CLEAN-CHAR PROCESS

By
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U. S. Steel currently uses about 25 million tons of coal per year for production of the coke for our blast-furnace operations. In addition, we are one of the nation's leading holders of coal reserves. Accordingly, we have had a sustained interest in research and development work in coal, cokemaking, and coal utilization over the years. This interest was formalized in 1950 with the establishment of a coal and coke research and development group in U. S. Steel's Research Laboratory. The activities of that group have included the development of improved mining techniques, the development of new and improved coal and coke testing methods, the development and calibration of experimental coke ovens that would simulate the performance of commercial ovens with reference to the quality of coke produced, studies on coal beneficiation and the development of improved coking blends and procedures, the development of petrographic procedures for characterizing coals and calculating suitable coking blends from these coals, and the investigation of methods for more effective utilization of our coal reserves.

With regard to this latter area of activity, in the early '60's, our management charged us with the responsibility for developing a means for utilizing U. S. Steel's extensive Illinois coal reserves. These coal reserves are high in sulfur and ash content and are normally not considered suitable for making coke by the coke-oven procedure. A number of coal-conversion processes were explored. However, the program made little progress because of the unattractive economics associated with coal-conversion processes at that time. It was not until the late '60's that the impending energy crisis was beginning to appear, together with the ecological factors that were increasing the cost of coke produced in coke ovens. As a result of these two developments, interest was renewed in conversion of the Illinois coal to coke by a method which would have economic and ecological advantages over the coke-oven route. Accordingly, the Clean-Coke Process was developed and evaluated in bench-scale equipment. This evaluation indicated that the Process would be technically and economically feasible. Because the project offered promise of interest to the chemical industry as well as the steel industry as a whole and had attractive ecological and energy and resource conservation features, it appeared that Government support was warranted. Accordingly, an unsolicited proposal was prepared and submitted to the Office of Coal Research. The program was accepted by OCR and is now in its second year of development. This program was reported in detail at the Philadelphia AIChE meeting last November and therefore will only be briefly discussed today to provide suitable background for the subject of the current paper.

Basically, the Process provides for obtaining about 34 percent of the coal fed to the process as metallurgical coke pellets—a fairly high-value carbonaceous product, generally considered to be worth about \$35 to\$40/ton or \$1.40 to \$1.60 per million Btu. The removal of this amount of high-carbon-containing product then results in a much more favorable hydrogen-to-carbon ratio in the remaining material, such that about 18 percent of the coal is recovered as chemical feedstocks valued at an average of $120/ton.

The Process (Figure 1) is most simply characterized as a unique combination of low-temperature carbonization and hydrogenation processes, integrated in a manner that permits optimum utilization of energy and materials. The coal fed to the Process, after beneficiation and sizing in a coal-preparation plant, is split into two fractions. Part of the coal is processed through a carbonization unit where it is devolatilized and partially desulfurized to produce the char that serves as the base material for production of the metallurgical coke. The second portion of the coal is slurried with a process-derived carrier oil and is hydrogenated to convert most of the coal to liquids. Liquid products from both carbonization and hydrogenation are composited and processed through a central liquids-treatment unit. In this unit, the liquids are processed into low-sulfur liquid fuels, chemical feedstocks, and three oil fractions that are recycled to other areas of the process. One of these recycle fractions is used primarily as a carrier oil for the hydrogenation reaction. A second recycle oil is sent to the carbonizer where it is converted to pitch coke. The pitch coke and char mixture is blended with the third recycle oil that serves as a binder, and the mixture is formed into pellets in the coke-preparation unit. These pellets are subsequently baked to produce a formed metallurgical coke with strength properties equivalent to blast-furnace coke made by a conventional coking operation. The coke-preparation cycle, from char production to final coke, is carried out in a closed system with the off-vapors collected and returned to the process. Thus, no significant emissions of volatile matter occur during these operations, and atmospheric pollution is practically nonexistent. Gaseous products from all operations are processed through a common system to provide chemical feedstocks, low-sulfur gaseous fuels, and hydrogen for recycle to hydrogenation and liquids treatment.

The objective of the current Clean-Coke Program is to develop design information for a pilot plant that will process up to 10 tons of coal per hour.

