Wood and Bark Residue Disposal in Wigwam Burners

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Bulletin 11
March 1970

Forest Research Laboratory
Oregon State University

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STATE OF OREGON

BOARD OF HIGHER EDUCATION

P. O. Box 3175, Eugene, Oregon 97403

R. E. Lieuallen, Chancellor
R. L. Collins, Secretary

March 27, 1970

TO: The Governor of Oregon
The Fifty-fifth Legislative Assembly
The State Department of Environmental Quality
The Forest Industries of Oregon

SUBJECT: Research on Disposal of Wood and Bark Residues at the Mill Site.

I have the pleasure of transmitting to you the final report entitled, "Wood and Bark Residue Disposal in Wigwam Burners", covering the results of the two-year study directed by the Fifty-fourth Legislative Assembly. The report is submitted in accordance with the requirements of Chapter 377, Oregon Laws 1967.

The Act refers to a research program on air and water pollution as it relates to the forest products industries of this state with particular attention to the prevention of such pollution by means that are consistent with the continued growth and development of such industries. When the bill for the Act was heard by the Fifty-fourth Legislative Assembly it was brought out clearly that the research to be conducted was to be directed toward development of acceptable disposal methods for wood and bark wastes at the mill site. The budget approved by the Joint Ways and Means Committee was based on such a program.

In addition to the report on wigwam burners, seven other reports are being published on various phases of wood and bark residue utilization and disposal. These will cover the following subjects: disposal of wood and bark residues by landfill, incinerators (other than wigwam burners) for disposal of wood and bark residues, economics of producing wax from Douglas fir bark, technical and economic aspects of using wood and bark residues on the soil, transportation costs for wood and bark mill residues, use and disposition of residues from lumber and plywood manufacture in Oregon, and wood and bark residues for fuel. The additional reports will be transmitted to you as they are completed.

Sincerely,

R. E. Lieuallen
Chancellor

TABLE OF CONTENTS

Page

LETTER OF TRANSMITTAL . . . 1

ACKNOWLEDGMENTS . . . 4

SUMMARY . . . 5

INTRODUCTION . . . 5
- Objective . . . 6
- Approach . . . 6

BACKGROUND . . . 7
- Combustion . . . 7
  - Emissions from Combustion . . . 8
  - Wigwam Burner as a Combustion Device . . . 8
- Air Quality Standards . . . 8
  - Ambient Air Standards . . . 8
  - Emission Standards . . . 8
  - Design Standards . . . 8
- Literature Review . . . 9

BASIS OF DECISION TO MODIFY AND TEST WIGWAM BURNER . . . 10
- Characteristics of Clean Burners . . . 11
- Underfire Air Systems . . . 11
- Overfire Air Systems . . . 11
- Refractory in Wigwams . . . 12
- Hot Gas Recirculation . . . 13
- Auxiliary Fuel . . . 14
- Gas Cleaning Equipment . . . 14
- Controls and Stack Damper . . . 14
- Findings of Consultants . . . 15
- . . . o
- Summary of Modifications . . . 16

ARRANGEMENT OF MODIFIED WIGWAM BURNER . . . 16
- Grates . . . 17
- Underfire-Air System . . . 17
- Overfire-Air System . . . 17
- Hot Gas Recirculation . . . 17
- Natural Draft . . . 18
- Natural Gas Burners . . . 18

BURNER INSTRUMENTATION . . . 18
- Air Rates . . . 18
- Gas Analysis . . . 18
- Particulate Sampling . . . 19
- Smoke Opacity . . . 20
- Temperatures . . . 20

TEST PROCEDURE . . . 20
- Fuel . . . 20
- Starting . . . 20
- Test Period . . . 20

RESULTS AND DISCUSSION . . . 21
- Smoke . . . 24
- Particulate . . . 24
- Gaseous Emissions . . . 24
- Fuel Rate . . . 25
- Heat Balance . . . 25
- Total Air . . . 26
- Underfire Air . . . 27
- Overfire Air . . . 27
- Fuel Moisture . . . 28
- Auxiliary Gas Fuel for Starting . . . 28
- Recirculation of Gases with Overfire Air . . . 28
- Top Damper . . . 28

COST FACTORS . . . 28
- Air Supply System and Gas Burners . . . 28
- Disposal Cost in Wigwam Burners . . . 29

DISCUSSION OF WIGWAM BURNER DESIGN . . . 29

CONCLUSIONS . . . 29
- Temperature . . . 29
- Fuel and Air Rate . . . 29
- Air Leakage . . . 30
- Fuel Moisture . . . 30
- Auxiliary Fuel . . . 30
- Gas Cleaners . . . 30

RECOMMENDATIONS . . . 30
- Burner Operation . . . 30
- Further Study . . . 30

REFERENCES CITED . . . 30

APPENDIXES

A. Control of Wigwam Burner Combustion (by Consultants) . . . 32
B. Modifications to Wigwam Burner Recommended by Consultants . . . 44
C. Removal of Particulate Matter from Wigwam Waste Burner Emission . . . 96
D. Drawings of Test Wigwam Burner . . . 58
E. Instrumentation for Test Wigwam Burner . . . 61
F. Cost Factors . . . 62
G. Wigwam Burner Design . . . 64

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Wood and Bark Residue Disposal in Wigwam Burners

SUMMARY

This report describes one aspect of a study directed toward the reduction of air pollution associated with disposal of wood and bark residues at forest products industries. The study was authorized by the Fifty-fourth Oregon Legislative Assembly in 1967. The overall approach to this study was to investigate alternatives for both utilization and disposal. This report is concerned with only one disposal alternative, an evaluation of the wigwam burner as a means of disposal for wood and bark waste. Other reports will describe other phases of the study.

A survey indicated there were 376 wigwam burners operating at Oregon forest industries in 1968. Wood and bark residue disposed of in these burners amounted to nearly three million tons (dry weight) in 1967.

Observations were made at many operating wigwam burners to note which operational features gave least smoke and air pollutants. Consultants also made recommendations for improved burner operation and assembled cost information for "off the shelf" gas cleaning equipment that might be applied to wigwam burners.

A wigwam burner of 40-foot diameter was modified to include a forced draft underfire and overfire air system and natural gas burners. A damper at the top of the wigwam burner was subsequently added. Tests were conducted with the modified burner, and results indicated regulations for air pollution control were generally met when temperatures of the burner exhaust were greater than 700 F. Such temperatures could be achieved by feeding Douglas fir and western hemlock bark at rates greater than two tons (dry weight) per hour (without a top damper), if there was effective control of both underfire and overfire air flow, and if auxiliary gas burners were on while starting.

Recommendations are made for improvement of burner operation and information is presented on cost of modifications. A discussion on design of wigwam burners is also included.

INTRODUCTION

The manufacture of forest products results in the generation of several types of residues. For example, in making lumber and plywood, less than half of the original log is converted to the primary products in the mills. At sawmills, the remainder of a log is residue in the form of slabs, edgings, lumber trim, sawdust, shavings, or bark. In plywood manufacture, residues occur as log trim, green veneer clippings and trim, dry veneer trim, panel trim, and sander dust.

When markets cannot be found for all residues developed in the manufacture of plywood and lumber, the remaining wood and bark waste must be disposed of in some manner. By far the most common method of disposal of wood and bark waste is by incineration in wigwam burners. Limited use has been made of landfills or dumps, but this is not common in the forest products industry. A wigwam burner is a metal enclosure, in the form of a truncated cone, topped with a dome-shaped screen (Figure 1). The incinerating device acquires its name from the general appearance of an Indian wigwam. In operation, fuel is dropped onto a pile inside the burner from a conveyor above and air is supplied to the combustion zone from openings at the base of the burner. Sometimes, fans and grate systems are used.

In 1968, a survey indicated there were 376 wigwam burners in operation at forest products industries in Oregon. Size distribution of these burners is shown in Figure 2, which indicates that burners of the most common size had a base of 50-foot diameter (When size of a wigwam burner is mentioned in this report, base diameter is implied.). Three hundred forty of these burners were at lumber, veneer, and plywood plants and 36 were at shake, shingle, and pole plants.

Wood residues generated from lumber and plywood manufacturing in Oregon in 1967 was nearly 11.6 million tons, dry weight (dry weight is the amount the material would have weighed if moisture had been excluded or removed; the actual weight included associated water). Bark residue produced in the same year was about 3.2 million tons, dry weight. Of these residues, 11.9 million dry tons were used, mainly for fuel and as raw material for paper and composition board. About 12 percent of the wood residue, or 1.4 million tons (dry weight), and 47 percent of the bark residue, or about 1.5 million tons (dry weight), were unused. Therefore, 2.9 million tons (dry weight) of wood and bark residue was disposed of as waste material in 1967. If the assumption is true that nearly all of this

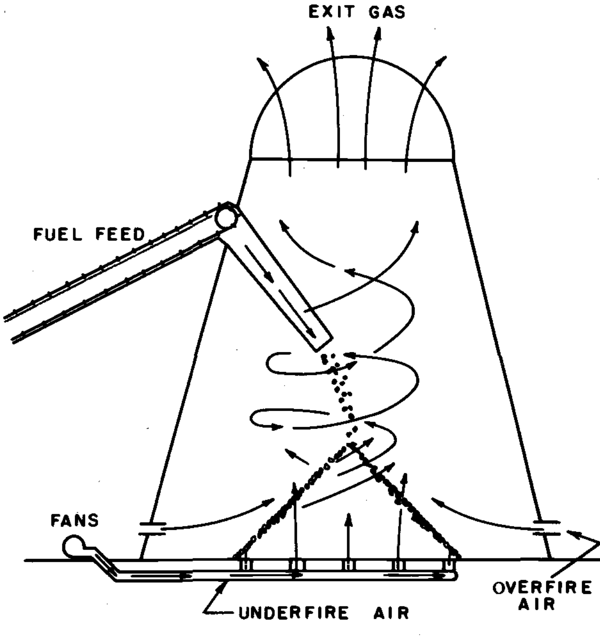

Figure 1. A typical wigwam burner.

waste was disposed of in wigwam burners and that there are 240 operating days per year, each of these 340 wigwam burners burned an average of 35 tons (dry weight) of residue each operating day.

In most past instances, wigwam burners have been rudimentary incinerators wherein conditions for combustion were frequently far from optimum. Consequently, these burners often emitted excessive smoke, cinders, and fly ash. In the past, air pollution from wigwam burners was tolerated by the public because other industries in the forest products regions of the United States were few and the total load of pollution upon the environment was minor. With increases in population and continued industrialization in the timbered regions, however, excessive pollution has caused increasing public demands that air quality be preserved or improved. These public pressures have resulted in anti-pollution regulations and the establishment of agencies charged with controlling air pollution. The wigwam burner, as an obvious source of air pollution, naturally was the subject of concentrated efforts by regulatory agencies. The forest products industry now is faced with compliance with air-quality standards that may result in elimination or extensive modification of the wigwam burner.

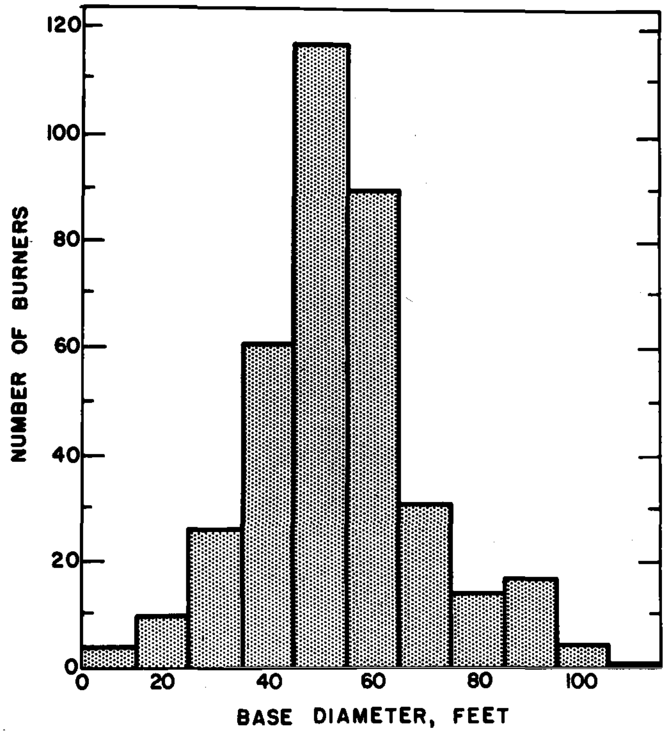

Figure 2. Distribution by size of 376 burners in Oregon in 1968.

Because of the urgency and the magnitude of air pollution in the forest products industry, the Oregon Legislature in 1967 directed the Forest Research Laboratory to seek solutions to the problem. Although the enabling legislation was broad, committee hearings indicated that first priority should be given to study of air pollution from wigwam burners.

A seemingly obvious way to eliminate pollution from wigwam burners is to use all of the material being incinerated. On the other hand, there likely always will be some wood waste from the manufacturing operations that must be disposed of by unprofitable means. Therefore, the approach devised by investigators was two-pronged in that a program was mapped out to devise and study means for both utilization and disposal. The means selected for study were determined by consultation with industry representatives, other researchers, and public officials. The six items selected for research were:

1. Improvement of incineration in wigwam burners;
2. Incineration in refractory-lined incinerators;
3. Landfill;
4. Increased use of wood and bark residues for steam generation;
5. Increased use of wood and bark residues for soil amendments, mulch and landscaping; and
6. Extraction of wax and certain chemicals from Douglas fir bark.

The first three can be considered as nonprofitable disposal and the latter three as utilization. Only the first item, "improved incineration in wigwam burners," is discussed in this report. Each of the others, plus results of ancillary studies, will be treated in separate reports.

Objective

Objectives in this study were:

1. To investigate ways of minimizing air pollution from wigwam burners;
2. To test and evaluate combustion characteristics of a modified wigwam burner; and
3. To make recommendations for modification and operation of wigwam burners.

Approach

The approach devised for this study was as follows:

1. To make a detailed survey of operating burners in the State of Oregon, cataloging their sizes and characteristic features of operation, the types of waste being burned, and the quantity of material being burned;
2. To single out for further observation those burners that function best so that common or unique characteristics of construction or operation could be determined;
3. To consult with operators, manufacturers, researchers, and air pollution control officials in the major timber-producing areas of the United States to discuss findings, observations, and approaches to the problem;
4. To engage consultants to study the problem and recommend modifications and additions to wigwam burners for improvement of combustion and to consider costs of gas-cleaning equipment that might be added to burners;
5. To study most important and pertinent literature relating to the problem;

6. To evaluate the information assembled and decide whether, in the opinion of researchers, wigwam burners could be modified to meet existing standards for air quality;

7. If the opinion was affirmative, to modify, test, and evaluate a wigwam burner; and

8. To publish a comprehensive report of the findings in this study, with recommendations for construction, modification, and method of operation of wigwam burners for minimal air pollution.

BACKGROUND

A limited discussion of certain basic principles, air-quality standards, and important literature follows.

Combustion

Good combustion requires time for burning to be completed, elevated temperatures so that the reaction is carried to completion, and intimate mixing of air and fuel so that oxygen can react with the fuel. These three factors of time, temperature, and turbulence are strongly influenced by configuration and quantity of air supply.

A typical analysis of some wigwam burner fuels is shown in Table 1 (8) (numbers in parentheses refer to references). This analysis shows that volatile matter in wood fuel amounts to 70-80 percent of its dry weight. The significance of the high content of volatile matter and moisture associated with wood fuel is that much of the air must be supplied over the fire rather than through the fuel pile. The resulting long, lazy flame requires an extended time in the combustion zone. From the ultimate analysis, one may see that the two combustible components in wood are hydrogen and carbon and that a part of the oxygen necessary for combustion already is contained within the fuel.

The combustion process is a chemical combination of hydrogen and carbon in fuel with oxygen present in the air. This is a process in which heat is evolved. If combustion is complete, hydrogen combines with oxygen to form water vapor, and carbon combines with oxygen to produce carbon dioxide. In practice, small amounts of carbon monoxide, hydrocarbons, and other gases usually are produced also as a result of failure of some of the carbon and hydrogen to combine completely with oxygen. Most nitrogen from the incoming air passes through the process unchanged. Ash in the fuel remains in the combustion zone, falls in an ash pit, or is carried out as small particles in the exhaust gases.

During combustion of wood or bark, there are three succeeding and somewhat overlapping steps; water evaporation, distillation and combustion of volatile matter, and reaction of fixed carbon with oxygen. Any and all of these three reactions may be taking place at the same time within different zones of the same fuel pile.

In the first of the three steps, water must be evaporated from the wood. Wet wood contains free water associated with wood substance. The amount of water frequently equals the weight of dry wood. Before the wood will ignite, water must be evaporated from it. Evaporation is a process during which heat is absorbed from surroundings. In the second step, hydrocarbon gases will be evolved as the wood is heated. If sufficient oxygen at an elevated temperature is mixed with the volatile matter, combustion and release of heat will take place. In the third and final step, the fixed carbon is the last part of the fuel to burn. Again, with high temperature and sufficient oxygen, the carbon combines with oxygen to form carbon dioxide (or carbon monoxide) and heat is released.

For furnaces burning wood fuels in a conical pile, some designers (17, 8) recommend that from 80 percent to 90 percent of the combustion air should be admitted over the fire. Previous discussion has indicated that the remaining 10 percent to 20 percent of combustion air should be admitted beneath the fuel pile. In itself, this apportionment of combustion air is not sufficient to insure proper combustion. The air should be introduced in such a way and at such a velocity that the solid and the volatilized fuel are supplied with readily available oxygen needed for combustion.

Using the fuel analysis shown in Table 1 and applying accepted stoichiometric relations, one can calculate the amount of air theoretically necessary to burn a given quantity of wood fuel completely to carbon dioxide and water. This is called *theoretical air*. In practice, however, a quantity of air greater than the amount indicated by theoretical calculations must be supplied to insure adequate mixing and optimum conditions for combustion. Furthermore, in some instances, air in addition to that necessary for optimum combustion may be supplied to insure that stack gases are cooled so structural damage to furnaces or incinerators will not result. On the other hand, care must be taken to limit excess air because too much may cool the combustion zone to the point that burning is adversely affected. All air in excess of theoretical air is defined as *excess air*. To illustrate this point, if 18 pounds of air were supplied for

Table 1. Typical Fuel Analysis for Mixed Wood and Bark (8).

Constituent	Douglas fir	Western hemlock
	Percent	*Percent*
Moisture, as received[1]	35.9(56.0)	57.9(137.5)
Proximate analysis of dry fuel by weight		
Volatile matter	82.0	74.2
Fixed carbon	17.2	23.6
Ash	0.8	2.2
Ultimate analysis of dry fuel by weight		
Hydrogen	6.3	5.8
Carbon	52.3	50.4
Nitrogen	0.1	0.1
Oxygen	40.5	41.4
Sulfur	0	0.1
Ash	0.8	2.2
Heating value, Btu/lb	9,050	8,620

[1] Moisture content can be expressed on a wet basis, which is the water weight divided by the total weight, or on a dry basis, which is the water weight divided by the dry weight contained in a sample. In this report, moisture content will be given on both bases. The number outside the parentheses is moisture content on a wet basis, and the figure inside the parentheses is the moisture content on a dry basis.

[2] By weight.

each pound of dry fuel and the fuel burned completely, and if theoretical air needed was 6 pounds per pound of fuel, the remaining 12 pounds would be excess air. Excess air would be expressed as 200 percent of that theoretically required.

Emissions from combustion. Emissions from combustion of wood waste can be broadly classified as gaseous or particulate. As previously mentioned, the gases consist mainly of carbon dioxide, water vapor, nitrogen, and oxygen. In addition, there are smaller concentrations of carbon monoxide, hydrocarbons, aldehydes, and oxides of nitrogen.

Particulate matter may consist of carbon, partially burned wood particles, and ash. If the particles are minute and of sufficient concentration to be seen in exhaust gases, they are identified as smoke. Smoke is the result of incomplete combustion. Particulates, smoke, and undesirable gaseous emissions can be minimized by optimizing conditions for combustion. Particulate matter also can be separated from exhaust gases by mechanical separation, water scrubbing, or electrostatic precipitation.

Wigwam burner as a combustion device. In the light of the foregoing discussion, how does the wigwam burner rate as a combustion device? There perhaps should be an 80 to 20 (4 to 1) ratio of overfire to underfire air, excess air should be regulated for optimum combustion, temperature in the combustion zone should be high, turbulence and good mixing of the air and fuel should take place, residence time should provide for long flame-travel, and final temperature of gas should be controlled to prevent structural damage to the burner. Few wigwam burners now operate with an optimum quantity of overfire and underfire air. Moreover, in many instances, air leakage into the burner is so great that temperatures in the combustion zone are too low for proper burning. In poorly equipped and maintained burners, turbulence and intimate mixing of air and fuel are difficult to attain. Turbulence can best be provided by overfire fans providing modulated quantities of high-velocity air, strategically directed into the combustion zone. Turbulence and well-directed overfire air also affect residence time for gases within the burner. By proper direction of overfire air, gases can be made to follow a spinning, helical path as they rise within the burner, which increases residence time and perhaps spins out some of the gas-borne particles by cyclonic action. In poorly equipped, operated, and maintained wigwam burners, such spinning action is not present.

Air Quality Standards

During the past decade,the public has become increasingly aware and less tolerant of air pollution. Evidence has been accumulated to show that some types of air pollution may damage health and plants, corrode and damage materials, and restrict visibility and sunlight when certain concentrations of given pollutants are exceeded. To insure that minimum standards of air quality are maintained, regulatory agencies have been established with the legal responsibility to set and enforce regulations.

Ambient air standards. Ambient air standards relate to the concentration of a particular pollutant in air or to the rate of fallout of a pollutant. For example, the State of Oregon has set ambient air standards for particulate matter. One provision of this standard limits fallout to 15 tons per square mile per month (above normal background) in residential and commercial areas and 30 tons per square mile per month in heavy industrial areas. Suspended particles (frequently termed particulates) are limited to 150 and 250 micrograms per cubic meter (above normal background) in residential-commercial and heavy industrial areas. A difficulty in applying ambient air standards for control purposes is that there may be many sources of emission in a particular area and the contribution of each is not easily determined without measuring emissions from each source.

Emission standards. Emission standards that limit the concentration of pollutants emitted from a source are the most common type of control standard. Two types of emission standards are used for particulates. One is a subjective measure of the opacity of light obscuration of a plume, and the other is an objective measure of the weight of particulates for a quantity of carrier gas or process quantity. Gaseous pollutants often are measured in parts per million of carrier gas.

Subjective measurements of opacity of light obscuration commonly are based upon visual comparison with the Ringelmann chart (18). The Ringelmann chart is a basis of smoke-density measurement in nearly all air-pollution control regulations in the United States. The shade of a smoke plume is compared to different shades in the Ringelmann chart, numbered 0-5. A clear gas is rated 0, and a completely black plume is rated 5, with variations of the shades ranging between the two extremes. If the smoke is not black, the Ringelmann number cannot be used and smoke density is evaluated in terms of equivalent opacity. For example, a visual estimate of 20 percent obscuration of light would be equivalent to Ringelmann No. 1 and 40 percent to Ringelmann No. 2. Because Ringelmann number and relative opacity are subjective evaluations, they can be influenced by the judgment of the observer as well as by light conditions, and observers must be trained if reproducibility of results is to be attained.

Most standards for opacity restrict emissions to a shade less than Ringelmann No. 2, except for brief periods. Table 2 shows opacity limitations that have been adopted by a few selected jurisdictions. Los Angeles County, California, was selected because this air-pollution control district is one of the forerunners in establishment of air-quality control regulations. Washingtonn and Kentucky were selected because the forest products industry in these states is of considerable size.

In the specifications of weight-emission standards (for example, if particulates are reported as grains per cubic foot of carrier gas), the volume of the carrier gas must be specified at certain standard conditions of temperature and pressure. To account for dilution of the carrier gas with air, in specifying standards for control of combustion emissions, the custom is to correct the volume of the carrier gas (in the ratio of weight of particulate matter per unit volume of carrier gas) to the volume that would be produced with a given amount of excess air or a given percentage of carbon dioxide in the stack gas. Limitations on weight emission for selected jurisdictions are shown in Table 2. Opacity is not necessarily directly related to the weight of particles emitted because of the effect of their type and size in obscuring light.

Design standards. Most regulations incorporate design standards that specify the type of equipment acceptable to the air-quality control agencies. Other types of equipment can usually be approved where tests indicate acceptable performance. In most air-pollution control districts, installation of new wigwam burners or other types of incinerators usually requires prior approval of plans and specifications by the control agencies.

Table 2. Emission Standards for Particulate Matter from Combustion of Refuse.

Jurisdiction	Smoke opacity		Weight emission	
	Existing installation	New installation	Existing installation	New installation
	Ringelmann number[1]		*Grain per cu ft*[2]	
OREGON				
State	2	2	none	none
Columbia-Willamette APA	2[4]	2[4]	0.2[3]	0.2[3]
Mid-Willamette Valley APCA	2	1	0.2	0.1
Lane Regional APA	2[5]	1	0.2	0.2
WASHINGTON				
Puget Sound APCA	2	1	0.2	0.1
CALIFORNIA				
Los Angeles County APCD	2	2	0.3	0.3
KENTUCKY				
State	2	2	0.2[6]	0.2[6]

[1] Emission greater than this Ringelmann number or equivalent opacity prohibited for more than three minutes in any one-hour period.

[2] Corrected to standard temperature of 60 F, pressure of 14.7 psi, and 12 percent carbon dioxide.

[3] Correction to 12 percent carbon dioxide not specified.

[4] Incinerators limited to not more than one minute in any hour.

[5] Existing installations reduced to Ringelmann No. 1 after January 1, 1975.

[6] Converted from stated emission of 0.4 lb per 1,000 lb gases with 50 percent excess air.

Literature Review

Boubel and co-workers (1,2,3,4,5,27) have conducted the most extensive investigations related to wigwam burners. In the first 20 years of this century, refractory-lined burners were commonly used for disposing of wood waste (4). The present wigwam burner reportedly was first introduced in 1916 and has been used extensively since that time. The primary advantage of the conventional wigwam compared to the earlier refractory burners, of course, is lower cost.

The following summary of results was based on tests of existing wigwam burners by Boubel *et al* (4):

1. Most satisfactory burners use tangential entry of overfire air and are fired with the door closed.

2. State of repair of the burner (tightness, lack of leaks, well-fitting doors) is a good indicator of burning efficiency.

3. Light fuels, such as shavings and sawdust, result in high emission of particulates.

4. Excessive smokiness usually occurs during starting when temperatures are low and excess air is high.

5. Burners emitting greatest amounts of particulates also are the ones that smoke most.

6. Smoke and particulates may be reasonably well predicted by the variable of excess air. For good combustion and low emission of cinders excess air should be between 300 percent and 500 percent.

A later report (27) discussed tests of a 15-foot-diameter model wigwam burner. This report re-emphasized that excess air should be from 300 percent to 400 percent, or less, so that exit-gas temperatures would be in the range from 600 F to 1,000 F and that smoke-free operation was most likely to result under these conditions. The report (27) recommended that overfire air enter tangentially to provide a cyclonic action within the burner. Underfire air was recommended as from 10 percent to 35 percent of total air, with the lower figure applying to low-moisture fuel and the higher figure to high-moisture fuel. The report stated that burner capacity varied about as the cube of its base diameter. The investigators noted that waste wood was difficult to burn in any furnace or incinerator when its moisture content exceeded 50 percent, wet basis, or 100 percent, dry basis. The use of auxiliary fuels was suggested to improve combustion of excessively wet fuels.

A study by Boubel (2) in 1968 pointed out the importance of low excess air in reducing smoke and particulate matter. A wigwam burner was operated with access doors both open and closed. With doors open, exit-gas temperatures were lower, smoke denser, and particulates in exhaust gases about three times more than with doors closed.

Nineteen burners sampled in 1967 in another study (1) emitted particulates that averaged 0.168 grain per standard cubic foot of stack gas (corrected). Particulates emitted by 14 of the burners was less than 0.2 grain per cubic foot of gas, which indicated that at the time of sampling, emission from these burners was within the maximum value permitted by regional air-pollution agencies in Oregon.

McKenzie (21, 22) has prepared a manual that gives practical advice on operation of wigwam burners.

Gaseous emissions from wigwam burners was measured by Droege (10). Average carbon monoxide emissions of 130 pounds and average total hydrocarbon emissions of 11 pounds per ton of fuel, respectively, were reported. When burner shell temperature increased from 290 F to 420 F, carbon monoxide emissions decreased 40 percent and hydrocarbon emissions decreased about 90 percent.

Kogap Lumber Industries, Medford, Oregon, has modified a 70-foot-diameter burner which was reported (25) to give improved burning. The burner has a conical shield at the top and incorporates a hot-gas recirculation system that withdraws exhaust gases from the top of the burner and reintroduces them at the base.

Eckerline (11) reported that a temperature-control system had been installed on a wigwam burner in Memphis, Tennessee. This control system was reported to have reduced smoke and particulates to an acceptable level. The system incorporated a thermocouple in the hot gas stream at the top of the burner, a temperature controller, and a motor-operated damper on the combustion-air fan. The system was set to control exit-gas temperature at a specified level and within a range of 50 F. An adjustable damper was installed at the top of the burner to regulate gas flow and maintain desired temperatures.

The Texas Forest Products Laboratory (30) conducted field tests on two modified wigwam burners during September through November 1969. Test burners were installed by two different manufacturers at operating sawmills. One burner was located at Kountze, Texas, and the other at Livingston, Texas. Both modified burners incorporated a damper at the top of the burners with air rate automatically controlled by exhaust-gas temperature. Their evaluation indicated that both burners were capable of operating on sawmill waste under conditions that will meet regulations of the Texas Air Control Board.

A study by Kreichelt (16) on disposal of municipal refuse in wigwam burners reported that none of the 15 burners observed met the Ringelmann No. 2 requirement set by air-quality ordinances of many municipalities.

Several investigators (7, 12, 29, 31) have emphasized the importance of overfire air in achieving turbulence to reduce smoke and permit more complete combustion.

BASIS OF DECISION TO MODIFY AND TEST WIGWAM BURNER

In initial phases of this study, researchers consulted with forest products industry representatives, air-pollution control officials, public health agencies, other researchers, and burner manufacturers in major timber-producing regions of the United States. In addition, nearly 500 wigwam burners were observed and the best of these were studied in detail. Grate systems, air systems, controls, burner shapes, methods of feeding, scrubbers and gas cleaners, dampers, recirculation systems—all were observed to visually evaluate their effect on combustion. Consultants, specialists in the combustion field, were engaged to study the wigwam burner problem and make recommendations. Air-quality laws and regulations were studied. A digest of pertinent literature was made.

At the outset of this phase of the study, one of the major questions confronting researchers was, "Can the wigwam burner in its present or modified form be made to operate in conformance with air-quality regulations, or must the device be abandoned altogether?". Considering the large investment in this device in the forest products industry, and the even larger investment required to devise other means of disposal if the

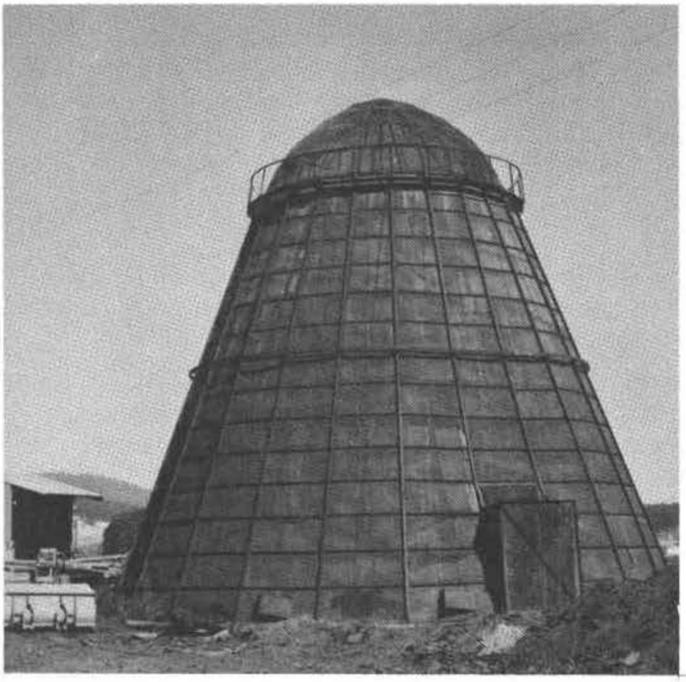

Figure 3. A burner operating near Corvallis, Oregon, with western hemlock and white fir bark.

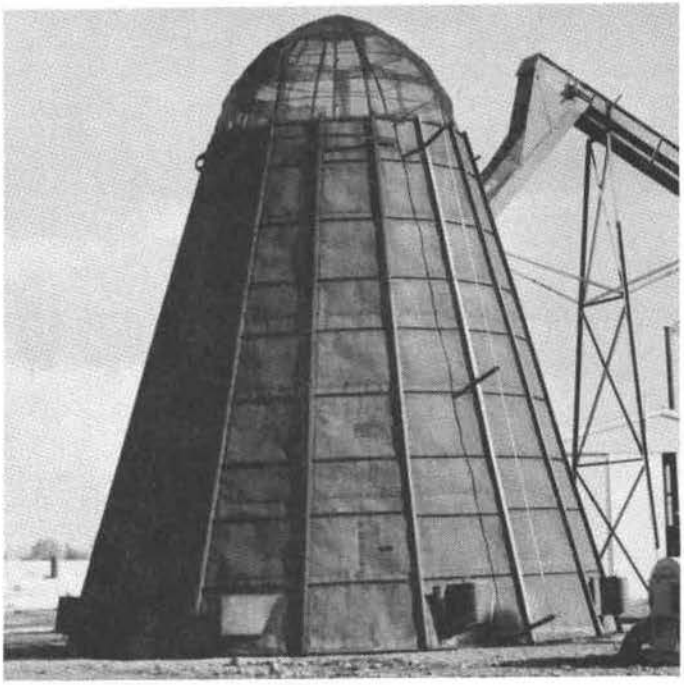

Figure 4. A burner at a pole and piling plant near Sheridan, Oregon.

wigwam burner were abandoned, researchers concluded that in this particular phase of the project, their research should provide facts upon which an answer to this important question could be based.

The decision was that it was probable that modified wigwam burners in many instances could be made to operate within air-quality standards. In brief, this decision was based on observations of "clean" burners that operated with little or no visual smoke or particulate emission. The decision was further reinforced by tests of others, notably those of Boubel (1), the State of Kentucky (14), and the Texas Forest Products Laboratory (30).

In 1969, the decision was made to acquire, modify, instrument, and test a full-size wigwam burner. Modifications to be made were selected on the basis of cost and expected improvement of air quality. The reasoning behind selection of modifications for the test burner is presented in the following discussion of possible modifications that were considered.

