJ/min
Inerts =	0.010	MJ/min
Total =	**0.305**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	9.8	CFM	11.5	mols/min
Primary =	48.0	CFM	56.5	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	62.8	CFM	73.9	mols/min
Flue Gas Temperature at Exit =			973.2	K
Measured Excess Oxygen =			4.2	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	59.69
Hydrogen	24.50	5.29
Oxygen	0.00	26.17
Nitrogen	1.21	0.05
Sulphur	0.00	1.92
Total	100.00	93.12

Fuel Supplied to the Kiln

Natural Gas =	39.6	L/min
mols of Natural Gas =	1.65	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	1.331	MJ/min
Lignin =	180.0	g/min
Moisture =	5.19	%
Calorific Heating Value =	24.42	MJ/kg
Net Energy =	3.948	MJ/min
Energy Supplied by Fuels =	**5.279**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	16.453	21.18	0.0324	0.533
H_2O	8.289		0.0250	0.207
N_2	58.429	75.21	0.0207	1.207
SO_2	0.102		0.0330	
O_2	2.806	3.61	0.0216	0.060
Total	77.688			**2.007**

ENERGY BALANCE

ENERGY IN

Limestone =	0.508	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.279	MJ/min
Total =	**5.787**	MJ/min

ENERGY OUT

Lime =	0.305	MJ/min
Flue Gas =	2.007	MJ/min
Calcination =	1.141	MJ/min
Total =	**3.454**	MJ/min

ENERGY LOSS

Input - Output =	**2.333**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	16.453	20.59	0.0324	0.533
H_2O	8.289		0.0250	0.207
N_2	60.117	75.21	0.0207	1.242
SO_2	0.102		0.0330	
O_2	3.357	4.20	0.0216	0.072
Total	79.927			**2.054**

ENERGY BALANCE

ENERGY IN		
Limestone =	0.508	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.279	MJ/min
Total =	**5.787**	MJ/min
ENERGY OUT		
Lime =	0.305	MJ/min
Flue Gas =	2.054	MJ/min
Calcination =	1.141	MJ/min
Total =	**3.500**	MJ/min
ENERGY LOSS		
Input - Output =	**2.287**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1423.9	K
Flue Gas Temperature at Exit =	973.2	K
Flue Gas Velocity at Tmax =	1.439	m/sec
Flue Gas Velocity at Exit =	0.984	m/sec
Avg Flue Gas Velocity =	1.211	m/sec

Energy Balance for LG10B

Limestone

Limestone Feed Rate =	36.1	kg/Hr
Purity of Limestone =	97.95	%
Temperature of Limestone =	934.9	K
Energy Entering with Limestone		
$CaCO_3$ =	0.470	MJ/min
Inerts =	0.006	MJ/min
Total =	**0.476**	MJ/min
Calcination =	99.37	%
Lime Output =	20.5	kg/Hr
Temperature of Lime =	1167.4	K
Energy Required for Calcination =	1.056	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.002	MJ/min
CaO =	0.243	MJ/min
Inerts =	0.009	MJ/min
Total =	**0.254**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	9.8	CFM	11.5	mols/min
Primary =	46.0	CFM	54.2	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	60.8	CFM	71.6	mols/min
Flue Gas Temperature at Exit =			1013.6	K
Measured Excess Oxygen =			4.0	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	59.69
Hydrogen	24.50	5.29
Oxygen	0.00	26.17
Nitrogen	1.21	0.09
Sulphur	0.00	1.92
Total	100.00	93.16

Fuel Supplied to the Kiln

Natural Gas =	0.0	L/min
mols of Natural Gas =	0.00	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	0.000	MJ/min
Lignin =	240.0	g/min
Moisture =	5.19	%
Calorific Heating Value =	24.42	MJ/kg
Net Energy =	5.263	MJ/min
Energy Supplied by Fuels =	**5.263**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	17.165	22.53	0.0347	0.596
H_2O	6.662		0.0266	0.177
N_2	56.553	74.24	0.0220	1.241
SO_2	0.136		0.0353	
O_2	2.461	3.23	0.0229	0.056
Total	76.180			**2.071**

ENERGY BALANCE

ENERGY IN

Limestone =	0.476	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.263	MJ/min
Total =	**5.739**	MJ/min

ENERGY OUT

Lime =	0.254	MJ/min
Flue Gas =	2.071	MJ/min
Calcination =	1.056	MJ/min
Total =	**3.381**	MJ/min

ENERGY LOSS

Input - Output =	**2.358**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	17.165	21.73	0.0347	0.596
H_2O	6.662		0.0266	0.177
N_2	58.667	74.27	0.0220	1.288
SO_2	0.136		0.0353	
O_2	3.160	4.00	0.0229	0.072
Total	78.992			**2.134**

