MECHANICAL SEED EXTRACTION

OF LODGEPOLE PINE

by

JAMES DONALD MACAULAY, P.ENG.

B.S.A. University of Guelph, 1965

M.Sc. University of Guelph, 1967

A THESIS SUBMITTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in the

FACULTY OF FORESTRY

We accept this thesis as conforming to
the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

May, 1975

Department of Agricultural Engineering and Faculty of Forestry

The University of British Columbia
Vancouver 8, Canada

Date May 22, 1975

-6

ABSTRACT

Seed extraction from serotinous lodgepole pine cones (*Pinus contorta* var. *latifolia* Englem.) was investigated to identify the physical properties and characteristics which affect seed extraction by both conventional kiln drying techniques and by mechanical means. This information provided a basis for systematic design of specific processing tools for a portable continuous flow mechanical seed extraction system.

Cone scale deflection was characterized and its effect on seed release is reported. The effect of moisture content upon scale stress relaxation during storage and subsequent reduction in seed release is discussed.

Flash heating of cones in hot water and hot gas was found to effectively release serotinous seals without incurring thermal seed damage.

Two continuous flow flash heating seal breaking tools were designed and tested. A flame seal breaker proved most suitable for commercial operation, and this tool was calibrated for use on both young and weathered cones.

Mechanical seed extraction by cone core removal was effective, but asymmetrical cones prevented accurate core boring, thus resulting in considerable seed destruction.

Seed extraction by threshing also was effective. Testing of first and second generation threshing tools was carried out on lodgepole pine, Douglas fir, white spruce and western hemlock. Further study is recommended to identify the optimum values of the many biological variables, machine variables and operating conditions which affect cone threshing.

TABLE OF CONTENTS

		PAGE
ABSTRACT		i
TABLE OF CONTENTS		iii
LIST OF TABLES		vi
LIST OF FIGURES		ix
TERMINOLOGY		xiii
ACKNOWLEDGEMENTS		xvii
I	INTRODUCTION	1
II	CURRENT SEED EXTRACTION TECHNIQUES	3
III	OBJECTIVE	7
IV	SYSTEMATIC DESIGN PROCEDURE	8
V	COMPARISON OF KILN AND MECHANICAL EXTRACTION SYSTEMS	12

PART ONE

(*Physical Properties of lodgepole pine cones*)

VI	PHYSICAL PROPERTIES AFFECTING MECHANIZATION OF SEED EXTRACTION	16
	1. Fruiting	16
	2. Serotinous Cone Scale Seals	17
	3. Scale Opening Mechanism	20
	4. Cone Opening at Maturity	22
	5. Resistance to Thermal Damage	22
	6. Resistance to Mechanical Damage	24
	7. Stress Relaxation of Cone Scales	26
	8. Thermal Properties	28
	9. Drying Rate	29
VII	PRELIMINARY INVESTIGATIONS	31
	1. Identification and Description of Cones	31
	2. Preparation of Material	32
	3. Degree of Serotiny of Cone Seed Lot	32

TABLE OF CONTENTS (Continued) PAGE

VII PRELIMINARY INVESTIGATIONS (Continued)

4. Viability of Seeds by Location in the Cone 34
5. Viability of Seeds and Ease of Extraction 37
6. Viability of Kiln Treated Seeds 38
7. Moisture Content 40

VIII INVESTIGATION OF PHYSICAL PROPERTIES OF CONES 41

1. Equilibrium Moisture Content 41
2. Melting Point Determination for Serotinous Bonds 43
3. Scale Deflection vs. Moisture Content 45
4. Scale Deflection of Stress Relaxed Cones 49
5. Degree of Seed Release With Respect to Scale Deflection 52
6. Hot Water Seal Breaking 54
7. Flame Treatment Seal Breaking 58
8. Moisture Content on Seal Breaking Effectiveness 60

PART TWO

(Development of Processing Tools)

IX PROPOSED MECHANICAL EXTRACTION SYSTEM 65

X DEVELOPMENT OF SEROTINOUS SEAL BREAKING TOOL 67

1. Preliminary Analysis 67
2. Heat Transfer Analysis of Flash Heated Cones 69
3. Hot Water Immersing Tool 80
4. Flame Treating Tool 84
5. Calibration of Flame Treating Seal Breaker 90

XI DEVELOPMENT OF MECHANICAL CONIFER SEED EXTRACTION TOOL 94

1. Alternative Methods 94
2. Extraction by Cone Abrasion 95
3. Extraction by Core Boring 97
4. Extraction by Threshing 103

TABLE OF CONTENTS (Continued) PAGE

XI DEVELOPMENT OF MECHANICAL CONIFER SEED EXTRACTION TOOL (Continued)

(i) Analysis 103
(ii) First Prototype Tool 107
(iii) Testing 109
(iv) Second Generation Prototype 115
(v) Testing 117
(vi) Threshing Performance on Other Species 122

PART THREE

(Conclusions and Recommendations)

XII CONCLUSIONS 126

1. Physical Properties of Lodgepole Pine Cones Which Affect Seed Extraction 126
2. Development of Seal Breaking Tool 128
3. Development of Mechanical Conifer Seed Extracting Tool 128

XIII RECOMMENDATIONS 131

LITERATURE CITED 134

APPENDIX A 139

LIST OF TABLES

TABLE		PAGE
I	Seed viability by location in cone	36
II	Germination percent for ease of extraction test	38
III	Scale deflection angle at various cone moisture contents	48
IV	Effect of hot water immersion on cone opening and seed viability	57
V	Effect of flame treatment on cone opening and seed viability	61
VI	Seal breaking results at three moisture contents	63
VII	Simple correlation among variables of cone geometry	99

TABLES IN APPENDIX A

A-1	Number of seeds per cone, by location	140
A-2	Viability of oven dried cones	142
A-3	Equilibrium moisture content (wet basis) of cones over saturated salt solution for 30 days	143
A-4	Cone scale release temperature	144
A-5	Maximum cone scale angles of cones at 21.2% MC	145
A-6	Maximum cone scale angles of cones at 17.4% MC	146
A-7	Maximum cone scale angles of cones at 13.5% MC	147
A-8	Maximum cone scale angles of cones at 9.5% MC	148
A-9	Maximum cone scale angles of cones at 7.5% MC	149

TABLE		PAGE
A-10	Maximum cone scale angles of cones at 4.8% MC	150
A-11	Maximum cone scale angles of cones oven dry	151
A-12	Maximum scale angle of cones stored six months at 11.2% MC (wb) unsealed and dried to 9.9% MC	152
A-13	Maximum scale angle of cones stored six months at 11.2% MC (wb) unsealed, rewetted and dried to 11.1% MC (wb)	153
A-14	Maximum scale angle of cones stored six months at 11.2% MC (wb), unsealed, rewetted and dried to oven dry	154
A-15	Maximum cone scale angles for first seed release test	155
A-16	Maximum cone scale angles for second seed release test	156
A-17	Maximum cone scale angles for third seed release test	157
A-18	Maximum cone scale angles for fourth seed release test	158
A-19	Degree of serotinous seal breaking in Class I (young) cones by flame treatment	159
A-20	Degree of serotinous seal breaking in Class II weathered cones by flame treatment	161
A-21	Geometric variables affecting core boring of lodgepole pine cones	163
A-22	Results of threshing tests on lodgepole pine	164
A-23	Results of improved thresher tests on lodgepole pine	167
A-24	Lodgepole pine seeds recovered through concaves from 100 cones	168

TABLE		PAGE
A-25	Lodgepole pine seeds recovered through sieve from 100 cones	169
A-26	Results of threshing tests on Douglas fir	170
A-27	Results of threshing tests on white spruce	171
A-28	Results of threshing tests on western hemlock	172

LIST OF FIGURES

FIGURE		PAGE
1.	Steps in the systematic design procedure	9
2.	Defining the alternative processes	10
3.	Flow charts comparing separate kiln drying andtumbling to mobile mechanical extraction.	14
4.	Cross section of typical cones showing location of serotinous seal	33
5.	Location of serotinous seals on abaxial and adaxial surfaces of typical cone scales	33
6.	Typical partially opened cones from commercially collected cone lots	35
7.	Technique for manual opening of sealed cones	35
8.	Curve of germination percent with treatment time for cones in 140^{o}F (60^{o}C) oven	39
9.	Containers for equilibrium moisture content determination	42
10.	Equilibrium moisture content during drying of lodgepole pine cones	42
11.	Apparatus for determination of seal melting temperatures	44
12.	Cones prepared for scale deflection measurement before and after opening	46
13.	Alignment of cross hair with ground scale surface	46
14.	Apparatus for measuring cone scale deflection angles	46
15.	Maximum scale angle vs. equilibrium moisture content	48

FIGURE		PAGE
16.	Cones showing typical degree of opening when unsealed and brought to 10% M.C. after one month of storage at indicated moisture contents	50
17.	Cross section of open stress relaxed and non-stress relaxed cones	50
18.	Seed extraction vs. cone scale angle	53
19.	Hot water immersion apparatus	55
20.	Cone drying racks	55
21.	Flame treating apparatus	60
22.	Seal breaking by crushing	69
23.	Dimensional data of cone for heat transfer analysis	73
24.	Prototype hot water seal breaking tool	83
25.	View of seal breaker showing heating and drive mechanisms	83
26.	Prototype flame treating seal breaker	87
27.	View of flame treater showing drive mechanism	87
28.	Curve of exhaust temperature vs. fuel pressure for flame treating seal breaker	89
29.	Viability vs. treatment time for flame treater operating at 1000°F (538°C)	89
30.	Flame treater calibration curves for complete seal breaking of class I (young) lodgepole pine cones	92
31.	Flame treater calibration curves for complete seal breaking of class II (weathered) lodgepole pine cones	93
32.	Cone abrasion tool	96
33.	Geometric variables of cones influencing seed extraction by removal of cone core	98

FIGURE		PAGE
34.	Cross section of typical cones showing degree of asymmetry	101
35.	Cone boring tool	101
36.	Cross section of bored cones	101
37.	Bored and unsealed cones	101
38.	Schematic diagram of threshing machine	104
39.	Cylinder and concaves of threshing tool	108
40.	Cylinder and concaves installed in frame	108
41.	Threshing tool with plenum chamber	108
42.	Assembled prototype cone thresher	110
43.	Scalping sieve with partially threshed cones	110
44.	Partially threshed cones after two passes with cylinder speed of 2000 ft/min.	110
45.	Material passing through scalping sieve	112
46.	Air-screen seed cleaner	112
47.	Typical damaged and apparently undamaged seeds extracted by threshing	112
48.	Viable seed recovery rate vs. cylinder speed for lodgepole pine cones	114
49.	Internal components showing location of cushioning material	116
50.	Detail of cushion material on concaves	116
51.	Location of deceleration curtain in plenum chamber	116
52.	Curves of seed recovery vs. cylinder speed for lodgepole pine extracted by the rubberized threshing tool	119

FIGURE		PAGE
53.	Accumulated viable seed recovery from cones at 15% moisture content at 2000 ft/min cylinder speed	121
54.	Seed recovery by threshing of fir, spruce, and hemlock cones	123

TERMINOLOGY

ABAXIAL - pertaining to the region of an object remote from its central axis.

ADAXIAL - pertaining to that region of an object at or near its central axis.

APOPHYSIS - the prominent portion or externally visible tip region of a cone scale.

BIOT NUMBER - dimensionless heat transfer function, relating the ratio of internal to external thermal resistance.

CASE HARDENING - the process of imparting hard, brittle characteristics to the outher surface of an item, as in the carburizing and quenching of steel. Term also used to describe development of residual stresses in wood after kiln drying.

CELLULOSE MICROFIBRILS - fibrils of cellulose existing in the cell walls of plant material, and being largely responsible for the form and structural mechanics of the cell.

CONE AXIS - the central axis of the conical profile describing the outer surface of the conifer cones under study.

CONE CORE AXIS - the central axis of the conical profile describing the woody structure of a conifer cone to which the scales are attached.

CONE SCALE DEFLECTION ANGLE - the angle through which a cone scale deflects from its closed position during drying. The angle is measured at the tip of the scale. The average maximum scale deflection angle for a cone is the average of the angles of a number of scales which are located in a band around the cone at a point where scale deflection is greatest.

CYLINDER AND CONCAVE ASSEMBLY - a seed extracting tool used to separate agricultural seeds from the seed supporting portion of plants. The apparatus consists of a revolving cylinder having a number of transverse rub-bars and a stationary member, between which the seed containing material is passed during threshing.

EQUILIBRIUM MOISTURE CONTENT - that moisture content of a hygroscopic material at which the moisture within that material is in equilibrium with the moisture in the surrounding air.

EXTRACTION (SEED) - the removal of seeds from the cones of conifer trees.

FLASH HEATING - the brief exposure of serotinous cones to very high temperatures for the purpose of melting the resinous bond holding the cone scales in a closed position.

FOURIER NUMBER - dimensionless heat transfer function relating the thermal diffusivity and heat transfer time to body geometry.

GERMINATION PERCENT - percent of a given number of seeds producing normal germinants within a given period of time under optimum conditions. May be expressed as a percentage of total seed, or as a percentage of filled seed.

GERMINATIVE CAPACITY - the percent of seeds in a given sample producing normal germinants, irrespective of time. Usually considered to be the total of germinated seed plus all ungerminated seeds still sound at the end of the test period.

HYGROSCOPIC - pertaining to the ability of a material to imbibe water from the atmosphere.

MECHANICAL SEED DAMAGE - damage caused by the occurrence of stresses in a seed which exceed the yield strength of the tissues involved.

MOISTURE CONTENT - the amount of water retained by a hygroscopic material, expressed as a percentage, by weight of the total dry matter of the material (dry basis) or of the total dry matter plus water (wet basis).

NORMAL GERMINANT - germinant whose structures appear normal once its development has produced a radicle equal in length to that of the seed.

PEDUNCLE - the woody connective structure which attaches a cone to the tree branch.

RELATIVE HUMIDITY - the ratio, expressed as a percentage, of the partial pressure of water vapor of an air-vapor mixture to the pressure of saturated water vapor at the same dry bulb temperature.

RHEOLOGY - the study of the mechanical properties of materials which result in deformation and flow of a material.

SCLERENCHYMA - that tissue within plant structure whose primary role is to provide strength and mechanical support for the plant body.

SEAL BREAKING - the breaking of the resinous bonds which seal the scales of serotinous conifer cones in a closed position.

SEROTINY - a term used to describe the condition of conifer cones in which the scales are sealed in a closed position by a resinous bond between the overlapping surfaces. Cones having this characteristic are referred to as "serotinous cones" or "closed cones".

SHORE HARDNESS - an index indicating the hardness, or resistance to penetration of a material. Determined by measuring the rebound of a diamond tipped tool which is dropped onto the surface to be evaluated.

STRESS RELAXATION - the decay of stress with time when a material is subjected to a constant strain.

THERMAL CONDUCTIVITY - a coefficient expressing a proportionality between heat flux and temperature gradient within a media which transmits thermal energy by conduction.

THERMAL DIFFUSIVITY - a heat transfer parameter defining the ratio of the thermal conductivity to the thermal capacitance of a material.

THERMAL SEAL BREAKING - the opening, or breaking of the serotinous bond on sealed cones by the application of heat.

TOOL - the specific operational device which performs the basic function in a process or machine.

TRANSIENT HEAT FLOW - unsteady heat flow during the transitional period before and after steady state heat flow.

UMBO - the central protuberance or spike on the abaxial side of the tip of the cone scale of certain conifer species.

UNIT SURFACE CONDUCTANCE - the heat transfer coefficient combining the effects of heat flow by convection and radiation between a surface and a fluid.

VAPOR PRESSURE DIFFERENTIAL - the difference between the vapor pressure of water contained in a material at a given temperature and the partial vapor pressure existing in surrounding air.

VIABILITY - the percentage of a group of seeds expected to be capable of producing normal germinants under optimum conditions.

VISCO ELASTIC MATERIAL - a material displaying liquid-like and solid-like characteristics which result in the stress-strain relationship within the material being dependent upon the rate of deformation.

WET BULB TEMPERATURE - for practical purposes is considered to be the adiabatic saturation temperature of water in the air. It is the lowest temperature indicated by a moistened thermometer when evaporation takes place in a current of air.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. E.O. Nyborg for his inspiration and continuing guidance throughout this investigation, and to Dr. N.C. Franz for coordinating this interdisciplinary program between the Department of Agricultural Engineering and the Faculty of Forestry.

The author also wishes to express his thanks to Dr. P.G. Haddock, Dr. O. Sziklai, and Professor E.L. Watson for their interest in the investigation and to Mr. J. Konishi and Miss M. Henrich, B.C. Forest Service, for their technical assistance.

Thanks is extended to Mrs. E. Stewart for typing of the manuscripts.

The author wishes to express his gratitude to the British Columbia Forest Service, whose financial assistance made this study possible.

I. INTRODUCTION

Present techniques for the collection and extraction of conifer seeds for reforestation are expensive and time consuming due to the extensive use of manual operations. The transporting of bulky seed bearing cones over long distances to central extractories further adds to the high cost of the seed.

Conventional conifer seed extractories take the form of large permanent installations in which cones are kiln dried, and extracted by tumbling. The capacity of these extractories is limited due to the time required for kiln treatment. Thus the large capital and operating costs of such installations must be absorbed by a relatively small quantity of extracted seed.

It is apparent that extraction costs can be reduced by the use of an efficient, continuous flow mechanical extraction system, and that shipping costs can be reduced by operating the extractor at regional cone collection stations. Further, it is probable that a portable mechanical extraction system for conifer seed can be developed through the adaptation of the principle of threshing, as is used for extraction of agricultural seeds.

The adaptation of threshing to conifer seed extraction appears simple for the soft-coned species. Threshing of the hard-coned species may be more difficult, while the greatest challenge would appear to be the extraction of the hard-coned species, having serotinous scale seals, which bond the cone scales together in a closed position. To be suitable for use in British Columbia, a mechanical seed extraction system must be capable of handling all three types of cones. It is also apparent that a threshing system which can operate successfully on the hard-coned group, can be adjusted to operate on the other types of cones.

For this reason, the investigation of the mechanical extraction of conifer seeds dealt with in this report has been largely confined to lodgepole pine (Pinus contorta var. latifolia Englem). This species falls in the difficult to extract group, and constitutes a significant portion of the cone crop harvested for reforestation purposes in the Pacific Northwest.

II. CURRENT SEED EXTRACTION TECHNIQUES

Virtually all conifer seed extraction systems currently in use operate on the principle of kiln drying and tumbling. Drying of the cones causes the outward deflection of the cone scales, while the tumbling treatment shakes the seeds free after scale deflection has taken place.

Kiln extractories are generally large, permanent installations and may be classified into the two following forms: (i) Separate drying and tumbling, where the cones are dried in thin layers on stationary racks in the kiln and tumbling is performed after the drying treatment. (ii) Combined drying and tumbling, where the cones are tumbled during kiln treatment.

Processing of the cones is strictly on a batch basis in systems using separate operations, while systems using simultaneous treatment may operate either on a batch basis, or on a continuous flow basis where the cones pass through the system at a steady rate.

Kiln temperatures and treatment duration are controlled according to the cone species. In some installations, steam, or water mist, is injected into the kiln in order to reduce the rapid cone drying rate caused by the high dry bulb air temperatures.

Without regard for economic considerations, the kiln-tumbling extraction system is effective in extracting the seeds of the soft-coned species. The use of this technique for the extraction of seeds of the hard-coned species has been less satisfactory. This is due chiefly to the reduced seed viability believed to be caused by the high kiln temperatures required to unseal the cones, and the poor recovery of seeds caused by the incomplete cone scale deflection frequently encountered.

Although many reports outline in detail the design and operation of kiln extraction systems (7, 9, 41, 43)* little conclusive information is available on the techniques for and the factors affecting seed extraction of serotinous cones.

The use of high temperature kilns for conifer seed extraction was outlined in 1941 by Rietz (41). He recommended a drying schedule using the highest temperature which the green cones can withstand, and the lowest relative humidity that will dry the seeds to the desired storage moisture content within the desired drying period. He reported that a kiln temperature of 170°F (76.7°C) and a relative humidity of 30% had been found safe for jack pine (Pinus banksiana) cones when treated for 5 to 6 hours.

---

* Numbers in parentheses refer to references listed in the Literature Cited.

Baldwin (7) in 1942 indicated that there is an optimum moisture content of seeds for both storage and resistance to elevated temperatures, and recommended the lowest drying temperature and the shortest treatment time which will yield satisfactory seed release by the cones. He also described several designs for kiln drying and extracting equipment, but noted that there was considerable latitude in the range of drying conditions recommended for optimum seed extraction.

Edwards (18) in 1955 recommended a kiln treatment for extraction of lodgepole pine of 6 to 8 hours at a temperature of 140°F (60°C).

Kiln temperatures as high as 160°F (71°C) for serotinous cones were reported in 1971 by Schubert (43). He noted, however, that temperatures 20° to 30° lower would be used for initial drying of damp cones before the higher temperatures are applied to complete cone opening.

Wang (47) 1973, reported that seeds are commercially extracted from lodgepole pine cones after a 16 hour treatment at 60°C. He also reported that rewetting and additional kiln drying of such cones resulted in further seeds being removed from the cones, but that these had a reduced germinability as compared with the seeds from the first kiln treatment.

Pitkin (39) in 1961 reported the development of a combination kiln and extractor in which the cones were tumbled during the kiln drying process. The advantage of this combination is that the seeds are removed from the elevated temperature of the kiln as soon as they are released by the cone, hence receive a less severe heat treatment without reducing the quantity of seed recovered.

Nyborg and Brisbin (37) in 1973 investigated the heat transfer mechanism of the flash heating of lodgepole pine cones. Their report expressed concern for reduction in viability due to thermal seed damage during kiln treatments. They proposed a technique of flash heating of serotinous cones whereby the resinous bond could be broken by melting, without exposing the seeds to high temperatures. Experimental results confirmed that the cone scales of lodgepole pine cones can be released by exposure of the cones to air at approximately 300°F (149°C) for a period of approximately 15 seconds. Furthermore, they found that the temperature of the seeds in cones so treated was raised by approximately 15°F (8°C) above the pre-treatment temperatures of the cones.

III. OBJECTIVE

The object of this project was to investigate alternate methods of conifer seed extraction and modifications to existing seed extraction techniques. Because of the added difficulties of extracting seed from serotinous cones, and the goal of achieving a mechanical extraction system capable of handling all species, particular emphasis was placed on the extraction of lodgepole pine.

The specific areas of investigation of this project are as follows:

A. To investigate the physical and mechanical properties of the cones of *Pinus contorta* var. *latifolia* Englem, (lodgepole pine) for the purpose of identifying:

   (i) the factors which influence seed extraction from serotinous cones;

   (ii) the factors which affect seal release in serotinous cones;

   (iii) the effect of various cone treatment techniques on seed viability.

B. To design, fabricate and test the principal components of a portable continuous flow mechanical seed extraction system.

IV. SYSTEMATIC DESIGN PROCEDURE

The design and development procedure used in this study follows that used by Persson (38) and Nyborg and Shikaze (36), and takes the form of a systematic procedure oriented toward the design and testing of a machine system to handle biological materials. The steps of this procedure are outlined schematically in Figure 1.

The systematic procedure is initially carried out at two levels. In the first level of analysis, flow charts (Figure 2) of possible sequences of operation between the initial and final conditions of the product are constructed. The most appropriate sequence is then selected on the basis of economic considerations, mechanical limitations of machine and product, and other pertinent criteria. In the second phase of the procedure, each individual treatment device, or "tool" is analyzed in terms of its function and operating principle. The input conditions, output conditions and operational requirements of each tool in the process are determined and preliminary tool analysis is undertaken.

In most design projects involving the processing of biological materials, complete information on the physical and mechanical properties of the product is not available. The third step in this procedure is therefore the determination of the engineering properties necessary to complete the tool analysis. This allows the mathematical models of the individual tools of the process to be completed.

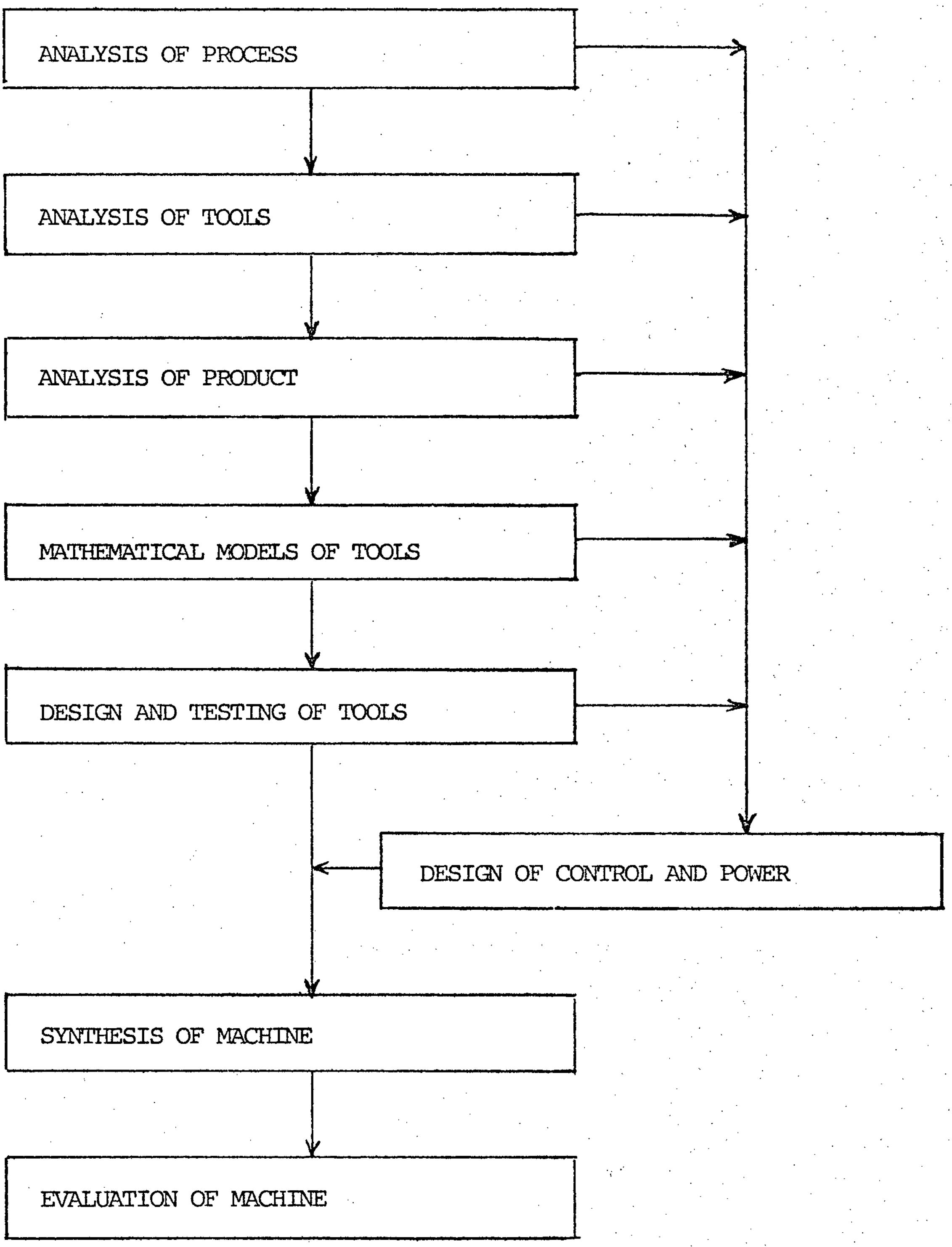


Figure 1. Steps in systematic design procedure.

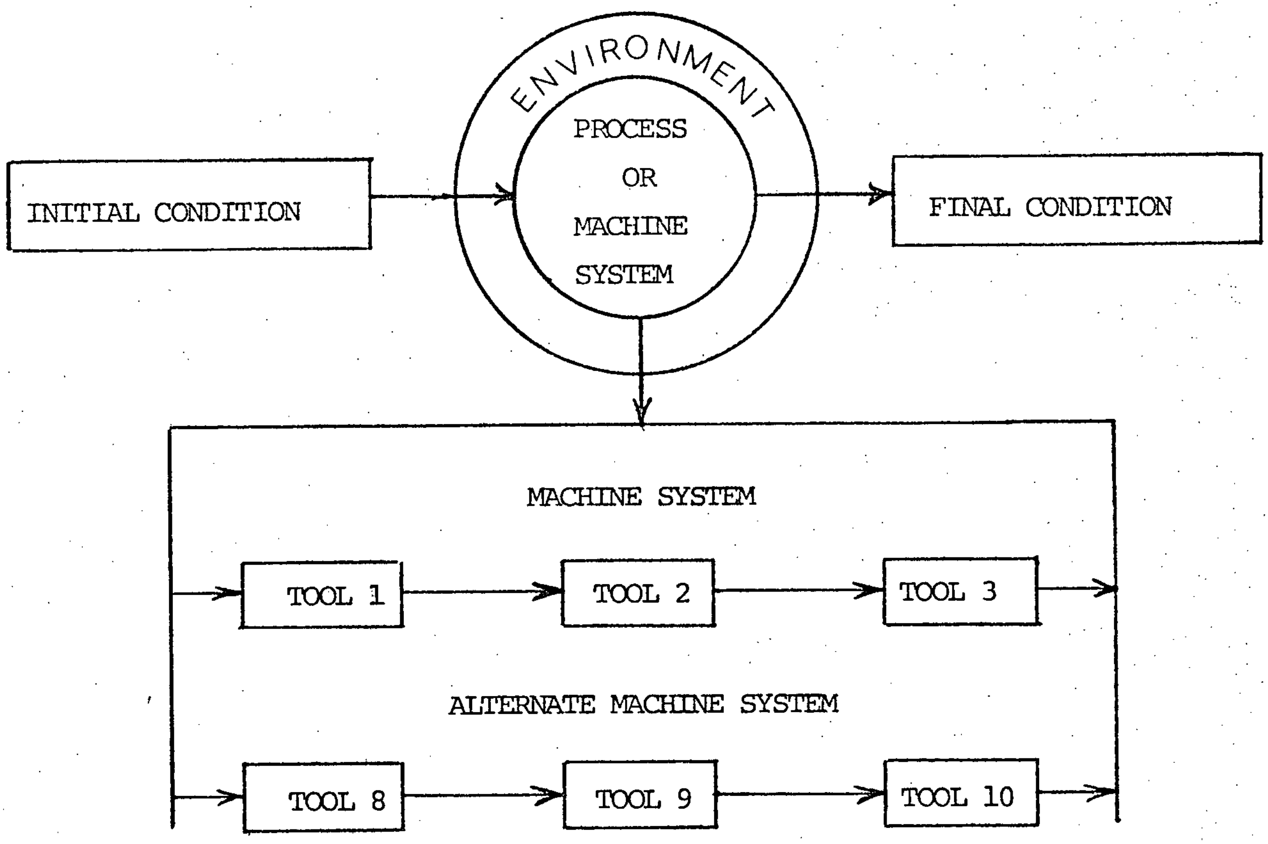


Figure 2. Defining the alternative processes

The fourth step in the procedure involves the design, fabrication, testing and calibration of the individual tools of the proposed machine system. This step includes the progressive redesigning of individual tools for optimization of tool performance as is found necessary by the testing procedures.

The final step involves the incorporation of the individual tools into the machine, and providing the control mechanisms and power systems appropriate to the operational requirements and material properties. The machine is then field tested to evaluate its functional performance and durability.

The research project outlined in this report was undertaken following this general design procedure. Although the magnitude of the development of a complete conifer seed extraction system capable of handling serotinous cones is beyond the scope of this research project, the investigations and development work reported here were organized according to the outlined procedure.

The major portion of the work dealt with in this report, therefore, deals with the investigation of the physical and mechanical properties of lodgepole pine cones which affect mechanical seed extraction. The machine design work is limited to the development of a continuous flow tool for breaking the serotinous cone scale seals, and a continuous flow tool for mechanical extraction of seeds from the unsealed cones.

V. COMPARISON OF KILN AND MECHANICAL EXTRACTION SYSTEMS

As noted earlier, the procurement of tree seed for reforestation purposes is expensive, due in part, to the large number of manual operations employed. A considerable improvement in the efficiency of handling and processing of cones after they reach the regional cone collection station can be achieved through a modest level of mechanization.

A comparison of the unit operations of a kiln extraction system using separate drying and tumbling treatments to those of a continuous flow mechanical seed extraction system is shown in Figure 3. The comparison is based on steps involved in converting seed filled cones at the regional collection station into semi cleaned seeds at the nursery.

The most notable characteristic of the kiln extracting system shown, is the large number of times which the cones must be handled, most of which are manually performed. Kiln extraction varies greatly from mechanical extraction because of the length of the waiting period required for drying, which commonly runs from 12 to 24 hours per batch.

The cost of kiln extracted seed is further raised by the cost of transporting large quantities of bulky material from the collection stations to the extractory, as well as by the large capital investment in storage and processing facilities required for this type of operation.

A portable mechanical extraction system such as the one exemplified in Figure 3 differs from kiln extraction systems in both its operating location and its method of operation. In this case, seed extraction is carried out at the regional cone collection stations, and only the semi-cleaned seeds are transported from that point.

The most notable feature of a continuous flow mechanical extraction system is its high production capacity. The ability to process cones on a continuous flow basis enables this relatively small portable piece of equipment to have a production capacity equivalent to a large commercial extractory. It is anticipated that a portable cone thresher could have a capacity in the order of one bushel of cones per minute.

The continuous flow processing performed by the system makes it particularly suited to automated materials handling systems which greatly reduce the manual labour requirement.

The magnitude of the savings in transportation costs achieved by extraction of seed at regional depots is exemplified in that fact that approximately 220 pounds of lodgepole pine cones yield one pound of seeds.

