FINAL PROJECT REPORT**UNITED STATES DEPARTMENT OF ENERGY****Project No. DE-FG01-89CE15437**

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**STEAM GENERATOR
with
INTEGRAL DOWNDRAFT DRYER** **BY****F.W. HOCHMUTH
CONSULTING SERVICES
POSTAL BOX 637
BREWER MAINE**

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INTRODUCTION

On June 30, 1989 a financial assistance award was granted by the United States Department of Energy, the purpose of which was to study and evaluate the technical aspect, the economic viability, and commercial possibilities of a new furnace design for burning high moisture cellulose type fuels. Prior to the award the then patented design was evaluated by the National Bureau of Standards Office of Energy Related Inventions. The first-stage consisted of reviews by three separate consultants. A second level evaluation was made by Mr. L.W. Carlson, a private consultant, then employed by the Argonne National Laboratories.

The new design is an invention by F.W. Hochmuth, P.Eng. and has received United States Patents Nos. 4,480,557 and 4,502,397. It was conceived as a method to improve the general operation and efficiency of waste wood burning boilers, to avoid the use of stabilizing fuels such as oil or gas, and to reduce objectionable stack emissions. A further objective was to obtain such benefits at relatively low cost by integrating all new material requirements within the furnace itself thereby avoiding the need for costly external equipment. The proposed integral down-draft dryer avoids the use of external dryer systems that are very expensive, have high power consumption, and require a large amount of maintenance.

The forest industries produce large amounts of shredded wood waste that has a large percentage of fines and a high moisture content. It is not unusual to find moisture contents greater than fifty percent (wet basis analysis) and in certain extreme cases as high as seventy percent. With such large amounts of water that must be evaporated before active burning can begin it is understandable why wood burning boilers are not easy to operate.

An appreciation of the effect high moisture has on the burning of wood can be had from the following example to which most people can relate. Fresh cut firewood will have a moisture content of about 50% which means that one pound of water must be evaporated for every pound of dry wood burned. Those who have tried to operate a fireplace or domestic stove with such fuel are aware of the difficulties. On the other hand if the wood is well seasoned, say down to 20% moisture, the amount of water to be evaporated is reduced to 0.25 pounds per pound of dry wood. Under such conditions the fire burns well. By contrast the wood waste furnished to many industrial boilers can have moistures of 50% to 70%, or 1.0 to 2.3 pounds of water per pound of dry wood. From the above the problem is rather obvious.

Due to the extreme difficulty in burning wood in the very high moisture ranges, 60 to 70%, mechanical dewatering is sometimes employed. However it is not practical to reduce moisture below 55% by that means, so there is still about 1.2 pounds of water to evaporate per pound of dry wood. To ensure stable combustion at low loads, and improve load following, the normal practice is to fire an auxiliary fuel such as oil or gas. The amount of the premium fuel may vary but is usually in the range of 10 to 15% of the full load heat input.

The purpose of the Hochmuth Downdraft Furnace is to provide an in-furnace system that will evaporate a significant amount of water from the fuel before it reaches the combustion zone. By so doing the need for a premium auxiliary fuel is avoided, and the overall combustion efficiency of the furnace is greatly improved. How all this is to be achieved will be explained in the main body of the report.

SUMMARY

On June 30, 1989 the United States Department of Energy (DOE) approved a project grant to examine the technical and commercial possibilities of a new wood burning boiler design described in U.S. Patent Nos. 4,480,557 and 4,502,397. These patents cover the invention of a wood fuel drying system that is made an integral part of the furnace in a wood fired boiler. Very high temperature combustion gases are used to dry moisture containing fuel as it falls down a vertical shaft that is located inside of, and integrated with, the furnace of a wood fired boiler.

The invention was submitted by Frank W. Hochmuth, the inventor, of Brewer, Maine, on January 28, 1986, under Section 14 of the Federal Nonnuclear Energy Research and Development Act of 1974. At that time the invention had been patented and was at the concept and engineering design stage.

The objective of the DOE funded project was to determine, to the extent possible, the technical feasibility and commercial potential of the patented in-furnace dryer design. To accomplish the foregoing several major tasks were proposed and carried out. On the following page is an illustration taken from the patent that shows a typical boiler in side elevation, that incorporates the in-furnace drying shaft. It is hoped that the information gained from the project will lead to a prototype installation or a license agreement with a boiler manufacturer or supplier of fuel burning equipment.

The following paragraphs will define and outline the various tasks undertaken. More detailed information will be found in the discussion section of this report as well as in the referenced appendices.

Technical Analysis

Several changes were made to the computer program that had been produced by L.W. Carlson as part of his Second Stage Evaluation Report to the National Bureau of Standards. The modifications were necessary to permit investigating various parameters that affect dryer shaft performance such as, height, cross sectional area, inlet gas temperature, gas flow rates, fuel feed rate, and moisture content of the fuel feed.

As exploratory computer runs were studied it was discovered that dryer shaft height was not as critical as it was once thought to be. The major portion of the drying, of the small particles, occurs in the first 25 to 30 feet of the dryer shaft. This is important since it indicates that the dryer can be installed in boilers having a moderate furnace height. On the other hand it was found out that the cross sectional area of the dryer shaft is quite important since it has a significant effect on the residence time of the small (4 mm or less) particles.

Using as an example a moderate size boiler located in Western Canada, a design and performance study was made to determine the applicability of the in-furnace dryer in that case. Details of study can be found in Appendix A. It was shown that about 20% of the fuel would be dried to zero percent moisture, and about 45% of the total dried to about an average of 34% moisture. With a fuel improvement such as that the steam output of the boiler could be increased from 70,000 lb/hr to 100,000 lb/hr, an increase of over 40 percent. A detailed performance comparison of this No.3 boiler with a more modern boiler, No.9, in the same plant indicates superior performance in many important areas.

A preliminary estimate of the cost to retrofit the No.3 boiler with an in-furnace down draft dryer system is \$1,500,000.00.

Experimental Work

One of the important requirements that was identified at the very beginning of the project was the need to obtain the proper distribution of fuel to the burning grate as it leaves the dryer shaft. Although most of the minus 4 mm particles, because of their low moisture content and small size, will burn above the grate, the remaining 50 to 60 percent made up of larger pieces must be burned on the grate. To do so efficiently requires that the fuel be distributed uniformly across the width of the grate, and in a controlled thickness from front to rear.

Since mechanical means for distribution, such as rotating distributors were impractical, it was decided to use a portion of the overfire air to pneumatically distribute the fuel.

The conceptual design of the distribution system consisted of an inclined shelf at the bottom of the dryer shaft upon which the fuel would fall. The shelf would be made of thick heat and wear resistant metallic castings made with passages for distribution air. In principle, the free falling fuel would strike the inclined shelf and lose its vertical velocity, then it would be caught in the distribution air streams and air swept into the lower furnace where the larger pieces would drop onto the grate.

For the above described distribution system to operate properly it is first necessary to feed the fuel uniformly across the width of the dryer shaft, and at a steady rate. There are ways and means known as to how that can be done. However obtaining the desired distribution and spreading from the bottom of the shaft was a new problem. Without prior experience as a guide it was necessary to determine the proper slope of the shelf, the air quantity, the air slot size/shape/velocity, and their geometric relationship to each other and the dryer shaft.

It became apparent that in order to obtain such information it would be necessary to develop the various parameters experimentally. Because of its convenient location, and previous work in the handling of wood chips, it was decided to discuss the matter with the Engineering Department of the University of Maine at their Orono campus. After several meetings with senior faculty their proposal for an experimental test program was obtained in February of 1989. It was proposed that laboratory tests be conducted in a full scale cross-sectional cold flow model with wood chips sized to be representative of the coarse fraction expected in a typical commercial installation. The object of the tests being to study fuel distribution patterns on a simulated grate, and to optimize the pattern by variation of the geometry of the dryer and deflection shelf, and of the distribution air slot shape and size, and air velocity.

An order was placed for the work in August of 1989. The tests were completed early in 1990 and a formal report summarizing the experimental work was issued in July, 1990. A complete copy of The report can be found in Appendix B. The results of the work are very satisfying. Apart from establishing the parameters for the air slots and air flows, a very critical geometric relationship between the air slots and the dryer shaft was discovered. It was first thought that the slots should be upstream of, or directly below the dryer shaft. Tests of those arrangements were unsatisfactory and it was not until a baffle was installed to direct the falling fuel to the top of the shelf ahead of the air slots that the desired distributuon was obtained. It is important that the falling fuel first give up its kinetic energy by striking the shelf, then sliding downward over the air slots where it is picked up and rides a carpet of air into the main furnace. The information gained from the experimental work will be extremely valuable during the detail design of a first commercial prototype installation.

Cost-Benefit Study

In October of 1989 an order was placed with Sandwell Swan Wooster Inc. (now Sandwell Inc.) of Atlanta Georgia, for the services described in their proposal No. QS1310/3-228, dated December 20, 1988. The purpose of this work was to study the retrofit of the Hochmuth in-furnace downdraft dryer design to an existing boiler and compare the order-of-magnitude costs of this retrofit to those of an external fuel dryer and a more conventional boiler upgrade. No.9 hog fuel boiler at the MacMillan Bloedel Harmac mill in Nanaimo, B.C. Canada, was selected as a model for the study.

A complete copy of the Sandwell Study is included in Appendix C. Of the three alternatives studied the evaluation indicates that the annual cost of the in-furnace dryer will be \$128,000.00 less than that for a system with an external dryer. The other alternative, a conventional system with some refractory added to the lower furnace, has an annual cost of \$71,000.00 more than the in-furnace dryer system.

Although the above comparison is favorable the estimates of the capital costs tend to present a distorted picture. It overburdens the in-furnace design with costs that are not directly related to the design and would not appear as incremental costs if the comparisons had been based on a new boiler installation instead of a retrofit to an existing boiler.

Cost estimates previously made by a leading boiler supplier show that the in-furnace dryer would increase the cost only 5% to 6% over that of a conventional design. The Sandwell study has the difference for the retrofit example estimated to be 56% greater. The main reason for the difference is in the amount of material

removed and totally replaced in the retrofit whereas for a new boiler there would be only a small incremental increase in the overall cost. This should be understandable since the amount of additional material is small and the cost of supplying the bulk portion is essentially the same since it is only fabricated to a different set of details. To show how this would affect the total first year operating costs a revised form of the Sandwell Evaluation of Alternatives, Table 8 - page 21, is shown below.

		Alt.1	Alt.2	Alt.3
<u>Items</u>	<u>Units</u>	<u>Hochmuth</u>	<u>Conv.</u>	<u>Dryer</u>
<u>Performance</u>				
Steam from hog fuel alone	lb/h	300,000	260,000	307,000
Steam from fuel oil	lb/h	7,000	47,000	0
Total steam generation	lb/h	307,000	307,000	307,000
Hog fuel consumption	BDlb/h	53,900	48,300	50,900
Hog fuel consumption	BD T/y	226,380	202,860	229,942
Fuel oil consumption	bbl/h	1.31	8.77	0
Fuel oil consumption	bbl/y	10,967	73,663	0
Auxiliary power	kW	54	28	585
<u>Capital Costs</u>				
Boiler modifications	\$1,000 US	8,045	7,590	7,620
Conveyor modifications	\$1,000 US	850	0	1,250
Hog fuel dryer	\$1,000 US	0	0	3,620
Overheads (35%)	\$1,000 US	3,113	2,660	4,370
Total capital costs	\$1,000 US	12,008	10,250	16,860
<u>Operating Costs</u>				
Capital Charges	\$1,000 US/y	2,126	1,814	2,984
Fuel oil	\$1,000 US/y	196	1,311	0
Auxiliary	\$1,000 US/y	19	10	209
<u>Total First Year</u>				
<u>Operating Cost</u>	\$1,000 US/y	2,341	3,136	3,193
<u>Differential</u>	\$1,000 US/y	Base	795	852

Note: The above evaluation is based on the following criteria:

- Capital charges of 12% per annum over 10 years on the total direct capital cost.
- 8,400 hours of annual operation.
- Incremental hog fuel cost of zero.
- Fuel oil cost of \$18 US per barrel.
- Auxiliary power cost of \$0.04 per kilowatt hr.

Market Analysis

An important task, if not the most important, was to determine if the Hochmuth in-furnace dryer concept could be marketed. To that end a market analysis was carried out by way of discussions with select groups consisting of boiler suppliers, end users, and consulting engineers.

During a period of 24 months the design was discussed in face to face meetings with four leading boiler suppliers, two consulting engineering firms, and several potential end users. Appendix D contains information typical of that presented in the meetings. Although information regarding the total potential market for wood burning boilers in North America was hard to come by, a survey made by one boiler supplier was obtained. A blinded copy of that survey is also included in the Appendix.

The purpose of these meetings, in the case of the four boiler suppliers, was to negotiate a license agreement or sell the patents to one of them. In the case of the users and consulting engineers the objective was to gauge their interest in the concept, and hopefully have one of them specify the design so that a prototype demonstration unit would be built.

In general the technical aspects of the presentations were well received by most parties. There was some evidence of the "not invented here" syndrome on the part of two boiler suppliers. None of the parties had any serious concern that the concept would not perform as predicted. One boiler supplier commented that although the concept was interesting and probably workable there was no need to improve wood burning technology since their present equipment was satisfactory. The users and consulting engineers did not agree with that philosophy. On balance the users were more enthusiastic than either of the other parties.

In spite of a considerable amount of effort all attempts to sell or license the technology have been unsuccessful. The same can be said with regard to a prototype demonstration installation. To a great extent the lack of success in one endeavor is because of a failure in the other. The boiler suppliers want to see the test results from an operating installation so they can write performance guarantees with a minimum risk to themselves. On the other hand a user is reluctant to invest in a large capital expenditure unless guarantees are offered.

The importance of a performance guarantee is more critical today than it was 10 or 15 years ago. The major concern of a supplier or user in today's world relates to meeting environmental regulations. In such cases where fuel burning is involved emission limits for such gases as oxides of nitrogen (NO_x), carbon monoxide (CO), and volatile organic compounds (VOC) must be met and guaranteed. For new technology a demonstration plant is the only real way to obtain the necessary information. To make the matter even worse it is usually required that such information be supplied during the permitting process before permission to install a prototype can be obtained.

Of course there are other reasons why it has not been possible to site a demonstration unit. For the past 3 to 4 years the economic health of the industries that could employ this new technology has been very poor. The same can be said for the business climate of the boiler suppliers which makes them reluctant to get involved in a new technology that may involve some risk, regardless of how small it might be.

DESCRIPTION OF DRYER SYSTEM

A conceptual design of the Hochmuth Down-draft Dryer is shown in Figure 1. The drying shaft is separated from the main furnace by a water cooled, fully welded division wall. The division wall tubes are separated and spaced at their upper ends so as to provide a screened entrance to the dryer shaft. The lower end of the division wall terminates in a horizontal header that is supplied by the furnace downtake system. In the illustration shown the tubes are arranged to form a shielded cavity that encloses the front wall overfire air nozzle supply duct.

The front and sides of the dryer shaft are also constructed as water cooled walls. They are supplied by horizontal lower headers, and terminate in upper front and sidewall headers. The lower ends of the front wall tubes are bent to form an inclined shelf below the dryer shaft, extending to the main furnace and overhanging the ash discharge end of the grate. The tubes that form the inclined shelf support, and are protected by erosion resistant castings. Some of the castings are provided with air openings or slots, strategically located so when provided with air in the required amount and pressure will effectively deliver the fuel to the main furnace and burning grate.

Some of the hot furnace gas enters the top of the dryer shaft through the spaced-tube screen. Moisture containing fuel, such as hog fuel, is introduced uniformly at the top of the drying shaft. As it falls in turbulent parallel flow with the hot and high temperature furnace gas moisture is evaporated. The hot gases are cooled by the evaporation process and their increasing density causes them to travel downward in the shaft and draw more hot gas into the top of the drying shaft through the upper screen opening. At the lower end of the shaft, the

now cooled moisture laden gas returns to the main furnace carrying along some of the dry fines. The remainder of the fuel, both coarse and fine strike the inclined shelf giving up most of their kinetic energy. The distribution air nozzles are located downstream of where the fuel strikes the inclined shelf. As the fuel passes downward on the shelf it must pass over the air slots and is caught up in and rides the carpet of distribution into the lower part of the furnace. Front to rear distribution of fuel to the grate can be controlled by the velocity and/or amount of air leaving the slots. Most of the fine fuel that is smaller than 4 mm will separate from the coarser fraction and burn in suspension above the grate.

