A SOLVENT REFINED COAL PROCESS FOR "CLEAN" UTILITY FUEL

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INTRODUCTION

Several processes for conversion of coal to clean fuels are underoing development at various stages. The solvent-refining of coal, o non-catalytic process under development by the Pittsburg and Midway Coal Mining Company for the Office of Coal Research, is an outstandingly advantageous conversion process from the point of view of its potential economics. In comparison to other coal conversion processes it requires less costly equipment and less severe operating conditions. It consumes less hydrogen and has no need for catalyst[1]. The earlier work in hydrogenation of coal was directed toward production of distillate fuels and the use of catalysts was found to be necessary to obtain reasonable yields. Despite improvements in catalysts and in process technology this route of coal conversion is still not economically attractive. In solvent-refining the coal is not converted to distillate fuel, but to a de-ashed, low-sulfur semisolid fuel resembling pitch.

The fuel product of this process has a very consistent heating value of 16,000 Btu per pound regardless of the coal feed stock to the process. This uniformity has been demonstrated in pilot productions from both lignite and bituminous coal[1]. The principal variation in the product is in the sulfur content, due to the variation in feed stock sulfur content. This orises from the characteristic of the process to remove all of the mineral sulfur (pyrites) and a part of the organic sulfur ranging above 60%. High ash, high sulfur coals can as readily be brought to a processed fuel of less than 1% sulfur as a lower ash content coal having appreciable organic sulfur content. Typically it can be expected that overall 85% of the sulfur content of the coal can be removed in the processing, a 4% sulfur coal, for exomple, resulting in an 0.8% sulfur solvent refined coal at heating value of 16,000 Btu per pound.

The process in brief is to mix pulverized coal feed stock with a coal-derived solvent oil having a 550-800°F boiling range, passing the mixture with hydrogen through a preheat and reactor, separating excess hydrogen plus the hydrogen sulfide and light hydrocarbons formed, filtering the solution, flash evaporating the solvent and recovering the bottoms as either a hot liquid fuel or a cooled solid product. During the reaction phase, the hydrogen reacts with organic sulfur compounds forming the hydrogen sulfide. The hydrogen also stabilizes the solubilized coal products. The pyritic sulfur leaves the process in the filtration step, as does the ash components.

In this discussion the sole market for solvent refined coal considered is that of the fuel for power-generating utilities, since this market has been shown to be the overwhelming large one for this product[2]. The legislation regarding atmospheric pollution will eventually restrict the sulfur dioxide emissions for the entire nation, and it appears that fuels will be limited to sulfur content less than 1% in general and to less than 0.5% in several highly populated regions. The impact of these restrictions on the direct use of coal as a power-generation fuel will be great, since the supplies of coal of such low sulfur content are quite small compared to the total U.S. coal reserves and they are very inconveniently located relative to the power needs. The use of the solvent refining process, though, allows the coal supply to be used, regardless of its sulfur content. When considered as a clean fuel for power generation, then solvent refined coal not only comes into competition with coal itself in conjunction with stack gas treatments, but also with natural gas, fuel oil and nuclear power.

DISCUSSION OF TECHNOLOGY

The schematic of the recent process technology for the Pittsburg and Midway Solvent Refined Coal process is shown in Figure 1. The salient aspects of the process technology as they affect economics are:

- o the delivery of the product as a solid fuel product or as a hot liquid
- o the by-products: light liquid hydrocarbon, sulfur, and electrical power
- o the fly ash or mineral residue waste
- o hydrogen or process fuel feeds to the process.

The distinction between the solid form or liquid form of solvent-refined product is principally one of whether or not the distillation bottoms are cooled below the 300°F solidification point prior to disposition. Probably this issue will depend on whether or not the product is used in an on-site or nearby power plant as apposed to shipping to a distant location. It has been estimated that the additional processing cost to solidify for shipping is 2¢/MMBtu[1].

The liquid hydrocarbon by-product has a high cyclic content and so is useful as a petroleum refinery feed stock or as a source of aromatic organic chemicals. Since a large part of the nitrogen content of the original coal winds up in this by-product, the use as a refinery feed stock would require additional nitrogen removal processing by the refinery.