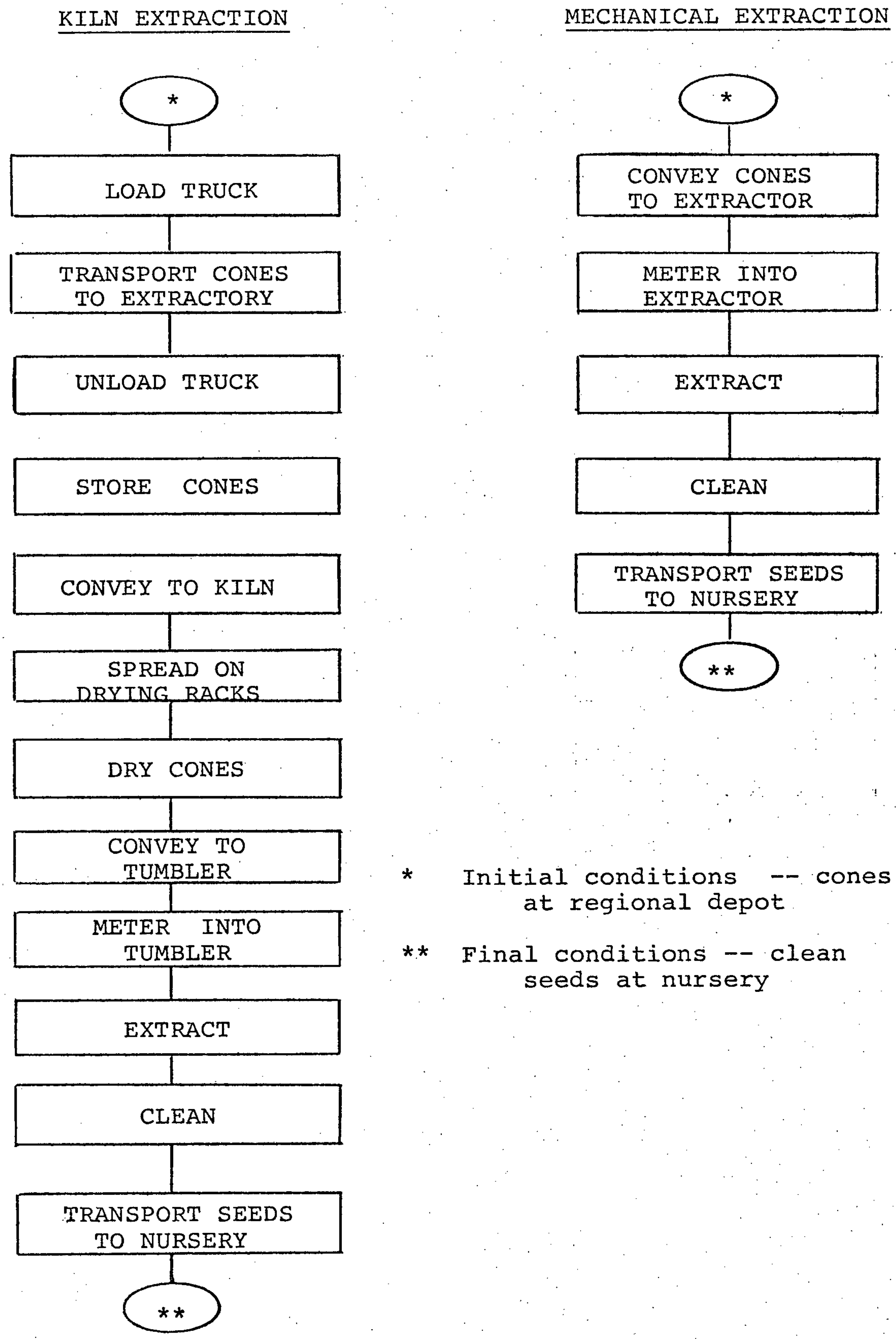


Figure 3. Flow charts comparing separate kiln drying and tumbling extraction to mobile mechanical extraction.

PART ONE

PHYSICAL PROPERTIES OF LODGEPOLE PINE CONES

VI PHYSICAL PROPERTIES AND CHARACTERISTICS WHICH AFFECT MECHANIZATION OF SEED EXTRACTION

Over the past fifty years reforestation in North America has grown from a few isolated plantations to a point where many millions of dollars are spent on reforestation each year in British Columbia alone.

During this time a wealth of knowledge has been gained in the techniques for and factors affecting the production of conifer seedlings for reforestation purposes. Only a small quantity of information has, however, been reported on the factors which influence seed extraction and the quality of recovered seed (35).

A review of the literature dealing with the properties and characteristics which affect the extraction of lodgepole pine is summarized.

1. Fruiting

The female seed bearing cones of lodgepole pine require two years to develop to maturity. In the first year the flower is developed, and pollination takes place, while the development of the ovary begins in the second year. By the fall of the second year, maturation of the cones and their seeds has been completed (44).

The opening of the cones at this time and the resulting dispersal of seed is dependent upon the presence of serotinous seals on the cone scales (12). Unsealed or non-serotinous cones open according to their moisture content and dispense most of their seed immediately while sealed cones remain on the tree, and can retain their seeds for many years with little reduction in seed viability (1, 14, 15).

The magnitude of annual seed crops of Lodgepole pine is highly variable, but the ability to retain viable seeds in serotinous cones on the tree ensures that a source of seed is available at all times for cone harvesting or for natural regeneration. The number of cones on a mature tree varies from a few hundred to a few thousand (16), and the average number of seeds per cone is frequently in excess of forty seeds (12).

2. Serotinous Cone Scale Seals

Lotan (29) reported that the term "serotinous" is used to define the condition of the cones of certain conifer species on which the scales are bonded together by a resinous seal located near the tip of the scales. The term is derived from the Latin *serus*, meaning late, and refers to the fact that the bonding of the scale occurs late in the development of the cones, just prior to the full maturation.

This characteristic is reported (8,46) to occur in several species of *Pinus*, including: *Pinus contorta*, *P. banksiana*, *P. serotina*, *P. rigida*, *P. radiata*, *P. clausa*, and *P. attenuata*.

The serotinous characteristic varies within lodgepole pine not only with geographic location and variety, but also with trees within a stand and from cone to cone on a tree (29). Crossley (14) reported that open or non-serotinous cones release some of their seeds in almost every month of the year, while the serotinous cones require exposure to high temperatures in order to break the seals and initiate seed dispersal.

This characteristic plays a major role in the rapid regeneration of lodgepole pine in areas which have been ravaged by wild fire. In this case, the heat of the fire breaks the seals of the cones and those which are not consumed, open and release a bountiful supply of seed after the fire has passed (29).

Lotan (29), in 1970, studied the characteristics of serotinous and non-serotinous lodgepole pine cones in order to identify the factors which determine whether or not the cones will be sealed. Both chemical and anatomical analyses failed to identify the controlling factor. His work did, however, rule out the possibility of the scale seals being broken by the flexural forces of the cone scales. He determined that the force required to break typical serotinous bonds is approximately thirty times the flexural strength of the scales.

The opening of sealed cones by raising the cone temperature was reported in 1910 by Clements (12) who indicated that seal breaking took place at temperatures of

45°C to 50°C.

Cameron (11) in 1953 measured the temperature at which six cones of lodgepole pine opened in a water bath and found a range from 44.5°C to 49°C, with a mean value of 45.3°C. He also measured the melting temperature of an ether extraction of material removed from the bond area of cone scales and obtained melting temperatures of 45°C and 46°C for the two tests.

Thompson (45) found, in 1969, that 140°F (60°C) was the lowest temperature at which all cone scales of lodgepole pine would open.

Crossley (13) in 1956 studied the opening of lodgepole pine cones under the influence of solar radiation. He found that air temperatures up to 3.5 feet above the ground of 80°F (26.7°C) could result in sufficient heating to break serotinous seals provided that direct sunlight or reflected radiation from some nearby surface could add additional heat.

Special treatment of serotinous cones to break the resinous bond of the scales has been proposed in a few instances. Hebb (24) in 1954, reported complete opening of the cones of pond pine after a sackful of the cones were placed in a tank of boiling water for "a moment". The effect on seed viability was not reported.

Meseman (32) in 1973, reported improved seed recovery from jack pine and certain other species by submerging the cones in a solution consisting of one part Javex (hypochlorite bleaching solution) to 20 parts water. The solution was held at a temperature of 150°F (65.5°C) and cones were treated for 1 to 2 minutes, after which they were dried at 145°F for 6 to 12 hours. No reference was made to the effect of this treatment on seed viability.

Beaufait (10) in 1960 studied the effects of high temperatures on the cones and seeds of jack pine. He found that cones opened in a matter of seconds when placed in an oven at temperatures up to 1300°F (704°C).

Nyborg and Brisbin (37) in 1974, evaluated the thermal gradient within lodgepole pine cones briefly heated by a blast of hot air. They found that 15 seconds of treatment was required to break the seals of cones subjected to an air blast of 312°F (155°C), and that the temperature rise of the seeds at the time of seal release was 14°F (7.8°C). A mathematical transient heat flow analysis indicated that seed temperatures for such treatments could be fairly accurately estimated.

3. <u>Scale Opening Mechanism</u>

The opening mechanism of the scales of conifer cones, and the relationship between scale deflection and cone moisture content has been discussed in the literature of several investigators (17, 19, 21, 26, 33). Although these reports have dealt with several species, none have dealt specifically with lodgepole pine.

Harlow, Cote and Day (21), in 1964, studied the cell structure of the cone scale tissue of five species of pine, and reported that cone scales are made up of two distinct layers. The inner or abaxial layer is made up of wood fibres which extend from the cone axis, while the outer or adaxial layer is made up of short rectangular thick walled cells. They found that during drying, the fibrous tissue displayed negligible lengthwise shrinkage, while the outer tissue shrank, upon drying, from 10 to 36 percent, depending upon the species.

A comprehensive study of this mechanism was conducted by Allen and Wardrop (3) in 1964, and dealt with the opening and shedding of female cones of _Pinus_ _radiata_. In order to explain the hygroscopic mechanism of the adaxial vascular tissue and the abaxial sclerenchyma tissue of the cone scale, they studied these tissues by means of electron microscopy. They found that in the vascular tissues, the cellulose microfibrils, which make up the structural portion of the cell walls, are oriented largely in line with the longitudinal axis of the scale. In the sclerenchyma tissues, however, the majority of the microfibrils of the individual cells are oriented parallel to the transverse axis of the scales. They reported that since shrinkage of cell wall material is greatest in a direction perpendicular to the direction of microfibril orientation, the differential shrinkage during drying of the two layers of cone scales can be explained in terms of the predominant orientation of the microfibrils within these two tissues. The longitudinal shrinkage during drying of the vascular tissue of the cone scales measured in this investigation was reported to be 1.5%, while that of the sclerenchyma tissue of the same scales was found to be 15%.

4. Cone Opening at Maturity

The opening of the seed bearing cones of most conifer species is attributed to the differential shrinkage between the adaxial vascular tissue and the abaxial sclerenchyma of the cone scale (3, 21, 30).

Allen and Wardrop (3), in 1964, studied the physiology of cone maturation and opening, and the subsequent shedding of the scales. They defined four stages in the maturation of the cones of *Pinus radiata*, and examined the anatomy of the cones in each stage.

They found that until the development of the cone was complete, the moisture content of fruiting cones was established by the water economy of the overall tree. Upon maturation, however, a barrier of resin develops in the tissue at the base of the cone peduncle which inhibits the movement of moisture from the branch into the cone. This isolation of the cone from its source of moisture leaves the cone to be dependent upon atmospheric conditions for the establishment of its moisture content.

5. Resistance to Thermal Damage

Although many references (2, 7, 10, 13, 41, 47) have been made throughout the literature regarding the maximum temperature which conifer seeds can tolerate, little detail has been provided with respect to the type and duration of the treatment referred to. Additionally, researchers have shown little concurrence on the safe limit for high temperature treatment of seeds. Most authors dealing with this aspect have cited a single mortality temperature for various species, with no reference to seed moisture content or duration of high temperature treatment. Research on agricultural seeds has shown, however, that the lethal temperature for seeds is dependent upon both moisture content and duration of heating.

Allen (2) in 1957 reported that Douglas fir seed which had been precured showed no ill effect when kiln dried at 122°F (50°C) but at 140°F (60°C) losses in viability of 20% or more were observed. Immature cones showed heavy losses when dried at 122°F after precuring, and at 104°F (40°C) when placed into the kiln in a green state.

Woodforde and Lawton (52) found in 1965 that treatments of one hour duration at temperatures as low as 47°C initiated depression of the germination of carrot seeds. This threshold temperature was reported to be slightly raised as seed moisture content was reduced to approximately 12%.

Beaufait (10) in 1960 studied high temperature treatment for the purpose of breaking the serotinous seals of jack pine cones. He reported that when cones were treated at 1300°F (704°C) the seeds in cones which ignited did not remain viable but that the seeds in cones which did not ignite exhibited very little reduction in germinative capacity.

Watson (48) in 1965 studied the heating of wheat in sealed containers. He found that a temperature of 140°F (60°C) for 6 hrs caused complete loss of viability if moisture content was above 15% w.b., but if the moisture content was less than 9%, a temperature, of 140°F for 10 hours caused no reduction in germination.

Continuing this work in 1970, Watson (49) reported that the rate of loss of germination capacity was a logarithmic function of time, and that the reduction was at a slow rate in the initial phase of treatment, and took on a more rapid rate after a period of treatment. The rate of loss of germination capacity and the time to initiate rapid reduction of germination capacity was found to be dependent upon seed moisture content and treatment temperature. He confirmed this relationship by replotting data reported by other investigators using other seed species. He also clarified the fact that the concept of a "killing temperature" and "initiation of damage" are ill defined terms which did not reflect the time-temperature relationship of the loss of viability of seeds.

6. Resistance to Mechanical Damage

Mechanical damage in seeds is reported by Mohsenin (34) to be due either to external forces under static or dynamic conditions or to internal forces caused by changes in moisture or temperature. The forces of external origin which cause damage to seeds generally arise from the various handling treatments employed in the harvesting, separating and cleaning processes.

Damage from external forces which results in loss of viability occurs either in the form of abrasion of the seed coat during handling, or as rupture of the seed coat and/or the internal seed structure by excessive stresses. These forces may be either static or dynamic.

The ability of seeds to resist mechanical damage has been shown (34) to be very dependent upon moisture content. Each seed species has an optimum moisture content for handling. Above the optimum, the seeds are soft and easily incur plastic deformation, while below the optimum the seeds are hard and incur brittle failure. Gregg et al. (20) indicate that this optimum moisture content lies between 10 and 16 percent wet basis for most seeds.

Mohsenin also reported that the mechanical strength of biological materials, and hence the resistance to mechanical damage, is up to five times greater under dynamic loading than it is under static loading conditions.

The main source of mechanical damage incurred by forest tree seeds which are kiln extracted is from the action of the dewinging treatment (17). This is most severe on those species whose seed wings are an integral part of the seed coat. Mechanical damage may also be incurred during other treatments, including extraction by tumbling and most other cleaning operations.

The susceptibility to mechanical damage of seeds still contained in their cones was investigated in 1958 by Lyle and Gilmore (31) who worked with ripe cones of loblolly pine (Pinus taeda). They found that as long as seeds remained in their original position inside cones, any action short of crushing the cones did not affect the germination percent of the seeds.

The susceptibility to mechanical damage of seeds extracted by threshing is reported by Bainer et al (6) to be a function of the seed moisture content, the peripheral threshing cylinder speed, and the configuration and adjustment of the cylinder and concaves. Damage is lowest at low cylinder speeds, but the threshing effectiveness is also reduced at lower speeds. They also state that there appears to be an optimum rub-bar and concave configuration for each species, and that the use of rubber covered surfaces reduces the amount of seed damage under a given set of conditions.

7. Stress Relaxation of Cone Scales

Baldwin (7) in 1942 described the poor release of seeds of some cones which is caused by inadequate cone scale deflection during kiln drying. He reported that this condition is most prevalent in serotinous cones which have dried prior to kiln extraction, and termed the condition "case hardening". To improve seed yield of these cones he recommended that they be soaked in water, then dried once more in the kiln.

The term "case hardening" as used in the above context is not compatible with the use of this term in describing the surface hardening treatment of metal components or the development of residual stresses within wood during drying (34). The condition described by Baldwin and others (29, 32, 47) is more accurately identified as a condition caused by stress relaxation in the cone scales. Stress relaxation is defined (34) as the process whereby stresses in a material subjected to a constant strain or deformation undergo a decay with time.

The classical study of rheology indicates that stress relaxation takes place only in viscoelastic materials and that virtually all biological materials fall into this classification.

The process of stress relaxation in the scales of serotinous cones takes place while the cones have a low moisture content which causes stresses within the scales. These stresses act to open the scales, but because of the serotinous bond the scales are held in the closed position and hence remain in a stressed condition. While cones are held in this stressed condition, the cone scale material deforms and the scale deflecting stresses diminish within the scale. The result of this process is that cones whose scale tissue has undergone a stress relaxation are unable to deflect outward to their full extend after the seals are broken.

8. Thermal Properties

The thermal properties of the cones of Pinus banksiana were investigated in 1961 by Lee and Beaufait (28). Their work was carried out on young cones one and two years old, and on old cones over three years old, which had a moisture content of 6% ± 1% wet basis.

Using a cylindrical shell analysis, they found the thermal conductivity of young and old cones to be respectively, 0.123 and 0.114 BTU's per hour, foot, degree F. Using a thin plate analysis, the thermal conductivity of young cones was found to be 0.113. The thermal diffusivity of young and old cones was found to be 0.0073 and 0.0090 square feet per hour respectively.

The heat transfer analysis carried out in 1973 by Nyborg and Brisbin (37) on the flash heating of lodgepole pine cones was done using a thermal conductivity of 0.07 BTU's per hour, foot, degree F, and a thermal diffusivity of 0.005 square feet per hour. The temperature of seeds during flash heating determined by this analysis was found to correlate well with measured seed temperatures.

9. Drying Rate

The kiln treatment of serotinous cones serves two functions, namely to break the resinous bonds and to dry the cone scales to cause their outward deflection and the release of the seeds.

As reported in Chapter II, kiln temperatures in excess of 140°F (60°C) are frequently used for the extraction of serotinous cones, while temperatures up to this value are used for non-serotinous cones. In addition to elevated dry bulb temperatures, the wet bulb temperature of kiln air is frequently elevated by the injection of steam or water mist (41, 47).

The elevation of the dry bulb temperature to a point which effects seal breakage is a necessary step in seed extraction by the conventional kiln-tumbler method. Once seal breakage has been achieved, however, temperatures in the order of 140°F are no longer required because satisfactory cone drying can be achieved at much lower temperatures.

The practice of adding water vapor to the kiln air in order to reduce the drying rate from that established by the heated kiln air is inconsistent with effective drying, seed quality and energy economy.

A study of the mass transfer process whereby water is moved from a hygroscopic material into the air (25, 40) reveals that the drying rate is solely dependent upon the magnitude of the vapor pressure differential between the wet material and the immediately adjacent air. In other words, the drying of cones is dependent upon the differential in vapor pressure between the water within the material and the vapor pressure of the air in the boundary layer surrounding the wet cone surface. The effect of injecting water vapor into the kiln air is to increase the vapor pressure in the boundary layer adjacent to the cones. The same effect can be achieved either by reducing the velocity of air over the cones, which reduces the vapor pressure gradient at the surface of the cones or by reducing the dry bulb temperature of the air in the kiln. The latter is clearly more desirable because it reduces the danger of thermal damage to the seed, and also reduces the quantity of heat required.

It can be seen that the most suitable cone drying process is achieved by keeping the wet bulb temperature low, the air circulation rate high, and by minimal raising of the dry bulb temperature of the kiln air. These conditions can be achieved by eliminating the injection of water, increasing the rate of air exchange, and by raising the dry bulb temperature only sufficiently to provide an acceptable rate of drying.

In the case of serotinous cones, the breaking of the seals prior to kiln treatment eliminates the need for high temperatures within the kiln. Alternatively, the dry bulb temperature of the kiln can be lowered as soon as seal breaking is achieved so that excessive drying rates and the resulting seed damage are avoided.

VII. PRELIMINARY INVESTIGATIONS

A number of preliminary tests were carried out on lodgepole pine cones in order to determine certain basic physical properties and characteristics. These data were utilized in the development of subsequent testing programs and procedures. These preliminary studies are discussed individually below.

1. Identification and Description of Cones

All tests were conducted on cones of interior lodgepole pine (*Pinus contorta* var. *latifolia* Englem.) which were identified by the British Columbia Forest Service seed lot classification as Nelson 3-3.

The cones were obtained from a commercially harvested seed lot and thus were a representative sample of the type of cones of this species which would be processed by a commercial seed extractory.

The cones varied in length from approximately 0.75 in (1.9 cm) to 2 in (5.1 cm) and had an overall conical profile varying between approximately 25 and 65 degrees. The appearance of the cones was consistent with the graphic description presented in the B.C.F.S. lodgepole pine cone collecting guide (4).

A cross-sectional view of three typical cones is shown in Figure 4, and the location of the serotinous cone scale seals is identified. Figure 5 shows a view of the adaxial and abaxial surfaces of typical cone scales.

2. Preparation of Material

The cones used for all tests were collected during the fall of 1973, and were dried on outdoor racks to a moisture content of approximately 25% wet basis. The cones were then mixed to ensure uniformity of samples for subsequent testing.

The mixing technique consisted of layering approximately 15 bushels of cones into a large pile and shovelling them over into a new pile by lifting cones from the side of the original pile and layering them across the top of the new pile. This layering process was repeated seven times, after which, cones meeting the Class 1 specifications of the B.C. Forest Service Lodgepole Pine Cone Collecting Guide (4) were sorted out. Class 1 cones consist of those cones maturing in the year of harvest, and having all scales sealed. The cones for subsequent testing were then placed in sealed containers and stored at $34^{o}F$ ($1^{o}C$).

3. Degree of Serotiny of Cone Seed Lot

The degree of serotiny of the cones under study was determined at the time of cone sorting by selecting a sample of the cones and classifying them according to their condition of serotiny. These cones were grouped into: (i) cones having all of their scales open, (ii) cones having a portion of their

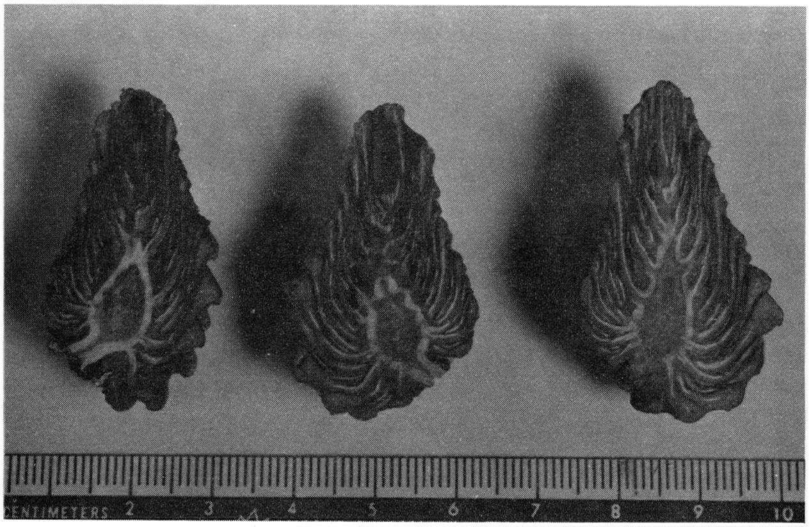


Figure 4. Cross section of typical cones showing location of serotinous seals.

Figure 5. Location of serotinous seals on abaxial (above) and adaxial surfaces of typical cone scales.

scales open, and (iii) cones having all their scales sealed in the closed position. A group of typical partially opened cones is shown in Figure 6.

Of the 425 cones in the sample evaluated, the percentage of cones falling into each group was found to be as follows:

(i)	Cones fully unsealed	2.2%
(ii)	Cones partially unsealed	1.2%
(iii)	Cones fully sealed	96.6%

The cones used for all subsequent testing in this project were presorted and only completely sealed cones were studied.

4. Viability of Seeds by Location in the Cone

To identify the viability of seeds from untreated cones, a control group of 100 cones was manually opened to extract and count all seeds in the cones.

The extraction was accomplished by removing individual scales from the cones using side-cutting pliers as shown in Figure 7. As each scale was broken free of the serotinous seal and peeled back, the seeds thus exposed were collected for testing.

During the extraction process the seeds were separated into three groups, according to their position in the cone. The three groups were (i) those seeds originating toward the base or peduncle end of the cone, (ii) those originating in the central portion of the seed bearing region

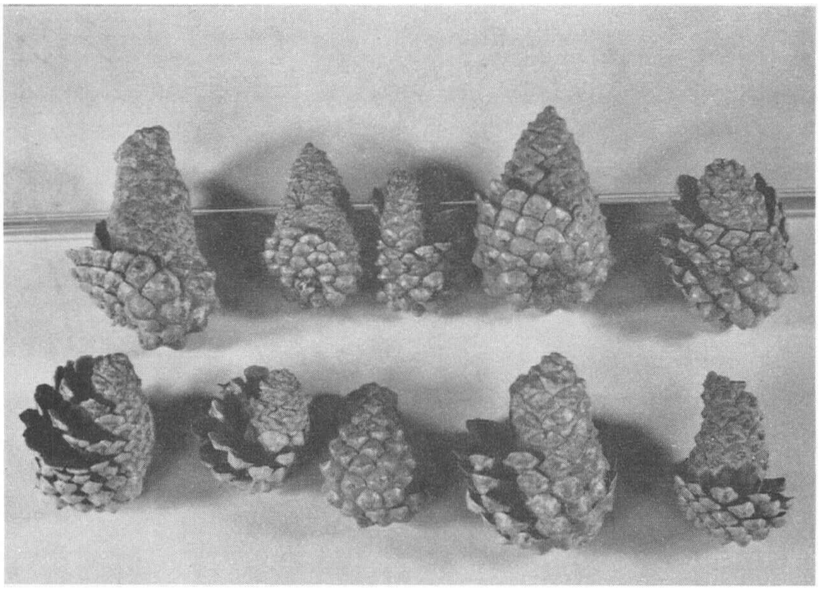


Figure 6. Typical partially opened cones from commercially collected cone lots.

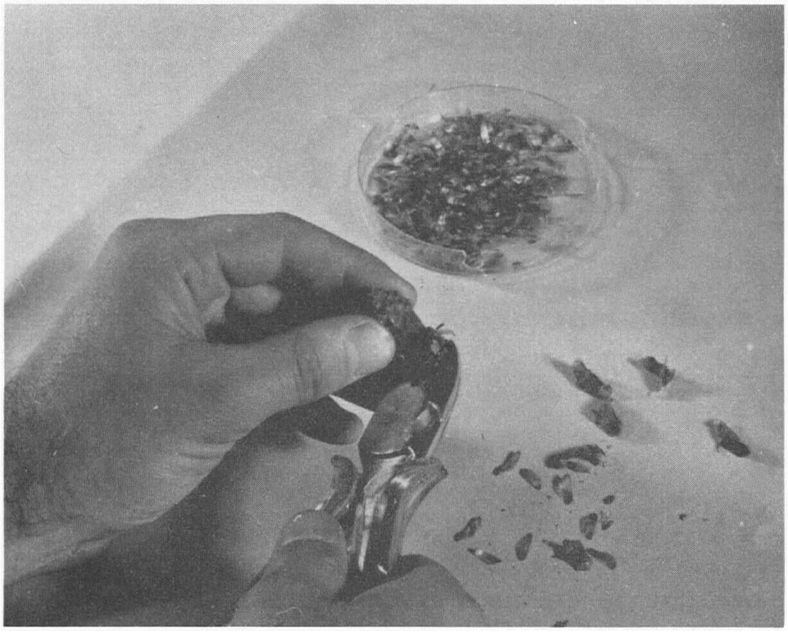


Figure 7. Technieque for manual opening of sealed cones.

of the cone, and (iii) those originating near the tip of the cone. The division point between groups was arbitrarily chosen to provide proportions of the total seed quantities of approximately 25%, 50% and 25% respectively. The number of seeds from each cone going into the three groups was recorded and is reported in Table A-1* in the Appendix.

The viability of seeds from each of these groups was subsequently determined, and the germination percent for each group was obtained. These data are shown in Table 1.

The results of this test indicate that a slightly higher percentage of seeds at the extremities of the seed bearing region of these cones are empty, but filled seed show essentially the same germination percent in the three regions of the cones.

TABLE 1. SEED VIABILITY BY LOCATION IN CONE

	Lower	Mid	Tip	Total
Total Seeds	592	1076	724	2392
% of Seeds Filled	83.0%	88.0%	79.3%	84.1%
Number of Filled Seeds	491	947	574	2012
% Filled Seed Producing Normal Germinants	91.2%	90.9%	91.6%	91.1%
Number of Viable Seeds	448	861	526	1835
% Total Seed Producing Normal Germinants	75.5%	80.0%	72.6%	76.7%
Number of Viable Seeds/Cone	4.5	8.6	5.3	18.4

Weighted Average Germination Percent for Total Sample -- 91.2% for Filled Seed
-- 76.6% for Total Seed

* Tables whose numbers are prefixed by the letter A appear in Appendix A.

5. Viability of Seeds with Respect to Ease of Extraction

The relationship between the viability of Lodgepole pine seeds and the ease of their extraction after seal breaking was investigated. The purpose of this was to determine whether or not the more difficult to remove seeds had a lower viability than the easily extracted seeds.

In this test, approximately two hundred class 1 cones were removed from storage at 34°F (1°C) and were immersed for thirty seconds in water having a temperature of 205°F (96°C). The cones were then dried at room temperature for four days and manually extracted.

Each cone was individually treated to extract first the easily removed seeds, then the difficult to extract seeds. Those seeds which were removed from their cone by five light taps on the tip end of the open cone, while it was held with the scales opening downwards, were considered to be easily extracted seeds. Those seeds remaining in the cones after this treatment were considered to be difficult-to-extract seeds, and were recovered by manually dissecting the cones by individually tearing the scales from the cone to free the seeds.

The light tapping treatment used in this test extracted approximately three-quarters of the total seed contained by the cones. The seeds remaining in the cones after the tapping treatment were found to be mainly concentrated in the lower or basal end of the seed bearing region of the cones.

The results of this test, as shown in Table II indicate that the easy-to-extract seeds of Lodgepole pine have a higher percentage of filled seed, and a slightly higher germination percent of the filled seeds. The fact that the less easily extracted seeds have a lower portion of filled seeds concurs with the observation that these seeds tend to be concentrated in the lower region of the cones where the previous test found a higher portion of empty seeds.

TABLE II GERMINATION PERCENT FOR EASE OF EXTRACTION TEST

	% of Filled Seeds in Sample	% Germination of filled Seeds	% Germination of Total Seeds
Easily Extracted Seed	83.8	98.7	82.7
Difficult to Extract Seed	70.1	93.2	65.3

6. Viability of Kiln Treated Seeds

In order to assess the sensitivity of Lodgepole pine seed to thermal damage during conventional kiln extraction, viability tests were carried out on seeds recovered from cones treated for various periods in a constant temperature oven.

A temperature of $140^{\circ}F \pm 3^{\circ}$ ($60^{\circ}C \pm 1.5^{\circ}$) corresponding to temperatures commonly used for the kiln extraction of serotinous cones, was used for this preliminary investigation. Groups of cones having an initial moisture content of 23% w.b. were oven treated for periods ranging from 4 to 72 hrs.

The germination percent of these groups are tabulated in Table A-2 in Appendix A, and the plot of viability against treatment time is shown in Figure 8.

The results of this test indicate that seed germination percdnt is not appreciably reduced by drying cones from a moisture content of 25% wet basis in a non-circulating oven for periods up to 72 hours.

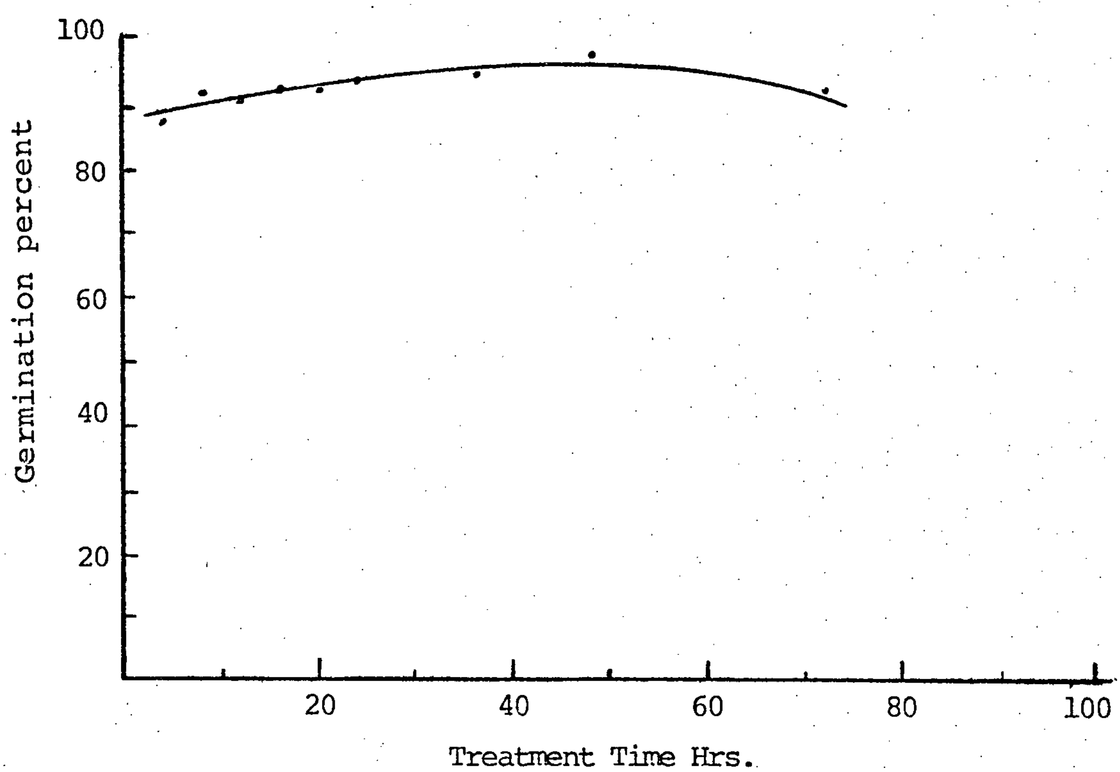


Figure 8. Curve of germination percent with treatment time for cones dried in a 140°F (60°C) oven.