Hog fuel as produced or purchased by typical pulp mills, or other users, contains a high percentage of fine particles. From a large number of size distribution tests it has been shown that on average about 50 percent of the wood refuse fuel will pass a 4 mm sieve cut size. Typical distribution curves are shown in Figure 2 which summarizes data developed by the ENFOR Project C-96, sponsored by the Canadian Forestry Service Department of Environment.

Because of the high temperature in the drying shaft, and the large surface to volume ratio of the fines it is predicted that about 40 to 50 percent of the total fuel feed will be dried to about 25 percent moisture. On a weight basis more than half of that 50 percent fraction will have its moisture content reduced to zero. It can be expected that the 50 percent fraction will burn mostly in suspension above the grate. The adiabatic, or theoretical, flame temperature of the fireball will be considerably higher than if the same amount of fuel were burned with its original moisture. The reason for this is that latent heat of evaporation of the water has been supplied in the dryer shaft, rather than from the fireball in the main furnace.

The larger pieces of fuel in the 50 percent coarse fraction lose very little moisture. This appears to be true for all present large capacity dryers. The reason for this is that for large pieces the moisture evaporation rate is controlled by diffusion, rather than surface heat transfer. Because of the relatively short residence time in these dryers the amount of moisture that can migrate by diffusion from the interior to the surface of the larger pieces is quite small.

As the coarser fuel arrives at the bottom of the dryer shaft it strikes the sloping surface of the shelf and is propelled into the furnace where because of its size and density it falls to the surface of the burning grate. The in-furnace downdraft dryer concept can be used with any of the various grate systems now in common use, that is to say they can be stationary, dumping, continuous ash discharge, and may be either horizontal or inclined. Experimental work has shown that the coarse fraction of the fuel can be satisfactorily distributed on a grate having commercial dimensions.

One of the problems common to present hog fuel burning systems can be described as bed-blanketing. That term describes a situation where significant amounts of undried fines, mixed with coarse fuel collect on the grate and block the flow of hot undergrate air. This prevents the hot air from drying the wet fuel, a cold spot develops, and combustion in that area is retarded. If under grate air flow is maintained then the air quantities, and velocities, in other areas where the fuel bed is thin will increase. This leads to blowholes that increase the amount of char carried up into the main furnace, and consequently the particulate emissions from the boiler. All this is no longer a problem if the fines are well dried and burned above the grate. Without the fines the fuel on the grate has a freeness that allows undergrate air to pass easily and uniformly.

When the larger fuel pieces land on the grate they still contain almost all of their original moisture content. Before it can be completely burned three distinctly different processes must take place. These in the order of occurrence are drying, devolatilization, and gasification of the residual charcoal. As might be expected there is some overlapping of the reactions. With the smaller sizes the reactions are more distinct and progress from one to the next very rapidly. For large thick pieces the outside may be dry and charring while moisture is still migrating from the center. In all instances wood must be devolatilized (reduced to charcoal) before the carbon can be gasified by the oxygen in the undergrate air to carbon monoxide.

The heat required to carry out the grate reactions is provided mainly from two sources. For the drying process some comes from preheated undergrate air but most is supplied as radiation from above. Most of the heat of combustion is liberated in the flame made up of the burning volatile matter and carbon monoxide emanating from the coarse fuel on the grate and the very dry fines in the fireball above.

It is important that a large quantity of fuel be retained on the grate, i.e. a thick fuel bed. Having such a reserve of fuel ensures the stability of operation, since it serves as a thermal flywheel to level out variations that might otherwise occur from erratic fuel feed. It is almost impossible to operate with a thick fuel bed if wet fines are intermixed with the fuel on the grate such as when the fines are not predried and treated separately. As previously pointed out this problem is avoided in down draft furnace design since the fines are handled "off the grate". A further advantage of a fuel inventory on the grate is that better load following can be achieved by using a control strategy by increasing undergrate air a certain amount more than that required by any additional fuel fired.

When first conceived the in-furnace down draft dryer was thought to be applicable only to tall furnaces, to provide the longest possible residence time. However after an extensive analytical investigation it was found that by proper sizing of the dryer shaft, and other adjustments, the concept could be successfully used with much shorter furnaces. Appendix A contains examples showing proposed designs, and predicted performance, of the dryer having shaft heights of 25 and 60 feet. As would be expected performance is better with the taller dryer, however the shorter one still produces acceptable results.

CONCLUSIONS

With a mathematical analysis of the drying process and computer modelling of the dryer shaft operation the technical feasibility of the in-furnace down draft dryer has been established.

Experimental work with a full scale cold flow section of a dryer shaft has demonstrated that a satisfactory distribution of fuel can be obtained across the width and along the length of typical burning grates.

Cost-benefit studies show a favorable rate of return for the new in-furnace dryer concept when compared to a conventional boiler without a dryer system or fitted with an external dryer system. In some site specific cases a retrofit installation will not show as favorable a return as would be obtained from a new boiler installation.

Discussions with leading North American boiler suppliers shows a strong reluctance on their part to adopt new technology that has not been conceived and developed "in house". There is also desire to avoid risk by staying with accepted products. This is especially true regarding products that interface with the environment. With respect to boilers the Clean-Air Act amendments have been particularly chilling.

Mainly because of the attitude taken by boiler suppliers there has not been an installation of the in-furnace downdraft dryer made to date. Potential users in the pulp and paper industry have shown considerable interest and enthusiasm but are unwilling to be the first to install especially since suppliers are reluctant to provide performance guarantees.

* * * * *

A P P E N D I X A

MACMILLAN BLOEDEL - HARMAC
BOILER UPGRADE STUDY

		<u>3</u>		<u>9</u>
		C-E VU-X		C-E VU-40
		Upgraded		Present
Mill Boiler No.				
Boiler Type				
Boiler Status				
Furnace Width	ft	15.6	15.6	22.2
Furnace Depth	ft	12.0	12.0	17.9
Furnace Height	ft	32.0	32.0	65.0
Furnace Plan Area	sq ft	187	187	396
Furnace Volume	cu ft	5990	5990	25930
Furnace EPRS	sq ft	1950	1950	5100
Grate Type	-	Dump	Dump	Pinhole
Grate Surface	sq ft	140	140	396
Dryer Shaft Width	ft	15.6	15.6	-
Dryer Shaft Depth	ft	2.0	2.5	-
Dryer Shaft Height	ft	25.0	25.0	-
Dryer Shaft Area	sq ft	31.2	39.0	-
Steam From Hog	lb/hr	90000	100000	250000
Dry Wood Weight	lb/hr	16400	18200	46800
Fuel Heat Value	btu/lb	8700	8700	8700
Moisture In Fuel	%	55.0	55.0	55.0
Water In Fuel	lb/hr	20600	22900	57200
Gross Heat Input	MMbtu/hr	142.4	158.2	407.2
Net Heat Available	MMbtu/hr	125.2	139.1	358.0
Combustion Rate	btu/cu ft	23800	26400	15700
Net Heat Release	btu/sq ft	64200	71300	67500
Fuel To Grate	lbs/hr	10700	11900	42100
Grate Comb. Rate	btu/sq ft hr	665000	740000	925400
Fur. Plan Comb. Rate	btu/sq ft hr	763000	847000	1028000
Wet Gas Weight	lb/hr	160000	178000	456000
Dryer Recirc. Gas	lb/hr	24000	30000	-
Dryer Recirc. Rate	%	15.0	16.8	-
Gas Temp. To Dryer	deg F	1700	1750	-
Gas Temp. From "	deg F	825	932	-
Excess Air	%	25.0	25.0	25.0
Comb. Air Required	lb/hr	127600	141800	358300
Undergrate Air	%	25.0	25.0	50.0
Overfire Air	%	75.0	75.0	50.0
Fuel Distib. Air	% of total	16.0	16.0	-
Gas Vel. Mid Furnace	ft/sec	17.3	19.5	20.0
Gas Vel. Above Grate	ft/sec	5.5	6.1	10.8
Furn. Residence Time	sec	2.1	1.9	3.0

Note: Original Rating of No.3 Boiler 70,000 lb/hr on wood.

1-8-91

MacMillan Blo 1 No. 3 Boiler

Dryer Height = 25.0 ft.

Dryer Width = 15.6 ft.

Dryer Depth = 2.0 ft.

Steam Generation 90,000 lb/hr.

EXAMPLE NO.7

INPUT VALUES	a	b	c	d	e
Dry Hot Gas Flow Rate - lb/hr	128000	128000	128000	128000	128000
Wet Hot Gas Flow Rate - lb/hr	160000	160000	160000	160000	160000
Recirc. Hot Gas Rate - lb/hr	22000	24000 ✓	26000	28000	30000
Dry Fuel Feed Rate - lb/hr	16400	16400	16400	16400	16400
Water In Fuel - lb/hr	20000	20000	20000	20000	20000
Fuel Density (Dry) - lb/ft ³	45.0	45.0	45.0	45.0	45.0
Fuel L/D Ratio - L/d	2.0	2.0	2.0	2.0	2.0
Temp. Hot Gas To Dryer - deg F	1700	1700	1700	1700	1700
Temp. Dryer Walls - deg F	497	497	497	497	497
Step Size (Interval) - ft	0.20	0.20	0.20	0.20	0.20
Dryer Length (Height) - ft	25.0	25.0	25.0	25.0	25.0
Excess Air - %	25.0	25.0	25.0	25.0	25.0
Fuel Carbon Multiplier - 20	20.0	20.0	20.0	20.0	20.0
Printout Interval -	228	228	228	228	228
Perf Pass Mesh - mm	0.30	0.30	0.30	0.30	0.30
Temp. Gas In. Dryer - deg F	768	825	877	922	964
Percent Dried - %	29.8	30.0	30.1	30.2	30.3
Average Moisture In - %	55.0	55.0 ✓	55.0	55.0	55.0
Average Moisture Out - %	46.1	46.0	46.0	45.9	45.9
Ave. Vel. Gas In Dryer - ft/sec	6.4	7.3	8.2	9.0	9.9
Ave. Residence (0-4 mm) - sec	2.40	2.22	2.07	1.94	1.82
Ave. Residence (5-53 mm) - sec	1.32	1.30	1.29	1.28	1.27
Ave. Moisture (0-4 mm) - %	34.1	34.0	33.8	33.7	33.7
Ave. Moisture (5-53 mm) - %	54.5	54.5	54.5	54.4	54.4
Recirc. Gas To Total Gas - ratio	0.137	0.150	0.162	0.175	0.187
Dryer Moisture Component - % weight	20.0	20.0 ✓	20.0	20.0	20.0

MacMillan Bl. el No.3 Boiler

EXAMPLE NO.8 Dryer Width = 15.6 ft Dryer Depth = 2.5 ft. Dryer Height = 25 ft.
 Steam Generation 100,000 lb/hr.

INPUT VALUES	a	b	c	d	e
Dry Hot Gas Flow Rate - lb/hr	142000	142000	142000	142000	142000
Wet Hot Gas Flow Rate - lb/hr	178000	178000	178000	178000	178000
Recirc. Hot Gas Rate - lb/hr	26000	28000	30000 ✓	32000	34000
Dry Fuel Feed Rate - lb/hr	18200	18200	18200	18200	18200
Water In Fuel - lb/hr	22200	22200	22200	22200	22200
Fuel Density (Dry) - lb/ft ³	45.0	45.0	45.0	45.0	45.0
Fuel L/D Ratio - 1/d	2.0	2.0	2.0	2.0	2.0
Temp. Hot Gas To Dryer - deg F	1750	1750	1750	1750	1750
Temp. Dryer Walls - deg F	497	497	497	497	497
Step Size (Interval) - ft	0.20	0.20	0.20	0.20	0.20
Dryer Length (Height) - ft	25.0	25.0	25.0	25.0	25.0
Excess Air - %	25.0	25.0	25.0	25.0	25.0
Fuel Carbon Multiplier - 20	20.0	20.0	20.0	20.0	20.0
Printout Interval -	228	228	228	228	228
Zero Pass Mesh - mm	0.30	0.30	0.30	0.30	0.30
Temp. Gas Lvg. Dryer - deg F	836	882	932	972	1006
Percent Dried - %	31.1	31.3	31.1 ✓	31.2	31.4
Average Moisture In - %	55.0	55.0	55.0	55.0	55.0
Average Moisture Out - %	45.9	45.8	45.9	45.9	45.8
Ave. Vel. Gas In Dryer - ft/sec	6.5	7.2	7.9	8.6	9.4
Ave. Residence (0-4 mm) - sec	2.40	2.25	2.12	2.00	1.90
Ave. Residence (5-53 mm) - sec	1.32	1.30	1.29	1.29	1.28
Ave Moisture (0-4 mm) - %	33.0	32.8	32.6 ✓	32.5	32.5
Ave. Moisture (5-53 mm) - %	54.3	54.2	54.2	54.2	54.2
Recirc. Gas To Total Gas - ratio	0.146	0.157	0.168	0.179	0.191
Zero Moisture Component - % weight	20.0	20.0	20.0 ✓	20.0	20.0

MacMillan Block No. 3 Boiler

EXAMPLE No. 9 Dryer Width = 15.6 ft Dryer Depth = 2.5 ft Dryer Height = 25 ft
 Steam Generation 80,000 lb/hr

INPUT VALUES

	a	b	c	d	e
Dry Hot Gas Flow Rate - lb/hr	116000	116000	116000	116000	116000
Wet Hot Gas Flow Rate - lb/hr	135600	135600	135600	135600	135600
Recirc. Hot Gas Rate - lb/hr	16000	18000	20000	22000	24000
Dry Fuel Feed Rate - lb/hr	14850	14850	14850	14850	14850
Water In Fuel - lb/hr	19650	19650	19650	19650	19650
Fuel Density (Dry) - lb/ft ³	45.0	45.0	45.0	45.0	45.0
Fuel L/D Ratio - l/d	2.0	2.0	2.0	2.0	2.0
Temp. Hot Gas To Dryer - deg F	1675	1675	1675	1675	1675
Temp. Dryer Walls - deg F	497	497	497	497	497
Step Size (Interval) - ft	0.10	0.10	0.10	0.10	0.10
Dryer Length (Height) - ft	25.0	25.0	25.0	25.0	25.0
Excess Air - %	25.0	25.0	25.0	25.0	25.0
Fuel Carbon Multiplier - 20	20.0	20.0	20.0	20.0	20.0
Printout Interval	1	2	228	228	228
Zero Pass Mesh - mm	0.30	0.30	0.30	0.30	0.30
Temp. Gas Lvg. Dryer - deg F	540	612	682	745	796
Percent Dried - %	28.3	29.2	29.9	30.0	30.4
Average Moisture In - %	57.0	57.0	57.0	57.0	57.0
Average Moisture Out - %	48.7	48.4	48.1	48.0	47.9
Ave. Vel. Gas In Dryer - ft/sec	2.8	3.5	4.1	4.8	5.4
Ave. Residence (0-4 mm) - sec	3.86	3.48	3.17	2.92	2.71
Ave. Residence (5-53 mm) - sec	1.41	1.38	1.36	1.35	1.34
Ave Moisture (0-4 mm) - %	37.2	36.6	36.0	35.5	35.2
Ave. Moisture (5-53 mm) - %	56.7	56.6	56.6	56.6	56.6
Recirc. Gas To Total Gas - ratio	0.118	0.133	0.147	0.162	0.177
Zero Moisture Component - % weight	20.0	20.0	20.0	20.0	20.0

MacMillan Bland No. 3 Boiler

EXAMPLE No. 10 Dryer Width = 15.6 ft Dryer Depth = 2.5 ft Dryer Height = 25 ft
 Steam Generation 90,000 lb/hr

INPUT VALUES	a	b	c	d	e
Dry Hot Gas Flow Rate - lb/hr	130500	130500	130500	130500	130500
Wet Hot Gas Flow Rate - lb/hr	152500	152500	152500	152500	152500
Recirc. Hot Gas Rate - lb/hr	18000	20000	22000	24000	26000
Dry Fuel Feed Rate - lb/hr	16700	16700	16700	16700	16700
Water In Fuel - lb/hr	22100	22100	22100	22100	22100
Fuel Density (Dry) - lb/ft ³	45.0	45.0	45.0	45.0	45.0
Fuel L/D Ratio - l/d	2.0	2.0	2.0	2.0	2.0
Temp. Hot Gas To Dryer - deg F	1700	1700	1700	1700	1700
Temp. Dryer Walls - deg F	497	497	497	497	497
Step Size (Interval) - ft	0.10	0.10	0.10	0.10	0.10
Dryer Length (Height) - ft	25.0	25.0	25.0	25.0	25.0
Excess Air - %	25.0	25.0	25.0	25.0	25.0
Fuel Carbon Multiplier - 20	20.0	20.0	20.0	20.0	20.0
Printout Interval -	2	228	228	228	228
Zero Pass Mesh - mm	0.30	0.30	0.30	0.30	0.30
Temp. Gas Lvg. Dryer - deg F	562	627	692	750	800
Percent Dried - %	28.5	29.2	29.6	29.9	30.2
Average Moisture In - %	57.0	57.0	57.0	57.0	57.0
Average Moisture Out - %	48.6	48.4	48.2	48.1	48.0
Ave. Vel. Gas In Dryer - ft/sec	3.3	4.0	4.6	5.3	6.0
Ave. Residence (0-4 mm) - sec	3.54	3.22	2.95	2.73	2.54
Ave. Residence (5-53 mm) - sec	1.39	1.37	1.35	1.34	1.33
Ave Moisture (0-4 mm) - %	38.0	36.6	36.1	35.7	35.5
Ave. Moisture (5-53 mm) - %	56.6	56.6	56.6	56.6	56.5
Recirc. Gas To Total Gas - ratio	0.118	0.131	0.144	0.157	0.170
Zero Moisture Component - % weight	20.0	20.0	20.0	20.0	20.0

COMBUSTION ENGINEERING-SUPERHEATER LTD.
MONTREAL

TYPE VU-X STEAM GENERATOR

FOR

MACMILLAN & BLOEDEL LTD.