In view of the recent high level of interest on clean energy, and especially on clean power-plant and industrial fuels, the technology of the Clean-Coke Process was studied to determine whether it might be applicable to the industrial fuel problem. The Environmental Protection Agency has suggested as a guideline that coal containing the equivalent of 0.6 lb of sulfur per million Btu be utilized to achieve the 1975 ambient air criteria. This is equivalent to 0.7 percent sulfur in coal having a heating value of 12,000 Btu/lb, and would mean only the Western coals and some limited tonnages of West Virginia, Kentucky, and Alabama coals would be suitable for use. In view of the fact that the carbonization-desulfurization portion of the Clean-Coke Process converts 2.0 percent sulfur coal into char containing 0.4 to 0.6 percent sulfur, it is apparent that this operation could be utilized for production of an ecologically acceptable boiler fuel. Accordingly, this approach—called the "Clean-Char" Process—was further studied for technical and economical feasibility.

The proposed Clean-Char Process is illustrated in Figure 2. In this process, the carbonizer feed coal, after pulverization and sizing to minus 1/8 inch by plus 100 mesh, is first fed to a fluid-bed preheater where it is dried and preheated to about 400 F, utilizing stack gases from the main carbonizer heater which are boosted in temperature by passing them through an additional furnace. The off-gases from the preheater, after removal of particulate matter in a cyclone, go to a stack. The preheated coal then enters the fluid-bed carbonizer where it is heated by the fluidizing gas and carbonized at temperatures from 1200 F to 1400 F at about 90 to 100 psi pressure. By maintaining the hydrogen content at about 33 percent and the sulfur content at a low level, the fluidizing gas serves to simultaneously carbonize and desulfurize the coal fed to the carbonizer. After separation of particulates, the carbonizer off-gas is cooled in three steps and desulfurized to provide the gas for recycle to the carbonizer and the surplus gas which is suitable for use as a low-sulfur, medium Btu (about 636 Btu/SCF) fuel gas. The condensed tars and moisture are separated from the system and the water sent to a waste-treatment unit. The tar contains about 1.0 to 1.2 percent sulfur and therefore would not be suitable for fuel, in view of the 0.7 percent sulfur limitation. However, there are three possibilities for its use: (1) It could be sold to a refinery for processing; (2) it could be burned along with the char. (Because the weight of the char amounts to about 3.5 times that of the tar, the blend of 0.5 percent sulfur char and 1.2 percent sulfur tar would have a sulfur content of only 0.66 percent),and (3) it could be recycled to the carbonizer and thus be converted to fluid coke and gas. The material balance information is summarized in Figure 3. Properties of the coal and char are given in Table I and the composition and calculated heating value of the gas are given in Table II.

An economic evaluation of the process was then made to enable the cost of the Clean Char to be compared with other alternatives. In the evaluation, capital and operating costs have been developed for a plant to supply a 1000 megawatt (MW) power plant with a 60 percent load factor. This would require 38,970,000 million (MM) Btu (or 1,457,041 tons) of char plus 14,100,000 MM Btu (or 416,713 tons) of tar. Thus, the material balance for the economic study corresponds to that of Figure 3. Economics have been evaluated using "The Office of Coal Research Tentative Standard for Cost Estimating of Investor-Owned Plants for Producing Pipeline Gas from Coal," (June 4, 1965).

Table III presents a summary of the estimated items comprising the total capital investment. Total fixed investment, including battery limits, utilities, offsites, and construction loan interest is $90.3 million. The addition of $5.6 million working capital results in a total capital investment of $95.9 million.

Table IV shows estimated annual operating expenses. By-product credits of $10.3 million include a $9.35 million fuel gas credit, an $835,000 sulfur credit, a $97,000 steam credit, and a $21,200 ammonia credit. These credits reduce operating expenses to a net $27.86 million.

