Results of the coal charring process at Montana State College

by William O Munson

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

Abstract:
A medium temperature, continuous coal retorting process has been developed at Montana State College. This process will produce from noncoking coals, a char that will meet coke specifications set by industries in the surrounding area.

The Montana State College char process employs a stainless steel retort which is comprised of four concentric, vertical cylinders. Coal flows by gravity down the two-inch annular space between the second and third cylinders. The coal is heated to a temperature of 1300 to 1500 degrees Fahrenheit by hot flue gases from a gas-fired furnace. The coal is agitated by means of a mechanical lift that gives the inner cylinder a slight vertical movement.

The char plant operated for extended periods of time without deterioration of equipment, Coals and lignites from Montana and a high-volatile char from Wyoming were tested in the retort. The Wyoming char, after being re-duced in volatile matter, was tested by the Victor Chemical Works . The tests proved that Superior, Wyoming, char will work as well as coke in the phosphorus industry.

Estimates show that it would be profitable to build a char plant in Roundup, Montana, A char plant using lignites would not be profitable for the locations studied.

RESULTS OF THE COAL CHARRING PROCESS AT MONTANA STATE COLLEGE

by

WILLIAM O. MUNSON

A THESIS

Submitted to the Graduate Faculty

in

partial fulfillment of the requirements

for the degree of

Master of Science in Chemical Engineering

at

Montana State College

Approved:

Lloyd Berg

Head, Major Department

Lloyd Berg

Chairman, Examining Committee

Leon Johnson

Dean, Graduate Division

Bozeman, Montana
September, 1958

TABLE OF CONTENTS

ABSTRACT

A medium temperature, continuous coal retorting process has been developed at Montana State College. This process will produce from non-coking coals, a char that will meet coke specifications set by industries in the surrounding area.

The Montana State College char process employs a stainless steel retort which is comprised of four concentric, vertical cylinders. Coal flows by gravity down the two-inch annular space between the second and third cylinders. The coal is heated to a temperature of 1300 to 1500 degrees Fahrenheit by hot flue gases from a gas-fired furnace. The coal is agitated by means of a mechanical lift that gives the inner cylinder a slight vertical movement.

The char plant operated for extended periods of time without deterioration of equipment.

Coals and lignites from Montana and a high-volatile char from Wyoming were tested in the retort. The Wyoming char, after being reduced in volatile matter, was tested by the Victor Chemical Works. The tests proved that Superior, Wyoming, char will work as well as coke in the phosphorus industry.

Estimates show that it would be profitable to build a char plant in Roundup, Montana. A char plant using lignites would not be profitable for the locations studied.

INTRODUCTION

Montana, along with most of the surrounding states and provinces, has huge deposits of coal. Over 200 billion short tons of coal are found in Montana alone. This coal is of three main types: bituminous, sub-bituminous, and lignite.

At the turn of the century many people realized that coal was losing out to oil, natural gas, and electricity as a source of power in the United States. They realized that coal would be in over-supply in the future. As a result of this, many processes were devised to up-grade non-coking coal and let them compete as a source of fixed carbon in industry (5, 8, 9, 11). A market for about 900,000 tons of char per year exists in the states of Montana, Idaho, and Utah alone (7). This market is being supplied by an excess of coking coals used in the steel industry. The disadvantage of this is that when the steel industry is booming, the coke available is in short supply. Although the market is being supplied by coke, non-coking coals will produce a coke-like product that will fit the specifications of industry in this area.