HARIMAG, B.C.

CONSULTING ENGINEER—J.A. SINGH LIMITED, VANCOUVER, B.C.
125,000 LBS. STEAM PER HOUR (AT FULL DESIGN CAPACITY)

No. 3 Boiler
As Presently Installed

SCOPE OF SUPPLY

MACMILLAN BLOEDEL - HARMAC BOILER UPGRADE STUDY

Boiler Modifications	Drum Drilling & Internals
Waterwalls & Headers	Front & Side wall Extension
Dryer Shaft Wall	Tubes & Headers
New Supply Tubes	Front Wall & Dryer Shaft
Roof Tubes	Front Extensions
Settings & Casing	Lower Front & Roof
Casing & Buckstays	Front & Partial Side
Insulation & Lagging	New Front Wall & "
Special Castings	Fuel Distribution Shelf
Air Nozzles	Front & Rear O.F. Air (9)
Air Ducts	Over Fire & Distribution Air
Insulation & Lagging	Air Ducts
Damper & Expan. Joints	Distribution & O.F. Air System
Doors & Miscellaneous	Boiler Front & Observation Doors
Misc. Steel	Boiler
Booster Fan & Motor	To Boost Static (75% Total Air)
Oil Guns	Starting Burner Service (4)
Doors & Misc.	Dump Grate Front
Drain Valves	Two New Lower Headers (8)
Field Erection	All Furnished Material

Not Included:

Fuel Feeders
Combustion Controls
Asbestos Removal
Oil Burner Piping
Demolition - External Interferences
Operating Manuals
Start-up Services

Note: Boiler is presently out of service. Erection can be on a straight time basis.

COMBUSTION ENGINE

Furnace Dimensions:

Width	-	15' 7 $\frac{1}{4}$ "
Depth	-	12' 0"
Height above grate-	-	32'
Drum Centers	-	28' 0"

Wall Construction: (New)

Front - Welded	-	2 $\frac{1}{2}$ " @ 3 $\frac{1}{2}$ "
Side Extensions	-	2 $\frac{1}{2}$ " @ 3 $\frac{1}{2}$ "
Roof - Finned	-	3" @ 5-1/8"
Division - Welded	-	2 $\frac{1}{2}$ " @ 3 $\frac{1}{2}$ "

Design & Performance:

Design Pressure	-	675 psi
Operating "	-	625 psi
Steam Temperature	-	725 deg F
Generation	-	100,000 lb/
Air Preheat	-	365 deg F

No. 3 Boiler Upgraded
Furnace Dryer Installed

A P P E N D I X B

WOOD FUEL DISTRIBUTION TESTS FOR STEAM
GENERATORS WITH INTEGRAL DOWN-DRAFT DRYER

A Report prepared for

F. W. Hochmuth

by

John G. Riley, Professor
Bio-Resource Engineering Department
University of Maine
Orono, Maine
04469

July, 1990

WOOD FUEL DISTRIBUTION TESTS FOR STEAM
GENERATORS WITH INTEGRAL DOWN-DRAFT DRYER

INTRODUCTION

Throughout the United States the lumber and paper industries utilize wood wastes as a boiler fuel for power generation and process steam production. Most wood wastes are at a moisture content of 50-80%; this results in combustion inefficiency due to the energy required to evaporate this moisture, and reduced combustion temperatures with potentially increased emissions. Drying of the fuel prior to combustion alleviates these problems but no satisfactory system has yet been developed. F. W. Hochmuth has proposed and patented a method for pre-drying of the fuel by introducing it at the top of a drying shaft that forms one wall of the furnace. Hot furnace gases recirculate down through the drying shaft. The wood waste falls through the hot gas toward the bottom of the shaft, with the various particle sizes being heated and dried to different degrees. At the base of the drying shaft the wood fuel is then distributed onto the grate of the boiler.

It has been proposed that this distribution could be accomplished by means of an inclined shelf at the base of the shaft, with air nozzles in the shelf designed to deflect and project the fuel particles onto the grate, while at the same time providing a portion of the required overfire combustion air. This study was initiated to establish the design of the

shelf and nozzle size and configuration which would optimize the fuel distribution on the grate. It has previously been determined that with the traveling-grate furnaces typical of proposed installations, the fuel-bed profile shown in Figure 1 would be optimum, with as uniform a particle size distribution over this profile as possible.

EXPERIMENTAL DESIGN

In order to achieve the above objective, it was proposed that a full-scale cold model of the drying shaft, shelf, nozzles and grate be fabricated, and a series of tests conducted to determine the fuel distribution pattern as a function of dryer and deflection plate geometry, distribution air nozzle shape and size, and air velocity. Although the drying shaft on a boiler might be 18 ft. or more wide, the model, although full-scale, would represent only a 4 ft. wide section of the shaft and grate. Although in practice the drying shaft would be 30 ft. or more in height, to maximize the drying time, in the cold model this height would not be necessary. Experiments were conducted to determine the mean terminal velocity of the fuel particles, and a shaft was then fabricated of sufficient height to enable this velocity to be reached before the particles impinged on the shelf.

The following system parameters were established for the 4/18 scale model:

	<u>Full Scale</u>	<u>Model</u>
Fuel Feed Rate - lbs/min (dry)	586	130
Grate Length - ft.	20	20
Grate Width - ft.	18	4
Total Combustion Air - lbs/min	4,500	1,000
Underfire Air - percent	40	40
Overfire Air - percent	45-35	45-35
Distribution Air - percent	15-25	15-25
Air Temperature - deg F	450	80
Fuel Moisture - percent	40-50	40-50

It was also determined that the particle size distribution of the fuels used in the tests be similar to those which would commonly be used in the full-scale boilers.

Three minute fuel feed runs were planned, with variations in deflection plate angle, nozzle size and shape, and air velocity. Initial runs indicated that consistent results were being obtained with tests of shorter duration, and subsequent runs were limited to 1-1/2 minutes. It was planned to investigate plate angles of 30, 35, 40, 45, 50, 55 and 60 degrees (from horizontal), for each of four different nozzle sizes. It became apparent at an early stage (see Results section) that this range of testing was unnecessary. For the purposes of establishing fuel distribution profiles it was proposed that the grate be represented by a matrix of boxes into which the fuel would be blown, and the contents of

which would then provide data for establishing longitudinal and lateral fuel profiles on the grate.

This experimental design underwent several modifications as testing proceeded.

APPARATUS

Design:

Prior to the final design for the test apparatus it was necessary to determine (a) drying tower height and (b) range of nozzle numbers, sizes and air velocities.

Tower Height:

It was hypothesized that in a cold model the only variable affecting distribution at a constant feed rate, plate angle, nozzle size and air velocity would be the downward velocity of the fuel prior to striking the distribution plate. In the full-scale boiler with vertical drops of 30 ft. or more the particles would have ample time to reach maximum velocity and then continue falling at a constant rate. It was therefore necessary that the model be high enough to allow the particles to reach at least this velocity. To determine this, laboratory tests were conducted to calculate the mean terminal velocity of the fuel particles and thus the height needed to achieve this.

The apparatus used is shown in Figure 2. A variable speed fan blows air upwards through a 4"

diameter clear plexiglas pipe equipped with flow straighteners and a pitot tube air velocity sensor. Fuel particles were dropped into the tube and the fan speed adjusted until the particle was just suspended in the airstream. The air velocity determined from the pitot tube and a manometer then represents the terminal velocity of that particle. A series of runs was made, covering the expected range of particle sizes and moisture contents. The results are shown in Table 1. From this table it was determined that the maximum expected terminal velocity for any particle was 34 ft/sec.

From the equation:

$$V_2^2 - U_2^2 = 2 a S$$

where V = Final Velocity, ft/sec

U = Initial Velocity, ft/sec = 0

a = Acceleration due to gravity,
32.2 ft/sec²

S = Vertical distance, ft.

$$S = \frac{V^2 - U^2}{2a} = \frac{34^2 - 0^2}{64.4} = 17.89 \text{ ft} \approx 18 \text{ ft.}$$

Therefore the model would need to provide a vertical distance of at least 18 ft. before the fuel particles hit the shelf.

For these calculations the downward velocity of the drying gas in the prototype was omitted. While this would certainly affect the particles' terminal velocity the results indicated that in fact distribution over the grate was dependent on the nozzle geometry and airflow rather than any velocity-related "bouncing" of the particles on the shelf.

Nozzle Size & Airflow:

Air velocities needed to distribute the fuel over the length of the 20' grate were unknown and considering the shape of the particles would be extremely difficult to calculate from first principles. Therefore an empirical approach was taken, with a best estimate used for the first design, with subsequent design modifications made as a result of actual results.

Total air needed in model = 1,000 lbs/min

Distribution air = 15% = 150 lbs/min

= 2,000 cfm @ 70°F

Air deliveries were calculated for 2", 3" and 4" diameter nozzles, at static pressures of 10, 15, 20 and 25 in H₂O.

$$\text{Velocity} = C_d \sqrt{2gh} = C_d \sqrt{\frac{h * 64.4 * 62.4}{12 * d_a}}$$

where C_d = Discharge coefficient = 0.7

h = Static pressure in inches H₂O

d_a = Air density @ 60°F = 0.076 lbs/ft³

		<u>Air Discharge (lbs/min)</u>		
<u>h</u>	<u>V</u>	<u>2"</u>	<u>3"</u>	<u>4"</u>
25"	232 ft/sec	22	52	92
20"	207	20	46	82
15"	179	17	40	71
10"	147	14	32	58

Although in the cold model tests would be conducted with air at 60°F, in the prototype this combustion air would be preheated to approximately 500°F. At this temperature air density = 0.041 lbs/ft³ and the above table becomes:

		<u>Air Discharge (lbs/min)</u>		
<u>h</u>	<u>V</u>	<u>2"</u>	<u>3"</u>	<u>4"</u>
25"	316 ft/sec	17	38	68
20"	283	15	34	61
15"	245	13	29	53
10"	200	11	24	43

Thus to deliver the same mass of air at the same velocity at this increased temperature, it would be necessary to increase either nozzle size or number proportionately--see Conclusions section.

In the model however, at, for example 15" static pressure, each 2" diameter nozzle would deliver 17 lbs air/min. With a total requirement of 150 lbs/min, 9 nozzles would be needed. However, it was felt that flat rather than round nozzles would be more effective. A 2.5" diameter pipe squashed to a 1" x 3" shape has the same cross sectional area as a 2.0" diameter round nozzle.

Thus the first design called for nine 1" x 3" nozzles arranged in the deflection shelf as shown in Fig. 3. These calculations were based on air at 60°F.

Fabrication:

The model drying tower, firebox and grate were fabricated from 1/2" plywood with 2 x 4 corner reinforcements. Figures 4 and 5 show the layout and dimensions of the model. Fuel feed into the drying tower was achieved using an 8' x 4' x 1' tray, with a moving headboard winched forward by a 1/4 HP gearmotor. The tray held sufficient fuel for a 3 minute run, and the winch speed was set to deliver the required 130 lbs (dry) fuel/minute.

The deflection shelf was initially constructed of plywood, with slots cut in for the nozzles. Steel

exhaust tubing (2-1/2" diameter) was used for the nozzles. Six inch long pieces were flattened at one end to give the 1" x 3" shape, and the pieces were then attached to the plate and sealed. A 15" wheel diameter radial blade centrifugal blower was attached to the plenum, belt driven from (initially) a 5 HP electric motor.

The grate was represented by a series of 10 plywood boxes, 4' x 2' x 1'. These could be removed after a run and the contents weighed to determine the distribution. After each run and weighing, the chips were put into a tipping hopper and hoisted back up to the feed tray.

TEST PROGRAM & RESULTS

Initial runs were made with the nozzle shelf at 45° and the nozzles themselves at 10° (upwards) to the horizontal. Fuel moisture content was 45% (wet basis), and particle size distribution as follows:

<u>Sieve Size</u> <u>(ins)</u>	<u>% Passing</u> <u>(by weight)</u>
1-1/2	100
1	95
3/4	93
1/2	55
3/8	36
1/4	3

This size distribution is not completely representative of the material that might be encountered in the prototype,

particularly in regard to the absence of fines. However it was felt that particle separation would occur at the discharge, and that the fines would undergo combustion before they could fall to the grate, and thus their effect on fuel distribution on the grate is minimal.

After each run the weight of chips in each box was plotted on a graph and a profile drawn. Samples of these data sheets are included in the Appendix. It had initially been planned to take lateral as well as longitudinal profiles but it became apparent immediately that all the lateral profiles would be flat, i.e., distribution across the grate was uniform. At this point the collection boxes were removed entirely, and profiles plotted using measurements of the bed depth along the side of the chamber.

Profiles from early runs showed very little projection down the length of the grate. Little of the fuel appeared to be entrained in the airstream from the nozzles, and most of the chips simply bounced off the angled plate and formed a heap approximately 4 ft. down the grate. Measurement of static pressure in the plenum gave figures of only 8-10" H₂O. It was found that there were significant leaks around the shelf, and in the plenum itself. Sealing these leaks improved the profiles somewhat. The plate angle was then varied from 30-60° to the horizontal. Surprisingly this had minimal effect on the profile.

Fan speed was then increased resulting in static pressures in the range of 12-15" H₂O. This improved the distribution pattern but there was still a marked peak at the 4' mark indicating that many of the chips were not being entrained.

A plexiglas window was installed in the side of the chamber, allowing direct observation of the chips as they hit the shelf. It was noted that the chips were falling in clumps, but that this was probably a realistic situation. It was also seen that those chips which hit the plate above the nozzles and slid across them were more likely to be entrained than those which landed directly on the nozzles. There are probably two reasons for this: (1) the chips hitting above are dissipating their kinetic energy to the plate, rather than to the airstream itself; and (2) after hitting the plate they slide flat across the nozzle thus presenting the greatest surface area to the airstream. Those chips hitting the nozzles directly present random profiles to the airstream, i.e., some flat, some on edge.

In order to force the chips to hit above the nozzles and slide over them, a deflection plate was installed at the base of the drying tower - see Figure 5. Although there was some concern about the practicality of such a plate in the real boiler, it was felt that the same effect could be achieved by lengthening the nozzle shelf and locating the nozzles further down.

With this deflection plate in place the profiles again improved somewhat. The first shelf and nozzle assembly was now removed and replaced with a steel plate shelf with slotted nozzles 4" x 5/8" machined into the plate. The profile (Run #30) showed a reduction in the 4' peak, and increased distribution to the far end of the grate--a more desirable profile. Variation of plate angle under these conditions again had little or no effect.

Although the profile was improving, direct observations showed that many chips were still not being entrained, but were somehow being swept around the nozzles in both rows. Therefore it was decided that longer slots might be better, providing overlap and reducing the possibility of the chips missing the nozzles altogether. A new plate was made, with 9 slot nozzles, each 6" long, 3/8" wide. With this plate the profiles showed a marked improvement (see Runs 36 and 37).

