Results of continuous coal charring operations
by Allen Ackers

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering
Montana State University

Abstract:
In order to produce soft coke or char from the non-coking coals of the northwestern United States, a medium temperature, continuous retorting process was developed at Montana State College. Originally sponsored by the P.D.P. Processing, Incorporated, the development has been supported by the State of Montana for the past two years and the work has been diverted towards the commercial utilization of western coals.

The P.D.P. char process employs a stainless steel retort which comprises four concentric, vertical cylinders. The coal flows by gravity down the two-inch annular space between the two innermost cylinders. Hot flue gas is circulated on both sides of this annular space. The inner tube is rotated, thus assuring all char particles the same time-temperature history.

The retort will produce char having less than 5 percent volatile matter, no moisture, and a 75 percent or more fixed carbon content. Char can be made from bituminous coal, sub-bituminous coal, and lignite. Specification grade creosote was made from bituminous coal.

Coals from Red Lodge, Montana; Colstrip, Montana; Roundup, Montana; Sheridan, Wyoming; Spring Canyon, Utah; and Beulah, North Dakota were tested in the pilot plant. The retort operated with great success during the runs. The operating temperature of the retort was held around 11OO°F. The char produced meets specifications set by industries in the surrounding area.

Estimated plant costs are $350,000 for a 100 ton/day plant, and $900,000 for a 500 ton/day plant. Under reasonably favorable circumstances, indicated payout time was under six years for four western locations.

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Head, Major Department

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1098

TABLE OF CONTENTS

ABSTRACT

In order to produce soft coke or char from the non-coking coals of the northwestern United States, a medium temperature, continuous retorting process was developed at Montana State College. Originally sponsored by the P.D.P. Processing, Incorporated, the development has been supported by the State of Montana for the past two years and the work has been diverted towards the commercial utilization of western coals.

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INTRODUCTION

During the first years of this century, a multitude of low-temperature carbonization processes were developed (4, 5, 7, 8). Some of these never passed the design state, some were tried out in laboratory or pilot size units, and some commercial size plants were built. None was an unqualified success. In retrospect, the difficulties seem to have been due to the unavailability of proper materials of construction, difficulty in collecting the volatile portions, and lack of markets for the tars and oils produced. Furthermore, the char had to compete price-wise with coke breeze which, more often than not, was in oversupply. The situation has altered considerably. Today we find that coking coal is not as abundant as formerly and that large losses to breeze in coke-making are not tolerated. Still further, breeze itself can now profitably be reworked and fed to the blast furnaces. The decline in the availability of breeze has led to a stronger demand for anthracite fines, but these are limited by production rates and location.

Non-coking coals are in great abundance throughout most of the United States, and char, which results from their carbonization, is thus readily available. Modern high temperature alloys make possible equipment to carry out successfully the charring operation at an economical cost. Finally, the ever increasing demand for carbon as a reducing agent creates a market which can be filled by char. Examples where char appears to be an acceptable form of carbon are taconite roasting, non-ferrous metal smelting, and the production of elemental phosphorus.

If the charring temperature is sufficiently high and the proper grade of bituminous coal is used, the volatile portion contains a creosote fraction which meets American Wood Preservers' Association specifications. The light oil and the tars have a ready market as solvents and coating, respectively. Thus, it appears that there is a definite place in the economy for an efficient char process.

With these economic factors in mind, a group of businessmen from Lewiston, Idaho founded the P.D.P. Processing, Incorporated. This group erected a small plant at Melstone, Montana, basing their designs more or less on the Hobson patent (6). This plant never operated successfully. Failure appears to have been due to improper materials of construction and inability to condense the volatile fraction. In 1954 the process was moved to the laboratories of the Engineering Experiment Station at Montana State College and the development has been carried on there ever since.

EQUIPMENT AND PROCEDURE

Retort

Three different retorts are mentioned in this thesis. They are the batch retort, pilot plant, and commercial retort. The batch retort is used only to get estimates on the amount of char, oils, and dry gas that can be produced from various coals. The batch retort will hold approximately one pound of coal and is heated electrically. The pilot plant is built for continuous operation and will produce $2\frac{1}{2}$-tons of char in a 24-hour period. The pilot plant is used to produce samples of char and oils for testing purposes. The commercial retort is being built in Red Lodge, Montana, and is a modified design of the pilot plant.