7. Moisture Content

All cone moisture content determinations made throughout this investigation were carried out according to the method of analysis for plant materials recommended by the Association of Agricultural Chemists (5), where the samples were dried for two hours at a temperature of 135°C.

Moisture contents are reported on a wet basis, which is determined by weight according to the following equation:

$$\text{Moisture Content (wet basis)} = \frac{\text{Moisture}}{\text{Dry Matter + Moisture}} \times 100\%.$$

The average overall moisture content of cones received for testing was approximately 25% wet basis. These cones were immediately stored in sealed containers, hence all subsequent tests were conducted on cones whose initial moisture content was very close to this value.

VIII. INVESTIGATIONS CONDUCTED ON PHYSICAL PROPERTIES OF CONES

Eight investigations were conducted to determine the physical properties and characteristics considered to be influential in the extraction of lodgepole pine cones. These are detailed individually below.

1. Equilibrium Moisture Content of Cones

The equilibrium moisture content during drying was determined at several points over a range of relative humidities from 11.3% to 100%. Determinations were made by placing a number of cones over saturated salt solutions in sealed containers (Figure 9) and allowing them to stand at room temperature for thirty days to achieve equilibrium.

The specific salts used and the reported equilibrium relative humidity for each (50) are as follows:

Barium chloride 90.2%

Ammonium chloride 78%

Ammonium nitrate 61%

Sodium iodide 39%

Potassium acetate 23%

Lithium chloride 11.3%.

Distilled water was used to establish a relative humidity of 100%.

Prior to being placed in the sealed chambers, the serotinous seals were broken by immersing the cones in boiling water for approximately 20 seconds. This allowed the cones to open, thus exposing a greater surface area, and permitting a more rapid exchange of moisture.

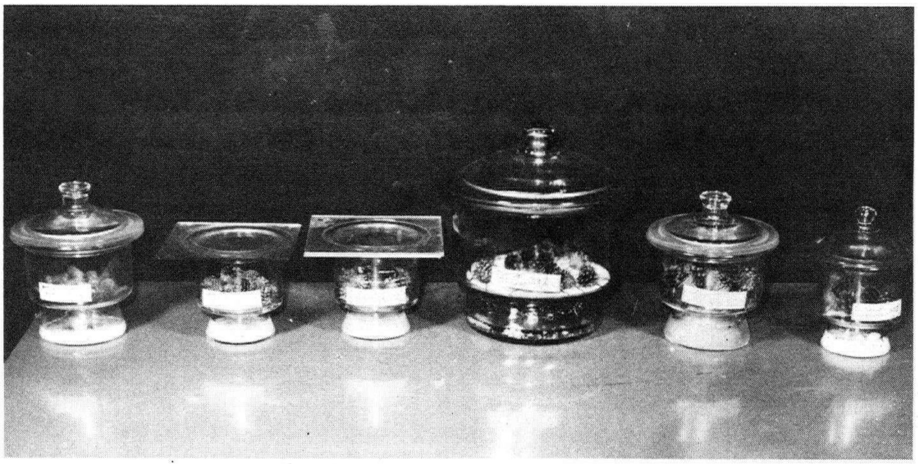


Figure 9. Containers for equilibrium moisture content determination.

The equilibrium moisture content of cones during drying is shown in Table A-3 in the Appendix and is plotted in Figure 10 below. The range of values determined, and the shape of the drying curve for these cones is typical of most biological materials.

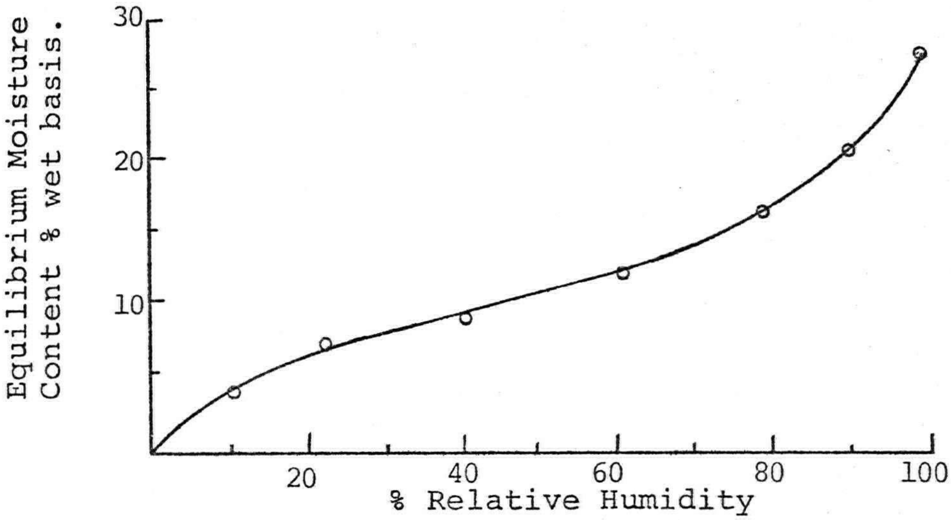


Figure 10. Equilibrium moisture content during drying of lodgepole pine cones.

2. Melting Point Determination for Serotinous Bonds

The breaking of the resinous bond holding serotinous cones closed is essential for seed extraction. Conventional extraction requires kiln temperatures sufficiently high to cause melting of the bond material, but not so high as to cause damage to the seeds.

The melting point temperature of the serotinous seals of lodgepole pine cones, assumed to be the temperature at which scale separation takes place, was determined. Young cones, harvested in the year in which they matured, and weathered cones several years old were studied.

Cones to be tested were cut in two by sawing the cones axially. One part of each cone was placed in a closed glass jar which was immersed in a constant temperature water bath, as shown in Figure 11. Sixty cones from each age class were tested.

The cone halves were allowed to reach equilibrium temperature with the bath water, and were individually examined to detect scale separation. Cone halves which had undergone seal separation on the majority of the scales in the seed bearing region were considered to have reached the seal melting temperature and were removed and counted. The jars containing the cones were then returned to the bath and the temperature was increased by approximately 0.5^{o}C. This process was carried out on three to four hour intervals for the duration of the tests.

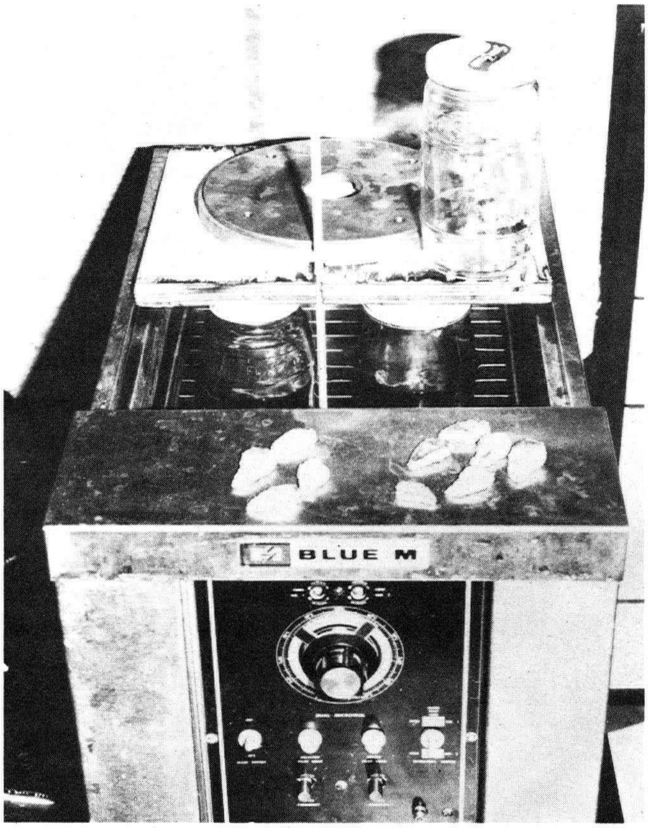


Figure 11. Apparatus for determination of seal melting temperatures.

The number of cones whose scales were released at each test temperature is shown in Table A-4. The results of these tests indicate a relatively wide range of temperatures over which the seals are broken. The mean temperature at which new cones opened was found to be 52.5°C with a standard deviation of ± 5.7°C. The mean temperature at which old cones opened was found to be 54.5°C with a standard deviation of ± 5.8°C.

3. Scale Deflection Angle vs. Moisture Content

The relationship between moisture content and the angle of cone scale deflection after cone opening was studied by evaluating the maximum scale deflection angles on individual cones. The cone scale angles were measured by optically observing the angular orientation of a reference plane cut into the tip of the cone scales prior to seal breakage. The reference plane was made by grinding a flat surface on the umbo of each scale to be measured.

Cones to be studied were fitted with an alignment pin which was inserted into a small hole drilled into the cone core. This pin served as the angular reference for both the cutting of the flat surface on the sealed cones, and the measuring of the scale deflection angle of the opened cones. Figure 12 shows typical cones prepared in this way, both before and after scale deflection.

The flat surface on the scale umbos used for detecting scale deflection was cut by means of a table saw fitted with a side cutting grinding wheel. During cutting, the alignment pin was held parallel to the cutting face by a machine tool holder. The umbo of all suitable scales located around the mid point of the cones under study were surfaced in this manner.

The apparatus used to measure scale angles is shown in Figure 14 and consists of a modified drafting machine

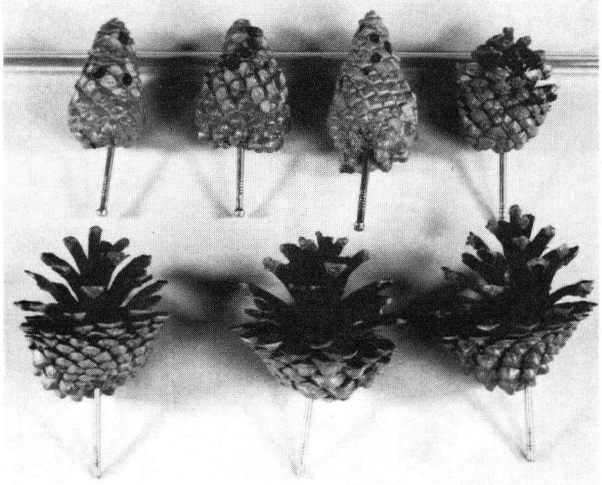


Figure 12. Cones prepared for scale deflection measurement before and after opening.

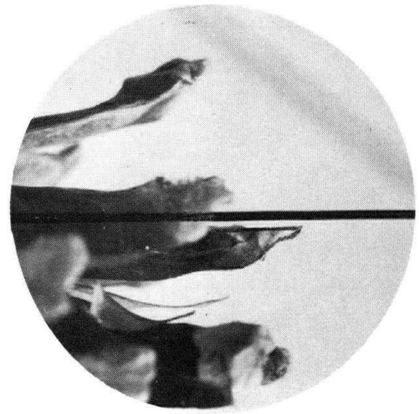


Figure 13. Alignment of cross hair with ground scale surface.

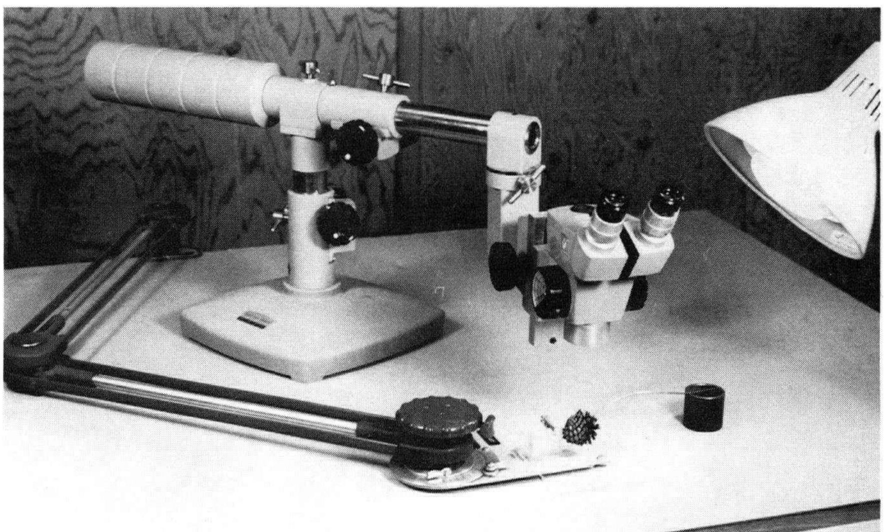


Figure 14. Apparatus for measuring cone scale deflection angles.

and a binocular microscope. The scale of the drafting machine is replaced with a "vee-block" clamp which grips the alignment pin and orients the axis of the cone parallel to the cross hair of the microscope when the drafting machine head was in the zero position. Scale angles are read from the drafting machine vernier after the head and the attached cone are rotated to orient the edge view of the ground surface of each scale, parallel to the microscope cross hair, as shown in Figure 13. Scale deflection angles can, in this way, be measured to the nearest degree.

The datum reported to represent each cone in this study was the average deflection angle of the five to nine scales having the greatest deflection on that cone. The scales measured for this purpose were chosen after the cones opened, and were located in a band around the cone near its midpoint. Groups of sixteen cones were used for each test.

Cones for scale angle measurement were removed from storage and their seals broken by hot water treatment. By the method described in Section 1, above, they were then brought to the wet basis equilibrium moisture contents shown in Table III.

The maximum scale deflection data for cones at each moisture content are shown in Tables A-5 to A-11. These are summarized in Table III, and plotted in Figure 15.

From Figure 15 it is apparent that the onset of scale deflection of open lodgepole pine cones occurs as the wet basis moisture content is reduced below approximately 25%. Sealed cones in this moisture range acquire stresses which tend to open the scales.

TABLE III. SCALE DEFLECTION ANGLE AT VARIOUS CONE MOISTURE CONTENTS

Equilibrium Moisture Content, Wet Basis.	Average Maximum Cone Scale Deflection Angle
28.3%	0^o
21.2%	$8.5^o \pm 3.8^o$
17.4%	$31.7^o \pm 7.8^o$
13.5%	$50.0^o \pm 9.4^o$
9.5%	$62.6^o \pm 11.5^o$
7.5%	$71.8^o \pm 12.8^o$
4.8%	$86.6^o \pm 13.1^o$
Oven Dry	$97.0^o \pm 15.7^o$

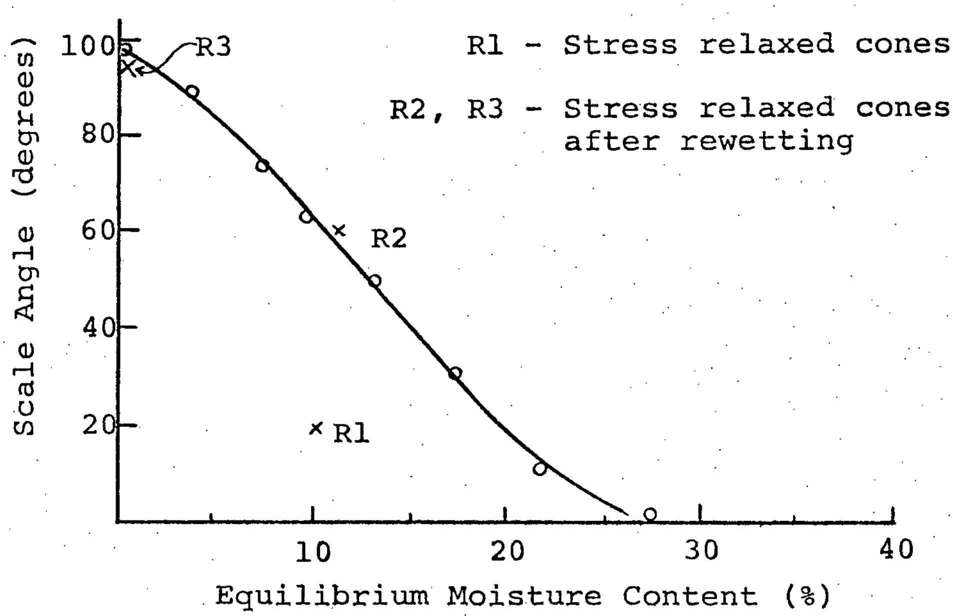


Figure 15. Maximum scale angle vs. equilibrium moisture content for non-stress relaxed cones.

4. Scale Deflection Angles of Stress Relaxed Cones

Stress relaxation occurs in the scales of sealed serotinous cones while the cones are at a moisture content which would cause outward scale deflection if the serotinous seals did not restrain such movement. This occurs in lodgepole pine cones at moisture contents below approximately 25% wet basis.

The degree to which cone scale deflection is impaired by stress relaxation is illustrated in Figure 16. The cones shown were stored for one month at the moisture contents noted, and after their seals were released by hot air, they were brought to a moisture content of approximately 10% wet basis.

The cross sectional view of stress relaxed and non-stress relaxed cones shown in Figure 17 indicates the form of scale flexure and the width of the seed exiting path for cones in both conditions.

The effect of stress relaxation on scale deflection was investigated by studying cones whose scales were kept in a stressed condition for a period of one month.

For this study, cones were prepared for scale angle measurement as described above, but the serotinous seals were not broken until the end of the stress relaxation period. A test group of twenty cones was allowed to dry to approximately

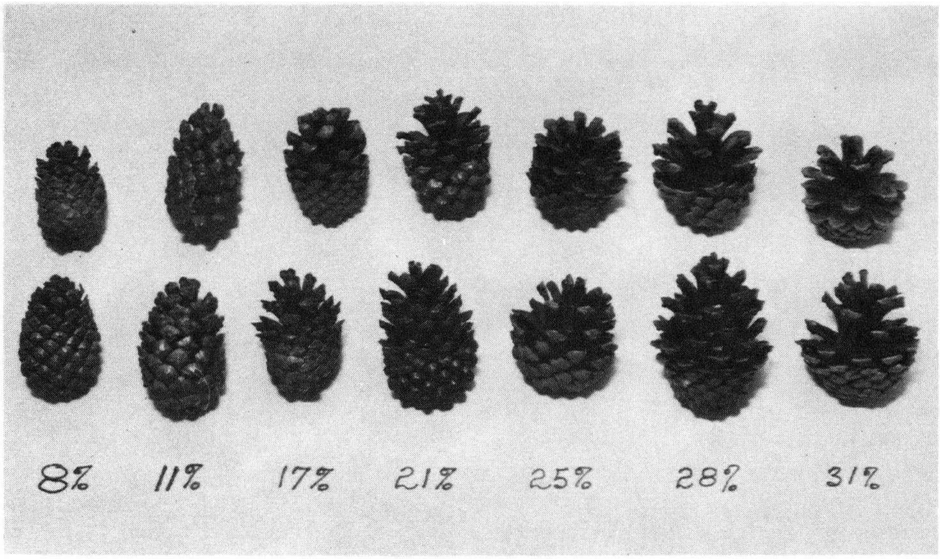
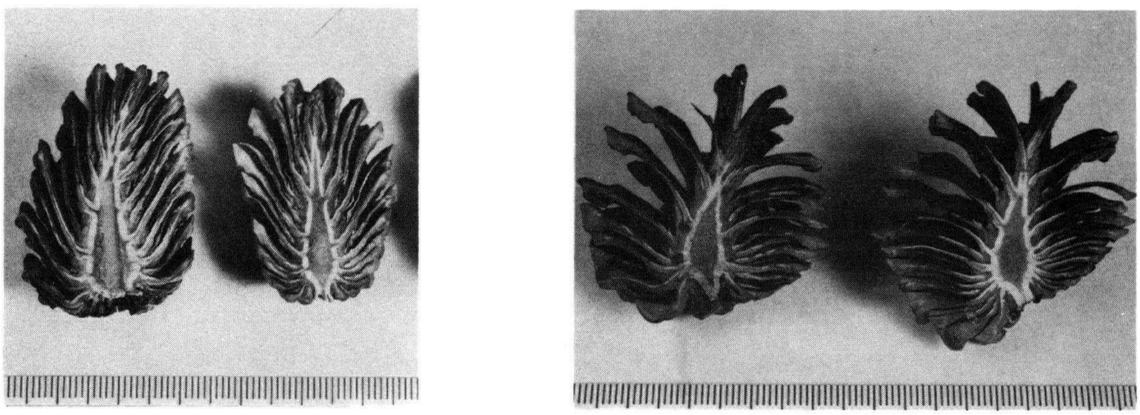


Figure 16. Cones showing typical degree of opening when unsealed and brought to 10% M.C. after one month of storage at indicated moisture contents.



Stress Relaxed　　　　Not Stress Relaxed

Figure 17. Cross section of typical open stress relaxed and non-stress relaxed cones.

10% moisture content, wet basis, and was stored for one month at this moisture content. The cones were then treated with hot air to break the scales, and were allowed to stand for four days during which scale deflection took place. The maximum scale deflection angles were measured, and the moisture content determined.

In order to determine the permanence of the reduction in scale deflection caused by stress relaxation, an attempt was made to revive the scale flexing ability of the cones described above. The cones were soaked in water for six hours and were allowed to dry to a moisture content close to that of the earlier test. The maximum scale deflection angles were again measured, and the moisture content determined.

Finally, the effect of stress relaxation on scale deflection and its elimination by rewetting, was evaluated at the oven dry condition. The cones from the above two treatments were subsequently oven dried at 105^{o}C, and the scale angles once more measured.

The scale deflection data for the above three treatments are reported in Tables A-12, A-13, and A-14 respectively.

The mean value of maximum scale deflection of the stress relaxed cones was found to be 20.3^{o} at a moisture content of 9.9% wet basis. This compares to deflection of approximately 60^{o} for cones at the same moisture content but which did not undergo stress relaxation.

The effect of rewetting these stress relaxed cones was to permit them to deflect to an average angle of 62.6^{o} when they were redried to a moisture content of 11.1% wet basis. When these cones were dried to an oven dry condition, the average deflection angle was found to be 93.6^{o}. These results are plotted in Figure 15 as points R1, R2, and R3 respectively. From this, it is apparent that stress relaxation reduces the opening ability of sealed lodgepole pine cones, and that the opening ability can be almost completely restored by rewetting of the affected cones.

5. <u>Degree of Seed Release with Respect to Scale Deflection</u>

As discussed earlier, the degree of cone scale deflection influences the percentage of seeds which can be extracted from cones by tumbling. This relationship was evaluated by extracting the free seeds from a group of cones at several moisture levels during their drying, and idenifying the mean scale deflection angle at each point.

A group of twenty cones was removed from storage and prepared for scale angle measurement as described above. They were then treated with hot air to release the resinous seals, and were allowed to partially dry under room conditions.

The seeds were then extracted by tapping the inverted cones five times into a tray, and the cone scale deflection angles were immediately measured. This process was repeated at four moisture contents. The final measurements were made on oven dry cones, and the remaining seeds were removed from the cones.

The maximum cone scale deflection data, and the number of seeds recovered at each point are reported in Tables A-15, to A-18.

The results of this test are plotted in Figure 18 which shows the cumulative percentage of total seed easily extracted against the maximum scale angle. From this plot, it can be seen that maximum scale angles of approximately 100° are required in order to achieve complete seed extraction by a mild tumbling treatment.

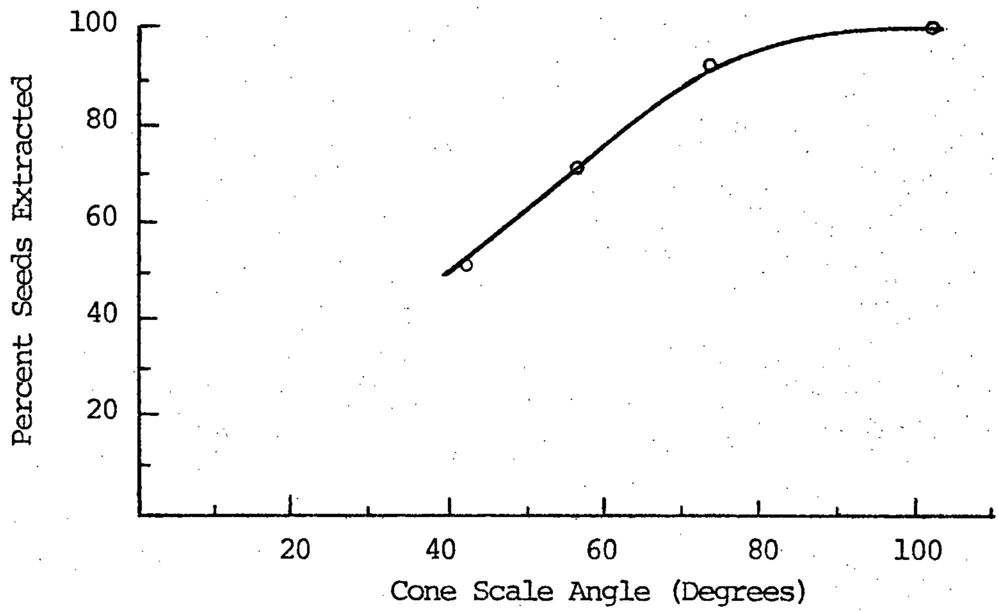


Figure 18. Seed extraction vs. cone scale angle.

6. Hot Water Seal Breaking

The breaking of serotinous scale seals of lodgepole pine cones by means of momentarily immersing the cones in hot water was investigated from two points of view. These were (i) the effectiveness in achieving seal breakage, and (ii) the extent of thermal damage to the seeds as revealed by reduced seed viability.

Hot water immersion was carried out by submerging groups of one hundred cones, contained in a mesh basket, in water heated in a steam kettle. The basket, shown in Figure 19 was covered so that the cones were forced down into the water for complete immersion. Continuous movement of the submerged basket ensured that the cones were surrounded by water at tank temperature.

At the end of the specified treatment time, the cones were lifted from the water and immediately spilled onto a draining rack. The cones were dried in individual mesh bottom drying racks (Figure 20) in an air conditioned room which was held at 72°F (22.2°C) and having a relative humidity ranging between 44% and 56%. Drying was aided by the use of a circulating fan which moved the air over the drying racks.

All tests were carried out using water at a temperature of 205°F $\pm$ 2° (96.1°C $\pm$ 1°), and immersion time was varied from 10 to 120 seconds. The initial temperature of the cones was 34°F (1°C) and the initial cone moisture

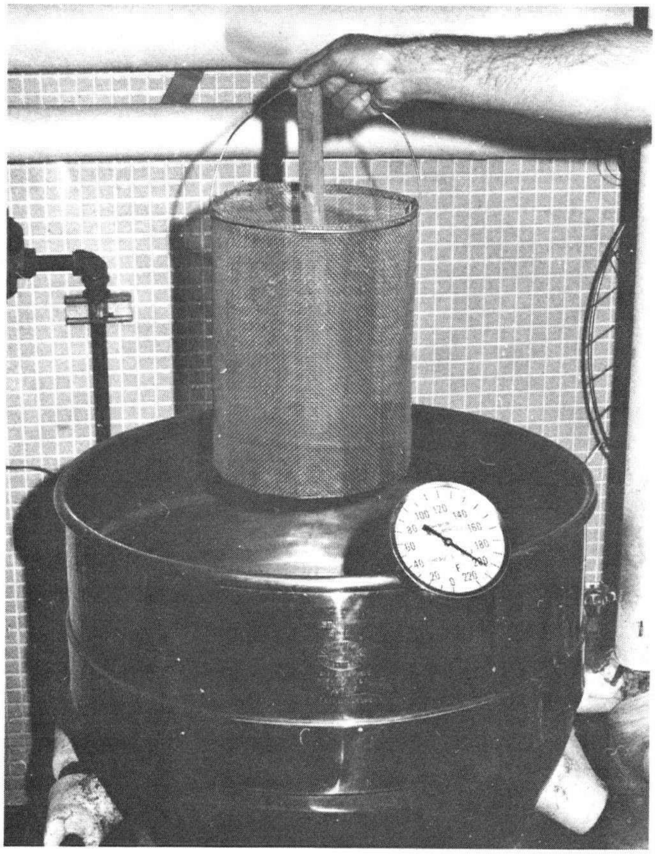


Figure 19. Hot water immersion apparatus.

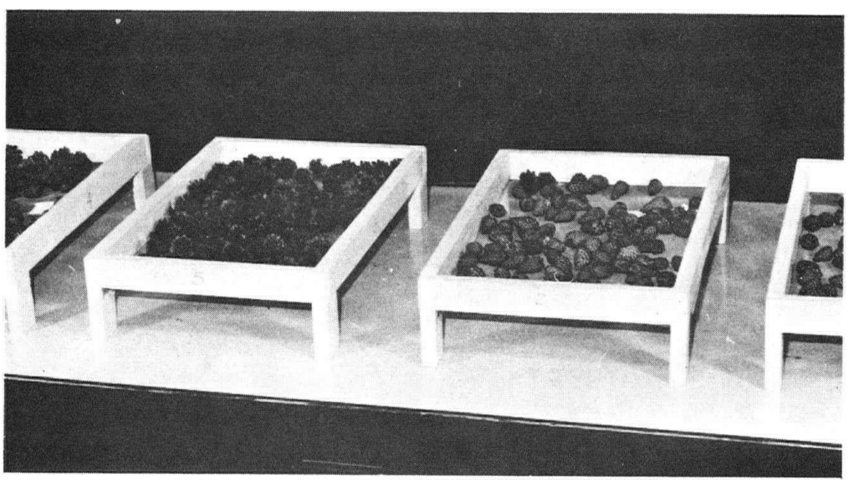


Figure 20. Cone drying racks.

content for these tests was 25% ± 3%, wet basis.

After drying until the degree of seal breaking on each cone was clearly evident by the open or closed position of the cone scales, the cones were sorted into the following classifications:

(i) Fully opened -- cones in which all scale seals in the seed bearing region of the cone were broken.

(ii) Partially opened -- cones on which only a portion of the scales in the seed bearing region were broken.

(iii) Fully closed -- cones on which no scale seals in the seed bearing region of the cone were broken.

All seeds from opened cones were subsequently extracted first by tapping, then by manually removing the scales in the manner described earlier in this report.

Germination tests were conducted on seeds from each group, and the viability was reported as the percentage of filled seeds producing normal germinants. The data used for the control in this test were those reported in Section VII (4) of this report which indicated a viability of 91.2% of the filled seeds producing normal germinants.

The results of the cone opening tests and the viability of the seeds so treated are shown in Table IV.

From Table IV it can be seen that immersion times of 20 seconds, or more resulted in over 90% of the cones being completely unsealed. Longer treatment of cones did not

TABLE IV. EFFECT OF HOT WATER IMMERSION ON CONE OPENING AND SEED VIABILITY

Immersion Time Seconds	Cones Fully Closed	Cones Partially Opened	Cones Fully Opened	Seed Viability*
10	35	33	32	95.2%
15	15	28	57	96.8%
20	2	8	90	98.2%
25	2	5	93	97.0%
27.5	2	9	89	97.5%
30	2	4	94	98.0%
40	2	3	95	97.5%
60	1	2	97	90.0%
120	0	0	100	0%

* Expressed as % of filled seed producing normal germinants

IMMERSION CONDITIONS:

Water Temperature : $205^{o}F \pm 2^{o}F$ ($96.1^{o}C \pm 1^{o}C$)

Initial Cone Temperature : $34^{o}F$ ($1^{o}C$)

Initial Cone Moisture Content: 25% ± 2% (w.b.)

significantly improve seal breakage without incurring a reduction in viability.

From Table IV, it can also be seen that the seed viability showed no appreciable deviation from that of the control group for all treatments up to 40 seconds in duration. The viability was slightly lower for those cones which received a 60 second treatment, but immersion of sealed cones in 205^{o}F water for 120 seconds resulted in complete seed mortality.

7. Flame Treatment Seal Breaking

The breaking of the serotinous seals by passing cones through an open flame was investigated. As in the case of hot water immersion treatment, flame treating was studied from the point of view of seal breaking effectiveness and thermal seed damage.

The apparatus shown in Figure 21 was constructed to flame treat cones by causing them to tumble down an inclined tube into which a flame was introduced. The apparatus consisted of a four inch diameter insulated tube which was inclined at angles between thirty and forty degrees. A feed chute directed manually metered cones into the upper end of the tube and a collecting screen gathered the cones as they emerged from the lower end. Heat was supplied by a propane torch which was oriented to direct its flame into the lower end of the tube.

Temperatures within the tube were controlled by maintaining a constant gas pressure of the fuel being delivered to the torch. The temperature of the tube at a point six feet from the lower end was monitored with an iron-constantan thermocouple to ensure uniformity of treatment conditions. The range of temperatures at this point during the various treatments was from 900°F (482°C) to 1350°F (732°C).

Treatment duration was controlled by varying the tube length between fifteen and thirty feet by the addition or removal of pipe sections, and also by varying the angle of inclination of the tube. Treatment times from four to twelve seconds were used.

After the flame treatment, the cones were allowed to cool and placed on mesh bottomed racks to air dry. After reaching approximately 10% moisture content, the cones were evaluated in the same manner as were the hot water immersed cones as described in the previous section of this report.

Testing was carried out on groups of 100 cones which had an initial moisture content of 25% ± 2% wet basis, and had an initial temperature of 34°F (1°C).

The results of the cone opening tests and the viability of the seeds treated in the flame tube are presented in Table V. From the table, it can be seen that the degree of cone opening achieved increased with increasing

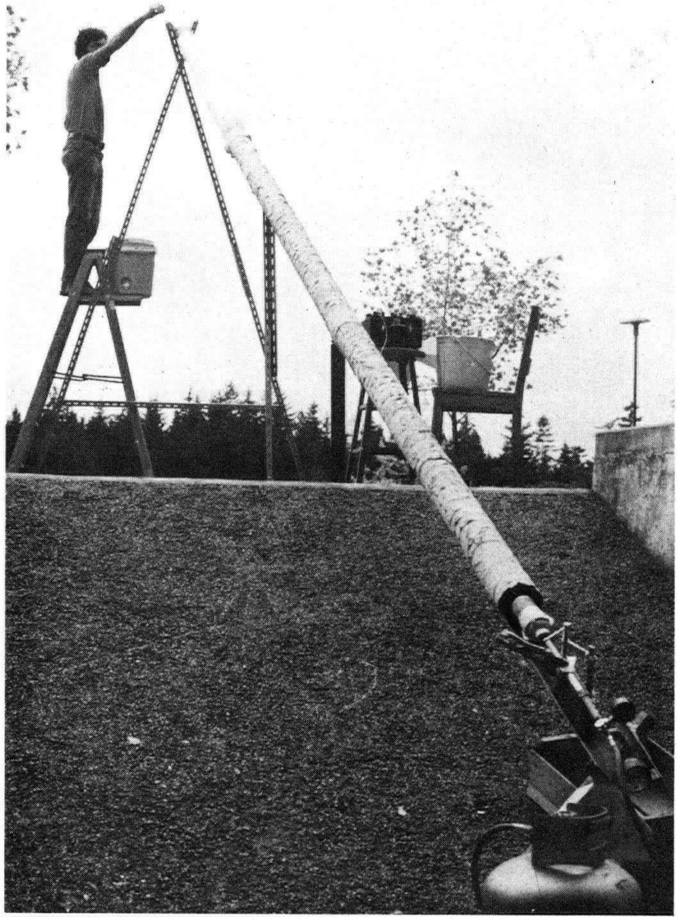


Figure 21. Flame treating apparatus.

flame treatment intensity, and that complete seal breaking was accomplished by a treatment at 6.5 seconds at a reference temperature of 1280°F (693°C).