If the solids from the filtration operation are burned to obtain the heating value, the sulfur dioxide produced can be combined with the hydrogen sulfide from the process to produce elemental sulfur by a Claus-type procedure. This appears to be practical in this case becaouse of the concentrated gas streams encountered. One to 2% of the coal feed weight is the hydrogen requirement for the process. The by-product gas can be used to form all of the required hydrogen by steam reforming. This would eliminate the need for a hydrogen raw material input. The use of a part of the fuel product as process fuel would also eliminate the need for natural gas feed to the process. Whether or not these steps are taken in a given solvent-refining plant depends on local availability of low cost by-product streams of hydrogen and low cost availability of natural gas. It is important to bear in mind that the efficient operation of this process does not require their availability.

Catalytic Conversion of Coal

The most recent catalytic method for converting coal to low-sulfur fuel is the process called the H-Coal Process, also under development by sponsorship of the Office of Coal Research. This process uses a desulfurization catalyst and is very effective in reducing the organic sulfur content to levels of 0.1 to 0.2%. The process, however, is more costly than the solvent refining because of the catalyst and the internal recycle required for its use. The coordinated use of the solvent refining and H-Coal processes for their peculiar individual advantages has been suggested[1] and this may be the most economical way to achieve very low (less than 0.5%) sulfur contents in the fuel when required.

Coal Gasification

Although the costs for producing synthetic gas from coal would be higher than the production of heavy fuel from coal by solvent refining, several of such coal gasification processes are now being developed. The hydrogen requirements are greater and the processing conditions more severe for these. The gas fuel product from such a process will very likely compete as a premium fuel with natural gas and will not be in primary contentation for the bulk of the power generation fuel needs.

Degree of Sulfur Reduction

The present state of development of the solvent refining process allows for about 85% of the sulfur in the feed coal to be removed. All of the pyritic sulfur and some 60-70% of the organic sulfur is removed. On the type of coal that is very common in which the sulfur is roughly 50-50 in these two forms, the final product sulfur content is well below 1%, of the order of 0.8%. Further reduction of the organic sulfur content by utilizing greater quantities of hydrogen than in the present design is believed possible[3], although in the extreme this merges with the catalytic processes such as the H-Coal.

PROJECTED ECONOMICS

Solvent-refined coal as a low sulfur fuel for power generation would compete primarily with such other energy sources as fuel oil, gas and nuclear power, as well as with coal itself fired in boilers served by stack gas treatment processes. The latter, a much studied method of combating pollution from combustion of coal, is an awkward expedient to permit the extended use of high sulfur coals. The principal reason for this is that the electric power companies should not be nor do they desire to be in the chemical production and marketing business, which is the natural outcome of using a stack gas treatment process on a coal-fired boiler and having to dispose of the wastes and by-products. It makes far more sense for the chemical processing industry to provide low sulfur fuel from efficient, optimally-located, and optimally-sized coal conversion plants.

There are two obvious strategies for carrying out this processing-distribution sequence. One is the location of a solvent-refining plants at minehead sites more or less centrally located to the principal marketing areas, to which the product is shipped as a solid fuel. The other is to have consolidated minehead processing plants and power generating facilities in regions where both the coal supplies and the power requirements are in reasonable conjunction. The latter type of facility could, of course, also furnish solid fuel for shipment.

Projection of Demand for Fossil Fuel for Power Generation

Projections of electric power generation anticipate growth in fossil fuel consumption through the next two decades[3]. As shown in Table I, the total expected use of fossil fuels should grow from 13.6 x 10^{15} Btu in 1970 to 19.5 x 10^{15} Btu in 1980 and to 25 x 10^{15} Btu in 1990, nearly a doubling in two decades.

Table I. Fossil Fuel Projection for Electric Power Generation

Year	1970	1980	1990
Coal, 10^{15} Btu	8.1	12.5	16
Oil, 10^{15} Btu	2.1	4.0	5
Gas, 10^{15} Btu	3.4	3.0	4
Total, 10^{15} Btu	13.6	19.5	25

Growth is expected in both coal and oil, but not in gas. In fact an actual decline in gas use is projected between 1975 and 1980, and the whole rate of growth of gas use will fall off dramatically after the vigorous growth prior to 1970.