A simplified diagram of the pilot plant at Montana State College is shown in Figure 1. The retort consists of a series of concentric cylinders, the inner one being 14 inches in diameter and eight feet long. The carbonization takes place within the two-inch wide annular space formed by the two innermost concentric vertical cylinders. Hot gases are passed on the outside of this annular space and thus heat to the coal is from both directions by conduction through these walls. Coal, crushed to 1½-inch minus, is fed into the annulus from above by gravity. The inner cylinder is rotated slowly on its vertical axis, keeping the coal in slight agitation so that each particle has a uniform time-temperature history, which makes for a uniform product. The inner tube has nubs welded on its outer surface to aid in agitating the coal and operation has been successful when rotation rate was varied from 0.5 to 2 r.p.m. Temperature during the process varies from 1100 to 1200°F; pressure is maintained slightly sub-atmospheric (negative) by the effluent gas blower to remove the volatile matter from the coal, and retention time is generally in the order of 15-20 minutes. Twin six-inch stainless steel screw conveyors of adjustable speed remove the hot char from the bottom of the retort. Cooling of the char is accomplished by passing it through a series of water-jacketed screw conveyors before it emits into the air.

The second annular space, which contains hot circulating flue gas, must be bridged to permit removal of the volatile matter and moisture from the coal to the third annular space. This is accomplished in two ways. Originally, this was done by placing 80 two-inch-diameter stainless steel tubes at a 45-degree angle across the annular space. They worked satisfactorily except with very dusty coals, in which case there was a tendency for them to plug. To overcome this objection, a slot was constructed between the two tubes and a series of louvers, much like a Venetian blind, placed in it. Here the volatile matter, moisture and dust came off easily, yet no coal spilled over. So satisfactorily did these louvers operate that the first commercial retort will have them exclusively. The four concentric tubes of the retort are made of No. 304 stainless steel. The commercial retort is being constructed of No. 310 because of its even better heat-resisting ability; however, after two and one-half years of intermittant use, the stainless steel in the pilot plant shows no appreciable deterioration.

Heat for the pilot plant is furnished by burning natural gas in a furnace. Originally, these gases were passed through the retort once and then sent to the flue. It was found that such a procedure gave insufficient heat utilization and too much heat passed up the stack. The heat spaces are now joined at the top with a manifold and the hot gases recirculated to the furnace by means of a blower. The excess gases are vented to the stack. Rotation of the center tube without loss of gases is accomplished by means of a conventional water seal at the top and a close fit on a centering tube at the bottom.

By-Product Recovery System

The volatile fraction recovery system is rather conventional and quite flexible because of the variety of coals and lignites to be investigated. The hot gases from the retort are withdrawn through the effluent gas blower. The first piece of equipment encountered is a cyclone for dust removal. The amount of dust varies greatly, depending on the nature of the coal being carbonized. Next comes the tar knock-out drum. This is equipped with a water spray at the top and most of the tar and creosote can be condensed here. If the coal contains appreciable moisture, this is a good procedure. The absorption columns following contain screen plates and creosote and/or light oil is recirculated by means of Pesco gear pumps. The gas emitting from the last absorber can by recycled to the furnace as a source of heat. In the pilot plant, frequent starts and stops make this undesirable and natural gas is used in the furnace. All the bituminous and sub-bituminous coals tested gave more than enough B.T.U.'s in the off-gas to meet the furnace requirements. The lignites tested, however, were deficient in this respect and an economic balance on them would have to include some additional heat.

Furnace

The furnace was designed to produce 500,000 B.T.U./hour at maximum capacity. The heat required to raise the temperature of 500 pounds of raw coal in one hour from 70°F to 900°F is 234,000 B.T.U./hour. This value was found by using 0.37 cal/g^{o}C as the specific heat of dry coal and assuming the raw coal has 20 percent moisture (2). The theoretical heat requirements are approximately one-half of the amount of heat the furnace can furnish. The furnace is equipped with a recycle system to give efficient utilization of the heat.

Commercial Retort

Figure 2 shows the design of a commercial retort modified to process coal at a rate of about two tons an hour. The retort is 16 feet high and the inner tube is 40 inches in diameter. The two-inch annular space for coal is maintained and all the volatile matter is removed by the louver and slot arrangement as described above. To eliminate difficulty due to expansion, the furnace is offset to one side instead of being placed beneath the retort as in the pilot plant.

RESULTS

Test Runs

Lignite coal from Harding County, South Dakota was retorted in the Montana State College char plant. The run lasted 16 hours during which six tons of lignite was run through the retort.

The purpose of the run was to see if the uranium in the lignite could be leached out better after the lignite was charred. Small samples of char were leached with a hot solution of sodium carbonate. The uranium was leached out of the char satisfactorily after the lignite was charred at retort temperatures above 800^{o}F according to the representative of the Atomic Energy Commission. The analysis of the lignite and char were of no importance, since the only interest was to leach out the uranium from the char.

A four-ton sample of lignite coal from Beulah, North Dakota was run through the pilot plant. The temperature of the retort was held approximately at 1060°F. The outlet temperature of the second absorption column was kept between 150°F and 200°F. This assured maximum recovery of the by-products. The char produced was fairly high in ash content, see Table II, in comparison with other chars produced in the retort. The fixed carbon content of the char did not meet the requirements of the industries that can use char in their processes. Such a small amount of by-product was collected that no tests were made on the oils. From previous experiences with lignite and sub-bituminous coals, it was found that specification grade creosote could not be made from the by-products produced when charring the coals. A test run was made in the small batch retort to estimate the ultimate yields of oils and char from the lignite. Seven gallons of oils, 2010 pounds of char, and 5800 cubic feet of dry gas were produced per one ton of Beulah lignite. There was not enough dry gas, with an estimated heating value of 425 B.T.U./cu.ft. of dry gas, to make the retort self-sufficient in the heat requirements (3).