From the table, it can also be seen that the seed viability did not suffer an appreciable reduction by flame treatment severe enough to effect complete seal breakage.

8. Effect of Moisture Content on Seal Breaking Effectiveness

Experience from the above flash heating tests suggests that cone moisture content influences the effectiveness

TABLE V. EFFECT OF FLAME TREATMENT ON CONE OPENING AND SEED VIABILITY

Average Treatment Time Seconds	Flame Tube Reference Temp. °F	Cones Fully Closed	Cones Partially Opened	Cones Fully Opened	Seed Viability*
4.5	1155	75	12	13	**
5.0	1280	66	16	18	93.9%
5.5	1195	28	24	48	97.3%
7.5	1160	35	10	55	98.0%
5.1	1345	8	15	77	95.6%
6.5	1252	0	6	94	94.9%
6.5	1280	0	0	100	93.4%

* Expressed as % of filled seeds producing normal germinants

** Insufficient seeds released for viability determination

TREATMENT CONDITIONS:

Initial Cone Temperature : 34°F (1°C)

Initial Cone Moisture Content: 25% ± 2% (w.b.)

of heat treatment for the purpose of breaking serotinous cone scale seals.

The mechanism believed to cause this effect was the degree of stress within the cone scales tending to deflect the scales outward which is present in the scales at the time the resinous sealing material is melted. The effect of such stresses at this time would be to spring the scales slightly apart while the resinous seal is melted. The result of this would be that upon resolidification of the resin, the bond surfaces would no longer be in contact with each other, and hence the resin could not re-bond them.

This phenomenon was investigated by evaluating the effectiveness of a specific seal breaking treatment on cones at different moisture contents, thus having different levels of scale deflecting stress.

Three groups of 100 cones were prepared for seal breaking as follows: one group was soaked in water for 24 hours to raise the moisture content above 30% wet basis, the second group was dried at room temperature to a moisture content of approximately 10% wet basis, and the third group was treated as they came from storage at approximately 25% M.C. wet basis.

Each group of cones was brought to a temperature of 34°F (1°C) and was immersed for 27.5 seconds in water at 205°F (96.1°C). After drying at room temperature, the cones were classified into the three categories of cone opening described in earlier tests.

The results of this test are shown in Table VI and indicate that seal breakage effectiveness for a given heat treatment increases with a decrease in cone moisture content.

TABLE VI. SEAL BREAKING RESULTS AT THREE MOISTURE CONTENTS

1. Cones heat treated at moisture content in excess of 30% wet basis:	
Fully opened	32%
Partially opened	54%
Closed	14%
2. Cones heat treated at moisture content of approximately 25% wet basis:	
Fully opened	89%
Partially opened	9%
Closed	2%
3. Cones heat treated at moisture content of approximately 10% wet basis:	
Fully opened	98%
Partially opened	2%
Closed	0%

PART TWO

DEVELOPMENT OF PROCESSING TOOLS

IX. PROPOSED MECHANICAL EXTRACTION SYSTEM

The second phase of this project involves the systematic design, fabrication, and testing of a mechanical conifer seed extraction system. The proposed system consists of a portable machine which operates at the regional seed collection stations to mechanically separate seeds from cones on a continuous flow basis.

The purpose of this system is to provide a more efficient and economical means of conifer seed extraction which requires a lower labour input and which eliminates the transportation of large quantities of waste cone material to central extractories. The operating principle of this system was described in Chapter V and flow charts comparing it with a conventional kiln extraction system were presented.

The successful development of the proposed extraction equipment is dependent upon the achievement of a number of specific operational requirements, as listed below:

(a) Must provide a high seed recovery rate with minimum seed damage.

(b) Must be capable of extracting seed from both serotinous and non-serotinous cones.

(c) Must be capable of operating satisfactorily on cones over a reasonable range of moisture content.

(d) Must provide a production rate commensurate with the economic operation of the system.

(e) Must operate with a minimum manpower input.

(f) Must be easily transported on a light duty truck.

(g) Must be easily set up and taken down at each operating site.

(h) Must have a simple, durable design so that breakdowns are minimized and the machine is easy to service in the field.

The findings of the preliminary investigations of the physical properties of lodgepole pine cones, as previously discussed, indicate that the serotinous scale seals of this species can be easily broken by flash heating, with little damage to the seeds. The breaking of serotinous seals prior to mechanical extraction will undoubtedly reduce the severity of the mechanical treatment required to achieve full extraction, and hence will reduce the likelihood of mechanical seed damage. For this reason a thermal seal breaking process was included in the design of the proposed mechanical extraction system.

The development of each of the two primary tools of the proposed extraction system is detailed in the following sections of this report.

X. DEVELOPMENT OF SEROTINOUS SEAL BREAKING TOOL

1. Preliminary Analysis

Experience from the study of the physical properties of lodgepole pine cones indicated that breaking the serotinous seals would significantly reduce the degree of severity of treatment necessary to mechanically extract the seeds of such cones. Additionally, the use of an effective seal breaking device can result in more efficient extraction of serotinous cones using the conventional kiln extraction process.

Study of the physical properties of serotinous cones also indicated that the bonds holding the cone scales in a closed position can be broken by both mechanical fracture of the seal and by melting of the resinous bonding material.

A preliminary analysis of mechanical seal breaking by crushing and thermal seal breaking by flash heating is outlined below.

(i) Crushing -- Mechanical fracturing of scale seals can be achieved by slightly crushing the cones thereby causing the bonds to fail as a result of stresses which exceed the yield stress of the bond material. The deflection of this crushing action must be applied evenly over the length of the tapered cone. Furthermore, crushing must be applied at several points around the periphery of the cone and must be carried out after the cone has been dried to a fairly low moisture content, in order to ensure the release of all cone scales.

The effectiveness of seal breaking by this method was quantitatively evaluated by crushing a number of cones with a hydraulic press as shown in Figure 22. Cones having a range of moisture contents were tested.

Seal breakage was achieved in all cones tested, but as cone moisture increased, the degree of deflection required to achieve seal breakage increased sharply. Cones below approximately 10% M.C. wet basis were almost completely opened by a small deflection applied at two or three points around the cones. Cones above 20% M.C. wet basis, however, required severe crushing, which probably damaged the seeds, in order to open most of the scales.

The complexity of automated equipment necessary to orient individual cones and provide this treatment at several angular positions, to the wide range cone size and profile which exists in commercially harvested cones renders this operating principle unsuitable. Furthermore, the low production rate inherent in a system which treats cones individually, and the possibility of seed damage, further reduce the suitability of this method.

(ii) Flash heating -- Breaking of serotinous seals by the application of heat has traditionally been the method used for the purpose of extracting seed from such cones. In the past, this treatment has been employed during normal kiln drying by the use of higher kiln temperatures.

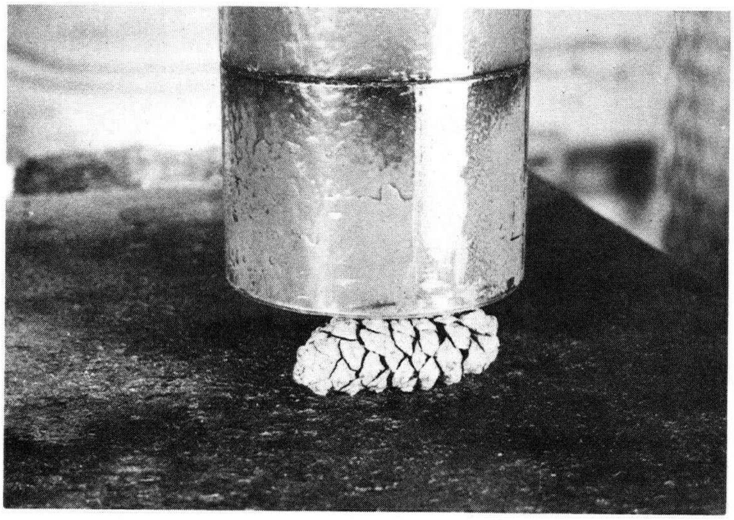


Figure 22. Seal breaking by crushing.

Flash heating of cones for the purpose of breaking the seals of lodgepole pine cones was investigated in part one of this report. Based on the information and experience gained from that study, two prototype seal breaking tools were fabricated for testing.

The prototype tools designed were a hot water immersing device, and a flame treating device. Both of these tools were designed for continuous flow operation and were used to evaluate the suitability of their respective performance for use in a portable mechanical conifer seed extraction system and for use with present kiln extraction facilities.

The analysis, design and testing of these two prototype flash heating tools is described below.

2. <u>Heat Transfer Analysis of Flash Heated Cones</u>

In order to evaluate the flash heating process of cones, a heat transfer analysis was carried out to identify the thermal gradients within flash heated cones and the resulting internal temperatures during the process.

The concept of flash heating with very high temperatures for the purpose of seal breaking is based on the principle that rapid heating of the outer region of the cone will achieve melting of the resinous seal before the central regions which contain the seeds are heated much above their initial temperature. This situation is possible because of the relative position of the seals and the seeds within the cone, and the relatively low thermal conductivity of the cone scale tissues.

The maximum temperature to which the seeds are exposed is, however, attained after the cones have been removed from the heat source. This occurs because the high level of thermal energy present in the outer regions of the cone at the end of the heating period moves through the cone to establish equilibrium conditions. If the cones are subjected to cooling immediately upon emerging from heat treatment, much of this energy will be dissipated to the surroundings, so that the effect of the inward moving wave of heat will not cause appreciable further increase in the seed temperature.

A quantitative analysis of this heat transfer process was carried out by employing the techniques used for transient heat flow in stationary systems which are heated by convection, and which have high internal temperature gradients. These techniques are outlined by Kreith (27), Rohsenow and Choi (42).

The analysis consists of defining the functional relationship among a dimensionless ratio defining the temperature gradient, a functional relationship describing the ratio of internal and external thermal resistances, and a ratio relating time of heating to thermal energy velocity in the material. Due to the complex nature of these relationships, analysis is carried out using graphical solutions which have been formulated for certain geometric shapes under ideal conditions of homogenity, uniformity and accurately known material properties.

The relationship of these characteristics is given by the following equation:

$$Y = \frac{T - T_\infty}{T_o - T_\infty} = f\left(Bi,\ Fo,\ \frac{x}{L}\right). \qquad (1)$$

More specifically this is

$$Y = f\left(\frac{hL}{k},\ \frac{\alpha t}{L^2}\ \frac{x}{L}\right) \qquad (2)$$

where: Y = dimensionless ratio of the change of internal energy due to heating, with relation to the stored internal energy.

T = temperature of any point at time t.

T_∞ = temperature of surrounding fluid.

T_o = initial temperature of body

h = unit surface conductance of body

L = characteristic dimension of body (radius)

k = thermal conductivity of material of body

α = thermal diffusivity of material of body

t = time measured from beginning of process

x = dimension of length, locating the point under study

Bi = Biot number, dimensionless heat transfer ratio

Fo = Fourier number, dimensionless time ratio.

Graphical solutions to these relationships have been prepared for ideal shapes, including sphere, infinite slabs, infinite cylinders, semi-infinite slabs, etc. (27, 42).

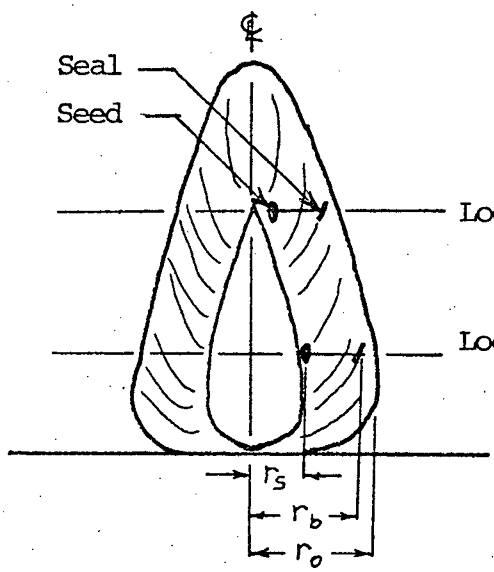
In order to apply this technique to the flash heating of cones the following assumptions are made:

- Sealed cones can be analyzed as an infinite cylinder having a diameter equal to that of the cone at the point under study.
- Sealed cones are homogeneous having uniform physical properties within the region of the cone under study.
- The heat of fusion of the resinous seal is negligible.

- The film coefficient (unit surface conductances) remains constant.
- The fluid, into which the cones are immersed maintains a constant temperature.
- Heat is transmitted to the cones by convection only.

The heat transfer analysis carried out was based on the average dimensional data taken from a number of cones considered to represent the typical size and shape of cones from the cone lot under study. The data used are listed below and shown in Figure 23.

Cone length 1.65 in. (4.2 cm)
Maximum diameter .70 in. (1.8 cm)
Diameter at top of seed bearing region .42 in. (1.1 cm)
Diameter at base of seed bearing region .70 in. (1.8 cm)
Seal depth .060 in. (0.15 cm)
Depth of seed .140 in. (0.36 cm)



	r_o Radius of Cone	r_b Radius of Seal	r_s Radius of Seed
Location 1	.21 in.	.15 in.	.07 in.
Location 2	.35 in.	.29 in.	.21 in.

Figure 23. Dimensional data of cone for heat transfer analysis.

The thermal properties for cones used for this analysis was that reported by Lee and Beaufait (28) for young cones of <u>Pinus banksiana</u>, and are as follows:

Thermal conductivity k = 0.123 BTU/hr ft^2 F^o

Thermal diffusivity = 0.0073 ft^2/hr.

The unit surface conductance for cones in hot water and hot gas, based on typical values for comparable conditions (42), was assumed to be, respectively, 100 BTU/hr ft^2 F^o, and 20 BTU/hr ft^2 F^o.

Calculations were carried out to determine the time required to raise the temperature of the material at the resinous seal to its melting point, which was earlier determined to be 52.5°C (126°F).

The first series of calculations was made to identify the conditions when newly matured cones are flash heated from an initial temperature of 34°F (1°C) by immersion in water at 205°F (96.1°C).

Using dimensional data for conditions at the tip of the seed bearing region of the cone, the calculations are as follows:

$$\frac{1}{Bi} = \frac{k}{h\ r_o} = \frac{.123 \times 12}{100 \times .21} = .070$$

$$\text{Position ratio, } \frac{r_b}{r_o} = \frac{.150}{.210} = .714$$

$$\frac{T_{(.15")} - T_\infty}{T_o - T_\infty} = \frac{126 - 205}{34 - 205} = .462$$

From the graphical solutions (27, 42) for heat transfer in an infinite cylinder, a Fourier Number of .14 is identified. This, in turn, enables the calculation of the immersion time t required to bring the seals to the melting temperature.

$$t = \frac{r_o^2 F_o}{\alpha} = \frac{.21^2 \times .14}{.0073 \times 144} = .00587 \text{ hrs}$$
$$= 21.1 \text{ seconds}$$

The temperature to which seeds located at the tip of the seed bearing region would be heated after 21.1 seconds treatment is determined as follows:

$$\text{Position ratio for seeds, } \frac{r_s}{r_o} = \frac{.070}{.210} = .333$$

Using the curves of the graphical solution of heat transfer in an infinite cylinder again, and these data indicate a temperature ratio of .78. From this, the seed temperature is found to be:

$$T_{(seed)} = .78\ (T_o - T_\infty) + T_\infty$$
$$= .78\ (34 - 205) + 205 = \underline{71.6^oF\ (22.0^oC)}.$$

Using the same analysis, calculations were carried out to determine the time required to melt the seals at the lower or peduncle end of the seed bearing region of the cone.

These are shown below:

$$\frac{1}{Bi} = \frac{k}{h\ r_o} = \frac{.123 \times 12}{100 \times .35} = .042$$

$$\frac{r_o}{r_o} = \frac{.29}{.35} = .83$$

$$\frac{T_{(.35")} - T_\infty}{T_o - T_\infty} = \frac{126 - 205}{34 - 205} = .462$$

The graphical heat transfer data indicate a Fourier Number of .09.

The time to bring the seals in this region to the melting temperature is:

$$t = \frac{r_o^2 F_o}{\alpha} = \frac{.35^2 \times .09}{.0073 \times 144} = .0105 \text{ hrs} = 37.7 \text{ seconds}$$

The temperature of seeds at this location at the end of 37.7 seconds is found as follows:

$$\frac{r_{(seed)}}{r_o} = \frac{.21}{.35} = .6$$

This indicates a temperature ratio of .70 which gives a seed temperature T_s of:

$$T_{seed} = .70\ (T_o - T_\infty) + T_\infty$$

$$= .70\ (34 - 205) + 205 = \underline{85.3^oF = (29.6^oC).}$$

As a result of the longer time required to melt the seals in the lower region of the cone, the temperature of seeds in the tip region of the cone will be heated above the temperature previously calculated. The temperature of seeds in the tip region after treatment for 37.7 seconds is found as follows:

$$\frac{1}{Bi} = .070$$

$$\frac{r_s}{r_o} = \frac{.070}{.21} = .333$$

$$F_o = \frac{\alpha t}{r_o^2} = \frac{.0073 \times 37.7 \times 144}{.21^2 \times 3600} = .249$$

This indicates a temperature ratio of .42 which, in turn, gives a seed temperature of:

$$T_{(seed)} = .42\ (34 - 205) + 205 = \underline{133.2^{o}F\ (56.2^{o}C)}$$

A second series of calculations was carried out to determine the same seed temperatures under the conditions of flash heating in air at $1000^{o}F$ ($538^{o}C$).

These calculations are shown below:

$$\frac{1}{Bi} = \frac{k}{h\ r_o} = \frac{.123 \times 12}{20 \times .21} = .351$$

Position ratio $\frac{r_s}{r_o} = \frac{.150}{.210} = .714$

$$\frac{T_{(.15")} - T_\infty}{T_o - T_\infty} = \frac{126 - 1000}{34 - 1000} = .907$$

Data from the references indicate a Fourier Number of .070. This, in turn, gives a treatment time of:

$$t = \frac{r_o^{\ 2}\ F_o}{\alpha} = \frac{.21^2 \times .070}{.0073 \times 144} = .00294 \text{ hrs}$$

$$= 10.6 \text{ seconds}$$

Seed temperature at this point is calculated as follows:

Position ratio $\frac{r_s}{r_o} = \frac{.070}{.210} = .333.$

The graphical data indicate a temperature ratio of .97 which, in turn, gives a seed temperature of:

$$T_{seed} = .97\ (34 - 1000) + 1000 = \underline{63.0^{o}F\ (17.2^{o}C)}$$

The time to bring the seals in the lower region of the cone to the melting temperature is calculated in a similar fashion:

$$\frac{1}{Bi} = \frac{k}{h\ r_o} = \frac{.123 \times 12}{20 \times .35} = .21$$

$$\frac{r_o}{r_o} = \frac{.29}{.35} = .83$$

$$\frac{T_{(.35")} - T_\infty}{T_o - T_\infty} = \frac{126 - 1000}{34 - 1000} = .907$$

This indicates a Fourier Number of .04, which gives a seal breaking time t of:

$$t = \frac{r_o^{\ 2}\ F_o}{\alpha} = \frac{.25^2 \times .04}{.0073 \times 144} = .0046 \text{ hrs}$$

$$= 16.7 \text{ seconds.}$$

The temperature of seeds at this point after 16.7 seconds of treatment is found by the following:

$$\frac{1}{Bi} = .21, \quad \frac{r_s}{r_o} = .6, \quad F_o = .04$$

and from this the temperature ratio is .96, thus:

$$T_{seed} = .96\ (34 - 1000) + 1000 = \underline{72.6^{o}F\ (22.6^{o}C)}$$

The temperature of seeds in the tip region of the cone after the 16.7 seconds of treatment required to melt the seals in the lower region of the cone is similarly determined as follows:

$$\frac{1}{Bi} = .351, \quad \frac{r_s}{r_o} = .333$$

$$F_o = \frac{\alpha t}{r_o^2} = \frac{.0073 \times 144 \times 16.7}{.21 \times 3600} = .023$$

From this the temperature ratio is .92 which gives a seed temperature of:

$$T_{seed} = .92\ (34 - 1000) + 1000 = \underline{111.3^{\circ}F\ (44.1^{\circ}C}$$

Treatment times calculated by the above analyses correspond well with the treatment times which were determined experimentally and reported in Part One of this report. Calculated seed temperatures are in the general range of temperatures measured by Nyborg and Brisbin (37).

The above calculations indicate the suitability of flash heating for seal breaking of serotinous cones. In all probability, the actual heating of seeds in the cones would be less severe than that predicted by these calculations for the reasons outlined below.

It was assumed that cones are homogeneous throughout, when in fact they are not. Most seeds of lodgepole pine are covered within the cone by three or four scales, lying one over the other. Thus the seeds are not sheltered from external heat by a uniform layer of woody tissue, but by three or four layers, each separated by an air gap. The overall thermal conductance between the seed and the cone surface would therefore be lower than that used in the calculations, hence the actual seed temperatures would be lower than the calculated values.

It was also assumed in the case of flame heating that heat was imparted to the surface of the cones by convection only, while in fact, heat is transmitted by radiation as well. The result of this additional heat transfer would be to cause a more rapid transfer of thermal energy to the surface of the cone, which, in turn, would cause a steeper temperature gradient within the cone. The actual seed temperature would therefore be further reduced from the calculated values at the time of seal melting.

The temperatures and heat treatment times determined above are considered to be well within the acceptable limits for a continuous flow system and for freedom from thermal damage to the seeds. The process of flash heating can therefore be considered to be an acceptable and efficient method of breaking the serotinous seals of Lodgepole pine cones.

3. Hot Water Immersion Tool

A prototype hot water immersion tool was designed and fabricated in order to evaluate this process for thermal seal breaking of serotinous cones.

The operational requirements of a seal breaking tool suitable for operation in conjunction with a mechanical seed extraction system or for use with conventional kiln extraction are listed below.

- Operate on a continuous basis.
- Possess adequate production capacity.
- Be portable.
- Operate with a minimum of labour input.
- Exhibit efficient fuel utilization.
- Be adjustable in treatment duration.

The hot water immersion tool was designed to accommodate the various characteristics and properties of the cones which were determined in part one of this report. In this respect, the range of water temperature and treatment times at which this tool could operate was designed to coincide with the optimum conditions determined by the immersion tests. The design included the ability to handle both sealed and unsealed cones, and thermal damage from excessive treatment was averted by the inclusion of a positive transport capability of the immersing tool.

The design of the immersion tool chosen for fabrication consists of a revolving drum having several compartments around its periphery and which is partially immersed in a tank of heated water. The cones are fed into these compartments just above the water line, and as the drum revolves, the cones are carried down into the water. The buoyancy of the cones holds them up against the wall of the compartments, during submergence. As each compartment emerges from the water an elevating chute supports the cones until they are lifted to a point where they are dumped into the delivery chute.

A feed hopper and a metering device was also incorporated into the design of the experimental apparatus in order to identify the performance characteristics of the tool under continuous flow operation.

The immersing drum is electrically powered and is driven by a variable speed drive mechanism. Immersion time is controlled by adjusting the speed at which the immersion wheel is driven. The feed auger is chain driven by a separate motor.

Water in the tank is maintained at a uniform temperature by electrical heating elements, while the temperature is monitored by a thermocouple located near the centre of the tank. The exposed surfaces of the tank are insulated and an enclosing chamber covers the upper region of the revolving drum in order to reduce evaporative cooling.

The prototype hot water immersion tool is shown with its insulating drum cover removed in Figures 24 and 25.

Extensive testing was carried out on the immersion seal breaking device, both in the laboratory and under conditions existing at a typical commercial seed extraction plant. A qualitative evaluation of this prototype seal breaking tool identified the following points:

- A hot water immersing tool is an effective device for the breaking of scale seal of serotinous

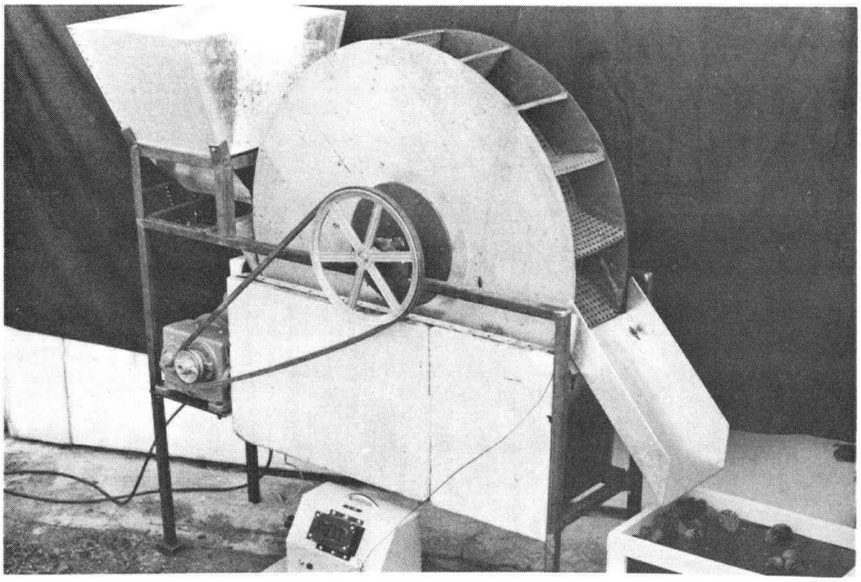


Figure 24. Prototype hot water seal breaking tool.

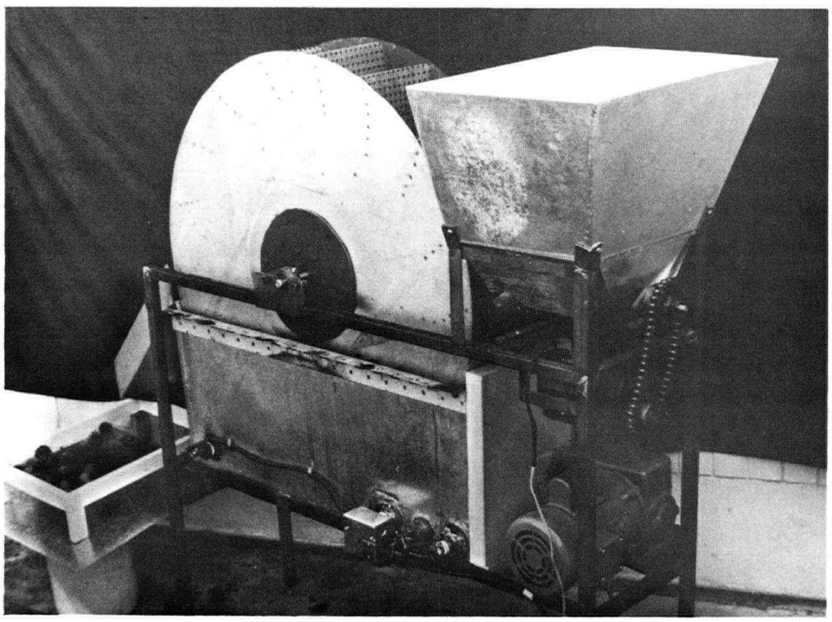


Figure 25. View of seal breaker showing heating and drive mechanisms.

cones.

- Cones whose seals are broken with hot water require a moderate drying process before other phases of either mechanical or kiln extraction can effectively be carried out.
- The energy requirement of this type of seal breaking tool is high due to evaporative cooling of the machine components and the loss of hot liquid.
- Cones having a moisture content in excess of 25% w.b. pose operational problems due to their tendency to sink in the heating water.
- A hot water seal breaking tool has a long start up time due to the large mass of water and components which operate at elevated temperatures.

Problems of freezing exist during shutdown when a hot water seal breaking tool is used in an unheated location during winter operation.

The results of the above evaluation indicate that a hot water immersing device performs effectively as a continuous flow serotinous seal breaking tool, but that this type of tool has a number of disadvantages which reduce its suitability for commercial operation.

4. Flame Treating Tool

The designing and fabrication of an alternate seal breaking tool, which flash heats cones in a flame, was undertaken as an alternative to the hot water immersion tool.

The operational requirements stated for the hot water seal breaker, above, apply to the design of the flame treating tool as well. The information on the physical properties and characteristics of serotinous cones, which was determined in part one of this report, was similarly utilized in the design of this tool.

The operating principle of the flame treating seal breaker is that of tumbling the cones within a horizontal tube into which a flame is introduced.

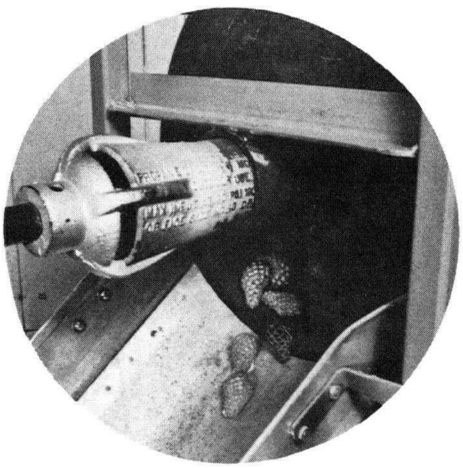
The design of this prototype flash heater is based on a 10 inch diameter tube, 30 inches in length, inside of which is a four turn single pitch auger flight. The three inch flight is attached to the wall of the tube, and flame deflecting baffles are located at several points along the flight and extended into the region of the tube axis. The purpose of the auger flight is to transport the cones through the tube as it rotates.

The ends of the tube are capped with 14 inch diameter end plates which support the tube by resting on the drive pulleys. At the centre of the plate on the inlet end of the tube is 3 inch diameter hole through which the cones are fed into the tube, and exhaust gases escape. The plate on the exit end of the tube has a similar hole through which the flame is introduced, but which is extended at one point to the circumference of the tube to provide a discharge port for treated cones as shown in Figure 26.

The flame tube is supported by four driving pulleys which are attached to two powered shafts held in bearings attached to the frame at either side of the tube. These shafts are diven by a variable speed electric motor thus permitting the drum to be rotated at all speeds over a range from ten seconds per revolution to one second per revolution. In this way treatment time can be controlled over a range from four to forty seconds.

Cones to be treated are metered out of the feed hopper by an auger and are directed into the flash heating tool by a chute. The cones are propelled through the flame tube as they tumble against the spiral flight inside the revolving tube. The tumbling action also serves to ensure that all surfaces of the cones receive uniform exposure to the hot surface of the tube and the hot gases from the flame. Treated cones are discharged from the tube into a discharge chute which carries them to a conveyor or suitable container.

Heat is supplied to the tool by a 190,000 BTU per hour propane torch which delivers its flame directly into the treating tube. Temperatures within the flash heater are monitored by the use of a thermocouple located just inside the cone inlet port where the exhaust gases are discharged. This is shown in the detail of Figure 27. The drum temperature is controlled by



Detail of torch and
discharge chute.

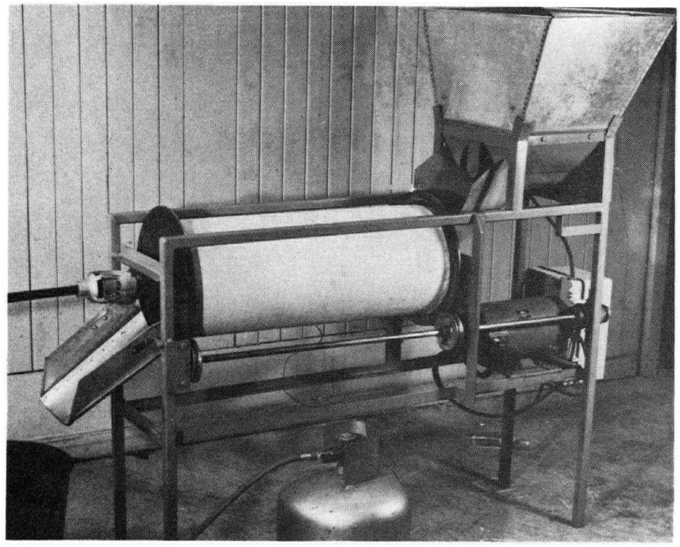
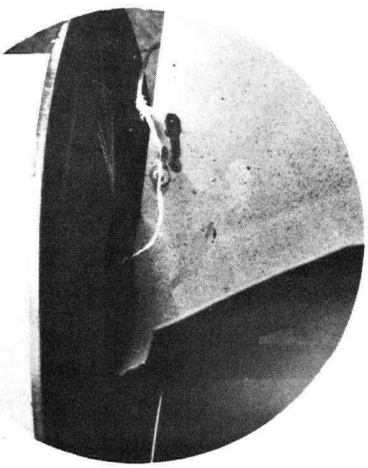


Figure 26. Prototype flame treating seal breaker.



Detail of thermo-
couple location
in exhaust port.