The Federally mandated emission standard for new and modified fossil solid fuel-fired steam generators with capacity exceeding about 25 megawatts (equivalent) for construction commenced after August 17, 1971 is 1.2 pounds of sulfur per million Btu. This corresponds to roughly 0.8% sulfur in a high heat content coal and about 0.4% for lignite. Even the vast Western coals of markedly low sulfur content are unsuitable for this without further control efforts. Thus essentially all of the coal market for power generation is potentially available to a sulfur-reduced coal product such as solvent refined coal at some not too distant time in the future. Looking at the fossil fuel market for its potential in regard to solvent refined coal production leads to the possibilities shown in Figure 2. In view of the recent cost studies of solvent refined coal[2,4] a sales price range of 50 to 100 cents per million Btu seems to be within a reasonable range. The projections of market potential through 1990 at prices in this range are shown on two assumptions: the limiting one in which all the fossel fuel market for power generation is captured and the more reasonable one which sizes the market at that estimated for coal. A vast sales market ranging between about 4 and 25 billions of dollars is potentially available to the investors in such a process.

Oil Prices for Power Generation

A feasible range of price for solvent refined coal can be inferred by examining the price range of competitive low sulfur fuels for power generation. Low sulfur fuel oils are currently in great demand for power generation in highly populated areas and the demand should, if anything, intensify in upcoming years. Recent quotations of oil prices in several locations[5] have been put on a consistent fuel basis of cents per million Btu in Table II.

Table II. Current Price Variation in Oil for Power Generation

Location	% Sulfur	Price, ¢/MMBtu
New York	0.3 max.	73
	0.5 max.	69
	1.0 max.	61
	Bunker C	53

Table II. Current Price Variation in Oil for Power Generation (Cont.)

Location	% Sulfur	Price, ¢/MMBtu
Chicago	1.0 max.	75
	1.25 max.	73
	1.5 max.	71
Oklahoma	over 1, under 2	40-42

It is well to note the effect of supply and demand in the prices in Table II. In Oklahoma, the demand for oil for power generation is nil because gas is used for all power plants. Residual oil from Substitute Natural Gas plants has been valued at 57-60 ¢/MMBtu at the plant. Based on these facts, very low sulfur residual oil can be valued at 66-69 ¢/MMBtu currently at the ports. Delivery costs are superimposed on these.

The effect on future prices of processing to desulfurize residual oils can be estimated by using processing data for the hydrodesulfurization process[6]. Operating cost data vary between 7 to 19 ¢/MMBtu to reduce to the 1% sulfur level on the type of residual oil feed stock, with vacuum residual oils consuming the most hydrogen and hence having the highest operating costs. The above figures do not include a return on investment. Nevertheless we could expect a desulfurized residual oil product at about the 1% sulfur level to be no less than 50 ¢/MMBtu at a low demand location like Oklahoma and to be at least 65 ¢/MMBtu at a high demand seacoast location like New York. With increased legislative pressure on low sulfur fuels in the future the price at the power plant that most of the major utilities burning fuel oil will face seems to certainly be in the 70-100 ¢/MMBtu range at current dollar values. This helps to define a competitive price range for solvent refined coal product for such use.

Impact of the By-Product Sulfur From Processing of Coal

The supplies of natural low-sulfur fuel will clearly not be equal to the demands upon them in the upcoming decades. The desulfurization of oil and coal by one or another means must make up the deficit. If we look at the recent experience in coal use with regard to sulfur content as shown in Figure 3, we see that the amounts of sulfur to be removed will be considerable. The weight-averaged sulfur content of all the coal fired to power generation in 1969 was 2.6%[3] and we can assume that the coal mined in the future if an economically feasible desulfurization process is being used will not be lower than this experience. If the overall sulfur content allowed in solid fuels is reduced to an average of 0.6% of the weight of coal used in 1990, the by-product sulfur generated by desulfurization of coal will rise in the vicinity of 12-13 million tons in 1990. This figure is sufficiently high to make the recovery of significant economic value by sale of sulfur improbable on the whole. The sulfuric acid market, the principal use of sulfur, recently consumed about 9 million tons of sulfur, so the existence of by-product sulfur of the quantities possible are certain to cause them to be stockpiled and not sold in any significant quantities at current price levels. So it would seem that no credits for sale of sulfur by-product should be taken in realistic projection.