Characteristics of Clean Burners

Before discussing modifications in detail, some of the clean burners observed will be discussed. Some of these burners operated smoke-free most of the time. The burners were not identical, but did seem to have the following features in common:

1. The burners were tight and well-maintained, with minimal air leakage.
2. Operators had made adjustments of underfire and overfire air to obtain good burning conditions.
3. Burners were operating at high temperature.

One of the clean burners is shown in Figure 3. The waste burned in this wigwam was Douglas fir or western hemlock bark. Fuel rate for the 60-foot burner was about 8 tons (wet) per hour at 50 (100, dry basis) percent moisture content. Three flat grates, each about 3 feet by 4 feet, near the center of the burner admitted underfire air. A test by Boubel (2) indicated this burner emitted visible smoke for about one-half hour after staring, then burned cleanly. Average loading of particulates was 0.069 grain per standard cubic foot of stack gas. Many visual observations over a long time indicated smoke opacity was commonly less than Ringelmann No. 1.

The burner in Figure 4, based on a considerable number of observations, appeared to conform usually to air-quality standards. This 30-foot burner was equipped with flat grates. The estimated average fuel rate was about 5 tons (wet) per hour of Douglas fir bark and wood, at a moisture content of 55 (122, dry basis) percent. Usual operating temperature was from 800 F to 1,000 F, as indicated by a thermocouple at the top of the burner. Plant personnel noted that smoke occurred if the exhaust temperature dropped much below 800 F. This burner was installed in 1967, according to guidelines and with approval of the Oregon State Sanitary Authority (now Department of Environmental Quality).

A large 67-foot burner is shown in Figure 5. This wigwam burned fairly clean. It was equipped with an underfire air-supply system similar to that in Figure 6. When installed, only the elbows of this system extended above the floor of the burner; the rest of the piping was underground. The burner operated on bark and sawdust of Douglas fir, white fir, and ponderosa pine. The mill manager reported a fuel rate of 40 tons of wet fuel per hour had been measured. Operation of the burner was said to have been improved by patching the burner to reduce air leaks so that it was possible to attain a maximum exit-gas temperature from 600 F to 900 F.

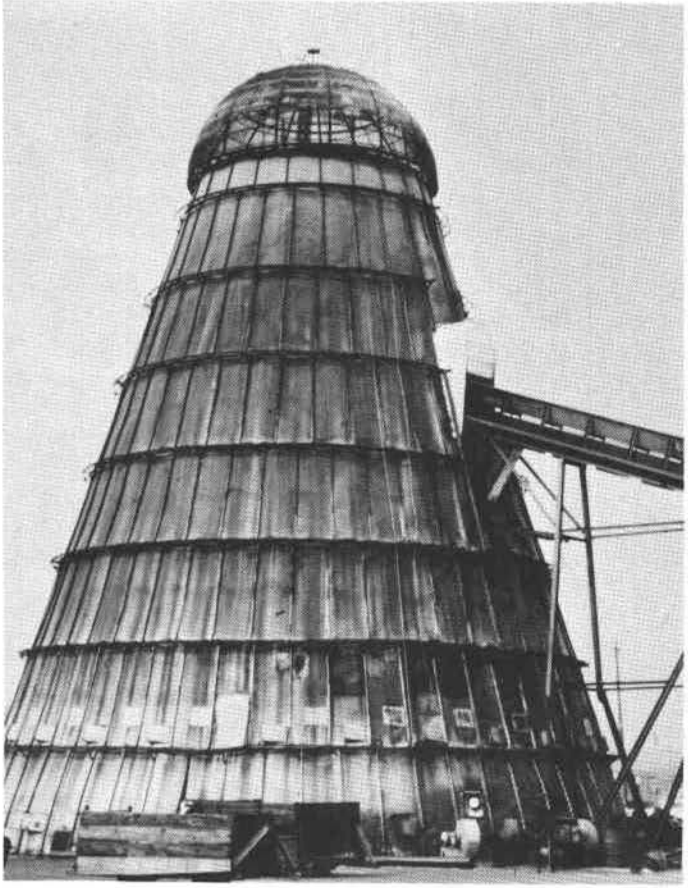

Figure 5. A 67-foot burner near Medford, Oregon, operating with bark and sawdust.

Underfire Air Systems

Some of the previously discussed burners had flat grates, but others had systems such as shown in Figure 6. In some of the other burners observed, no underfire air was provided, but burners without underfire air usually operated with noticeable smoke. A few burners observed (Figure 7) had natural-draft underfire air systems, but most clean burners had forced-draft fans (Figure 8) to provide underfire air. Our decision was to use flat grates in conjunction with forced-draft fans for the underfire air-supply system in the modified wigwam burner.

Overfire Air Systems

The importance of overfire air in creating turbulence, increasing flame travel, and providing intimate mixing of fuel and air has previously been emphasized. Higher velocities, increased turbulence, and simplified control of air rate is possible by using fans rather than natural draft for supplying overfire air. Although some of the clean burners observed had natural draft for overfire air, there were also some that had fans to force overfire air either through an underground elbow system (Figure 6) or through ducts in the burner wall (Figure 9). Decision was to incorporate overfire air fans, adjustable air nozzles, and an optional natural-draft system on the test burner.

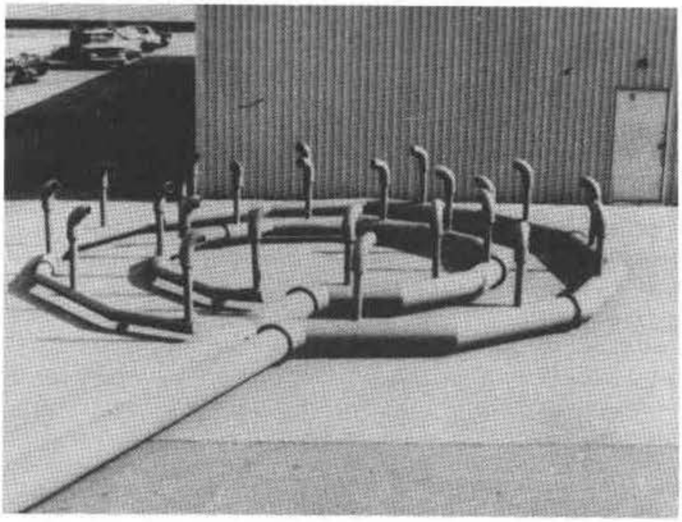

Figure 6. An elbow-type air supply system.

Refractory in Wigwams

Combustion in wigwam burners no doubt could be improved by use of strategically placed refractory surfaces. Refractory tends to heat by radiation from the burning fuel pile, then reradiates heat back to the surface of the pile. The net result is raised temperature and increased efficiency of combustion in the burning zone.

Tests by the California State Board of Health on a 45-foot burner at Redding, California, were observed by project engineers. The burner contained a cylindrical ring of fire brick about 10 feet in diameter and 6 feet high, which was centered in the burner. Fuel entered in an airstream tangentially at the periphery of the refractory cylinder. Fairly clean burning was achieved with sawdust and shavings at about 12 (14, dry basis) percent moisture, but tests with wet fuels were unsuccessful.

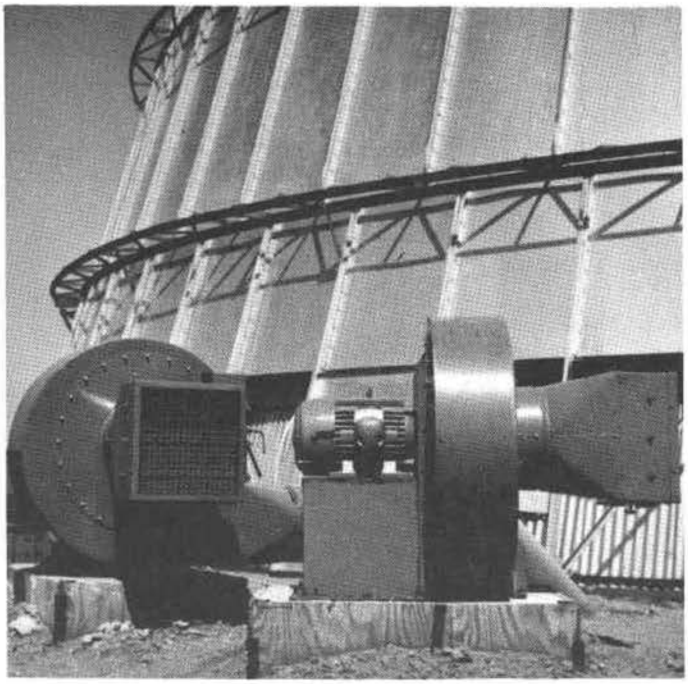

Figure 8. Forced-draft underfire air fans.

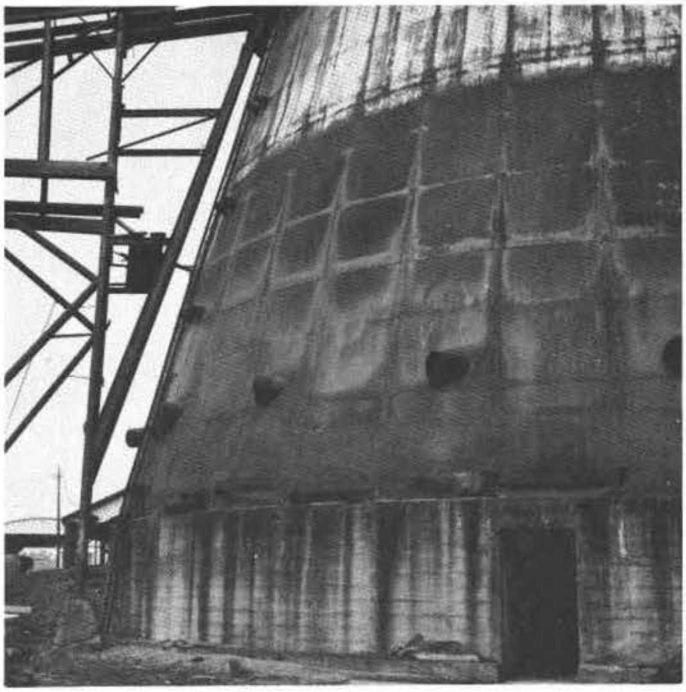

Figure 7. A wigwam burner with natural-draft underfire air.

The 61-foot burner of Figure 9 has a refractory cylinder 15 feet in diameter and 6 feet high. There is provision for adding forced-draft overfire air and for recirculating hot gases from inside the burner. Underfire air was provided by a fan and elbow-type air-supply system located inside the refractory ring. The unit was burning dry planer shavings with an assumed moisture content of 12 (14, dry basis) percent, at a rate of about 2 tons per hour according to the mill operator.

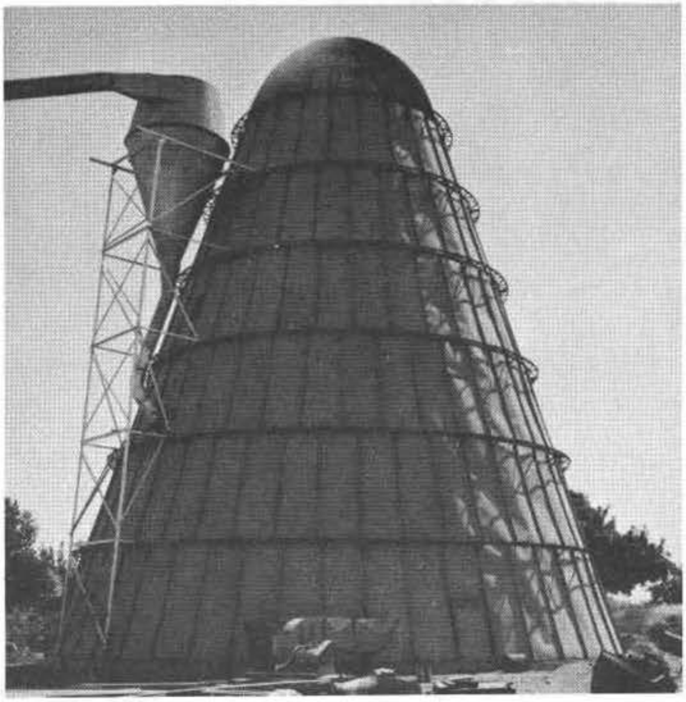

Figure 9. A burner at Live Oak, California, with a refractory cylinder inside and forced draft fans outside.

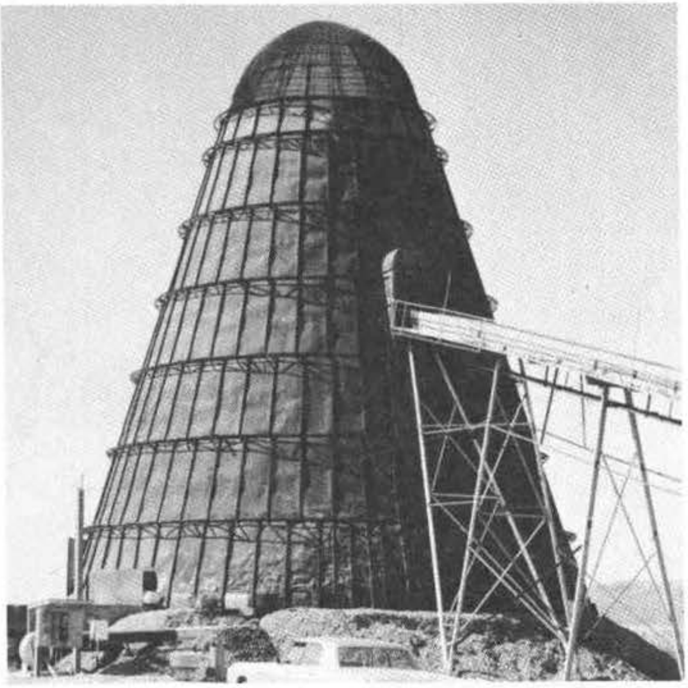

Figure 10. A burner at Klamath Falls, Oregon, which has an interior refractory fire pit.

During the observation period, there was no visible smoke and plant personnel said this was typical operation.

An oblong refractory fire pit with an average diameter of about 25 feet and a depth of 6 feet was installed in the 65-foot burner of Figure 10. Air nozzles at the base, half-way up the pit wall, and in a ring around the top of the pit, provide combustion air. The estimated burning rate was about 16 tons per hour of white fir bark and sawdust at about 50 (100, dry basis) percent moisture. Smoke-free operation was not attained when this installation was observed, but the operator indicated that there was considerable improvement over combustion in a previous burner.

Refractory was not installed in the modified wigwam test burner because it appeared costly, with no clear-cut benefits observed over some of the burners without refractory. This is not to say that researchers believed that refractory would not improve combustion. On the contrary, combustion obviously could be improved by the addition of refractory to wigwam burners, but the cost may not justify such addition.

Hot Gas Recirculation

The 70-foot wigwam burner (25) in Figure 11 is equipped with a metal cone at the top and provision for recirculating hot gases from the top to the base of the burner. Forced-draft underfire air enters through "mushroom-style" grates. Normal fuel rate on this burner is about 8 tons of wet bark per hour with a maximum reported rate (25) of up to 29 tons per hour. During the period of observation, there was no visible smoke and little evidence of particulate fallout. Certain aspects of the construction of this burner are the subject of a patent application. Recirculation also was provided on the burner in Figure 9, previously discussed.

A recirculation system (Figure 12) was installed on a 67-foot burner. The installer of this recirculation system reported that there was considerable visual improvement in combustion at high fuel rates. A project engineer from this study reported some improvement in combustion by means of the recirculation system when the burner was operating at low fuel rates.

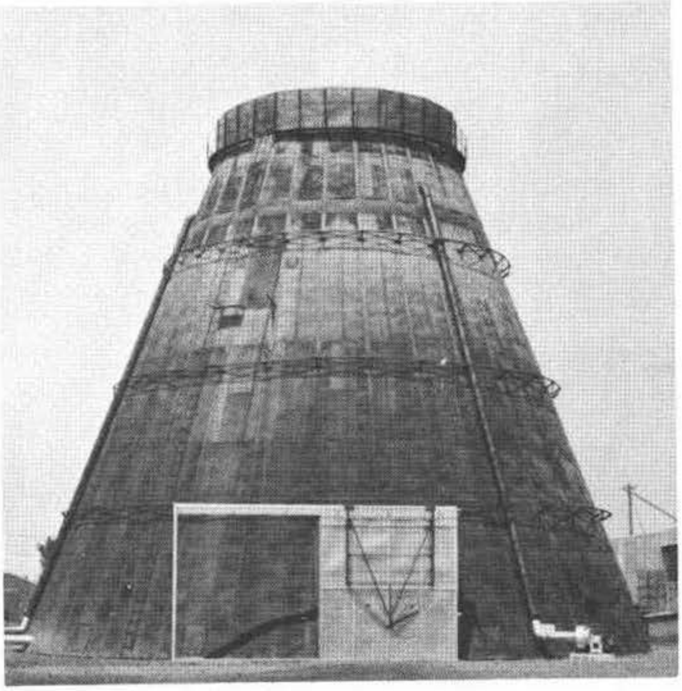

Figure 11. A modified wigwam burner at Medford, Oregon, which incorporates gas recirculation.

Because gas recirculation seemed to offer potential for improved burner operation and installation cost was low, provision was made for gas recirculation in the test burner.

Figure 12. A combination forced-overfire-air and gas-recirculation system.

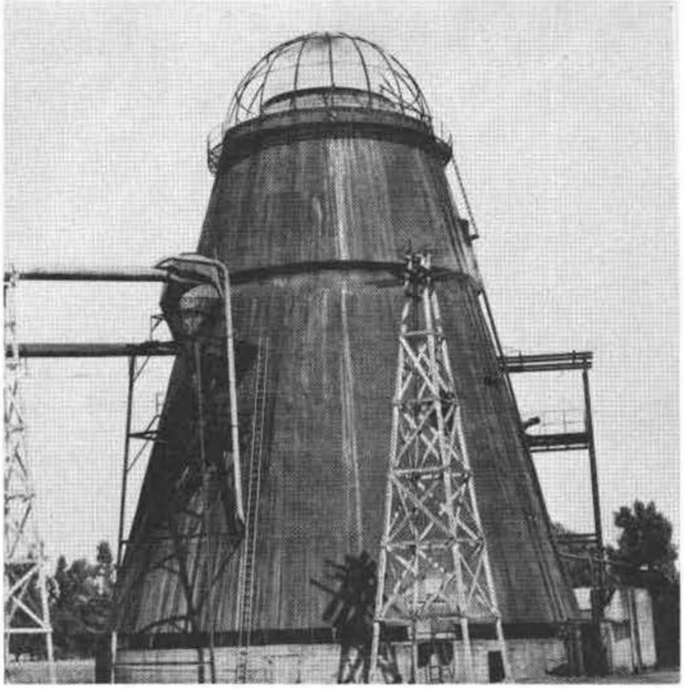

Figure 13. Water-wash gas scrubber on a wigwam burner at Chico, California.

Figure 14. A water-wash scrubber on a new burner at Memphis, Tennessee.

Auxiliary Fuel

Auxiliary fuel has been suggested (5, 27) as a method to improve starting conditions and to improve burning of high-moisture fuels (see also Findings of Consultants, appended). No operating burners with auxiliary fuel-firing equipment were found, however. Cost of adding auxiliary fuel was moderate and definite benefits seemed assured, so the modified test unit was equipped with natural-gas burners.

Gas-Cleaning Equipment

Gas-cleaning equipment has been installed on some wigwam burners to reduce particulate emissions, but no test data were obtained to substantiate the effectiveness of such equipment in use. Figure 13 shows a wet-gas scrubber installed on a burner. Waste burned was dry sawdust and shavings. Observations of the burner indicated that smoke was not eliminated, but that the scrubber was removing particles. Overall effectiveness of this particular scrubber is not known. Another scrubber of the same type is shown in Figure 14. This unit was installed on a 72-foot burner, but the mill was under construction and no operating experience was available.

Scrubbers similar to those in the preceding paragraph have been installed at several other forest industry operations. Scrubbers have been installed on wigwam burners by Rees Blowpipe Manufacturing Company at Berkeley, California; Rees Burner and BlowPipe Company at Memphis, Tennessee; Steelcraft Company at Memphis, Tennessee; and American Compressed Steel Corporation at Louisville, Kentucky.

George Koch and Sons, Inc., of Evansville, Indiana, reportedly has developed and installed an after-burner system for wigwam burners. This equipment has been installed on a burner consuming municipal refuse, but none has been installed in a forest products mill.

Although the installation of gas-cleaning equipment on wigwam burners would reduce particulate emissions, this equipment will not necessarily eliminate smoke. Moreover, scrubbers are expensive to install and operate (see Findings of Consultants, appended). Therefore, researchers decided that efforts to improve combustion would result in lower cost and be more effective in reducing smoke and emissions than would gas-cleaning equipment. Gas cleaners, therefore, were not installed on the test burner.

Controls and Stack Damper

Simple controls have been installed on wigwam burners to regulate burner temperature. One control system (11) developed by a burner manufacturer in Memphis, Tennessee, has stack-gas temperature as the indicator by which air flow through fans is regulated to maintain desired temperature. This system incorporates a damper in the upper part of the burner to further regulate gas flow. This control system has been installed on a 39-foot burner (Figures 15 and 16) that consumes dry shavings and sawdust. At the time of observation, indicated exhaust-gas temperature was about 800 F, with but a trace of visible smoke. The manufacturer stated that the damper was important to successful operation of the burner. He observed that without the damper, it was difficult to attain high temperature and smoke-free burning.

Several similar installations have been made in Kentucky. These burners have been tested (14) by personnel of the Kentucky Air Pollution Control Commission. One of the test burners was 30 feet in diameter and burned from one to two tons per hour of shavings at 12 (14, dry basis) percent moisture content. Results of tests (14) showed particulate emissions reduced by a factor of about 30 after modification of the burner to include a control system and a damper. Particulate emission was 0.07 pound per thousand pounds of gas, adjusted to 50 percent excess air. Before modification, exhaust-gas temperature was about 340 F, compared to 820 F after modification. Conclusion drawn from the Kentucky tests was

Figure 15. Temperature recorder-controller on a wigwam burner at Memphis, Tennessee.

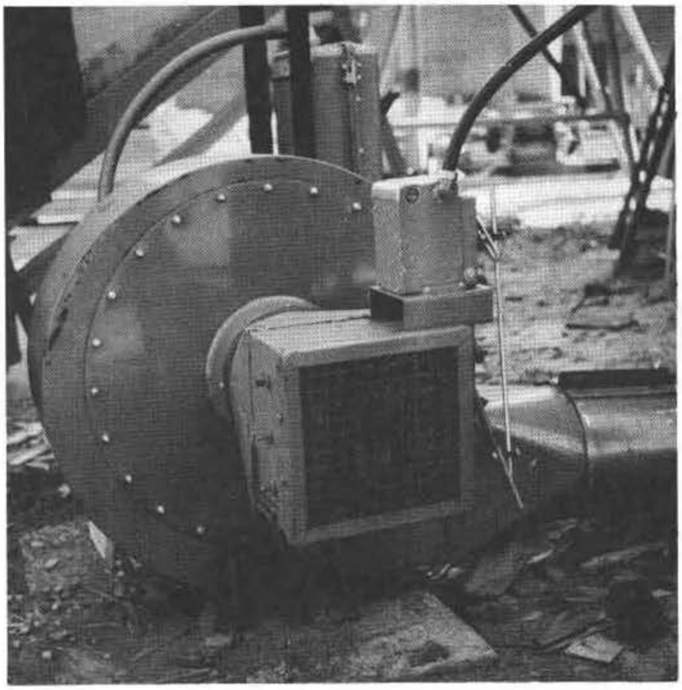

Figure 16. Fan dampers actuated by temperature controller.

that the described burner met Kentucky requirements for particulate emission of 0.4 pound per thousand pounds of gas, adjusted to 50 percent excess air. The above requirement is about equivalent to 0.2 grain per standard cubic foot of gas adopted by regional control agencies in Oregon.

The above installations were burning dry wood waste. Other similar installations have been made on burners operating with wet wood and bark waste with reported (24, 30) satisfactory results.

No doubt use of proper automatic controls will reduce smoke and particulate emissions in many instances. A major criticism of wigwam burners is that adjustment for varying combustion conditions has been lax and that much of the undesirable emissions could be reduced by proper control of air to the burner. Although it may not be possible to completely regulate burners by automatic controls, our conclusion is that much improvement can be realized. Therefore, we decided that automatic controls and a stack damper should be installed on the test burner, but such equipment had not yet been installed at the time tests described in this report were made.

Findings of Consultants

Consultants were asked to make recommendations for improvement of combustion in wigwam burners and to estimate costs of these improvements. Table 3 was prepared by one firm. A copy of their report entitled, "An Engineering Report on Control of Wigwam Burner Combustion," is included in Appendix A. Note that the modifications for drying fuel, addition of Dutch-oven refractory, and equipment for controlling fuel sizing and fuel rate are the most costly modifications. The circular masonry wall appears to be low in cost, but in the one installation where such a wall was observed, satisfactory combustion of wet fuels was not achieved. Modifications from this list that have been, or are planned to be, incorporated into the test burner are automatic overfire-air control, smoke-density measurement, and gas recirculation. The modified test burner also has provision for controlling fuel-feed rate, but fuel drying is not included. Although fuel-sizing equipment is not included on the test burner, tests run to date have been with fuel hogged before delivery. The reason for using hogged bark is that unhogged bark would have been difficult to handle.

Another consulting firm (see Appendix B) made the following recommendations for modification and operation of wigwam burners (no cost estimates were made):

1. Provide a tight steel skin to insure that air is admitted only under controlled conditions.

2. Provide separate blowers for underfire and overfire air.

Table 3. Consultants' Recommended Methods and Estimated Costs of Modifications for Improvement of Wigwam Burner Combustion.[1]

Type of modification	Burner diameter, *feet* 40	65
	$	*$*
Automatic overfire-air control	5,000	7,000
Smoke-density measurement	3,500	3,500
Fuel sizing and controlled feed rate	32,100	41,100
Fuel drying, including sizing and controlled feed	63,800	106,600
Air preheating		
Natural gas	15,600	26,700
Exhaust gas recirculation	9,600	23,500
Circular masonry wall addition	1,750	3,600
Refractory Dutch-oven addition	18,600	35,900

[1] From consultants' report in Appendix A.

Figure 17. Wigwam burner test site.

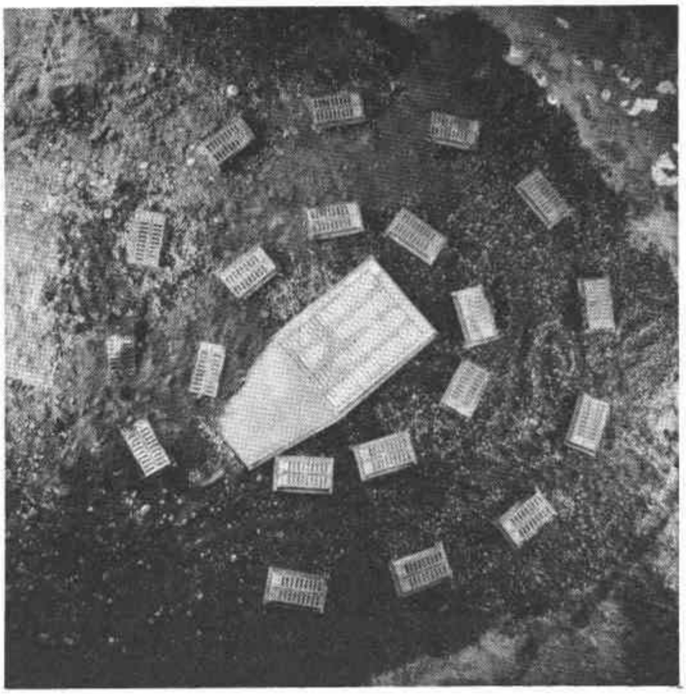

Figure 18. The grate system of the test burner viewed from above.

3. Control overfire air by using exhaust-gas temperature as an indicator.

4. Pre-dry the fuel with exhaust gas or auxiliary fuel, or pre-heat combustion air with exhaust gas or auxiliary fuel.

Consultants also made a study on "Removal of Particulate from Wigwam Waste Burner Emissions." A copy of their report is included in Appendix C. The estimated costs of adding equipment for removal of particulates from exhaust gases of wigwam burners, summarized from Appendix C, is shown in Table 4. Consultants recommended the multiple cyclone separator as the most acceptable equipment for wigwam burners.

Summary of Modifications

The previous paragraphs discuss modifications that were considered by project personnel for improvement of wigwam burner combustion. The usual reason for rejection of a possible modification was that the expected cost-benefit ratio was too high.

In brief, the modifications selected for study through testing of a wigwam burner were a three-zone, forced-draft, underfire air system, forced-draft overfire air fans with adjustable nozzles, natural draft vents, hot-gas recirculation ducts, provision for firing with auxiliary fuel, and a variable-speed fuel conveyor. A damper at the top of the burner was subsequently added. The burner, of course, was placed in good repair to reduce air leakage. Construction of the burner and the configuration and functioning of modifications will be explained in detail in the following section.

ARRANGEMENT OF MODIFIED WIGWAM BURNER

The 40-foot wigwam burner that was selected for modification and testing is shown in Figure 17. The conveyor, fans, and ductwork shown were not part of the original burner, but were equipment installed for this study. Note the instrumentation platform near the top of the burner and a fuel storage area and a quantity of fuel in the foreground. At the outset of the study, the burner was in good condition with a tight shell and well-fitting door. Leaks such as existed were welded shut insofar as practical. A variable-speed conveyor was installed to permit modulation of the fuel rate as desired. Fuel from the conveyor dropped into a fuel chute that extended angularly downward toward the center of the burner to 12 feet above its floor. Actual dimensions of the burner and more detailed information on construction of the burner and subsequently described modifications may be found in Appendix D.

Table 4. Consultants' Cost Estimate for Particulate Removal Equipment.[1]

Type of equipment	Burner diameter, *feet* 40	65
	$	$
Low-resistance separator	17,300	59,700
Single-cyclone separator	21,400	81,500
Multiple-cyclone separator	23,050	62,600
Wet-gas scrubber	30,100	99,400

[1] From consultants' report in Appendix C.

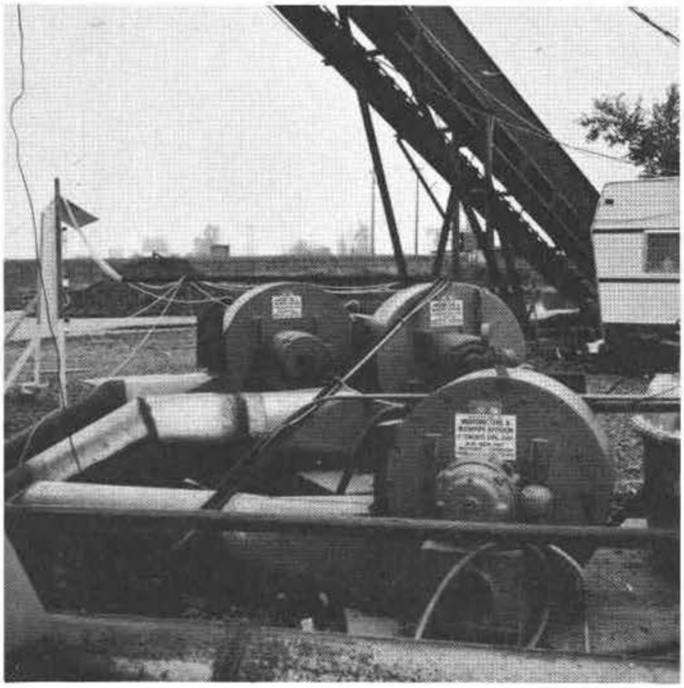

Figure 19. Underfire air fans of the test burner.

Grates

The grate system used in the test burner is shown in Figure 18, which is a photograph taken looking directly downward on the burner floor from above. Note that there are two outer rings of grate boxes and a large center grate. Each of these two rings and the center grate area are supplied with air independently by each of three fans. An auxiliary gas burner also is mounted to fire into the large central grate box. Grates in the outer rings are cast iron and have sloping ports so that some measure of horizontal direction may be imparted to the incoming underfire air. The central grate was constructed of spaced refractory brick.

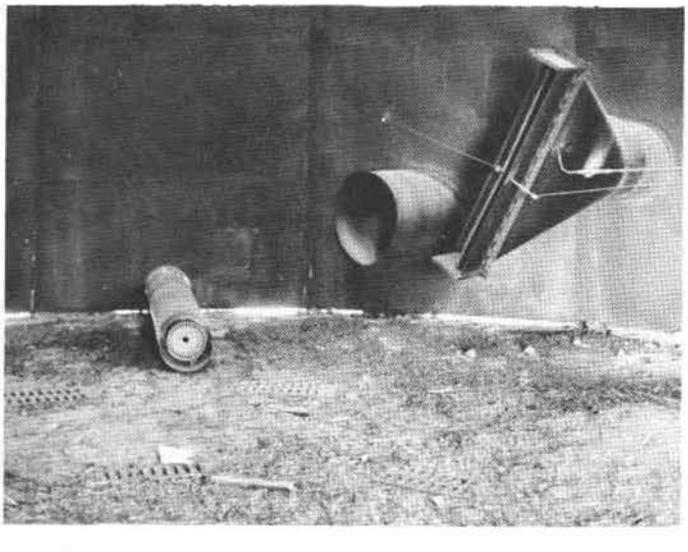

Figure 21. View from inside the test burner showing gas burner (lower left), natural-draft air duct (center), which was not used, and overfire air nozzle (upper right).

Figure 20. Overfire air fan viewed from the top of the test burner.

Underfire-Air System

The underfire-air fan system is shown in Figure 19. The small fan supplies the central grate, the next larger fan the intermediate grate ring, and the largest fan the outer ring. The three zones were employed independently, depending upon the size of the fuel pile. When the fuel pile was small, air was supplied only to the center grate area, and as the size of the fuel pile increased, air was supplied to the outer rings of grates.

Overfire-Air System

The overfire-air system consisted of four fans spaced 90 degrees apart around the periphery of the burner. One such fan is shown in Figure 20. An adjustable, rectangular nozzle (upper right, Figure 21) was connected to the discharge of each fan. This nozzle was rotatable about the horizontal axis to change the slope of the fan-shaped jet of overfire air to conform to the slope of the fuel pile. The nozzle was aimed so that the projected line of the air jet would tend to be tangent to the surface of the fuel pile. The width of the rectangular slot is adjustable from outside the burner.

Hot Gas Recirculation

The overfire-air system had provisions for taking hot gas from inside the burner and reintroducing it into the fan intake. One such recirculation intake is shown in Figure 22. At the middle right of the figure, an intake orifice is mounted on the recirculation duct. Viewed from outside the burner, the recirculation duct is shown in Figure 20 where it comes out through the burner wall about 45 degrees clockwise from the fan's cold air inlet. During operation of the recirculation system, hot gas could be mixed with outside air. The mixture of air and recirculated gases entered the burner through the overfire nozzle of Figure 21.