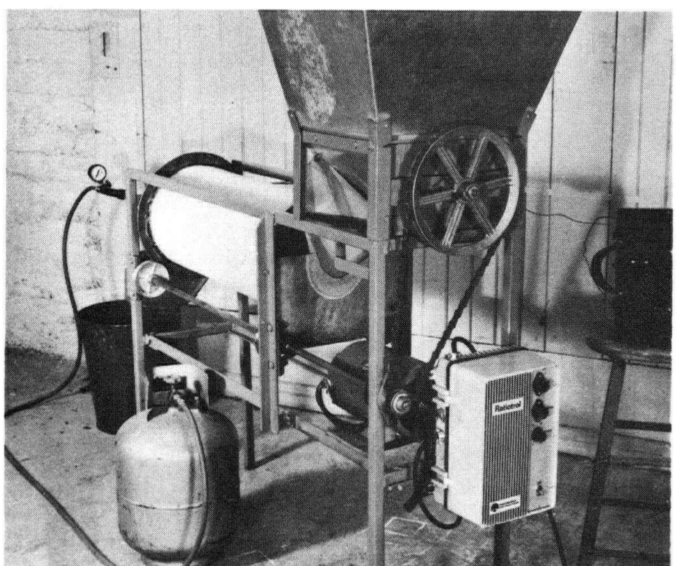


Figure 27. View of seal breaker showing drive mechanism.

regulating the pressure of fuel delivered to the nozzle. Heat loss is reduced by a layer of asbestos insulation on the outer surface of the treating tube.

Preliminary testing was carried out under laboratory conditions to identify the operating characteristics of the flame treating seal breaker.

The effect of fuel pressure on temperature of gas in the tube, as measured at the exhaust port, was studied. The curve of gas temperature in terms of fuel pressure for the prototype tool is plotted in Figure 28.

The effect of treatment time on seed viability of cones having a moisture content of 12.5% wet basis, and an initial temperature of 34°F (1°C) was determined for an operating temperature of 1000°F (538°C). The viability, expressed as the percentage of filled seeds producing normal germinants, of seeds from cones treated for periods up to 100 seconds is plotted in Figure 29.

The results of the qualitative evaluation of the performance of this prototype flash heating tool indicate the following conclusions:

- A flame treating tool provides an effective and versatile method of flash heating serotinous cones for the purpose of seal breaking.
- A flame treating tool for seal breaking has a number of advantages over the hot water tool.

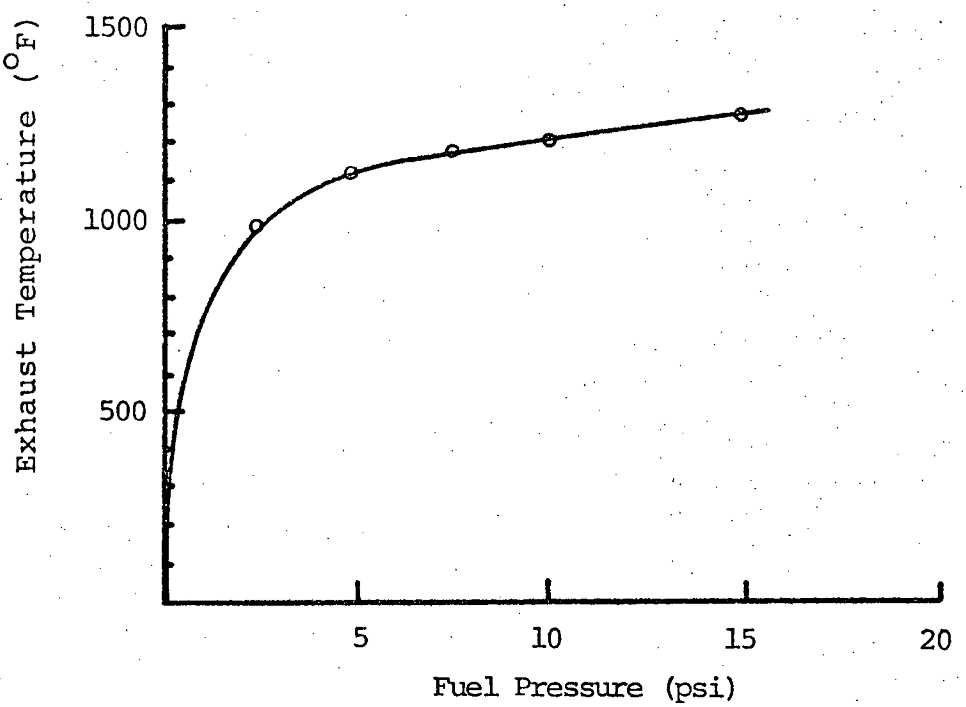


FIGURE 28. Exhaust temperature vs. fuel pressure for flame treating seal breaker.

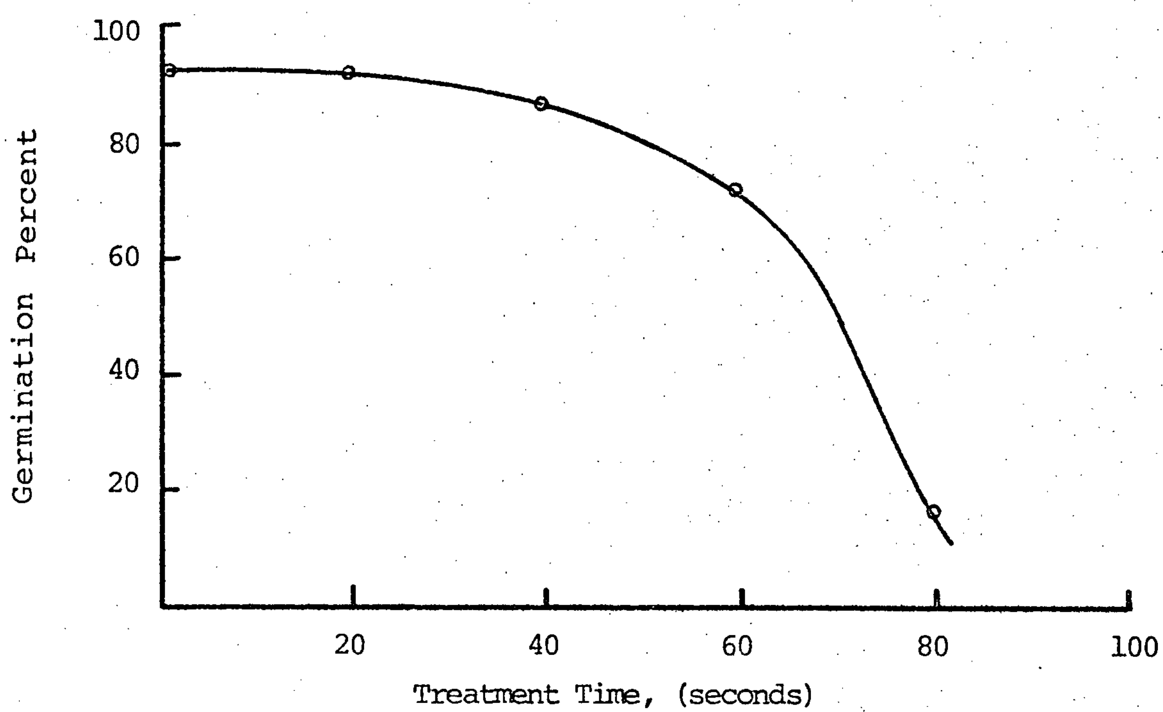


FIGURE 29. Viability vs. treatment time for flame treater operating with an exhaust temperature of 1000°F (538°C)

These are: lower weight, quicker startup, no cone drying required, no cones lost during treatment, more efficient heat utilization.

- The fire hazard posed by a flame treating tool is low, particularly if needles and other material are scalped from the cones prior to treatment. Under normal operating conditions cones are not ignited by the treatment, and only when treatment time is more than 25 to 30 seconds does the pitch on heavily coated cones become ignited. Such flames quickly extinguish themselves upon emerging from the treatment tube.

5. Calibration of Flame Treating Seal Breaker

In view of the satisfactory performance of flame treating seal breaking tool, detailed calibration of this tool was undertaken for the purpose of predicting the optimum treatment for specific cone conditions.

The tool was calibrated over a range of moisture content for fresh class I cones and for old weathered class III cones.

All calibration was carried out with the flame treater operating under ambient temperature conditions between $65^{o}F$ and $70^{o}F$ ($18^{o}C$ and $21^{o}C$). The gas temperature, as measured at the exhaust port was maintained at $1000^{o}F \pm 20^{o}F$ ($538^{o}C \pm 11^{o}C$).

The initial temperature of all cones treated was 34°F (1°C), and the calibration tests were conducted on cones which had been conditioned to a number of moisture contents ranging from 9% to 32% wet basis. Groups of 100 cones from each classification and moisture content were processed by the tool for treatment times of 5, 10, 15, 20, 25 and 30 seconds.

After treatment, cones were dried at room temperature so that the degree of seal breaking on each was clearly evident by the open or closed position of the cone scales. The cones were then sorted into the classifications of (i) Fully unsealed, (ii) Partially unsealed, and (iii) Not unsealed, which have been reported earlier in this report.

The calibration data from these tests are reported for young and weathered cones in Tables A-19 and A-20, respectively. Curves showing the percent of cones achieving full seal breakage in each of the two cone classifications, are shown in Figures 30 and 31.

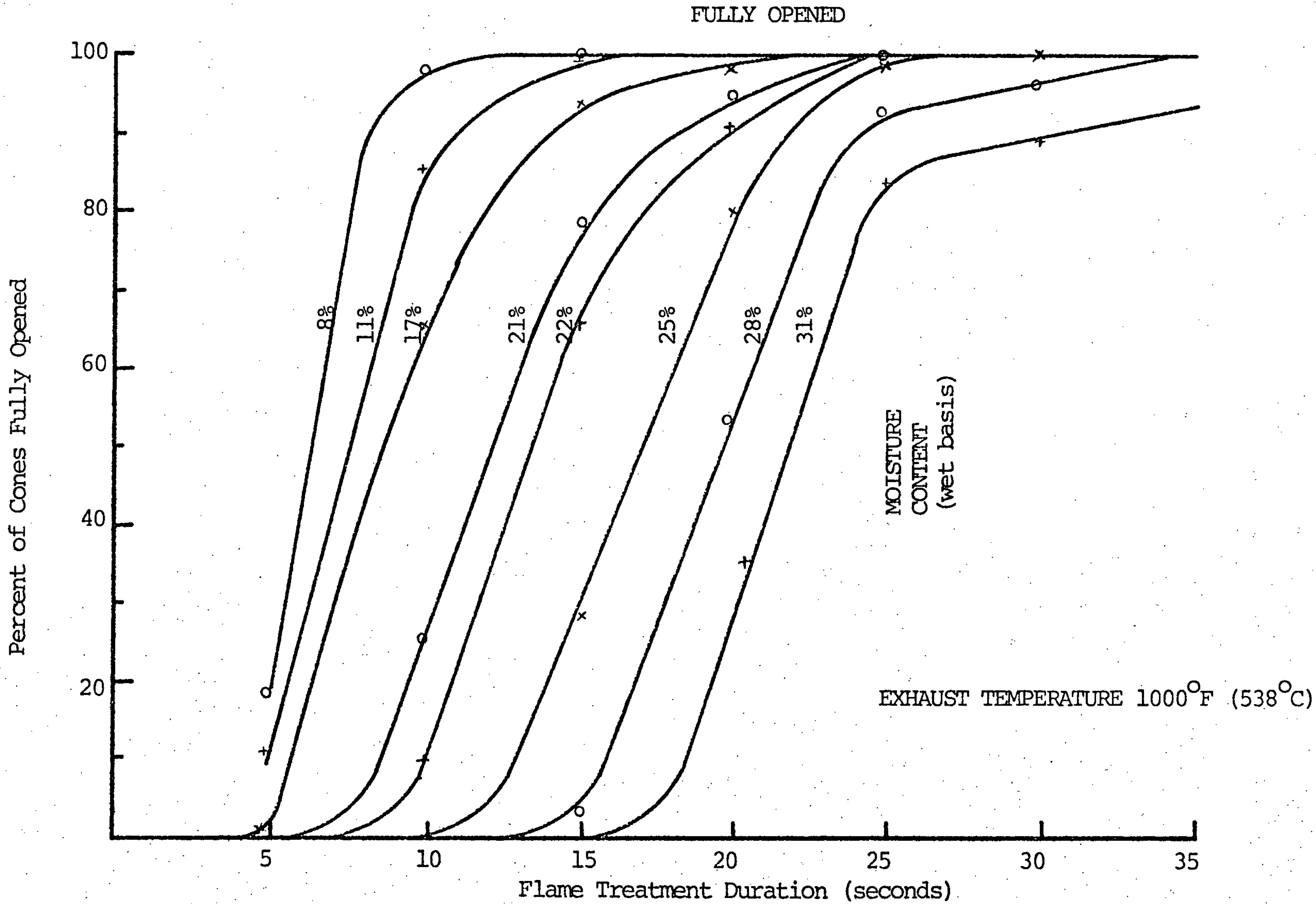


FIGURE 30. Flame treater calibration curves for complete seal breaking of Class I (young) Lodgepole Pine cones.

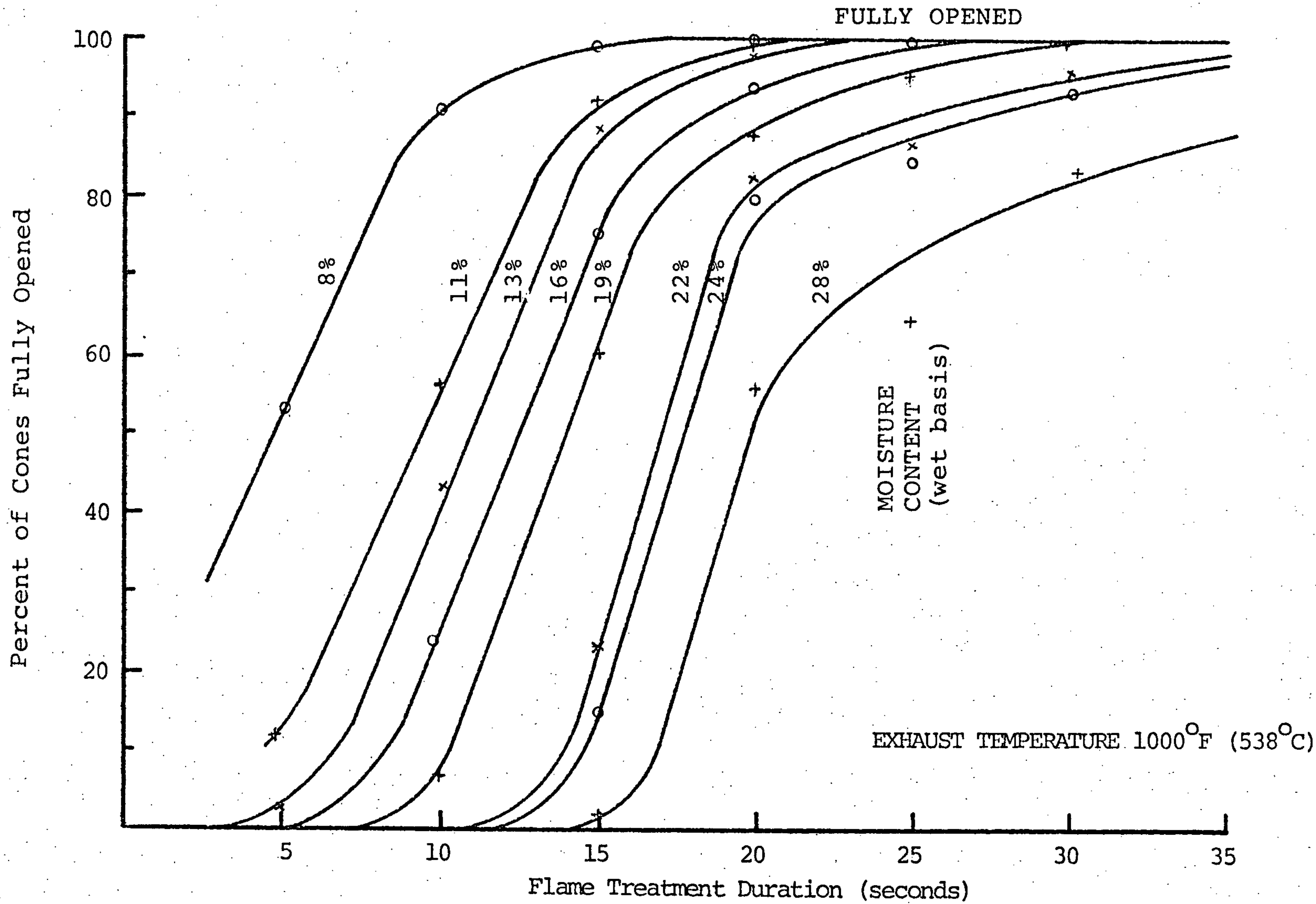


FIGURE 31. Flame treater calibration curves for complete seal breaking of Class III (weathered) Lodgepole pine cones.

XI. DEVELOPMENT OF MECHANICAL CONIFER SEED EXTRACTING TOOL.

1. Alternative Methods

The development of a mechanical conifer seed extraction system is dependent upon the successful development of an effective mechanical extraction tool. The function and importance of this type of tool in the design and operation of a portable conifer seed extraction system was discussed in Chapters I and V of this report.

Three alternative operating principles were proposed for the design of the extraction tool under consideration. These are: (i) the removal by abrasion of the outer regions of the cone scales and a reduced kiln treatment for seed extraction, (ii) the removal by boring or drilling of the central woody core of the cones which would reduce the cones to a mass of free scales mixed with the seed, (iii) the threshing of entire cones in a manner similar to that used for agricultural crops.

In each of the above processes, the function of the extraction tool is to release the seeds from their position within the cone. A subsequent tool is required to perform the task of separating the seed from the cone debris. Each of these processes must also be supplemented with heat treatment. Process (i) requires a kiln drying treatment and subsequent tumbling extraction, and process (ii) requires a heat treating process to break the serotinous seals after boring, and process (iii) appears to require a heat treatment to break the serotinous bonds prior to threshing.

Each of the above extraction methods was evaluated by preliminary testing. The most promising extraction tool was developed into a first and a second generation prototype each of which was subjected to extensive testing.

2. Extraction by Cone Abrasion

The treatment of conifer cones by abrading the cone scales to remove the outer portion and the serotinous bond region is not intended to achieve seed extraction in itself, but is proposed as a means to reduce kiln treatment and to speed the conventional kiln extraction process.

The abrasion tool used to evaluate this concept is shown in Figure 32, and consists of a stationary and a rotating concave disk mounted one above the other on a common axis.

Cones are introduced between the disks through a hole at the centre of the stationary disk. As the outer portion of the cone scales are abraded away, the cones move radially outward from the centre of the two concave surfaces. When the cones are reduced to a size determined by the distance between the disks at their periphery, the cones are discharged radially from between the disks.

After treatment by this tool, the seeds are extracted from the remaining cone material by the conventional kiln

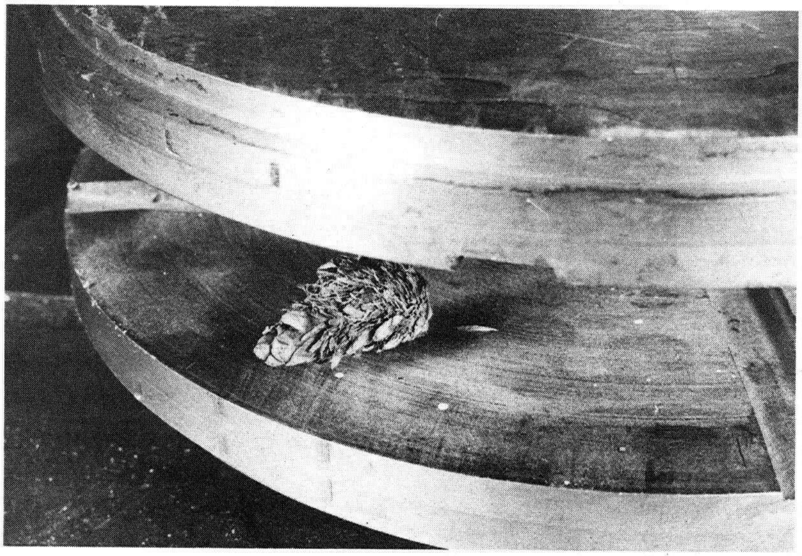


Figure 32. Cone abrasion tool.

extraction process. Abraded cones do not, however, require as long a drying time, and the high temperatures used for seal breaking are also unnecessary.

Preliminary investigation of this technique indicated that this tool did not meet the operational requirements of the proposed mechanical conifer seed extracting tool. This failure was due to the fact that after treatment, cones still required a certain period of drying, followed by a tumbling or vibration process in order to extract the seeds. Also, the reduction in kiln treatment achieved did not appear to outweigh the extra handling required to abrade the cones prior to drying. Additionally, the successful development of the flame treating flash heater for breaking the seals of serotinous cones further reduced the utility of this tool.

3. Extraction by Core Boring

The function of a core boring extracting tool is to remove the woody core from sealed serotinous cones. The purpose of the removal of the core is to remove the structure to which all cone scales are attached, thereby causing the cone scales to have no means of remaining attached to one another once the serotinous seals are released.

When the seals are broken by crushing or flash heating, bored cones are reduced to an accumulation of individual cone scales, amongst which the seeds are mixed. Separation of the seeds from the cone scale debris would be effected by conventional scalping and seed cleaning techniques.

The feasibility of this technique was first investigated by analyzing the geometry of a sample of lodgepole pine cones. A group of cones was studied to determine the range of variability of a number of geometric variables which would characterize the shape and size of cones. These variables were determined by measuring a group of cones which had been cut through the longitudinal axis to provide a cross sectional view as is shown in Figure 34. These data were required in order to identify the shape and size of both the cutting tool and the holding tool, as well as the relative position of each at the deepest point of the core removing operation

The cone variables which were studied are identified schematically in Figure 33, and are reported in Table A-21.

The data of Table A-21 are summarized in Table VII which also shows the simple correlation coefficients among the geometric variables under study.

From the data, it is evident that there is a large range in cone profile angles (Θ) and core profile angles (Ø) within a given seed lot. This, along with the wide range of cone dimensions indicates that a large number of boring tools and cutting depths are required to remove the core of all cones without damaging the nearby seeds. The low degree of symmetry in the cones further hinders the mechanization of this operation. The correlation coefficients of Table VII also indicate that there is no simple combination of these variables which would reduce the complexity of the mechanizing of this operation.

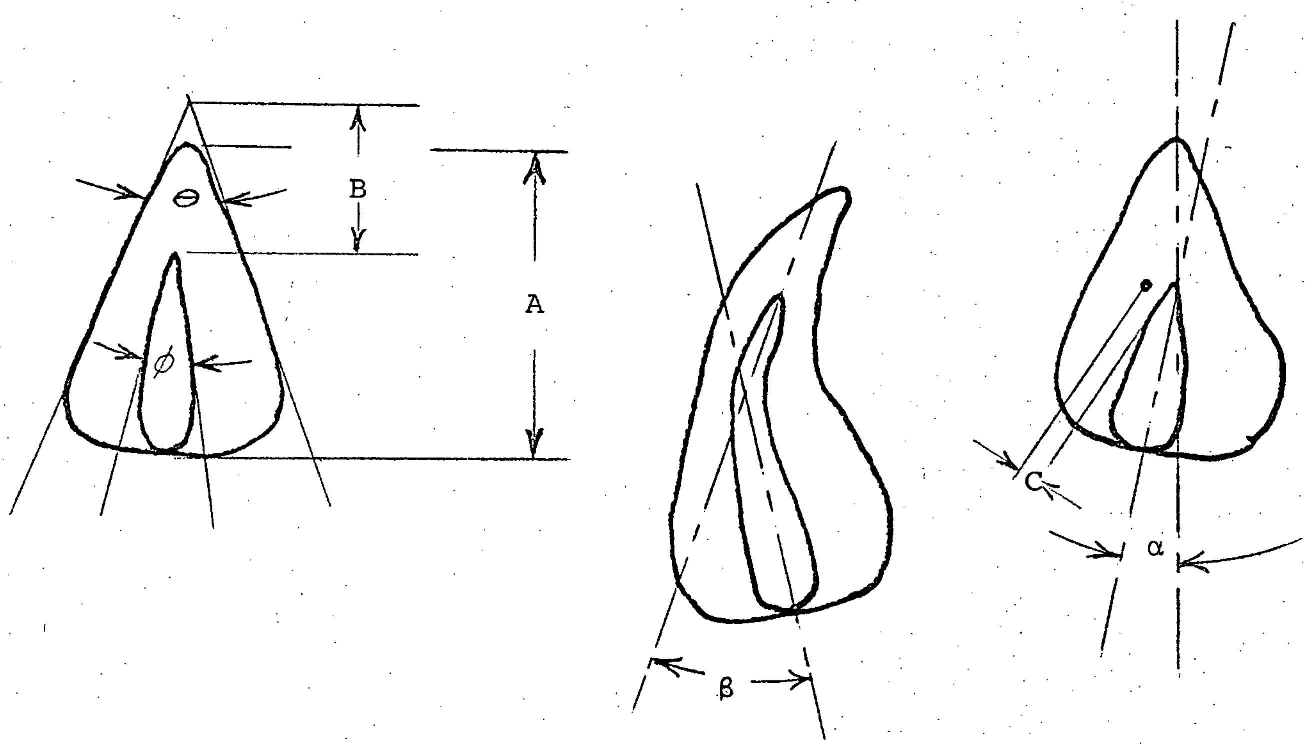


Figure 33. Geometric variables of cones influencing seed extraction by removal of cone core.

TABLE VII. SIMPLE CORRELATION AMONG VARIABLES OF CONE GEOMETRY

(Sample Size - 60 Cones)

	Cone Length L in.	Cone Angle θ^o	Core Angle ϕ^o	Core Tip to Core Apex B in.	Core Axis to Cone Axis α^o	Core Axis Misalignment β^o	Core Edge to Seed C in.
Mean Value	1.396	37.9	25.5	.966	6.9	4.0	.034
Std. Dev.	±.245	±11.4	±8.4	±.301	±4.1	±9.4	±.011
Cone Length	1.00						
Cone Angle	-.32	1.00					
Core Angle	-.25	.57	1.00				
Tip to Apex	.57	-.71	-.36	1.00			
Core to Cone Axis	.24	.20	.35	-.02	1.00		
Core Axis Misalign.	.22	.08	-.02	-.02	.15	1.00	
Core Edge to Seed	.07	-.05	.05	.8	-.20	-.07	1.00

Preliminary investigation of the operating characteristics of a core removing tool was carried out by drilling the core region of several groups of cones using a number of tapered cutting tools. This was done by operating the cutters in a lathe, and holding individual cones in the lathe chuck as shown in Figure 35.

In the cutting process, a tool was chosen having a profile angle considered to be near to that of the apex of the cone core and it was guided to cut as close as possible to the centre of the cone core axis. The tool was stopped when it reached the point estimated to be the tip of the core tissue. The cones, which at this point were still held together by the serotinous seals, were then removed from the chuck jaws for evaluation.

The effectiveness of this core boring process was evalauted by inspecting sealed cones which were cut through the central axis, as shown in Figure 36, and by inspecting these cone halves after they received thermal seal breaking as shown in Figure 37.

The attempts to remove cone cores by boring resulted in virtually no cones being completely reduced to free scales without a significant portion of the seeds being destroyed in the process. The cutter achieved complete core removal only in the symmetrical cones, and in cones which were bored with a wide angled cutting tool. In the symmetrical cones the tool angle and depth of cut were the factors controlling seed damage, while the use of the wide angle tool removed the core and part of the scale tissue taking with it a large portion of the seeds.

The biggest problem in core removal was, however, the alignment of the cutter with the core axis of the large number of asymmetrical cones which occur in this species. In this case, even the proper tool angle and cutting depth did not achieve complete core removal, and frequently destroyed a portion of the seeds. The incomplete removal of the core resulted

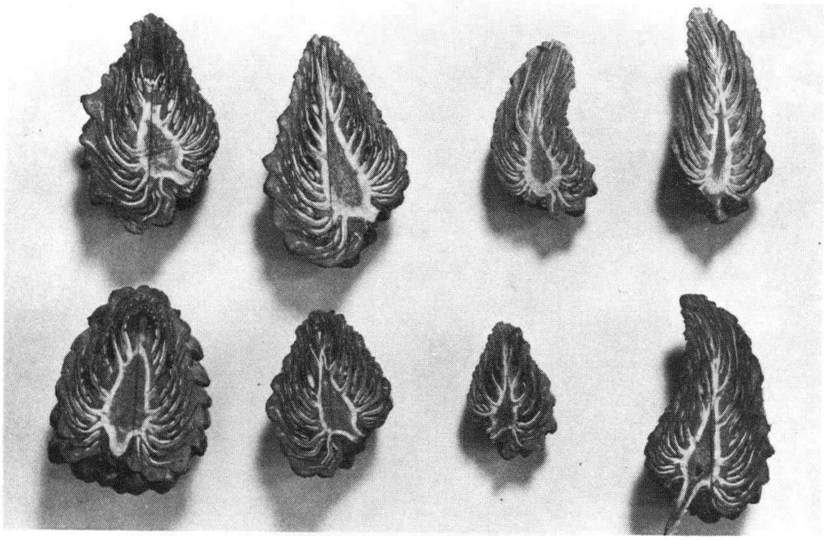


Figure 34. Cross section of typical cones showing degree of asymmetry.

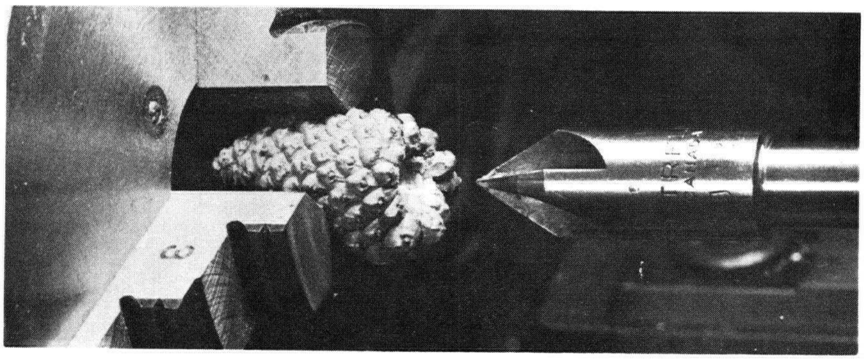


Figure 35. Core boring tool.

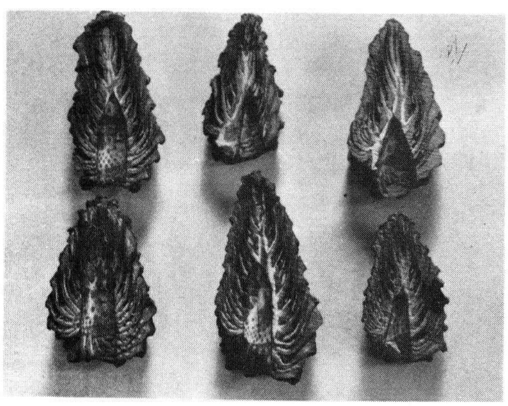


Figure 36. Cross section of bored cones.

Figure37. Bored and unsealed cones.

in only partial fragmentation of the cone and hence partial seed release after seal breaking. This condition is shown in Figure 37.

The qualitative evaluation of seed extraction of sealed Lodgepole pine cones by removing the cone cores indicates the following conclusions:

- Seed extraction can be achieved by removal of the core tissue of cones, but this technique does not lend itself to the design of a simple portable seed extraction system.
- The wide range of cone shape and size found in commercially collected cones necessitates pre-sorting of the cones to ensure that all cones are bored by a suitable cutter and to the appropriate depth. This is necessary in order to achieve complete scale separation and to minimize seed destruction.
- Thermal breaking of the serotinous seals of cones cannot be performed prior to boring as the cone would disintegrate during boring, causing damage to the seeds. During seal breaking, after boring, the basal end of cones must be protected from the heat so that the seeds are not exposed to high temperatures through the bore holes. Thus cones cannot be flash heated while tumbling, but must be

treated while oriented to protect the basal region of the cone.

- The complexity of an automated machine system capable of meeting the above criteria would result in prohibitive initial and operating costs.
- The production rate of an extraction system employing this type of extraction tool would be low, due to the necessity of treating cones individually. It is estimated that a highly automated system of this type could handle from 20 to 30 cones per tool, per minute.

4. Extraction by Threshing

(i) Analysis

The extraction of conifer seeds by threshing is proposed as an adaption of the technique which has long been used to extract seeds from agricultural crops. The extraction of seed by threshing involves the manipulation of seed bearing material between a revolving threshing cylinder and a set of stationary separating concaves or grates. The free seeds are then separated from the other material by a subsequent mechanism which, in most cases, is an air-screen seed cleaner.

The layout of a typical agricultural threshing system is shown schematically in Figure 38. The diagram shows both the extracting tool and the seed separating tool which are combined into what is traditionally termed a threshing machine.

The function of the cylinder and concaves extracting tool in a threshing machine is to free the seeds from their attachment to and/or location in the protective plant tissue. The function of the separating tool is to separate the output of the extracting tool into: (i) coarse material which is discharged directly; (ii) partially threshed material which is returned to the entrance of the extracting tool for re-threshing; (iii) fine material smaller in size than the seeds, and (iv) seeds combined with a quantity of debris similar to the seeds.

The operation of a conifer seed thresher would be very similar to that described above. Extraction of serotinous

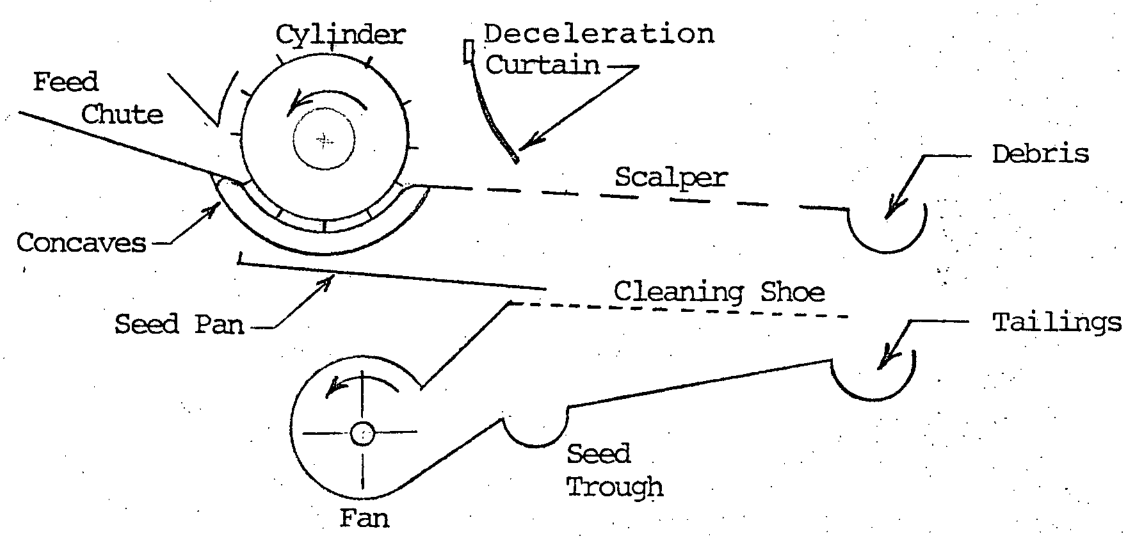


Figure 38. Schematic diagram of threshing machine.

cones, using this system, would include a seal breaking operation prior to threshing, while the soft-cone species would be fed directly into the threshing tool.