Table V presents an economic summary. The OCR standard includes provision for construction loan and working capital, 20-year straightline depreciation, and a 65-35 debt-to-equity ratio. The standard guarantees a gross return of 7 percent of the rate base (total fixed investment declining on a 20-year basis plus working capital). Total revenue is calculated by adding net operating expenses (including 5 percent interest on unpaid debt), gross return, and income tax. The 65 percent debt portion of the investment is paid off in equal installments over a 20-year period. Selling price, which is total revenue divided by annual through-put, varies from year to year. The average price for a 20-year period is the reported value. Applying the OCR standard, the revenue requirement for char and tar fuels is $0.63 per MM Btu.

Coal cost is the major cost element. Figure 4 shows the effect of coal cost on fuel selling price. A $2.00/ton increase in coal cost increases solid and liquid fuel price by about $0.107 per MM Btu (including operating-cost contingency).

In view of the fact that there are limited supplies of low-sulfur coals in the central and eastern United States and that low-sulfur oil is becoming scarce and expensive, many utilities and industrial plants are considering stack-gas scrubbing to enable them to use higher sulfur coals and still comply with emission standards. It is our understanding that there is no commercial stack-gas scrubbing unit operating satisfactorily and that recent costs for stack-gas scrubbing have been estimated at $50 to $90 capital per KW and $0.80 to $0.95 per MM Btu total fuel cost (coal cost plus scrubbing cost). It would therefore appear that the Clean-Char Process with its $90 per KW capital plant investment and $0.63 per MM Btu total fuel cost should be of interest.

Table I

Properties of Coal and Char

	Percent by Weight Coal	Char
H_2O	8.51	--
Ash	5.17	6.57
Elemental Analysis		
Carbon	68.77	86.73
Hydrogen	4.79	2.47
Nitrogen	1.24	1.48
Oxygen	9.73	2.28
Sulfur	1.79	0.47

Heating value, Btu/lb 13,373

Table II

Properties of Fuel Gas

Composition, percent by Volume	
Hydrogen	33.52
Methane	37.06
Ethylene	12.95
Ethane	2.87
C_3 and C_4	1.60
Carbon Monoxide	10.66
Carbon Dioxide	.85
Moisture	.49
	100.00

Heating Value 636 Btu/SCF

Table III

Investment Summary

Section	Title	Cost, $MM	
100	Carbonization	52.7	(a)
200	Gas Cleaning	12.4	(b)
300	Claus	2.0	(c)
400	Tar Handling	1.3	(d)
500	Utilities and Waste Water	4.2	(e)
600	Off site facilities	7.3	(f)
	Subtotal	79.9	(g)
	Contractor's Overhead and Profit	6.1	(h)
	Subtotal	86.0	(i)
	Interest During Construction (5% of (i))	4.3	(j)
	TOTAL FIXED INVESTMENT	90.3	(k)
	Working Capital		
	30 days coal inventory	2.0	(l)
	30 days catalyst, etc., inventory	-	(m)
	Accounts receivable	3.6	(n)
	Total working capital	5.6	(o)
	TOTAL CAPITAL INVESTMENT	95.9	(p)

Table IV

Operating Expense

	$/Year	
Raw Material (Coal) @ $8.00/ton	22,372,300	(A)
Utilities	2,124,700	(B)
Direct Operating Labor @ $5.75/hr	891,500	(C)
Maintenance (3% of (g))	2,397,000	(D)
Supplies (15% of (D))	359,600	(E)
Supervision (10% of (C))	89,200	(F)
Payroll Overhead (10% of (C) + (F))	98,100	(G)
General Overhead (50% of (C)+(F)+(D)+(E))	1,868,700	(H)
Plant Operating Expenses Subtotal	30,201,100	(I)
Depreciation (5% of TOTAL FIXED INVESTMENT)	4,515,000	(J)
Local Taxes and Insurance (3% of TOTAL FIXED INVESTMENT)	2,709,000	(K)
Subtotal	37,425,100	(L)
Contingencies (2% of (L))	748,500	(M)
TOTAL OPERATING EXPENSE	38,173,600	(N)
By-Product Credits	10,311,600	
NET OPERATING EXPENSE	27,862,000	

Table V

Economic Summary[1)]

Annual Production		38,971,000 MM Btu Char
		14,099,000 MM Btu Liquids
		53,070,000 MM Btu Total
Plant Investment,[2)] MM$		90.3
Working Capital, MM$		5.6
Total Capital, MM$		95.9
Costs, $MM Btu		
Gross Raw Materials	0.4216	
By-Product Credits[3)]	0.1943	
Net Raw Materials		0.2273
Utilities	0.0400	
Labor	0.0203	
Maintenance and Supplies	0.0520	
General Overhead	0.0352	
Depreciation, Taxes, Insurance	0.1360	
Contingencies	0.0141	
Net Operating Expense		0.2976
Profit, Taxes, Interest[4)]	0.1060	0.1060
SELLING PRICE, $/MM Btu		0.6309

1) February 1973 dollars.