ENERGY BALANCE

ENERGY IN

Limestone =	0.476	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.263	MJ/min
Total =	**5.739**	MJ/min

ENERGY OUT

Lime =	0.254	MJ/min
Flue Gas =	2.134	MJ/min
Calcination =	1.056	MJ/min
Total =	**3.444**	MJ/min

ENERGY LOSS

Input - Output =	**2.295**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1467.0	K
Flue Gas Temperature at Exit =	1013.6	K
Flue Gas Velocity at Tmax =	1.440	m/sec
Flue Gas Velocity at Exit =	0.995	m/sec
Avg Flue Gas Velocity =	1.217	m/sec

Energy Balance for LG11

Limestone

Limestone Feed Rate =	36.8	kg/Hr
Purity of Limestone =	97.95	%
Temperature of Limestone =	897.4	K
Energy Entering with Limestone		
$CaCO_3$ =	0.445	MJ/min
Inerts =	0.006	MJ/min
Total =	**0.450**	MJ/min
Calcination =	98.70	%
Lime Output =	21.0	kg/Hr
Temperature of Lime =	1148.1	K
Energy Required for Calcination =	1.070	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.005	MJ/min
CaO =	0.239	MJ/min
Inerts =	0.009	MJ/min
Total =	**0.253**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	12.6	CFM	14.8	mols/min
Primary =	36.5	CFM	43.0	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	54.1	CFM	63.7	mols/min
Flue Gas Temperature at Exit =			949.7	K
Measured Excess Oxygen =			2.7	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	61.10
Hydrogen	24.50	5.48
Oxygen	0.00	26.21
Nitrogen	1.21	1.69
Sulphur	0.00	0.75
Total	100.00	95.23

Fuel Supplied to the Kiln

Natural Gas =	0.0	L/min
mols of Natural Gas =	0.00	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	0.000	MJ/min
Lignin =	218.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	25.28	MJ/kg
Net Energy =	5.250	MJ/min
Energy Supplied by Fuels =	**5.250**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	17.020	24.84	0.0311	0.529
H_2O	5.926		0.0240	0.142
N_2	50.446	73.62	0.0199	1.004
SO_2	0.051		0.0317	
O_2	1.056	1.54	0.0208	0.022
Total	68.522			**1.697**

ENERGY BALANCE

ENERGY IN

Limestone =	0.450	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.250	MJ/min
Total =	**5.701**	MJ/min

ENERGY OUT

Lime =	0.253	MJ/min
Flue Gas =	1.697	MJ/min
Calcination =	1.070	MJ/min
Total =	**3.020**	MJ/min

ENERGY LOSS

Input - Output =	**2.681**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	17.020	23.43	0.0311	0.529
H_2O	5.926		0.0240	0.142
N_2	53.661	73.87	0.0199	1.068
SO_2	0.051		0.0317	
O_2	1.961	2.70	0.0208	0.041
Total	72.642			**1.780**

ENERGY BALANCE

ENERGY IN

Limestone =	0.450	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.250	MJ/min
Total =	**5.701**	MJ/min

ENERGY OUT

Lime =	0.253	MJ/min
Flue Gas =	1.780	MJ/min
Calcination =	1.070	MJ/min
Total =	**3.102**	MJ/min

ENERGY LOSS

Input - Output =	**2.598**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1520.9	K
Flue Gas Temperature at Exit =	949.7	K
Flue Gas Velocity at Tmax =	1.369	m/sec
Flue Gas Velocity at Exit =	0.855	m/sec
Avg Flue Gas Velocity =	1.112	m/sec

Energy Balance for LG12A

Limestone

Limestone Feed Rate =	35.4	kg/Hr
Purity of Limestone =	97.95	%
Temperature of Limestone =	885.1	K
Energy Entering with Limestone		
$CaCO_3$ =	0.417	MJ/min
Inerts =	0.005	MJ/min
Total =	**0.422**	MJ/min
Calcination =	99.17	%
Lime Output =	20.1	kg/Hr
Temperature of Lime =	1225.6	K
Energy Required for Calcination =	1.034	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.003	MJ/min
CaO =	0.261	MJ/min
Inerts =	0.009	MJ/min
Total =	**0.274**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	14.0	CFM	16.5	mols/min
Primary =	36.5	CFM	43.0	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	55.5	CFM	65.3	mols/min
Flue Gas Temperature at Exit =			905.4	K
Measured Excess Oxygen =			1.9	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	61.11
Hydrogen	24.50	5.58
Oxygen	0.00	26.56
Nitrogen	1.21	1.69
Sulphur	0.00	0.94
Total	100.00	95.88