The variables involved in the analysis of cylinder-concave seed extracting tools include: cylinder velocity, cylinder to concave clearance, type of material to be extracted, moisture content of material, arc length of concave, configuration, number, and material of cylinder rub bars, type and size of concave surfaces, feed rate and velocity, type and location of deceleration surfaces. The analysis of many of these variables is empirical, and all of them involve a degree of subjective evaluation.

Although little is known of the use of this method of extraction for conifer seeds, a vast quantity of information has been published on the extraction of agricultural seeds by threshing. Obviously much of this has dealt with the classical threshing of grain crops, but equally significant is the literature dealing with the threshing of other crops. The seeds for both consumption and replanting of virtually every agricultural crop with the exception of fruit crops is presently extracted by means of a conventional cylinder and concaves threshing mechanism.

A partial list of the crops whose seeds are extracted by threshing (51) is: cereal grains, corn, peas, beans, rice, clover, timothy, alfalfa, rape, flax, carrots, lettuce, turnips.

Bainer et al. (6) described the extraction process of a threshing cylinder as one depending upon impact of the cylinder bar upon the seed containing capsule which results in the shattering of the capsule and the freeing of the seed from the protective covering material. Further threshing is obtained by the rubbing action as the material is accelerated and passed through the clearance between the cylinder and the concave.

The effectiveness of threshing is stated (6) to be a function of the following: cylinder speed, concave clearance, cylinder-concave design, type of crop, moisture content of crop, and rate of feed of material. For each crop, there is an optimum point for each of these variables which will result in a maximum seed recovery and minimum seed damage.

Hawthorne and Pollard (23) in 1954 described the construction of an all purpose cylinder and concave threshing tool which was capable of extracting the seeds of a wide range of vegetable, flower and grain crops. The thresher is designed with rubber covered raspbars and concaves, and the speed and concaves position are easily adjustable to operate over a wide range of settings.

The removal of the seeds from the cone debris discharged from the thresher involves the use of a cleaning tool in the flow path of the extraction systems. A wide range of tools for this function are commercially available (22) and are readily adaptable to the proposed conifer seed extraction system.

(ii) First prototype tool

A prototype cone threshing tool was designed for laboratory investigation of the extraction of conifer seeds by threshing.

The key components of the prototype extracting tool are the threshing cylinder and concaves which are shown in Figure 39. The cylinder is six inches in width, and has six one-inch high rub-bars mounted on its periphery. The diameter of the cylinder measured at the top of the rub-bars is ten inches. The concave set is constructed of ¼" x 1" steel bars mounted at 7/8" spacing over an arc of approximately 150^{o} of the cylinder. The 3/16" retaining rods running through the length of the concaves are spaced at 3/8" intervals. During fabrication, all concave parts were welded into a single assembled unit.

These components are mounted in a frame as shown in Figure 40, and the plenum chamber in Figure 41 was added to provide a means to collect the material coming off the cylinder. This chamber holds a manually operated scalping sieve which separates partially threshed cones for their return to the input and further treatment. Threshed material passing through the cylinder was collected below the scalping sieve, while that passing through the concaves was collected in a separate pan. The assembled prototype cone thresher is shown in Figure 42.

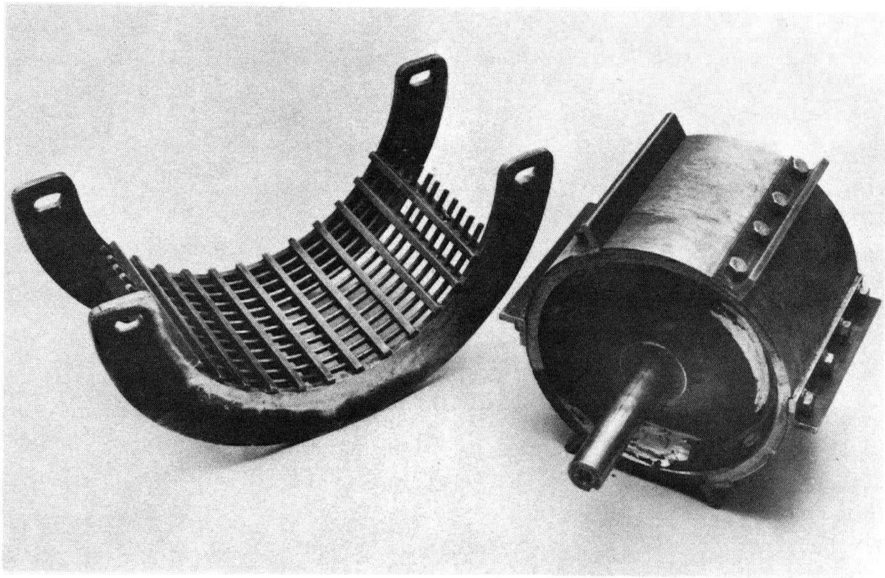


Figure 39. Cylinder and concaves of threshing tool.

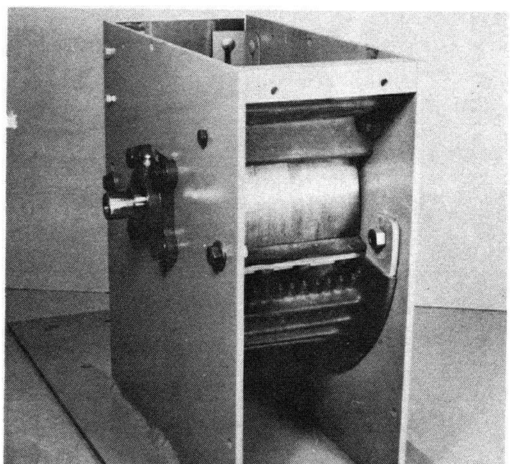


Figure 40. Cylinder and concaves installed in frame.

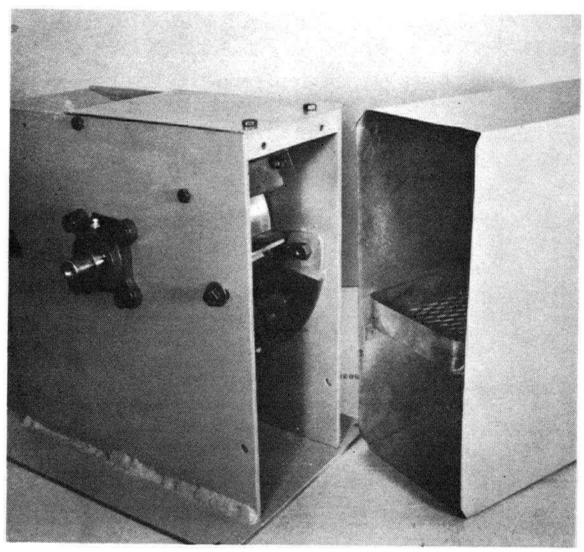


Figure 41. Threshing tool with plenum chamber.

The threshing cylinder is belt driven and is powered by a variable speed electric motor which is capable of driving the cylinder at peripheral speeds up to 8000 feet per minute (2438 meters per minute).

A uniform feed rate for test batches is provided by an inclined feed chute and hopper. Uniformity of flow is achieved by a feed gate and a pneumatic ball vibrator mounted below the delivery trough as shown in Figure 42.

(iii) Testing

For reasons discussed earlier, testing of the first generation prototype cone threshing tool was confined to lodgepole pine cones whose cone scales had been previously released by flash heat treating. Groups of approximately 100 cones having moisture contents of 8.5, 12.8, 15.8, 19.9 percent were threshed using cylinder speeds of 1800, 2300, 2800, 3300, 3800, and 4300 feet per minute (548, 701, 854, 1006, 1158, and 1310 meters per minute) respectively.

Because only partial threshing is usually achieved in each pass through the extracting tool, the cone fragments retained on the scalping sieve were returned to be rethreshed in the same manner as the tailings from an agricultural thresher. For this series of tests, the material was returned as necessary, up to a total of five passes through the cylinder. At high speeds this treatment was sufficient to completely reduce the cones in two or three passes, but at low speeds, some seeds still remained unextracted within cone particles.

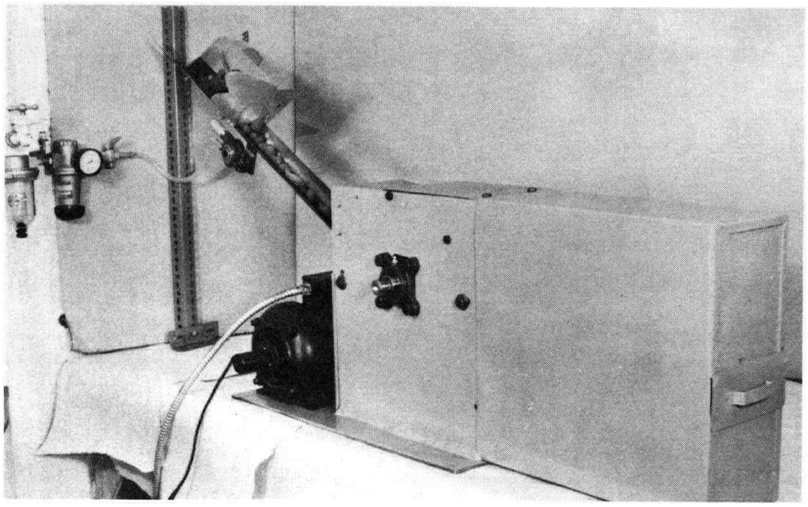


Figure 42. Assembled prototype cone thresher.

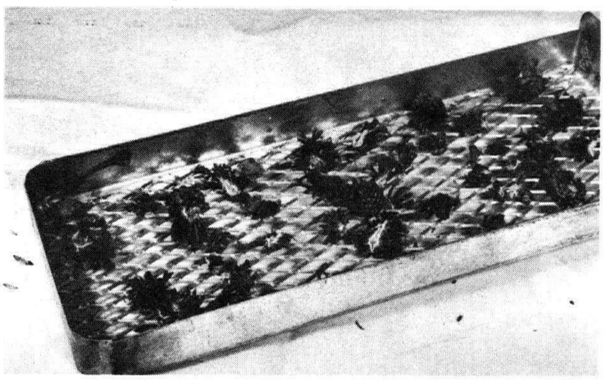


Figure 43. Scalping sieve with partially threshed cones.

Figure 44. Partially threshed cones after two passes with cylinder speed of 2000 ft./min.

The condition of partially threshed cones is exemplified in Figure 44 which shows cone fragments from 20 cones retained by the scalping sieve after two passes at a cylinder speed of 2000 ft/min. Figure 45 shows typical material passing through the sieve under the same conditions.

After extraction, the mixture of cone debris and seeds was separated using the air-screen cleaner shown in Figure 46. In the first cleaning treatment, the large particles were scalped using a number 11 round hole sieve with no air flow. The remaining seed mixture was processed again using a number 8 round hole sieve and a number 6 X 27 screen. The final material was then hand sorted using a spatula and smooth table surface to separate those seeds which showed no visible mechanical damage from the damaged seed as shown in Figure 47.

The sound seeds from each test were weighed after drying, and sample counts taken to determine the number of seeds recovered from each group of cones. All cone material from each test was also retained, dried and weighed for calculation purposes.

Germination tests were then conducted on representative samples of unstratified seeds from each test. The germination percent was reported as the percentage of total seeds producing normal germinants having radicles at least twice the length of the seed.

Cones in the control group were extracted by flash heating to break the seals, drying for several days at room

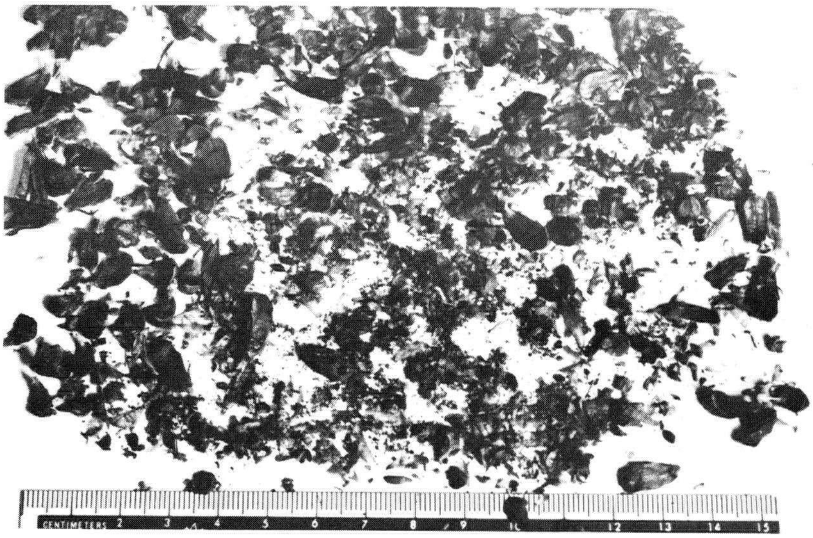


Figure 45. Material passing through scalping sieve.

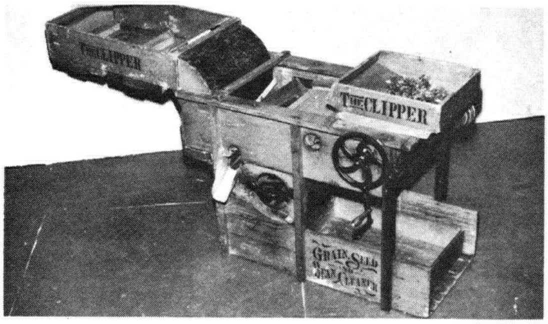


Figure 46. Air-screen seed cleaner.

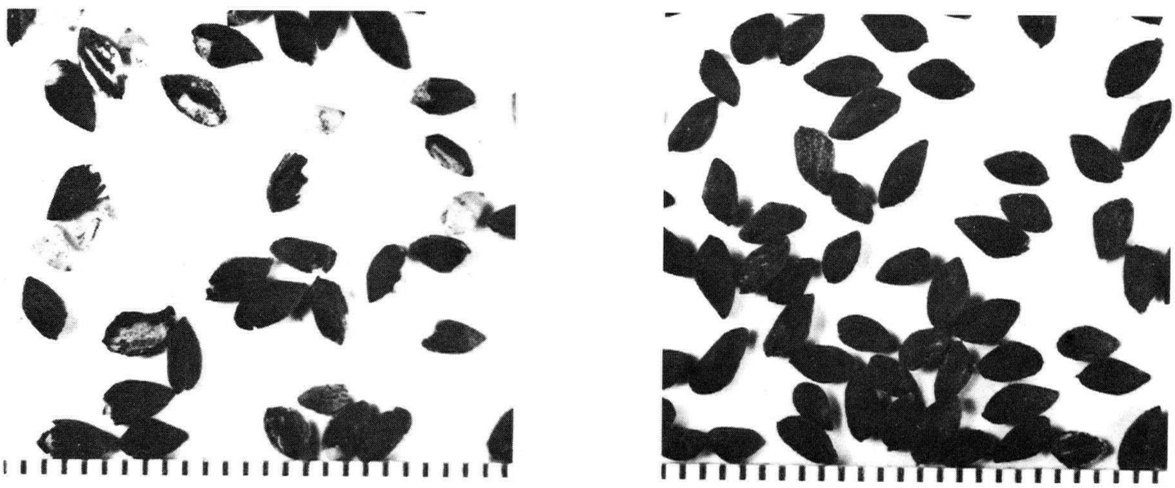


Figure 47. Typical damaged and apparently undamaged seeds extracted by threshing.

temperature and shaking in a mesh bottomed container. Seeds in the control group were treated by passing them through the air-screen seed cleaner in order to eliminate variability caused by cleaning.

The data obtained from the above testing are reported in Table A-22. Analysis was carried out to determine the average number of viable seeds contained in each cone, and the expected number of viable seeds recovered by each threshing treatment at each moisture content. The difference in these two numbers represents the sum of the number of seeds remaining in the cone fragments after five passes and the number of seeds damaged in the extraction process. From this, the percentage of viable seeds recovered by the prototype thresher at the one setting of thresher variables was determined and is reported as the recovery rate.

The recovery rate determined for the various moisture contents and operating speeds are shown in Table A-22 and are plotted in Figure 48. The results of this first series of tests indicate that the unbroken seed extraction rate was reasonably high, but that internal mechanical damage greatly reduced the viable seed recovery rate. The fact that some seeds remained in cone fragements at the end of five passes, also reduced the overall recovery rate. This factor is particularly important at low speeds where both the degree of extraction per pass and the degree of seed damage is low.

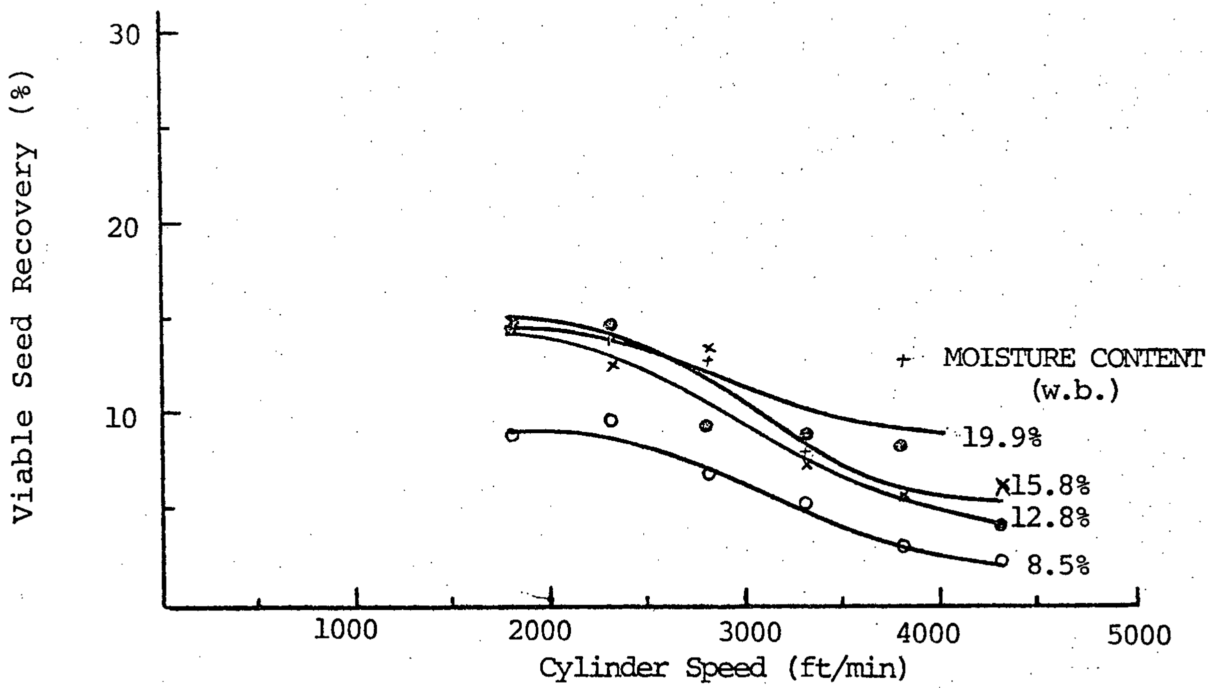


Figure 48. Viable seed recovery rate in lodgepole pine for first prototype thresher.

Figure 48 also shows that viable seed recovery is highest at the lower cylinder speeds, where the impact forces are low. The best moisture content for extraction appears to be in the range of 12 to 20 percent wet basis.

Although the recovery rates of these tests on the first prototype cone threshing tool are low, much information was gained concerning the design and performance of this type of tool.

The results of these tests and the experience gained from them indicate that further developmental work on this extraction tool can result in higher seed recovery rates and much lower seed damage. The fact that the functional operation of this prototype meets all the other operational requirements necessary for a portable mechanical conifer seed extraction tool holds similar promise of the successful development of the proposed extraction system.

(iv) Second generation prototype

Based on the information gained from the above tests, a number of modifications were carried out on the design of the original prototype threshing tool. The chief goal of these modifications was the reduction of damage to extracted seeds by their impact with the internal contact areas of the thresher.

This seed protection was provided by the installation of cushioning material on all internal surfaces coming in contact with the threshed seeds. For this purpose, the inner surfaces of the top plate and feed-end plate, as shown in Figure 49, were covered with a one-eighth inch thick layer of natural rubber having a Shore hardness of 40 to 45. The leading surfaces of the cylinder rub bars were covered with natural rubber having a Shore hardness of 70. A vulcanizing process was used to bond all rubber to the surfaces they covered.

The cushioning, shown in Figure 50, was applied to the concaves assembly by dipping the component in a vinyl plastisol material, and curing to a Shore hardness of 70 to 75.

A cylinder stripper bar, which was rubber coated, was also added to reduce the recirculation of material around

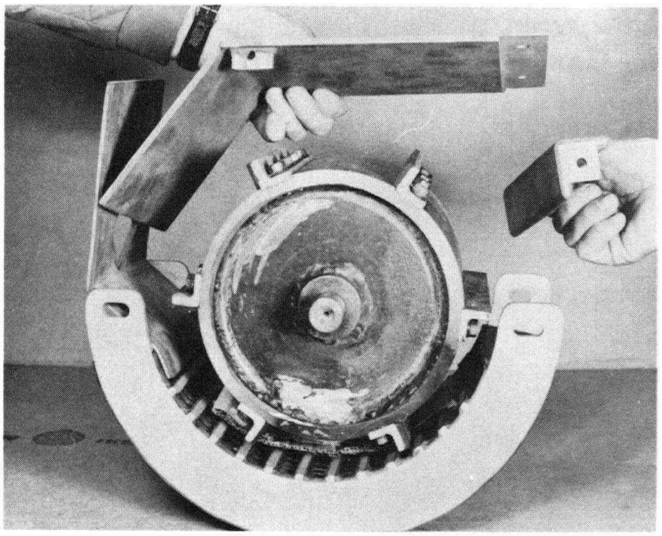


Figure 49. Internal components showing location of cushioning material.

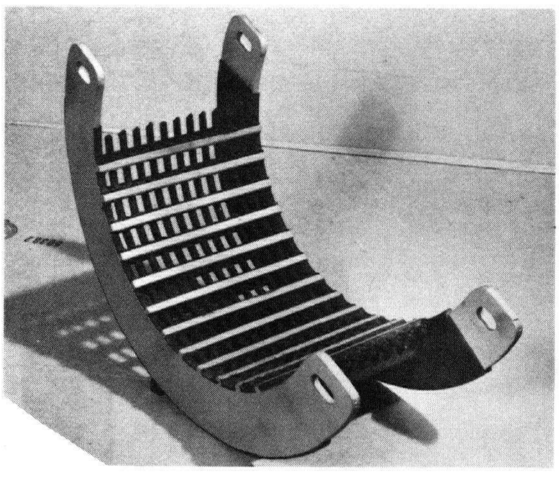


Figure 50. Detail of cushion material on concaves.

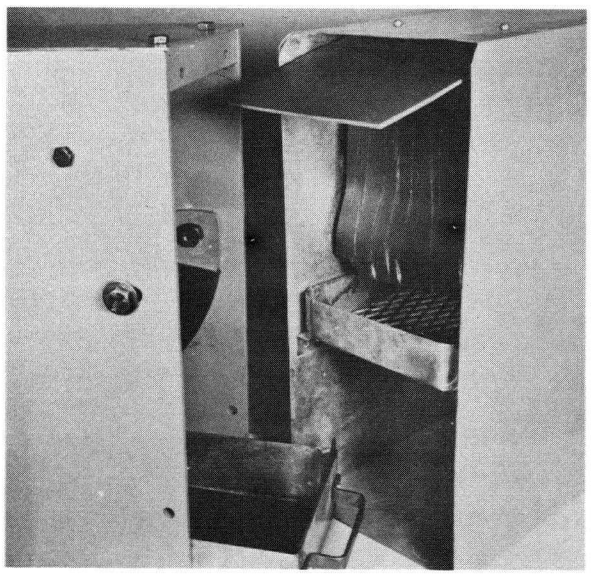


Figure 51. Location of deceleration curtain in plenum chamber.

the cylinder. This is also shown in Figure 49.

A rubber decleration curtain was added to the housing so as to intercept the path of material exiting from between the cylinder and concaves. This curtain, shown in Figure 51, is hung just to the rear of the stripping bar, and acts to slow the high velocity material, and drop it onto the scalping sieve.

(v) Testing

Upon completion of the modifications outlined above, the performance of this second generation threshing tool was tested. A modified testing procedure was used to take advantage of experience gained in the earlier tests.

Tests were conducted on cones at 15% and 20% moisture content, corresponding to the moisture range which produced the highest recovery rates in the earlier tests. Based on the finding that the peak recovery is at the low end of the operating speed range, operating speeds of 1600, 2000, 2400 and 2800 feet per minute (487, 609, 732, and 853 meters per minute) respectively, were chosen for the second series of tests. Groups of 100 cones were used for each test.

In order to ensure complete extraction all cone fragments were recycled through the thresher until complete threshing was achieved. In the case of the low speed treatment, upwards of fifteen passes were required in order to reduce the last few cone fragments.

Separation of the seeds from the cone debris was carried out under the same conditions as the earlier tests. In the final cleaning, the hand sorting was replaced by passing the material over a manually oscillated cloth covered surface which was slightly inclined. In this process the smooth round seeds travelled down the incline sooner than the cone fragments, and the latter were removed from the cloth by vacuum. After all debris and obviously damaged seeds were removed from the samples, the seeds were counted on an electronic seed counter.

In order to account for seeds which may have been lost during the cleaning process, seeds from the control group were mixed with the debris from one group of threshed cones, and were re-separated using the same treatment given the threshed seeds.

Germination tests were carried out on seeds and the germination percents were correlated to give the number of viable seeds per cone, recovered by the extracting tool.

The results of these tests are tabulated in Table A-23 and the recovery rates are plotted against peripheral tool speed in Figure 52.

From the figure it can be seen that maximum recovery rate for Lodgepole pine is much higher for the second generation thresher than it was for the first prototype. The better of the two moisture contents tested in the rubberized thresher is clearly shown to be the 15.5% value. The optimum cylinder speed for the conditions tested is in the range of 2000 ft per minute. These figures for optimum moisture content and cylinder speed correspond well with those determined in the earlier series of tests.

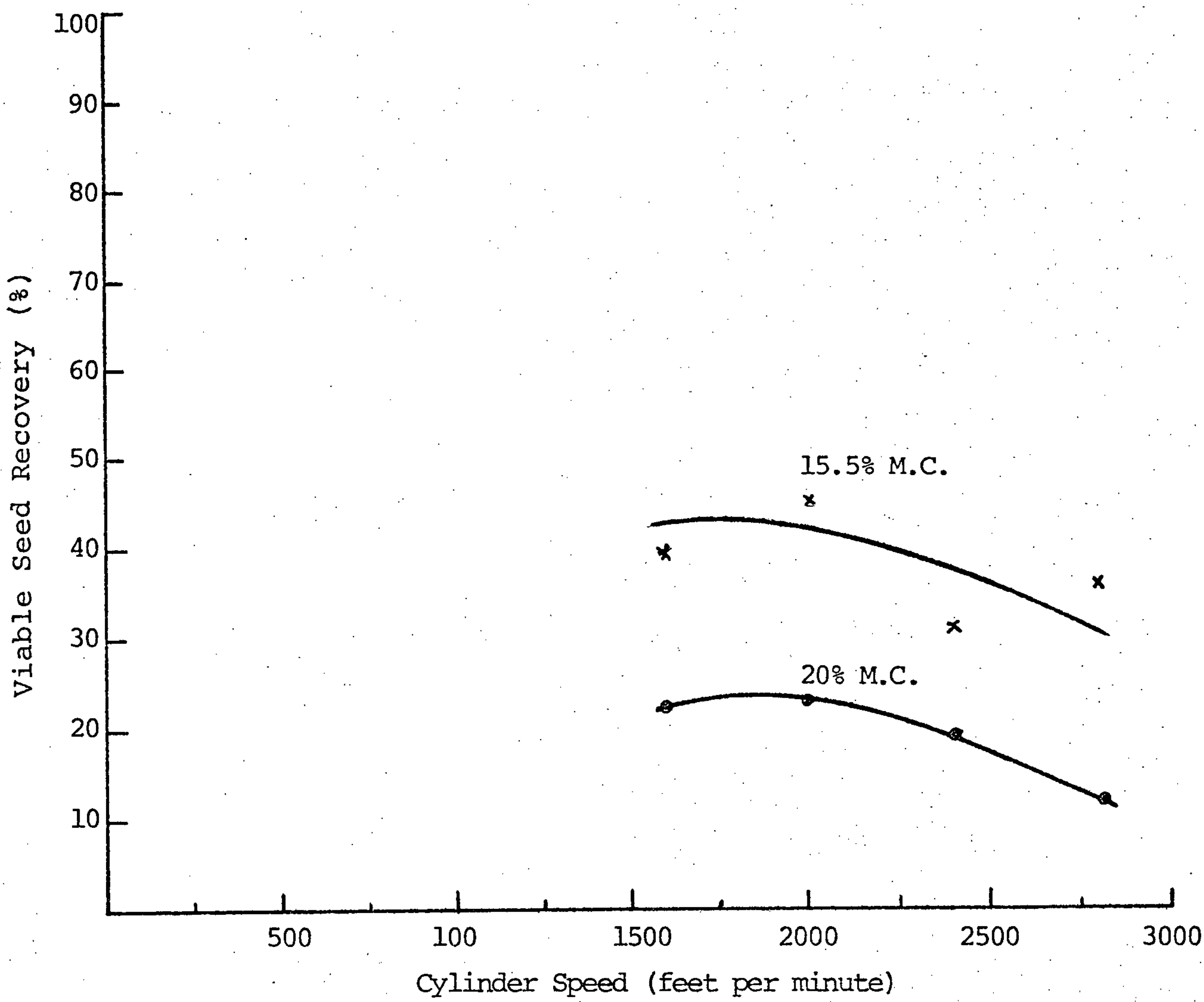


Figure 52. Curves of seed recovery vs. cylinder speed for Lodgepole pine extracted by the rubberized threshing tool.

The results of these tests show a marked improvement in the seed recovery rate of the thresher by the modification of only one of the many variables which affect the performance of such a machine. It is therefore apparent that additional developmental work with this and other variables which affect threshing effectiveness can be expected to result in further improvements in the rate of viable seed recovery from conifer seed threshing tools.

A further test was carried out on the second prototype in order to assess the degree of seed extraction achieved with successive passes through the threshing tool.

For this test, a group of 100 cones was studied under the optimum threshing conditions of 15.0% moisture content, and a cylinder speed of 2000 ft/min as determined earlier. The cones were passed through the thresher, and the seeds passing through the concaves and through the scalping sieve were collected. The unthreshed cones and cone fragments were then rethreshed nine times and the seeds were collected from each region of the thresher after each pass.

The number of seeds from each region after each pass was recorded, and germination percents determined for each group. From the data, the number of viable seeds recovered from the concaves and from the scalper sieve after each pass was determined, and is reported in Tables A-24 and A-25. Cumulative curves showing the portion of total viable seeds recovered through the concaves and through the sieve, for each successive pass, are plotted in Figure 53.

These curves show that less than half of the seeds are recovered through the concaves, and that approximately 95% of the viable seeds recovered are extracted in the first four passes through the thresher.

The data of Tables A-24 and A25 also show that the viability rate of seeds extracted in a certain pass is not significantly reduced by successive passes through the thresher.

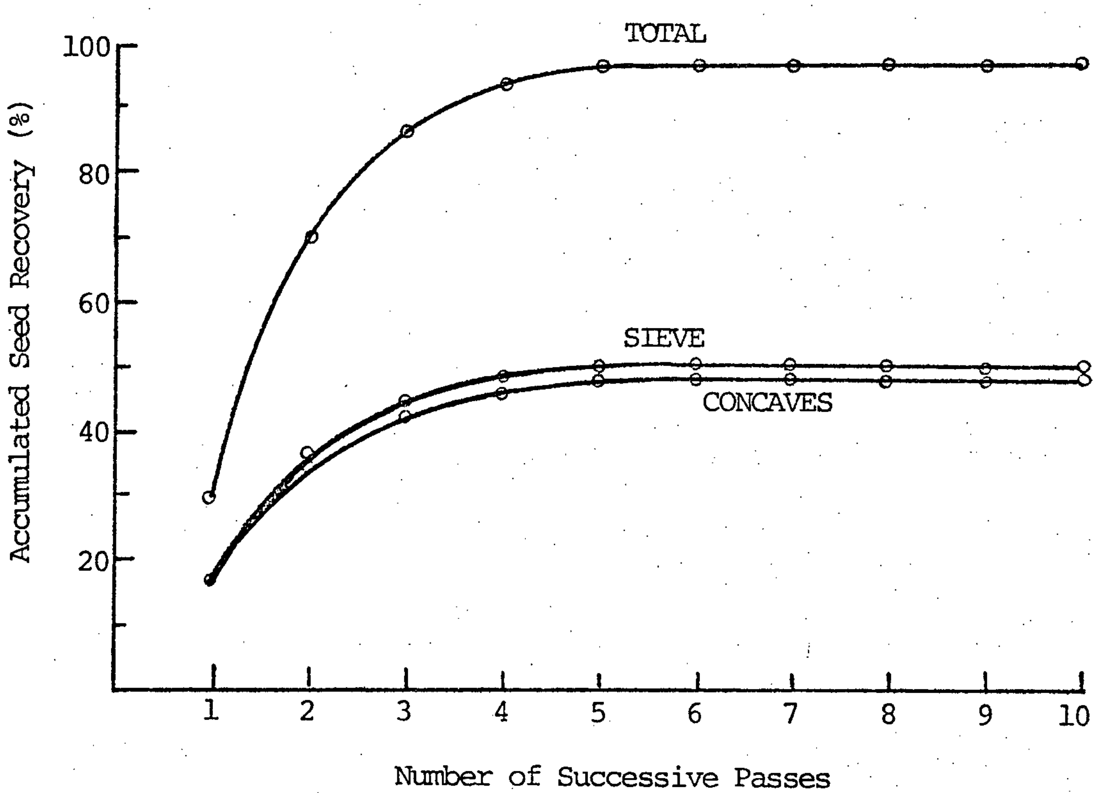


Figure 53. Accumulated viable seed recovery from cones at 15% moisture content threshed at a cylinder speed of 2000 ft/minute.