A coal carbonization pilot plant was built at Montana State College in 1954 under the sponsorship of the P D P Processing Corporation. A plant built by them at Melstone, Montana, in 1951 met with very limited success, so they decided to move the process to the Montana State College laboratory. The reason for the failure was that mild steel was used in the construction of the plant. The temperatures reached in retorting will disintegrate mild steel rapidly. The pilot plant at Montana State College was constructed of stainless steel where the temperature warranted. The sponsorship of the pilot plant was taken over by the Montana State College Experiment Station in 1955. This pilot plant operated for three years. A completely new pilot plant was built in 1957 by the Experiment Station because of mechanical and furnace difficulties which occurred in the first one. However, the first retort did produce char of the specifications required for the industries mentioned and the retort did not deteriorate appreciably during the process. The second pilot plant has done away with the minor difficulties of the first and operates very smoothly. Runs have been made of 28, 42, and 44 days, with only a few minor shut downs.

The purposes of the tests at Montana State College are to see how a coal will react in the retort and to determine the quality of the char and the quality and the quantity of the by-product oils produced. During the past year twenty-three different coals and lignites from Montana, Wyoming, and Utah were tested. A high volatile char (10 to 12 percent volatile matter) made from Superior, Wyoming, coal was also tested.

EQUIPMENT AND PROCEDURE

The char pilot plant at Montana State College has a capacity of from two to three tons of coal per day. A simplified flow diagram is shown in Figure 2. As shown, the main parts of the char plant are the furnace, the by-products recovery system, and the retort.

The retort is made up of four vertical concentric stainless steel cylinders. An outer shell which houses the retort is made of mild steel and has a diameter of 58 inches. The four inner cylinders which comprise the heated part of the retort are 12, 20, 24, and 38 inches in diameter. A loose Zonolite insulation is placed in the annular space between the shell and the outer cylinder. Coal is carried to the top of the retort in five-gallon buckets and fed into the four hoppers. The coal then flows by gravity through the two-inch annular space between the second and third cylinders. The innermost cylinder is given a slight vertical movement by a mechanical lift. This helps to prevent bridging between the two cylinders, thus insuring a uniform product, because no channels form. The retort stands 11 feet 4 inches high from the floor. The height of the annular space through which the coal flows is 34 inches. Air is prevented from entering this annular space by water seals at both the top and bottom.

The charred coal drops from the annular space into a funnel type stainless steel shell at the bottom of the retort. It then falls into an auger box and is removed by two screw conveyors. The through-put and thus the volatile matter of the char can be varied greatly depending upon the speed at which the conveyors are operated. The char then drops into a water-sealed barrel. When a barrel becomes full, it is removed and a new one is put in its place. The full barrel is weighed, then dumped. The char is cooled and put into storage on an open-air char deck. From the weight of the entering coal and the net barrel weight, the yield of char is determined.

Gases and vapors which are driven from the coal, during the charring operation, escape from the coal zone through louvers into four vertical slots which bridge the outer heat zone. The louvers, which may be seen in the A-A cross-sectional view in Figure 2, are arranged similarly to venetian blinds. The gases and vapors are pulled through the gas manifold by a blower located in the recovery system. Next, the gases pass through a cyclone which removes any dust that may be entrained in the gas stream. There is a heat jacket around both the manifold and the cyclone to prevent the volatile matter from condensing out.

The dust free gases are then sent to three condensers operating in series. Water and oils are condensed out by a cold water spray at the top of each condenser. The temperature of the last condenser is maintained under 100 degrees Fahrenheit to make certain that all the condensable matter has been removed from the gas stream. A centrifugal pump forces the condensed water and oils from the bottom of the condensers to a decanting drum. The tars, being more dense, are removed from the bottom. Water that is taken off the top is sent through a heat exchanger where it is cooled and forms the cold water spray for the condensing system. The permanent gases are flared. In a commercial plant, these gases would probably be used to heat the furnace.

The charring of the coal is accomplished by hot combustion gases from the furnace. These gases enter the outer-most annular space near the bottom of the retort and travel upward and then down through the innermost annular space, thus the coal is heated on both sides as it is retorted. The gases are then pulled by a blower up through the inner tube, and are recycled to the furnace.