Fuel Supplied to the Kiln

Natural Gas =	62.3	L/min
mols of Natural Gas =	2.59	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	2.095	MJ/min
Lignin =	131.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	25.08	MJ/kg
Net Energy =	3.126	MJ/min
Energy Supplied by Fuels =	**5.220**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	14.987	22.10	0.0286	0.429
H_2O	8.805		0.0222	0.196
N_2	51.727	76.27	0.0185	0.956
SO_2	0.038		0.0292	
O_2	1.112	1.64	0.0193	0.021
Total	67.825			**1.603**

ENERGY BALANCE

ENERGY IN

Limestone =	0.422	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.220	MJ/min
Total =	**5.643**	MJ/min

ENERGY OUT

Lime =	0.274	MJ/min
Flue Gas =	1.603	MJ/min
Calcination =	1.034	MJ/min
Total =	**2.911**	MJ/min

ENERGY LOSS

Input - Output =	**2.732**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	14.987	21.85	0.0286	0.429
H_2O	8.805		0.0222	0.196
N_2	52.304	76.25	0.0185	0.967
SO_2	0.038		0.0292	
O_2	1.303	1.90	0.0193	0.025
Total	68.593			**1.617**

ENERGY BALANCE

ENERGY IN		
Limestone =	0.422	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.220	MJ/min
Total =	**5.643**	MJ/min
ENERGY OUT		
Lime =	0.274	MJ/min
Flue Gas =	1.617	MJ/min
Calcination =	1.034	MJ/min
Total =	**2.925**	MJ/min
ENERGY LOSS		
Input - Output =	**2.718**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1492.0	K
Flue Gas Temperature at Exit =	905.4	K
Flue Gas Velocity at Tmax =	1.323	m/sec
Flue Gas Velocity at Exit =	0.803	m/sec
Avg Flue Gas Velocity =	1.063	m/sec

Energy Balance for LG12B

Limestone

Limestone Feed Rate =	35.5	kg/Hr
Purity of Limestone =	97.95	%
Temperature of Limestone =	900.6	K
Energy Entering with Limestone		
$CaCO_3$ =	0.432	MJ/min
Inerts =	0.005	MJ/min
Total =	**0.437**	MJ/min
Calcination =	99.63	%
Lime Output =	20.1	kg/Hr
Temperature of Lime =	1289.6	K
Energy Required for Calcination =	1.042	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.002	MJ/min
CaO =	0.288	MJ/min
Inerts =	0.010	MJ/min
Total =	**0.299**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	14.0	CFM	16.5	mols/min
Primary =	36.5	CFM	43.0	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	55.5	CFM	65.3	mols/min
Flue Gas Temperature at Exit =			924.6	K
Measured Excess Oxygen =			2.0	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	61.11
Hydrogen	24.50	5.58
Oxygen	0.00	26.56
Nitrogen	1.21	1.69
Sulphur	0.00	0.94
Total	100.00	95.88

Fuel Supplied to the Kiln

Natural Gas =	39.6	L/min
mols of Natural Gas =	1.65	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	1.331	MJ/min
Lignin =	163.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	25.08	MJ/kg
Net Energy =	3.889	MJ/min
Energy Supplied by Fuels =	**5.221**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	15.714	22.90	0.0297	0.466
H_2O	7.804		0.0230	0.180
N_2	51.735	75.38	0.0191	0.988
SO_2	0.048		0.0303	
O_2	1.184	1.73	0.0199	0.024
Total	68.633			**1.658**

ENERGY BALANCE

ENERGY IN

Limestone =	0.437	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.221	MJ/min
Total =	**5.658**	MJ/min

ENERGY OUT

Lime =	0.299	MJ/min
Flue Gas =	1.658	MJ/min
Calcination =	1.042	MJ/min
Total =	**2.999**	MJ/min

ENERGY LOSS

Input - Output =	**2.659**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	15.714	22.63	0.0297	0.466
H_2O	7.804		0.0230	0.180
N_2	52.325	75.37	0.0191	0.999
SO_2	0.048		0.0303	
O_2	1.389	2.00	0.0199	0.028
Total	69.427			**1.673**

ENERGY BALANCE

ENERGY IN

Limestone =	0.437	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.221	MJ/min
Total =	**5.658**	MJ/min

ENERGY OUT

Lime =	0.299	MJ/min
Flue Gas =	1.673	MJ/min
Calcination =	1.042	MJ/min
Total =	**3.014**	MJ/min