Figure 22. Recirculation intake (above) and movable gas burner (below) on the test burner.

The recirculation system was installed at the time of initial modification of the test burner, but as of this writing, time has not permitted evaluation of the recirculation system.

Natural Draft

The original modified wigwam burner was equipped with natural-draft openings around the periphery of the base. The existing natural-draft openings were sealed shut and four large natural-draft ducts were substituted. Just to the right of an overfire air fan (Figure 23) was a large-diameter duct with a sheet of steel welded over the opening. This was one of four natural-draft ducts that were installed on the modified burner. This substitution was made so that intake orifices could be used on the natural-draft ducts for air measurement. With the natural-draft ducts installed on the modified burner, tests can be run to compare the results of natural-draft overfire air with those attained with forced draft.

Tests to evaluate burner operation with natural-draft overfire air ducts have not been made as of this writing.

Natural Gas Burners

Four gas burners were installed in the wigwam burner with the twofold purpose of providing heat at starting and to facilitate burning of excessively wet fuels. One of the gas burners was installed in an underfire air duct to heat the air supply to the large central refractory grate. Hot gas from this burner was discharged directly under the base of the fuel pile. The other three gas burners were placed in metal ducts spaced 120 degrees apart near ground level around the base of the wigwam burner and directed radially toward the fuel pile (Figures 21 and 22). Each gas burner had a capacity of 3.6 million Btu per hour at 5 psi gas pressure and would discharge a flame about 8 feet long from the head of the burner nozzle. The burner head may be seen in the end of the duct (Figure 21). Burners were adjustable toward and away from the fuel pile (Figure 22) by sliding their ducts through thimbles in the wall of the wigwam and were connected to meters and gas supply by hoses that permitted withdrawal of the burners when not in use (Figure 24).

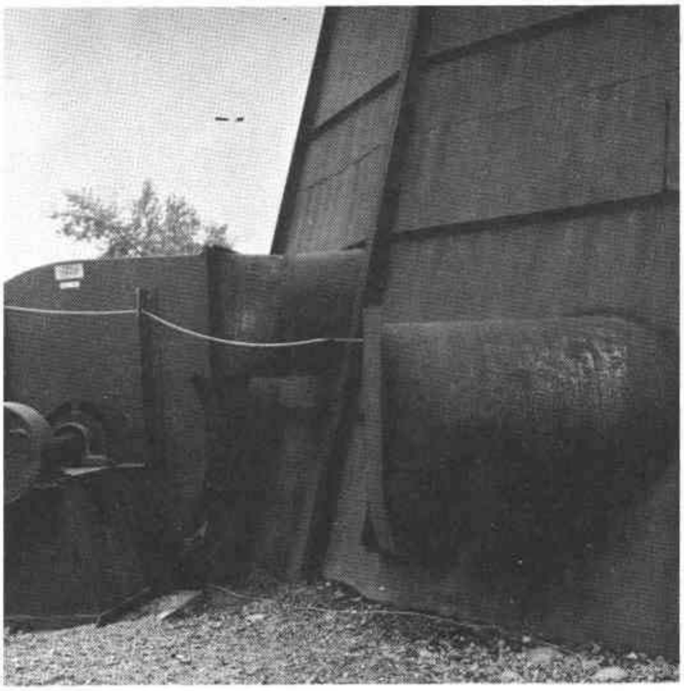

Figure 23. Natural-draft duct (right) and an overfire air fan (left) on the test burner.

BURNER INSTRUMENTATION

Instrumentation and equipment for gas sampling and analysis, sampling of particulates, measurement of smoke opacity, and measurement of temperature was centrally housed in a trailer (Figure 25). Other instrumentation such as gas meters and draft gages were located near the burner. More complete details and specifications on instrumentation may be found in Appendix E.

Air Rates

All gas-burner housing ducts, air ducts, fan inlets, and gas-recirculation ducts were equipped with intake orifices for air-flow measurement as shown in Figure 26. All of the various sources of air supply to the wigwam burner were controlled and measured (except for leakage). Orifice pressures were measured by draft gages mounted on manometer boards (Figure 27).

Gas Analysis

A continuous gas sample was taken from near the top of the burner to the instrument trailer where it was analyzed for

Figure 24. An auxiliary natural-gas burner duct (foreground) on the test burner.

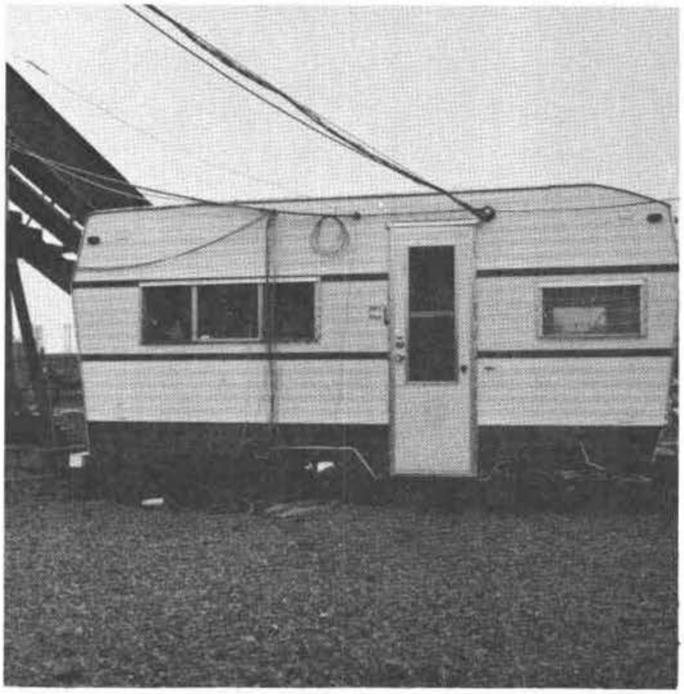

Figure 25. Instrumentation trailer at the test burner.

carbon dioxide, carbon monoxide, and hydrocarbons. Carbon dioxide and carbon monoxide were measured with continuous-recording infra-red analyzers, and hydrocarbons were measured with a flame-ionization instrument (Figure 28).

Particulate Sampling

Particulate concentration was determined by drawing a sample of exhaust gas from near the top of the burner (Figure 17) and then separating the particulates from the exhaust gas in the sampling train. Included in the sampling train, which is further explained in Appendix E, was a cyclone separator, three glass impingers, and a paper filter.

Velocity at the particulate sampling probe was detected with a pitot tube and micromanometer so that flow rate through the sampling system could be adjusted for isokinetic conditions at the probe.

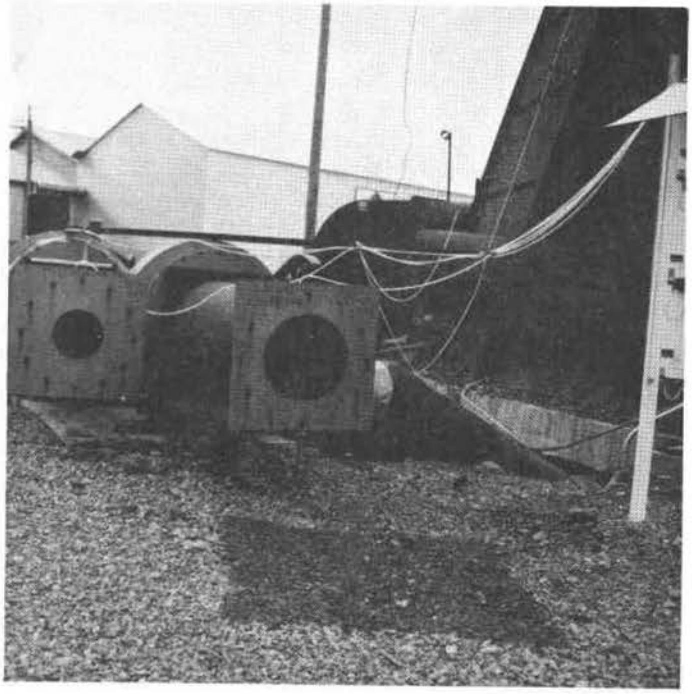

Figure 26. Intake orifices on the test burner.

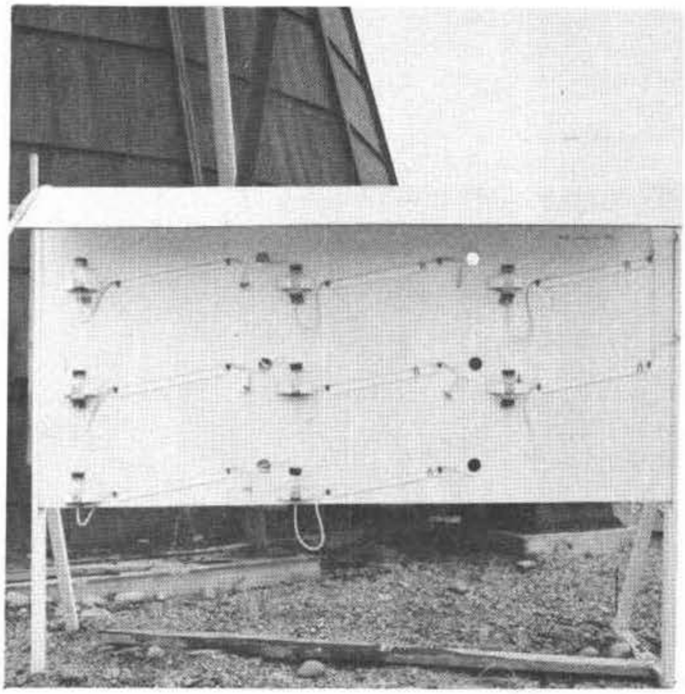

Figure 27. Manometer boards at the test burner.

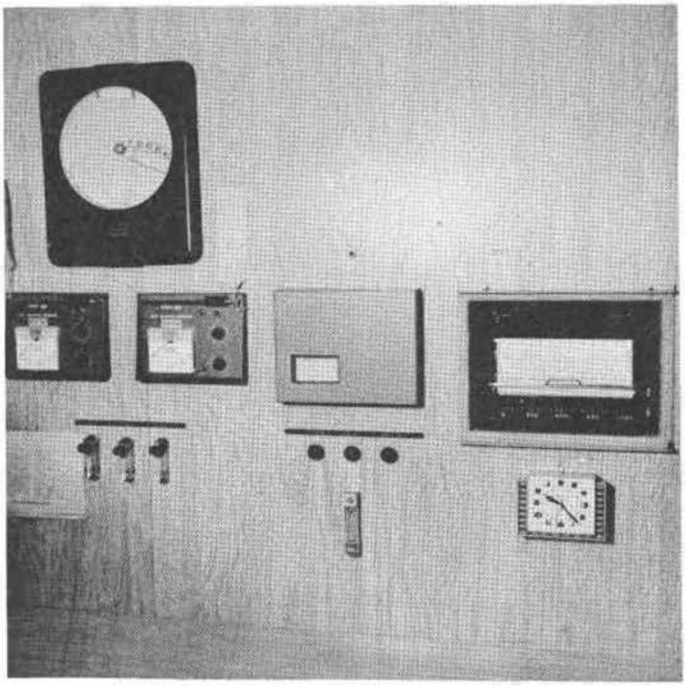

Figure 28. Instruments for analyzing gas and measuring smoke opacity and temperature at the test burner.

Smoke Opacity

Smoke opacity was indicated by a photoelectric system installed at the top of the burner. A sample of exhaust gases was drawn by a fan through a duct with a light source mounted at one end and detector at the other. A signal indicative of the extent of light obscuration was transmitted to the recorder shown at the lower left of Figure 28.

Smoke opacity also was evaluated visually by Ringelmann number or an equivalent opacity rating. This evaluation was by the same observer in all tests. The observer had participated previously in plume-evaluation training sessions by the Air Quality Control Division of the Oregon Department of Environmental Quality.

Temperatures

Temperatures of exhaust gases and the wigwam burner shell were measured by thermocouples. Temperature of exhaust gas was measured at 12 points along two diameters at the top of the wigwam burner. Temperature of the burner skin was measured at eight locations. Other measurements of temperature were taken at orifices, of ambient air, and on overfire air nozzles.

TEST PROCEDURE

Fuel

Fuel burned in these tests was hogged Douglas fir and western hemlock bark except for two runs made with western hemlock sawdust. The bark fuels contained a small amount of wood, which is normally removed from the log in the debarking process. Each truckload of fuel was weighed before delivery to the test site and samples were taken for moisture determinations. A composite sample was taken from several loads of fuel to determine its heating value and chemical composition.

Figure 29. Loader transferring fuel at the test burner.

During tests, fuel was transferred from the storage area to the fuel hopper by tractor (Figure 29). Desired rates of feeding were obtained by delivering scoops of fuel of known weight to the hopper at predetermined intervals, and adjusting the conveyor speed to accommodate the fuel rate. A shear (Figure 30) was installed in the conveyor hopper so that a steady rate could be maintained.

In two tests, water was sprayed on the fuel to increase its moisture content, as shown in Figure 31. In all other tests, fuel was burned at the as-received moisture content.

Starting

The general procedure for starting at the beginning of a day of testing was to start the conveyor and allow a pile of fuel to form in the burner until it extended to about the first ring of grates, or to about ten feet in base diameter. The three overfire gas burners then were ignited and the underfire air fans started and adjusted to a predetermined air rate. After about 20 minutes, there was a good fire at the fuel pile. The overfire fans were started and dampers adjusted for predetermined air rates. When the burner's exit-gas temperature approached 700 F and good combustion was well established, the gas burners were turned off and withdrawn from the wigwam. Total time for starting by this procedure was from one-half to one hour. The gas burners served to minimize smoke emission during the starting period.

Test Period

After starting, the wigwam burner was operated until equilibrium conditions apparently had been established, as indicated by steady temperatures, gas analysis, and visual observations. With equilibrium established, the particulate sampling pump was started, fuel and air were maintained at constant rates, and readings of temperature, gas analysis, smoke

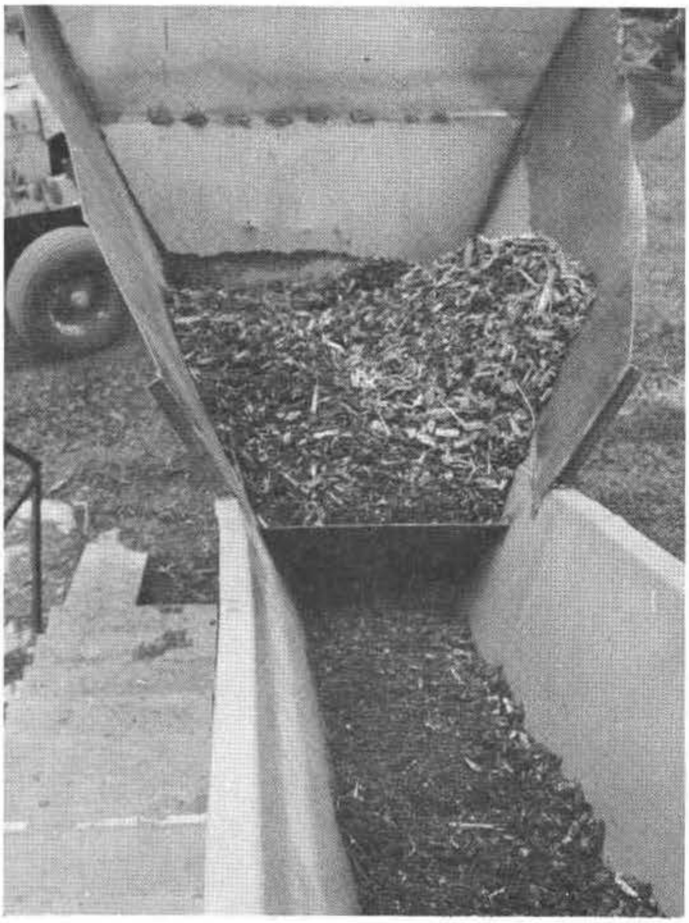

Figure 30. Fuel feed hopper and conveyor for the test burner.

opacity, and visual observations were recorded at 15-minute intervals. A test run usually lasted one hour.

For subsequent tests, appropriate changes in predetermined rates for air or fuel were made and the burner was operated until equilibrium was re-established, after which another test was conducted. Although most tests were run at or near equilibrium, a few runs were made where equilibrium had not been fully established. These nonequilibrium conditions were indicated if, at the end of a test, temperatures, gas analysis, or size of fuel pile were different than at the beginning of a test.

Figure 31. Water added to bark fuel going into the test burner.

RESULTS AND DISCUSSION

Analyses of composite samples of fuel from several loads of Douglas fir and western hemlock bark are shown in Table 5. The analyses are nearly the same for the two species except that Douglas fir had higher heating value and lower ash content. Thirty-four tests were made with the barks analyzed in Table 5. Two other runs were made with western hemlock sawdust, but no analyses of sawdust were made.

A summary of test results is shown in Table 6. In air-quality control, visual ratings of smoke and emission of particulates are the most important criteria of performance. In ten runs, particulate emission was less than 0.2 grain per standard cubic foot of gas and visual smoke rating was less than Ringelmann No. 1. During these ten tests, the burner would have met state and regional regulations for air pollution for existing burners in Oregon.

A discussion of operating variables that points the way to best operating conditions is presented in the rest of this section.

Table 5. Average Analyses for Bark Burned in Wigwam Burner Tests.

Analysis	Douglas fir	Western hemlock
Moisture as received, *Percent*	41.3(70.4)[1]	42.6(74.2)[1]
Heating value, *Btu per lb dry fuel*	9,400	8,900
Ultimate analysis, *Percent, dry basis*		
Carbon	53.0	51.2
Hydrogen	6.2	5.8
Oxygen	39.3	39.2
Nitrogen	0.0	0.1
Sulfur	0.0	0.0
Ash	1.5	3.7

[1] Based on dry weight of fuel.

Table 6. Summary of Results

Test	Moisture content, basis		Fuel per hour		Air				
	Wet	Dry			Theoretical	Underfire	Overfire	Leakage[4]	Excess[5]
	%	%	*Units*	*Dry tons*	*Cfm*[2]	%[3]	%[3]	%[3]	%[3]
DOUGLAS FIR BARK									
16	40.0	66.7	0.9	1.22	3,470	31	0	2,148	2,080
23	38.8	63.4	0.9	1.23	3,520	18	147	1,145	1,210
15	40.0	66.7	0.9	1.22	3,470	34	101	1,175	1,210
24	38.8	63.4	0.9	1.23	3,520	18	236	1,056	1,210
14	40.0	66.7	0.9	1.22	3,470	70	97	770	837
22	39.0	63.9	0.9	1.23	3,510	26	147	614	687
1	40.6	68.4	1.7	2.43	6,950	19	400	---	---
2	40.6	68.4	1.7	2.43	6,950	15	355	---	---
4	44.5	80.2	1.7	2.43	6,950	31	195	---	---
20	40.3	67.5	1.7	2.41	7,020	13	145	558	616
3	40.8	68.9	1.7	2.43	6,950	49	242	412	603
19	42.0	72.4	1.7	2.41	7,010	22	145	549	616
21	39.3	64.7	1.7	2.41	7,020	13	240	216	469
5	42.6	74.2	1.7	2.43	6,950	31	146	479	556
7	42.6	74.2	1.7	2.43	6,950	31	198	427	556
6	42.6	74.2	1.7	2.43	6,950	31	97	434	462
10	40.0	66.7	2.3	3.26	9,260	35	292	304	531
11	40.0	66.7	2.3	3.26	9,260	18	294	264	476
13	40.0	66.7	2.3	3.26	9,260	15	204	273	392
12	40.0	66.7	2.3	3.26	9,260	17	203	208	328
25	38.4	62.3	2.6	3.74	10,700	12	178	512	602
26	38.4	62.3	2.6	3.74	10,700	20	180	276	376
9	40.1	66.9	3.4	4.86	13,900	32	225	181	338
8	40.1	66.9	3.4	4.86	13,900	31	197	210	338
WESTERN HEMLOCK BARK									
31	40.4	67.8	1.0	1.12	3,000	55	123	1,069	1,158
28	39.2	64.5	1.5	1.70	4,530	33	148	841	907
27	39.2	64.5	1.5	1.70	4,550	52	148	715	815
29	46.0	85.2	3.0	3.36	9,000	30	181	217	328
32	41.2	70.1	3.3	3.66	9,800	22	168	167	257
34	40.4	67.8	3.3	3.66	9,820	14	169	269	360
33	41.0	69.5	3.3	3.66	9,800	19	169	197	285
30	45.4	83.2	3.0	3.36	9,010	26	115	261	303
35	58.3	140.0[10]	3.0	3.40	9,100	22	114	491	527
36	59.0	144.0[10]	3.0	3.40	9,690	28	102	212	242
WESTERN HEMLOCK SAWDUST									
17	66.1	195.0	1.7	1.42	3,800	62	212	910	1,084
18	66.1	195.0	2.4	2.05	5,500	69	243	563	775

[1] One unit is 200 cubic feet.

[2] Standard cubic feet per minute calculated at 60 F and 14.7 psia.

[3] Based on theoretical air.

[4] Calculated based on measurements of carbon dioxide in stack, fuel feed rate, and fan air rates.

[5] Excess of air over that theoretically needed for complete combustion of fuel based on measurements of carbon dioxide in stack.

from Wigwam Burner Tests.

Probe temp	Exit-gas temp	Burner shell temp	Smoke rating	Particulates		Stack-gas analysis, dry		
				Emission	Ash	CO_2	CO	Hydrocarbons
F	*F*	*F*	*Ringelmann No.*	*Grains/ cu ft*	%[7]	%[8]	%[8]	*Ppm*
			DOUGLAS FIR BARK					
300	299	220	1 1/2-3	2.26	18	0.9	0.08	100
394	369	280	1 1/2-2 1/2	0.79	--	1.5	0.05	100
418	363	300	1 1/2-3	0.81	17	1.5	0.10	170
418	383	260	2-3	1.09	23	1.5	0.09	148
512	449	430	2-3	0.94	26	2.1	0.12	118
570	516	410	0	0.62	30	2.5	0.05	40
407	416	370	2-4	----	--	---	----	---
---	433	410	2 1/2	----	--	---	----	110
549	497	450	1/2	----	--	---	----	510
654	598	440	0-1/2	0.31	30	2.8	0.06	68
656	550	470	1	0.54	17	2.8	----	520
672	613	470	0	0.43	30	2.8	0.05	86
706	625	460	0-1/2	0.25	40	3.5	0.07	54
745	650	490	1/2	0.34	49	3.0	0.09	245
793	633	590	1/2-3/4	0.18	38	3.0	0.09	110
845	683	580	1/4	0.10	56	3.5	0.09	80
735	652	540	1 1/2	0.60	30	3.1	----	60
760	636	500	1 1/2	0.67	26	3.4	0.06	57
783	645	450	1-2	0.39	39	4.0	0.11	154
940	828	600	0-1/4	0.46	59	4.6	0.05	32
645	577	470	0-1/4	0.29	25	2.8	0.09	100
820	728	670	0-1/4	0.15	48	4.1	0.09	85
853	740	480	1	0.35	48	4.5	0.15	140
976	907	860	1/4-3/4	0.10	71	4.5	0.06	130
			WESTERN HEMLOCK BARK					
431	386	300	1 1/2-2	0.55	35	1.6	0.07	154
472	416	330	1/2	0.75	19	2.0	0.11	124
550	450	380	1/2-1	0.74	29	2.2	0.10	117
778	665	490	1/4	0.19	58	4.7	0.10	227
867	683	520	0	0.05	77	5.6	0.07	38
883	763	670	0	0.17	62	4.4	0.13	75
890	745	580	0	0.06	72	5.2	0.07	18
906	761	650	0-1/8	0.05	71	5.0	0.05	16
590	548	420	1	0.31	25	3.2	0.30	512
896	791	640	0-1/4	0.09	77	5.9	0.15	62
			WESTERN HEMLOCK SAWDUST					
480	459	300	1-2	0.91	19	1.7	0.15	350
567	524	350	1-1 1/2	1.02	16	2.3	0.41	755

---

[6] Gas volume was adjusted to 60 F, 14.7 psia, and 12% carbon dioxide by volume.

[7] By weight.

[8] By volume.

[9] Gas burners were on during the test.

[10] Water was added to increase moisture content to values shown.

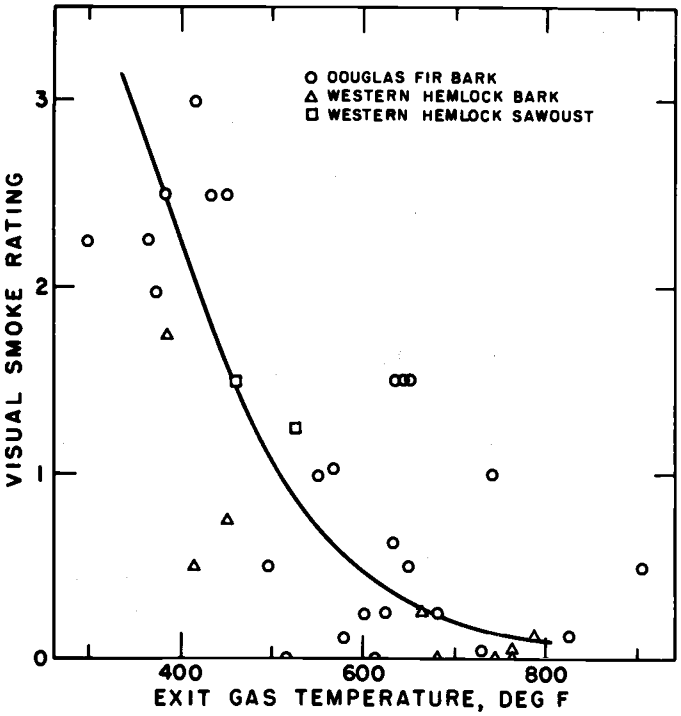

Figure 32. Visual smoke rating (Ringelmann number) related to exit-gas temperature.

Smoke

The relation of visual smoke rating to average exit-gas temperature is shown in Figure 32. Although the points are scattered, there is a trend toward reduced visual smoke with increasing temperatures. Whenever gas temperature was greater than 700 F, smoke rating was less than Ringelmann No. 1. A visual smoke rating less than Ringelmann No. 1 would comply with all existing regulations on air pollution in Oregon with regard to smoke.

Particulate

The upper curve in Figure 33 shows total emission of particulates related to average leaving-gas temperatures, and the lower curve shows the noncombustible portion (ash) of the particulates. Total particulates and ash emissions decrease with increase in temperature, but the ash portion decreases at a lower rate than total particulates. Total emissions are reduced, on the average, by a factor of about 4 with an increase of exit-gas temperature from 400 F to 800 F. The ash portion only decreases, on the average, by a factor of about 2 for the same change in exit-gas temperature. At exit temperatures of over 700 F, most runs had a total particulate emission of less than 0.2 grain, which would meet most regulations for particulate emissions of existing installations.

Particulate emissions also can be expressed in terms of their weight per quantity of fuel burned. For comparison, a particulate emission of 0.2 grain per standard cubic foot of gas (corrected to 12 percent carbon dioxide) is equivalent to 7.9 pounds of particulates per ton (dry weight) of fuel, or 4.8 pounds of particulates per ton (wet weight) when the fuel is Douglas fir hogged fuel with a moisture content of 40 percent (67 percent, dry basis).

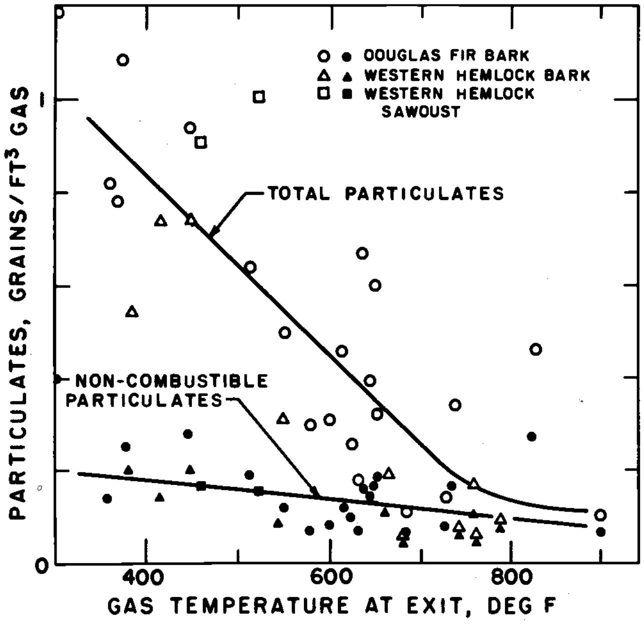

Figure 33. Particulate emission related to average temperature of exit gases. Volume of gas is corrected to standard temperature and pressure and 12 percent carbon dioxide.

The proportion of total particulates that was combustible also can be inferred from Figure 33. Combustible particulates decreased from about 75 percent of the total at 400 F exit-gas temperature to about 20 percent at 800 F exit-gas temperature. Conversely, ash increased from 25 percent to about 80 percent for the same change in temperature. The above relation indicates that higher gas temperatures provide conditions for burning more of the combustible portion of the particulates.

It is important that most of the ash contained in the fuel be retained in the burner rather than be carried out with exhaust gases. For example, if Douglas fir bark has 1.5 percent ash (dry basis) and all of the ash were carried out with exhaust gases, particulate emission from ash alone would be about 0.8 grain per standard cubic foot of gas (corrected). Western hemlock bark fired in these tests with 3.7 percent ash would give about 2½ times the particulates of that cited for Douglas fir, if all were emitted.

Gaseous Emissions

The concentration of carbon monoxide also shows a decrease with increasing exit temperatures (Figure 34). Average corrected concentration of carbon monoxide dropped to about 0.2 percent at 800 F, compared to about 0.6 percent at 400 F exit-gas temperature. A carbon monoxide concentration of 0.2 percent is equivalent to about 40 pounds of carbon monoxide per dry ton of fuel.

Heat loss as a result of incomplete combustion of carbon in burning to carbon monoxide rather than carbon dioxide was about three percent of the total heat in the fuel at an exit-gas temperature of 400 F and about one percent when gas temperature was 800 F. This means that less heat was available to raise temperatures, dry out the fuel, and sustain heat losses at 400 F exit temperature. This comparison again underscores the importance of maintaining high temperature within the burner, because high temperature results in reduced particulates and smoke emission.

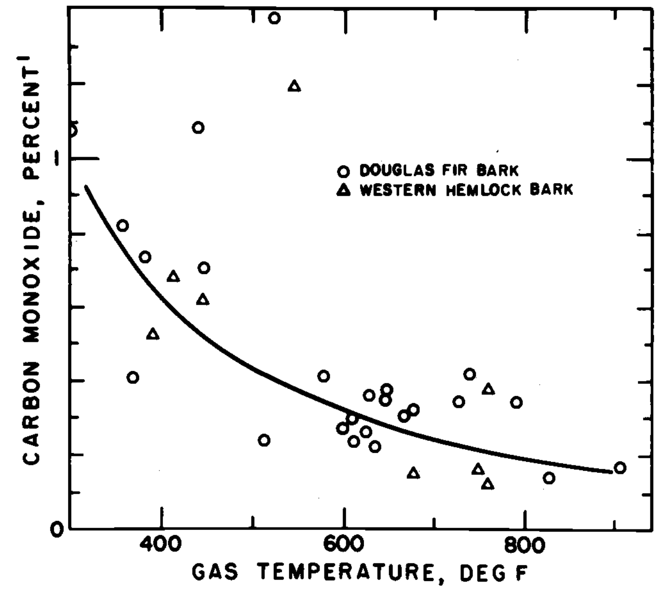

Figure 34. Carbon monoxide emission related to average temperature of exit gases. Volume of gas is corrected to standard temperature and pressure and 12 percent carbon dioxide.

Total hydrocarbon concentration in exit gas followed a similar pattern of decreasing in concentration as exit-gas temperatures increased (Figure 35). At an exit-gas temperature of 400 F, total concentration of hydrocarbon was about 900 ppm and dropped to about 100 ppm at 800 F. One hundred ppm and 900 ppm (adjusted to 12 percent carbon dioxide) would be equivalent to about one pound and nine pounds of hydrocarbons per ton of dry fuel.

There are two reasons for measuring hydrocarbons. One reason is to determine their contribution as an air pollutant and the other is to determine heat loss as a result of unburned hydrocarbons. Heat loss because of unburned hydrocarbons was 1 percent and 0.1 percent of the total heat in the fuel at gas temperatures of 400 F and 800 F.

Fuel Rate

Fuel rates in the testing ranged from 0.9 unit to 3.4 units (200 cubic feet in a unit) per hour or from 1.2 to 4.9 tons (dry weight) per hour. With an average moisture content of 40 percent (67 percent, dry basis), as in most tests, the average fuel rate by wet weight was 1.67 times the fuel rate by dry weight. Douglas fir bark averaged about 2,680 pounds, dry weight, per unit, and western hemlock bark contained an average of 2,240 pounds, dry weight, per unit.

The relation of fuel feed rate to average exit-gas temperature (Figure 36) shows that higher temperatures were obtained at higher fuel-feeding rates. There was moderate variation in exit-gas temperatures at any given fuel-feed rate. This variation was a result mainly of different air rates at a given fuel rate. It is significant, however, that at fuel feed rates below two tons per hour, dry weight, exit-gas temperatures of 700 F could not be reached even with minimum air rates. A later section of this report, which discusses the subsequent installation of a top damper, points out that higher temperatures were obtained with the top damper.

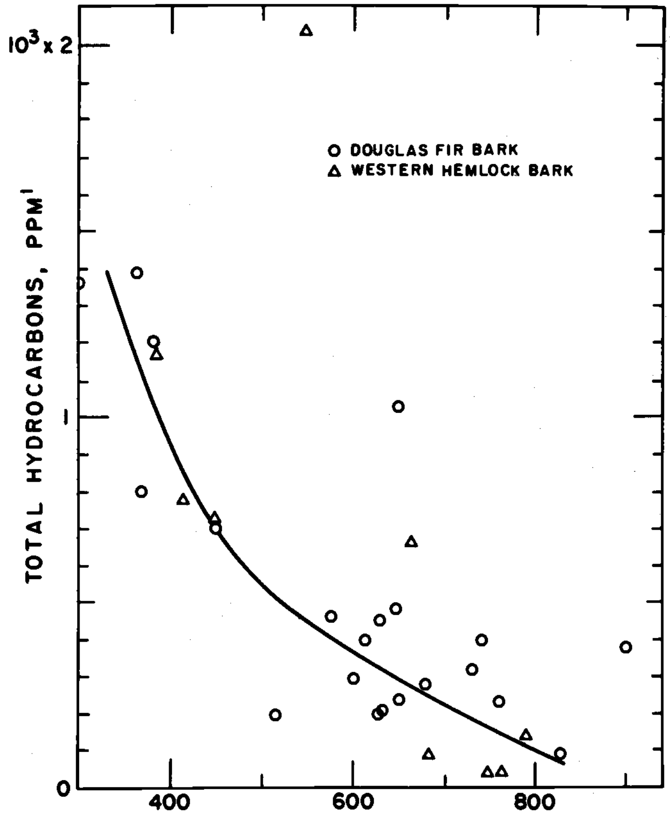

Figure 35. Total hydrocarbon emissions related to average temperature of exit gases.