Elements of Cost Pertaining to Solvent Refined Coal Price

The estimation of selling price of solvent-refined coal product has been undertaken for a minehead plant in the Ohio-Illinois-Kentucky area on a 10,000 ton per day basis[1, 4]. The most recent price estimates range from 41 ¢/MMBtu where all by-products are sold, to 47 ¢/MMBtu where none are sold. In the latter case the light liquid by-product is combined with the solvent refined coal for sale in the power plant fuel product. These prices do include a return on investment but no transportation charges. The annual sulfur by-product sale at $10 per ton we believe to be unrealistic for the long run in which the sulfur market is glutted with pollution control induced sulfur. Reducing the credit for by-products by this amount increases the necessary FOB plant selling price for the optimistic case to 42 ¢/MMBtu. The elements of cost that these estimates cover are: mining, solvent refining, and return on investment.

The transportation of product to the user is a widely variable cost element. A power plant located at the minehead-processing plant site would have effectively no transportation cost. Rail transport of solid product would probably experience the same costs as coal itself(2). This can be estimated in lieu of specific foreknowledge of rail rate schedules through 1990 as 1 ¢ per ton-mile. As an extreme but nonetheless typical example of current costs to ship coal, low sulfur western coal is currently being shipped to New Jersey at a cost of $22 per ton, which corresponds closely to 1 ¢ per ton-mile.

In a system of well-located processing plants, shipping in excess of 500 miles probably would not be necessary in most cases. The users remotely located from the processing plant would then pay an additional 3-17 ¢/MMBtu for the solid product delivered to the power plant, which includes a cost to solidify the product for shipment. This raises the total estimated price for solid product from 44 ¢/MMBtu at the plant to 45-64 ¢/MMBtu delivered.

Versus low sulfur oil as a competitive fuel, the local delivered price situation would determine the competitive balance. For example in the Chicago area where low sulfur fuel oils are selling for 71-75 ¢/MMBtu, the solvent refined coal could be furnished from the aforementioned hypothetical plant for 53-57 ¢/MMBtu.

However on seacoast locations such as New York, the Gulf Coast and the west coast, low sulfur fuel oil could be currently obtained in the 61-73 ¢/MMBtu region. For the east coast, a mine-processing plant complex in West Virginia could deliver solvent refined coal for 53-65 ¢/MMBtu at most population and industrial centers, which is certainly competitive. However the longer transportation distances between a plant in the Wyoming area and the west coast areas would probably be less attractive in comparison to delivered fuel oil.

Coal Costs

One cost element in the production of solvent refined coal that is likely to increase noticeably in the future is the cost of mined coal. This is due to several factors including increased labor cost and increased investment for mine safety. A minehead selling price for coal of $6 per ton seems realistic for the near future, which is about 24 ¢/MMBtu for a good quality coal. Adjusting the estimated solvent refined coal prices for this raw material cost would raise the price about 15 ¢/MMBtu. Adjustment for this higher coal cost would bring the estimated selling price of a solvent refined coal utility fuel to 56-63 ¢/MMBtu at the plant location, and to 59-94 ¢/MMBtu delivered, still well within a competitive range for low sulfur fuels even under present day price experience.

When selling in competition with coal itself in conjunction with stack gas treatment, the cost of the raw material coal in solvent refined coal is essentially irrelevant(2). The principal considerations are the lower transportation cost per MMBtu and the reduced investment and maintenance at the power plant with the SRC. In a similar way, the relative position between SRC and other coal-derived fuels would not shift principally due to coal cost.

Projected Market for Solvent Refined Coal

By considering efficient solvent refined coal plants at four U. S. locations; West Virginia, southern Illinois, Wyoming, and New Mexico, and examining the projected competitive price per million Btu for the several fossil fuels and derivative fuels in low sulfur emission power plant use, we projected the fractions of the potential market shown in Figure 2 that could be obtained by SRC by virtue of price. These market projections are given in Figure 4 over a range of SRC selling prices at the processing plants from 50 to 100¢/MMBtu. The mid-range selling price of 75¢/MMBtu should yield a market of about 300 million tons in 1980 and 550 million tons in 1990. This selling price also seems to be the optimum in 1990 for sales dollar volume.