2) Includes construction load interest.

3) Includes 9,358,000 MM Btu of gas credited at $1.00/MM Btu

4) Interest at 5 percent annual rate.

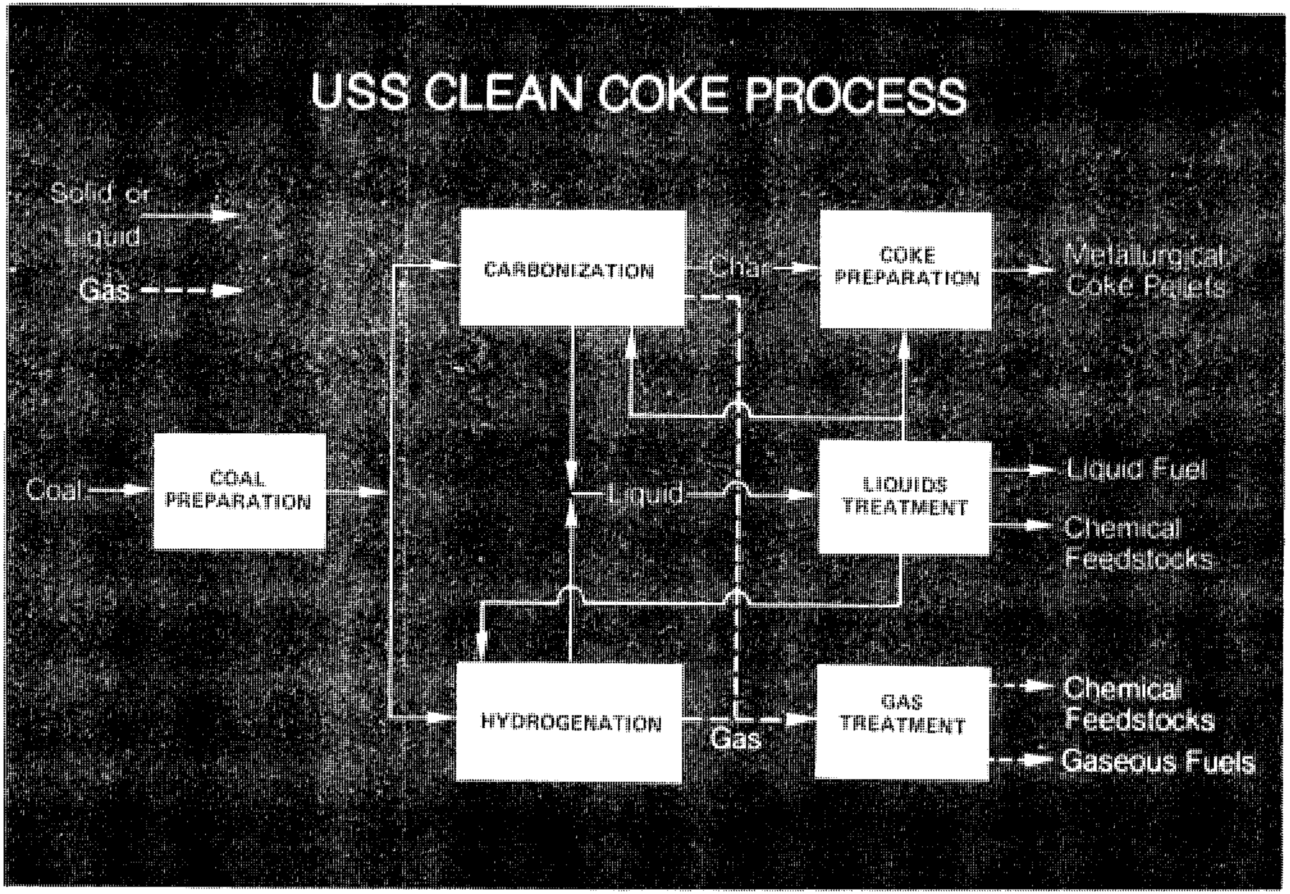

USS CLEAN COKE PROCESS
Solid or Liquid
Gas
Coal
COAL PREPARATION
CARBONIZATION
HYDROGENATION
Char
Liquid
Gas
COKE PREPARATION
LIQUIDS TREATMENT
GAS TREATMENT
Metallurgical Coke Pellets
Liquid Fuel
Chemical Feedstocks
Chemical Feedstocks
Gaseous Fuels