A test run was made on a 65-ton sample of Big Horn coal from Sheridan, Wyoming. The average rate that the coal was charged to the retort was 515 lbs/hr with the temperature of the retort at 1125°F. The char produced was low in ash and volatile matter while the fixed carbon content was high, see Table I. The only difficulty with the retorting of this coal was caused by the high moisture content. Some of the heat supplied to the retort had to be used to drive off the moisture which is only a waste by-product. The less the moisture content, the less the heat requirements to drive off the by-products. The large amount of moisture collected also caused difficulty in the collecting of the coal tars and light oils. With a large volume of water and a small volume of by-products, the lighter by-products could not readily be decanted off. Specification grade creosote was not made from Big Horn coal. The reason is that oils from the coal do not have a great enough density to meet standards. The specifications are made up by the American Wood-Preservers' Association. The main fraction of the by-products must then be classified as wood-preserver and sold at a lower price. The light oils in the by-products have a normal boiling point in the range 80°C to 210°C. This comprises approximately 10 percent of the coal tars removed from the coal. The heavy ends have a normal boiling point range of 355°C and above. Approximately five percent of the by-products was tar pitch. The amount of light and heavy ends may vary somewhat due to the thermo-cracking which takes place in the retort.

A small sample was retorted in a batch process to find the maximum yields of char and oils, see Table II. One ton of coal will produce approximately 1040 pounds of char, 22 gallons of oils, and 8000 cubic feet of dry gas. At 425 B.T.U./cu.ft. of dry gas, there is enough heat in the dry gas to retort a ton of raw coal.

The test run on Brophy coal from Red Lodge, Montana lasted approximately four months, which includes the time spent in redesigning and repairing the retort. The char was produced at a rate of 2½ tons/day, and the temperature of the retort was held at approximately 1120°F while the dry gas was flared at 130°F. As shown in Table I, the char produced has a 75 percent or better fixed carbon content which meets the specifications which were set by the non-ferrous and phosphorus industries in this area. The char produced from Brophy coal agglomerated more so than the rest of the coals charred in the retort. The agglomerated char is very desirable in the phosphorus industry because the physical and chemical properties of the char are similar to nut-size coke.

Specification grade creosote was made from the by-products as shown in Table III. The creosote was made by taking one part dehydrated crude oils and blending it with two parts of a fraction of the oils which has a boiling point range between 210° and 355°C. Dehydrated crude oils are the by-products with only the water driven off. The fraction which boils between 210°C and 355°C is minus the light oils and the heavy ends; therefore, the by-products are divided into three products which are light oils, creosote, and heavy ends.

The light oils are not in any pure form such as benzene, toluene, and other pure organic compounds. The light oils may be used as solvents for weed sprays and insecticides. The normal boiling range for them was 80°C to 210°C. The light oils comprise approximately 5 to 15 percent of the by-products condensed.

The heavy ends are solids which resemble the asphalt which is produced in the refining of petroleum. The heavy ends have a boiling range above 355°C. The heavy ends constitute approximately 5 to 10 percent of the crude by-products. The amount of light oils, creosote, and coal tar depends upon the amount of cracking that takes place in the retort. Since the products of the greatest interest are char and creosote, no extensive tests were made on the light oils and coal tar.

The test runs in the batch retort gave the following results as shown in Table II. Approximately 25 gallons of oils, 1070 pounds of char and 6450 cubic feet of dry gas will be produced from one ton of Red Lodge coal.

Coals from Colstrip, Montana; Roundup, Montana; and Spring Canyon, Utah were tested in the batch retort. The results of these tests are shown in Table II and are used to calculate economic balances for the various coals.

DISCUSSION

The coal analyses do not correspond with the char analyses in Table I. Coal and char analyses shown in Table I from the several coal fields are from samples taken at random with respect to time and place. Theoretically, the percent fixed carbon and percent ash for a given percent volatile matter can be calculated for the char from the analysis of the coal. The theoretical calculations will not always be the same or even close to the actual analyses of the chars. The thermo-cracking of the coal tars in the retort will produce carbon deposits on the char during the retorting of the coal. This will increase the amount of fixed carbon in the char. The ash content of the char may be less than theoretically calculated because of the char fines lost in retorting. Since most of the fines are collected in the cyclone, it seems reasonable that part of the ash is also collected in the cyclone.