ENERGY LOSS

Input - Output =	**2.644**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1518.2	K
Flue Gas Temperature at Exit =	924.6	K
Flue Gas Velocity at Tmax =	1.344	m/sec
Flue Gas Velocity at Exit =	0.818	m/sec
Avg Flue Gas Velocity =	1.081	m/sec

Energy Balance for LG13

Limestone

Limestone Feed Rate =	33.0	kg/Hr
Purity of Limestone =	97.95	%
Temperature of Limestone =	880.7	K
Energy Entering with Limestone		
$CaCO_3$ =	0.385	MJ/min
Inerts =	0.005	MJ/min
Total =	**0.390**	MJ/min
Calcination =	98.21	%
Lime Output =	19.0	kg/Hr
Temperature of Lime =	1296.1	K
Energy Required for Calcination =	0.954	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.008	MJ/min
CaO =	0.270	MJ/min
Inerts =	0.009	MJ/min
Total =	**0.287**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	9.8	CFM	11.5	mols/min
Primary =	5.0	CFM	5.9	mols/min
Secondary =	34.0	CFM	40.0	mols/min
Total =	48.8	CFM	57.5	mols/min
Flue Gas Temperature at Exit =			889.8	K
Calculated Excess Oxygen =			2.0	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	60.63
Hydrogen	24.50	5.35
Oxygen	0.00	26.19
Nitrogen	1.21	0.11
Sulphur	0.00	3.19
Total	100.00	95.47

Fuel Supplied to the Kiln

Natural Gas =	152.9	L/min
mols of Natural Gas =	6.36	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	5.141	MJ/min
Lignin =	0.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	22.56	MJ/kg
Net Energy =	0.000	MJ/min
Energy Supplied by Fuels =	**5.141**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	11.647	20.39	0.0278	0.323
H_2O	12.712		0.0216	0.275
N_2	45.463	79.61	0.0180	0.818
SO_2	0.000		0.0284	
O_2	-0.648	0.00	0.0187	0.000
Total	57.109			**1.416**

ENERGY BALANCE

ENERGY IN

Limestone =	0.390	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.141	MJ/min
Total =	**5.531**	MJ/min

ENERGY OUT

Lime =	0.287	MJ/min
Flue Gas =	1.416	MJ/min
Calcination =	0.954	MJ/min
Total =	**2.658**	MJ/min

ENERGY LOSS

Input - Output =	**2.873**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	11.647	17.70	0.0278	0.323
H_2O	12.712		0.0216	0.275
N_2	52.850	80.30	0.0180	0.951
SO_2	0.000		0.0284	
O_2	1.316	2.00	0.0187	0.025
Total	65.813			**1.574**

ENERGY BALANCE

ENERGY IN

Limestone =	0.390	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.141	MJ/min
Total =	**5.531**	MJ/min

ENERGY OUT

Lime =	0.287	MJ/min
Flue Gas =	1.574	MJ/min
Calcination =	0.954	MJ/min
Total =	**2.815**	MJ/min

ENERGY LOSS

Input - Output =	**2.715**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1463.8	K
Flue Gas Temperature at Exit =	889.8	K
Flue Gas Velocity at Tmax =	1.317	m/sec
Flue Gas Velocity at Exit =	0.801	m/sec
Avg Flue Gas Velocity =	1.059	m/sec

Energy Balance for LG14G

Limestone

Limestone Feed Rate =	37.2	kg/Hr
Purity of Limestone =	98.96	%
Temperature of Limestone =	860.6	K
Energy Entering with Limestone		
$CaCO_3$ =	0.420	MJ/min
Inerts =	0.003	MJ/min
Total =	**0.423**	MJ/min
Calcination =	98.78	%
Lime Output =	21.1	kg/Hr
Temperature of Lime =	1286.7	K
Energy Required for Calcination =	1.093	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.006	MJ/min
CaO =	0.302	MJ/min
Inerts =	0.005	MJ/min
Total =	**0.313**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	11.2	CFM	13.2	mols/min
Primary =	34.0	CFM	40.0	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	50.2	CFM	59.1	mols/min
Flue Gas Temperature at Exit =			868.9	K
Measured Excess Oxygen =			2.1	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	63.15
Hydrogen	24.50	5.42
Oxygen	0.00	25.15
Nitrogen	1.21	1.24
Sulphur	0.00	2.29
Total	100.00	97.25

Fuel Supplied to the Kiln

Natural Gas =	152.9	L/min
mols of Natural Gas =	6.36	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	5.141	MJ/min
Lignin =	0.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	26.11	MJ/kg
Net Energy =	0.000	MJ/min
Energy Supplied by Fuels =	**5.141**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	12.417	20.98	0.0266	0.331
H_2O	12.712		0.0208	0.264
N_2	46.765	79.02	0.0173	0.811
SO_2	0.000		0.0272	
O_2	-0.301	0.00	0.0180	0.000
Total	59.181			**1.406**