The fan speed was again increased to 4,015 RPM, using a 10 HP electric motor. Static pressures in the range 15-17" were now attainable. The resultant profiles (Runs 44, 45, and 46) were essentially identical to the ideal. For all these profiles the plate angle was 30°. At this point these last runs were repeated using new, wetter chips (average moisture content 55% wet basis) and samples taken from the resulting profiles for determination of particle size distribution. The data and resultant graphs are included in the Appendix. These runs were video taped.

CONCLUSIONS & RECOMMENDATIONS

This extensive series of experiments, involving a total of 46 runs, resulted in a final design which produced the optimum fuel distribution pattern on the grate. Although initially it was proposed to study the effect of a wide range of plate angles, nozzle sizes and airflows, not all of this was done as it appeared unnecessary. For example, the angle of the plate was shown to have little or not effect on distribution pattern, within the range tested (30° - 60°). Similarly the ideal size and configuration of the nozzles was arrived at through experimentation and it was not deemed necessary to look at other arrangements.

The final nozzle size for the cold model was 6" x $\frac{3}{8}$ ". Referring back to Page 7 indicates that to achieve the same mass/velocity characteristics with air at 500°F , and retain the same number of nozzles, the prototype nozzle would need to be increased by a factor equal to the square root of the ratio of the air densities at 60°F and 500°F . This results in a recommended nozzle dimension of 6" x $\frac{1}{2}$ ".

Thus the proposed design would be as shown in Figures 5 and 6, i.e., two rows of slotted nozzles 6" x $\frac{1}{2}$ ", with 17" static pressure. Under these conditions the distribution air (2,400 cfm) in the model represent 17% of the total air--this is within the range felt to be acceptable. The fuel distribution from this design is essentially flat, but with

slightly more fuel blown to the far end of the grate. With the travelling grate moving right to left on the profiles this is a desirable feature.

Although plate angle was a relatively insignificant variable compared to nozzle geometry and air velocity, 30° was selected as an appropriate setting. The nozzle centerline would be at an angle of 80° to the plate (see Appendix)--i.e., the nozzles are at an angle of 50° to the horizontal.

Particle size data were taken at 4' intervals along the bed for the final runs. As can be seen from the resultant curves (Figure 7) there was very little difference in size distribution along the bed and no obvious tendency for a particular size fraction to accumulate at a specific location.

TABLE 1. Terminal Velocity Data for Wood Fuel Particles

<u>Particle #</u>	<u>Terminal Velocity (ft/sec)</u>	
	33% M.C.	55% M.C.
1	27.5	34.0
2	26.7	30.6
3	24.1	27.5
4	26.7	32.0
5	28.7	--
6	27.5	33.4
7	26.7	32.7
Mean	26.8	31.7

TABLE 2. Particle size data for Run #44.

Sieve Size (Ins)	% Passing by weight				
	Distance from fuel feed end (ft)				
	4	8	12	16	20
1	100	100	100	100	100
3/4	94	88	93	96	97
1/2	68	54	67	70	72
3/8	48	31	41	47	51
1/4	27	12	17	24	27
Pan	0	0	0	0	0

FIGURE 1. Ideal fuel bed profile

FIGURE 2. Schematic of apparatus for measuring terminal velocity of fuel particles.

ED-RODZ POWERS DEPARTMENT	
UNIVERSITY OF MAINE	
INITIAL NOZZLE DESIGN	
DATE	1/20/78
BY	ED-RODZ
NO.	2

FIGURE 3. Initial Design for Nozzle Layout

EXPERIMENTAL RIG FOR DISTRIBUTION TESTS

Notes:

- 1) Angle theta normally 45 degrees but shelf hinged to permit adjusting ± 15 degrees
- 2) Dimension h to be determined by preliminary experiments.
- 3) Capacity of fuel bin sized to permit runs of 2 to 3 minutes.

FIGURE 4. Preliminary Design for Test Apparatus

FIGURE 5. Final Design for Test Apparatus

BIT-RESOURCE ENGINEERING DEPARTMENT			
UNIVERSITY OF MAINE			
AIR INJECTION PLATE			
DATE	BY	REVISION	REVISION NO.
2/18/98	2/18/98	2/18/98	2
REVISION	DATE	BY	REVISION NO.

FIGURE 6. Final Design of Nozzle Plate

FIGURE 7. Particle Size Distribution Along the Fuel Bed for Run #46

APPENDIX

Original data sheets and profiles for
Runs 30, 36, 37, 44, 45, and 46

<u>Run #</u>	<u>Plate Angle, α°</u>
30	45°
36	30°
37	30°
44	30°
45	30°
46	30°

Nozzle and plate geometry for final series of runs

BIO-RESOURCE ENGINEERING DEPARTMENT

Woodchip Fan Test

steel plate 2 var 4 hole
on top

Comments

RUN # 30

NOZZLES 45°

DATE Dec 4 1964

ANGLE

PEAK 5 ft

PRESSURE 15 1/4 sp. 1.1" water

by Beattie

FEET

Woodchip Fan Test

Comments

RUN # 34

DATE Jan 2 1996

PEAK

NOZZLES

ANGLE 300 Plywood dale

PRESSURE S.P. 15 1/2" 1.2" water

22200 CFM

Also 1/2 (9 1/2") baffle

BLU-NEED SOURCE ENGINEERING LUFAN, ILLINOIS
Woodchip Fan Test

Comments

RUN # 37

DATE Jan 3 1990

PEAK

NOZZLES 30° Source data
ANGLE 30° Source data
PRESSURE S.D. 15 1/2" 1.2" orifice
2200 CFM

DURNEBOUNCE ENGINEERING ULF AMPLIFIER
Woodchip Fan Test

Comments

RUN #

42

(44)

DATE

Jan 18 1990

PEAK

NOZZLES

ANGLE 30° Bounce

PRESSURE S.P. 17" 1.35" water

22400 CFM

BLU-RESOUNCE LONG-RUNNING BLANKET Woodchip Fan Test

Comments

RUN # 43616
DATE Jan 12, 1990
PEAK

~~80°~~ 6" SIKS 8-7/16

W/B Baffle

NOZZLES
ANGLE 30° Bounce
PRESSURE S.D. 16" 1.20" water
32275

DTD RESISTANCE ENVIRONMENTAL DEGRADATION Woodchip Fan Test

301 C's 15 10 7/15
 11/19/88

Comments (216)
 RUN # 44
 DATE Jan 18 1990

NOZZLES 300 Bourne
 ANGLE 5.015"
 PRESSURE 1.17" water

22200 CFM

PEAK

A P P E N D I X C

REPORT 112246/1
31 AUGUST 1990

F.W. HOCHMUTH CONSULTING
BREWER, MAINE

HOCHMUTH DRYER STUDY

STUDY OF THE RETROFIT OF THE HOCHMUTH
INTEGRAL DOWN-DRAFT FURNACE TO AN
EXISTING BOILER

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REPORT 112246/1
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F. W. HOCHMUTH CONSULTING
BREWER MAINE

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THE HOCHMUTH INTEGRAL
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EXISTING BOILER

DATE 31 AUGUST 1990

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SUMMARY

The integral down-draft boiler furnace design developed by F.W. Hochmuth can be retrofitted to an existing boiler. This design provides for the partial drying of wet woodwaste fuel inside the furnace to permit stable firing at higher furnace loadings than conventional designs with no supplementary fuel requirement.

Sandwell was retained to study the retrofit of the Hochmuth furnace design to an existing hog fuel boiler and compare the order-of-magnitude costs of this retrofit to those of an external fuel dryer and a more conventional boiler upgrade. No. 9 power boiler at the MacMillan Bloedel Harmac mill in Nanaimo, B.C., Canada, was selected as a model for the study.

No. 9 boiler is a 25 year old CE type VUX 40 fixed grate boiler, rated at 250,000 lb/h on hog fuel alone. This unit fires 55% and higher moisture hog fuel with supplementary fuel oil. Fuel oil costs for this boiler were in the order of \$1.4 million for 1989. The boiler will soon require a furnace rehabilitation, comprising a grate, lower furnace tube and air system replacement. The simple air system is of particular concern with respect to combustion stability and furnace carryover.

Three alternative retrofit schemes were therefore studied. All alternatives included replacement of the grate with a modern vibrating grate, replacement of the air system with a modern design overfire system and modification of the lower furnace. The scope of the alternative schemes is briefly described below:

1. Alternative 1 - Hochmuth furnace design
 - Replacement of the grate and combustion air system
 - Modification of the furnace to suit the Hochmuth furnace design and the new grate and air system requirements.
 - Modification of the fuel supply conveyors to introduce fuel higher in the furnace.
2. Alternative 2 - Conventional furnace retrofit
 - Replacement of the grate and combustion air system
 - Modification of the furnace to suit the new grate and air system requirements and to provide some refractory for greater heat retention in the lower furnace.

3. Alternative 3 - External fuel dryer

- Replacement of the grate and combustion air system
- Modification of the furnace to suit the new grate and combustion air system and to include two semi-suspension burners.
- Installation of a flue gas hog fuel dryer system
- Modification of the fuel supply conveyors to feed the dryer system separately.
- Modification of the flue gas breeching to include the dryer in the flue gas circuit.

All of the alternatives will increase hog fuel steam generation and virtually eliminate supplementary fuel requirements. Alternatives 1 (Hochmuth) and 3 (Dryer) will provide superior performance due to the dryer fuel fired. The particular arrangement of the hog-fuel handling system at Harmac is more favourable to the Hochmuth system than it would be at a typical plant. Alternative 1 costs provide for complete replacement of the Furnace front wall. The performance and order-of-magnitude capital costs of the alternatives are summarized in Table S-1.

Table S-1 - Summary Comparison of Alternatives

<u>Item</u>	<u>Units</u>	<u>Alt. 1 Hochmuth</u>	<u>Alt. 2 Conv.</u>	<u>Alt. 3 Dryer</u>
<u>Performance</u>				
Steam generated from hog fuel	lb/h	300,000	260,000	307,000
Hog fuel consumption	BDU/h	32	28	30
Additional auxilliary power	kW	54	28	585
<u>Capital Costs</u>				
Boiler and breeching modifications	\$1,000	11,050	7,600	8,800
Conveyor modifications	\$1,000	850	0	1,250
Hog fuel dryer	\$1,000	0	0	2,450
Overheads	\$1,000	4,200	2,700	4,400
Total capital	\$1,000	16,100	10,300	16,900

The alternatives were evaluated by assessing the maximum steam generation from hog fuel, and applying a cost for fuel oil generated steam to make up the difference to the alternative with the highest hog steam performance. These costs were added to the costs for incremental auxilliary power and capital recovery to arrive at a total first year differential operating cost.

This evaluation showed all alternatives to be very close in first year differential operating cost, with Alternative 1 (Hochmuth) the least cost alternative by \$128,000/y over Alternative 3 (dryer) and \$71,000/y over Alternative 2 (Conventional). This assessment does not include differential operating or maintenance costs, which can be expected to be much higher for Alternative 3.

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INTRODUCTION

F.W. Hochmuth Consulting has developed and patented a design for a unique furnace concept that permits in-furnace drying of wet wood waste fuels. In this design, high temperature, furnace flue gas is recycled past the wet fuel after the fuel is fed to the boiler furnace cavity, but before the fuel reaches the combustion zone, thereby evaporating moisture from the fuel. The result is more stable combustion and higher specific output from the furnace.

The Hochmuth in-furnace dryer could be used on a new boiler or could be applied to an existing power boiler to reduce dependency on oil, to burn more hog fuel, and to increase the steam generating capacity of the boiler.

The objective of this study is to examine the manner in which the Hochmuth technology could be applied to an existing boiler as an alternative to the conventional methods of improving the combustion of wet wood waste fuel. Two methods are considered for comparative purposes in this study. These are:

- External drying of hog fuel in a dryer using flue gas as the drying medium, and
- Retrofit of a modern, but conventional, design furnace, employing refractory covered tubes in the lower furnace area.

For the purposes of the study, the hog fuel will be assumed to have a moisture content of 55%, wet basis. The combustion of fuel with moisture content higher than 55% would not be guaranteed without supplementary fuel in conventional boilers of North American design.

An existing boiler has been selected to serve as a model for the retrofit study. No. 9 power boiler at the Macmillan Bloedel Harmac mill in Nanaimo, B.C., Canada, was selected by F.W. Hochmuth Consulting for this purpose. The boiler is a 25 year old CE VUX 40 fixed grate boiler with a design capacity of 250,000 lb/h on hog fuel alone. A side elevation of the boiler is shown in Figure 1 in Appendix 3. The unit is well maintained, but has a fixed grate and a rudimentary air system and consequently requires a substantial amount of supplementary fuel oil. Macmillan Bloedel, and in particular steam plant superintendent Fred Williamson, was very cooperative in providing access to the boiler and supplying information important to the development of the study.

Designs are developed for each of the three alternatives for the estimate of order-of-magnitude capital costs. A technical assessment of the Hochmuth system is incorporated, as well as an economic analysis of the retrofit.

This study was prepared for F.W. Hochmuth for the purpose of the feasibility assessment of the Hochmuth furnace design in a particular retrofit application.

BOILER DESIGNS FOR HIGH MOISTURE HOG FUEL

Woodwaste fuels are used for steam generation throughout the forest industry due to their high availability, low cost and generally high calorific value. There are some problems in the efficient combustion of these fuels, however, due to their high moisture content and variable properties.

Operators of woodwaste boilers frequently experience problems with poor combustion efficiency, high particulate carryover and unstable combustion conditions. This usually results in limitation of the quantity of hog fuel fired and burning of substantial amounts of relatively high cost supplementary fossil fuel. It generally also requires the addition of back end particulate control equipment to meet particulate emission limits.

Boiler designers have responded to the challenges of firing this difficult fuel with a variety of different furnace designs. These designs are intended to compensate for some (or all) of the problems of woodwaste fuel. The furnace designs include:

- Refractory lined cell-type furnaces
- Fixed grate waterwall furnaces
- Dumping, vibrating and travelling grate waterwall furnaces
- Sloping grate waterwall furnaces
- Fluidized bed furnaces
- Suspension fired furnaces.

Cell-type furnaces are refractory lined chambers designed to burn very high moisture (generally higher than 55%) fuels in a very hot zone. Radiant heat is reflected from the refractory walls back to the combustion zone on a fixed grate. Combustion zone temperatures are very high, and cell sizes are generally limited so a normal pulp mill boiler would require a number of cells. Load-following capability of this furnace design is limited. The cell must be shut down for removal of ash. Good burnout is achieved at the cost of reduced load prior to ashing.

Fixed grate waterwall furnaces are very common in the forest industry. Fuel is fed to the furnace and distributed evenly on the fixed grate, where it is burned in a thin even pile. A small quantity of radiant heat is reflected back to the combustion zone and the combustion air is preheated to assist in drying the fuel. In some cases, refractory is applied to the lower furnace wall tubes to increase the amount of radiant heat for fuel drying. Hog firing must be curtailed for ash removal, although these units can usually maintain steam production on supplementary fuel. In a modern unit, typical steam load swings can generally be followed on hog fuel alone.

Dumping, vibrating and travelling grate waterwall furnaces are similar in concept to the fixed grate furnaces except the fuel is moved on the grate. This facilitates the even spreading of the fuel and permits continuous on-line removal of ash. These units can also follow typical mill steam load swings on hog fuel alone.

Sloping grate waterwall furnaces are common in Scandinavia, and are applied in North America in installations where the fuel moisture is very high. These units employ one or two refractory-covered arches overhanging the grate and fuel is introduced to a steeply sloping section of fixed grate beneath the front arch. Hot combustion air and reflected radiant heat dry the fuel as it slumps down the grate. Ash is generally discharged automatically from a dumping section at the foot of the grate. Good burnout of

the fuel is generally achieved with no loss of load and steam load swings can generally be followed on hog fuel alone.

Fluidized bed furnaces are becoming increasingly popular in installations with poor fuels, particularly those with high sulphur and high ash. These boilers have high auxiliary power requirements and are not particularly suited to high moisture fuels, so are not commonly applied in the forest industry.