During most of the time covered by this report, burning of coal in the pilot plant retort occurred to some extent. Repairs during the period did not wholly correct the trouble. This situation will cause considerable variation in char analysis and yield when compared to results obtained with the batch retort. Ash will be removed both as fly-ash out of the stack and as dust in the cyclone. The more volatile fraction of coal tar oils are consumed, giving a higher ratio of tar to creosote than would be expected. To summarize, the ratio of fixed carbon to ash in the char may be different from that ratio in the coal for the following reasons: The volatile matter can be carbonized before it leaves the retort. Dirt, which shows up in the coal analyses as ash, is associated with the fines and will be removed in the cyclone as dust and as fly ash with the fines that fall into the furnace. These factors increase the carbon-to-ash ratio in the char. On the other hand, burning of the char or coal in the retort reduce the carbon-to-ash ratio in the char. Since most of the analyses in Table I indicate a decrease in carbon-to-ash ratio, it appears that in this pilot plant, burning was the largest factor.

The yields of char, oils, and dry coal gas shown in Table II were computed from the yields produced from the batch retort. This is only an estimate to give an economic study of the various coals. The coal was charged to the retort and heated to approximately 900°F. This temperature was maintained for one hour to insure that the volatile matter in the char was approximately five percent. The char yields found from the batch retort will not always be the same as the yields calculated from coal analyses. Again the thermo-cracking of the coal tars during the retorting will give an increase in the char. The amount of oils and dry coal gas produced are dependent upon the length of time the coal vapors are in the retort, and also the temperature of the coal vapors.

A number of different western coals have been tested in the pilot plant. The principal ones are listed in Table I and a wide variation in composition will be noted. The charring operation removes all of the moisture and most of the volatile matter and has some effect on the fixed carbon and ash. Some of the analyses are taken from char stored outside, and these show a moisture content caused by the weather. To make a low ash char, a low ash coal must be charged. Whether or not the process is self-sufficient with respect to heat depends upon the amount of non-condensible gas produced and the moisture content of a given coal. Of the coals listed in Table I, the lignites produce insufficient gas and contain too much moisture to be heat self-sufficient. To operate with one of the lignites on a commercial basis, one must be prepared to use a supplemental source of heat or a coal drier first. The coal from Sheridan, Wyoming contains so much moisture that the heat balance is close. The others produce an excess of gas above that required for retorting.

The char data in Table I are experimental and no significance should be attached to the variation in volatile matter content of the char. The amount of residual volatile matter is a function of the time-temperature history of the char and can be varied over a wide range. In fact, with a very high rate of throughput, the retort approaches a coal drier; it removes most of the moisture but very little of the volatile matter. In this case, however, it is far from heat self-sufficient. Minimum volatile matter content attainable in the char is in the range of one to two percent.

The yields of char and oils vary considerably with the different coals. In Table IV, this variation is indicated under Char, Creosote, and Tar Yields. Of the coals tested, Spring Canyon, Utah and Roundup, Montana have the highest char yields -- 1310 lbs/ton and 1280 lbs/ton, respectively. On the other hand, Colstrip, Montana coal and Beulah, North Dakota lignite gave only 1005 lbs/ton and 1050 lbs/ton, respectively.

Even harder to predict from the coal analysis is the yield of oils. Since this investigation has so far been confined to western coals and an area where the market demand for creosote is good, little consideration has been given to making liquid products other than creosote. Experiments to date indicate that creosote meeting the specifications of the American Wood Preservers' Association can be made only from bituminous coal. Of the coals listed in Table I, only that from Red Lodge, Montana and Spring Canyon, Utah yield this quality creosote. Table III shows a comparison of creosote from Red Lodge coal with the specifications. Specification grade creosote is worth about 24¢/gallon. Non-specification grade creosote can be sold as wood preserver for 14¢/gallon. Light oils and tar may be sold at 15¢/gallon. These values were used in calculating the liquid by-product values given in Table IV. For coals from which specification creosote could not be made, the entire by-product was considered as wood preserver and valued at 14¢/gallon. For coals from which specification grade creosote could be obtained, the liquid by-product yield was broken down into a light oil and tar fraction valued at 15¢/gallon and a specification creosote fraction valued at 24¢/gallon, and an average value placed on the composite liquid. For example, the Red Lodge coal yields 25 gallons of by-product per ton of coal from which 19 gallons of specification grade creosote can be made, leaving six gallons of light oil and tars. The value of the 25 gallons of by-product based on the above figures is $5.46, giving an average value of 22¢/gallon.

The economic attractiveness of the process varies greatly with the coal charged. The location must be one that is reasonably close to the consumers. The char must be of a quality that is attractive for the particular user. For example, the non-ferrous smelters want char containing less than five percent volatile matter, sized to 3/16-inch minus, and containing at least 75 percent fixed carbon. The elemental phosphorus manufacturers want char containing less than one percent sulfur and less than five percent volatile matter, at least 75 percent fixed carbon sized in the range 3/8 to 3/16-inch, and, in addition, the char must have agglomerated. We have yet to find a sub-bituminous coal or a lignite which will agglomerate on heating. For the zinc fume smelting operation, the char should contain 10-15 percent volatile matter and be sized to 200 mesh. By the proper selection of charge material, the retort may be operated to produce a char meeting any of the above specifications.