Heat Balance

To explain the difficulty in maintaining high temperatures at low fuel rates, one may look at heat balances for different conditions. Total heat supplied by the fuel can be considered to be distributed to the following:

1. Heat to evaporate moisture in the fuel and raise the vapor to exit temperature.

2. Heat to raise the combustion gases to exit temperature when dry fuel and theoretical air are burned.

3. Heat to raise excess air to exit temperature.

4. Heat losses by radiation and convection from the walls of the burner.

This heat balance neglects loss of heat as a result of incompletely burned carbon in stack gases, unburned carbon remaining with ash in the burner, and water vapor in air entering the burner. The above losses were judged small and have only minor effect on the overall heat balance.

Heat balances for selected tests (Table 7 and Figure 37) show distribution of heat for different conditions. The exit-gas temperature of test 14 at the low fuel rate of 1.22 dry tons per hour was only 449 F, compared to 763 F for test 34 in which the fuel rate was 3.66 dry tons per hour. To have raised temperatures in test 14, it would have been necessary to reduce

Table 7. Heat Balances for Selected Tests, in Millions of Btu Per Hour.

Test	Fuel			Avg temp exit gases	Heat distribution									
	Dry weight	Moisture, basis			Heat available		Fuel moisture		Combustion gases		Excess air		Burner walls	
		Wet	Dry											
	Tons/hr	%	%	*F*	*Btu*	%	*Btu*	%	*Btu*	%	*Btu*	%	*Btu*	%
14	1.22	40	67	449	21.5	100	2.0	9	1.8	8	12.0	56	5.7	27
20	2.41	40	67	598	42.5	100	4.2	10	4.9	12	24.5	57	8.9	21
34	3.66	40	67	763	61.2	100	6.8	11	10.0	16	26.1	43	18.3	30
36	3.40	59	144	791	56.8	100	13.6	24	9.1	16	16.9	30	17.2	30

[1] Total heat available from fuel

[2] Heat to raise temperature of and evaporate moisture in fuel

[3] Heat to raise temperature of gases from theoretical combustion

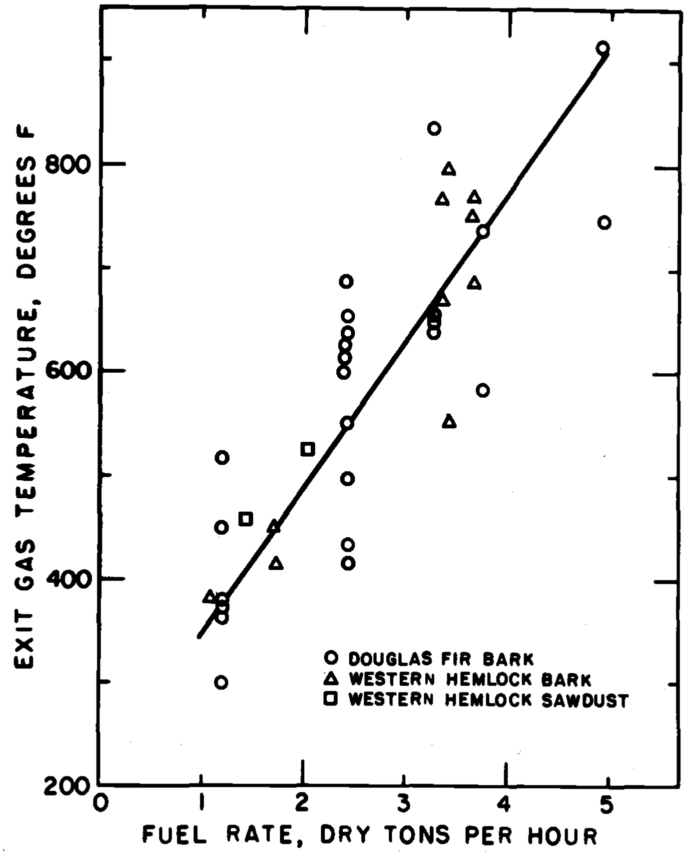

Figure 36. Feed rate of fuel related to average temperature of exit gases.

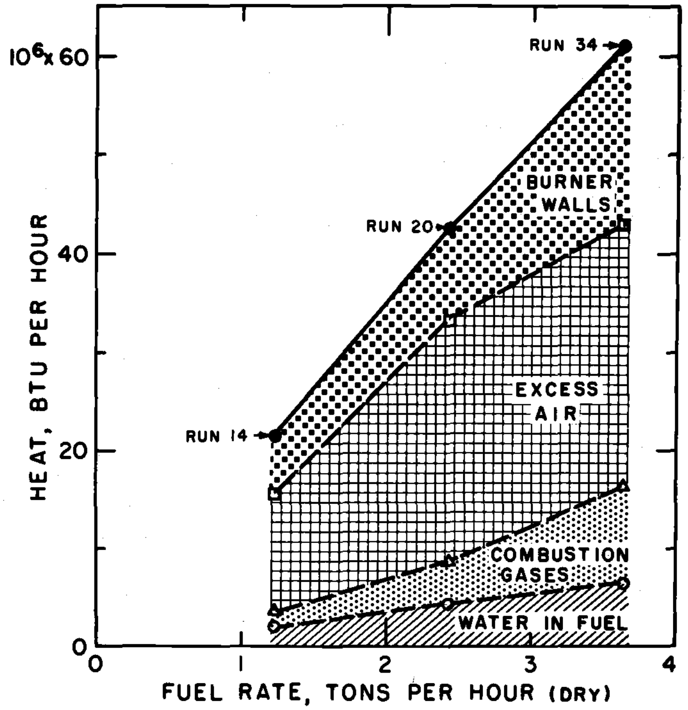

Figure 37. Heat balance of the test burner at selected fuel rates with fuel moisture about 40 percent (67 percent, dry basis).

excess air entering the burner so that this heat would be available to raise temperature.

For tests at low fuel rates, even though at low air rates, air leakage into the burner prevented attaining higher temperatures. Although higher temperatures could have been attained at low fuel rates with less excess air, temperature was limited at low fuel rates by heat losses from the burner walls.

The above discussion points out two factors important in the operation of wigwam burners. First, a burner should not be too large for the existing fuel rate. Excessive loss of heat from the walls of a too-large burner limits temperatures that can be attained. Second, because of difficulty in limiting air leakage into burners as presently constructed, an adjustable damper in the upper part of burners can be effective in reducing air leakage. With such a damper, higher temperatures and better combustion can be attained, especially at low fuel rates. A subsequent section discusses preliminary results with a top damper.

Total Air

For a given burner and fuel rate, the air rate is one of the most important factors in the operation of a burner, and one over which the operator has some control. Each pound of dry fuel theoretically requires about 6 pounds of air to burn completely to carbon dioxide and water vapor. Air admitted to the burner in addition to that theoretically necessary for combustion has been defined previously as *excess air*. Excess air can be related to the amount of carbon dioxide in exhaust gases. Figure 38 shows this relation for Douglas fir fuel (analysis as in Table 1) when the fuel is burned completely.

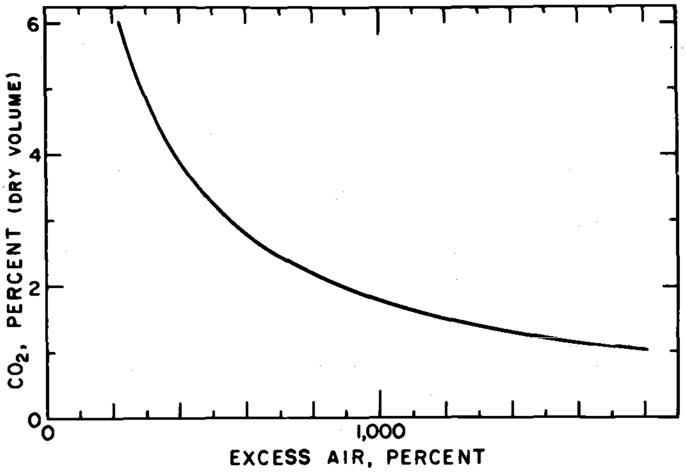

Figure 38. Carbon dioxide and exit gas related to excess air for Douglas fir fuel in the test burner.

Figure 39 shows how dilution of combustion gases with excess air acts to cool the burner and reduce exit-gas temperature. Because heat is needed to raise the temperature of excess air, and because combustion efficiency is otherwise reduced, low gas temperatures result with high amounts of excess air. Average exit-gas temperatures of over 700 F were generally realized only when excess air was less than about 400 percent.

Underfire Air

Underfire air in these tests varied from about 12 percent to 70 percent of theoretical air. When rate of underfire air was high, fuel was partially blown from the grates in a volcano-like effect. At low flows of underfire air, excessive slag and clinker formed on the grates. The rate of underfire air that gave best overall burning conditions was from 20 percent to 30 percent of theoretical air.

A change in the rate of underfire air caused an immediate change in the rate of burning fuel. If the underfire air was increased or decreased, a corresponding change in the burning rate resulted. When a change was made in underfire air, the fuel pile's size tended to change until the rate of burning equaled the rate of fuel feed and equilibrium was again established.

Overfire Air

Decrease in exit-gas temperature as a function of increasing rate of overfire air is shown in Figure 40. In most tests, the rate of overfire air was between 100 percent and 200 percent of the amount of theoretical air.

Burning results were compared at three different velocities of air from the overfire air nozzles. The three velocities were the result of pressure drops of about 0.2, 1.2, and 3.2 inches of water measured across the overfire air nozzles. There was no apparent difference in burning results with pressure drops of 1.2 and 3.2 inches of water. Both of these higher velocities resulted in a strong, circular motion of the gases in the burner and slight smoke and particulates. In the test with atmospheric pressure ahead of the overfire air nozzles (pressure drop of 0.2 inch of water, which could have been obtained without fans), there was much less observable circular turbulence in the combustion zone and volume of particulate emissions was about three times greater than for the other two tests.

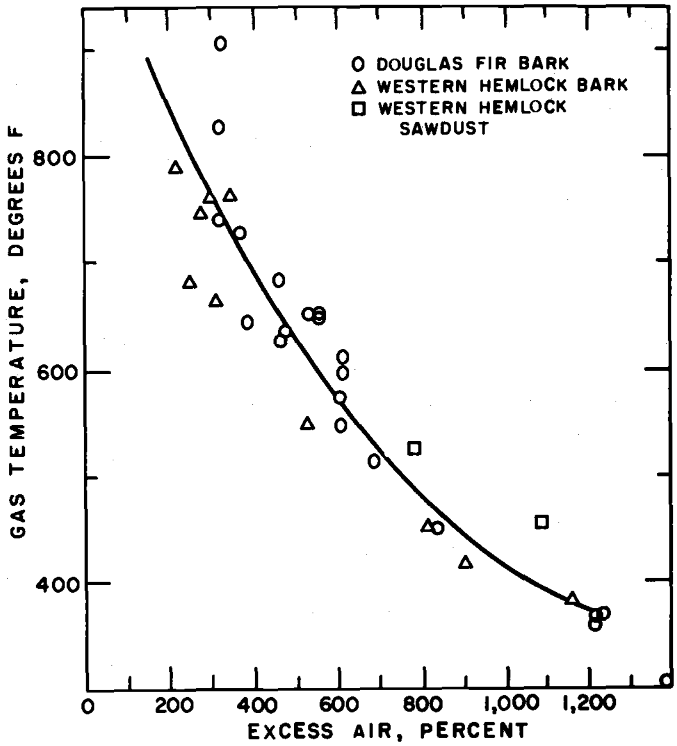

Figure 39. Effect of excess air on average temperature of exit gases.

To minimize particulate emissions, conditions in the burner must be such that ash and combustibles in the fuel are not carried out with exhaust gases. A strong circular motion of gases helps to retain ash and deposit it near the periphery of the burner as well as provide conditions for burning more of the combustible portion of the airborne particulates.

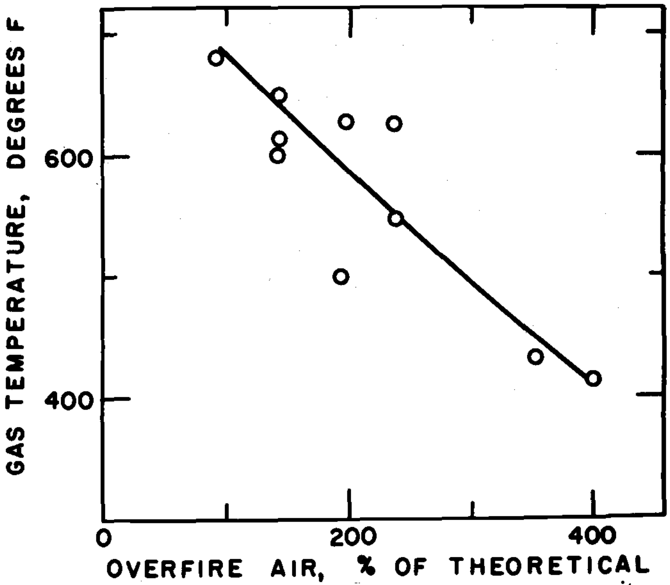

Figure 40. Relation of overfire air to average exit-gas temperature when fuel rate was 2.4 dry tons per hour in the test burner.

Fuel Moisture

Most test runs were conducted with hogged Douglas fir or western hemlock bark with moisture contents, as it came from the mills, of from 40 to 50 percent (67 to 100 percent, dry basis). Two test runs were made (tests 35 and 36) in which water was added to the fuel to increase moisture content to 59 percent (144 percent, dry basis). In test 36 with this wet fuel it was possible, by restricting excess air, to attain an exit-gas temperature of 791 F with resulting low smoke opacity and particulate emission. A comparison of heat balances (Figure 41) for test 36 with test 34 where the fuel was at 40 percent moisture content (67 percent, dry basis) shows the greater heat required for evaporating fuel moisture in the test with high-moisture fuel. This added heat was available mainly by a reduction of excess air.

Two test runs (17 and 18) were conducted with western hemlock sawdust at a moisture content of 66 percent (194 percent, dry basis). This high-moisture material was difficult to burn, and even though auxiliary gas fuel was burned at the rate of 18 million Btu per hour during these tests, particulate and gaseous emissions were among the highest of any tests. Tests with this high-moisture fuel were limited, however, and better burning might have been obtained with other conditions. For example, a reduction in overfire air probably would have improved conditions, but time limitations restricted further tests.

Auxiliary Gas Fuel for Starting

The overfire gas burners were effective in igniting the fuel pile and in reducing smoke when starting. Smoke was generally of an opacity less than Ringelmann No. 2 during the starting period by the use of auxiliary fuel.

The underfire gas burner was used for several starting periods. When the underfire gas burner was used, from two million to three million Btu of gas were used to get a fire started, but heavy smoke resulted. The use of an underfire gas burner is, therefore, not recommended. The overfire gas burners provided an "after-burner" effect that nearly eliminated smoke when starting. The heat provided by overfire gas burners for starting ranged from 5 million to 17 million Btu, with an average of about 10 million Btu per day. When dry fuel, such as dry planer shavings, was added to the fuel, starting time was shortened and quantity of gas was reduced. With gas cost at $0.045 per therm (interruptible), the cost for ten million Btu is $4.50. If the cost of gas is $0.10 per therm, ten million Btu's would cost $10.00.

Another advantage in using auxiliary gas fuel for starting compared to the customary method of manually building a bonfire is that the bonfire requires labor to build the fire before the mill begins operation. If gas burners are used, it is not necessary to have an attendant at the burner before fuel enters.

Table 8. Estimated Cost of Fans, Grates, and Gas Burners for a 40-foot Burner.[1]

Item	Cost
	$
Underfire air-supply system	4,300
Overfire air-supply system	4,200
Gas burner installation	2,800

[1]From Appendix F .

Recirculation of Gases with Overfire Air

The test burner had provision for withdrawing hot gases from inside the burner and mixing them with fresh overfire air. Limited observations on the test burner did not show improvement of combustion through recirculation of hot gases. We emphasize, however, that this was only an observation and time did not permit tests to evaluate effectiveness of the recirculation system. We assume that recirculation will improve combustion in many instances, but tests are needed to evaluate and verify this assumption.

Top Damper

All of the tests previously described were conducted without a damper at the top of the burner. A damper at the top of the burner was subsequently installed, as shown in Appendix D.

A few preliminary tests were made with the top damper that indicated higher exhaust temperatures could be obtained by its use. For example, when the fuel rate was about one unit per hour and about 200 percent of theoretical air was supplied by the fans, an exhaust temperature of 550 F was obtained with the top damper open. When the top damper was nearly closed and the fuel and air supplied were unchanged, the resulting exhaust temperature was over 900 F.

A top damper tends to increase the pressure or reduce the draft in a burner. There would, therefore, be less draft to obtain desirable high tangential velocities if natural draft were used for overfire air on a burner with a top damper. Because of reduced draft, a top damper would be more applicable for a burner using forced-draft overfire air than for one with natural-draft overfire air.

When a top damper is used, there is positive pressure at the top of the burner. A hinged baffle, or other system, is required at the fuel-conveyor inlet to minimize gases from the burner passing through the fuel-conveyor inlet.

COST FACTORS

Air Supply System and Gas Burners

Because underfire and overfire fans seem advisable and necessary for efficient operation of a wigwam burner and auxiliary fuel offers advantages in operation, the costs of these three modifications have been computed in Appendix F and are summarized in Table 8. The equipment is of sufficient capacity for a 40-foot burner with a fuel capacity of three units of bark per hour. The underfire air system consists of a single fan discharging air beneath the fuel pile through twenty grate boxes. The overfire system consists of four fans with nozzles as necessary to create overfire turbulence. Three natural-gas

Table 9. Cost of Disposal of Bark Waste in a 40-foot Wigwam Burner.[1]

Type of burner	Cost per unit
	$
Conventional burner with natural draft and underfire air system as in Table 8	1.45
Underfire and overfire fans plus gas burners	2.30

[1]From Appendix F.

burners are provided that have a combined rated heat output of about 10 million Btu per hour at 5 psi gas pressure.

Disposal Cost in Wigwam Burners

A cost analysis for disposal of wood waste in a wigwam burner also has been made in Appendix F. The analysis is based on a burning rate of 2½ units per hour, which is equivalent to the amount of bark produced by a sawmill cutting 100 M fbm of lumber in an 8-hour shift. A summary of the calculated costs of disposal is shown in Table 9. The disposal costs are for but one set of conditions. Variations in the assumptions on which the costs are based result in different costs for disposal. For example, disposal of greater quantities of waste or operation of the mill for more than one shift per day would have resulted in lower costs for disposal by all methods. Costs outlined in Appendix F do not include provision for fuel storage and fuel-feed regulation, but these may not be required if the mill operation gives a fairly constant supply of fuel.

DISCUSSION OF WIGWAM BURNER DESIGN

Additional tests of wigwam burners should be made before broadly applicable criteria for burner design can be developed. Tests to date, however, have indicated results that can be attained in a modified burner incinerating Douglas fir and western hemlock bark. Therefore, we have applied knowledge gained in these tests and experience from other phases of the study in developing a step-by-step example of wigwam burner design in Appendix G. In the design example, it was necessary to make certain judgments and assumptions. These judgments and the implications are discussed at appropriate places in the text.

The design method presented is not recommended as the only workable design. It is based on the only design we have tested. Other modifications may give results as good as those attained with the test burner. Additional tests of wigwam burners will provide a basis for modifying and improving the design method.

CONCLUSIONS

We concluded from the tests that wigwam burners can be made to operate with particulate emissions of 0.2 grain or less (corrected) and smoke opacity of Ringelmann No. 1 or less when burning bark fuels containing up to 60 percent moisture (150 percent, dry basis), provided the wigwam burner:

1. has a fairly "tight" shell to give minimum air leakage;

2. has an underfire air-supply system of adequate capacity that is properly controlled;

3. has overfire air fans suitably adjusted for air rate and arranged to result in a cyclonic, turbulent motion of gases in the combustion zone;

4. is equipped with auxiliary gas burners to reduce emissions at starting; and

5. has a fuel rate that is consistent with burner size.

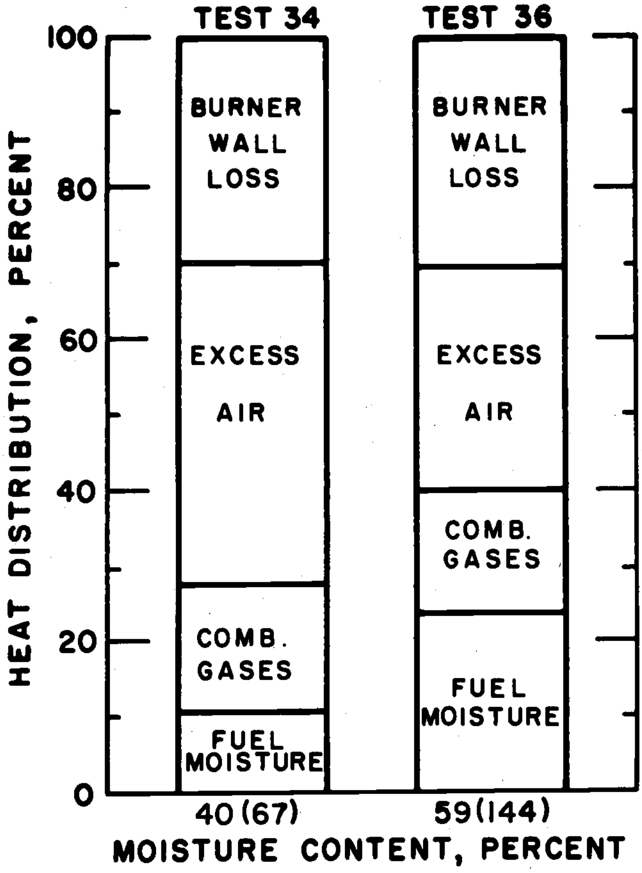

Figure 41. Heat balance with fuel at 40 percent moisture (67 percent, dry basis) and with fuel at 59 percent moisture (144 percent, dry basis). In test 36 with wet fuel, restricting the excess air allowed the extra moisture to be evaporated while maintaining the exit-gas temperature at 791 F.

We further concluded that combustion can be improved by use of a top damper, especially for low fuel rates and high-moisture fuels.

Temperature

Operation of a wigwam burner with exit-gas temperatures in the range from 700 F to 900 F results in minimum emissions of particulate, smoke, and gaseous air pollutants. When exit-gas temperatures were from 700 F to 900 F, smoke opacity was less than Ringelmann No. 1 and particulate emissions were generally less than 0.2 grain per cubic foot of gas (corrected). These low emissions comply with present air-pollution regulations for existing installations in Oregon.

Fuel and Air Rate

A certain minimum fuel rate was necessary to insure sufficiently high (700 F) gas temperatures. When fuel rates were greater than above minimums, it was possible to achieve high gas temperatures by controlling air rates. Automatic control of air rate, modulated by gas temperature, would reduce supervision needed to maintain best burning conditions. Such automatic controls have been installed and successfully used on wigwam burners.

Forced overfire air gave a turbulent cyclonic effect in the burner. Added cost for forced overfire air would be reasonable, in view of the potential benefit of such a system.

Air Leakage

Even though the test burner was in good condition with a moderately tight skin, much air leaked into the burner. This leakage prevented attainment of high temperatures when fuel rates were low. We concluded that a damper at the top of the burner reduces air leakage. Such dampers have been installed and found effective on some operating burners.

Fuel Moisture

Western hemlock bark with a moisture content of 59 percent (144 percent, dry basis) could be burned satisfactorily, but western hemlock sawdust with 66 percent (195 percent, dry basis) moisture could not be burned satisfactorily without supplemental fuel. Even with supplemental fuel, emissions of air pollutants were high when burning the high-moisture western hemlock sawdust. No doubt, burning of this fuel also could be improved by means of a damper to restrict leakage of excess air into the burner.

Auxiliary Fuel

Natural gas burners were effective in reducing smoke at starting and in simplifying starting procedures. Costs for gas burners are reasonable.

Gas Cleaners

It is more economical to reduce particulate emissions from burners by improving combustion conditions than it would be to install, operate, and maintain equipment for removing particulates.

RECOMMENDATIONS

Burner Construction and Equipment

1. A burner should be of proper size to accommodate the necessary fuel rate. If the burner is too large, high temperatures will be difficult to maintain. If the burner is too small, it will tend to overheat and require excessive maintenance.

2. A burner should have all openings and cracks eliminated as much as practical to reduce air leakage.

3. A burner should have an adequate underfire air-supply system capable of supplying thirty percent of the amount of air theoretically needed for combustion. (One manufacturer stated that the underfire air system should be able to supply at least 60 percent of theoretical air with high-moisture fuels.) There should be provision to regulate the amount of underfire air supplied. Different types of grates have given satisfactory results.

4. The overfire air-supply system on a burner should be controllable and air should enter tangentially to the fuel pile to give a horizontal, cyclonic, turbulent action in the burner. Fans are recommended for overfire air to improve control and permit high velocities of entering air.

5. Automatic control of air rate modulated by exit-gas temperature is recommended to reduce supervision needed to maintain good burning conditions. A temperature recorder should be provided to furnish a continuous record of operating conditions.

6. Air flow indicators, such as orifices and manometers, should be installed on air-supply systems to facilitate control of air rates.

7. Installation of auxiliary gas burners is recommended to minimize smoke and simplify procedures during starting and to assist in burning high-moisture fuels.

Burner Operation

1. To have optimum operation of a burner, management *must* take a continuing interest and supervisory role in the burner operation to insure that effective operational procedures are followed.

2. Operate the burner so exit-gas temperatures are from 700 F to 900 F, which will minimize emission of air pollutants.

3. Control air supply to the burner to attain above temperatures.

Further Study

There are unanswered questions on wigwam burner operation. To help answer some of these questions, we make the following recommendations for further study:

1. Other fuels should be tested, particularly high-moisture fuels that are difficult to burn. Fuels suggested for further tests are, a, cedar bark and wood wastes; b, a mixture of sugar pine or western hemlock sawdust and bark; and c, western hemlock bark as it comes from a debarker without being hogged.

2. The operation of the burner should be evaluated with intermittent fuel rates that are typical of actual mill conditions.

3. The damper at the top of the burner should be further evaluated for effectiveness in reducing air leakage and obtaining high temperatures at low fuel rates.

4. Effectiveness of regulating air supply with automatic controls should be evaluated.

5. Other types of grates should also be tried and compared with the flat grates used to date.

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APPENDIX A

CONTROL OF
WIGWAM BURNER COMBUSTION

REGISTERED PROFESSIONAL ENGINEER
3173
OREGON
MAY 11, 1951
RALPH W. MARTIN, JR.

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Corvallis, Oregon

August, 1968

SUMMARY

Preliminary field tests made by the Oregon State University Mechanical Experimentation Department on a burner in Benton County indicated that better conbustion control on any given burner, which is in good repair, can be obtained by careful control of the overfire air flow rate.

This report offers various equipment arrangements which can improve burner combustion and recommends a minimum amount of control equipment which would give the burner operator a better system of combustion control.

Estimated costs for the minimum combustion control equipment system would be $5,000.00 for a 40-foot burner and $7,000.00 for a 65-foot burner.

INTRODUCTION

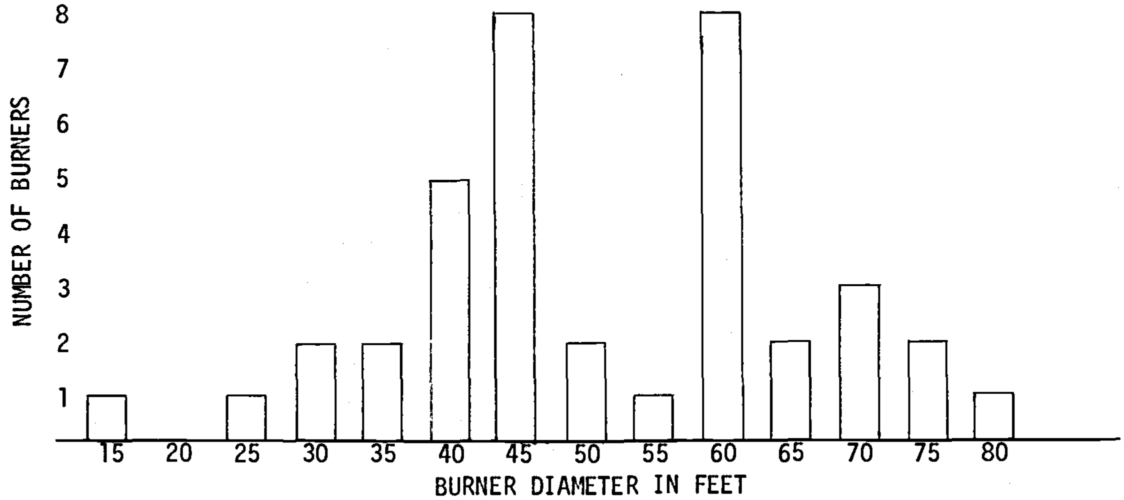
The purpose of this report is to outline some methods of improving fuel combustion within wigwam burners. The addition of automatic control equipment, hogging and drying of mill residue, preheating of combustion air and addition of a dutch oven furnace are the possible improvements considered in this report.

This report includes preliminary sketches, layouts and construction cost estimates for each of the methods considered.

THE TYPICAL WASTE BURNER

Information obtained by the Oregon State School of Forestry personnel at Corvallis, Oregon, on thirty-eight (38) burners in the Benton and Lane County areas provided information for Figure 1 showing the burner size distribution in these areas.

FIGURE 1

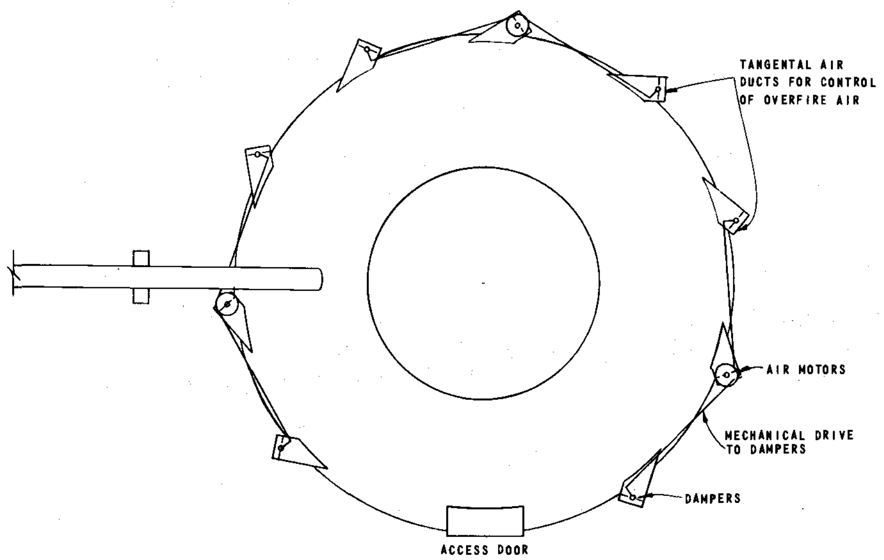


In order to limit the number of burners considered, it was agreed with the School of Forestry that the study would include two typical sizes of burners, those being burners with 40-foot and 65-foot base diameters.

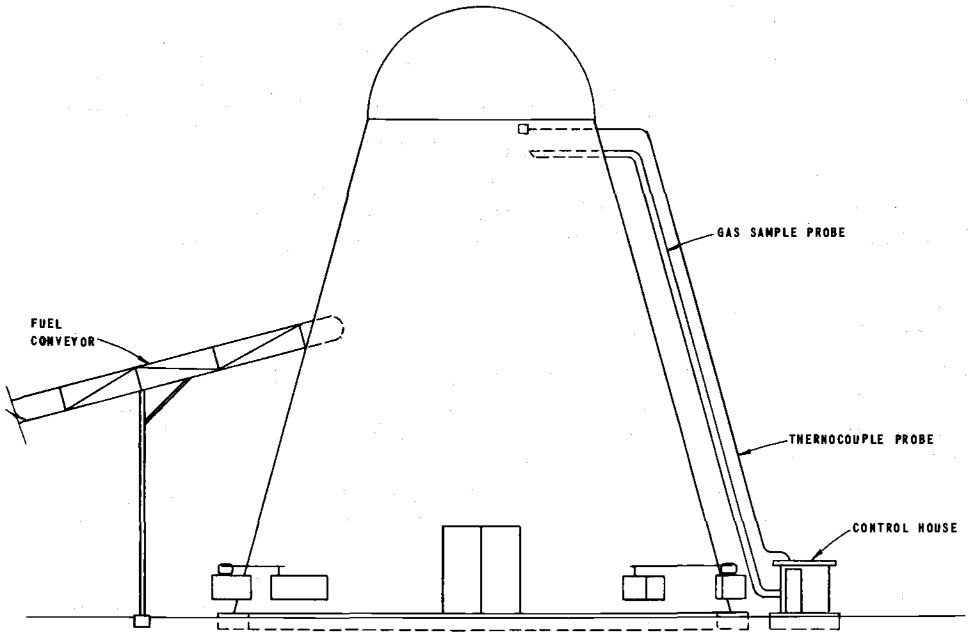
AUTOMATIC COMBUSTION CONTROL SYSTEM

In order to obtain complete combustion of any fuel it is necessary to provide a system which will cause an intimate mixing of the fuel with the oxidizing atmosphere (air) in proper amounts at proper temperatures for a sufficient amount of time to complete the combustion reaction. This can only be done by burning the fuel in a closed space of adequate size at temperatures above 1000 degrees F. and using controlled air to fuel ratios.

In considering combustion control for the wigwam burner, it is important to first consider the installation of an automatic device for controlling the rate of air flow into the burner to maintain a low total air input, consistant with the maximum desired combustion temperature. Figure 2 shows a schematic diagram of a somewhat inexpensive system for accomplishing control of air flow rate. Air flow control is accomplished by a temperature sensing device (thermocouple) which activates a recorder-controller instrument. The controller in turn activates the duct damper drive motors to open or close them depending on the temperature set point in the controller.