The outside dimensions of the furnace are: 11 feet 4 inches long; 5 feet 4 inches wide; 7 feet 8 inches high. The walls are constructed of two rows of fire brick covered on the outside with a row of insulation brick. A mild steel shell encases all four sides of the furnace. The roof, unattached to the walls of the furnace, is hung in place from three I-beam stands shaped somewhat similarly to inverted U's. The roof is made of plastic brick which may be molded into shape before hardening. The floor of the furnace is made of two rows of fire brick on top of ventilation tile. Air is blown through the slots in the ventilation tile and water pipes are placed between each row. In this way the furnace floor can be kept relatively cool so that the heat from the furnace will not crack the concrete floor of the laboratory.

There is an 18 inch baffle three-fourths of the way back in the furnace. The hot gases pass over the baffle and mix with the recycled gases from the furnace. This insures better combustion and a more uniform heat flow. The amount of natural gas fed to the furnace is regulated by an automatic controller which keeps the output temperature constant, usually at 1700 degrees Fahrenheit.

Temperature readings were taken every half hour throughout a run by means of thermocouples. The two most important temperatures were at the outlet of the last condenser, as mentioned before, and the char discharge temperature. The latter temperature was kept between 1300 and 1500 degrees Fahrenheit. This was found to be sufficient to drive off the required amount of volatile matter. The char discharge temperature was regulated by varying the speed of the discharge augers. A faster throughput will lower the temperature.

RESULTS AND CONCLUSIONS

There were twenty-three different coals and a high volatile char tested in the Montana State College char plant this past year. The coals studied in this report are listed in Table I, along with the type of coal and the mine location. The remaining coals were studied in a previous report by D. E. Skerritt (10).

East Belt coal presented a somewhat unique problem. Their coal seam consists of a one to two foot layer of coking coal beneath a two to three foot layer of non-coking coal with a six-inch layer of slate between them. Coking coals cause trouble in this type of process because they fuse to the sides of the retort (10). Therefore, the coal was run through first at 500 to 600 degrees Fahrenheit in hopes of oxidizing it. Oxidation of some coking coals is known to reduce the coking properties. This scheme did not work well and during the second time through, the coking coal caused some clogging. The layer of slate makes this coal have a high ash content and the char will not meet phosphorus company specifications. This char was not evaluated economically because of the high ash content and the low oil yields obtained (see Tables II and III).

Seven of the coals tested were from the Roundup, Montana area. Each of these coals ran through the retort well and no trouble was encountered with them. Since none of the chars from these coals can pass the phosphorus industry's hardness test, the best market for char from Roundup coals is the ferrochrome manufacturing operations at Nye, Montana. The char specifications for this plant are: less than 0.2 percent sulfur; less than 5.0 percent volatile matter; and more than 84 percent fixed carbon. No size specifications were given. Of the seven coals tested, only three would produce a char which met the specifications. Those were Roundup Mining, Square Deal, and P.M. chars.

A little over 4.2 tons of Roundup Mining coal were run through the retort. A ton of coal yielded 1230 pounds of char and 8.9 gallons of oils. The char was produced at an average rate of 3230 pounds per day. As shown in Tables II and IV, the char had a fixed carbon content of 85.6 percent and a sulfur content of 0.18 percent.

Square Deal coal, which is mined from a continuation of the same seam as Roundup Mining, is of course very similar to the latter coal. Each ton of Square Deal coal yielded 1172 pounds of char and 10.7 gallons of oils. The char, which had fixed carbon and sulfur contents of 86.5 percent and 0.10 percent respectively, was put through at an average rate of 3050 pounds per day.

The creosote fraction of the oils produced would not quite meet the American Wood Preservers' specifications (2). A comparison of the creosote fraction with these specifications is shown in Table V.

Coal from the P.M. mine gave 1184 pounds of char and 11.7 gallons of oils for each ton charged. The char had a fixed carbon content of 84.2 percent and a sulfur content of 0.14 percent. The creosote did not meet

A.W.P. specifications as shown in Table VI. Table VII also shows the results of distillations on some other Roundup crosotes.