An abbreviated economic study is present in Table IV. An average char price of $12.00/ton is assigned to those coals which agglomerate on heating, $10.00/ton if they do not agglomerate. The basis for the creosote price is explained above. Operating expenses are itemized on Table VI. Plant amortization, plant labor, and property tax and insurance are based on a 100-ton of char/day. These will change slightly for a 500-ton of char/day plant when based on a per ton basis. Therefore, the value of $3.50/ton of coal for operating expense, shown in Table IV, is a fair estimate for both the 500-ton/day and 100-ton/day plants. Coal cost is based on personal investigation at the several sites. All the coals listed in Table IV were found to be fuel self-sufficient except the Beulah, North Dakota lignite, which required supplemental heat. This could be obtained by burning 0.3 pounds of lignite for each pound charred, and thus the 60¢/ton value shown for fuel cost. The income per ton varies greatly with quality and yield of char and creosote.

On the basis of early 1957 costs, char plants employing this process appear to cost as follows: 100 tons/day - $350,000; 200 tons/day - $500,000; 500 tons/day - $900,000; and 1,000 tons/day - $1,600,000 (1). These figures exclude working capital. Using these costs estimates,

Table V presents a comparative study of investment return for two different sized plants at the locations indicated in Table IV. The 100 ton/day plant appears to be economically attractive only at Spring Canyon, Utah and Red Lodge, Montana, where payout times are approximately 2.9 and 5.8 years, respectively. For the 500 ton/day plant, however, all the locations listed in Tables IV and V appear to be reasonably sound economically except possibly Roundup, Montana.

A 100 ton/day plant is currently being constructed at Red Lodge, Montana. It is expected to serve the non-ferrous smelters in Montana and the elemental phosphorus industry in Montana and Idaho.

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APPENDIX

TABLE I

COAL AND CHAR ANALYSES

Analyses in Percent

Red Lodge, Montana Stoker Coal

Coal

Moisture	Volatile Matter	Fixed Carbon	Ash
8.6	35.1	48.3	8.0
7.7	33.7	50.6	8.1
8.2	33.5	50.1	8.2
12.7	32.0	47.8	7.6
12.1	32.7	48.6	6.6
11.8	32.2	48.5	7.5
12.8	32.0	48.7	6.5
10.1	31.2	50.0	9.7
9.8	31.1	47.9	11.2
9.9	33.5	44.5	12.1

Char

Moisture	Volatile Matter	Fixed Carbon	Ash
negligible	1.33	82.9	15.6
negligible	1.4	83.5	15.3
negligible	1.4	83.2	15.5
negligible	6.3	82.5	11.1
negligible	7.3	78.7	14.0
negligible	6.3	81.0	12.7
negligible	6.5	81.6	11.9
negligible	6.2	82.1	11.8
negligible	5.2	81.2	13.9
5.2	6.4	75.1	13.3
5.2	6.3	74.9	13.8
5.1	7.4	74.8	12.7
5.2	5.0	78.9	11.1
5.0	5.7	77.1	12.2
5.0	5.8	75.3	14.0

TABLE I (continued)

COAL AND CHAR ANALYSES

Analyses in Percent

Roundup, Montana - Slack Coal

Coal

Moisture	Volatile Matter	Fixed Carbon	Ash
13.0	31.0	46.5	9.5
10.6	32.4	47.1	9.9
12.7	30.5	47.3	9.5

Char

Moisture	Volatile Matter	Fixed Carbon	Ash
negligible	12.1	72.5	15.4
negligible	11.4	73.4	15.2
negligible	11.0	73.8	15.2
negligible	7.8	78.0	14.3
negligible	8.3	77.0	14.7
negligible	7.4	77.7	14.9

Colstrip, Montana - Slack Coal

Coal

Moisture	Volatile Matter	Fixed Carbon	Ash
14.2	36.1	40.5	9.2
16.5	35.2	40.8	8.5

Char

Moisture	Volatile Matter	Fixed Carbon	Ash
negligible	13.5	70.9	15.6
negligible	12.9	71.6	15.5
negligible	6.2	76.4	17.4

TABLE I (continued)

COAL AND CHAR ANALYSES

Analyses in Percent

Sheridan, Wyoming - Slack Coal

Coal

Moisture	Volatile Matter	Fixed Carbon	Ash
20.2	32.8	43.6	3.4
21.1	33.2	43.2	2.5
22.2	34.8	39.0	4.0
20.9	35.4	39.6	4.1
21.4	34.8	39.8	4.0
22.2	33.0	39.0	5.8
23.4	32.6	40.9	4.1
22.8	31.1	38.0	8.1