PLAN VIEW



ELEVATION VIEW

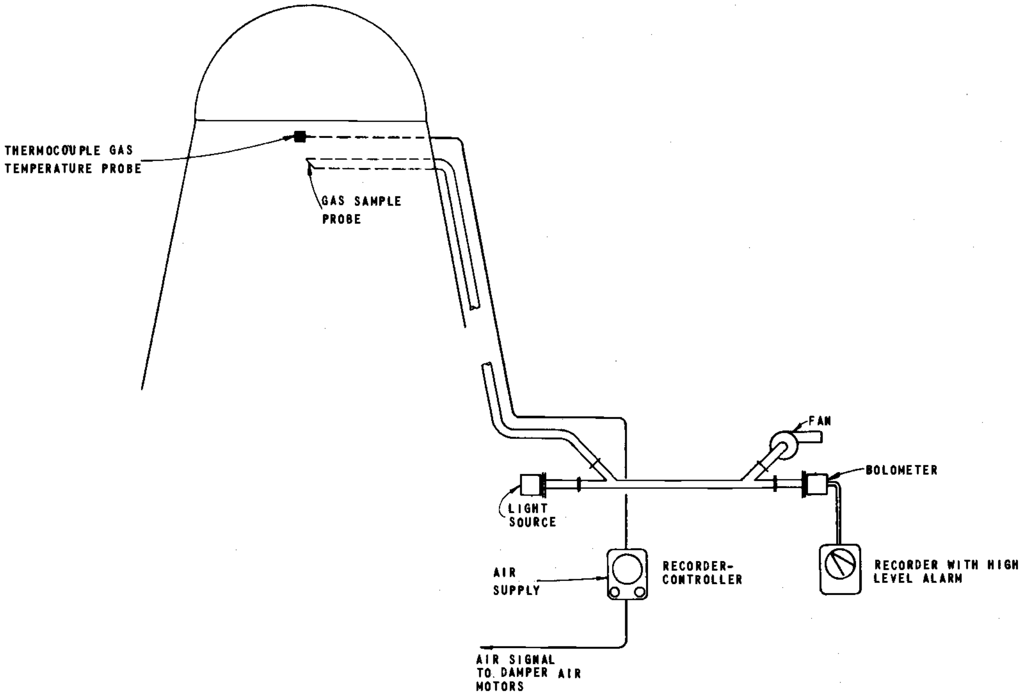


FIG. 2

WIGWAM BURNER
COMBUSTION CONTROL SCHEMATIC

CONTROL INSTRUMENTION SYSTEM

The cost of such a system for a wigwam waste burner would be:

Item	Burner Diameter 40 Ft.	Burner Diameter 65 Ft.
1. Primary Sensing Element	$ 200.00	$ 200.00
2. Electrical Hookup	600.00	600.00
3. Recorder - Controller	700.00	700.00
4. Air Compressor	400.00	400.00
5. Damper Control Motors	500.00	1,800.00
6. Dampers, Ducts, Tangential Inlets	1,700.00	1,900.00
Subtotal	$4,100.00	$5,600.00
Contingencies (Add 25%)	1,000.00	1,400.00
TOTAL	$5,000.00	$7,000.00

SMOKE DENSITY MEASUREMENT

From a legal position it may be desirable to substantiate wigwam burner performance by keeping accurate data on the actual emissions from a burner. As such, it would be necessary to continuously measure and record the smoke density of the gases being discharged. This measurement could be accomplished using a system as shown on Figure 2, where a sample of the burner emission gas is brought out of the top of the burner and down to the Bolometer. The Bolometer is a sensing device which measures the opacity value of the emission gases. This value is then plotted on a recorder chart as a Ringelman number.

An alarm can be included in the device to warn of smoke conditions. The costs for such a system for 40-foot and 65-foot diameter burners would be:

1. Stack Sample Piping	$ 400.00
2. Sampling Fan and Motor	300.00
3. Bolometer and Recorder	1,000.00
4. Electrical, Install	1,100.00
Subtotal	$2,800.00
Contingencies (Add 25%)	700.00
TOTAL	$3,500.00

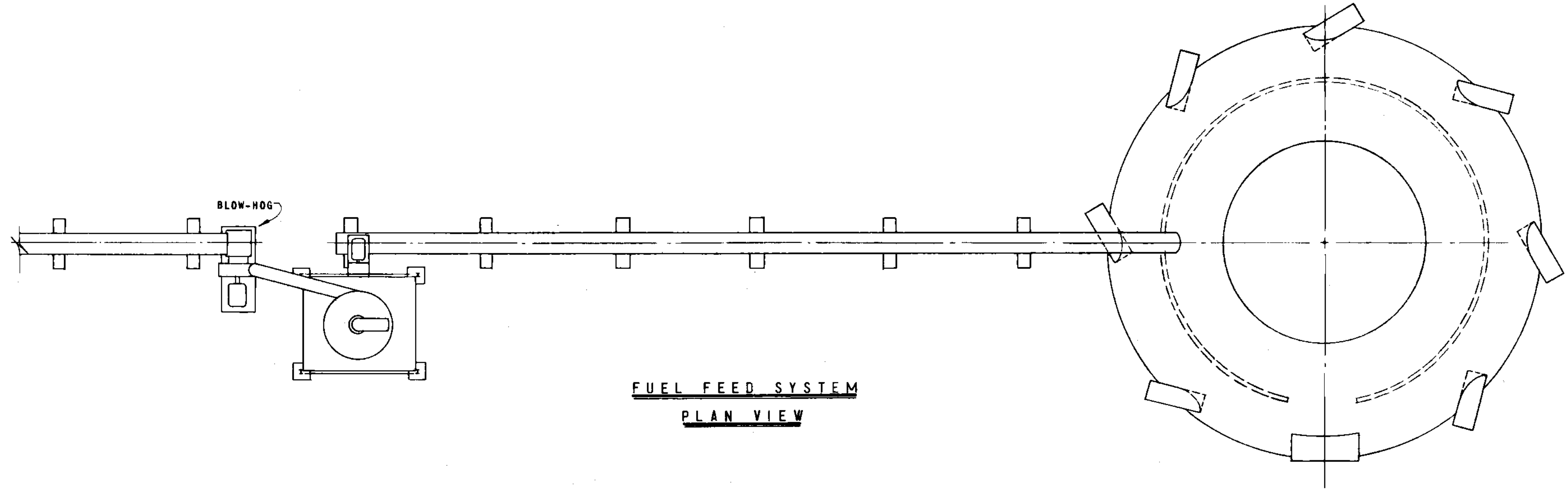
IMPROVEMENT IN WASTE FUEL PREPARATION

Fuel Sizing. Another method for improving wigwam burner combustion would be to supply the wood waste to the burner as a relatively homogeneous hogged fuel mixture. This, of course, would require the installation and maintenance of a hog to size all of the wood waste. In addition, it would also be desirable to even out the fuel feed rate to the burner to maintain a uniform fuel pile size inside the burner. The latter could be accomplished by the installation of a hogged fuel storage bin. Figure 3 shows a system for waste burner fuel sizing and storage. The costs for such a system would be:

	Burner Diameter	
	40 Ft.	65 Ft.
Blow-Hog Machine and Motor	$10,500.00	$12,300.00
Conveyors	5,000.00	5,700.00
Electrical	3,600.00	5,200.00
Foundations	1,100.00	1,300.00
Cyclone and Ductwork	1,100.00	4,000.00
Storage Bin	4,400.00	4,400.00
Subtotal	$25,700.00	$32,900.00
Contingencies (Add 25%)	6,400.00	8,200.00
TOTAL	$32,100.00	$41,100.00

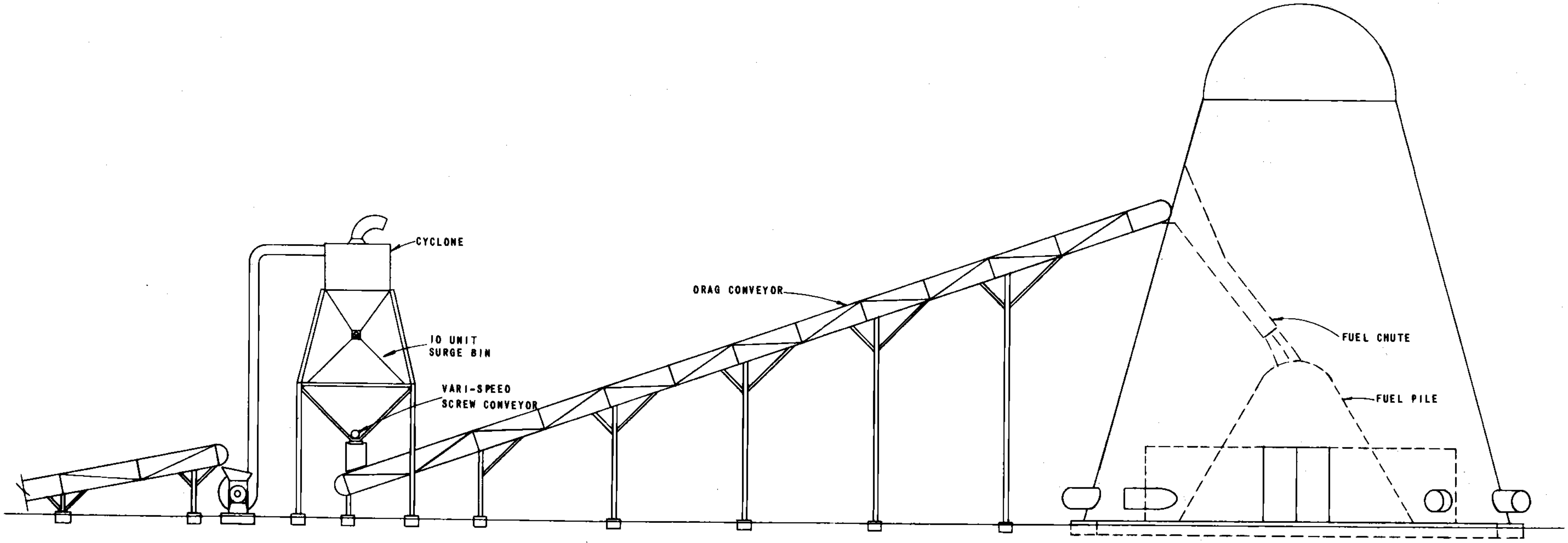
Fuel Drying. In the cases where waste fuel has a moisture content above 50 percent, such as that which occurs when burning Hemlock, Bull pine, or wet Douglas fir, drying the fuel prior to putting it in the burner would substantially improve the combustion. Figure 4 shows a fuel drying system which could be used for this purpose. Effective fuel drying can be accomplished only if the fuel surface area to weight ratio is increased. As shown in Figure 4, sizing and surge control would be accomplished with a hog and a storage bin. The costs for such a system would be:

	Burner Diameter	
	40 Ft.	65 Ft.
Hog and Motor	$ 9,000.00	$10,800.00
Conveyors	6,800.00	8,100.00
Electrical	4,700.00	7,000.00
Foundations	1,100.00	1,300.00
Storage Bin	4,400.00	4,400.00
Cyclone, Ductwork, Rotary Dryer	25,000.00	53,700.00
Subtotal	$51,000.00	$85,300.00
Contingencies (Add 25%)	12,800.00	21,300.00
TOTAL	$63,800.00	$106,600.00



FUEL FEED SYSTEM

PLAN VIEW

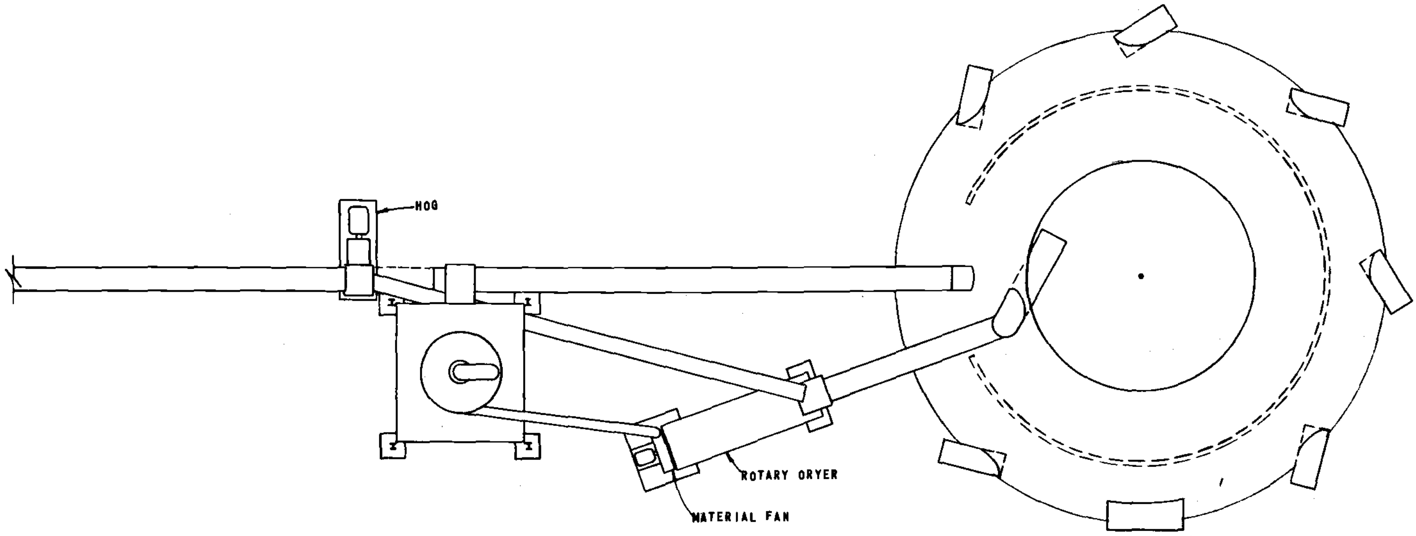


FUEL FEED SYSTEM

ELEVATION VIEW

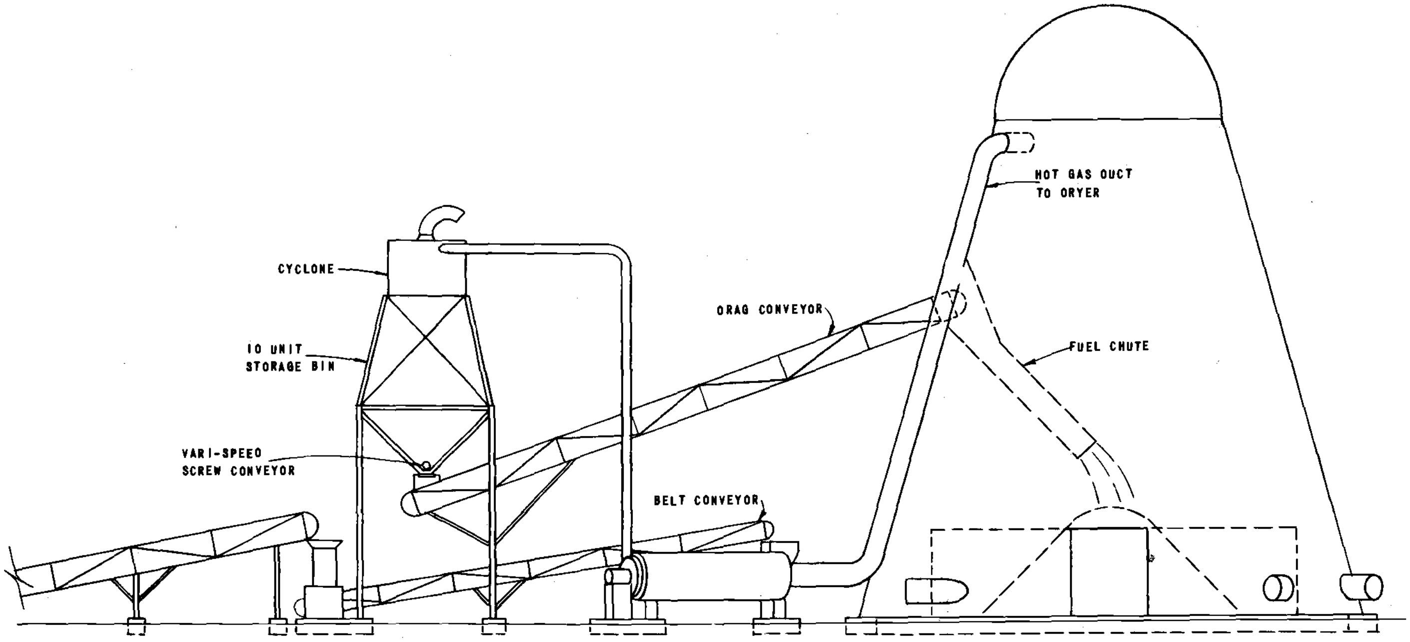
FIG. 3

FUEL FEED SYSTEM



FUEL FEED AND DRYER SYSTEM

PLAN VIEW



ELEVATION VIEW

FIG. 4

FUEL FEED & DRYER SYSTEM

AIR PREHEATING

Wigwam waste burners presently provide relatively poor combustion conditions when supplied with particularly high moisture content fuels and also when first fired up in the morning from cold conditions. The burners are normally supplied with low temperature (ambient) air for both their primary (underfire) and their secondary (overfire) air. Preheating of this air up to 400 degrees F. would materially improve the combustion and thereby reduce smoke and cinder emissions. This would be very beneficial especially during startup conditions.

Air preheating could be accomplished by either of two methods. These are:

1. The use of interruptable natural gas or oil-fired preheating.

2. Recirculation of a portion of the wigwam burner emission gases either directly to the air supply or to a gas to air heat exchanger system for preheating the air.

However, for startup conditions preheating with gas or oil-fired preheating would be the only practical method. The recirculation method would shorten the startup period, but would not be as effective as the direct fired preheating method.

Since either system will permit controlled operation of the waste burner at temperatures in the order of 800 degrees F. to 1000 degrees F., the systems should be designed to provide up to 400 degrees F. of preheating for air quantities of sufficient volume to cool the emitted gases to 800 degrees F.

Preheating would be required for the following air volumes:

Burner Size	Air Volume scfm	Air Wt. lbs/hr.	Heat to Raise Temp. (40° F. to 400° F.)
40 feet	19,000 cfm	85,000 lbs/hr.	7,350,000 Btu/hr.
65 feet	83,500 cfm	375,000 lbs/hr.	32,500,000 Btu/hr.

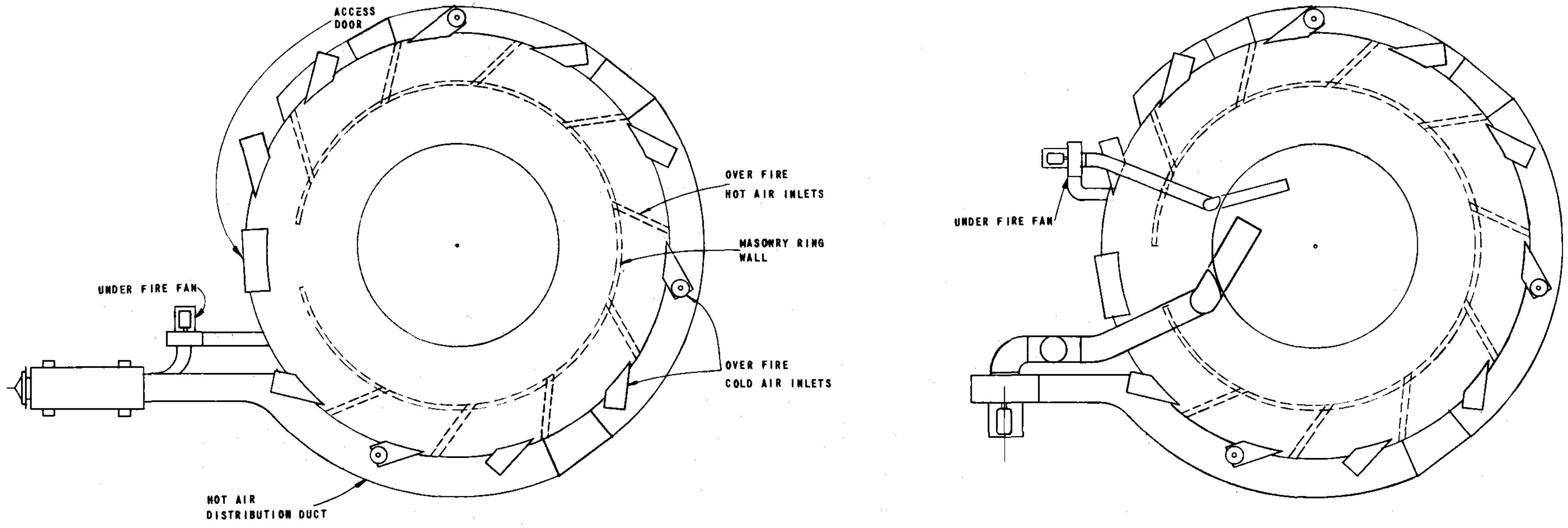
Assuming that interruptable natural gas would be available at approximately $0.04 per therm, the costs for preheating from 40 degrees F. to 400 degrees F. would be:

Burner Size	Btu/Hour	Fuel Cost/Hour
40 Foot	7,350,000	$ 2.94
65 Foot	32,500,000	$13.00

Figure 5 shows an installation which could be used to accomplish the required preheating.

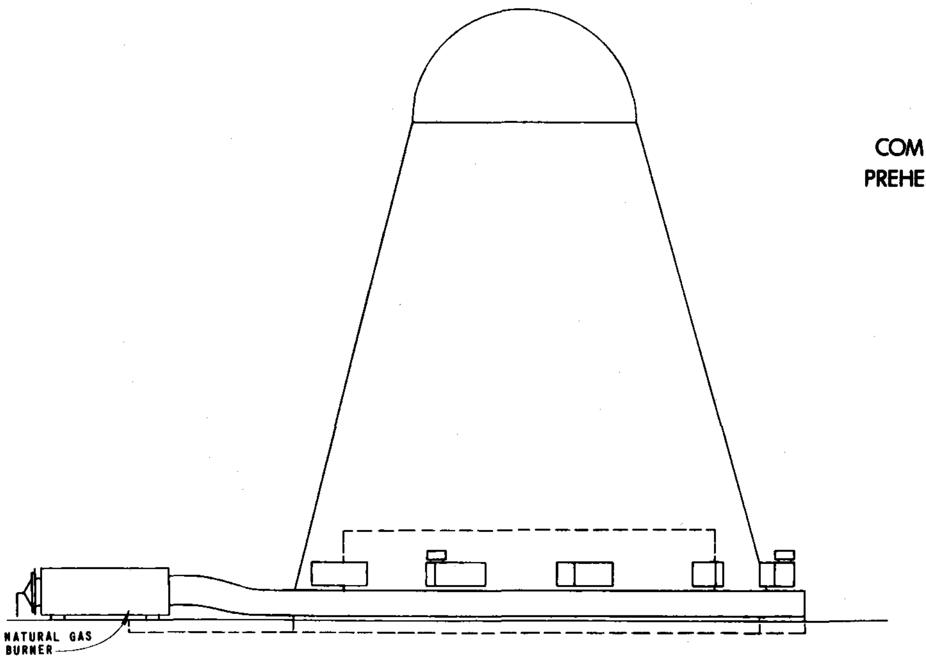
The costs of installing natural gas preheating equipment for primary and secondary (underfire and overfire) air would be:

	Burner Diameter	
	40 Ft.	65 Ft.
Natural Gas Burner and Combustion Chamber	$ 9,500.00	$13,000.00
Ductwork	1,300.00	5,500.00
Foundations	200.00	300.00
Electrical	900.00	1,100.00
Primary Air Fan	600.00	1,500.00
Subtotal	$12,500.00	$21,400.00
Contingencies (Add 25%)	3,100.00	5,300.00
TOTAL	$15,600.00	$26,700.00



PLAN VIEW
PREHEATED AIR SYSTEM

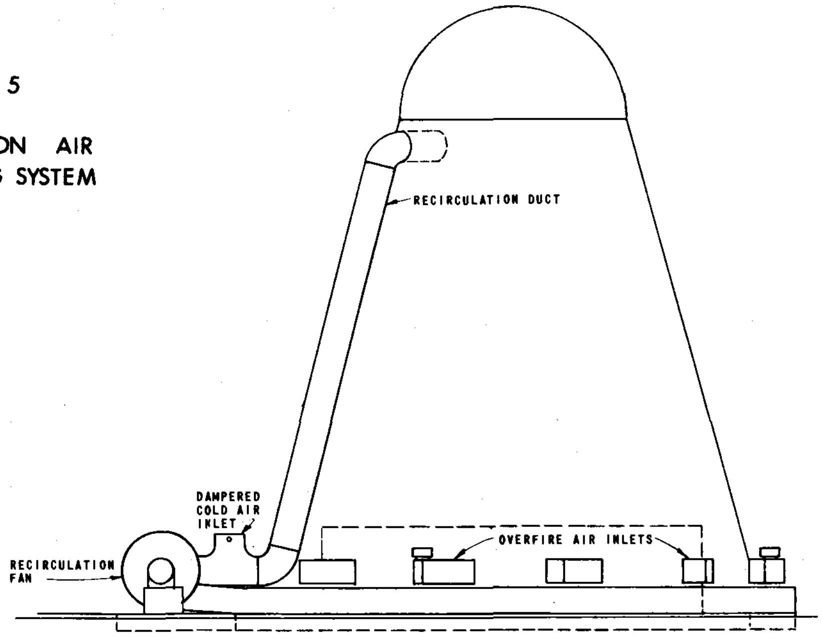
PLAN VIEW
RECIRCULATED HOT AIR SYSTEM



ELEVATION VIEW

FIG. 5

COMBUSTION AIR
PREHEATING SYSTEM



ELEVATION VIEW

The costs of recirculating air to heat primary and secondary air would be:

	Burner Diameter	
	40 Ft.	65 Ft.
Primary Air Fan	$ 600.00	$ 1,500.00
Secondary Air Fan	1,350.00	3,100.00
Blending Air Damper	250.00	350.00
Temperature Controls	1,200.00	1,400.00
Ductwork	2,100.00	9,550.00
Electrical	2,100.00	2,700.00
Foundations	100.00	150.00
Subtotal	$7,700.00	$18,750.00
Contingencies (Add 25%)	1,900.00	4,700.00
TOTAL	$9,600.00	$23,450.00

Figure 5 shows the arrangement of ducts, heaters, and fans to accomplish the heating. The circular masonry wall would improve combustion for two reasons:

1. The cold overfire air would not be directed toward the fuel pile. Instead, it would be admitted between the masonry wall and the burner. This would allow combustion of the fuel pile at higher temperatures since the overfire air would not impinge in the fuel pile causing a cooling effect.

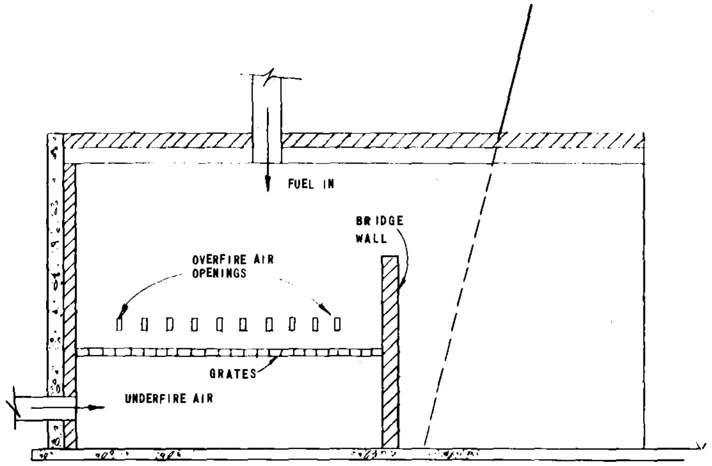
2. Radiant heat would be reflected back toward the fuel pile by the masonry wall. Together with the introduction of heating air to the inner chamber, combustion could be improved with the increased temperatures. The cost of such a wall would be:

	Burner Diameter	
	40 Ft.	65 Ft.
Masonry (8" Block)	$ 900.00	$1,800.00
Foundations	500.00	1,100.00
Subtotal	$1,400.00	$2,900.00
Contingencies (Add 25%)	350.00	700.00
TOTAL	$1,750.00	$3,600.00

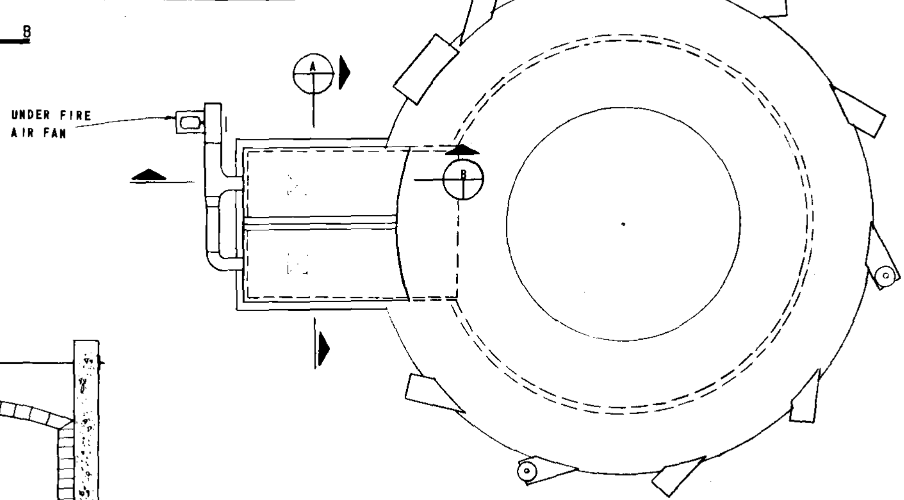
DUTCH OVEN

The addition of a dutch oven, as shown on Figure 6, would greatly improve combustion. A more complete incineration of the fuel in a smaller chamber at higher temperatures would be made possible by reflected radiant heat and by closely controlling secondary (overfire) air. However, a wigwam burner is not too suitable as a secondary combustion chamber. In addition, firebrick replacement and grate cleaning for the dutch oven would be high in maintenance costs. The addition of a dutch oven would cost:

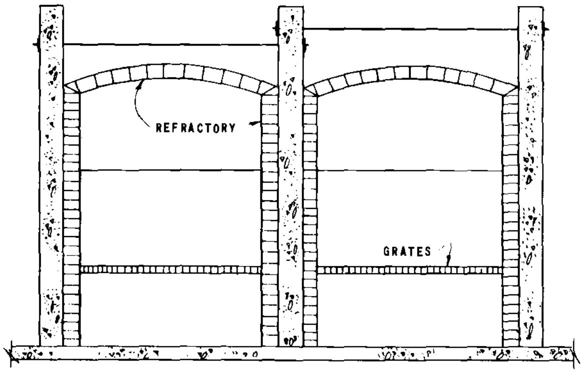
	Burner Diameter	
	40 Ft.	65 Ft.
Brickwork	$ 5,000.00	$10,100.00
Grates	2,500.00	5,000.00
Concrete and Foundations	4,000.00	6,800.00
Electrical	1,000.00	1,800.00
F.D. Fan System	2,400.00	5,000.00
Subtotal	$14,900.00	$28,700.00
Contingencies (Add 25%)	3,700.00	7,200.00
TOTAL	$18,600.00	$35,900.00



SECTION B



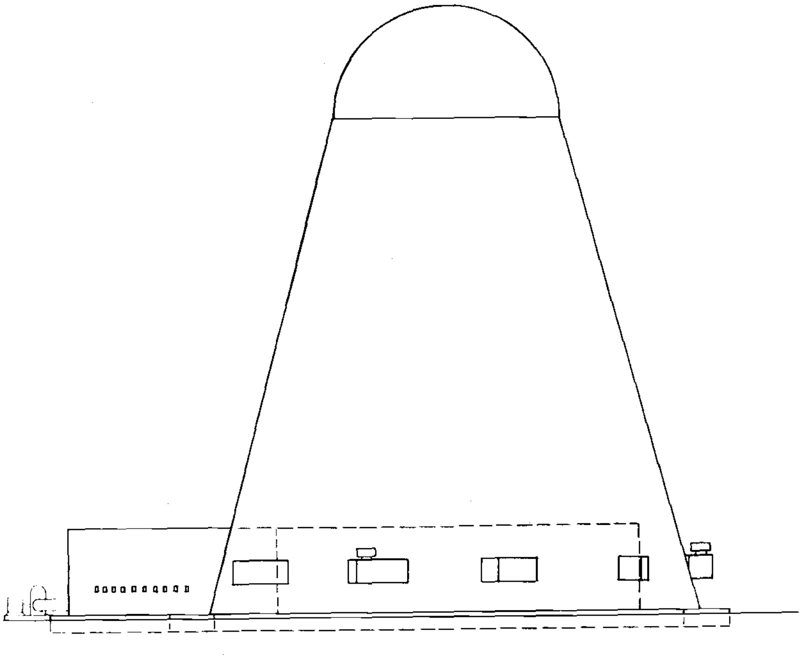
PLAN VIEW
DUTCH OVEN AND WIGWAM BURNER



SECTION A

FIG. 6

DUTCH OVEN ARRANGEMENT



ELEVATION VIEW

CONCLUSIONS

1. Previous tests on wigwam burners and accepted principles for obtaining good combustion show that controlling of the overfire air input to maintain gas temperatures at the burners exit of 800° F. to 1000° F. will improve combustion and reduce smoke and cinder emissions without destruction of the burner structure.

2. Presently on most existing wigwam waste burners, an attempt is made to manually control overfire air and exit temperature. The addition of automatic overfire air damper controls would relieve a man of routine overfire damper adjustments, would provide better temperature regulation than can be obtained manually, and, thus, would provide protection against either too high or too low burner temperatures.

3. Combustion in wigwam burners could be improved further by uniform fuel sizing, continuous uniform fuel feeding to the burner, and in some instances by predrying of the waste fuel. The magnitude of the combustion improvements which could be accomplished by these methods, as evidenced by a reduction in smoke and cinder emissions, can only be determined by experiments.

4. Similarly, the practicality of air preheating, reflective refractory walls, and the use of precombustion chambers (dutch ovens) which would all improve combustion could only be evaluated by field testing.

5. It is logical that the search for and testing of methods for the improvement of wigwam waste burners be performed by an industry-wide agency such as the Forest Research Laboratory of the Oregon State University School of Forestry.

RECOMMENDATIONS

To initiate improved combustion performance from wigwam burners, it is recommended that:

1. Where needed, burners should be refurbished and made as leak-tight as possible.

2. An adequately sized underfire air system with a manually controlled damper be installed in those burners that have no underfire air system.

3. All burners be equipped with the minimum equipment shown on Figure 2 of this report. This equipment consists of:

   a. Thermocouple probe and recorder-controller

   b. Automatic dampers with drive motors

   c. Bolometer with recorder and smoke alarm.

4. A testing program be pursued to evaluate the improvements that can be made by the methods suggested in this report and any other logical means which may present itself in further review of this study.

The suggested order of testing listed in declining order of expected combustion improvements as evidenced by smoke and cinder emission is:

a. Resizing of waste fuel by hogging and controlled fuel feed rate.

b. Resizing of fuel and controlled feed rate combined with fuel drying.

c. Preheating of combustion air by using combustion gas or an auxiliary air heating system.

d. Installation of a precombustion chamber (dutch oven) and refractory walls.

APPENDIX B

MODIFICATIONS TO WIGWAM BURNERS RECOMMENDED BY CONSULTANTS

Copy of a letter of transmittal for a report by Garretson, Elmendorf, Klein, and Reibin; Architects and Engineers.