Several Eastern Montana lignites were run through the Montana State College char plant. All the lignites acted similarly while retorting. They all broke into fines and were quite dusty, however no trouble was encountered because of this. The results of the tests are recorded in Tables II and III. The C. Sorenson mine at Savage, Montana will serve as an example of the others. From each ton of this lignite came 1004 pounds of char and 5.8 gallons of oils. The char was 77.3 percent fixed carbon and 14.5 percent ash. The liquid by-products from lignites will not meet A.W.P. specifications because of their low specific gravity and the large amount of material found in the lower boiling ranges (11).

All chars, while cooling, pick up moisture from the atmosphere. Most chars rarely adsorb more than one to two percent moisture. However, lignite chars will adsorb up to six percent water. This is probably due to the greater number of cracks and holes in a soft char than in a hard one, thus giving the soft char a much larger surface area on which to hold water. A test was made to see how long it would take a lignite char, dried in air at 103 degrees Centigrade to regain all its moisture while cooling. As shown in Figure 3, all the water was regained after one hour.

Bulk densities of all the chars, ground to approximately 80 percent minus 100 mesh, were taken. A correlation was thought to exist between bulk density and ash content or a combination of ash and volatile matter contents. No correlation was found to exist, probably because the chars did not all have the same type of ash. The unground bulk densities were taken in hopes of a correlation with through-put. This, however, failed to show any sound results.

Approximately 80 tons of a high volatile char was run through the Montana State College retort at an average rate of 4140 pounds per day. This high volatile char was made from Superior, Wyoming coal by putting it through a Lurgi Process char plant at Beinfait, Saskatchewan, Canada. The Lurgi Process, it was found, did not produce a char with low enough volatiles to meet phosphorus company specifications. The char was then shipped to Montana State College where the volatile matter was reduced to around three percent from its original eleven percent. This low volatile char was tested by a phosphorus producer, the Victor Chemical Works at Silver Bow, Montana. The test was performed by mixing the char with coke in varying amounts. No difference in operation was noted between pure coke and the mixtures. The test proved that Superior char will perform equally as well as coke in making elemental phosphorus. A previous report by D. E. Skerritt shows that a char plant in Superior, Wyoming, would be economically successful (10).

Economic consideration was given to Roundup Mining, Square Deal, and P.M. coals of Roundup and C. Sorenson lignite of Savage. Square Deal coal is so similar to Roundup Mining that the two are considered the same for the remainder of this report. Also, the economics of Savage lignite will not be greatly different than any other lignite tested this past year. The factors which influence the economics are: the yields of char and oils, the price obtainable for these, the distance from the markets, and the price of coal.

Ferrochrome grade char will bring $22.70 per ton delivered to Nye, Montana (6). The market for lignite char is the taconite industry in eastern Minnesota. They will pay $12.40 per ton delivered to the plant (4). The char prices listed in Table VII are net prices f.o.b. plant site. In calculating these values, freight rates were taken from Figure 1, a plot of freight cost per ton of coke breeze versus rail miles (10). Since the oils produced would not meet A.W.P. specifications, the average price was taken to be 14 cents per gallon (1).

The economic comparison for the various chars has been based upon the size of plant needed. The Ferrochrome mill will use 25 tons of char per day while the taconite industry will use a great deal more. In view of this, a 100 ton per day plant was proposed for Savage. Estimated operating expenses are listed in Tables VII and VIII. The final results are shown in Table X.

A charring operation for any of the three sites mentioned in Roundup would be profitable. The Savage site would lose money due to its distance from the markets.

ACKNOWLEDGMENTS

The author wishes to thank the Montana State College Engineering Experiment Station for its sponsorship of this project; also, to thank Mr. D. E. Atkinson and Dr. Lloyd Berg for their valuable guidance and assistance.