ENERGY BALANCE

ENERGY IN

Limestone =	0.423	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.141	MJ/min
Total =	**5.563**	MJ/min

ENERGY OUT

Lime =	0.313	MJ/min
Flue Gas =	1.406	MJ/min
Calcination =	1.093	MJ/min
Total =	**2.812**	MJ/min

ENERGY LOSS

Input - Output =	**2.751**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	12.417	18.53	0.0266	0.331
H_2O	12.712		0.0208	0.264
N_2	53.193	79.37	0.0173	0.922
SO_2	0.000		0.0272	
O_2	1.407	2.10	0.0180	0.025
Total	67.017			**1.542**

ENERGY BALANCE

ENERGY IN		
Limestone =	0.423	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.141	MJ/min
Total =	**5.563**	MJ/min
ENERGY OUT		
Lime =	0.313	MJ/min
Flue Gas =	1.542	MJ/min
Calcination =	1.093	MJ/min
Total =	**2.949**	MJ/min
ENERGY LOSS		
Input - Output =	**2.614**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1505.1	K
Flue Gas Temperature at Exit =	868.9	K
Flue Gas Velocity at Tmax =	1.375	m/sec
Flue Gas Velocity at Exit =	0.794	m/sec
Avg Flue Gas Velocity =	1.084	m/sec

Energy Balance for LG14

Limestone

Limestone Feed Rate =	37.2	kg/Hr
Purity of Limestone =	98.96	%
Temperature of Limestone =	910.9	K
Energy Entering with Limestone		
$CaCO_3$ =	0.467	MJ/min
Inerts =	0.003	MJ/min
Total =	**0.470**	MJ/min
Calcination =	98.82	%
Lime Output =	21.1	kg/Hr
Temperature of Lime =	1242.2	K
Energy Required for Calcination =	1.094	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.005	MJ/min
CaO =	0.284	MJ/min
Inerts =	0.005	MJ/min
Total =	**0.294**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	11.2	CFM	13.2	mols/min
Primary =	34.0	CFM	40.0	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	50.2	CFM	59.1	mols/min
Flue Gas Temperature at Exit =			882.8	K
Measured Excess Oxygen =			2.8	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	63.15
Hydrogen	24.50	5.42
Oxygen	0.00	25.15
Nitrogen	1.21	1.24
Sulphur	0.00	2.24
Total	100.00	97.20

Fuel Supplied to the Kiln

Natural Gas =	0.0	L/min
mols of Natural Gas =	0.00	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	0.000	MJ/min
Lignin =	220.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	26.11	MJ/kg
Net Energy =	5.484	MJ/min
Energy Supplied by Fuels =	**5.484**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	17.631	27.37	0.0274	0.483
H_2O	5.915		0.0213	0.126
N_2	46.785	72.63	0.0178	0.832
SO_2	0.154		0.0280	
O_2	-0.539	0.00	0.0185	0.000
Total	64.416			**1.440**

ENERGY BALANCE

ENERGY IN

Limestone =	0.470	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.484	MJ/min
Total =	**5.954**	MJ/min

ENERGY OUT

Lime =	0.294	MJ/min
Flue Gas =	1.440	MJ/min
Calcination =	1.094	MJ/min
Total =	**2.828**	MJ/min

ENERGY LOSS

Input - Output =	**3.126**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	17.631	23.20	0.0274	0.483
H_2O	5.915		0.0213	0.126
N_2	56.240	74.00	0.0178	1.000
SO_2	0.154		0.0280	
O_2	2.128	2.80	0.0185	0.039
Total	75.999			**1.648**

ENERGY BALANCE

ENERGY IN

Limestone =	0.470	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.484	MJ/min
Total =	**5.954**	MJ/min

ENERGY OUT

Lime =	0.294	MJ/min
Flue Gas =	1.648	MJ/min
Calcination =	1.094	MJ/min
Total =	**3.036**	MJ/min

ENERGY LOSS

Input - Output =	**2.918**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1491.5	K
Flue Gas Temperature at Exit =	882.8	K
Flue Gas Velocity at Tmax =	1.400	m/sec
Flue Gas Velocity at Exit =	0.829	m/sec
Avg Flue Gas Velocity =	1.114	m/sec