CONCLUSION

The continued wide use of coal in the United States as a fossil-fuel source of energy for power generation is inescapable in the upcoming decade and beyond. Of the several developing processes for producing clean fuels from coal, solvent refining is the most simple and economical. SRC can be used as either a solid or a liquid fuel and has been estimated to capture a very large market in direct competition with other low sulfur forms of fossil fuels in power generation.

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SOLVENT REFINED COAL PROCESS

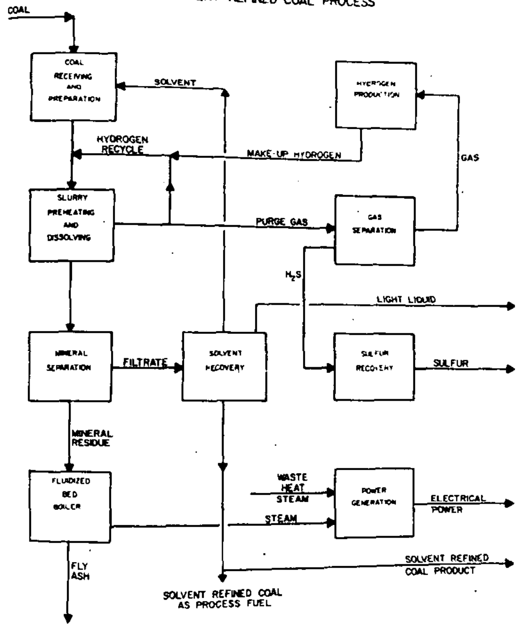

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FIGURE 1

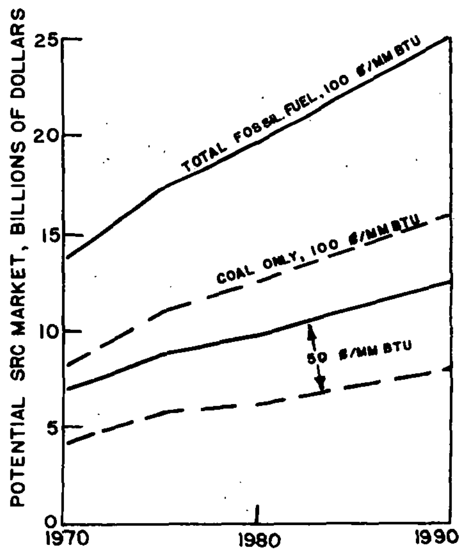


FIGURE 2

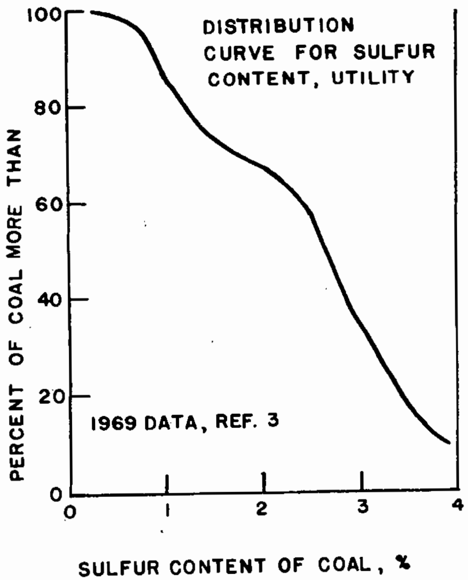
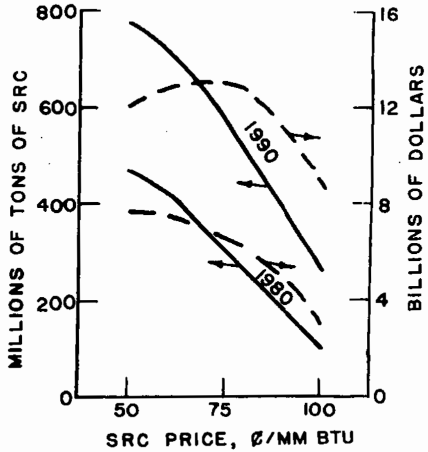


FIGURE 3



PROJECTED SRC MARKET

FIGURE 4