Boiler grates are limited by the amount of heat which can be generated on them. The amount of fuel fired can be further limited in order to reduce particulate carryover with wet fuels. The maximum amount of heat that can be applied to these grates is usually limited to 850,000 Btu/ft².h, although this can be as high as 1,000,000 Btu/ft².h with relatively dry fuel and modern air systems. Suspension fired boilers can be fired at specific loadings up to 40% higher, expressed over the furnace cross sectional area, because the heat is released higher in the furnace and is absorbed to a higher degree by the water walls.

Suspension burning woodwaste boilers are not common because of the high costs for preparation of the fuel before firing. The fuel must be dried to 10 - 15% moisture by weight, wet basis and finely pulverized and fed through special air mixing burners. Suspension firing permits high specific furnace outputs on woodwaste fuels, good load swing capability and high combustion efficiency. Ash is generally carried out of the furnace and removed by downstream collectors. An electrostatic precipitator or baghouse is required to satisfy particulate emission regulations in most cases.

Another method of dealing with high moisture fuel is to dry it before introducing it to the furnace. This is commonly done in external dryers that are heated either by supplementary heat or by hot air or recirculated flue gas. Dry fuel requires a smaller furnace volume, therefore a smaller and cheaper boiler could be installed in a new installation or more fuel can be fired in a boiler retrofitted with a dryer. Fuel dryers are described further in the next section.

The objective of the Hochmuth furnace design is to dry the wet woodwaste fuel before it reaches the combustion zone. This is a similar concept to an external fuel dryer, but will not require the additional dryer equipment. Conventional boiler designs do not permit predrying of the fuel, and must resort to covering the heat transfer surface in the lower furnace with refractory or accept lower specific outputs on woodwaste fuel.

HOG FUEL DRYING

External hog fuel dryers are a proven method of improving the performance of woodwaste fired boilers. A variety of different types of dryers are available on the market, and some operating experience is available in local pulp mills. A hog fuel dryer can be expected to reduce fuel moisture content sufficiently to increase boiler hog fuel burning capacity and improve boiler operation.

Two basic types of dryers are in use on woodwaste materials: dryers using hot air or boiler flue gas in direct contact with the hog fuel, and dryers using steam to indirectly dry the material. Indirect-type dryers are not common in the forest industry and there is little successful operating experience in this application, so these were not considered candidate technologies for this study. Effort was therefore focused on direct contact dryers.

There are four basic types of direct contact hog fuel dryers: rotary, cascade, flash and hot conveyors. The first three types are usually heated with boiler flue gas and the hot conveyor is generally heated by hot air. The flue gas dryers are most commonly applied in the forest industry, and once again, there is little operating experience with the hot air type. This type was therefore excluded for consideration.

The flue gas hog fuel dryers all operate on the principal of evaporating hog fuel moisture in hot dry boiler flue gas that is mixed with the woodwaste material. The different dryer types are differentiated primarily by the method of contacting the hog fuel with the flue gas. In the rotary dryer, wet hog fuel is mechanically conveyed through a horizontal rotating drum (similar to a rotary lime or cement kiln), through which the gas stream passes in intimate contact with the hog fuel to assist in conveying and drying the material. In the cascade dryer, wet hog fuel is fed near the bottom of a vertical stationary vessel and hot gas is blown in through the bottom to carry the fuel up and out of the vessel and thereby dry the material. In the flash dryer, hog fuel entrained in a stream of hot flue gas is carried through a hammermill to simultaneously dry and pulverize the material.

With an initial fuel moisture content of 55% by weight, wet basis, the rotary and cascade dryers can be expected to dry the material to 40 - 45% moisture, with the fines somewhat dryer due to the larger surface area per unit volume of particle. Flash dryers produce a very dry, fine, pulverized product down to 10 - 15 % moisture. Pulverized fuel must be fired in dedicated suspension burners and requires special handling because of the explosive nature of wood dust. Costs for flash dryers are significantly higher than the other types, and since No.9 boiler is not designed for this type of firing this dryer was not considered further. Rotary and cascade dryers were therefore considered the candidate dryer technologies for this study.

Two Steams-Roger rotary dryers are installed at the Macmillan Bloedel Powell River pulp mill in Powell River, B.C., where they have been in operation since 1982. In this system, fines (which are very dry) are collected separately and fired in suspension, and the remaining material is fired on the grate. An increase of about 9% in hog fuel fired steam generation has been reported, but the system has been plagued with operating and maintenance problems. These include failures in the hog fuel conveying system and serious corrosion of the shell, ducting and fans (caused, no doubt, by the high salt content of the coastal hog fuel). This has resulted in disappointing equipment availability and high maintenance costs.

Two Bahco cascade dryers were installed at the Fletcher Challenge Canada pulp mill in Crofton, B.C., in 1982, and are still in operation. Steam generation from hog fuel has increased by a reported maximum of 54%, although this installation has also experienced a variety of operating and maintenance problems. These have included several fires in the dryer system, poor reliability of materials handling equipment due to wear and inadequate design and excessive corrosion and wear in the dryer shell. Despite these problems, this system has performed to performance expectations with reasonable availability, particularly since the furnace design was modified and a modern overfire air system, engineered by Sandwell, was installed.

The dryer suppliers claim to have learned from the problems experienced at these mills and advise that the current generation of dryer designs will perform much better in the Harmac environment.

THE HOCHMUTH INTEGRAL DOWN-DRAFT DRYER BOILER

The Hochmuth integral down-draft boiler is a patented furnace design for improving the operation and efficiency of steam generating furnaces which burn high moisture woodwaste fuels by predrying the fuel prior to its entry into the combustion chamber.

The furnace includes a vertical shaft the full width of the unit, down through which hog fuel is fed into the combustion zone. This fuel is fed at the top of the shaft and entrained with high temperature recirculated flue gas also introduced at the top of the shaft. As the fuel and hot gas travel in turbulent fashion down the shaft a significant portion of the fuel moisture is evaporated. Larger particles are dried to a lesser extent than fine particles, which give up nearly all their moisture.

The fuel feeders are installed at the top of the furnace cavity to give the greatest possible residence time in the drying shaft. The shaft will be open to the furnace at the top to allow flue gas to circulate through the cavity, and at the bottom to allow the dry fuel and flue gas to enter the combustion zone. The downward flowing fuel is deflected into the furnace by air nozzles installed through an inclined ledge that extends into the furnace at the bottom of the shaft.

The recirculated flue gas has no appreciable oxygen, so there will be no combustion in the drying shaft. Gas recirculation is caused by the difference in densities of gases in the furnace and the drying shaft. The gas in the shaft will be cooled as it picks up moisture from the wet fuel, thus reducing the average temperature in the shaft. This temperature difference will cause the lower density furnace gas to flow upward in the furnace and the cooler, denser gas to flow downward in the drying shaft. The gas recirculation should be self regulating, as the more moisture in the fuel in the drying shaft, the cooler will be the recirculated gas, and the greater the recirculation.

The Hochmuth furnace is shown schematically in Figure 2. This side view of the furnace shows the drying shaft with the top and bottom openings, the elevated fuel feeders and the deflection ledge.

The division wall forming the inside wall of the drying shaft is water cooled, so there is a small increase in the heating surface of the unit.

The advantages of the Hochmuth furnace are claimed to be:

- Permits stable firing of wood waste fuels with greater than 55% moisture.
- Eliminates or reduces the requirements for use of auxiliary or stabilizing fuels when firing high moisture content fuels.
- Provides a degree of suspension firing of fines, which will be dried to a greater degree than larger material. This should result in reduced furnace carryover and improved combustion on the bed.
- Because of this, the unit should be capable of higher grate combustion rates.
- No additional equipment, power consumption or space is required or fire hazard introduced, in comparison to systems employing external fuel dryers.

The furnace is equally capable of being retrofitted to an existing boiler or installed in a new unit, and can be used in conjunction with any of the present grate designs in common use.

DESCRIPTION OF THE EXISTING BOILER AND HOG FUEL SUPPLY SYSTEM

General Description of Boiler

The Harmac steam plant raises steam in three recovery boilers and four power boilers. The power boilers (numbered 1,2,3 and 9) are arranged in a line from west to east, with No. 9 the most easterly.

No. 1 and 2 power boilers are each rated at 80,000 lb/h and No. 3 boiler is rated at 100,000 lb/h. These are older units and supply approximately 40% of the total steam from hog fuel.

No. 3 boiler is currently used to absorb steam system load swings and the other boilers are generally base loaded. However, the other boilers are reaching the end of their useful lives, and this is particularly true for No. 3 boiler. Therefore, No. 9 boiler can be expected in future to take the plant swing loads.

No. 9 boiler is a Type VUX 40 manufactured by Combustion Engineering and started up in 1965. The single pass bi-drum boiler is designed for an evaporation of 450,000 lb/h on oil alone and 250,000 lb/h on hog fuel alone. Design and operating data for the boiler are summarized in the following table. The unit is shown schematically in Figure 1 in Appendix 3.

Table 1 - No. 9 Power Boiler Design and Operating Data

<u>Item</u>	<u>Units</u>	<u>Amount</u>
Manufacturer and type		CE VUX 40
Startup year		1965
Design pressure	psig	725
Superheater outlet conditions:		
- Steam pressure	psig	620
- Steam temperature	°F	750
Grate Type		Pinhole
Grate size:		
- Width x depth	ft	22.23 x 17.93
- Total surface area	ft ²	399
Feedwater temperature	°F	350
Gas exit temperature:		
- Design	°F	400
- Operating	°F	390
Design maximum evaporation (MCR):		
- Oil alone	lb/h	450,000
- Hog alone	lb/h	250,000

Sandwell

<u>Item</u>	<u>Units</u>	<u>Amount</u>
Operating maximum steam loads:		
- Summer, hog and oil	lb/h	285,000
- Summer, hog only	lb/h	275,000
- Winter, hog and oil	lb/h	340,000
- Winter, hog only	lb/h	230,000
Combustion air temperature:		
- Summer	°F	450
- Winter	°F	450
Average fuel moisture:		
- Summer	%	50
- Winter	%	58
- Annual average	%	55

The rectangular furnace measures 22'-2-3/4" wide by 17'-11-7/32" deep, and is constructed of 3 in. O.D. waterwall tubes on 3-1/32 in. centres. The furnace height from the pinhole grate to the roof is about 75 ft. The bottom 8 ft of the furnace cavity is refractory lined. The grate surface area and the furnace volumes are therefore 399 sq. ft and 25,950 cu. ft respectively.

The sloped, water-cooled pinhole grate consists of 12 in. by 6 in. alloy cast iron blocks, with integral air passages, bolted to 2-1/8 in. O.D. floor tubes on 3-1/32 in. centres.

Hog fuel is fed to the grate through four 24 in. wide pneumatic distributors, mounted about 12 ft above the grate.

The boiler will soon require a furnace rehabilitation, comprising a grate, lower furnace tube and air system replacement. The existing simple air system is of particular concern with respect to combustion stability and furnace carryover.

Combustion Air System

Combustion air is supplied by a constant speed forced draft fan equipped with variable inlet vanes, which discharges through a (disused) steam coil airheater and a tubular airheater. Preheated air is ducted down the rear of the furnace and is split into two parallel branches, one on each sidewall. Two branch ducts from these main branches feed the oil burner windboxes and the overfire air ports.

The first branch, equipped with a remotely-operated damper, feeds the burner windbox, which occupies the full width of each furnace sidewall and supplies air to the two burners on each corner at different elevations.

The second branch, also equipped with a remotely operated damper for pressure control, supplies air to the overfire air ports in the front, side and rear walls. Each branch supplies half the boiler.

The overfire air ports are located low in the furnace (at a maximum of 6 ft above the sloping grate), and are sloped downward at 30 degrees toward the bed. The design and number of overfire air ports has been changed from the original design. Fifteen ports are located across the rear wall (at about 6 ft above the

grate), three ports are located in each sidewall (at about 2 ft above the grate) and seven ports are located across the front wall (at about 4 ft above the grate). The overfire air ports are equipped with individual finger dampers, which can be remotely operated in 4 groups - one for each of the four walls.

The main branch extends on to the undergrate air plenum. It, too, is equipped with a remotely-operated damper.

There is no partitioning of the undergrate plenum or flow measurement of the separate airstreams.

Flue Gas System

The flue gas system for No. 9 boiler has been considerably modified since the original installation. The major change is the recent installation of an electrostatic precipitator to collect particulate from all four hog fuel boilers and the construction of a common stack. Prior to that, the original ID fan was removed and replaced with two 80% capacity fans, which run in parallel. This latter installation included bypass of a secondary dust collection system, which was not effective in controlling particulate emission from the boiler.

Flue gas from No. 9 boiler now passes through a Viscodyne separator, then through a primary mechanical dust collector, through twin ID fans, to the precipitator and is finally discharged through the stack.

The ID fans are located in a building extension to the north of No.9 boiler. The fan discharge is approximately at the 195 ft elevation, and the breeching rises to join the common precipitator inlet breeching at about the 232 ft elevation. The precipitator is installed outside, north east of the No. 9 boiler building, immediately east of the ID fan building. The new stack is on the north side of the precipitator.

Hog Fuel Consumption

Average hog fuel consumption of the power boilers is indicated in the following table.

Table 2 - Normal Hog Fuel Consumption

<u>Boiler</u>	<u>Boiler MCR (lb/h on hog)</u>	<u>Hog Consumption (lb/h @ 55% M.C.)</u>	<u>Equiv. Steam (lb/h)</u>
1	80,000	15,500	37,000
2	80,000	15,500	37,000
3	100,000	22,000	53,000
9	250,000	83,800	202,000
Totals		136,800	329,000

The total plant hog fuel consumption is about 100,000 to 150,000 lb/h, or about 27 to 40 units/h. There is significant salt content in the hog fuel, resulting in flue-gas-side corrosion problems.

Fuel Oil Consumption

Average fuel oil consumption in the power boilers is indicated in the following table.

Table 3 - Normal Fuel Oil Consumption

<u>Boiler</u>	<u>Annual Total (1989)</u> <u>(bbl/y)</u>	<u>Hourly Average</u> <u>(bbl/h)</u>	<u>Equiv. Steam</u> <u>(lb/h)</u>
1-3	28,453	3.39	18,000
9	<u>67,439</u>	<u>8.03</u>	<u>43,000</u>
Totals	95,892	11.42	61,000

Hog Fuel Supply System

Fuel is delivered to all boilers from the bottom of a concrete hog fuel storage building. A 42 in. belt conveyor (Conveyor 186) supplies fuel to a 48 in. distribution flight conveyor (Conveyor 187) at floor elevation 167'-0". Conveyor 187 supplies the feeders for No. 9 boiler and also discharges to a 30 in. flight conveyor (Conveyor 26) that feeds the other power boilers. Overfeed is returned via a 42 in. belt conveyor (Conveyor 23), in plan view roughly parallel to Conveyor 186, discharging at the top of the hog fuel building at elevation 215'-4". The returns are dropped down a long chute to an outside pile north of the building. A four strand reclaim conveyor takes the fuel to a Rader screen inside the building. Screen accepts are discharged to Conveyor 186 inside at the bottom of the building.

The hog fuel storage building is no longer used for storage, and now functions only as a structure for the hog fuel conveyors.

The hog fuel is therefore supplied to No. 9 boiler first, then to boilers 1, 2 and 3, in that order. The hog fuel handling system is illustrated schematically in Figure 8 in Appendix 3.

Hog Fuel Characteristics

The hog fuel, mainly Western Hemlock and Douglas Fir and a small amount of Western Red Cedar, is roughly 50% fines (1/8 in. minus) and is very moist. Moisture content varies from 50 to 60% through the year, but averages 55%. The wood is salt water transported and the sea-salt content of the hog fuel is significant. An assumed analysis of the hog fuel is given in the following table, and the size distribution of the hog fuel is described in Figure 9 in Appendix 3.