March 14, 1969

Oregon State University
Forest Research Laboratory
Corvallis, Oregon 97331

Attention: Mr. Stanley E. Corder
Project Director

Reference:	731-17
Contract:	Agreement of October 31, 1968
Project:	Feasibility Study, Incinerators (Other than Wigwam Burners) for Disposal of Wood and Bark Residues
Subject:	Letter Report on Improvement of Wigwam Burners

Gentlemen:

In accordance with paragraph seven of "Exhibit A" to our contract, we are submitting herewith our findings regarding improvement of wigwam burners.

Our investigation confirms the significance of several factors to the successful operation of a wigwam burner. In the most general terms, however, successful operation is dependent upon complete combustion of the waste wood fuel. Partial combustion results in air pollution. The products of complete combustion are largely carbon dioxide and water vapor, with small amounts of oxides of nitrogen and ash. Although the latter two items are both pollutants in the atmosphere, oxides of nitrogen are generated in insignificant quantities, and ash can largely be kept out of the gas stream by proper combustion chamber and gas flow design. Incomplete combustion results in a large number of particles of unburned carbon of fuel emanating from the burner and creating substantial amounts of pollution. It is also accompanied by emission of polluting gases, largely unburned hydrocarbons.

Incomplete combustion occurs when the thermal equilibrium between the heat release of the fuel and its absorption by the surrounding media is attained at a temperature inadequate for complete combustion. The heat released may be absorbed (1) by evaporating the moisture in the fuel, (2) by raising the temperature of the excess combustion air, or (3) by conduction through the wigwam shell and conduction or re-radiation to the atmosphere. Theory and experience have shown that with moderately dry fuel, combustion air can be regulated so that an equilibrium temperature for complete combustion can be established. Mills or industries with a preponderance of dry wood waste generally experience no great difficulty obtaining complete, pollution free combustion provided some attention is given to air regulation. Insufficient excess air may result in extreme temperatures damaging to the wigwam structure.

Too much excess air will reduce temperatures below the requirement for complete combustion, resulting in smoke. As the moisture content of the fuel is raised, air quantities must be correspondingly reduced in order to maintain the desired thermal equilibrium. At some fuel moisture content, the amount of air will approach the theoretical combustion air and it will no longer be practically possible to maintain combustion temperatures. The net effect will be incomplete combustion and air pollution.

Since this "smoking" moisture content is well within the range of many fuels, particularly bark, it follows that uniform and reliable air pollution control through the entire spectrum of fuel moisture content can only be obtained with some modifications of present wigwam burner methods and equipment. There are two general areas where we would like to recommend modifications: first, regarding control of combustion air, and second, relative to moisture in the fuel.

To provide better combustion air control, we recommend consideration of:

> A relatively tight steel skin on the wigwam, with air admitted only under controlled conditions.
>
> Provision of two separate air blowers, one for underfire air, primarily designed for combustion of fixed carbon, and an overfire air fan supplying the combustion air for volatiles plus the excess air required for temperature control. The underfire air fan should be designed and dampered to provide a range of from 0 to 50 percent or more of the theoretical combustion air which should be admitted through a ductwork system under the floor or from ducts in the pile, similar to the so called "Medford System". The overfire air should be furnished by a dampered fan providing from 0 to 200 or 300 percent of the theoretical combustion air, and admitted through adjustable nozzles on the periphery of the cone. The nozzles should have the capability of directing the air either towards the fire or in a tangential direction, and with a velocity causing it to mix with the volatiles. Experience would show the best nozzle setting for optimum combustion.
>
> Control of the overfire air fan should be provided by use of a thermocouple in the exhaust gas stream which could sound an alarm for manual operation of the dampers, or which could activate modulating dampers. The underfire air fan would require less adjustment and the damper could be set based on the experience and judgement of the attendant, or controlled by a thermocouple in the pile, similar to the overfire air damper.

Compensation for the excess moisture in the fuel should be investigated in two general ways: by utilization of the waste heat from combustion, or by consumption of supplementary fuel. It would appear that by proper use of the waste heat which typically goes for raising the fuel moisture to exit gas temperature, and of that which is conveyed to the atmosphere, sufficient fuel pre-drying could be obtained. This could be accomplished in one of several ways:

> Duct the exit gases, or a portion thereof, to a drum or kiln type dryer for the fuel.
>
> Add a stack and cyclone to the wigwam and introduce the fuel into the stack so that it passes through the stack gas in a counterflow direction. The airborne particles collected from the stack gas by the cyclone would be returned to the fuel pile.
>
> Another utilization of the waste heat would be to preheat the combustion air. This could be achieved by (1) drawing a portion of the combustion air directly from the top of the wigwam and mixing it with fresh air as required, (2) by taking in fresh air near the wigwam top into the space between a double shell and extracting near the bottom with the supply air fan(s), or (3) by withdrawing portions of the hot combustion gases with an exhaust fan and passing it through an air to air heater to pre-heat the combustion air, the heated air then being supplied to the burner by another fan.

Predrying of the fuel, or preheating of the combustion air could also be accomplished by use of auxiliary gas fuel, but at the additional operating expense of the gas. Also, supplementary fuel could fire an afterburner, or be introduced directly with the combustion air. This latter method would undoubtedly involve the least amount of construction expense, but would have to be compared with waste heat methods on the basis of the operating cost of supplementary fuel.

Very truly yours,

GARRETSON-ELMENDORF-KLEIN-REIBIN
ARCHITECTS-ENGINEERS

Bradley B. Garretson

BBG/shb

APPENDIX C

A REPORT ON
REMOVAL OF
PARTICULATE MATTER FROM
WIGWAM WASTE BURNER EMISSION

3173
MAY 11, 1951
RALPH W. MARTIN, JR.

Ralph W Martin Jr

Cornell, Howland, Hayes & Merryfield
Engineers and Planners
Corvallis, Oregon

August 1968

SUMMARY

The results of this study indicate that while there is available "off the shelf" emission collection equipment which can be installed on wigwam burners, it is somewhat questionable at the present time to install a collector for the purpose of meeting a particular emission requirement. Before any firm collector application can be recommended for emission control, additional information is needed on collector performance as applied to wigwam burner emissions. This information can be obtained from a test facility using a commercial collector under controlled burner operating conditions.

The study also points out the necessity of combining the need of burner emission control and the control of burner combustion to optimize operation of the burners.

Average gas exit temperature from a burner ranges around 500° F. In order to optimize the required equipment it would be necessary to design the emission system for operation at 800° F. which would be a more ideal temperature to maximize the combustion process.

A summary of the costs for purchasing and installing the various types of collectors covered in this study are:

System	Installed Cost Per Burner	
	w/40' Dia.	w/60' Dia.
Low-drop collector	$17,300.00	$59,700.00
Single cyclone collector	$21,400.00	$81,500.00
Multiple Cyclone Collector	$23,500.00	$62,000.00
Wet Gas Scrubber	$30,000.00	$99,000.00
Electrostatic Precipitator	$47,000.00	$200,000.00

INTRODUCTION

Effective control of waste burner emission to the atmosphere is necessary to minimize pollution of our air. The purpose of this study and report was to consider a number of methods of controlling the particulate emission which occurs during operation of most wood waste wigwam burners in Oregon.

The methods of emission control investigated in this report are:

1. Wet scrubbing of the combustion gas.

2. Centrifugal separation of emission particles from the combustion gas with small, high efficiency cyclones.

3. Centrifugal separation of emission particles with large cyclones.

4. Separation of emission particles by reduced velocity and impingment.

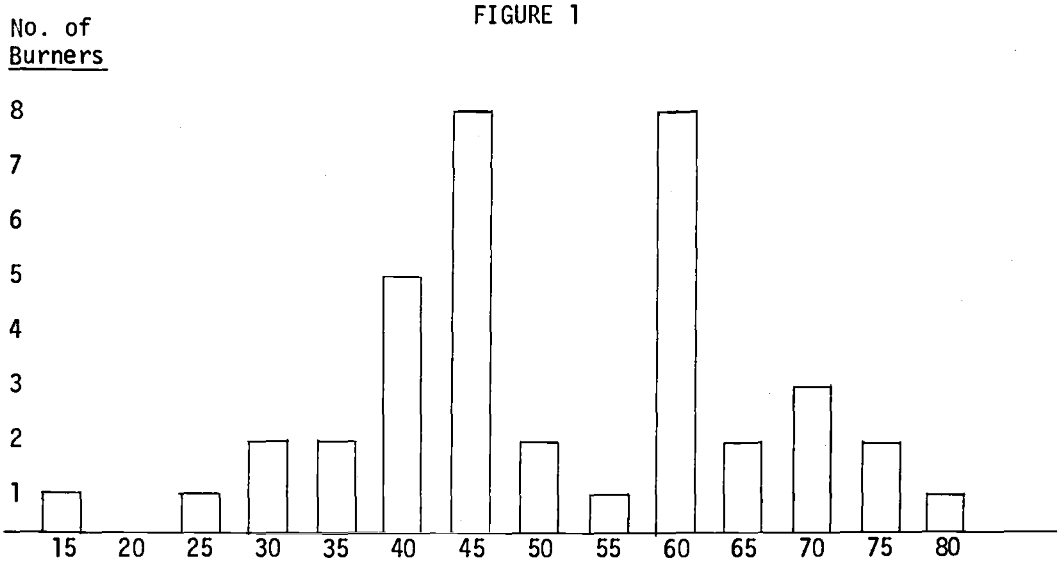
5. Electrostatic precipitation of emission particles.

This report includes preliminary sketches, layouts and construction cost estimates for each of the methods considered.

SIZE OF TYPICAL WASTE BURNER

Information obtained by the Forest Research Laboratory personnel of the Oregon State University School of Forestry at Corvallis, Oregon, on thirty-eight (38) burners in the Benton and Lane County areas provided information for Figure 1 which shows the burner size distribution in these areas.

FIGURE 1



Base Dia. of Burners - Ft.

In order to limit the number of burner sizes considered, it was agreed that the study would include two typical sizes of burners, those being burners with 40-foot and 65-foot base diameters.

THE WASTE BURNER FUEL

Wood waste from timber products manufacturing includes bark, sawdust, shavings, slabs, sander dust, and veneer trim.

As the pulp and paper, particleboard, and hardboard industries expand, their use of all of these wastes, with the exception of bark, is increasing. The present market demand for bark is quite limited, thus necessitating its continued disposal by burning until adequate uses can be developed.

The moisture content of these wood wastes, which must presently be burned, varies from 30 percent* to 70 percent* and averages about 50 percent* as burned in the wigwam burner.

WIGWAM BURNER EMISSIONS

Emissions from wigwam burners consist mainly of the following:

1. For a 40-foot burner consuming 5300 pounds per hour of 50 percent by wet weight basis wood waste with a gas outlet temperature of about 800 degrees F., the weights of gases, vapors, and particulate matter would be:

Nitrogen	65,000 lb/hr
Oxygen	15,500 lb/hr
Carbon Dioxide	5,000 lb/hr
Water Vapor	4,600 lb/hr
Particulate (cinders and smoke)	** 25 lb/hr
Total Weight	90,125 lb/hr

$$\text{Specific Humidity} = \frac{4600}{85{,}525} = 0.053 \ \frac{\text{lbs Water Vapor}}{\text{lb dry gas}}$$

Dew Point = 92 degrees F.

2. For a 65-foot burner consuming 22,000 pounds per hour of 50 percent by wet weight basis wood waste with a gas outlet temperature of about 800 degrees F., the weights would be:

Nitrogen	278,000 lb/hr
Oxygen	66,000 lb/hr
Carbon Dioxide	21,400 lb/hr
Water Vapor	19,600 lb/hr
Particulate (cinders and smoke)	110 lb/hr
Total Weight	385,110 lb/hr

The visible portions of the burner emissions are the water vapor, cinders, and smoke.

The emissions of nitrogen, oxygen, and carbon dioxide from wigwam burners are not presently objectionable in that these are all normal useful constituents of our atmosphere.

Similarly the emission of small amounts of water vapor is not objectionable except as it may effect the visual appearance of the emissions. Its visual appearance can be eliminated by operating at sufficiently high temperatures to maintain the water vapor in the gaseous state.

The smoke may only be eliminated by complete combustion while the majority of the cinders could be removed by some type of effective scrubbing or collection equipment.

---

* All moisture content values are stated as percentages of the total weight of dry wood plus contained moisture.

** Based on tests by Boubel in Particulate Emissions from Sawmill Waste Burners. Paper 6.8-164, Oregon State University.

EMISSION COLLECTION SYSTEMS

Bases of Cost Estimates. In arriving at the estimated cost for the various types of particulate matter scrubbers and collectors, equipment costs have been obtained from manufacturers while the costs of foundations, ducting, and structural components and installation labor have been obtained by estimating the weights, volumes, or areas of materials required and using unit cost for recent and similar construction work. Using these values, the system components were then grouped together to obtain a unit installed cost for each type of collector system. In doing this, the more efficient collectors were found to be generally more expensive to purchase and install.

Because of the high gas exit temperatures possible (800 degrees F and above), the hopper normally supplied with standard (dry type) collectors cannot be used as a storage bin for the collected ash and cinders. In order to overcome this shortcoming, the hoppers will need to be continuously emptied to preclude the possibility of a fire in the hopper. This procedure will necessitate the use of an additional separate cinder storage bin or continuous reinjection of the cinders to the burner and require a gas tight valve for continuous dumping of the hopper.

Low Pressure Drop Collector. Figures 2 and 2A show a typical installation of a low pressure drop collector with a stack installation to create the necessary draft required for operation of the collector. A stack is shown for this installation since the draft losses for this type of collector are low. The estimated cost for a fan was found to be slightly higher than the stack costs and, of course, there are no power costs for the stack system.

The cost estimate breakdown is as follows:

Item	Burner Diameter	
	40'	65'
Collector and Hopper	$ 6,000.00	$24,000.00
Structural Support (steel and concrete)	2,000.00	6,400.00
Ductwork and Stack (≈ 100' high)	5,300.00	15,300.00
Hopper Valve and Storage Bin	500.00	2,000.00
Subtotal Cost	$13,800.00	$47,700.00
Contingencies (Add 25%)	3,500.00	12,000.00
TOTAL COST	$17,300.00	$59,700.00

The efficiency performance of this type of collector is shown on Figure 3 Efficiency curves for the other types of collectors are also shown on Figure 3 for direct comparison of the fractional efficiencies.

Single Cyclone Separator. Figure 4 shows the large cyclone separator collector with an induced draft fan installation.

The cost breakdown for this system is as follows:

Item	Burners Diameter	
	40'	65'
Cyclone(s)	$ 7,300.00	$29,200.00
Structural Support (steel and concrete)	2,000.00	6,000.00
Fan and Ductwork	7,300.00	28,000.00
Hopper Valve and Storage Bin	500.00	2,000.00
Subtotal Cost	$17,100.00	$65,200.00
Contingencies (Add 25%)	4,300.00	16,300.00
TOTAL COST	$21,400.00	$81,500.00

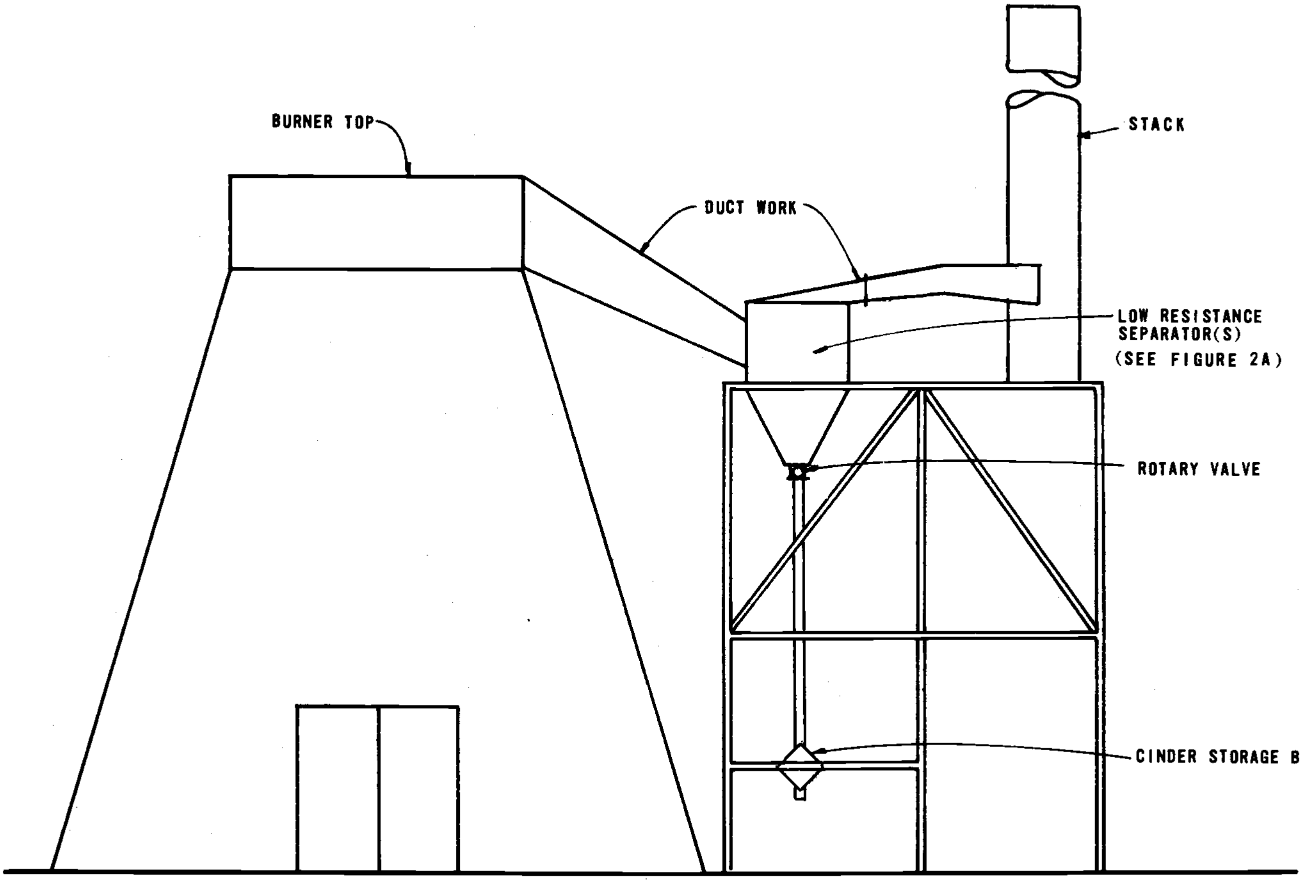


FIGURE 2
TEPEE BURNER AND LOW-RESISTANCE SEPARATOR

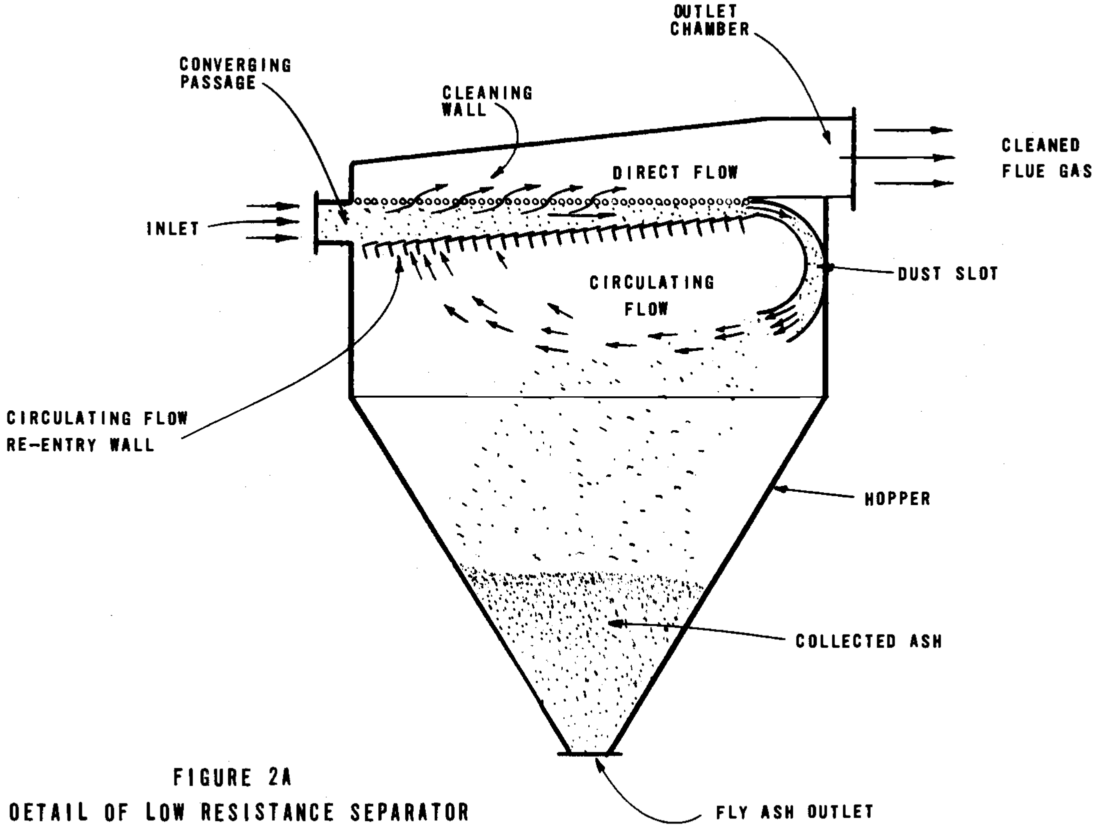


FIGURE 2A
DETAIL OF LOW RESISTANCE SEPARATOR

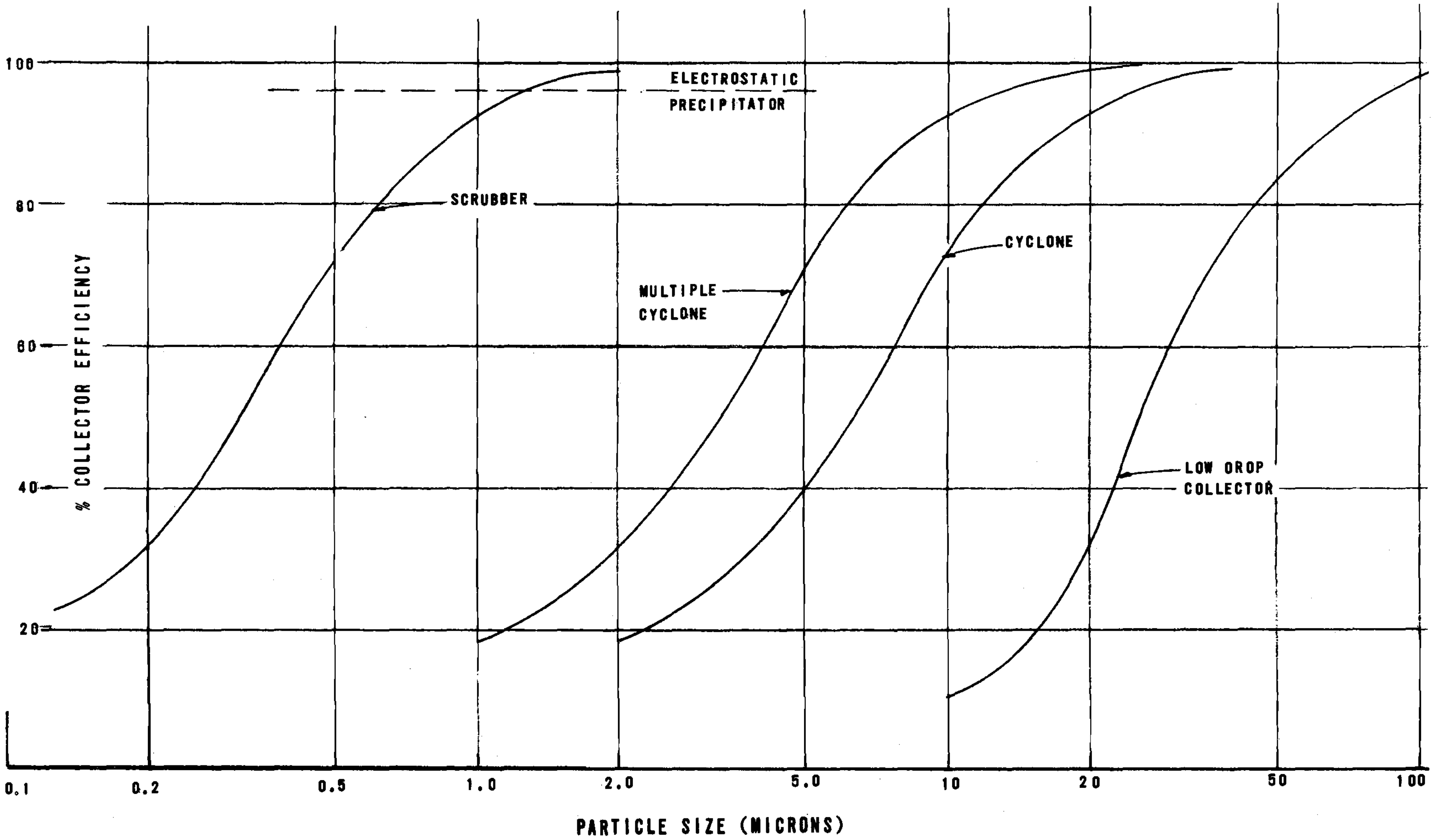


FIGURE 3
COLLECTOR EFFICIENCY CURVES

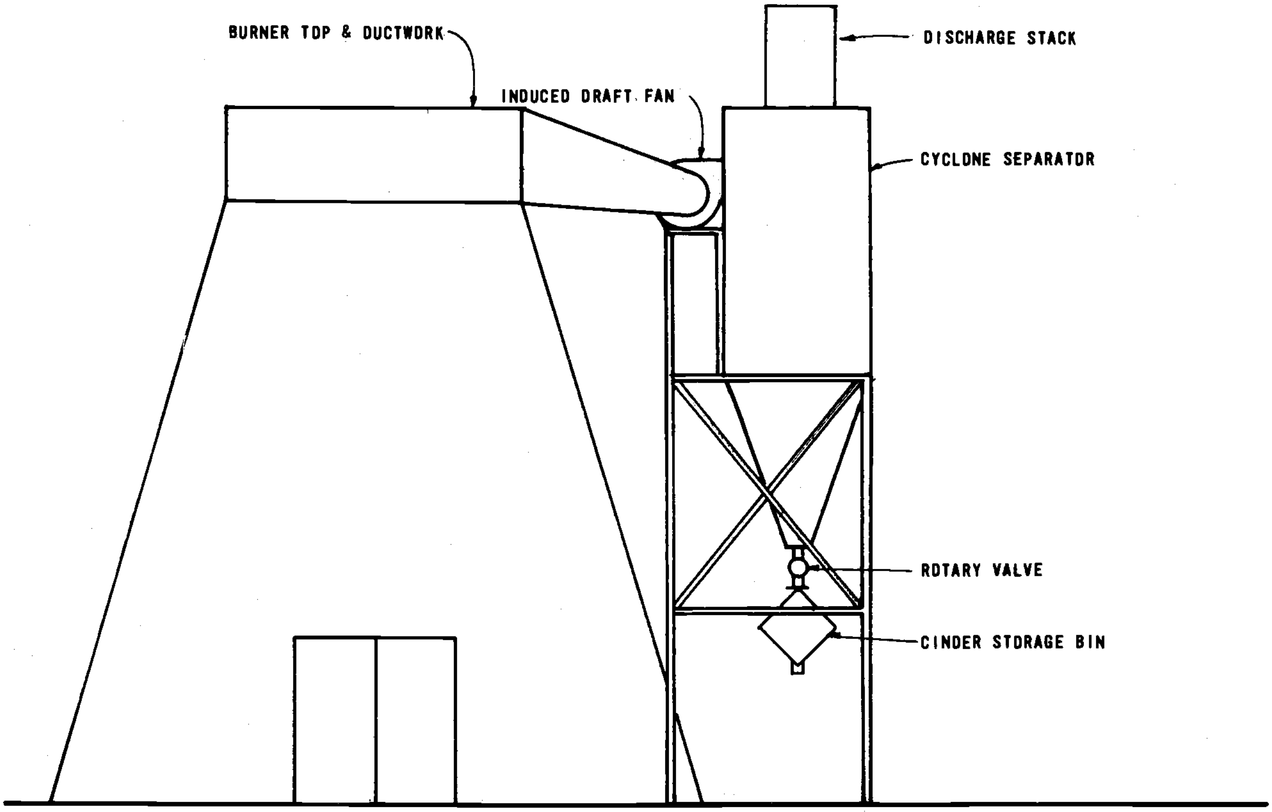


FIGURE 4
TEPEE BURNER AND CYCLONE SEPARATOR

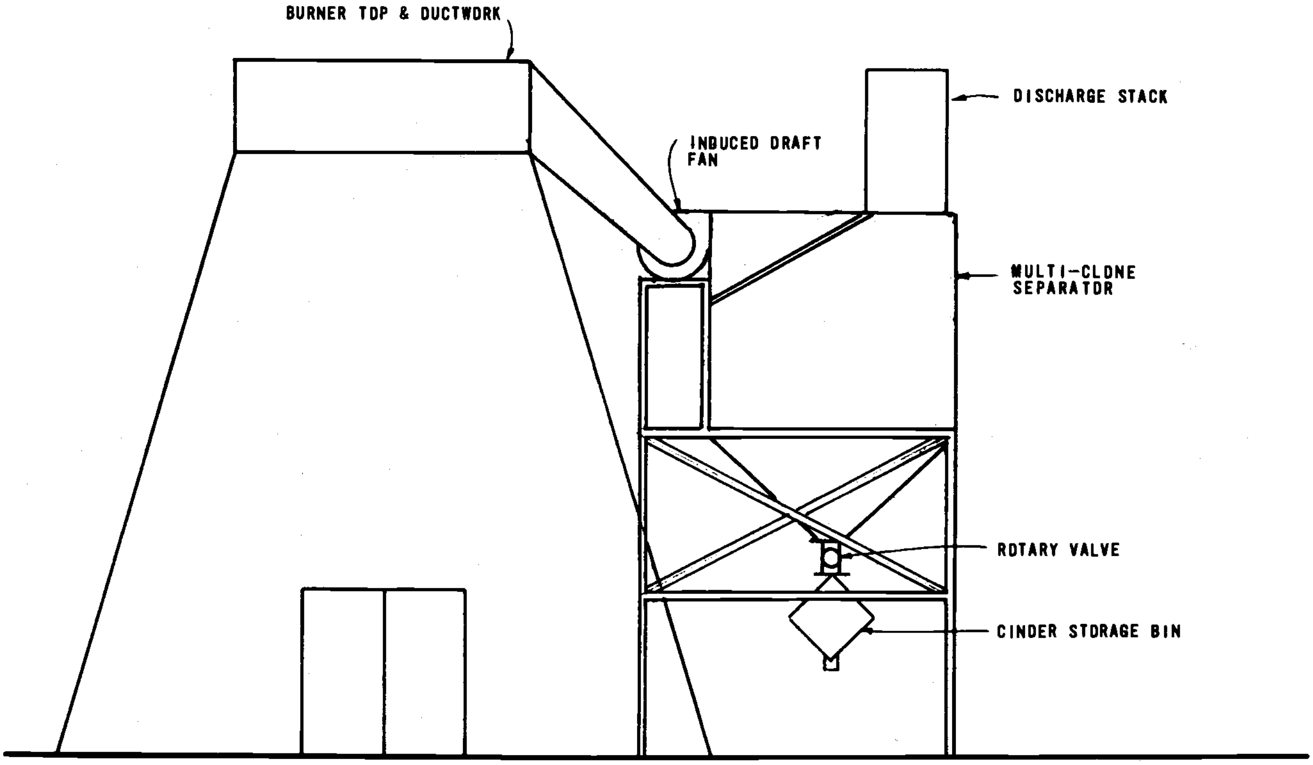


FIGURE 5
TEPEE BURNER AND MULTI-CLONE SEPARATOR

Comparative efficiencies, Figure 3, show the large type cyclone to be more efficient than the low pressure collector of Figure 2

Multiple Cyclone Separator. Figure 5 shows the multiple cyclone type cinder collector which is more efficient than its large counterpart, the single large cyclone. See Figure 3 for comparative efficiencies. Costs for the multiple cyclone type are:

Item	Burner Diameter 40'	Burner Diameter 65'
Multiple Cyclone and Hopper	$ 6,250.00	$18,200.00
Structural Supports (steel and concrete)	2,000.00	3,500.00
Fan and Ductwork	9,400.00	27,400.00
Hopper Valve(s) and Bin(s)	800.00	1,000.00
Subtotal Costs	$18,450.00	$50,100.00
Contingencies (Add 25%)	4,600.00	12,500.00
TOTAL COSTS	$23,050.00	$62,600.00

Wet Gas Scrubber. Several wet scrubbers were considered in this study and one was selected on the basis of known efficiency. Figure 6 shows the wet scrubber and fan arrangement. Costs for the installation are shown, as follows:

Item	Burner Diameter 40'	Burner Diameter 65'
Scrubber(s) and Piping	$11,800.00	$44,500.00
Structural Supports (steel and concrete)	3,000.00	5,250.00
Fan and Ductwork	7,200.00	25,500.00
Retention Basin	2,100.00	4,150.00
Subtotal Costs	$24,100.00	$79,400.00
Contingencies (Add 25%)	6,000.00	20,000.00
TOTAL COSTS	$30,100.00	$99,400.00

It will be noted in Figure 3 that the wet scrubber provides a better overall efficiency than the three previously discussed dry type collectors while the cost is somewhat higher than the most efficient cyclone type collector.

A make-up water supply of approximately 45 gpm is required for the 40' burner and 200 gpm for the 65' burner. In addition to the disadvantage of the higher costs of such a system, is the disadvantage of adding a large quantity of objectionable water vapor to the atmosphere in the form of a steam plume.

Electrostatic Precipitators. The cost investigation of this type of collection system, see Figure 7, shows that the initial cost is extremely high for the larger burner. The cost amounts to about one dollar per cfm of combustion gas for a total cost in excess of $200,000.00 for the 65-foot burner.

Since this type of collector would create a very high fire risk when used in this application, it was not considered compatible to the waste burner system. Figure 3 does include an expected efficiency curve for the electrostatic precipitator for comparison with the other collectors.