LITERATURE CITED

(1) Ackers, Allen, Results of Continuous Coal Charring Operations, Thesis, Chemical Engineering Department, Montana State College, 17, May (1957).

(2) American Society For Testing Materials: 1949 Book of A.S.T.M. Standards, Part 4, 739.

(3) Atkinson-Berg Company, Personal Communications.

(4) Haslip, William and Gerald, Economic Study for a Char Plant in Eastern Montana, Chemical Engineering Department, Montana State College, June (1958).

(5) Hobson, Frank E., U. S. Patent 1,924,788; August 29, 1933.

(6) Jensen, Roger D., and Savoy, George S., The Economics of Establishing a Char Plant for Central Montana Coals, Chemical Engineering Department, Montana State College, June (1958).

(7) Lengemann, Robert A., Market Development Survey For Continuous Coal Charring Process, Thesis, Chemical Engineering Department, Montana State College, 4, September (1957).

(8) Minet, R. G., Smith, H. B., Jr., and Trilling, C. A., Chemical Engineering Progress, 50, 342 (1954).

(9) Prostel, E., and Rice, N., Industrial and Engineering Chemistry, 47, 2317 (1955).

(10) Skerritt, D. E., Charring of Coals From Montana and Neighboring States, Thesis, Chemical Engineering Department, Montana State College, July (1958).

(11) "Low Temperature Carbonization of Utah Coals," A Report of the Utah Conservation and Research Foundation to the Governor and State Legislature; May, 1939.

APPENDIX

TABLE I

COALS STUDIED IN THIS REPORT

Mine	Location	Type of Coal
East Belt Coal Co.	Belt, Mont.	Bituminous
Mountain States Mng.	Roundup, Montana	Sub-bituminous
Roundup Mining Co.	" "	"
Square Deal Mining	" "	"
Johnies Coal Co.	" "	"
Divide Coal Co.	" "	"
Gildroy Coal Co.	" "	"
P.M. Coal Co.	" "	"
North Star Coal	Coalwood, Mont.	Lignite
Thiel Bros.	Sidney, Mont.	"
J. Albrecht	Bloomfield, Mont.	"
Peuse Bros.	Glendive, Mont.	"
C. Sorenson	Savage, Mont.	"
D. O. Clark Mine	Superior, Wyo.	High Volatile Char

TABLE II

ANALYSIS OF VARIOUS CHARS

Mine	Percent Moisture	Percent Volatiles	Percent Fixed Carbon	Percent Ash
East Belt		4.0	81.3	14.7
Mtn. States		4.0	82.0	14.0
Roundup Mng.		4.0	85.6	10.4
Square Deal		1.9	86.5	11.6
Johnies		2.9	88.1	9.0
Divide		3.8	88.8	7.4
Gildroy		4.1	86.0	9.9
P.M.		4.0	84.2	11.8
North Star	3.9	5.3	76.7	14.2
Thiel Bros.	3.7	4.8	73.5	18.0
J. Albrecht	3.2	5.8	76.2	14.8
Peuse Bros.	5.8	6.2	80.4	7.6
C. Sorenson	4.2	4.0	77.3	14.5
D. O. Clark		3.9	90.1	6.0

TABLE III

DATA ON VARIOUS COALS

Mine	Char Yield % by Wt.	Oil Yield gal/ton of coal	Production Rate lb. char/day
East Belt	64.2	5.8	3500*
Mtn. States	48.0	8.5	2530
Roundup Mining	61.5	8.9	3230
Square Deal	58.6	10.7	3050
Johnies	52.4	12.0	2250
Divide	48.1	10.3	1960
Gildroy	52.2	14.0	2375
P.M.	59.2	11.7	2090
North Star	49.3	4.2	1670
Thiel Bros.	45.7	5.7	1500
J. Albrecht	51.2	4.8	1080
Peuse Bros.	40.6	3.1	1150
C. Sorenson	50.2	4.8	980
D. O. Clark	89.7	-----	4136