Char

Moisture	Volatile Matter	Fixed Carbon	Ash
negligible	18.5	74.3	7.1
negligible	19.6	73.3	7.0
negligible	21.6	71.6	6.7
1.7	3.8	87.2	6.8
negligible	3.8	88.6	7.6
negligible	3.9	87.0	9.1

TABLE I (continued)

COAL AND CHAR ANALYSES

Analyses in Percent

Spring Canyon, Utah - Stoker Coal

Coal

Moisture	Volatile Matter	Fixed Carbon	Ash
3.7	43.0	50.6	2.7
3.4	42.4	49.7	4.5
3.9	41.9	49.0	5.2

Char

Moisture	Volatile Matter	Fixed Carbon	Ash
negligible	10.3	79.1	10.6
negligible	11.0	78.0	11.0
negligible	11.2	78.6	10.2

Beulah, North Dakota - Lignite

Coal

Moisture	Volatile Matter	Fixed Carbon	Ash
11.7	31.8	44.8	11.7
12.4	30.5	45.5	11.5
12.4	30.4	46.0	11.3
11.2	32.2	45.4	11.1
11.4	31.8	45.0	11.8
15.1	32.2	41.2	11.6
14.4	32.2	42.4	11.1

TABLE I (continued)

COAL AND CHAR ANALYSES

Analyses in Percent

Beulah, North Dakota - Lignite

Char

Moisture	Volatile Matter	Fixed Carbon	Ash
negligible	9.5	74.8	16.7
negligible	9.3	74.2	16.4
negligible	10.1	73.2	16.8
negligible	9.4	73.1	17.4
negligible	9.3	72.5	18.2
negligible	8.0	73.0	19.1
negligible	9.2	73.5	17.4

TABLE II

DATA ON VARIOUS COAL FROM BATCH RETORT

Coal	Char %	Oils %	Water %	Gals. oil/ ton of coal	Cu.ft. of dry gas/ton of coal
Sheridan, Wyo.	52.9	9.7	17.8	18.7	8000
Roundup, Mont. (Sample No. 1)	64.0	4.95	17.5	11.9	8000
Brophy (washed)	53.4	10.5	13.3	25.2	6450
Spring Canyon, Utah	65.5	14.6	4.5	35	—
Colstrip, Mont.	50.2	6.1	21.2	14.4	7900
Beulah, N.D. Lignite	51	3.1	29.2	7.5	5800

TABLE III

COMPARISON OF CREOSOTE FROM RED LODGE, MONTANA COAL WITH AMERICAN WOOD PRESERVERS' SPECIFICATIONS

Specification		Creosote from Red Lodge Coal
1. It shall contain not more than 3% water.		1. No water.
2. It shall contain not more than 2% of material insoluble in benzol.		2. 0.85%.
3. The specific gravity of the creosote at 38°C shall be not less than 1.03.		3. Specific gravity is 1.032.
4. The distillate shall be:		4.
Up to 210°C	$< 5\%$	5%
Up to 235°C	5-25%	22.2%
Up to 315°C	$> 36\%$	71.4%
Up to 355°C	$> 60\%$	82.6%
5. The creosote shall yield not more than 5% of coke residue.		5. 4.23%

TABLE IV

COMPARATIVE ECONOMICS OF SEVERAL CHARS

	Coal Source					
	Red Lodge, Mont.	Colstrip, Mont.	Roundup, Mont.	Sheridan, Wyo.	Spring Canyon Utah	Beulah, N.D.
Revenue						
Char Price - $/ton	$12.00	$10.00	$10.00	$10.00	$12.00	$10.00
Char Yield - lbs/ton	1070	1005	1280	1040	1310	1050
Income from Char - $/ton coal	$ 6.40	$ 5.00	$ 6.40	$ 5.20	$ 7.85	$ 5.25
Liquid by-product Yield - gal/ton	25	14	12	19	35	8
Liquid by-product Value - ¢/gal	22	14	14	14	22	14
Income from by-products $/ton of coal	$ 5.50	$ 1.96	$ 1.68	$ 2.66	$ 7.70	$ 1.12
Total Income - $/ton	$11.90	$ 6.96	$ 8.08	$ 7.86	$15.55	$ 6.37
Expenses						
Operating Expenses - $/ton of coal	$ 3.50	$ 3.50	$ 3.50	$ 3.50	$ 3.50	$ 3.50
Coal Cost - $/ton	$ 4.75	$ 2.25	$ 4.50	$ 2.65	$ 5.00	$ 2.00
Fuel Cost - $/ton	- - -	- - -	- - -	- - -	- - -	$ 0.60
Total Cost - $/ton	$ 8.25	$ 5.75	$ 8.00	$ 6.15	$ 8.50	$ 6.10
Net Income before Income Tax - $/ton	$ 3.65	$ 1.21	$ 0.08	$ 1.71	$ 7.05	$ 0.27