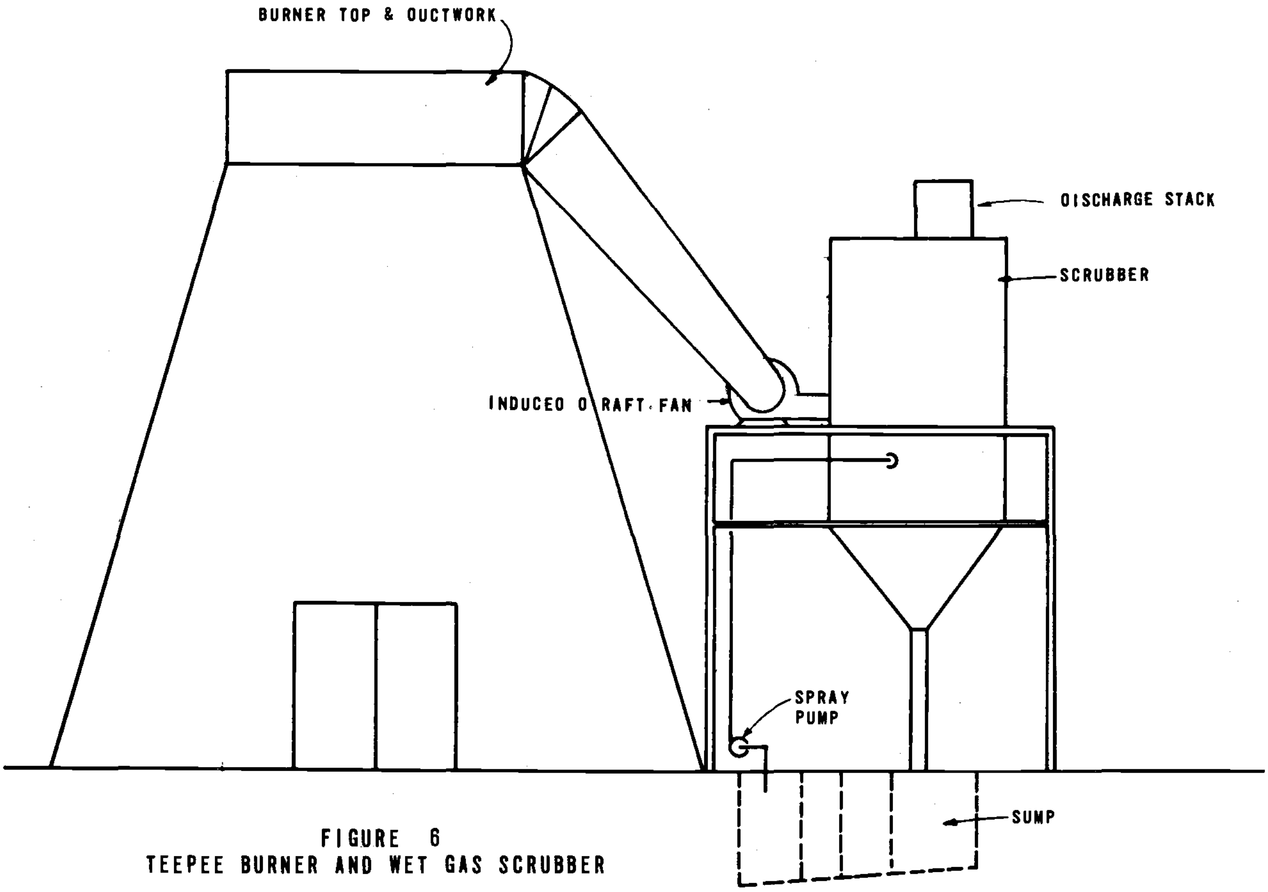


FIGURE 6
TEEPEE BURNER AND WET GAS SCRUBBER

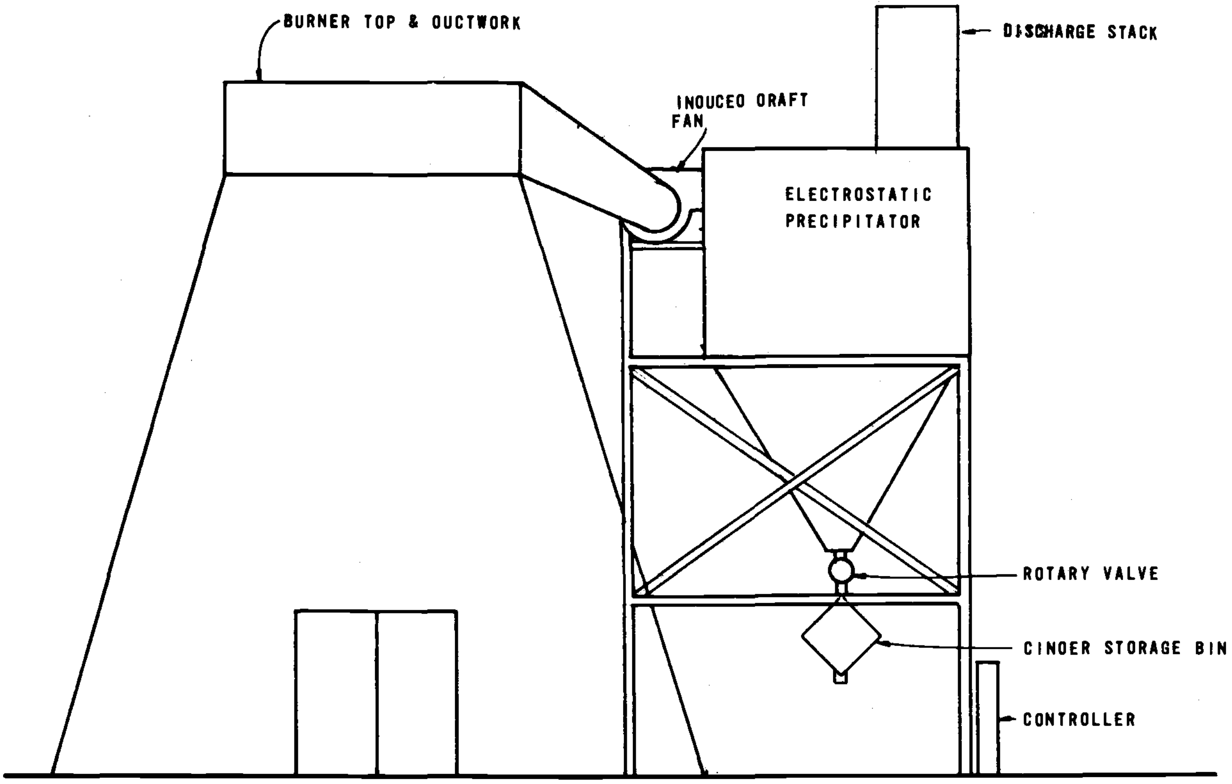


FIGURE 7
TEPEE BURNER AND ELECTROSTATIC PRECIPITATOR

Comparative Efficiencies. Figure 9 is a compilation of emission distribution curves drawn from about 10 percent of the samples of particle weights taken from a recent series of tests on wigwam burner emissions. The tests were conducted by the Oregon State University Mechanical Experimentation Department.** These sample particle weights were a random selected sampling and may not represent the average distribution of emission particles as collected during the recent tests.

If we can assume that the sampling is somewhat average, then a mean particle distribution of the selection can be used to determine the total number of particles that can be collected in any given collector when the collector efficiency is known.

When the assumed average emission sample curves shown on Figure 9 are normalized and then related to the known collector efficiencies shown on Figure 3, the results show that a high efficiency separator such as the multiple cyclone type, can be expected to remove about 90 percent of the sample emissions. When relating the low pressure drop collector efficiency to the normalized sample curve, it shows that this collector can be expected to remove about 70 percent of the particle sample from the gas stream.

It should be noted that all of the collection devices will remove only a certain percent of given size particles. To minimize particulate emitted from a collector, the collector input must also be minimized. This is most easily done by maintaining burner exit temperatures from 600 to 900 degrees F. so that combustion efficiency is improved.

CONCLUSIONS

A cost verses efficiency review shows, except for the electrostatic precipitator, the wet scrubber to be the most expensive and also the most efficient system. The wet scrubber is probably a more expensive particle collection system than would be required for most wigwam burners but it does have the advantage of being best able to handle the worst combustion conditions which would occur at burner startup, burner shutdown, and during rapid fuel rate fluctuations. Maintenance on the wet scrubber would be a higher cost item compared to the dry type collector. After considering the cost factors and comparing overall efficiencies of the collectors, the high efficiency multiple cyclone type would be the most acceptable collector for the average wigwam burner.

Collected costs based on the multiple cyclone type separators mounted on 40-foot and 65-foot wigwam burners are projected on the installed cost curve shown on Figure 8.

RECOMMENDATIONS

Because of the indefinite physical nature of wigwam burner emissions and lack of collector efficiency data relative to wigwam burner emission collection, it is recommended that additional sample collection testing be done based on actual application of the high efficiency type collector to a small selected wigwam burner. This type of testing can best be accomplished by an industry-wide oriented agency such as the Forest Research Laboratory of the Oregon State University School of Forestry.

** Based on tests by Boubel in Particulate Emissions from Sawmill Waste Burners. Paper 6.8-164, Oregon State University

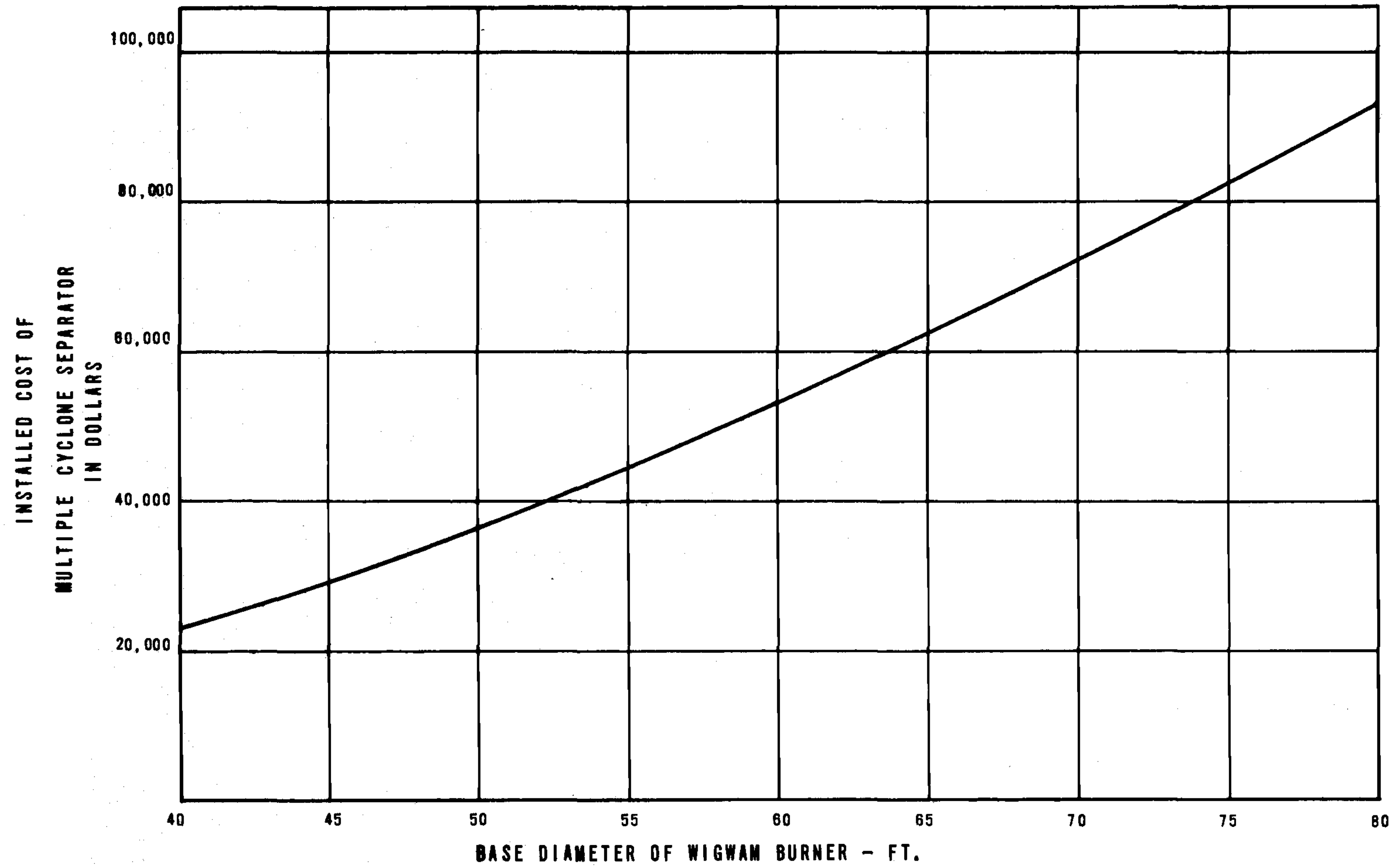


FIGURE 8

INSTALLED COSTS OF MULTIPLE CYCLONE COLLECTORS

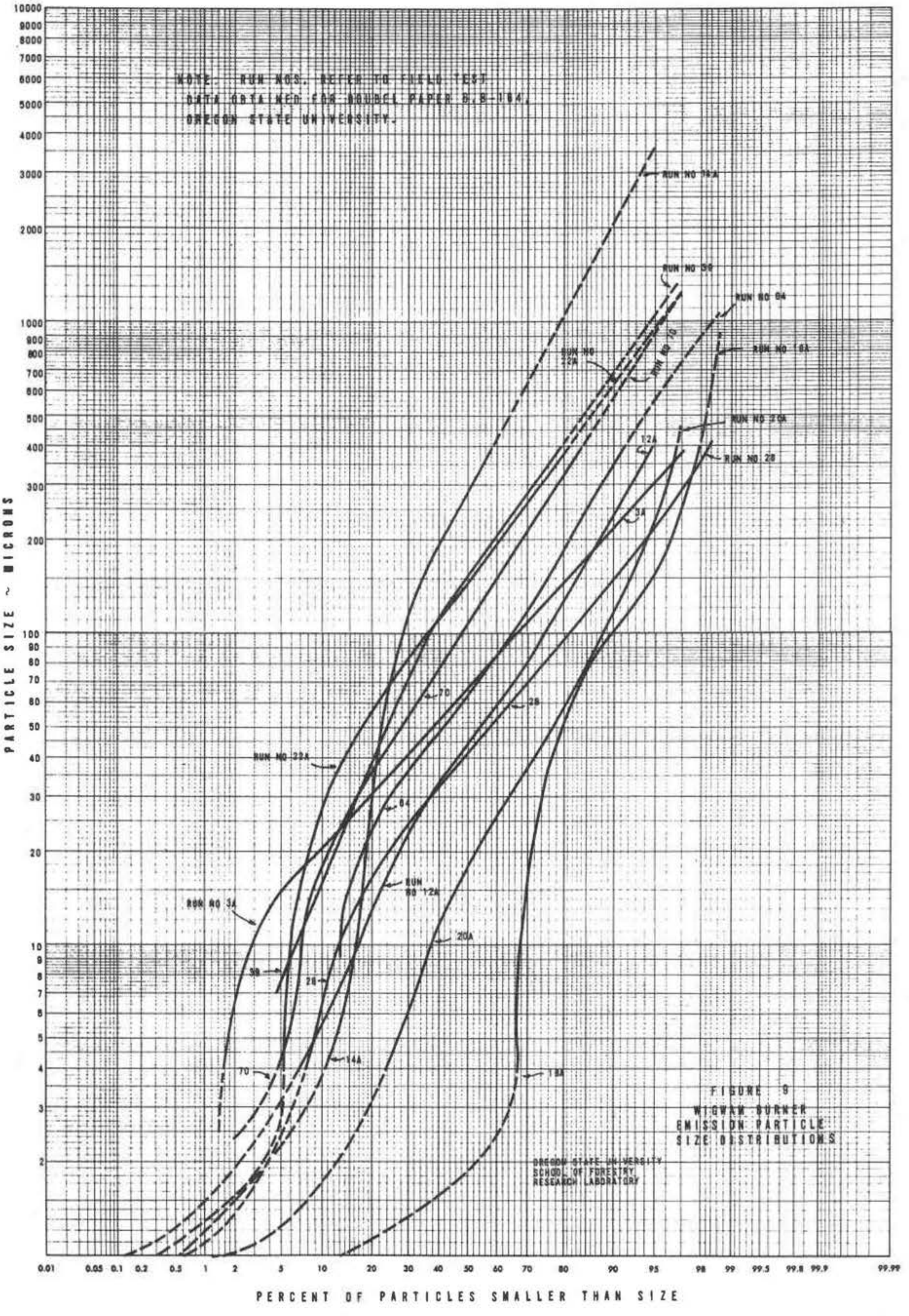


FIGURE 9
WIGWAM BURNER
EMISSION PARTICLE
SIZE DISTRIBUTIONS

APPENDIX D

DRAWINGS OF TEST WIGWAM BURNER

General features of the test burner are illustrated by photographs in a previous section of this report. Arrangement and construction details of the test burner are included here.

A vertical section (Figure D-1) is a general view of the test burner that includes the variable-speed conveyor, the platform from which exhaust gases were sampled, the fuel spout, and one of four overfire fans.

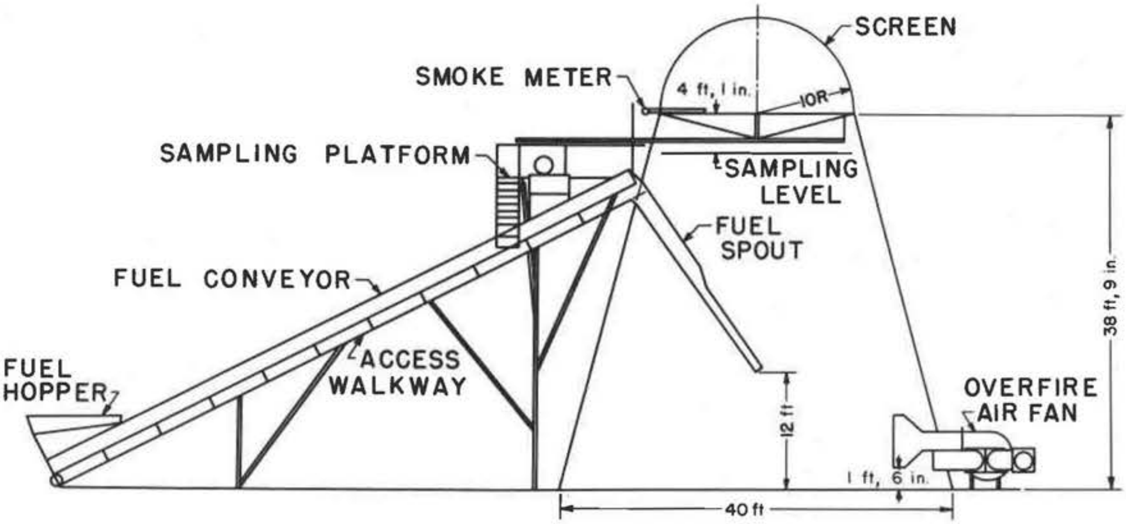


Figure D-1. A cross section of the test burner to show the fuel conveyor, sampling platform, and an overfire fan.

Underfire Air System

The underfire air supply was divided into three zones (Figure D-2) so that air could be apportioned to different areas of the fuel pile as desired. Fan capacity, which was much greater than would be needed in a commercial unit, was enough so a wide range of air-fuel ratios could be evaluated.

The center grate-box (Figure D-2) was about 4 feet wide, 5 feet long, and 2 feet deep. It was made of spaced refractory firebrick. Details of grate boxes in the outer rings are shown in Figure D-3. Two castiron grates were mounted in each rectangular grate box. Each grate box was welded to a pipe riser, which in turn was welded to the underfire air ductwork. The grates were at ground level with the air supply ducts underground.

Underfire Gas Burner

A gas burner was mounted in the duct leading to the large central refractory grate box (Figure D-4). The gas burner was equipped with an igniter for the pilot light and a flame rod to detect either flameout or ignition failure. The burner could be ignited or turned off from a control panel outside the wigwam burner. Gas and control lines ran to the burner through the underfire air duct.

Overfire Air Fans

Figure D-5 is a horizontal section through the wigwam burner just above the overfire air fans. It shows the underfire system and the overfire fans, recirculation provision, and gas burners. The four 30-hp fans were mounted on concrete pads equally spaced at ground level around the periphery of the wigwam burner. The fans were much larger than would be needed on a commercial unit, but large air capacity was

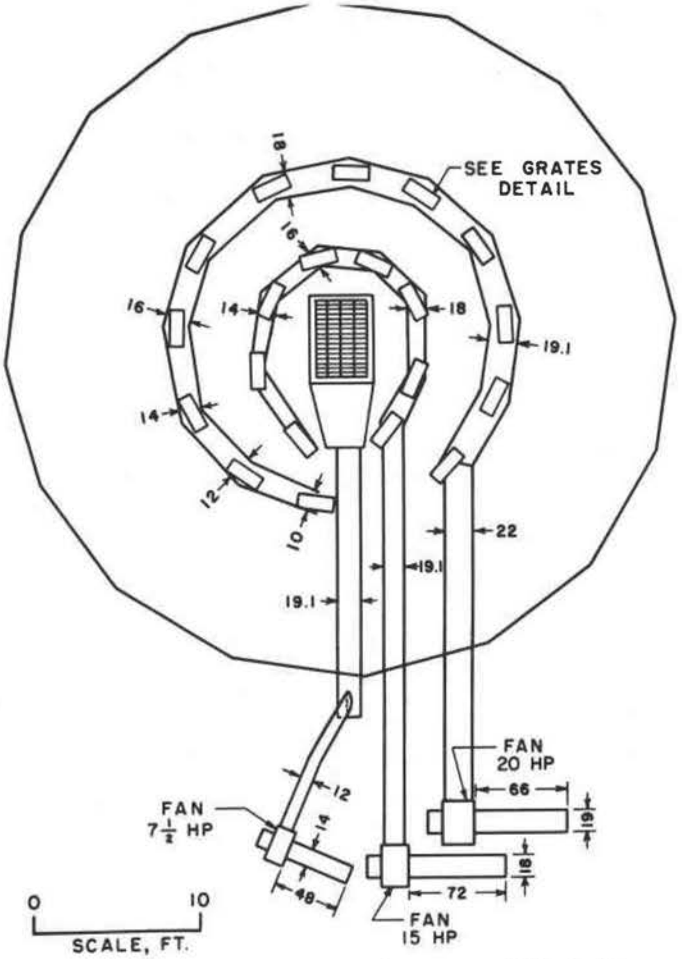


Figure D-2. The underfire air-supply system of the test burner.

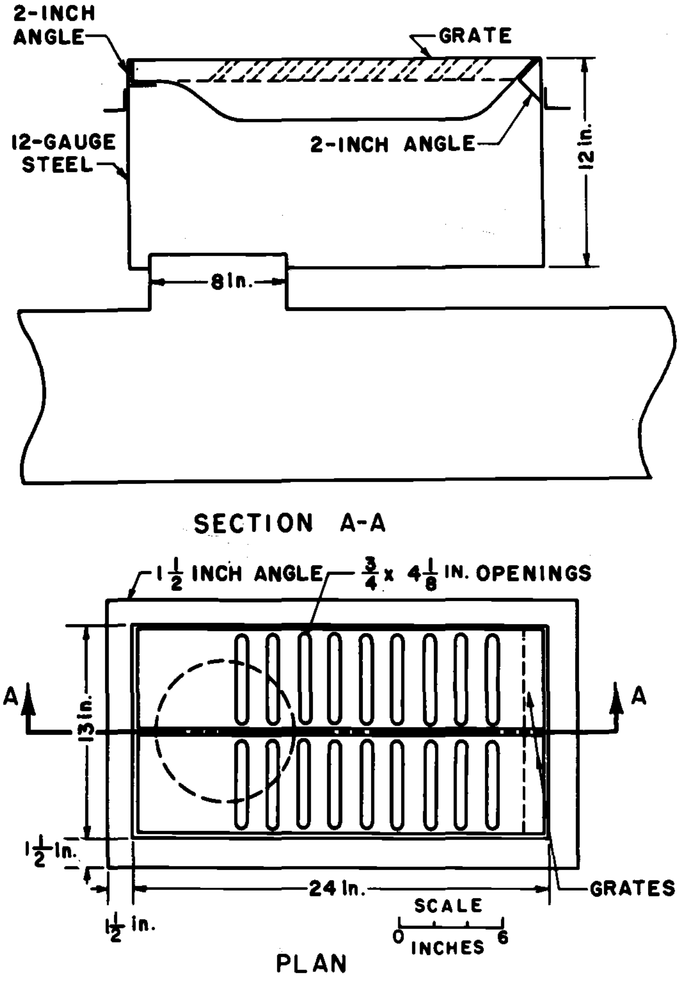


Figure D-3. Grate box detail of the test burner.

installed to explore a wide range of operating conditions. Each fan had dampers in divided inlets to allow selection of any percentage of recirculated gases or outside air. Although the nozzle slots are shown as vertical (see also Figure 21, which is a photograph of an overfire air nozzle) in Figure D-5, the nozzles were sloped about 30 degrees from vertical. The nozzles were aimed approximately at the surface of the conical fuel pile when the pile extended slightly beyond the outer ring of grates. Figure D-6 shows construction of the overfire air nozzles.

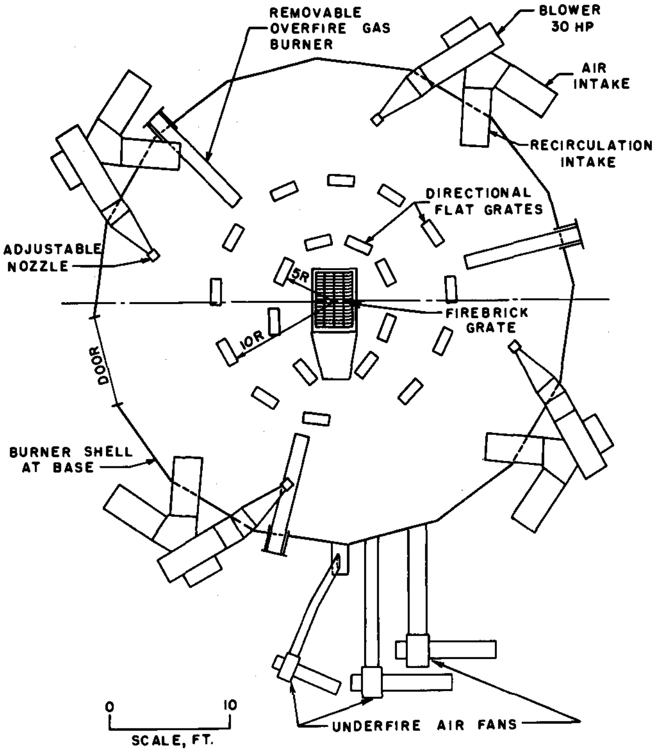


Figure D-5. Overfire fans, recirculation ducts, and gas burners of the test burner.

Overfire Gas Burners

Three gas burners were installed in retractable ducts (Figure D-5) spaced 120 degrees apart around the periphery of the wigwam burner. A sketch of one such burner is shown in Figure D-7. These burners were installed at ground level. Ignition was manual by lighting a pilot and opening a gas valve. The aspiration effect of the gas flow supplied combustion air for the gas burners.

Top Damper

The butterfly damper shown schematically in Figure D-8 was mounted at the top of the wigwam burner just under the dome screen. There were two provisions for opening the damper. In one method, two center slides could be drawn toward the periphery of the burner to expose a large opening in the butterfly dampers through which combustion gases could

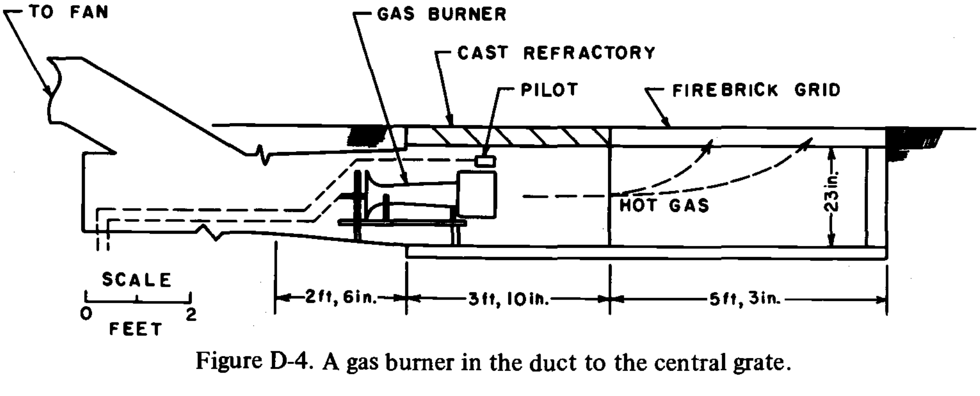


Figure D-4. A gas burner in the duct to the central grate.

exhaust to atmosphere. Or, the slides could be left closed and the butterfly damper opened. Both means of damper opening were by cable, winch, and pulleys. With center slides fully withdrawn, the open area was about 100 square feet. When the butterfly damper was fully open, all of the burner top was open.

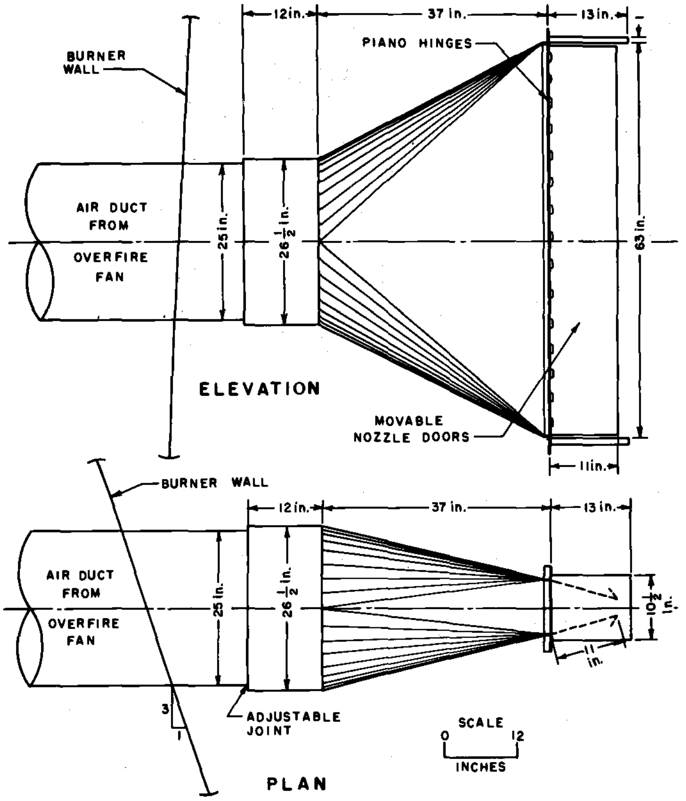


Figure D-6. Detail of adjustable overfire air nozzles in the test burner.

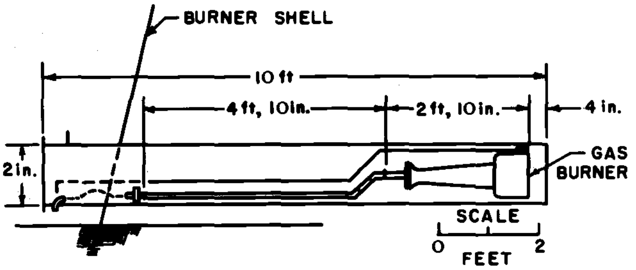


Figure D-7. Overfire gas burner in a duct of the test burner.

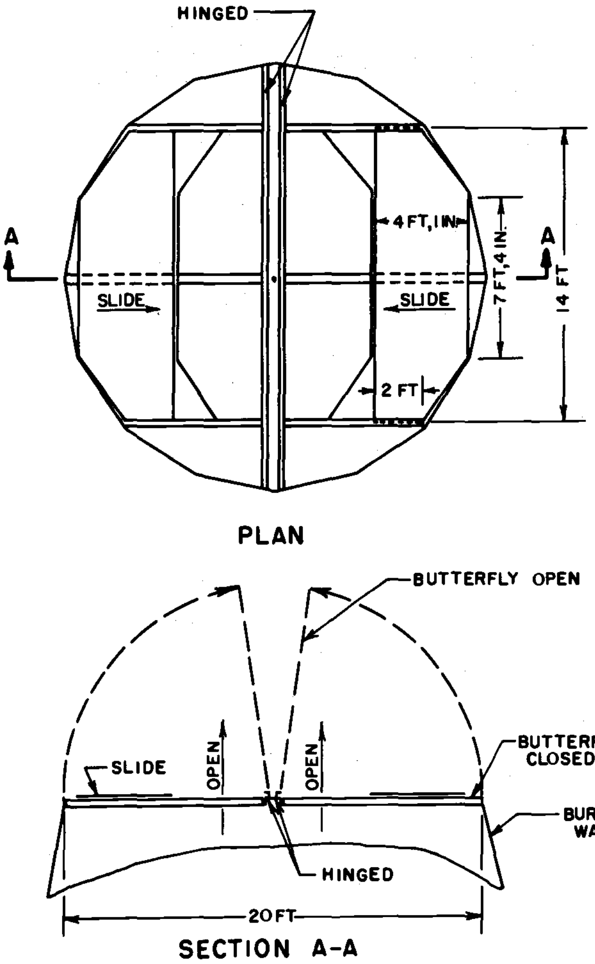


Figure D-8. Butterfly damper on the 40-foot wigwam burner tested.

APPENDIX E

INSTRUMENTATION FOR TEST WIGWAM BURNER

A brief discussion of instrumentation has been given earlier in this report. This Appendix provides a more detailed description of instrumentation.

Temperatures

In most instances, temperatures were sensed by chromel-alumel thermocouples and recorded by multi-point recorders. Temperatures were measured for the following:

1. Exit gas at 13 points, six on each of two diametric traverses across the top of the burner and one near the particulate-sampling probe (Figure E-1).

2. Eight places on the burner shell ranging from top to bottom and around the shell.

3. Each of the four overfire air nozzles within the burner.

4. Preheated underfire air to the central grate when the underfire gas burners operated.

5. Two locations on the grates.

6. Ambient air at the orifices on the seven air supply fans.

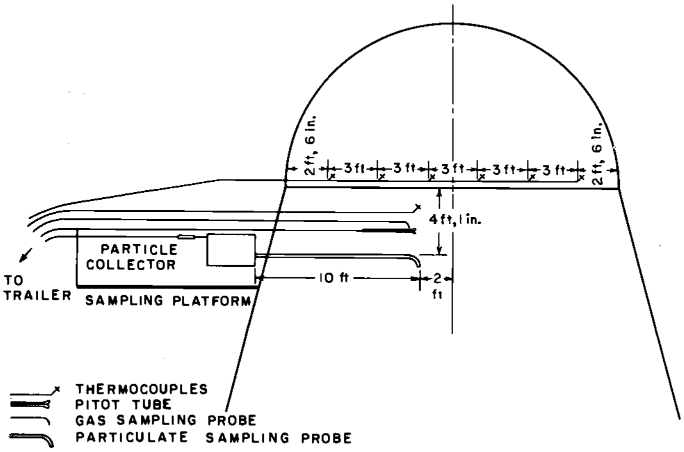


Figure E-1. Gas and particulate sampling station at the top of the test wigwam burner.