Figure 1.

CLEAN CHAR PROCESS

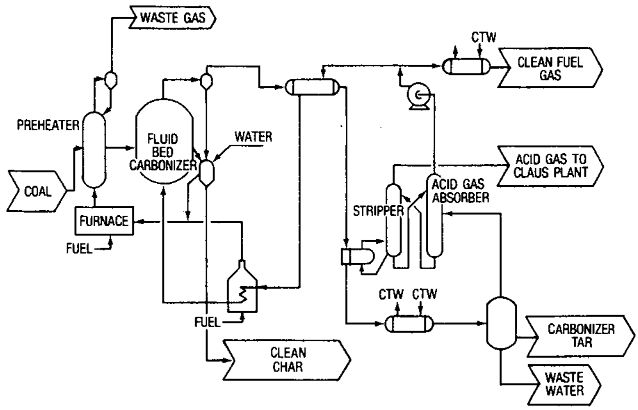
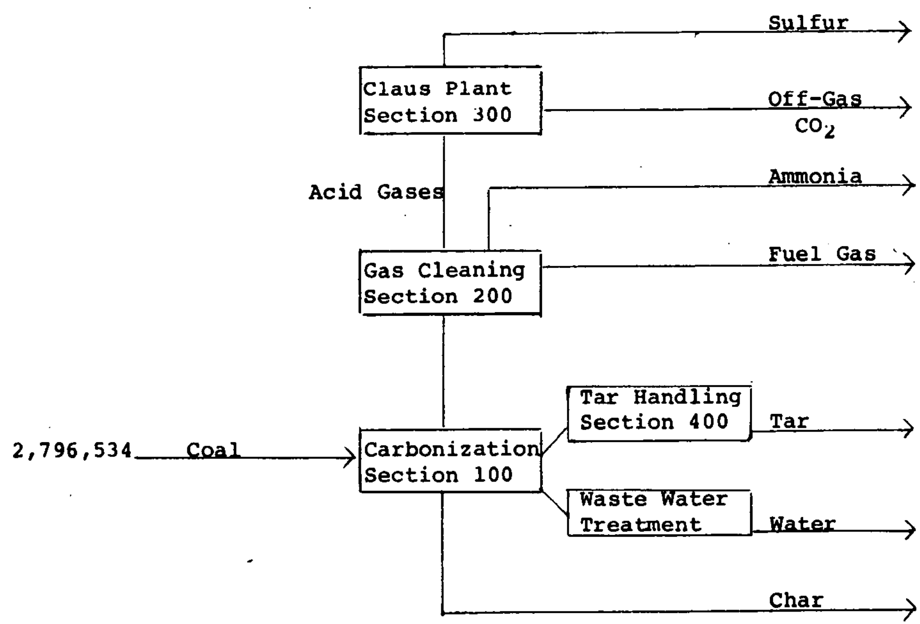


Figure 2.

CLEAN-CHAR PROCESS—MATERIAL BALANCE



	Annual Tons	Weight, %
Sulfur	37,598	1.3
Off-Gas CO_2	152,612	5.5
Ammonia	385	
Fuel Gas	273,911	9.8
Tar	416,713	14.9
Water	230,597	8.3
Char	1,457,041	52.1
Char for Internal Use as Fuel	160,274	5.7
	2,729,131	
Unaccounted for	67,403	2.4
Total	2,796,534	100.0

Figure 3.