Energy Balance for LG15A

Limestone

Limestone Feed Rate =	40.2	kg/Hr
Purity of Limestone =	98.96	%
Temperature of Limestone =	827.1	K
Energy Entering with Limestone		
$CaCO_3$ =	0.421	MJ/min
Inerts =	0.003	MJ/min
Total =	**0.423**	MJ/min
Calcination =	84.81	%
Lime Output =	26.5	kg/Hr
Temperature of Lime =	1256.7	K
Energy Required for Calcination =	1.014	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.086	MJ/min
CaO =	0.312	MJ/min
Inerts =	0.005	MJ/min
Total =	**0.404**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	9.8	CFM	11.5	mols/min
Primary =	34.0	CFM	40.0	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	48.8	CFM	57.5	mols/min
Flue Gas Temperature at Exit =			842.2	K
Measured Excess Oxygen =			2.1	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	60.63
Hydrogen	24.50	5.35
Oxygen	0.00	26.19
Nitrogen	1.21	0.11
Sulphur	0.00	3.19
Total	100.00	95.47

Fuel Supplied to the Kiln

Natural Gas =	152.9	L/min
mols of Natural Gas =	6.36	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	5.141	MJ/min
Lignin =	0.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	22.56	MJ/kg
Net Energy =	0.000	MJ/min
Energy Supplied by Fuels =	**5.141**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	11.979	20.85	0.0252	0.302
H_2O	12.712		0.0197	0.251
N_2	45.463	79.15	0.0165	0.750
SO_2	0.000		0.0258	
O_2	-0.648	0.00	0.0172	0.000
Total	57.442			**1.303**

ENERGY BALANCE

ENERGY IN

Limestone =	0.423	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.141	MJ/min
Total =	**5.564**	MJ/min

ENERGY OUT

Lime =	0.404	MJ/min
Flue Gas =	1.303	MJ/min
Calcination =	1.014	MJ/min
Total =	**2.721**	MJ/min

ENERGY LOSS

Input - Output =	**2.843**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	11.979	18.01	0.0252	0.302
H_2O	12.712		0.0197	0.251
N_2	53.154	79.89	0.0165	0.877
SO_2	0.000		0.0258	
O_2	1.397	2.10	0.0172	0.024
Total	66.531			**1.453**

ENERGY BALANCE

ENERGY IN

Limestone =	0.423	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.141	MJ/min
Total =	**5.564**	MJ/min

ENERGY OUT

Lime =	0.404	MJ/min
Flue Gas =	1.453	MJ/min
Calcination =	1.014	MJ/min
Total =	**2.872**	MJ/min

ENERGY LOSS

Input - Output =	**2.692**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1490.9	K
Flue Gas Temperature at Exit =	842.2	K
Flue Gas Velocity at Tmax =	1.354	m/sec
Flue Gas Velocity at Exit =	0.765	m/sec
Avg Flue Gas Velocity =	1.059	m/sec

Energy Balance for LG15B

Limestone

Limestone Feed Rate =	39.3	kg/Hr
Purity of Limestone =	98.96	%
Temperature of Limestone =	863.7	K
Energy Entering with Limestone		
$CaCO_3$ =	0.447	MJ/min
Inerts =	0.003	MJ/min
Total =	**0.450**	MJ/min
Calcination =	98.10	%
Lime Output =	22.5	kg/Hr
Temperature of Lime =	1308.8	K
Energy Required for Calcination =	1.147	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.010	MJ/min
CaO =	0.329	MJ/min
Inerts =	0.006	MJ/min
Total =	**0.345**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	9.8	CFM	11.5	mols/min
Primary =	39.0	CFM	45.9	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	53.8	CFM	63.3	mols/min
Flue Gas Temperature at Exit =			882.8	K
Measured Excess Oxygen =			2.5	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	60.63
Hydrogen	24.50	5.35
Oxygen	0.00	26.19
Nitrogen	1.21	0.11
Sulphur	0.00	3.19
Total	100.00	95.47

Fuel Supplied to the Kiln

Natural Gas =	164.3	L/min
mols of Natural Gas =	6.83	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	5.524	MJ/min
Lignin =	0.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	22.56	MJ/kg
Net Energy =	0.000	MJ/min
Energy Supplied by Fuels =	**5.524**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	13.189	20.83	0.0274	0.361
H_2O	13.660		0.0213	0.292
N_2	50.118	79.17	0.0178	0.891
SO_2	0.000		0.0280	
O_2	-0.359	0.00	0.0185	0.000
Total	63.307			**1.543**

ENERGY BALANCE

ENERGY IN

Limestone =	0.450	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.524	MJ/min
Total =	**5.974**	MJ/min

ENERGY OUT

Lime =	0.345	MJ/min
Flue Gas =	1.543	MJ/min
Calcination =	1.147	MJ/min
Total =	**3.035**	MJ/min