Table 4 - Assumed Hog Fuel Analysis

<u>Item</u>	<u>Units</u>	<u>Amount</u>
Gross calorific value, bone dry	Btu/BD lb	8,700
Density, bone dry	BD lb/ft ³	8.4
Ultimate analysis	weight %	
	C	49.25
	H,	5.50
	O,	40.25
	Ash	5.00

Table 5 - Definition of Alternatives

Criterion	Units	Existing Unit	Note	Alternative 1 Hochmuth	Note	Alternative 2 Conventional	Note	Alternative 3 External dryer	Note
Fuel treatment	--	None		In-furnace drying	1	None		External drying	2
Fuel moisture									
As received	%	55		55		55		55	
As fired - grate	%	55		53	3	55		40	
As fired - suspension	%	55		6	4	55		15	5
Grate Type Effective	-- ft ²	Pinhole 396	6	Hydrograte 321	7	Hydrograte 378	8	Hydrograte 378	8
Furnace Extended area	ft ²	6,018	9	5,568	11	5,778	11	5,778	11
Plan area	ft ²	396		365	11	396		396	
Volume	ft ³	25,950	9	22,813	12	24,750	12	24,750	12

NOTES

1. Fuel is dried in a flue gas recirculation shaft in the furnace.
2. Fuel is dried in a flue gas driven dryer before being fed to the furnace.
3. Larger particulate is dried to a lesser extent than the fine particles.
4. Smaller particulate is dried more completely and tends to burn in suspension.
5. Fines are captured separately and fed through a pneumatic system to dedicated suspension burners in the furnace.
6. Furnace area is 17'-11 7/32' by 22'-2 3/4'.
7. The furnace front wall is moved inward by 1'-6', reducing furnace plan area to 16'-5 7/32' by 22'-2 3/4'. A deflection ledge extends 2'-0" into the depth of the furnace, further reducing effective grate area to 14'-5 7/32' by 22'-2 3/4'.
8. The Hydrograte effective area is taken from the CE boiler upgrade study.
9. From the Vendor's design data.
10. The furnace area is reduced by 1'-6' (up each sidewall) and 3 ft at the grate, for a total reduction of 450 ft².
11. See Note 7.
12. The furnace bottom (grate) will be raised approximately 3 ft to accommodate the new hydrograte.

ALTERNATIVE MODIFICATIONS TO INCREASE HOG FUEL BURNING CAPACITY

Three alternatives were selected for further study to increase the hog fuel burning capacity of No. 9 Power Boiler. The scope of each alternative is described thoroughly in succeeding sections. All alternatives include replacement of the stationary grate and the combustion air system as these modifications would be required in any event. The alternatives selected are:

Alternative 1 - Boiler modification to the Hochmuth design

Alternative 2 - Boiler modification to a conventional design

Alternative 3 - Boiler retrofitted with external fuel dryer

Alternative 1 incorporates modifications to convert the boiler to the Hochmuth design. This includes changes to the furnace to construct a divided furnace cavity, replacement of the pinhole grate with a vibrating grate and the complete replacement of the combustion air system with a modern design for improved fuel burnout and combustion efficiency. Finally, the fuel feeders will be relocated to the top of the furnace and the fuel feed conveyors will be modified to supply these feeders.

Alternative 2 includes modifications to convert the boiler to a modern conventional design for the combustion of high moisture hog fuel. These modifications include replacement of the lower furnace with refractory covered tubes. They also include replacement of the pinhole grate with a vibrating grate and replacement of the combustion air system as in Alternative 1.

Alternative 3 includes modifications to add a flue gas-heated hog fuel dryer to the boiler and upgrade the design of the grate and air systems. These modifications include replacement of the pinhole grate with a vibrating grate and replacement of the combustion air system as in Alternatives 1 and 2, and replacement of the lower furnace to accommodate these changes. They also include construction of a hog fuel dryer, along with modifications to the flue gas breeching and the hog fuel supply conveyor system.

These alternatives are defined in Table 5 and discussed in more detail in the succeeding sections.

ALTERNATIVE 1 - HOCHMUTH FURNACE DESIGN

Furnace and Grate

The complete furnace front wall will be demolished and a new wall constructed 12 in. outward of the existing wall. A new water cooled division wall will be constructed 18 in. inside the furnace, parallel to the front wall. The upper tubes of the division wall will be separated and offset to provide a horizontal passageway to the upper portion of the furnace. The lower tubes of the division wall will be bent through the sidewalls to form a passageway to the bottom of the furnace. This arrangement is illustrated in Figures 3 to 6.

The new division wall will be fed with water from short risers extending up each side wall from a new ring header. A new header at the top of the wall completes the circulation back to the steam drum. A new header will be provided as well for the relocated front wall.

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An erosion-resistant inclined ledge will be constructed, extending into the lower furnace beneath, and slightly beyond, the lower portion of the division wall. Air nozzles installed in this ledge will provide for distribution of the fuel on to the grate.

The front corner burners will require to be relocated due to reconstruction of the front wall. These will be installed on new sidewall sections constructed to tie in the extended front wall to the existing sidewalls. The new, angled sidewall sections are illustrated in Figure 4.

The existing pinhole grate will be removed and replaced with a vibrating grate, such as a Detroit Stoker Hydrograte. To distribute the undergrate air as evenly as possible through the grate, even with poor fuel distribution, the air pressure drop at MCR on hog fuel alone should be about 5-8 in. wg. The hole pattern in the grate panel or grate blocks will be designed accordingly. The high velocities will also reduce the amount of siftings falling from the grate into the undergrate air plenum. The undergrate air compartments will be designed with adequate headroom and sloping lower surfaces to allow the siftings to be easily removed. A perforated water sluice header and associated piping will be provided in each compartment.

The lower furnace will be modified to suit the new grate and the requirements of the overfire air system described later. The grate heat release rate will be limited to 880,000 Btu/ft².h.

A new bottom ash hopper and vestibule will be constructed to suit the new grate. The front wall will be extended as required to provide water cooling of the top of the vestibule. New access doors and observation windows will be installed around the grate area as well.

Fuel Feed System

The existing fuel feeders and distributors will be removed and the feeders relocated to the top of the division wall, as illustrated in Figure 2. The distributors will no longer be required and will be discarded. Some modification will be required to the boiler casing in this area to seal the feeder installation from air infiltration.

The new division wall therefore provides for hot flue gas recirculation through the upper passageway of the division shaft and fuel feed to the furnace through the lower passageway via new openings at the top of the division wall.

Combustion Air System

The existing combustion air system will be completely removed and replaced with a modern design system, including undergrate, overfire and pneumatic fuel distribution systems. The undergrate and overfire air systems will be sized for an air capacity of 80% and 65%, respectively, for a total capacity of 145%. This will permit alteration of air ratios to compensate for varying fuel characteristics.

Side-by-side undergrate air zones will be provided, with three separately controllable zones in each side zone to facilitate optimum front-to-rear distribution control. Each front-to-rear air zone will be equipped with a venturi air measurement device and local airflow indication, located at the damper control station at the boiler front wall on the boiler operating floor.

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The overfire air system will be arranged into four separately controllable air zones, located in two levels in the boiler front and rear walls, approximately 12 feet above the grate. Each air zone will be equipped with a venturi air measurement device. Operating pressure of the overfire air system will be 8-12 in. wg at MCR on hog fuel.

The overfire air jets will consist of concentric large diameter (approximately 4 and 6 in.) heat-resistant alloy nozzles arranged in a staggered pattern to penetrate the furnace gases with high pressure air. Each nozzle will be provided with a bell-mouth inlet within its windbox. These nozzles will be angled downwards at about 20 degrees, meeting the jets from similar nozzles in the opposite wall in a partially interlaced fashion. The overfire air nozzles will be located just above the bottom of the division wall in order to get air to the hog fuel which will be passing into the furnace in this region.

The inner nozzles of each of the two air zones in each of the front and rear walls will be dimensioned for 0 to 65% MCR. The outer annulus zone formed by the inner and outer nozzles will be used together with the inner nozzle zone at loads above 65% MCR.

The jet trajectories will be angled downwards in such a manner as to intercept the hog fuel combustion gases rising from the grate above the trajectory of the hog fuel which is directed on to the grate by the distribution air in the inclined ledge.

A new forced draft (FD) fan may be provided to supply the required air at the necessary flow and pressure. The FD fan would be equipped with a suction duct, with integral venturi for total air flow measurement, extending upward to near the roof of the boiler building.

New air ducting will be provided to facilitate the division of the overfire and undergrate air into the four and six control zones previously described. The lower level of the overfire air can be supplied with about 30% of the total air from the lower registers of the existing burner windbox. The tilting registers will be modified to provide vertical, as well as horizontal, adjustment of air direction. The remaining 25 to 30% of the air is left for the rest of the overfire air system. Distribution air, amounting to about 20% of the air, will be ducted to the lower furnace ledge, and introduced at about 20 in. wg pressure. The remaining 0 to 15% of the air will be introduced through the rear wall to balance the distribution air from the ledge. A separate small booster fan for the hog distribution air might be considered as well.

Separate dampers will be provided for each undergrate and overfire air control zone.

Circulation Piping

Modifications will be required to the downcomer piping to accommodate the new Hydrograte. The division wall will be fed from two new headers extending part way up each side wall. A new header will be required to terminate the upper end of the division wall tubes and take their flow to the steam drum. The new front wall header will also be piped to the steam drum via the roof tubes, as shown in Figure 6. No new tube hole drillings in the drum are required.

Fuel Supply System

With the particular system at Harmac, the fuel system can be modified to feed No. 9 boiler at the penthouse floor and return overfeed to the hog fuel storage building with minimal disruption to the existing system. The modified system would then first feed boilers 1, 2 and 3 and then feed No. 9 boiler.

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A new feed conveyor will take material from the existing return conveyor at the top of the hog fuel storage building. This new conveyor, a 36 in. belt conveyor, will run in a new gallery across to the No.9 boiler building at the penthouse level. The overfeed return conveyor from No.9 boiler will follow roughly the same route and discharge back to the reclaimer pile. The new feed and return conveyors will be designed to handle the full flow for all four power boilers.

The new feed conveyor will discharge on to a new distribution conveyor across the front of the boiler, approximately 12 ft above the existing floor at El. 210'-0". New chutes will deliver hog fuel to the relocated feeders at approximately the same floor level, and overfeed will fall on to the return conveyor.

ALTERNATIVE 2 - CONVENTIONAL FURNACE DESIGN

Furnace and Grate

The existing pinhole grate will be removed and replaced with a vibrating grate, as in Alternative 1.

The lower furnace will be replaced to suit the requirements of the new grate and the new overfire air system. The new tubes will be pin studded and covered in impact resistant refractory to a height of 10 ft above the grate. This refractory will help stabilize the combustion of very wet hog fuel.

Combustion Air System

The existing combustion air system will be completely removed and replaced with a modern design system, as in Alternative 1.

The same modifications are included, with the exception of the distribution air to the furnace shelf.

Circulation Piping

The downcomer and supply piping will be modified to accomodate the new stoker.

Fuel Supply System

The existing 24 in. pneumatic distributors will be replaced by four 36 in. mechanical distributors to ensure effective distribution on the grate.

The distribution conveyor will be modified to accommodate the new distributors, but no other modifications are necessary to the fuel supply system.

ALTERNATIVE 3 - EXTERNAL FLUE GAS DRYER

General

This alternative will provide the boiler with dry fuel for grate firing (at about 45% moisture) and semi-suspension firing (at about 15% moisture). The dryer will provide a method for over-drying and separating the fines. These can be pneumatically conveyed to the boiler and burned in suspension through simple nozzles in the boiler front wall.

Furnace and Grate

The existing pinhole grate will be removed and replaced with a vibrating grate as in Alternatives 1 and 2.

The lower furnace will be replaced to suit the requirements of the new grate and the overfire air system. Refractory-covered tubes will not be necessary for this alternative, as the fuel will be much drier. Two fines burners will be installed in the lower furnace to burn the fines fraction from the dryer in suspension.

Combustion Air System

The combustion air system will be replaced as in Alternative 2.

Circulation Piping

The circulation piping will be modified to suit the new stoker, as in Alternative 2.

Hog Fuel Dryer

The dryer proposed for this study is a cascade type, as supplied by ESI/Bahco.

In this design, hot flue gas will be taken from the boiler ID fan discharge breeching and ducted to the hot flue gas inlet at the bottom of the dryer. The flue gas will be treated in a cyclone separator to remove entrained fine particulate, and returned to the precipitator inlet breeching by the dryer ID fan.

Wet hog fuel will be introduced to the dryer by a variable speed screw conveyor and will be dried in the flue gas stream. Large material will be discharged at approximately 45% moisture from the dryer and fine material, dried to about 15% moisture, will be discharged from the cyclone separator. These two streams will be collected and fed to the boiler separately.

Larger material will be fed by belt conveyor to the existing boiler distributors, to be burned on the grate. Fine material from the cyclone will be collected in a metering bin and conveyed to dedicated burners in the boiler front wall, to be burned in suspension in the furnace. It is estimated that 15 percent of the hog fuel fired can be burned in suspension in this manner.

A technical description of the dryer is included in Appendix 4. The system is illustrated schematically in Figure 7.

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The dryer will be installed adjacent to the new power boiler precipitator, northeast of No. 9 boiler. The equipment will be installed on structural steel above the access door to the east wall of the power boiler building, providing sufficient clearance so as not to obstruct access to the building.

An alternative location was considered for the fuel dryer, but was rejected due to the high cost and poor access to the flue gas breeching. This is in the location of No. 3 power boiler, which can be permanently shut down and removed when No. 9 boiler achieves the performance potential projected in this study. The advantage of this latter location is that it would not interfere with access to the boiler building and could relieve some of the congestion on the site.

The ESI cascade type dryer installation will include the following equipment:

- One cascade dryer
- Four fines cyclones
- One feed fan, complete with 150 hp drive and damper control
- One booster fan, complete with 600 hp drive and damper control
- One twin metering screw conveyor, complete with 25 hp drive
- One twin infeed screw conveyor, complete with 15 hp drive
- Two fines transfer screw conveyors, complete with 5 hp drives
- Three dryer rotary airlocks, complete with 10 hp drives
- Four cyclone rotary airlocks, complete with 3 hp drives
- One fines overflow hopper
- One fines metering screw conveyor, complete with 10 hp variable speed drive
- Two fines conveying fans, complete with 30 hp drives
- Two pneumatic fines conveying lines, complete with control valves
- Two fines burner nozzles
- One flame scanner system, complete with controls
- Structural support steel
- Control system, complete with field instruments.

Wet wood is fed to the dryer by a variable speed metering screw. Hog fuel feed rate is controlled to maintain a constant wet flue gas outlet temperature of about 230 °F. Flue gas temperature entering the dryer is maintained between 450 to 580 °F by modulating a bypass around the air side of the tubular airheater. When fuel moisture increases, causing the gas outlet temperature and the fuel feed rate to decrease, the bypass can be opened up to restore the previous fuel feed rate.

The dryer will also be equipped with a flue gas bypass, to permit isolation of the unit while the boiler is in operation or when burning fuel oil.

Flue Gas Breeching

Hot flue gas will be taken from the two vertical risers from the ID fan discharge at approximately 210 ft elevation. Takeoffs at this level, equipped with individual shutoff dampers, will run south, join in a common duct and then turn east to enter the hot gas inlet of the hog fuel dryer.

Cold flue gas is ducted from the dryer outlet straight up to about 230 ft, then horizontally west to the inlet area of the precipitator, where it will turn at that level into the precipitator breeching. This breeching will also be equipped with shutoff dampers.

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A bypass around the airheater will be constructed on the air side. This will be equipped with variable dampers to control the bypass flow.

Fuel Supply System

The fuel handling system will be modified to feed No. 9 boiler with dried hog fuel from the dryer, without affecting the feed to boilers 1,2 and 3.

Conveyor 186, which currently supplies hog fuel to all boilers, will be converted into two conveyors in order to provide a separate feed to the dryer for No. 9 boiler. The head end of the first section will feed the dryer via a metering screw conveyor. Overflow from this metering conveyor will be transferred on a new belt conveyor to bypass No. 9 boiler and feed directly on to distribution conveyor 26, which feeds boilers 1,2 and 3. The dry hog fuel discharged from the dryer will be transferred by a screw and a belt conveyor to the second section of divided conveyor 186, to feed the No. 9 boiler distribution conveyor.

Fine material separated in the dryer cyclones, will be discharged into an overflow hopper. Two variable speed metering screws will discharge the fines into two pneumatic blow lines, which will convey the material to two burners at the boiler front wall. A flame scanner system will verify the fire on the grate before the fines firing system can operate.

The existing 24 in. pneumatic distributors will be replaced by four 36 in. mechanical distributors.

CAPITAL AND OPERATING COST ESTIMATES

Summary of Capital Costs

Order-of-magnitude level capital costs for the three alternative boiler modification schemes are summarized below and are presented in more detail in Appendix 2. All costs are given in US funds.