TABLE V

ECONOMIC COMPARISON

	Red Lodge, Mont.	Colstrip, Mont.	Roundup, Mont.	Sheridan, Wyo.	Spring Canyon, Utah	Beulah, N.D.
100 ton/day Plant						
Plant Investment	$350,000	$350,000	$350,000	$350,000	$350,000	$350,000
Net Income after Fed. Inc. Tax	$ 61,400	$ 20,400	$ 1,350	$ 28,800	$119,000	$ 4,550
Annual Return on Investment - %	17.5	5.8	0.4	8.2	34.0	1.3
Plant Payout Time - yrs.	5.8	17.2	---	12.2	2.9	---
500 ton/day Plant						
Plant Investment	$900,000	$900,000	$900,000	$900,000	$900,000	$900,000
Net Income after Fed. Inc. Tax	$370,000	$165,000	$ 70,000	$207,000	$655,000	$ 86,000
Annual Return on Investment - %	41	18.3	7.8	23	73	9.6
Plant Payout Time - yrs.	2.4	5.5	12.8	4.4	1.4	10.4

TABLE VI

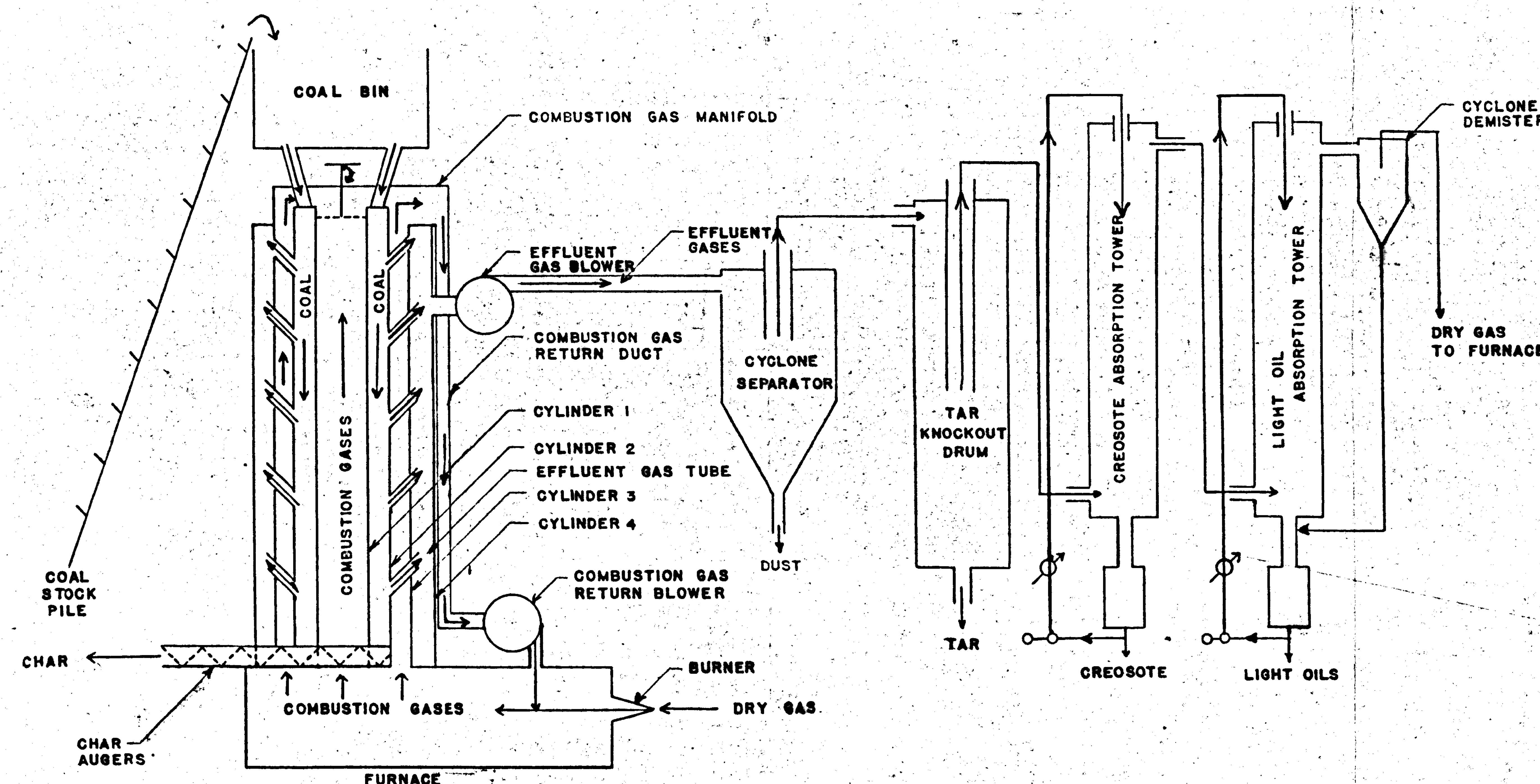
ESTIMATED OPERATING EXPENSES

Charge -- 170 tons of coal/day yields 100 tons/day of char, 350 days/year.