ENERGY LOSS

Input - Output =	**2.939**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	13.189	17.97	0.0274	0.361
H_2O	13.660		0.0213	0.292
N_2	58.372	79.53	0.0178	1.037
SO_2	0.000		0.0280	
O_2	1.835	2.50	0.0185	0.034
Total	73.396			**1.724**

ENERGY BALANCE

ENERGY IN

Limestone =	0.450	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.524	MJ/min
Total =	**5.974**	MJ/min

ENERGY OUT

Lime =	0.345	MJ/min
Flue Gas =	1.724	MJ/min
Calcination =	1.147	MJ/min
Total =	**3.216**	MJ/min

ENERGY LOSS

Input - Output =	**2.758**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1522.5	K
Flue Gas Temperature at Exit =	882.8	K
Flue Gas Velocity at Tmax =	1.519	m/sec
Flue Gas Velocity at Exit =	0.881	m/sec
Avg Flue Gas Velocity =	1.200	m/sec

Energy Balance for LG16

Limestone

Limestone Feed Rate =	41.5	kg/Hr
Purity of Limestone =	98.96	%
Temperature of Limestone =	878.7	K
Energy Entering with Limestone		
$CaCO_3$ =	0.487	MJ/min
Inerts =	0.003	MJ/min
Total =	**0.491**	MJ/min
Calcination =	95.58	%
Lime Output =	24.3	kg/Hr
Temperature of Lime =	1185.0*	K
Energy Required for Calcination =	1.180	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.021	MJ/min
CaO =	0.289	MJ/min
Inerts =	0.005	MJ/min
Total =	**0.315**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	12.6	CFM	14.8	mols/min
Primary =	34.0	CFM	40.0	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	51.6	CFM	60.7	mols/min
Flue Gas Temperature at Exit =			950.0*	K
Measured Excess Oxygen =			2.3	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	62.46
Hydrogen	24.50	5.39
Oxygen	0.00	25.95
Nitrogen	1.21	0.10
Sulphur	0.00	2.15
Total	100.00	96.05

Fuel Supplied to the Kiln

Natural Gas =	39.6	L/min
mols of Natural Gas =	1.65	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	1.331	MJ/min
Lignin =	165.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	25.78	MJ/kg
Net Energy =	4.060	MJ/min
Energy Supplied by Fuels =	**5.391**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	16.769	25.88	0.0311	0.521
H_2O	7.704		0.0240	0.185
N_2	48.016	74.12	0.0199	0.956
SO_2	0.111		0.0317	
O_2	-0.095	0.00	0.0208	0.000
Total	64.785			**1.662**

ENERGY BALANCE

ENERGY IN

Limestone =	0.491	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.391	MJ/min
Total =	**5.881**	MJ/min

ENERGY OUT

Lime =	0.315	MJ/min
Flue Gas =	1.662	MJ/min
Calcination =	1.180	MJ/min
Total =	**3.158**	MJ/min

ENERGY LOSS

Input - Output =	**2.724**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	16.769	23.07	0.0311	0.521
H_2O	7.704		0.0240	0.185
N_2	54.246	74.63	0.0199	1.080
SO_2	0.111		0.0317	
O_2	1.672	2.30	0.0208	0.035
Total	72.687			**1.821**

ENERGY BALANCE

ENERGY IN		
Limestone =	0.491	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.391	MJ/min
Total =	**5.881**	MJ/min
ENERGY OUT		
Lime =	0.315	MJ/min
Flue Gas =	1.821	MJ/min
Calcination =	1.180	MJ/min
Total =	**3.317**	MJ/min
ENERGY LOSS		
Input - Output =	**2.565**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1398.5	K
Flue Gas Temperature at Exit =	950.0*	K
Flue Gas Velocity at Tmax =	1.288	m/sec
Flue Gas Velocity at Exit =	0.875	m/sec
Avg Flue Gas Velocity =	1.082	m/sec

* an estimated value

Energy Balance for LG17

Limestone

Limestone Feed Rate =	41.8	kg/Hr
Purity of Limestone =	98.96	%
Temperature of Limestone =	851.3	K
Energy Entering with Limestone		
$CaCO_3$ =	0.462	MJ/min
Inerts =	0.003	MJ/min
Total =	**0.465**	MJ/min
Calcination =	97.04	%
Lime Output =	24.2	kg/Hr
Temperature of Lime =	1197.7	K
Energy Required for Calcination =	1.207	MJ/min
Energy Leaving with Lime		
$CaCO_3$ =	0.014	MJ/min
CaO =	0.297	MJ/min
Inerts =	0.005	MJ/min
Total =	**0.317**	MJ/min