$90,300,000 Total Fixed Investment
38,971,000 MM Btu Char
14,099,000 MM Btu Tar
53,070,000 MM Btu Total
9,358,000 MM Btu Gas as By-Product
at $1.00/MM Btu

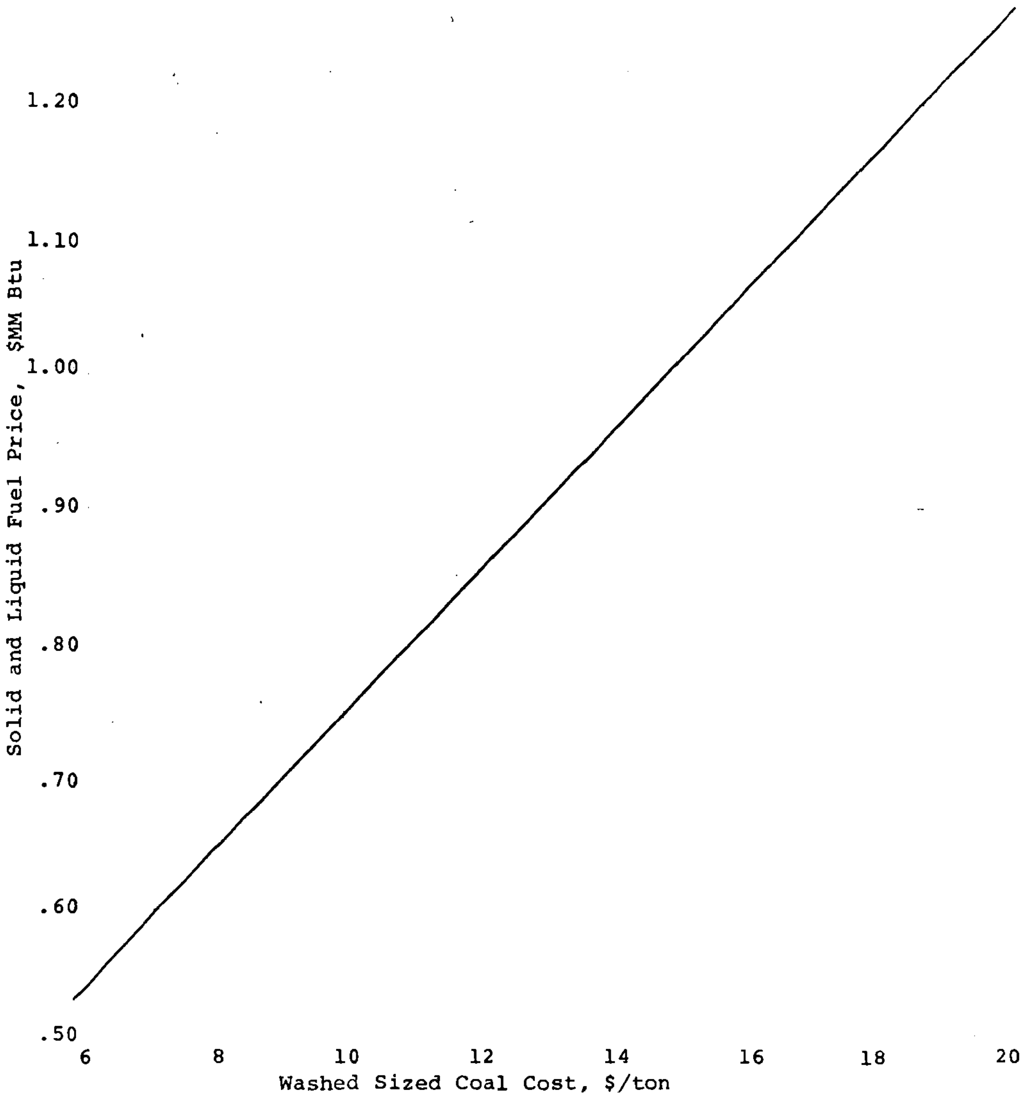


Figure 4. EFFECT OF COAL COST ON SOLID AND LIQUID FUEL PRICE USING OCR STANDARD