(vi) Threshing Performance on Other Species

The performance of the second generation threshing tool was also evaluated by extracting cones of the following species: Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco)), white spruce (*Picea glauca* (Moench) Voss)), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)). These cones were identified by the B.C. Forest Service seed lot numbers as C7-2, N7-3, and N22-5 respectively.

Tests were conducted on each species at two moisture contents. One moisture level was where the cones were just dry enough to shed seeds, the other, where the cones were wet enough to remain closed. The concaves of the threshing tool was set at one arbitrary position for the tests which were carried out at five cylinder speeds. Partially extracted cones were reprocessed until threshing was complete.

Separation of the seeds from the cone debris was carried out using the same techniques as used for lodgepole pine above, except that sieve sizes appropriate to each seed size were used.

Seeds in the control group were extracted by drying and shaking in a mesh bottom container. These control seeds were mixed with the debris from a group of cones and then re-separated using the same techniques as the threshed seeds.

Germination tests were carried out on each group of seeds, and the number of viable seeds recovered in each test was determined. This was compared to the number of viable seeds recovered from the control group in order to determine the percent recovery.

The data from the tests on fir, spruce and hemlock cones are shown in Tables A-26, A-27 and A-28 respectively. The rates of recovery of viable seed for each group of tests is plotted against cylinder speed in Figure 54.

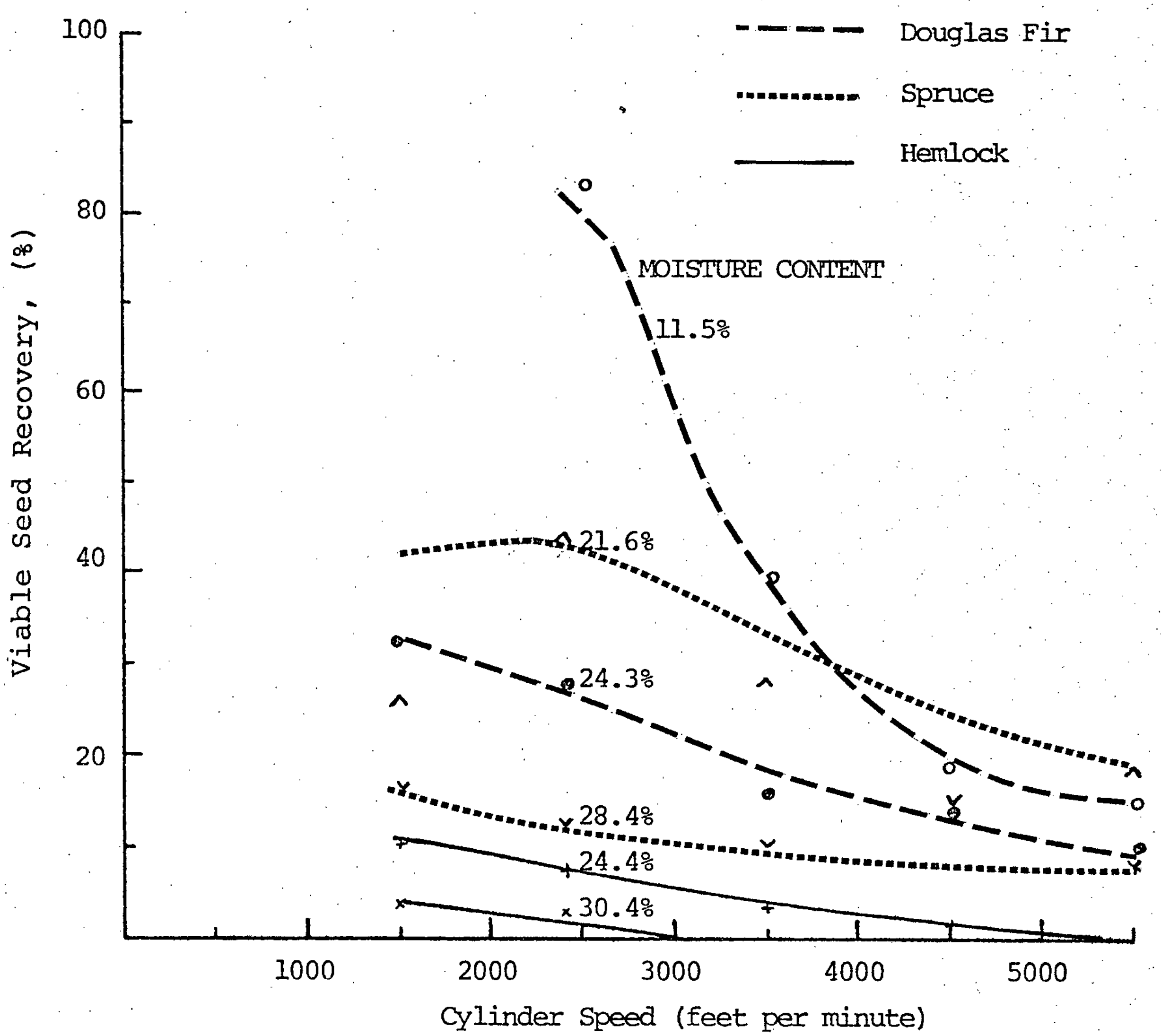


Figure 54. Seed recovery by threshing of fir, spruce and hemlock cones.

The curves of Figure 54 indicate that the best seed recovery rate for the particular condition of thresher variables used in these tests was achieved with Douglas fir cones, at 11.5% moisture content. Unfortunately the results of the test at this moisture content at a cylinder speed of 1500 ft/minute were destroyed during cleaning. The curve did, however, indicate a maximum seed recovery rate in excess of 80%.

The maximum recovery rate achieved in spruce was slightly above 40%, while that of hemlock was below 20%. It is also evident from the curves that the maximum recovery rate for the particular thresher configuration and adjustment used in these tests was achieved at cylinder speeds between 2000 and 3000 feet per minute.

The results of these tests indicate that satisfactory seed extraction can be achieved by threshing once the optimum condition of each of the many variables of machine parameters and biological material conditions are identified.

P A R T T H R E E

C O N C L U S I O N S

A N D

R E C O M M E N D A T I O N S

XII CONCLUSIONS

The conclusions arising from the investigations outlined in this report are listed in point form below.

1. Physical Properties of Lodgepole Pine Cones which Affect Seed Extraction

- Seeds located in the extremities of the seed bearing region of lodgepole pine cones have a slightly higher percentage of empty seeds, but filled seeds from all regions of the cones have essentially the same germination percent.
- Seeds which are easily extracted by tumbling tend to have a higher portion of filled seeds than those which are more difficult to extract.
- A decline in germination percent is initiated within 72 hours in seeds of wet cones which are slowly dried in a non-circulating kiln at 140°F (60°C).
- The equilibrium moisture content, during drying, of lodgepole pine cones has been determined and the characteristic is consistent with that of other hygroscopic biological materials.
- The mean temperature at which the serotinous seals of young cones of lodgepole pine are broken is 52.51°C ± 5.7°C. Old weathered cones are opened at a mean temperature of 54.50°C ± 5.8°C.
- The angle to which the scales of lodgepole pine cones open upon drying, after seal breaking, has been

determined, and is approximately a linear relationship with cone moisture content in the range of moisture content below 25% wet basis.

- The scales of lodgepole pine cones undergo a process of stress relaxation when they are held at moisture contents below 25% wet basis while their scales are sealed in the closed position. Cones which experience this process suffer a reduction in the angle to which their scales will open for any given moisture content after their seals are broken.
- Cones which have undergone a stress relaxation process can recover most of their scale deflecting ability if their moisture content is raised to a high level before redrying.
- The portion of total seeds contained by cones which can be easily extracted by tumbling increases at a diminishing rate as the angle of scale deflection is increased beyond 60° by drying.
- The serotinous seal of lodgepole pine cones can be broken by flash heating in either hot water, or in a flame, without causing a reduction in seed viability.
- Complete seal breakage can be achieved with a mild heat treatment if the cones are at a moisture content below 25% wet basis, so that scale flexing stresses separate the scales when the sealing material is melted.

2. <u>Development of Seal Breaking Tool</u>

- Mechanical seal breaking can be achieved by a crushing process, but this technique does not lend itself to continuous flow commercial operation.
- Thermal seal breaking by flash heating cones is an effective method of opening cones which lends itself to continuous flow commercial operation. Seed temperatures within cones so treated can be predicted with reasonable accuracy.
- A continuous flow hot water flash heating tool for seal breaking was developed and found to operate effectively, but had certain disadvantages which reduce its suitability for commercial operation.
- A continuous flow flame treating flash heating tool for seal breaking was developed and found to operate effectively. This device was the most suitable tool found for opening serotinous cones under commercial operating conditions and was calibrated over a range of moisture contents for two classes of lodgepole pine cones.

3. <u>Development of Mechanical Conifer Seed Extracting Tool</u>

- Mechanical abrasion of the outer portion of serotinous cones will reduce kiln treatment for seed extraction purposes, but does not appear suitable as a tool for commercial operation.

- Seed extraction by the removal of the core of serotinous cones is an effective alternative, but the high degree of asymmetry of the cones of lodgepole pine causes extensive seed damage when the core boring tool cuts beyond the woody core. This occurs when the boring tool, which can automatically align itself only with the axis of the external cone profile, is operated on cones whose woody core is not concentric with the external cone profile.
- The extraction of conifer seed by threshing is an acceptable alternative in terms of the design of a mechanized seed handling system. A first and second generation conifer threshing tool was developed and tested. With a limited degree of optimization of machine variables, viable seed recovery rates as high as 44% were achieved with this tool on unsealed lodgepole pine cones. Further developmental work on this tool can be expected to raise this figure significantly.
- Preliminary tests performed with this prototype threshing tool on cones of Douglas fir, white spruce and western hemlock, indicate that the

optimum condition of the many machine and material variables which affect threshing must be determined for each individual species.

XIII RECOMMENDATIONS

Recommendations for the application of the findings of this investigation to the commercial seed extraction of the serotinous conifer species, as well as general comments on the development of a mechanized conifer seed extraction system are listed below:

- Serotinous cones which are to be extracted by kiln drying and tumbling should be stored at low temperatures, at a moisture content of approximately 25% wet basis in order to minimize the occurrence of stress relaxation in the cone scales.
- Non-serotinous cones which are to be kiln extracted should not be allowed to dry below approximately 25% unless they are in containers which permit free deflection of the scales. This is because stress relaxation occurs in non-serotinous cones which are dried, but whose cone scales are prevented from deflecting fully.
- It is recommended that further work be carried out to complete the development of the design of a flame treating flash heater for the seal breaking of serotinous cones. This machine will be a valuable tool for seal breaking prior to conventional kiln treatment, as well as for future

development of a mechanized conifer seed extraction system.

The following design features are recommended for inclusion in the design of subsequent machines:

- Longer flame tube having larger diameter and at least double run conveying flights.
- Hopper feeding and metering system based on vibration.
- Double enclosure over flame tube to reduce heat losses.

\- It is recommended that further study be carried out to determine the optimum conditions of the machine and material variables which affect the threshing of cones.

The following parameters are suggested as possible avenues to improved threshing performance.

- A study of cone and seed morphology and physiology to identify the characteristics of, and means to reduce mechanical seed damage.
- The utilization of a larger threshing cylinder diameter, and the resulting greater concave length.
- Experimentation with shorter, closer spaced cylinder rub-bars, including spike tooth cylinder and concaves.

- Experimentation with alternate concave designs, and settings.
- Investigation of air assisted transport of seeds out of the area of the cylinder.

LITERATURE CITED

1. Ackerman, R.F. 1966. Effect of storage in slash on quality and quantity of Lodgepole Pine seeds available for regeneration. Canada Dept. For. & Rural Development, Alberta/Ter. Reg. Forest Res. Lab. Inf. Rep. A-K-3, 22 pp.

2. Allen, G.S. 1957. "Better Handling of a Scarce Commodity". B.C. Lumberman, 41, 32-36.

3. Allen, R. and Wardrop, A. 1964. "The Opening and Shedding Mechanism of Female Cones of Pinus radiata". Aust. J. Botany 12, 125.

4. Anon. 1972. Interior Lodgepole Pine Cone Collection Guide. B.C. Forest Service Publication B.61, Victoria, B.C.

5. Association of Official Agricultural Chemists. 1960. Official Methods of Analysis. 9th ed., Washington, D.C.

6. Bainer, R., Kepner, R.A. and Barger, E.L. 1965. Principles of Farm Machinery. John Wiley & Sons Press, New York.

7. Baldwin, H.I. 1942. Forest Tree Seeds of the North Temperate Regions with Special Reference to North America. Chronica Botanica Co., Waltham, Mass.

8. Barton, L.V. 1967. Bibliography of Seeds. Columbia University Press, New York.

9. Bates, C.G. 1930. Production, Extraction and Germination of Lodgepole Pine Seed. Technical Bulletin, U.S. Department of Agriculture No. 191.

10. Beaufait, W.R. 1960. "Some effects of high temperatures on the cones and seeds of Jack Pine". Forest Sci. 6(30).

11. Cameron, H. 1953. Melting Point of the Bonding Material in Lodgepole Pine and Jack Pine Cones. Silviculture Leaflet, Div. of Forest Research, Canada Dept. of Resources & Development, Ottawa.

12. Clements, F.E. 1910. The Life History of Lodgepole Burn Forests. USDA Forest Service, Bull. No. 79, Washington, D.C.

13. Crossley, D.I. 1955. Lodgepole Pine Studies at the Strachan Experimental Block in Alberta. Canada Dept. NA & NR, Forestry Branch, Forest Research Division, Technical Note No. 19.

14. Crossley, D.I. 1955. The Production and Disposal of Lodgepole Pine Seed, Canada Dept. NA & NR Forestry Branch, Forest Research Division, Technical Note No. 25.

15. Crossley, D.I. 1955. "Viability of the Seed of Lodgepole Pine after 20 Years in Artificial Storage", Forestry Chronicle, Vol. 31, No. 3, pp 250.

16. Crossley, D.I. 1956. Fruiting Habits of Lodgepole Pine. Canada Dept. NA & NR, Forestry Branch, Forest Research Division, Technical Note No. 35.

17. Darby, S.P. 1956. "Georgia's New Dewinger", Journal of Forestry, Vol. 54, No. 9, pp 579.

18. Edwards, M.V. 1955. "Summary of Information on Pinus Contorta". Forestry Abstracts, Vol. 16, No. 1, pp 3.

19. Fielding, J.M. 1947. Pinus radiata Studies. Bulletin No. 29, Commonwealth Forestry Timber Bureau.

20. Gregg, B.R., Law, A.G., Virdi, S.S. and Balis, J.S. 1970. Seed Processing. Agency for International Development, Avion Printers, New Delhi, India.

21. Harlow, W.M., Cote, W.A. and Day, A.C. 1964. "The Opening Mechanism of Pine Cone Scales". Journal of Forestry Vol. 62, pp 538.

22. Harmond, J.E., Brandenburg, N.R. and Klein, L.M. 1968. Mechanical Seed Cleaning and Handling, USDA Agric. Res. Serv. Agricultural Handbook No. 354, Washington, D.C.

23. Hawthorn, L.R. and Pollard, L.H. 1954. Vegetable and Flower Seed Production, The Blakiston Co., Inc., New York.

24. Hebb, E.A. 1954. "How to Open Pond Pine Cones". Journal of Forestry, Vol. 52, No. 10, pp 770.

25. Henderson, S.M. and Perry, R.L. 1966. Agricultural Process Engineering, 2nd ed., Edwards Publishing Co., Michigan, U.S.A.

26. Kozlowski, T.T. 1962. Growth and Development of Trees. Academic Press, New York.

27. Kreith, F. 1973. Principles of Heat Transfer, 3rd ed. Intertext Educational Publishers, New York.

28. Lee, L. and Beaufait, W.R. 1961. Thermal Conductivity and Diffusivity of Cones of Pinus Banksiana. Tech. Bull. 8, Michigan College of Mining and Technology, Houghton, Michigan.

29. Lotan, J.E. 1970. "Cone Serotiny in Pinus Contorta". Ph.D. thesis, University of Michigan, Ann Arbor, Michigan.

30. Luckwill, L.C. and Cutting, C.V. 1970. "Physiology of Tree Crops". Proceedings of Conference on Tree Crops Academic Press, London.

31. Lyle, E.S. and Gilmore, A.R. 1958. "The Effect of Rough Handling of Lablolly Pine Cones on Seed Germination, J. Forestry, v.56, 8.

32. Meseman, W.T. 1973. "Hot Water and Javex Enhance Pine and Spruce Seed Extraction". Tree Planters Notes.

33. Mirov, N.T. 1967. The Genus Pinus. The Ronald Press Co., New York.

34. Mohsenin, N.N. 1970. Physical Properties of Plant and Animal Materials. Vol. 1, Gordon & Breach Science Publishers, New York.

35. Narsted, B., Nyborg, E., Sziklai, O. "Automatic On-line Detection of Viable Conifer Seed". CSAE Paper No. 72-319, Charlottetown, P.E.I., June 1972.

36. Nyborg, E.O. and Shakaze, G., 1974. "Development of High Capacity Precision Seeding Loading and Handling Equipment for Container Nurseries". Proceedings of the North American Containerized Forest Tree Seedling Symposium, Denver, Colorado.

37. Nyborg, E.O. and Brisbin, P.E. 1973. "Conditioning of Lodgepole Pine Cones for Seed Extraction". CSAE Paper No. 73-311, presented to Annual Meeting, Victoria, B.C.

38. Persson, S.P.E. 1969. "An Engineering Analysis of Mushroom Harvesting". Paper No. 69-828, American Society of Agricultural Engineering, St. Joseph, Michigan.

39. Pitkin, F.H. 1961. "Combination Cone Kiln and Extractor". Tree Planters' Notes, No. 48.

40. Richey, C.B. (Editor). 1961. Agricultural Engineers Handbook, McGraw-Hill Book Co., New York.

41. Rietz, R.C. 1941. Kiln Design and Development of Schedules for Extracting Seeds from Cones. U.S.D.A. Tech. Bull. No. 773, Washington. D.B.

42. Rohsenow, W.M. and Choi, H. 1961. Heat Mass and Momentum Transfer, Prentice Hall Inc., Englewood Cliffs, New Jersey.

43. Schubert, G.H. and Adams, R.S. 1971. Reforestation Practices for Conifers in California. Publication Div. of Forestry, State of California, Sacramento.

44. Smithers, L.A. 1961. Lodgepole Pine in Alberta. Can. Dept. of Forestry, Bulletin 127, Queen's Printer, Ottawa.

45. Thompson, R.E. 1969. "Relationship of seed yield and viability to the age of cones of Lodgepole Pine". University of Mass. Master's Thesis, 72 pp.

46. U.S. Forest Service. 1948. Wood Plant Seed Manual. U.S. Dept. of Agriculture, Forest Service, Misc. Publication No. 654.

47. Wang, B.S.P. 1973. "Collecting, Processing and Storing Tree Seed for Research Use". I.U.F.R.O. Proceedings of Symposium on Seed Processing, Vol. 1, Paper No.17, Bergen, Norway.

48. Watson, E.L. 1965. "Effect of Heat on the Germination of Wheat", Paper presented at the 1965 Annual Meeting Pacific Northwest Region, American Society of Agricultural Engineers, Moscow, Idaho.

49. Watson, E.L. 1970. "Effect of Heat Treatment Upon the Germination of Wheat". Can. J. of Plant Science, Vol. 50, 107.

50. Wexler, A. and Wildhack, W.A. (Editors). 1965. Humidity and Moisture Measurement and Control, Vol. 3, Reinhold Publishing Corp., New York.

51. Wheeler, W.A. and Hill, D.D. 1959. Grassland Seeds. Van Nostrand Co. Inc., Princeton, New Jersey.

52. Woodforde, J. and Lawton, P.J. 1965. "The Drying of Seeds". J. of Agric. Eng. Research, Vol. 10, 283.

A P P E N D I X A

TABLE A-1. NUMBER OF SEEDS PER CONE, BY LOCATION

Basal Region	Central Region	Upper Region	Total Seeds/Cone	Basal Region	Central Region	Upper Region	Total Seeds/Cone
4	8	7	19	17	15	21	53
0	5	2	7	10	14	6	30
4	5	5	14	3	14	18	35
8	14	6	28	7	10	7	24
11	16	6	33	3	4	2	9
9	17	12	38	8	14	4	26
16	8	7	31	5	12	1	18
6	10	5	21	4	11	5	20
9	9	6	24	8	14	12	34
5	10	5	20	6	8	4	18
4	12	6	22	1	12	4	17
11	12	3	26	9	13	3	25
4	10	2	16	1	12	2	15
13	16	10	39	3	13	6	22
2	5	7	14	13	11	4	28
13	13	9	35	9	13	10	32
6	15	4	25	5	13	8	26
5	8	4	17	0	8	6	14
4	6	6	16	4	10	11	25
7	7	15	29	5	15	6	26
10	16	22	48	7	18	15	40
9	10	5	24	6	12	4	22
4	4	0	8	6	11	10	27
3	17	10	30	6	13	5	24
8	4	2	14	5	10	3	18
4	7	6	17	7	11	9	27
5	6	2	13	7	14	10	31
7	15	11	33	5	15	11	31
8	11	6	25	5	6	3	14
6	11	13	30	5	11	13	29
3	10	6	19	16	23	25	64

TABLE A-1 (Continued)

Basal Region	Central Region	Upper Region	Total Seeds/Cone	Basal Region	Central Region	Upper Region	Total Seeds/Cone
0	6	3	19	7	9	15	31
2	13	5	20	5	4	1	10
6	5	4	15	7	17	10	34
2	10	13	25	6	14	4	24
4	9	10	23	10	22	11	43
2	8	3	13	4	5	8	17
10	12	10	32	2	6	5	13
6	14	7	27	5	12	7	24
2	7	3	12	7	9	2	18
0	5	2	7	5	17	4	26
2	11	17	30	5	6	6	17
7	8	13	28	5	15	6	26
4	6	4	14	6	10	8	24
7	11	6	24	3	8	10	21
5	10	6	21	7	13	3	23
6	10	8	24	9	11	3	23
6	5	1	12	5	21	11	38
5	7	11	23	5	14	15	34
6	5	8	19	3	5	2	10

	Basal	Central	Upper	Total
TOTAL	592	1076	724	2392
AVERAGE SEEDS PER CONE	5.9	10.8	7.2	23.9
PERCENT OF TOTAL SEEDS	25%	45%	30%	
GERMINATION % OF GROUP	91.2%	90.9%	91.6%	
AVERAGE GERMINATION % OF ALL SEEDS	91.21%			

TABLE A-2 VIABILITY OF OVEN DRIED CONES

Initial cone conditions $34^{o}F$ ($2^{o}C$), 23% MC (w.b.).

Oven temperature $140^{o}F \pm 3^{o}F$ ($60^{o}C \pm 1.5^{o}C$).

Open air movement by convection only.

Sample Number	Treatment Time in Hours	Germination % of Filled Seed
1	4	87%
2	8	93%
3	12	91%
4	16	92%
5	20	92%
6	24	94%
7	36	95%
8	48	97%
9	72	93%

0

TABLE A-3 EQUILIBRIUM MOISTURE CONTENT (WET BASIS) OF CONES OVER SATURATED SALT SOLUTIONS AFTER 30 DAYS

Salt Solution	Distilled Water	Barium Chloride	Ammonium Chloride	Ammonium Nitrate	Sodium Iodide	Potassium Acetate	Lithium Chloride
Equilibrium R.H. @ 72°F	100%	90.2%	78.0%	61.0%	39.0%	23.0%	11.3%
	27.88	22.14	17.89	13.21	9.51	7.70	4.67
	27.81	21.95	16.93	13.55	9.59	7.28	4.96
	27.97	20.58	17.66	13.61	9.91	7.56	4.81
	26.35	21.29	17.87	13.13	9.80	7.56	4.85
INDIVIDUAL	29.79	20.51	17.46	13.50	9.64	7.39	4.84
	29.89	20.12	17.18	13.34	9.64	7.43	4.60
CONE		21.82	16.89	13.94	9.65	7.45	4.76
		22.85	17.64	13.35	9.47	7.21	4.71
MOISTURE		20.95	16.82	13.55	9.50	7.33	4.92
		20.92	16.80	13.45	9.54	7.59	4.86
CONTENTS		20.98	17.37	13.08	8.03	7.32	4.87
		20.73	17.53	13.62	9.74	7.38	5.01
		21.35	17.59	13.09	9.21	7.36	4.60
		21.44	17.44	13.64	10.18	7.27	4.78
		21.68	17.96	13.43	9.52	7.78	4.72
		20.72		13.78	9.48	7.56	4.98
Mean Equb'm Moisture Content	28.28% ±1.35	21.23% ±0.73	17.40% ±0.39	13.45% ±0.25	9.52% ±0.45	7.45% ±0.16	4.81% ±0.13

TABLE A-4 CONE SCALE RELEASE TEMPERATURES

Bath Temp °C	Number of New Cones Opened	Number of Old Cones Opened	Bath Temp °C	Number of New Cones Opened	Number of Old Cones Opened
42.3	1	1	52.6	1	0
43.1	2	2	52.8	2	1
43.2	1	1	53.3	1	0
43.8	2	0	53.4	3	1
44.5	3	2	54.1	4	1
44.8	0	1	54.3	2	2
45.1	1	1	54.7	1	1
45.4	0	1	54.8	0	3
45.7	2	1	55.0	0	0
46.0	0	1	55.5	0	1
46.4	1	0	55.6	1	1
46.5	2	0	56.3	1	3
47.0	1	0	56.8	0	3
47.1	0	0	57.0	1	0
47.7	0	2	57.5	0	4
48.3	0	0	57.6	0	1
48.4	0	0	58.0	1	2
48.9	0	0	58.1	3	1
49.2	0	0	58.7	1	2
49.7	1	0	59.2	4	3
49.9	2	0	59.3	1	2
50.5	2	1	59.7	1	2
50.6	0	0	60.1	0	2
51.0	0	1	60.4	1	2
51.1	1	1	61.2	2	3
51.8	0	0	61.6	1	1
51.9	5	1	62.5	1	1

	New Cones	Old Cones
Mean Temperature	52.51 °C	54.50 °C
Std. Deviation	±5.7 °C	±5.8 °C
Number of Cones	60	60

TABLE A-5 MAXIMUM CONE SCALE ANGLES OF CONES 21.2% M.C. (w.b.)

(In Degrees)

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	12	15.5	6.5	10	9	8.5	12		11	9	4	4	6	15	8	11
	12	14	4.5	7	6	4.5	15.5		11	9	8.5	10	5	20.5	5.5	14.5
	10	12	4	4.5	5.5	3	17		11.5	6	7	8		20	8	13
	8	8	6	3.5	2	2.5	10.5		11	2	4	8.5		18.5	7	11
	8.5	9.5	5	2	5	5.5	9.0	Unopened	9	4.5	4	7	Partly opened	19.5	8	13.5
	9	9	4	7.5	4	2	8		9	10	3	9.5		18	7	11.5
	9.5	14.5		7	5.5	4.5	10.5		11.5	10.5	9	6		16.5		8.5
Mean Value	9.86	11.78	5.00	5.93	5.28	4.50	11.78		10.57	7.29	5.64	7.57	5.5	18.28	7.25	11.86
Std. Deviation	1.60	2.98	1.05	2.73	2.12	2.10	3.33		1.09	3.18	2.46	2.09	0.71	1.98	0.99	1.99

OVERALL AVERAGE SCALE DEFLECTION $8.54^{\circ} \pm 3.79^{\circ}$

TABLE A-6 MAXIMUM CONE SCALE ANGLES OF CONES AT 17.4% M.C. (w.b.)

(In Degrees)

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	44.5	38	51.5	25	32	22	33.5	23	30	31	24	21	Poorly Opened	34	31	Not Fully Opened
	47	30	51	31.5	34.5	25	29	31	26.5	24.5	30	28.5		34	31	
	43.5	39.5	48.5	35	33	35	29.5	39	25.5	22	25	26		29	27	
	45	30	47	35	42	32	23.5	31	24.5	22	17	26		22	26.5	
	45	39	54	33	34.5	24	34	34	24.5	30	28	21		24	22	
		33	50.5	33	36	32	31	31	28	30.5	27.5	19.5		25.5	29.5	
		28	53	32	34	26		30		26	27	21		32.5	24	
Mean Value	45.00	33.93	50.78	33.50	35.14	28.00	30.08	31.29	26.50	26.57	24.07	23.28		28.71	27.36	
Std. Deviation	1.27	4.83	2.43	1.50	3.27	4.93	3.81	4.78	2.17	3.94	4.14	3.46		4.96	3.55	

OVERALL AVERAGE SCALE DEFLECTION $31.73^{\circ} \pm 7.78^{\circ}$

TABLE A-7 MAXIMUM CONE SCALE ANGLES OF CONES AT 13.5% M.C. (w.b.)

(In degrees)

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	67	55	42	38	45	78	41	49.5	43	59.5	59	54		54	43.5	
	65	54	46.5	36.5	52	68	61	45.5	44	60.5	64	48.5		42	49.5	
	59	57	51	35	51	45.5	53	51.5	47	54	64	42		43	55	
	60	58.5	43	30	50	60	53	46	41	50.5	51.5	35.5	Poorly Opened	44	44.5	Not Fully Opened
	77	54	32	26	56.5	69	57	40	40	61.5	54	47		38		
	71	54	42	33	47	71	50.5	39	35	52	51.5	32		36		
	64.5	58	50	41	45		50	42	44	59	51	38		33.5		
	71.5															
Mean Value	66.85	55.78	43.78	34.21	49.42	65.25	52.21	44.78	42.0	56.71	56.5	42.42		41.5	48.12	
Std. Deviation	2.00	6.38	5.05	4.56	11.26	6.26	4.72	3.83	4.44	5.42	7.84	7.84		6.73	5.28	

OVERALL AVERAGE SCALE DEFLECTION $49.97^{\circ} \pm 9.42^{\circ}$

TABLE A-8 MAXIMUM CONE SCALE ANGLES OF CONES AT 9.5% M.C. (w.b.)

(In degrees)

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	74.5	70	58.5	6.85	49	58.5	89.5	75.5	65	52	45	75	49	65.5	62	
	48	57	62	88	57	59	72.5	65.5	70	58	35.5	64.5	50	68.5	61.5	
	43	58	60	76	52	68.5	63	61	72	60.5	34	71	49	67.5	62.5	
	67	71	48	72.5	54	66	50.5	70	69.5	52	34	71.5	52	68	58	
	74.5	71.5	64		59.5	61	60	84	67	61.5	33	66	54	56	64	
	73	68			52.5	58.5	72.5	76	75	58	41	63	53	64		
	70	65			58.5		74		69			81.5		70		
Mean Value	64.36	65.78	58.59	76.25	54.64	60.25	68.86	72.99	69.64	57.00	37.08	72.31	51.17	65.59	61.60	
Std. Deviation	13.2	6.1	6.2	8.4	3.8	3.0	12.4	8.2	3.13	4.1	4.8	8.2	2.1	4.7	2.2	

OVERALL AVERAGE SCALE DEFLECTION $62.57^{\circ} \pm 11.5^{\circ}$

TABLE A-9 MAXIMUM CONE SCALE ANGLES OF CONES AT 7.5% M.C. (w.b.)

(In degrees)

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	99.5	57.5	64.5	67	83	82	58	81	104.5	74	72.5	51.5	63	65	57	56.5
	102.5	66	64	79	61	85	60	70	87	79.5	76	62	61	69	57.5	70.5
	94.5	59.5	72	88	48	88	62	71	103	74	66.5	54	69	66	71.5	68
	91	69	67	87.5	55	98	69	85.5	95	70	72	49	56	72	71	60.5
	93.5	61	69.5	74	58	88.5	69	77.5	102	59	75.5	49	64	71	63	75.5
	89	59	69.5	69	59	99.5	78	76.5		73	79			66	67	57
	92	58	56	69.5		89.5	68	79		79	78			63	55	
Mean Value	94.57	61.43	66.07	76.28	60.67	90.07	66.28	77.21	98.30	72.64	74.21	53.10	62.60	67.42	63.14	64.67
Std. Deviation	4.81	4.38	5.29	8.76	11.84	6.45	6.85	5.44	7.29	6.88	4.27	5.39	4.72	3.31	6.86	7.81

OVERALL AVERAGE SCALE DEFLECTION $71.79^{\circ} \pm 12.82^{\circ}$

TABLE A-10 MAXIMUM CONE SCALE ANGLES OF CONES AT 4.8% M.C. (w.b.)