Combustion Air

Temperature of Air =			293.2	K
Lance =	12.6	CFM	14.8	mols/min
Primary =	31.0	CFM	36.5	mols/min
Secondary =	5.0	CFM	5.9	mols/min
Total =	48.6	CFM	57.2	mols/min
Flue Gas Temperature at Exit =			925.0*	K
Measured Excess Oxygen =			2.2	%

Fuel Composition

	Natural Gas vol%	Lignin wt%
Carbon	74.29	61.45
Hydrogen	24.50	5.39
Oxygen	0.00	25.83
Nitrogen	1.21	0.11
Sulphur	0.00	2.13
Total	100.00	94.91

Fuel Supplied to the Kiln

Natural Gas =	62.3	L/min
mols of Natural Gas =	2.59	mols/min
Higher Heating Value =	37.28	kJ/L
Net Energy =	2.095	MJ/min
Lignin =	132.0	g/min
Moisture =	0.00	%
Calorific Heating Value =	25.43	MJ/kg
Net Energy =	3.201	MJ/min
Energy Supplied by Fuels =	**5.296**	MJ/min

Calculation by Supplied Air

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	16.034	26.17	0.0297	0.476
H_2O	8.709		0.0230	0.201
N_2	45.236	73.83	0.0191	0.865
SO_2	0.088		0.0303	
O_2	-0.705	0.00	0.0199	0.000
Total	61.270			**1.541**

ENERGY BALANCE

ENERGY IN

Limestone =	0.465	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.296	MJ/min
Total =	**5.761**	MJ/min

ENERGY OUT

Lime =	0.317	MJ/min
Flue Gas =	1.541	MJ/min
Calcination =	1.207	MJ/min
Total =	**3.065**	MJ/min

ENERGY LOSS

Input - Output =	**2.697**	MJ/min

Calculation by Excess Air, GC Analyses

	Flue Gas mols/min	%	Enthalpy MJ/mols	Enthalpy MJ/min
CO_2	16.034	22.57	0.0297	0.476
H_2O	8.709		0.0230	0.201
N_2	53.438	75.23	0.0191	1.021
SO_2	0.088		0.0303	
O_2	1.563	2.20	0.0199	0.031
Total	71.035			**1.729**

ENERGY BALANCE

ENERGY IN

Limestone =	0.465	MJ/min
Combustion Air =	0.000	MJ/min
Fuel =	5.296	MJ/min
Total =	**5.761**	MJ/min

ENERGY OUT

Lime =	0.317	MJ/min
Flue Gas =	1.729	MJ/min
Calcination =	1.207	MJ/min
Total =	**3.253**	MJ/min

ENERGY LOSS

Input - Output =	**2.509**	MJ/min

Freeboard Gas Velocity

Inside Radius of Kiln =	0.203	m
Height of Bed =	0.054	m
X-Area of Kiln =	0.1296	m^2
X-Area of Kiln Bed =	0.0102	m^2
FreeBoard Area =	0.1194	m^2
Maximum Gas Temperature =	1422.0*	K
Flue Gas Temperature at Exit =	925.0*	K
Flue Gas Velocity at Tmax =	1.299	m/sec
Flue Gas Velocity at Exit =	0.845	m/sec
Avg Flue Gas Velocity =	1.072	m/sec

* an estimated value

Table G–1. Listing of maximum gas, bed temperatures & flue gas velocities

Run	Lignin	% Gas Replaced	$CaCO_3$ kg/h†	Percent Calcination	Max. Temperature °C‡‡ Gas	Bed	Flue Gas m/sec
LG9	IR	60	39.3	98.6	1157.88	1058.71	1.279
LG10A		75	39.3	98.3	1150.74	1058.40	1.211
LG10B		100	36.0	97.7	1193.83	1107.04	1.217
LG12A	WV	60	35.3	99.2	1218.82	1128.07	1.063
LG12B		75	35.4	99.6	1245.03‡	1158.34	1.081
LG11		100	36.6	98.7	1247.78	1112.21	1.112
LG17	PG	60	42.0	97.0	N/A	1048.38	N/A
LG16		75	41.7	95.6	1125.38	1029.06	1.082
LG14		100	37.3	98.8	1218.33‡	1080.46	1.114
	Gas						
LG13	G1	0	33.2	98.2	1190.66‡	1071.31	1.059
LG14G	G2	0	36.8	97.8	1231.98‡	1036.16	1.084
LG15A	G3	0	40.4	84.8	1217.72‡	1029.01	1.059
LG15B	G4	0	39.5	98.1	1249.39‡	1045.14	1.200

† calculated based on output of lime ‡ 0.464 metres, ‡‡ 0.921 metres from the discharge