Table 6 - Summary of Capital Costs - (\$ 1,000 US)

<u>Item</u>	<u>Alt. 1 Hochmuth</u>	<u>Alt. 2 Conv.</u>	<u>Alt. 3 Dryer</u>
Fuel supply and distribution			
- Hog fuel conveyor modifications	850	0	1,250
- Hog fuel dryer	0	0	2,450
Steam supply and distribution			
- Boiler modifications	11,050	7,600	7,620
- Breeching mods.	0	0	1,180
Total direct cost	11,900	7,600	12,500
Overhead, engineering and contingencies	4,200	2,700	4,400
Total plant capital	16,100	10,300	16,900

Costs for the boiler modifications are based on manufacturers' budget estimates obtained in response to a preliminary purchase inquiry. Two estimates were received, with a spread of 7% for the Alternative 2 (Conventional) modifications and 72% for the Alternative 1 (Hochmuth) modifications. An average of the two budget estimates was used for the manufacturer's portion of the Alternative 2 cost estimate. A judgement was made of the estimates for the Alternative 1 modifications due to the large spread. This estimate could still be high, as the original manufacturer was very conservative in its estimate.

Costs for the fuel dryer were also based on equipment suppliers' budget price estimates. Three prices were received, and these estimates are felt to be fairly accurate as they were generally based on recent project pricing.

Remaining costs for items such as the hog fuel conveyor modifications, electrical equipment, breeching modifications and other items of equipment were based on Sandwell's cost records for projects of similar type and scope.

Table 7 - Performance Comparison of Alternatives

<u>Item</u>	<u>Units</u>	<u>Existing Unit</u>	<u>Alternative 1 Hochmuth</u>	<u>Alternative 2 Conventional</u>	<u>Alternative 3 Dryer</u>
Hog fuel moisture					
As received	%	55	55	55	55
As fired - grate	%	55	53	55	46
As fired - suspension	%	55	6	55	15
Boiler efficiency	%	65.0	67.4	65.8	71.4
MCR evaporation					
Hog fuel alone	lb/h	250,000	300,000	260,000	307,000
Fuel oil and hog fuel	lb/h	350,000	390,000	350,000	350,000
Fuel oil alone	lb/h	450,000	450,000	450,000	450,000
Hog fuel burned					
Grate firing	BD lb/h	46,800	32,300	43,500	43,400
	%	0	60	90	85
Suspension firing	BD lb/h	0	21,600	4,800	7,500
	%	0	40	10	15
Total	BD lb/h	46,800	53,900	48,300	50,900
Fuel oil burned	GPM	360	0	0	0
Auxiliary power	kW	Base	54	28	585

ASSESSMENT OF THE BOILER MODIFICATIONS

The predicted performance of the boiler modification alternatives is shown in Table 7.

Alternative 2 (conventional furnace) shows a modest increase in hog fuel firing capability, but Alternative 1 (Hochmuth furnace) and Alternative 3 (fuel dryer) show significant increases, generally due to the dryer fuel being fed to the furnace.

Furnace carryover will be significantly reduced for all alternatives, although Alternatives 1 and 3 are expected to demonstrate the greatest reductions as they will burn the driest fuel.

All of the alternative boiler modification schemes will increase the amount of steam generated from hog fuel and virtually eliminate supplementary fuel requirements for load stabilization and grate cleaning. Alternatives 1 and 3 will provide better load following with hog fuel alone. The cost of supplementary fuel oil for No. 9 boiler alone amounted to \$1.2 million US in 1989.

No. 9 boiler will require modifications to the overfire air system and the grate in any event because of a needed rehabilitation - the result of many years of service. Alternative 2 (Conventional) represents the scope of modifications that would normally be proposed for a boiler of this type firing wet woodwaste fuel. These modifications are predicted to produce a modest increase in hog fuel steam generation and hog fuel throughput. The continuous de-ashing provided by the vibrating grate eliminates the supplementary fossil fuel which is presently required to maintain boiler load during manual de-ashing of the grate. Additional auxiliary power requirements are modest, and little modification is required to the auxiliary systems, resulting in the lowest capital cost of the three modification schemes. With the exception of the Hydrograte, no additional auxiliary equipment is required for this alternative, hence there should be only a marginal increase in operating costs.

The Alternative 3 (dryer) modifications will achieve the greatest hog fuel steam generation, however the additional fan and conveyor equipment impose a significant increase in auxiliary power requirements, resulting in significantly higher operating costs. The capital cost of this alternative, while significantly higher than the conventional alternative, is marginally higher than Alternative 1 (Hochmuth). This alternative requires substantial additional auxiliary equipment, comprising the hog fuel dryer with its auxiliaries and new hog fuel supply conveyors, and can be predicted to experience some operating and maintenance problems with the dryer equipment that could result in increased operating costs. The availability of the dryer system is expected to be 90-95% of the availability of the Hochmuth and conventional systems.

The Alternative 1 (Hochmuth) modifications are predicted to achieve marginally less hog fuel steam generation than the Alternative 3 modifications, but the auxiliary power requirements are substantially less. The capital costs of these two alternatives are very similar. This alternative requires considerably less auxiliary equipment (such as the hog fuel dryer and its auxiliaries) and the modified hog fuel supply conveyor system is much simpler than that required for the Alternative 3 modifications. The operating cost increase for this alternative should therefore be marginally higher than that for Alternative 2 (Conventional).

Table 8 - Evaluation of Alternatives

<u>Item</u>	<u>Units</u>	<u>Alt. 1 Hochmuth</u>	<u>Alt. 2 Conv.</u>	<u>Alt. 3 Dryer</u>
<u>Performance</u>				
Steam generated from hog fuel alone	lb/h	300,000	260,000	307,000
Steam generated from fuel oil	lb/h	7,000	47,000	0
Total steam generation	lb/h	307,000	307,000	307,000
Hog fuel consumption	BD lb/h	53,900	48,300	50,900
Hog fuel consumption	BD T/y	226,380	202,860	229,942
Fuel oil consumption	bbl/h	1.31	8.77	0
Fuel oil consumption	bbl/y	10,967	73,663	0
Auxiliary power	kW	54	28	585
<u>Capital Costs</u>				
Boiler modifications	\$1,000 US	11,050	7,590	7,620
Conveyor modifications	\$1,000 US	850	0	1,250
Hog fuel dryer	\$1,000 US	0	0	3,620
Overheads	\$1,000 US	4,200	2,660	4,370
Total capital costs	\$1,000 US	16,100	10,250	16,860
<u>Operating Costs</u>				
Capital charges	\$1000 US/y	2,850	1,814	2,984
Fuel oil	\$1000 US/y	196	1,311	0
Auxiliary	\$1000 US/y	19	10	209
Total First Year Operating Costs	\$1000 US/y	3,065	3,136	3,193
Differential	\$1000 US/y	Base	71	128

The selection of a preferred alternative is difficult, given the similarity in costs and performance between Alternatives 1 and 3. One way of assessing the alternatives is to evaluate the maximum steam generation from hog fuel. The base case will be the alternative with the best hog generation performance, and the other alternatives will make up the difference in steam output with oil fired generation for evaluation purposes. The cost of fuel oil will then be applied, along with the capital recovery and auxiliary power costs as first year operating costs in order to determine the least cost alternative. The operating labour and maintenance costs and hog-fuel handling and dryer system downtime can not be precisely calculated, so these were not included in the quantitative evaluation.

The results of this evaluation are given in Table 8.

The evaluation indicates that Alternative 1 (Hochmuth) will cost \$128,000/y less than Alternative 3 (dryer) and \$71,000/y less than Alternative 2 (conventional), under the assumptions of the evaluation. It should be pointed out that these costs do not include additional operating labour and maintenance costs, which can be predicted to be much higher for Alternative 3.

Alternative 1 (Hochmuth) therefore represents the least cost alternative for the modification of No. 9 boiler.

The evaluation is based on the following criteria:

- Capital charges of 12% per annum over 10 years on the total direct capital cost.
- 8,400 hours of annual operation.
- Incremental hog fuel cost of zero.
- Fuel oil cost of \$18 US per barrel (this is the cost over the previous year).
- Auxiliary power cost of \$0.04 per kilowatt hour.

CONCLUSIONS

1. The Hochmuth furnace technology can be retrofitted to No. 9 boiler at Harmac to increase the steam generated on hog fuel alone from 250,000 lb/h to 300,000 lb/h, representing an increase in hog fuel burned from 29 BDU/h to 32 BDU/h.
2. The total capital cost of this retrofit using the Hochmuth system is estimated as \$16.1 million. This is considerably more than the estimated cost of a conventional furnace upgrade, but provides significantly more steam generation from hog fuel. The particular arrangement of the hog-fuel-handling system at Harmac is more favourable to the Hochmuth system than it would be at a typical plant.
3. A hog fuel dryer could be retrofitted to No. 9 boiler for a total capital cost of \$16.9 million. This alternative is predicted to increase steam generated from hog fuel to 307,000 lb/h and the amount of hog fuel consumed to 30 BDU/h. This scheme has a higher boiler efficiency, so consumes a smaller amount of hog fuel.
4. A conventional upgrade to No. 9 boiler is estimated to cost \$10.3 million, but will result in only a marginal increase in steam from hog fuel to 260,000 lb/h.

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5. The evaluation of the alternative boiler modification schemes shows that the Hochmuth furnace retrofit is the least cost alternative, cheaper by \$128,000 per year over the fuel dryer alternative and by \$71,000 per year over the conventional upgrade alternative. This evaluation is based on first year operating costs and takes into account the differential in the amount of steam from hog fuel, differential fuel oil and auxiliary power costs and capital recovery costs.

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APPENDIX 1

GLOSSARY

REPORT 112246/1
HOCHMUTH DRYER STUDY

F. W. HOCHMUTH CONSULTING
BREWER MAINE

STUDY OF THE RETROFIT OF
THE HOCHMUTH INTEGRAL
DOWN-DRAFT FURNACE TO AN
EXISTING BOILER

DATE 31 AUGUST 1990

APPENDIX 1 - GLOSSARY

ACFM	actual cubic feet per minute
AC	alternating current
a	annum (see also year)
BD	bone dry
BDU	bone dry unit
Btu	British thermal unit
BWC	Babcock & Wilcox Canada
Can.	Canadian
CE	Combustion Engineering
CIF	cost, insurance, freight
CFM	cubic feet per minute
d	day
Deg (or °)	degree
DC	direct current
DCS	distributed control system
Dwg	drawing
elv.	elevation
ESP	Electrostatic precipitator
FD	forced draft
fig.	figure
FOB	free on board
ft	foot
ft ²	square foot
ft ³	cubic foot
G	gallon (US)
gal	gallon (US)
GCV	gross calorific value
GPM	gallon per minute
ga.	gauge
h	hour
hp	horsepower
Hz	cycles per second

(GLOSSARY - Cont'd)

ID	induced draft
IMP	Imperial
in.	inch
kV	kilovolt
kVA	kilovolt ampere
kW	kilowatt
lb	pound
MCC	motor control center
m	metre
MBtu	million British Thermal units
MCR	Maximum continuous rating
min.	minute
OD	oven dry
%	percent
ppb	parts per billion
ppm	parts per million
psia	pounds per square inch (absolute)
psig	pounds per square inch (gauge)
rpm	revolutions per minute
s	second
SDCF	Standard Dry Cubic Foot
t	metric tonne
T	Imperial ton
TEFC	totally enclosed fan cooled
unit	200 cubic feet of wood waste
US	United States
wg	water gauge
wk	week
wt	wet
y	year
yd	yard

APPENDIX 2
CAPITAL COST ESTIMATES

REPORT 112246/1
HOCHMUTH DRYER STUDY

F. W. HOCHMUTH CONSULTING
BREWER MAINE

STUDY OF THE RETROFIT OF
THE HOCHMUTH INTEGRAL
DOWN-DRAFT FURNACE TO AN
EXISTING BOILER

DATE 31 AUGUST 1990

APPENDIX 2 - CAPITAL COST ESTIMATES

CASE: ALTERNATIVE 1 - HOCHMUTH FURNACE DESIGN

<u>ACCOUNT</u>	<u>DESCRIPTION</u>	<u>MATERIAL</u>	<u>LABOUR</u>	<u>TOTAL</u>
<u>Department 261 - Fuel Supply and Handling</u>				
261.10	Demolition	1,000	2,000	3,000
261.14	Structural and Misc. steel	449,000	34,000	483,000
261.26	Lighting	5,000	10,000	15,000
261.37	Materials Handling	218,000	102,000	320,000
261.38	Process Controls	2,000	3,000	5,000
261.41	Electrical	<u>9,000</u>	<u>16,000</u>	<u>25,000</u>
	TOTAL DEPARTMENT COST	684,000	167,000	851,000
<u>Department 281 - Steam Supply and Distribution</u>				
281.10	Demolition	0	17,000	17,000
281.13	Concrete	10,000	13,000	23,000
281.14	Structural and Misc. Steel	43,000	34,000	77,000
281.38	Process Controls	17,000	17,000	34,000
281.41	Electrical	64,000	10,000	74,000
281.51	Boiler Modifications	6,545,000	4,250,000	10,795,000
281.67	Ash Handling	<u>17,000</u>	<u>17,000</u>	<u>34,000</u>
	TOTAL DEPARTMENT COST	6,696,000	4,358,000	11,054,000
	TOTAL DIRECT CAPITAL COST - ALTERNATIVE 1			11,905,000

CASE: ALTERNATIVE 2 - CONVENTIONAL FURNACE DESIGN

<u>ACCOUNT</u>	<u>DESCRIPTION</u>	<u>MATERIAL</u>	<u>LABOUR</u>	<u>TOTAL</u>
<u>Department 261 - Fuel Supply and Handling</u>				
(No modifications are required)				
<u>Department 281 - Steam Supply and Distribution</u>				
281.10	Demolition	0	27,000	27,000
281.13	Concrete	12,000	16,000	28,000
281.14	Structural and Misc. Steel	38,000	24,000	62,000
281.34	Piping	13,000	20,000	33,000
281.38	Process Controls	17,000	17,000	34,000
281.41	Electrical	84,000	20,000	104,000
281.51	Boiler Modifications	4,130,000	3,139,000	7,269,000
281.67	Ash Handling	<u>17,000</u>	<u>17,000</u>	<u>34,000</u>
TOTAL DEPARTMENT COST		4,311,000	3,280,000	7,591,000
TOTAL DIRECT CAPITAL COST - ALTERNATIVE 2				7,591,000

CASE: ALTERNATIVE 3 - EXTERNAL FUEL DRYER

<u>ACCOUNT</u>	<u>DESCRIPTION</u>	<u>MATERIAL</u>	<u>LABOUR</u>	<u>TOTAL</u>
<u>Department 261 - Fuel Supply and Handling</u>				
261.10	Demolition	2,000	9,000	10,000
261.13	Concrete	26,000	34,000	60,000
261.14	Structural and Misc. Steel	170,000	79,000	249,000
261.26	Lighting	17,000	17,000	34,000
261.34	Piping, Valves and Fittings	13,000	13,000	26,000
261.35	Insulation	201,000	108,000	309,000
261.37	Materials Handling	198,000	86,000	284,000
261.38	Process Controls	17,000	21,000	38,000
261.41	Electrical	133,000	105,000	238,000
261.87	Hog Fuel Dryer	<u>994,000</u>	<u>1,459,000</u>	<u>2,453,000</u>
	TOTAL DEPARTMENT COST	1,771,000	1,931,000	3,702,000
<u>Department 281 - Steam Supply and Distribution</u>				
281.10	Demolition	0	27,000	27,000
281.13	Concrete	12,000	16,000	28,000
281.14	Structural and Misc. Steel	55,000	41,000	96,000
281.34	Piping, Valves and Fitting	13,000	20,000	33,000
281.38	Process Controls	17,000	17,000	34,000
281.41	Electrical	84,000	20,000	104,000
281.51	Boiler Modifications	4,130,000	3,139,000	7,269,000
281.58	Breeching & Ductwork	635,500	530,000	1,165,000
281.67	Ash Handling	<u>17,000</u>	<u>17,000</u>	<u>34,000</u>
	TOTAL DEPARTMENT COST	4,963,500	3,827,000	8,790,500
	TOTAL DIRECT CAPITAL COST - ALTERNATIVE 3			12,492,000

APPENDIX 3
ILLUSTRATIONS

COMBUSTION ENGINEERING-SUPERHEATER LTD.

TYPE VUX 40 STEAM GENERATOR
FOR

MACMILLAN BLOEDEL LIMITED

HARMAK PULP DIVISION
NANAIMO B.C.