(In degrees)

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	91	106	72.5	79	79	94.5	88.5	68	74	97.5	94	114	81.5	87	85	80
	83	122	77	105.5	76	74.5	99	73	107.5	86.5	86	109.5	79.5	91	80	77
	82.5	116.5	84	87	82	80	87	73	91	90.5	80.5	131	78.5	90.5	77	81
	93	117	84	84	80	95.5	87.5	70	94	85	91.5	95	71	79	74	88.5
	92	121.5	81.5	89	76	121	84.5	69	79	79.5	79.5	106.5	70	74.5	76	75
	89.5	118	90	83	82.5	92.5	74.5	69	88	74	87.5	103.5	84.5	75.5	76	92
			79.5	88	75.5	91	78	69		95.5	94		75	83.5	87	81.5
Mean Value	88.50	116.83	81.21	87.93	78.71	92.71	85.57	70.14	88.92	86.93	87.57	109.92	77.14	83.00	79.28	82.14
Std. Deviation	4.60	5.78	5.62	8.47	2.94	14.76	7.91	2.03	11.81	8.41	6.00	12.14	5.38	6.84	4.96	6.07

OVERALL AVERAGE SCALE DEFLECTION $86.59^{\circ} \pm 13.09^{\circ}$

TABLE A-11 MAXIMUM CONE SCALE ANGLE OF CONES OVEN DRY

Cone No.	1	2	3	4	5	6	7	8	9	10
	88.0	106.0	75.0	82.0	108.0	89.0	111.0	82.5	127.0	96.5
	103.5	128.0	87.0	126.0	105.0	90.5	110.0	77.5	122.0	106.0
	89.5	125.0	87.0	112.0	108.0	97.0	112.0	95.5	117.0	104.0
	89.0	125.0	86.5	117.0	115.5	83.0	107.0	97.0	109.5	102.0
	84.5	107.0	87.0	113.0	107.0	81.0	122.5	109.0	101.5	94.5
	87.5	101.0	76.5	112.0	107.0	85.0	123.0	104.0	107.0	98.5
	95.0	125.0	81.0	116.0	107.0	93.0	117.0	102.0	115.0	103.5
Mean Value	91.00	116.71	82.85	111.14	108.21	88.36	114.64	95.36	114.14	100.71
Std. Deviation	6.35	11.47	5.32	13.74	3.36	5.71	6.29	11.49	8.82	4.27

Cone No.	11	12	13	14	15	16	17	18	19	20
	76.5	91.0	84.0	108.5	88.5	74.0	132.0	90.0	103.0	87.5
	70.0	76.0	90.0	97.5	83.5	88.0	128.5	96.0	94.5	95.5
	62.5	76.0	89.0	102.0	81.0	88.0	121.0	98.0	90.0	86.0
	66.5	77.5	88.5	99.5	81.5	84.0	117.0	101.0	107.0	93.0
	79.5	66.5	87.0	99.0	79.0	85.5	110.5	106.0	101.5	93.5
	71.0	71.5	94.5	105.0	79.0	90.5	123.0	97.0	113.0	92.0
	68.0	76.5	102.0	93.0	72.5	83.0	127.0	93.5	109.0	88.0
Mean Value	70.57	76.43	90.71	100.64	80.71	84.71	122.71	97.36	102.57	90.78
Std. Deviation	5.83	7.49	5.90	5.08	4.99	5.38	7.34	5.15	8.11	3.59

MEAN SCALE ANGLE $97.02^{o} \pm 15.68^{o}$

TABLE A-12 MAXIMUM SCALE ANGLES OF CONES STORED SIX MONTHS AT 11.2% M.C. (w.b.), UNSEALED AND DRIED TO 9.9% M.C.
(Stress Relaxed Cones)

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	22.0	13.0	14.0	20.0	17.5	18.5	19.5	20.0	23.0	14.5	20.0	22.5	24.5	24.5	29.0	25.0	18.0	18.0	17.0	29.5
	21.0	13.0	13.0	19.5	15.0	18.5	23.0	17.5	20.0	14.0	20.0	20.0	22.5	25.0	24.0	27.0	19.5	19.0	27.0	32.0
	21.0	12.0	12.5	11.5	17.0	17.0	19.5	20.0	23.0	10.5	22.5	19.0	19.5	21.5	24.5	20.5	18.0	20.0	24.0	37.0
	20.0	8.0	16.0	19.5	17.0	17.0	23.0	20.0	23.5	14.0	23.0	16.5	19.0	30.0	18.0	26.0	12.5	27.0	21.5	37.0
	19.5	11.0	15.5	16.0	19.0	18.0	23.0	19.0	23.5	14.0	25.0	17.0	18.0	26.0	18.0	26.0	13.0	25.0	21.5	36.5
	20.0	12.0	16.0	15.0	19.0	18.0	20.5	23.0	25.0	14.0	24.0	18.0	17.5	27.0	18.0	24.0	14.0	22.5	20.5	33.0
	20.0	11.5	19.5	16.0	19.0	18.0	18.0	24.0	21.0	15.0	24.5	17.5	23.0	28.0	21.0	21.0	14.0	30.5	19.5	32.5

MEAN SCALE ANGLE $20.28^{\circ} \pm 5.35^{\circ}$

TABLE A-13 MAXIMUM SCALE ANGLES OF CONES STORED SIX MONTHS AT 11.2% M.C. (w.b.) UNSEALED, REWETTED AND DRIED TO 11.1% M.C. (w.b.)
(Stress Relaxed Cones)

Cone No.	1	2	3	4	5	6	7	8	9	10
	52.0	61.0	57.0	53.0	62.5	66.0	64.0	63.0	78.0	58.0
	51.5	65.0	58.0	54.5	63.0	66.0	61.0	70.0	89.0	59.5
	50.5	61.0	54.0	60.0	61.5	72.0	60.5	79.5	88.5	53.5
	53.0	61.0	57.0	60.0	65.5	61.5	62.5	78.0	83.0	55.0
	51.5	64.5	56.5	64.0	65.0	64.0	70.5	64.0	70.5	53.5
	50.0	59.0	55.0	62.0	71.0	64.5	62.5	65.0	72.0	56.5
	46.0	61.0	49.0	62.0	66.0	70.0	62.0	62.5	71.5	64.0

MEAN SCALE ANGLE $62.63^{\circ} \pm 8.66^{\circ}$

TABLE A-14 MAXIMUM SCALE ANGLES OF CONES STORED SIX MONTHS AT 11.2% M.C. (w.b.) UNSEALED, REWETTED AND DRIED TO OVEN DRY

(Stress Relaxed Cones)

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	57.5	90.0	80.5	87.0	107.5	113.0	99.5	84.5	119.5	85.0	96.0	97.5	100.5	99.0	102.0	90.5	89.5	95.5	102.5	99.0
	72.0	89.0	84.0	87.0	97.0	96.5	101.0	83.0	102.0	84.5	86.0	96.5	101.0	101.5	104.0	91.0	91.0	94.5	114.0	105.0
	65.0	95.5	87.0	85.5	102.0	98.5	97.5	92.5	102.0	87.0	90.0	100.5	97.5	96.5	94.5	87.0	87.5	92.0	113.0	102.0
	66.0	86.5	86.0	83.5	92.0	91.5	85.0	92.0	95.5	89.0	88.0	99.5	98.5	105.5	96.5	85.5	88.5	87.0	122.0	106.0
	68.0	86.0	86.0	91.0	102.0	104.0	79.5	106.0	96.0	88.0	84.0	102.0	100.5	100.5	100.0	92.0	85.5	86.5	114.0	103.0
	64.0	86.0	79.5	89.5	96.0	98.5	85.0	99.5	96.5	89.0	81.0	102.0	100.5	100.0	108.0	90.0	100.5	92.5	110.0	99.0
	70.5	88.5	80.0	85.5	96.0	108.0	99.0	94.5	96.5	87.0	80.0	99.0	100.0	99.5	96.5	93.0	93.5	90.0	117.0	101.0

MEAN SCALE ANGLE $93.64^{\circ} \pm 10.65^{\circ}$

TABLE A-15

MAXIMUM CONE SCALE ANGLES FOR FIRST SEED RELEASE TEST

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	50.0	36.0	47.0	35.0	33.0	42.0	42.5	46.5	37.0	27.0	34.5	31.0	69.0	51.5	42.5	31.5	39.0	50.0	36.0	48.0
	50.0	33.5	43.0	29.0	36.0	38.0	55.0	48.0	39.0	37.0	34.0	32.0	76.0	55.0	40.5	37.5	44.5	47.0	33.5	49.5
	49.5	41.0	41.0	30.0	30.0	37.5	50.0	41.5	37.5	43.0	34.0	32.0	75.0	57.5	37.5	37.5	45.5	47.0	36.5	54.0
	43.5	46.0	44.0	39.0	45.0	32.0	57.5	44.5	41.5	42.0	31.0	34.0	69.0	53.5	34.0	34.0	50.0	45.0	35.0	51.5
	40.5	46.0	45.0	35.0	34.0	38.0	45.0	46.0	36.0	40.0	31.0	36.0	67.0	50.0	36.5	32.0	47.0	45.0	37.0	51.5
	45.0	46.0	42.0	33.0	37.0	36.0	50.5	43.5	31.0	37.0	34.0	31.0	67.0	41.0	35.5	35.0	49.0	40.0	29.0	53.5
	45.0	45.0	42.0	29.0	33.0	39.5	47.5	52.0	39.5	37.0	32.0	33.0	47.5	41.5	38.0	34.0	46.5	39.0	42.5	46.0

MEAN SCALE ANGLE $42.00^{o} \pm 9.20^{o}$

Number of Seeds Released this Test	226
Cumulative number of Seeds Released	226
Cumulative percentage of total Seeds Released	50%

TABLE A-16 MAXIMUM CONE SCALE ANGLES FOR <u>SECOND</u> SEED RELEASE TEST

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	62.5	60.5	54.0	42.0	44.5	48.0	66.0	57.0	46.5	48.0	41.0	45.0	88.5	66.5	39.0	50.0	66.5	60.0	52.0	73.5
	69.5	58.5	56.0	38.5	41.5	49.5	80.0	70.0	46.5	47.0	38.0	48.0	77.5	65.5	56.0	52.0	80.5	46.0	65.0	58.5
	63.0	53.0	62.0	47.0	44.0	52.0	79.0	60.0	45.0	45.0	41.0	44.5	74.5	54.5	52.0	53.0	74.5	57.0	50.0	72.5
	71.5	45.0	65.0	39.5	45.0	53.0	67.0	47.0	35.0	44.5	40.0	49.0	74.5	64.0	54.0	48.0	65.0	63.0	45.0	70.0
	72.0	63.0	62.0	39.5	33.5	59.0	60.0	64.0	45.0	45.0	44.0	55.0	90.0	75.5	51.0	45.5	72.0	57.5	38.0	67.0
	70.0	61.5	62.0	48.0	57.5	59.5	70.0	65.0	42.0	40.0	46.0	44.0	90.0	76.5	46.0	45.0	74.0	65.5	48.0	71.0
	70.0	64.5	58.5	44.5	50.0	65.0	64.0	67.0	43.0	41.0	47.0	47.5	87.5	75.0	48.0	50.0	78.5	60.0	58.5	73.0

MEAN SCALE ANGLE $56.97^{\circ} \pm 12.85^{\circ}$

Number of Seeds Released this Test 93

Cumulative number of Seeds Released 319

Cumulative percentage of total Seeds Released 70.3%

TABLE A-17 MAXIMUM CONE SCALE ANGLES FOR THIRD SEED RELEASE TEST

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	89.0	76.0	84.5	58.0	54.0	59.5	94.0	71.0	60.0	59.5	57.0	66.5	98.0	88.0	61.5	56.5	89.5	74.0	68.0	81.0
	83.5	71.5	85.5	66.0	64.5	67.0	96.0	71.0	60.5	64.5	55.0	72.5	103.5	86.5	59.0	66.5	79.0	73.0	64.0	81.0
	84.0	70.0	80.0	51.0	63.0	72.0	93.0	67.5	58.0	62.5	54.0	74.0	89.0	90.0	60.0	65.5	85.5	80.0	74.0	81.5
	88.0	74.5	86.0	62.0	60.0	77.0	84.5	76.5	61.0	59.0	50.0	74.0	87.6	82.5	65.0	67.0	86.0	75.0	62.5	84.0
	88.5	77.0	72.0	60.0	61.0	82.0	84.5	73.0	57.0	54.5	52.5	77.0	93.5	93.5	55.0	64.0	84.5	75.0	63.0	79.5
	78.0	75.0	80.0	58.0	68.0	73.5	91.0	74.0	54.0	56.0	55.0	72.0	105.0	91.0	56.5	60.0	90.0	76.0	73.0	85.0
	86.0	76.0	76.5	56.0	67.5	83.5	98.0	71.0	59.5	55.0	62.0	67.5	105.0	81.0	60.0	63.0	89.5	72.0	81.0	84.0

MEAN SCALE ANGLE $73.10^{o} \pm 12.92^{o}$

Number of Seeds Released this Test	65
Cumulative number of Seeds Released	384
Cumulative percentage of total Seeds Released	84.8%

TABLE A-18 MAXIMUM CONE SCALE ANGLES FOR FOURTH SEED RELEASE TEST

Cone No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	120.5	112.0	97.0	73.0	83.0	97.5	117.5	95.0	87.0	95.0	91.0	99.0	124.0	119.0	88.0	84.0	117.0	108.5	105.0	111.0
	122.0	110.5	109.0	87.5	81.0	95.5	125.0	94.5	83.5	94.0	95.0	97.5	131.0	124.0	99.0	101.0	134.0	107.0	115.5	113.0
	122.0	109.5	109.0	85.0	89.0	106.0	126.0	87.0	83.0	91.0	91.0	99.0	126.0	113.5	96.5	98.5	138.0	107.0	105.0	112.0
	115.0	101.5	100.0	85.5	92.0	118.0	126.0	109.0	88.0	84.0	86.5	103.0	117.0	114.0	89.0	92.5	138.0	104.0	101.0	113.0
	122.5	99.5	112.0	83.0	91.0	124.5	124.0	96.0	85.0	90.5	81.0	116.0	121.0	117.0	93.5	85.0	126.0	104.5	102.0	108.0
	122.0	102.5	110.0	87.5	98.5	123.0	124.0	93.0	88.0	92.0	91.0	116.0	126.0	112.0	97.0	92.0	115.0	101.5	91.5	102.0
	122.0	97.0	108.0	89.0	93.0	103.0	124.0	89.0	84.0	100.0	85.0	104.0	125.0	124.0	89.5	84.0	115.0	107.0	107.0	110.0

MEAN SCALE ANGLE $103.86^{\circ} \pm 13.60^{\circ}$

Number of Seeds Released this Test	69
Cumulative number of Seeds Released	453
Cumulative percentage of total Seeds Released	100%

TABLE A-19 DEGREE OF SEROTINOUS SEAL BREAKING IN CLASS I (YOUNG) CONES BY FLAME TREATMENT

Sample Number	Treatment Time	Number of Cones Remaining Sealed	Number of Cones Partially Unsealed	Number of Cones Fully Unsealed
		8.26% MOISTURE CONTENT		
1A	5 sec	62	22	16
1B	10 sec	0	2	98
1C	15 sec	0	0	100
1D	20 sec	0	0	100
1E	25 sec	0	0	100
1F	30 sec	–	–	–
		10.7% MOISTURE CONTENT		
2A	5 sec	71	18	11
2B	10 sec	3	12	85
2C	15 sec	0	1	99
2D	20 sec	0	2	98
2E	25 sec	0	0	100
2F	30 sec	–	–	–
		16.71% MOISTURE CONTENT		
3A	5 sec	98	1	1
3B	10 sec	9	26	65
3C	15 sec	1	5	94
3D	20 sec	0	2	98
3E	25 sec	0	0	100
3F	30 sec	–	–	–
		20.73% MOISTURE CONTENT		
4A	5 sec	100	0	0
4B	10 sec	63	12	25
4C	15 sec	5	16	79
4D	20 sec	0	1	99
4E	25 sec	0	1	99
4F	30 sec	0	0	100

TABLE A-19 (Continued)

Sample Number	Treatment Time	Number of Cones Remaining Sealed	Number of Cones Partially Unsealed	Number of Cones Fully Unsealed
		21.78% MOISTURE CONTENT		
5A	5 sec	-	-	-
5B	10 sec	74	16	10
5C	15 sec	14	20	66
5D	20 sec	1	8	91
5E	25 sec	0	0	100
5F	30 sec	0	0	100
		25.13% MOISTURE CONTENT		
6A	5 sec	-	-	-
6B	10 sec	95	1	4
6C	15 sec	63	10	27
6D	20 sec	12	8	80
6E	25 sec	0	1	99
6F	30 sec	0	0	100
		27.82% MOISTURE CONTENT		
7A	5 sec	-	-	-
7B	10 sec	100	0	0
7C	15 sec	92	6	2
7D	20 sec	34	12	54
7E	25 sec	3	5	92
7F	30 sec	0	4	96
		31.20% MOISTURE CONTENT		
8A	5 sec	-	-	-
8B	10 sec	99	1	0
8C	15 sec	97	3	0
8D	20 sec	61	10	29
8E	25 sec	5	11	84
8F	30 sec	7	4	89

TABLE A-20 DEGREE OF SEROTINOUS SEAL BREAKING IN CLASS III WEATHERED CONES BY FLAME TREATMENT

Sample Number	Treatment Time	Number of Cones Remaining Sealed	Number of Cones Partially Unsealed	Number of Cones Fully Unsealed
		8% MOISTURE CONTENT		
10A	5 sec	24	23	53
10B	10 sec	0	8	92
10C	15 sec	0	1	99
10D	20 sec	0	0	100
10E	25 sec	0	0	100
10F	30 sec	-	-	-
		11% MOISTURE CONTENT		
11A	5 sec	63	25	12
11B	10 sec	18	26	56
11C	15 sec	0	8	92
11D	20 sec	0	1	99
11E	25 sec	0	0	100
11F	30 sec	-	-	-
		13% MOISTURE CONTENT		
12A	5 sec	86	11	3
12B	10 sec	22	34	44
12C	15 sec	0	9	91
12D	20 sec	0	2	98
12E	25 sec	0	0	100
12F	30 sec	0	0	100
		16% MOISTURE CONTENT		
13A	5 sec	95	5	0
13B	10 sec	40	36	24
13C	15 sec	6	19	75
13D	20 sec	1	11	88
13E	25 sec	0	6	94
13F	30 sec	0	1	99

TABLE A-20 (Continued)

Sample Number	Treatment Time	Number of Cones Remaining Sealed	Number of Cones Partially Unsealed	Number of Cones Fully Unsealed
		19% MOISTURE CONTENT		
14A	5 sec	96	4	0
14B	10 sec	68	25	7
14C	15 sec	8	20	72
14D	20 sec	0	6	94
14E	25 sec	0	4	96
14F	30 sec	0	1	99
		22% MOISTURE CONTENT		
15A	5 sec	-	-	-
15B	10 sec	92	8	0
15C	15 sec	49	28	23
15D	20 sec	1	16	83
15E	25 sec	3	11	86
15F	30 sec	0	6	94
		24% MOISTURE CONTENT		
16A	5 sec	-	-	-
16B	10 sec	90	7	3
16C	15 sec	53	32	15
16D	20 sec	2	18	80
16E	25 sec	2	14	84
16F	30 sec	0	5	95
		28% MOISTURE CONTENT		
17A	5 sec	-	-	-
17B	10 sec	97	3	0
17C	15 sec	90	8	2
17D	20 sec	16	28	56
17E	25 sec	12	24	64
17F	30 sec	3	15	82

TABLE A-21 GEOMETRIC VARIABLES AFFECTING CORE BORING OF LODGEPOLE PINE CONES.*

Cone Length A Inches	Overall Cone Angle θ^o	Core Angle $\emptyset^o$	Core Tip to Cone Apex B Inches	Core Axis to Cone Axis Angle α^o	Core Axis Misalignment β^o	Core Edge to Seed C Inches
1.75	49	28	.73	11		.035
1.57	28	19	.99	4		.030
1.67	39	21	.77	8	28	.035
1.42	33	22	.90	6		.020
1.27	35	18	.84	10		.035
1.51	32	28	.98	7		.025
1.70	43	26	.73	10		.035
1.52	36	17	.98	4		.040
1.42	40	15	.80	8	10	.030
1.37	25	14	1.21	0		.045
1.42	36	22	.98	7		.025
1.35	34	25	1.00	1		.035
1.38	35	21	.88	8		.035
1.26	39	30	.80	3	8	.030
1.06	51	30	.59	7		.030
1.08	57	39	.77	2		.035
1.63	49	32	.78	7	26	.030
1.71	50	22	.80	5		.035
1.17	61	37	.60	11		.030
1.45	52	27	1.00	9		.050
1.01	37	20	1.05	0		.030
1.63	57	44	.72	14	20	.045
1.43	26	13	1.28	3	7	.040
1.31	43	31	.86	0		.040
1.51	27	19	1.22	5	10	.025
1.52	31	23	1.29	4		.040
1.58	24	23	1.26	6		.030

* Geometric variables are defined in Figure 33.

TABLE A-21 (Continued)

Cone Length A Inches	Overall Cone Angle θ^o	Core Angle ϕ^o	Core Tip to Cone Apex B Inches	Core Axis to Cone Axis Angle α^o	Core Axis Misalign-ment β^o	Core Edge to Seed C Inches
2.03	27	24	1.77	12		.055
2.06	26	19	1.84	12	25	.050
1.58	31	23	1.26	13		.045
1.30	52	27	.67	11	38	.045
1.31	30	38	1.12	18		.035
1.38	36	24	.88	9		.035
1.48	25	37	1.23	9		.035
1.37	27	32	.96	15		.025
.96	47	32	.48	7		.025
1.18	50	42	.64	3		.035
1.15	64	32	.63	8		.030
.98	44	46	.75	5		.040
1.39	31	15	.91	7		.020
1.46	24	27	1.37	7		.030
1.51	19	17	1.83	1		.035
1.19	26	20	.96	4	30	.025
1.13	32	12	.86	4		.030
.92	57	28	.62	13		.030
1.64	38	16	1.01	3		.050
1.33	29	24	1.16	10		.040
1.21	34	24	.94	6		.050
1.35	52	35	.84	10		.035
1.21	24	13	.69	0		.040
1.396	37.9	25.5	.966	6.9	4.0	.034
±.24	±11.4	±8.4	±.30	±4.2	±9.4	±.011

TABLE A-22 RESULTS OF THRESHING TESTS ON LODGEPOLE PINE CONES

(First Prototype)

Sample No.	Cone M.C. % wb	Cyl. Speed ft/min	Dry Wt. of Cone g.	No. of Cones	Wt. of Whole Seed g.	Wt. of Seeds/ 100 Cones g.	No. of Whole Seeds	Germ'n % (of Total)	No. Viable Seeds Per Cone	Recovery % *
4	8.5	1800	600.5	125.5	1.3613	1.0847	489	36.5	1.43	8.3%
5	8.5	2300	535.5	111.9	1.7431	1.5577	439	38.9	1.53	9.1%
6	8.5	2800	515.6	107.8	1.3513	1.2535	327	35.7	1.08	6.4%
7	8.5	3300	560.3	117.1	1.0600	.9488	256	36.1	.80	4.8%
7A	8.5	3800	536.1	112.0	1.2217	1.0908	321	17.0	.49	2.9%
7B	8.5	4300	555.4	116.0	.7670	.6872	200	20.5	.35	2.1%
8	12.8	1800	507.8	106.1	1.8859	1.7774	576	46.3	2.51	15.0%
9	12.8	2300	535.5	111.9	1.8842	1.6838	636	42.7	2.43	14.5%
10	12.8	2800	559.5	116.9	1.7392	1.4877	608	27.1	1.41	8.4%
11	12.8	3300	480.2	100.4	1.9040	1.8964	624	22.7	1.41	8.4%
11A	12.8	3800	515.3	107.7	.9420	.8746	340	25.3	.80	8.4%
11B	12.8	4300	573.5	119.8	.8600	.7178	303	21.6	.55	3.3%

* Viable seeds recovered, expressed as percentage of viable seeds in control.

TABLE A-22 (Continued)

Sample No.	Cone M.C. % wb	Cyl. Speed ft/min	Dry Wt. of Cone g.	No. of Cones	Wt. of Whole Seed g.	Wt. of Seeds/ 100 Cones g.	No. of Whole Seeds	Germ'n % (of Total)	No. Viable Seeds Per Cone	Recovery % *
12	15.8	1800	462.8	96.7	1.8370	1.8996	587	38.7	2.34	14.0%
13	15.8	2300	521.9	109.0	2.4400	2.2385	831	26.7	2.04	12.2%
14	15.8	2800	593.5	124.0	2.2008	1.7748	729	40.0	2.35	14.0%
15	15.8	3300	633.6	132.4	1.7022	1.2850	591	27.8	1.24	7.4%
15A	15.8	3800	579.8	121.2	1.1171	.9217	380	28.3	.89	5.3%
15B	15.8	4300	588.7	123.0	1.5347	1.2477	575	23.3	1.09	6.5%
16	19.9	1800	590.4	123.4	2.0560	1.6661	696	44.3	2.50	14.9%
17	19.9	2300	389.5	81.4	1.5541	1.9092	540	33.9	2.25	13.4%
18	19.9	2800	649.0	135.7	1.9288	1.4217	657	43.8	2.13	12.7%
19	19.9	3300	622.1	130.0	.9580	.7369	442	50.5	1.33	7.9%
19A	19.9	3800	562.1	117.5	1.7557	1.4942	618	41.7	2.19	13.0%
CONTROL				100			2129	89.3%	19.01	

* Viable seeds recovered, expressed as a percentage of viable seeds in control.

TABLE A-23 LODGEPOLE PINE SEED RECOVERY FROM RUBBERIZED THRESHER
(Second Prototype)

Test No.	Cyl. Speed ft/min	Moisture Content % w.b.	No. Seeds Recovered	% Filled	No. of Filled Seeds	Germ. % (of Filled Seeds)	No. Good Seeds Recovered	Recovery % *
1	1600	15.5	1230	89	1094	61	668	39.8%
2	2000	15.5	1403	90	1263	59	745	44.4%
3	2400	15.5	1171	91	1066	49.5	527	31.4%
4	2800	15.5	1271	87	1106	55	608	36.2%
5	1600	20.0	970	95	922	40.5	373	22.2%
6	2000	20.0	978	94	919	41	377	22.4%
7	2400	20.0	796	93	740	43	318	18.9%
8	2800	20.0	758	89	675	30	202	12.0%
CONTROL			2074	91	1887	89	1679	

* Viable seeds recovered expressed as a percentage of viable seeds contained by control.

TABLE A-24 LODGEPOLE PINE SEEDS RECOVERED THROUGH CONCAVES FROM 100 CONES

Pass No.	No.of Seeds Recovered	% Filled	No. of Filled Seeds	Germ.% (of Filled Seed)	No. of Viable Seeds Recovered	% of Viable Recovered by concaves	% Total Viable Recovered (Concaves & Sieve)
1	297	91	270	46	124	26.8	13.2
2	569	93	529	41	217	46.8	23.1
3	221	92	203	33	67	14.4	7.1
4	99	89	88	27	24	5.2	2.6
5	44	90	40	38	15	3.2	1.6
6	18	90	16	13	2	.4	.2
7	8	88	7	38	3	.6	.3
8	8	88	7	60	4	.8	.4
9	5	100	5	0	0	0	0
10	0	-	-	-			
TOTAL			1165	39.1%	456	100.0%	48.5%

TABLE A-25 LODGEPOLE PINE SEEDS RECOVERED THROUGH SIEVE FROM 100 CONES

Pass No.	No. of Seeds Recovered	% Filled	No. of Filled Seeds	Germ. % (of Filled Seeds)	No. of Viable Seeds Recovered	% of Viable Recovered by Sieve	% Total Viable Recovered (Concaves & Sieve)
1	484	88	426	36	153	31.5	16.3
2	513	95	487	37	180	37.1	19.1
3	292	89	260	32	82	16.9	8.7
4	131	82	107	35	38	7.8	4.0
5	54	90	49	24	12	2.5	1.2
6	24	92	22	20	4	.8	.4
7	18	88	16	36	6	1.2	.6
8	15	93	14	40	6	1.2	.6
9	9	100	9	33	3	.6	.3
10	4	100	4	25	1	.2	.1
	TOTAL		1394	34.8	485	100.0%	51.5%

TABLE A-26 DATA FROM THRESHING OF DOUGLAS FIR CONES

	Cyl Speed ft/min	Cone M.C. % wb	Wt. of Uncleaned Seed g.	Wt. of Seed Sample g.	No.Seeds in Sample	Wt. of Debris in Sample g.	Wt. of Clean Seed g.	No.of Seeds	% Filled Seed	Germ.% of Filled Seed	No.of Viable Seeds Recovered	Recovery % *
F-1	1500	11.5	SAMPLE DESTROYED									
F-2	2500	11.5	7.1954	.3784	60	.0745	6.0118	953	66	35	220	82.7%
F-3	3500	11.5	7.8325	.4200	60	.1368	5.9081	844	55.5	22	103	38.7%
F-4	4500	11.5	6.0582	.4854	63	.2430	4.0312	524	40	22.5	47	17.7%
F-5	5500	11.5	3.7438	.3600	61	.1158	2.8326	480	63.5	13	39	14.7%
F-6	1500	24.3	7.9290	.4432	58	.2581	5.0109	655	80	16	84	31.6%
F-7	2500	24.3	7.9176	.4476	58	.1562	5.8694	761	74	13	73	27.4%
F-8	3500	24.3	6.1868	.4466	55	.3186	3.6109	445	73	13	42	15.8%
F-9	4500	24.3	4.5265	.4346	54	.2500	2.8735	357	79	14	39	14.7%
F-10	5500	24.3	5.8110	.4328	58	.3353	3.2907	436	73	7.5	23	8.6%
CONTROL								1618	37.5%	44%	266	

Sample Size - 100 cones.

* Viable seeds recovered expressed as percentage of viable seeds contained by control

TABLE A-27 DATA FROM THRESHING OF WHITE SPRUCE CONES

	Cyl. Speed ft/min	Cone MC % (wb)	Wt.of Unclean Seed g.	Wt.of Seed Sample g.	No.of Seeds in Sample	Wt. of Debris in Sample g.	Wt. of Clean Seed	No.of Seeds	% Filled Seed	Germ. % of Filled Seed	No.Viable Seeds Recovered	Recovery % *
S-1	1500	21.6	5.4552	.1259	67	.6394	4.1550	2211	79.5	29	510	24.6%
S-2	2500	21.6	6.2669	.1068	69	.0439	4.4316	2884	89.5	35	903	43.6%
S-3	3500	21.6	6.1492	.1412	87	.1290	3.2134	1979	91.5	30	543	26.2%
S-4	4500	21.6	4.7788	.1353	83	.0716	3.1250	1917	88.5	34	577	27.9%
S-5	5500	21.6	4.3230	.1182	81	.1052	2.2873	1567	87.0	30	409	19.8%
S-6	1500	28.4	4.7324	.1672	90	.1010	2.9503	1588	89.0	23	325	15.7%
S-7	2500	28.4	4.9200	.0977	60	.0846	2.6368	1619	88.5	16	229	11.1%
S-8	3500	28.4	6.5427	.1428	83	.1300	3.4248	1990	85.0	10	169	8.2%
S-9	4500	28.4	6.9434	.0993	61	.1078	3.3292	2045	86.0	20	352	17.0%
S-10	5500	28.4	4.6170	.1040	57	.1049	2.2985	1259	82.0	18	186	9.0%
CONTROL			5.1928	.0350	50			7418	36.0%	77.5%	2069	

Sample Size = 100 cones.

* Viable seeds recovered expressed as percentage of viable seeds contained by control

TABLE A-28 DATA FROM THRESHING OF WESTERN HEMLOCK

	Cyl, Speed ft/min	Cone MC % (wb)	Wt. of Unclean Seed g.	Wt. of Seed Sample g.	No. of Seeds in Sample	Wt. of Debris in Sample g.	Wt. of Clean Seed g.	No. of Seeds	% Filled Seed	Germ. % of Filled Seed %	No. Viable Seeds Recovered	Recovery % *
H-1	1500	24.4	1.2567	.0955	50	.0430	.8665	1173	87	19.5	198.1	9.8%
H-2	2500	24.4	1.4717	.1017	51	.0379	1.1119	1279	80	15	153	7.6%
H-3	3500	24.4	1.5130	.1171	59	.0242	1.2538	1052	88	7.5	69	3.4%
H-4	4500	24.4	1.5472	.1007	52	.0524	1.0176	946	78	2.6	19	.9%
H-5	5500	24.4	1.7846	.1050	52	.0543	1.1763	768	85	6.0	39	1.9%
H-6	1500	30.4	2.2484	.1065	55	.0500	1.5300	970	80	5.6	43	2.1%
H-7	2500	30.4	3.0877	.1120	56	.0696	1.9043	146	80	6.9	61	3.0%
H-8	3500	30.4	2.1250	.1318	65	.0611	1.4519	915	78	6.4	46	2.3%
H-9	4500	30.4	2.3137	.1000	55	.0610	1.4371	989	72.5	.7	5	.3%
H-10	5500	30.4	2.0070	.1191	63	.1072	1.0562	664	82	3.7	20	1.0%
CONTROL			6.4946	.1142	54	.0080	6.069	3029	79.5%	83.5 %	2011	

Sample Size = 200 cones.

* Viable seeds recovered expressed as percentage of viable seeds contained by control

PUBLICATIONS

1. MacAulay, J.D. and W.K. Bilanski. "Mechanical Properties Affecting Leaf Loss in Birdsfoot Trefoil". Trans. of ASAE, Vol. 11, No. 4, 1968.

2. MacAulay, J.D. "The Agricultural Engineer in the Forest Industry", Canadian Agricultural Engineering Journal, Vol. 12, No. 1, 1970.

3. MacAulay, J.D. "Low Density, Rigid Polyrerethan Foam as an Integrated Insulation-Weather Protective Covering for Agricultural Buildings", Paper presented to Fall Meeting, Acadia Section, American Society of Agricultural Engineers, October, 1971.

4. MacAulay, J.D. "Physical Properties of Low Density Rigid Polyurethane Foam", Information Bulletin No. 1, Dept. of Bio-Resources Engineering, Nova Scotia Technical College, Halifax, N.S. October, 1972.

5. MacAulay, J.D. "Factors Affecting Traction and Flotation of Farm Equipment, Information Bulleting No. 2, Dept. of Bio-Resources Engineering, Nova Scotia Technical College, Halifax, N.S., May, 1973.

6. MacAulay, J.D. "Development of a Seed Covering Technique for Early Planting of Cereals". Paper No. 73-316, presented to Annual Meeting of Canadian Society of Agricultural Engineers, Victoria, B.C., August, 1973.

7. MacAulay, E.O. Nyborg and J. Metzger. "Development of Thermal Seal Breaking Techniques for Seed Release of Serotinous Conifer Cones". Paper No. 74-506, presented to Annual Meeting of Canadian Society of Agricultural Engineers, Quebec, P.Q., August, 1974.