Natural Gas Flow

Flow of natural gas was measured by conventional industrial gas meters (Figure 24). The meters were equipped with pressure gages and thermometers.

Exit-gas Sampling and Analysis

Figure E-1 is a sketch of the sampling station at the top of the wigwam burner. In this figure, the approximate location of the gas-sampling probe is shown. The sampling probe was constructed of ½-inch stainless steel tubing. In initial experiments, gas was sampled at several points on a traverse across the top of the wigwam burner. In most tests, however, gas samples were drawn from the single location shown in Figure E-1.

The gas sample was drawn through a filter by a vacuum pump, model G-3, Air Control, Inc., Norristown, Pennsylvania.

Carbon dioxide and monoxide analysis was by a Lira infra-red analyzer, Model 300, Mine Safety Appliances Co., Pittsburgh, Pennsylvania.

Total hydrocarbons analysis was by a flame ionization hydrocarbon analyzer, model 108 A, Beckman Instruments, Inc., Fullerton, California.

The proportion of the above gases in the wigwam burner exit gas was indicated continuously by meters. In addition, gas analyses could be continuously plotted by a conventional millivolt recorder.

Particulate Sampling

A pitot tube and micromanometer measured exit-gas velocity so isokinetic conditions could be attained at the particulate-sampling probe. The pitot tube was a combined-reversed type sometimes known as the "Stauscheibe" type.

The particulate-sampling probe is shown in Figure E-1 with a diagram of the particulate-sampling train in Figure E-2. The different components shown in Figure E-2 are:

Item 1. Stainless-steel sampling probe of three inside diameters–0.400, 0.687, and 0.902 inch diameter.

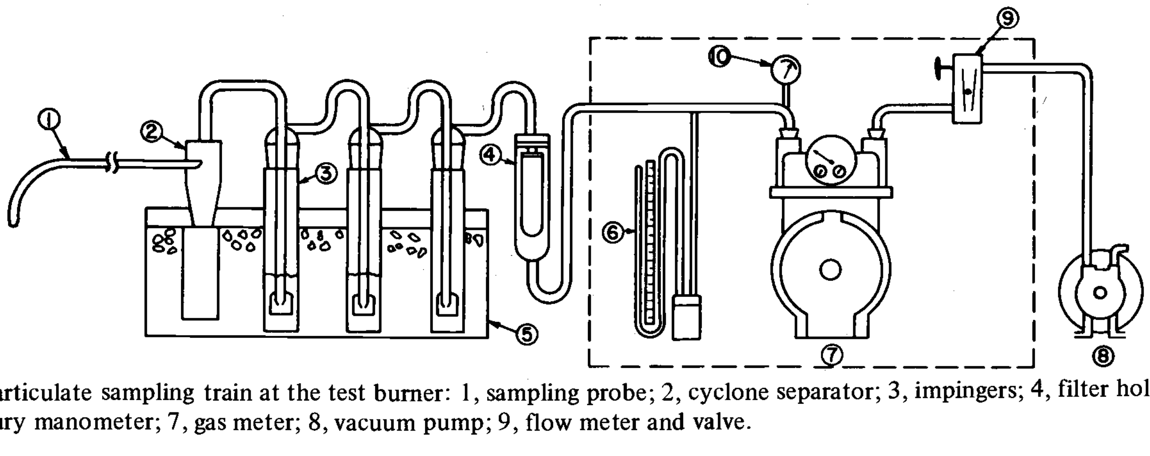


Figure E-2. Particulate sampling train at the test burner: 1, sampling probe; 2, cyclone separator; 3, impingers; 4, filter holders; 5, ice bath; 6, mercury manometer; 7, gas meter; 8, vacuum pump; 9, flow meter and valve.

Item 2. Cyclone separator, Aerotec sampler size ¾, capacity 2.4 cfm, at 4 inches wg, Process Equipment Company, Bellevue, Washington.

Item 3. Greenburg-Smith glass impingers, Gelman Instrument Co., Ann Arbor, Michigan.

Item 4. Whatman cellulose extraction thimbles, 43 by 123 mm, Van Waters and Rogers, Portland, Oregon.

Item 5. Ice bath container.

Item 6. Mercury monometer.

Item 7. Sprague dry gas meter, part D1006, capacity 175 cubic feet per hour at ½-inch mercury differential, Western Precipitation Group, Joy Manufacturing Company, Los Angeles, California.

Item 8. Belle and Gossett vacuum pump, model SYC-20, Rogers Machinery Co., Portland, Oregon.

Item 9. Brooks-Mite purge meter, model 2001-V, Brooks Instrument Co., Hatfield, Pennsylvania.

Air Flow

Air flow was measured by orifices mounted on inlet ducts of the seven air-supply fans. Orifices were cut from ¼-inch hardboard (Figure 26). Inclined manometers, such as shown in Figure 27, measured pressure drops across orifices.

Smoke Opacity

Figure E-3 shows the system for evaluating smoke opacity installed at the top of the wigwam burner. Exhaust gas was drawn continuously into the open ends of the 4-inch ducts by a small blower. A light was beamed through the exhaust gas sample to a detector. An electric signal from the detector actuated a continuously recording smoke meter.

Specifications were: Smoke density transmitter and receiver, class GN; smoke density meter, type WM 55A Model E100, Bailey Meter Company, Wickliffe, Ohio.

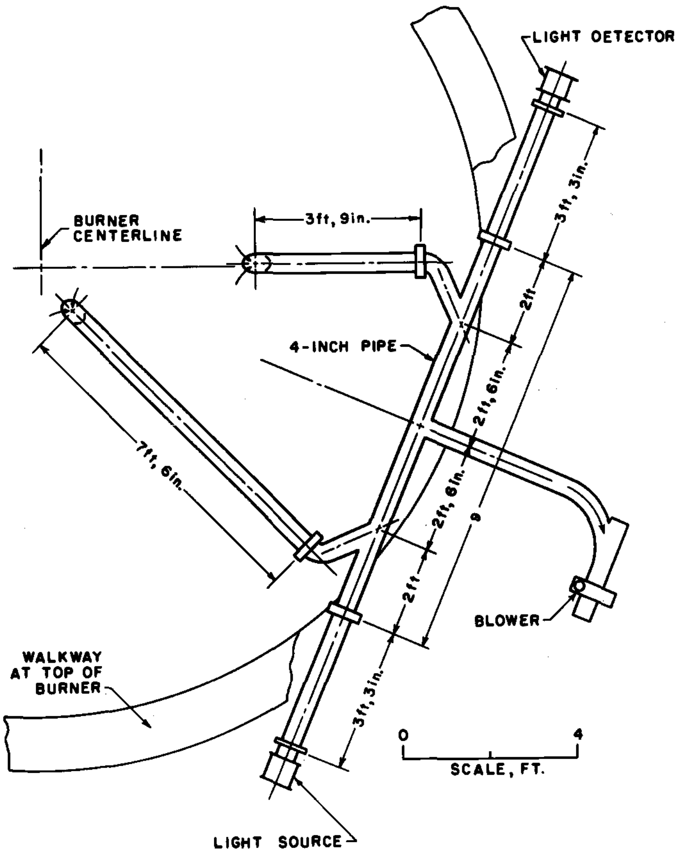


Figure E-3. Smoke-sampling system on the test burner.

APPENDIX F

COSTS OF CERTAIN MODIFICATIONS TO AND DISPOSAL OF WOOD WASTE IN WIGWAM BURNERS

Underfire Air System

The underfire air system on the test burner had three separate fans with sufficient capacity to provide a wide range of operating conditions for test purposes. Such versatility would not be necessary at an operating mill. The cost estimate in Table F-1 is for an underfire air system considered adequate for a burner of 40-foot diameter with a fuel capacity of about 3 units per hour of bark.

Overfire Air System

The overfire air system on the test burner was also of greater capacity than would be required for an operating burner. The cost estimate in Table F-2 is for a proposed overfire air system on a 40-foot burner to supply overfire air needed for combustion and give velocity for turbulent mixing and cyclonic effect. Provision should also be made to admit air by natural draft through conventional tangential openings, if necessary for cooling, or to provide air in event of fan or power failure.

Auxiliary Gas Fuel

Cost of providing auxiliary gas burners similar to the overfire gas burners used on the test burner is shown in Table F-3. Costs include provision for ignition and safety controls.

In addition to the costs for installing gas burners, there would be an additional cost for the fuel used. If 10 million Btu of gas were used daily for starting, cost of natural gas per day would be $6.00 with gas costing 6 cents per therm, such as might exist with a firm using large quantities of natural gas on a firm basis. If natural gas were available and used only for burner starting, natural gas might cost about 10 cents per therm on a firm basis, for a daily cost of $10.00.

Liquified petroleum gas, or propane, is available in western Oregon for about 11 cents per gallon in truckload quantities. Storage tanks would also be needed for the use of propane. If propane is stored in a 12,000-gallon tank and costs 11 cents per gallon, the cost of 10 million Btu per working day supplied by propane would be $14.70. Of the total daily cost, $12.00 is for propane and $2.70 is for rental of a storage tank.

Table F-1. Estimated Cost of Underfire Air System for 40-foot Burner.

Item	Cost
One 7 1/2-hp fan	$ 500
Electrical	200
40 grates in 20 grate boxes	1,200
Miscellaneous material and equipment rental	480
Labor	1,920
	$4,300

Table F-2. Estimated Cost of Overfire Air System on 40-foot Burner.

Item	Cost
Four 5-hp fans	$2,000
Electrical	900
Other material	300
Labor	1,000
	$4,200

Table F-3. Estimated Cost of Auxiliary Gas Burners on a 40-foot Burner.

Item	Cost
Three gas burners	$ 510
Ignition and safety controls	690
Other materials and equipment	420
Labor	1,180
	$2,800

Cost Basis of Wigwam Burner and Hogging Operation

I. Cost of 40-foot-diameter wigwam burner without modifications.

Construction Cost (without conveyor)

Burner structure and shell	$ 7,000
Concrete base	1,500
Underfire system	4,500
Total construction cost	$13,000

Operating Cost (yearly)
(based on one 8-hr shift/day, 240 operating days/yr)

Taxes @ 2 percent	$ 260
Interest @ 9 percent	1,170
Depreciation @ 20 percent	2,600
Insurance @ 1 percent	130
Labor (including overhead)	
Firing 2 hr/day @ $3.60/hr	1,730
Cleaning & maintenance 4 hr/wk @ $3.60/hr	720
Power cost for 7.5 hp @ 1 cent/kwh	350
Total yearly operating cost	$6,960

If the above burner operates one 8-hour shift per day, 240 operating days per year, with an average fuel rate of 2½ units per hour, total residue disposed of would be 4,800 units per year. Cost of disposal is $1.45 per unit. No cost was assessed for fuel feeding because, in an operating mill, a wigwam burner is fed by a waste conveyor from the mill so that labor is not normally required.

II. Cost of 40-foot-diameter wigwam burner with forced overfire air and gas burner modifications.

Construction Cost (without conveyor)

Burner structure and shell	$ 7,000
Concrete base	1,500
Underfire system	4,500
Gas burner system	2,800
Overfire air system	4,200
Total construction cost	$20,000

Operating Cost (yearly)
(same operating basis as previous example)

Taxes @ 2 percent	$ 400
Interest @ 9 percent	1,800
Depreciation @ 20 percent	4,000
Insurance @ 1 percent	200
Labor (including overhead)	
Firing 1 hr/day @ $3.60/hr	864
Cleaning & maintenance 4 hr/wk @ $3.60/hr	720
Power cost 275 hp @ 1 cent/kwh	636
Fuel cost for starting	
10 million Btu natural gas @ $0.10/therm	2,400
Total yearly operating cost	$11,020

With the same production basis as in the previous example, disposal cost of 4,800 units per year is $2.30 per unit.

III. Cost of producing hogged fuel, based on a fuel rate of 2½ units per hour on one 8-hour shift daily for 240 operating days a year.

Installed cost of a hogging installation that included hog, motor, bins, and conveyors was obtained from local equipment contractors and was stated to be $35,000.

Operating Cost of Hogging Installation

Taxes @ 2 percent	$ 700
Interest @ 9 percent	3,150
Depreciation @ 20 percent	7,000
Insurance @ 1 percent	350
Labor	
Operating 1 hr/day @ $3.60/hr	860
Maintenance, 4 hr/wk @ $3.60/hr	720
Power cost 200 hp @ 1 cent/kwh	2,860
Total yearly operating cost	$15,640

Cost of producing 4,800 units of hogged fuel per year with these assumptions would be $3.26 per unit.

Disposal Cost Comparison

In the preceding section, a cost comparison was made for disposal of 2½ units of waste per hour. That is about the amount that would be obtained from the bark at a sawmill producing 100 M fbm of lumber in an 8-hour shift.

Cost of disposal in a conventional 40-foot-diameter wigwam burner with an underfire air system was estimated at $1.45 per unit. If forced overfire air and natural gas burners were added and natural gas was used for starting, disposal cost would be $2.30 per unit. Cost of hogging the material amounted to $3.26 per unit. If a market existed for hogged fuel so the mill received $1.00 per unit, then disposal cost could be considered to be $3.26 minus $1.00, or $2.26 per unit.

The disposal costs calculated above are for only one set of conditions and other conditions would give different costs. For example, higher production of waste or operation for more than one shift would have resulted in lower disposal costs for all methods.

APPENDIX G

WIGWAM BURNER DESIGN

The information set forth in this section is based on observations, tests, and experience from the study. Although reasonably clean burning was achieved in the test burner, tests were specific, and further tests are needed to fill gaps in design information. Additional tests needed are listed in the section on recommendations for further study.

The design information presented in this section is considered valid for a well-maintained, tight burner equipped similarly to the test burner and consuming hogged Douglas fir bark at about 40 percent (67 percent, dry basis) moisture content with minor variations in feed rate. Pertinent features of the test burner were a forced-draft underfire air system with flat grates, four overfire air fans with nozzles aimed at the surface of the fuel pile, three overfire natural-gas burners, a recirculation system (not tested), an adjustable top-damper (not tested), a conventional fuel conveyor and chute, and instrumentation for measuring air rates.

To illustrate burner design, an example will be assumed where waste to be incinerated consists of Douglas fir hogged bark from a sawmill cutting 150 M fbm of lumber per 8-hour shift, and operating on two shifts. The barker operates 12 hours in barking logs for two shifts of the sawmill.

The best way to estimate fuel rate from a sawmill is to make provision in the burner conveyor so that the fuel can be diverted to trucks for weighing. Another method is to use established conversion factors to calculate bark fuel rate based on quantity of lumber produced in a given time interval. By the latter method, the rate for dry bark is

0.287 dry tons/M fbm x 300 M fbm/12 hours
= 7.2 dry tons/hour.

The rate for wet bark is
7.2/0.60 = 12 wet tons per hour.

Burner Sizing

A difficulty in burner design is lack of information on how capacity or fuel rate varies with burner size for different fuels. Figure G-1 has several curves that show how fuel rate varies with burner size. The curves have been adapted for Douglas fir bark at 40 percent (67 percent, dry basis) moisture. Curve B is from a report by Boubel (3), which indicates that fuel-burning capacity of a burner varies as the cube of the burner's base diameter. The relation can be represented by the equation:

$D = 34.3\ w^{1/3}$,
where D = base diameter in feet and
w = fuel rate in dry tons per hour.

The equation given by Boubel (3) was expressed in different units and has been converted for the conditions of the example given in this section.

Curve C is from information furnished by a burner manufacturer. The curve gives the relation $D = 26\ w^{1/2}$ (notations as above), which indicates that fuel burning capacity varies as the square of the burner diameter. Neither of these curves estimates minimum fuel rates that give satisfactory burning.

Based on experience, observations, and tests, we recommend curves A and D (Figure G-1) for estimating maximum and minimum fuel rates for the conditions of this design example. Fuel rates of curve A can be achieved without a damper, but to attain clean combustion at the minimum rates of curve D a top damper is necessary. Curve A has the relation $D = 20w^{1/2}$ and curve D gives $D = 36\ w^{1/2}$. If the burner does not have a top damper, the suggested curve for estimating minimum fuel rate is $D = 25.3w^{1/2}$.

At the previously determined maximum fuel rate of 7.2 dry tons per hour, curve A indicates that a burner with a base diameter of about 54 feet would be required. Minimum fuel rate in this burner to get clean burning would be about 2.2 dry tons per hour (curve D) if a top damper were used, or about 4.5 dry tons per hour without a top damper.

Grates

Flat grates were used in the test burner for tests reported in this study. Some mushroom-shaped grates of stainless steel were also installed and seemed to give satisfactory results in preliminary trials. There was not sufficient operating time, however, to evaluate the mushroom-type grate. Others (14) have reported satisfactory operation with underfire air supplied by an elbow system. For this example, flat grates similar to those on the test burner will be used, although other types might be satisfactory.

Figure G-2 shows diameter of the outer grate ring related to burner size. The relation is based on the reasoning that area of burner floor occupied by grates is directly proportioned to fuel rate, that fuel rate is proportional to the square of burner-base diameter, and that proportions are similar to those of the test burner. From Figure G-2, an outer grate ring 30 feet in diameter is indicated for a 54-foot burner.

Recommended arrangement of grates in the burner is shown in Figure G-3, with a grate box 3 feet square in the center of the floor area of the burner and succeeding grate rings at 4-foot intervals of radius out to a radius of 16 feet. Two

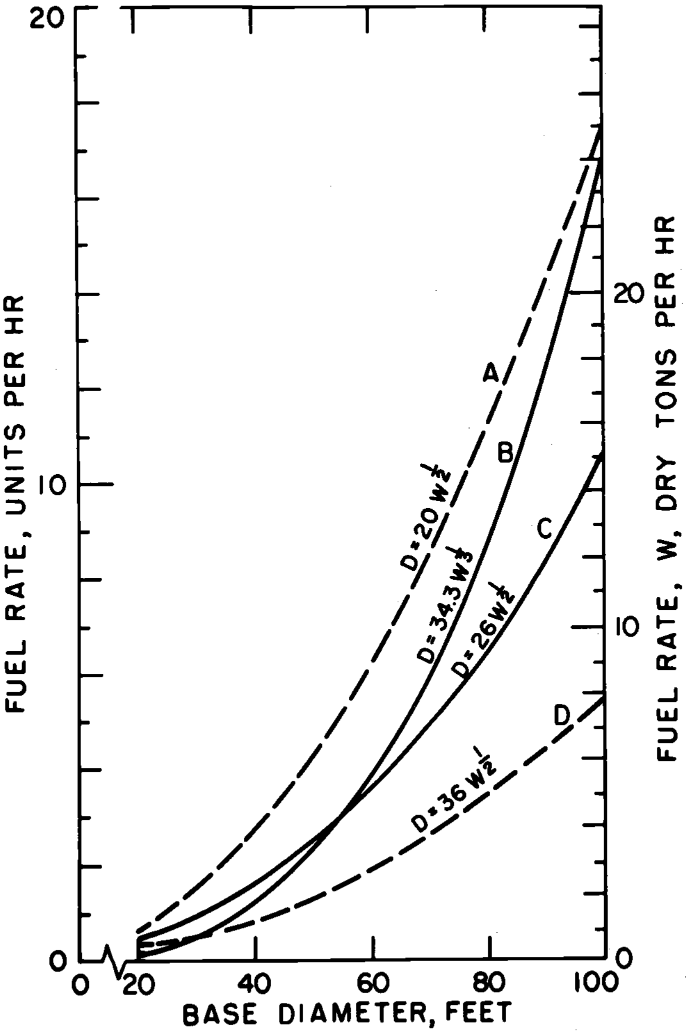


Figure G-1. A comparison of wigwam burner sizing curves for continuous fuel rate for Douglas fir hogged bark at 40 percent (67 percent, dry basis) moisture. Curve B is adapted from Reference 3, B and D are from our study, and C is from a burner manufacturer.

6-inch by 2-foot flat grates are provided for about each 15 square feet of floor area in that portion of the floor where grates are located. This results in 20, 15, 10, and 5 grate boxes for the four rings. Figure G-2 indicated that the diameter of the outer grate circle was 30 feet, but 32 feet were needed to maintain 4-foot spacing between rings.

Recommended distribution of air in the various grate zones is in proportion to the number of grates through which the air flows. The central grate box contains 8 grates for 7 percent of the air flow. Each grate box in the outer rings contains two grates. Therefore, the proportion of air through the rings of grates, proceeding from the smallest to largest diameter, would be 9, 19, 28, and 37 percent. The system can be served by a single fan, but the central grates and each of the grate rings should have a separate air duct with a damper to facilitate getting equal velocities through the grates. The dampers would also allow reducing the air flow to the outer grate rings if the fuel pile does not extend to those grates.

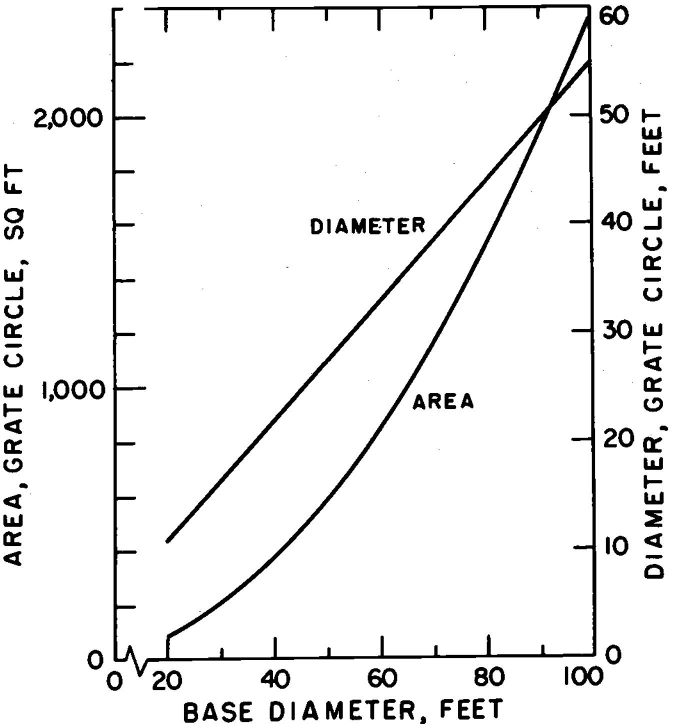


Figure G-2. Grate area and diameter of the outer grate circle related to burner size for Douglas fir hogged bark at 40 percent (67 percent, dry basis) percent moisture.

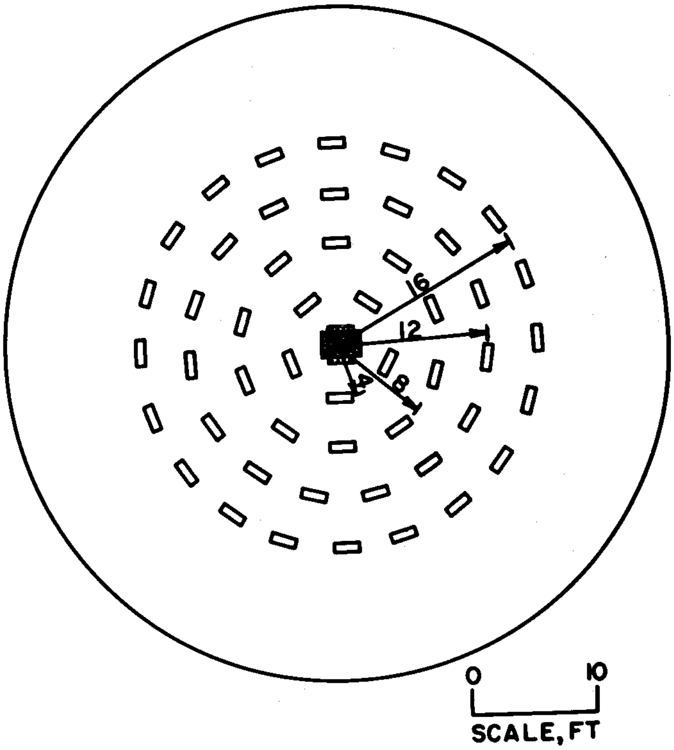


Figure G-3. Grate rings in wigwam burner with 54-foot base diameter.

Air Rates

Least air pollution resulted in the test burner when the quantity of underfire air was 30 percent or less of the theoretical air and when the overfire air was 200 percent or less of the theoretical air. (One burner manufacturer suggested that rates for underfire air about twice those stated here should be provided.) Therefore, the fan sizing curves of Figure G-4 have been based on these percentages. Air rate varies directly with fuel rate and fuel rate varies as the square of burner-base diameter; therefore, air rate varies as the square of burner-base diameter.

For a 54-foot burner Figure G-4 indicates a rate for underfire air of 480 pounds per minute and an overfire rate of 3,200 pounds per minute. These rates are equivalent to 6,300 and 42,000 cubic feet per minute when air temperature is 60 F and air pressure is 14.7 psia. Underfire air is to be supplied by a single fan and overfire air by four fans.

Top Damper

Figure D-8 in Appendix D shows the damper arrangement used on the test burner. The damper was installed at the top of the burner at the base of the fire screen. The damper was a large butterfly configuration with two adjustable sliding steel plates that covered a large opening in the center of the butterfly. With slides fully withdrawn to the periphery of the burner, the open area was about 30 percent of the area of the top burner. The butterfly also could be opened as shown in Figure D-8 to give nearly 100 percent open area. Other configurations of dampers are made by burner manufacturers. The damper described was used on the test burner because it best fit the construction features of the burner. The installation of an adjustable top damper is recommended for the burner in this example.

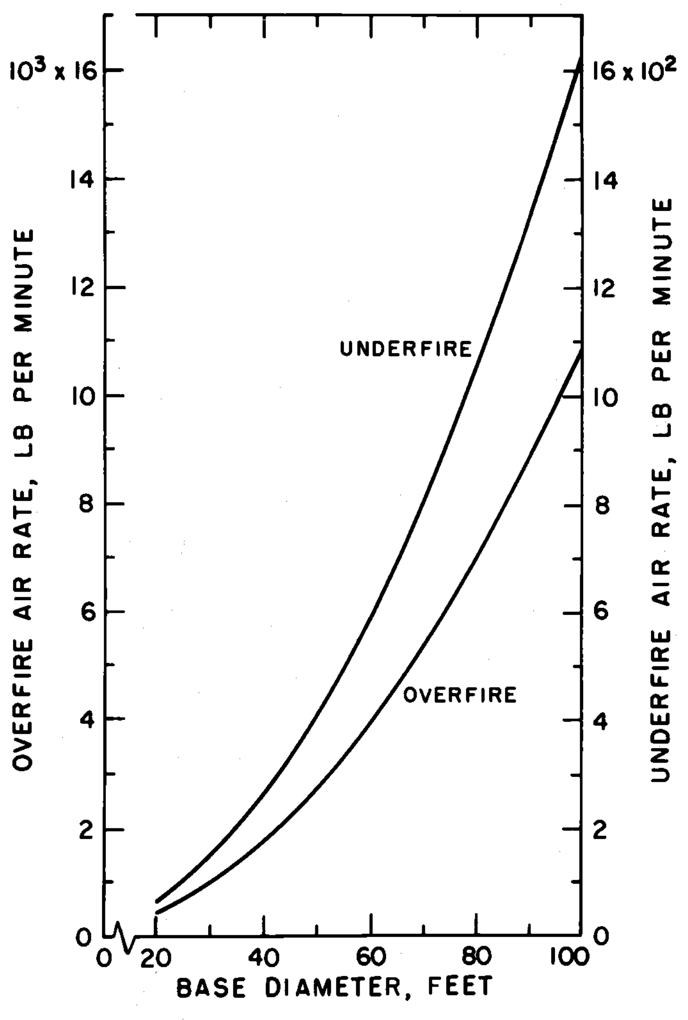


Figure G-4. Relation of air rate to burner size with 200 percent of theoretical air overfire and 30 percent of theoretical air underfire for Douglas fir hogged bark at 40 percent (67 percent, dry basis) moisture.

Fuel Size

Several short trials were made with fuels sized larger than hogged bark, but time did not permit full evaluation so no conclusions can be made as to the effect of fuel size on burning rate. Bark from some types of mechanical debarkers has a size similar to that of hogged bark.

Feed Rate Uniformity

Several short trials with nonuniform rates of fuel feed were made. These trials indicated that clean combustion could be attained with moderate surges of fuel, but further tests are needed to evaluate their effect. In this design example, we assumed that the feed rate is uniform with but minor surges.

Auxiliary Fuel

The test burner consistently was started from a cold condition without exceeding Ringelmann 2 by using gas burners for about an hour at the rate of about 10 million Btu per hour. Procedure was to allow fuel to build to a pile about 10 feet in base diameter before igniting the burners.

With the reasoning that the rate of supplying auxiliary fuel should be directly proportional to the rate of feeding bark and the square of burner-base diameter, the rate of supplying auxiliary fuel can be determined from Figure G-5. For a 54-foot burner, the recommended rate is 18 million Btu per hour.

Recirculation

Tests were not made with the recirculation system on the test burner. Therefore, no recommendations in regard to recirculation are made for this example.

Natural Draft

We recommend that natural-draft openings be eliminated from burners, or that they should have dampers to allow tight closure. Better combustion will result if all overfire air is introduced through fans at high velocity.

Instrumentation and Controls

All fans should be equipped with an orifice plate, a draft gage, and a thermometer so that air rates can be measured and initially adjusted to the estimated fuel rate. Automatic control of exit-gas temperature is recommended. There are different ways in which automatic control might be effected. The method to be followed in this design example is outlined in the following discussion.

Burning rate is to be controlled by a thermocouple monitoring exit-gas temperature. As exit-gas temperature approaches 800 F, dampers on fan inlets will reduce air flow through both underfire and overfire fans to decrease the burning rate and limit temperature to 900 F. Underfire and overfire fans previously will be manually set for the best ratio of

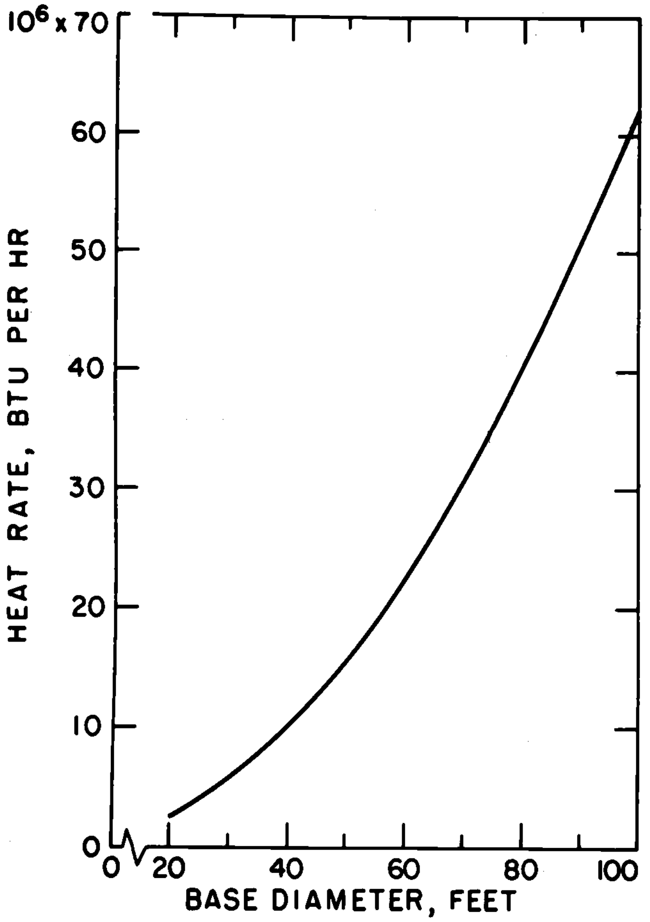


Figure G-5. Relation of burner size to auxiliary fuel firing capacity for starting with Douglas fir hogged bark at 40 percent (67 percent, dry basis) moisture content.

underfire to overfire air so that at all air-rate settings the ratio will be about the same. If exhaust-gas temperature decreases toward, say, 700 F, regulators on fan inlets will increase the air rate to increase the burning rate and maintain high temperature.

If exit-gas temperature exceeds 900 F, structural damage to the burner may occur. In fact, if structural supports are directly exposed to hot gases inside the burner, the burner may not be operated safely at 900 F. Operators should check with burner manufacturers to ascertain a safe temperature for their particular burner. For this design problem, maximum temperature selected was 900 F. When exit gas exceeds this temperature, a high-limit switch will sound a warning, stop fuel supply, and reduce air rates on all fans to a low predetermined rate. Air should not be completely shut off as this may result in damage to grates or overfire fan nozzles.

If exit-gas temperature is too low, say below 600 F, excessive air pollution will result. Therefore, a low-limit switch will ignite gas burners at 600 F. The burners will automatically shut off when exit-gas temperature reaches 700 F. To incorporate a signal to supervisory personnel when gas burners are on would be desirable, because adjustment of the burner damper or air rates may make auxiliary firing unnecessary in most instances.

Burners often smoke during short intervals when the mill is not operaing or after it has closed for the day. A time clock will be provided that automatically switches air rates to a predetermined setting at selected times. If smoke cannot be eliminated by this procedure, gas burners can be caused to automatically assist with completion of burning.

Starting will be manual by starting gas burners after enough fuel is on the grates. Burners will be shut off automatically by a limit switch at an exit-gas temperature of 700 F.

Automatic positioning of the burner damper dependent on exit-gas temperature may provide additional improvement in control. For example, if the damper opening is decreased as temperature decreases, leakage into the burner will decrease and exit-gas temperature will increase. Conversely, if exit-gas temperature tends to become too high, increasing the damper opening will encourage leakage and decrease exit-gas temperature. We assumed that adequate control can be attained by manual presetting of the damper. If the high-temperature warning signal is activated, the damper can be opened manually if necessary.

DESIGN SUMMARY

Fuel

Douglas fir hogged bark (or equivalent) at 40 percent (67 percent, dry basis) moisture content with reasonably uniform rate.

Maximum rate: 7.2 dry tons per hour, 12.0 wet tons per hour, or 5.1 units per hour.

Minimum rate (with damper): 2.2 dry tons per hour, 3.7 wet tons per hour, or 1.5 units per hour.

Burner Size

Base diameter of 54 feet.

Grates

Flat type with central grate box and four rings of grates with circle diameters of 8, 16, 24, and 32 feet.

Air Rates

Underfire: 480 pounds per minute; 6,300 cubic feet per minute from a single fan.

Overfire: total of 3,200 pounds per minute; 42,000 cubic feet per minute from four fans.

Top Damper

Recommended.

Fuel Size

Hogged or equivalent.

Auxiliary Fuel

Gas burners with capacity of 18 million Btu per hour.

Recirculation

No recommendations.

Natural-draft Openings

Eliminate or provide for tight closure.

Instrumentation and Controls

All fans controlled by exit-gas temperature. High-temperature cutoff of fuel, minimum air, and a warning signal. Low-temperature ignition of gas burners with indicator. Time clock for noon and evening control of air. Manual adjustment of top damper and proportions of underfire and overfire air.