FIGURE 1 - BOILER SIDE ELEVATION (BEFORE MODIFICATION)

FIGURE 2 - BOILER SIDE ELEVATION (ALTERNATIVE 1)

FIGURE 3 - LOWER FRONT WALL ELEVATION (ALTERNATIVE 1)

F

FIGURE 4 - FURNACE RIGHT FRONT CORNER DETAIL (ALTERNATIVE 1)

FIGURE 5 - ROOF RIGHT FRONT CORNER DETAIL (ALTERNATIVE 1)

FIGURE 6 - FURNACE TOP SECTIONAL SIDE VIEW (ALTERNATIVE 1)

FIGURE 7

HOG FUEL DRYER SYSTEM SCHEMATIC

FINES CONVEYING FAN

KEY

1 WOOD REFUSE STORAGE PILE	8 FEED CHUTES TO BOILERS NO 1, 2 AND 3
2 CHAIN CONVEYOR	9 RETURN CONVEYOR
3 DISC SCREEN	10 REAR STORAGE CONVEYOR
4 SCREEN REJECTS STORAGE PILE	11 CYCLONES (3)
5 PLITE CONVEYORS (2)	12 FEED CHUTE TO CHAIN CONVEYOR
6 SCREW FEEDERS TO BOILER NO 9 (4)	13 DIVERSION GATE TO REAR STORAGE
7 MANUAL DIVERSION GATE	14 DIVERSION GATE TO WOOD REFUSE STORAGE

FIGURE 8 - EXISTING HOG FUEL HANDLING SYSTEM

FIGURE 9 - HOG FUEL SIZE DISTRIBUTION

APPENDIX 4

FUEL DRYER LITERATURE

Energy Conservation Through Biomass Drying

IHI Inc. of Tennessee

DESIGN/BUILD ENGINEERS & CONTRACTORS
SPECIALISTS IN STEAM & COGENERATION SYSTEMS

System Operation

The biomass drying system operates with no moving parts other than conventional fans and material handling equipment. The simplicity of operation results in low maintenance, safe reliable service and long life.

Gas Flow

Hot gas entering the dryer is divided into two flows. About 20% of the entering gas is drawn off by the feed fan and discharged through the central feed tube into the bottom of the drying chamber. Concentric rings comprising the bottom periphery of the drying chamber distribute the balance of the flue gas entering the dryer.

The central feed tube imparts a strong vertical flow to the flue gas while the gas entering through the distribution rings flows laterally toward the center of the drying chamber. The central cone in the upper part of the dryer deflects the upward flowing gas downward and outward toward the wall of the drying chamber. Passing upward around the deflection cone, the flue gas immediately enters the fines collecting cyclones.

Biomass Flow

Wet biomass is supplied to the central feed tube by the feed screw. Hot gas from the feed fan carries the biomass into the dryer shell. As the gas stream carries the biomass upward, it becomes dispersed and loses velocity. Heavier biomass particles start to fall back toward the bottom of the dryer. Lighter particles are carried higher and are moved more toward the periphery before falling. The lifting and falling back of particles of varying mass causes a torus to form. The torus-shaped cascade segregates wetter, more massive particles toward the center and drier, lighter particles toward the outside.

Dried biomass particles on the outermost edge of the cascade are removed through an adjustable opening in the side shell. Normal distribution resulting from the random selection of the dried particles assures a consistent outlet moisture content. Particles less than 3/16" may be carried around the central cone and into the fines collecting cyclones. The fines fraction will normally comprise 25% of the input flow and average 12% moisture.

The flue gas in the feed tube will not support stones, tramp metal and other dense material. Items not supported by the central feed are discharged as scrap. Stones as small as 1/2" will be discharged from the scrap outlet.

The Hercules Biomass Drying System Operation

A. Fuel will burn faster and hotter because there is much less water to evaporate before combustion starts. At 30% moisture, maximum biomass input can be increased by 25% compared to biomass with a moisture level of 45% or greater.

B. Hot air is not required for combustion. At 30% moisture, the maximum air temperature is 300 °F and ambient air temperature is acceptable. Excess air may be reduced by 50%. The air heater can be drastically reduced in size or eliminated. Combustion air fans will operate at much lower horsepower.

C. Gas mass flows through the heat exchanging elements are reduced. Erosion and fouling problems are less likely to occur.

D. Lower gas mass flows mean less particulate carryover and lower unburned combustible losses.

E. The cascade is a torus formed by the tumbling biomass. Lighter, drier particles move toward the outside where they are removed. The cascade also has a scrubbing effect on fly ash particulate. The particulate load leaving the dryer system is less than entering.

F. The feed fan draws off 20% of the hot flue gas entering the dryer and uses it to transport the wet biomass into the dryer shell and to rotate the cascade.

I. The system is designed to bypass excess biomass which may cool the flue gas below 200 °F, or all of the biomass if the dryer inlet screw feeder is stopped. The bypass feature allows the drying system to compensate for large swings in biomass moisture levels or flue gas inlet temperatures while safely maintaining maximum heat transfer efficiency.

J. The large fraction (approximately 75%) of the dried biomass exits here. Since it is a random selection of a normal population, the moisture level is very consistent. An adjustable door allows the residence time of the biomass in the dryer to be varied from one-half to ten minutes.

K. The dryer and cyclone are hollow shells with no moving parts. If biomass is not present in the system, the equipment simply operates as gas fluework. Short residence time in the dryer and cyclone (normally less than one minute) means that should biomass inlet flow be interrupted, the material in the dryer will be discharged before problems can occur.

L. The fines fraction (approximately 25%) of the dried biomass is carried out of the dryer and into the fines collection cyclones. This material averages a one-eighth inch size and 12% moisture. The fines material can be used for suspension firing if desired.

M. Gas leaving the fines collection cyclones is cleaner than the flue gas entering the dryer. Particulate loading is guaranteed less than 0.4 gr/DSCF.

N. The I.D. fan after the drying system is conveying reduced amounts of much cooler (200 °F) and cleaner gas. Horsepower requirements are reduced dramatically and fan life is increased.

O. The reduced flue gas volume leaving the I.D. fan will reduce the size requirements and increase the efficiency of pollution control equipment. No "blue haze" or burnt smell is present because short dryer residence times mean that the biomass is removed as soon as drying is complete.

P. The recirculation damper is controlled inversely to the I.D. fan outlet damper and maintains a minimum flue gas flow through the drying system. The damper is normally closed down to 60% of full load operation.

G. Scrap, such as a one-half inch stone or a nail, will be automatically rejected through the rotary scrap valve.

H. The variable speed inlet screw controls the amount of wet biomass entering the dryer based on maintaining a flue gas temperature of 200 °F at the outlet of the dryer. Control is fast responding, automatic, and independent of the boiler system controls.

FIGURE 7
HOG FUEL DRYER SYSTEM SCHEMATIC

A P P E N D I X D

FRANK W. HOCHMUTH, B. Sc. P. E.
CONSULTING SERVICES
STEAM & POWER
POSTAL BOX 186
BREWER, MAINE 04412

A STEAM GENERATOR
with
INTEGRAL DOWN-DRAFT DRYER

The attached illustrations marked Figures Nos.1 to 6, describe a new and novel furnace design wherein high temperature gas from the furnace can be used to reduce the moisture of wet fuel prior to delivery to the combustion zone. Several patents have been issued covering the invention.

Briefly described the operation is as follows: Hot gas from the top of the furnace flows vertically down the drying shaft while wet fuel is introduced near or at the top of the shaft. The fuel and furnace gas move in turbulent contact downward to the bottom of the shaft where the fuel is distributed above and upon a grate surface located at the bottom of the main furnace. A portion of the fuel is burned on the grate and the drier fines are burned above the grate. The air is supplied through the grate, by overfire air nozzles, and through the fuel distribution system.

During the time the fuel is in contact with high temperature gas a predictable amount of water in the fuel evaporates. In a typical case the gas might enter the shaft at 1700 °F, and with a fuel fall of 70 feet about 0.60 pounds of water would be evaporated per pound of dry fuel. Approximately 0.50 pounds of that evaporation would occur from the fine particles that would approach bone dry conditions. Normal "hog fuel" contains between 40 to 50 percent by weight of fines and it is expected that most of that fraction would be burned above the grate, and the remainder of the fuel on the grate. Should the entering fuel have a moisture content of say 55 percent the the bulk moisture would be reduced to 40 percent.

The amount of furnace gas recirculation required to satisfy the preceding example is about 20 percent of the total weight of combustion gases. The gas recirculation will be driven by the differences in densities between the gases in the main furnace vs. those in the dryer shaft. The gases in the dryer shaft will be cooled through the evaporation of moisture from the fuel and the resultant average gas temperature will be much less than the average furnace temperature. This temperature difference will cause lower density gas to flow up in the furnace and down in the dryer shaft. The amount of recirculation can be reliably predicted using the same methods employed for analyzing water circuit circulation. It should be noted that the amount of gas recirculation is essentially self regulating, that is to say that as more wet fuel is fed to the drying shaft the cooler will be the gas and the greater the recirculation.

It is important to recognize that although the furnace receives the same amount of moisture as without the dryer, the latent heat of evaporation is supplied in the drying shaft and not in the combustion zone. Because of this the combustion of the fines burning over the grate are at a much higher temperature, thereby not only enhancing combustion of that fraction of the fuel, but also increasing radiation to the higher moisture fuel on the grate, thereby improving the grate combustion rate. The burning of fines above the grate will avoid "smothering" on the grate thereby also enhancing the burning of the larger particles of fuel.

Of course for any given set of conditions the size and height of the dryer shaft must be set to take into account the fuel characteristics, the gas temperature, and the desired water evaporation from the fuel.

FIG. 1

FIG. 2

FIG. 4

FIG. 3

FIG. 5

Down Draft DRYER Roller

A means for fuel dis-
tribution.

F. W. Hochmuth

F. W. Hochmuth

Nov. 25, 1981

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CONSULTING SERVICES
STEAM & POWER
POSTAL BOX 186
BREWER, MAINE 04412

DESIRABLE FEATURES
of the
DOWN-DRAFT DRYER BOILER

- 1) Permits stable firing of fibrous fuels having more than 55% moisture.
- 2) Improves the combustion of fibrous fuels having less than 55% moisture.
- 3) Eliminates or reduces the requirements for use of auxiliary stabilizing fuels such as gas, oil or predried wood fines.
- 4) Since the fines will be dried to a moisture content substantially below the average of the bulk fuel the burning of these small particles will be rapid and complete thereby reducing char carry-over from the furnace. For the same reasons more of the fines will burn just above the fuel bed and because of this the freeness of the material on the grate should be very much improved.
- 5) Because of item 4) above a thick fuel bed can be carried on the grate which should improve the load following ability of the boiler when fired by waste fuel only.
- 6) Drier and improved sizing of fuel on the grate will result in higher grate combustion rates.
- 7) Eliminates the need for complex external drying systems sometimes required for high moisture fuels.
- 8) Substantially less costly than external drying systems.
- 9) No additional power consumption, operating costs or maintenance required whereas with external dryer systems these items are significant.

- 10) Greatly reduced space requirements as compared to external dryer systems and some special boiler designs.
- 11) No potential for equipment damage in the event of system fires as contrasted external dryer systems that are constructed of non water cooled sheet metal.
- 12) No additional control systems are required since the system is self regulating.
- 13) Lower portion of division wall tubes can be arranged to protect the grate surface when auxiliary fuels such as gas, oil or coal are being burned alone.
- 14) The concept is such that the system could be retrofitted to certain existing boilers or retired black liquor recovery boilers that are being converted to hog/bark fired units.
- 15) Since circulation in the dryer shaft would occur even when not firing wet fuel the effect would be to temper the normally high furnace temperatures that occur when firing gas, oil or coal thereby suppressing the formation of oxides of Nitrogen (NO_x).

A NEW FURNACE DESIGN

For Wood Burning Boilers

Why A Boiler Supplier Should Be Interested

- 1) Wood burning boilers have been in the past, and will be in the future, a major market for large industrial boilers in North America.
- 2) Present wood burning furnace designs are based on concepts that are 40 to 50 years old. Newer, better, and more economical designs would be welcomed.
- 3) Recent attempts to improve furnace performance through the use of external dryers have resulted in costly high maintenance installations. External dryers add to the emission control problem.
- 4) As more chemi-thermomechanical pulp (CTMP) mills are built the market for the conventional kraft process chemical recovery boiler will decrease.
- 5) Wood waste, hog fuel, is common to both the kraft and CTMP pulping processes and therefore its availability as a fuel will not diminish. However the power requirements for the CTMP process is great and it can be expected that in-house power generation will be fully developed.
- 6) A boiler supplier that offers the industry an improved and more reliable boiler for medium to high moisture biomass fuels should be able to increase their share of the present and future market.

- 7) By offering a better wood burning boiler design, the supplier should be able to improve its profit margin since the cost of a boiler incorporating an internal drying system is much less than one employing other types of dryers.
- 8) There is an emerging retrofit market as retired recovery boilers are converted to wood/coal-gas-oil fuels. Existing wood fired boilers are also candidates for upgrading to obtain more capacity, and reduce the amount of gas or oil required to stabilize combustion.
- 9) An opportunity to obtain royalty income through the issuance of sub-licenses exists.
- 10) The high temperature internal dryer technology can be applied to other fuels, such as bagasse, peat, and other high moisture fuels. That would open opportunities in the third world and other foreign markets.

* * * * *

WOOD-FIRED FIELD ERECTED MARKET

- o From 1983-1988, wood-fired boilers have accounted for about 35% of the total, non-MSW field erected market.
- o C-E's share of the overall market has been 18% while taking 13% of the wood-fired market.
- o All of C-E's share has been the sale of three VU-40s, all over 400,000 lb/hr in size.
- o Top supported units account for roughly half the number of wood units sold, but with over 63% of the capacity. The average size of the top supported wood units has been 240,000 lb/hr.
- o The average size of bottom supported wood units is 120,000 lb/hr. Due to structural factors, B&W's CCZ technology is not applied to these units and does not appear to be a success factor in the bottom supported portion of the market.

WOOD FIRED FIELD ERECTED MARKET

	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>	<u>1987</u>	<u>1988</u>	<u>Total</u>
<u>Bottom Supported Units</u>							
Capacity, MM lb/hr	0.51	1.07	0.78	0.98	0.29	0.35	3.98
# of Units	5	8	7	8	4	2	34
<u>Top Supported Units</u>							
Capacity, MM lb/hr	0	1.29	1.46	0.84	1.21	2.44	7.24
# of Units	0	7	4	5	5	8	30
<u>C-E Market Share</u>							
Bottom Supported Units	0	0	0	0	0	0	0
Top Supported Units							
Capacity, MM lb/hr	0	0.40	0	0	0.40	0.68	1.48
# Units	0	1	0	0	1	1	3
<u>C-E Market Share</u>							
% of Total Wood	0	17%	0	0	27%	24%	13%
% of Top Supported Wood		31%	0	0	33%	28%	20%

May, 1989

TOP SUPPORTED WOOD UNIT MARKET

- o Between 1983 and 1988, C-E has won three units (10% share) which account for roughly 20% of the top supported wood capacity sold.
- o Above 300,000 lb/hr, ten units have been sold since 1983. Almost all units went to either B&W or C-E.
- o B&W has won three of the last four reportedly on the strength of their CCZ technology.
- o Below 300,000 lb/hr, neither B&W nor C-E has sold any wood units since 1983 with this market dominated by Zurn with FW and Riley as background players.
- o On the surface, it would appear that development of a combustion technology like CCZ will not help C-E penetrate the top supported wood fired units less than 300,000 lb/hr if B&W can be used as an example.

May, 1989

FUTURE MARKET POTENTIAL

- o Large wood fired negotiations have averaged 1-2 units per year from 1983-1988.
- o The orders recently have increased with the surge in pulp and paper markets. 1988 saw four units bid; in 1989, two units have been awarded, with three more expected.
- o Given the recent history with B&W's success, investment as an alternate technology to "CCZ" should be viewed as a defensive measure.
- o Assuming a market of three to four large wood units per year over the next three to four years, it is reasonable to expect than an alternative to B&W's CCZ design will win for C-E 2-3 incremental VU-40s at size around 450,000 lb/hr.
- o This incremental business is worth approximately \$2.2 million in gross margin which is roughly \$500,000 net of G&A (\$12/lb steam, 16% GM, 12% G&A, 2.5 incremental units over 3 years).

May, 1989

END

**DATE
FILMED**

4 / 08 / 92