*Predried Coal

TABLE IV

DATA ON SULFUR ANALYSIS AND BULK DENSITY FOR VARIOUS CHARS

Mine	% S	Bulk Density 80% minus 100 Mesh lb/cu. ft.	Bulk Density Unground lb/cu. ft.
East Belt	2.62	54.1	39.0
Mtn. States	0.30	50.3	41.2
Roundup Mng.	0.18	44.7	38.0
Square Deal	0.10	44.3	41.2
Johnies	0.26	48.4	36.5
Divide	0.44	48.8	35.6
Gildroy	0.43	52.0	42.6
P.M.	0.14	53.0	38.9
North Star	0.05	43.4	39.0
Thiel Bros.	0.06	39.6	36.5
J. Albrecht	0.17	40.0	36.5
Peuse Bros.	0.05	32.1	34.9
C. Sorenson	0.02	39.2	34.9
D. O. Clark	0.67	----	----

TABLE V

COMPARISON OF CREOSOTE FROM SQUARE DEAL COAL WITH AMERICAN WOOD PRESERVERS' SPECIFICATIONS

Creosote Test	Specifications	Square Deal Creosote
S. G. at 38/15.5°C.	1.03 +	1.025
Distillation up to 210°C.	5.0 - (wt.%)	1.7
up to 235°C.	5 - 25	11.7
up to 270°C.	20 +	27.1
up to 355°C.	60 - 85	71.0
Coke residue	2.0 -	1.2
Water Wt. %	3.0 -	pass
Benzene Insoluble Wt. %	0.5 -	pass

TABLE VI

COMPARISON OF CREOSOTE FROM OTHER ROUNDUP COALS WITH AMERICAN WOOD PRESERVERS' SPECIFICATIONS FOUND IN TABLE V

Creosote Test	Mtn. States	Gildroy	P.M.	Divide
S. G. at 38/15.5° C.	1.025	1.035	1.020	1.045
Distillation up to 210° C.	5.6	6.2	5.6	1.9
up to 235° C.	11.8	13.5	15.8	16.9
up to 270° C.	27.4	25.9	30.6	35.1
up to 355° C.	82.9	76.5	73.8	77.3
Coke Residue	0.9	1.2	1.4	1.9
Water Wt. %	pass	pass	pass	pass
Benzene Insoluble Wt. %	pass	pass	pass	pass

TABLE VII

COMPARATIVE ECONOMICS OF THE CHARS

Revenue	Roundup Mng.	P.M.	C. Sorenson
Plant Size - ton char/day	25	25	100
Char Price - $/ton	$19.70	$19.70	$ 4.90
Char Yield - lbs./ton	1230	1184	1004
Income from Char - $/ton coal	$12.30	$11.65	$ 2.46
Liquid By-product Yield - gal/ton coal	8.9	11.7	4.8
Income from By-products $/ton coal	$ 1.25	$ 1.64	$ 0.67
Total Income - $/ton coal	$13.55	$13.29	$ 3.13
Expenses			
Operating Expenses - $/ton coal	$ 6.28	$ 6.40	$ 3.49
Coal Cost - $/ton	4.50	4.50	2.10
Total Cost - $/ton coal	10.78	10.90	5.50
Net Income Before Income Taxes - $/ton coal	2.77	2.39	-2.46

TABLE VIII

ESTIMATED OPERATING EXPENSES

Charge -- 40.7 ton of coal/day yields 25 tons char/day
350 days/year

	Per Ton of Coal
Electricity	$ 0.08
Plant labor - 3 men/shift; 3 shifts/day at $2.00/hr.	3.55
Plant Superintendent - $550/mo.	0.45
Utilities - Steam, Gas, Water	0.11
Payroll Taxes and Office Overhead	0.06
Repair Materials	0.25
Administrative Expense	0.25
Plant Amortization - 10% of $200,000 Investment	1.48
TOTAL EXPENSE	$ 6.28