	Per Ton of Coal
Electricity	$ 0.08
Plant labor - 5 men/shift; 3 shifts/day; $2.00/hr.	$ 1.44
Plant Superintendent - $550/month	$ 0.11
Steam Gas Water	$ 0.09
Repair Materials	$ 0.25
Process Royalty	$ 0.50
Payroll Taxes and Office Overhead	$ 0.06
Property Tax & Insurance - 3% of Plant Investment	$ 0.10
Selling and Administrative Expenses	$ 0.28
Plant Amortization - 10% of $350,000 Investment	$ 0.60
TOTAL EXPENSE	$ 3.51

FIGURE 1

SIMPLIFIED FLOW DIAGRAM OF THE CHAR PLANT



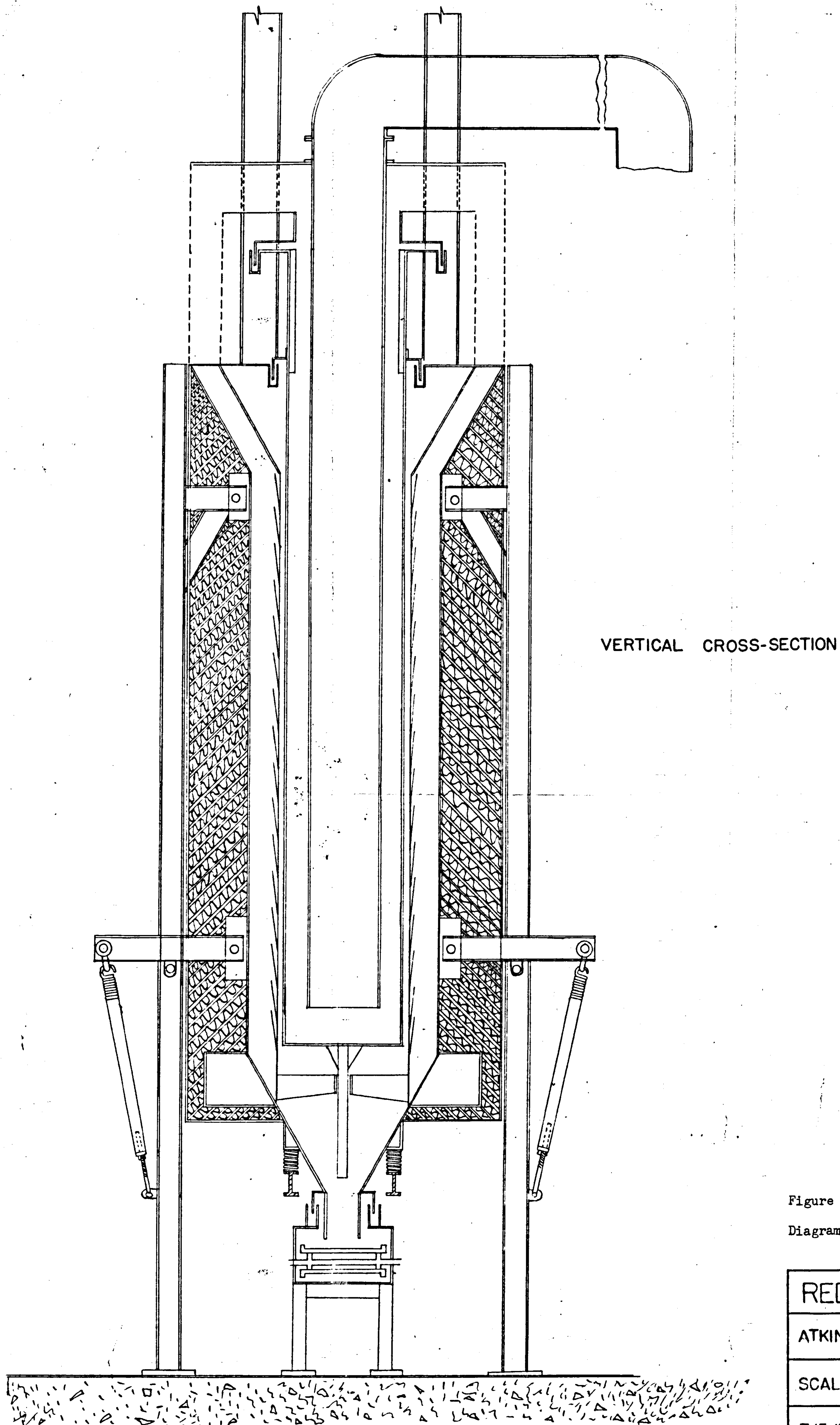


Figure 2.

Diagram of a Commercial Retort.

RED LODGE RETORT
ATKINSON-BERG COMPANY
SCALE- 1-INCH = 30-INCH
7/5/56 ATKINSON