ENERGY CONSERVATION IN COAL CONVERSION

Feasibility Study of a Combined Combustion-Gasification Facility

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ABSTRACT

This work examines the feasibility of mechanical deep cleaning of coal where the cleaned coal would be used for direct combustion and the rejected portion would be used in a coal gasification plant. To make this feasible, the reduced thermal efficiency from gasifying "dirty coal" must be offset by the reduced energy requirement for the flue gas desulfurization system.

Our study indicated, for the coal being considered for the Parsons Oil/Gas Complex - Illinois No. 6 - the energy saved by reduced flue gas desulfurization was approximately equal to the energy lost from gasifying the dirty coal. The methodology for this study is presented in such a way that other coals - particularly a high paritic sulfur content - could be studied.

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Introduction

The purpose of this investigation was to examine the feasibility of deep mechanical cleaning of coal prior to combustion. The rejected fraction of coal would be directed to a gasification process. We believe that energy could be saved by employing this concept in commercial sized gasification designs. The concept was applied to the Oil/Gas Complex designed by Ralph M. Parsons Company[1]. Quantitative results from this specific case were obtained to test our hypothesis.

We had hoped that the clean fraction of coal could be fired without additional clean-up of stack gases. This would alleviate the problem of meeting increasingly stringent emission standards[5]. The sulfur would be concentrated in the rejected (or dirty) coal feed to the gasifier, and eventually be reduced to elemental sulfur.

The overall energy efficiency of the proposed design was evaluated. Consideration was given to the reduced efficiency of gasifying "dirty" coal as well as the increased efficiency of directly combusting a portion of the coal.

The Proposed System

The addition of a deep cleaning and boiler system is the major alteration required in the proposed design. A sketch of the design is provided in Figure 1. The details of each of the processes involved will be discussed.

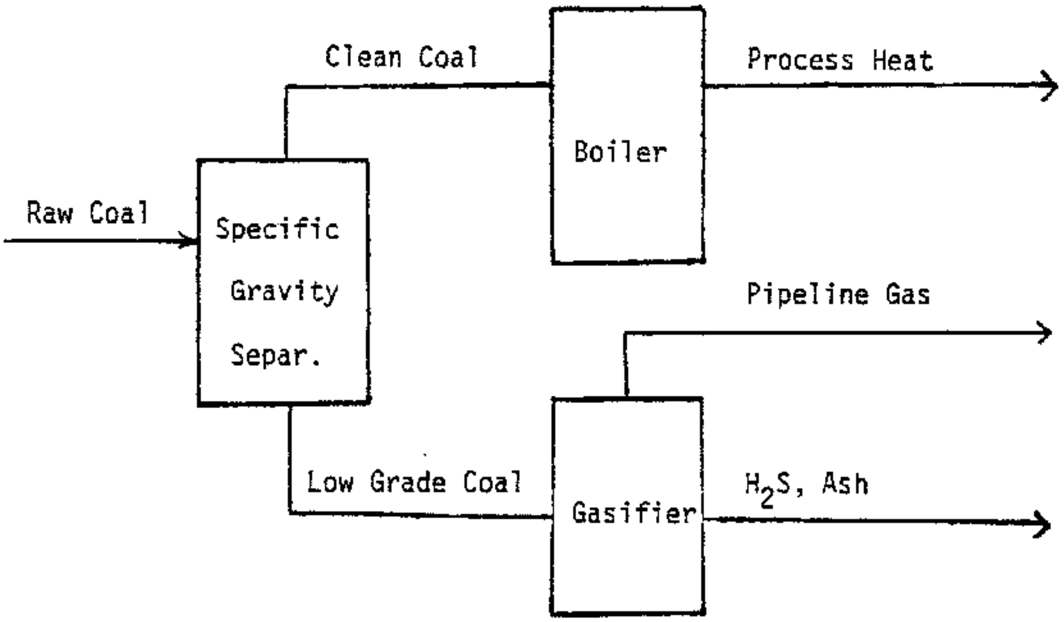

Figure 1

SCHEMATIC OF PROPOSED SYSTEM

The Deep Cleaning Unit

Deep cleaning involves the mechanical separation of raw coal to obtain a high grade coal (low sulfur and ash content). This procedure has been impractical for conventional uses because of the low recovery rate of clean coal. However, no real penalty for low recovery rates exist in this application since the remaining coal is directed to a gasifier rather than being discarded.

The deep cleaning is done by Specific Gravity Separation to deep clean the raw coal. This Specific Gravity Separation was chosen because of the availability of washability data. This method is also one of the best in terms of the quality of the clean coal recovered [2,3]. Studies performed by the Bureau of Mines[4], indicate that the degree of washability is a function of the specific gravity of the float medium used. As the specific gravity of separation decreases, so will the pyritic sulfur, ash, and the recovery rate of clean coal.

As the crushed coal enters the separation vessel, the heavier particles containing pyritic sulfur (spec. grav. = 5.1) will sink. The lighter clean coal (spec. grav. = 1.2) will float. The clean coal is screened off the top of the liquid, to be fired in a conventional boiler. The dirty fraction is used as feed for the gasifier.

The Clean Coal Boiler

A conventional boiler is used in the proposed design to burn the recovered coal. Because the sulfur content in the clean coal has been reduced, less energy is required for flue gas desulfurization to meet the EPA emission standards[5].

The Gasifier

The design of the gasifier was based on the Bituminous Coal Research work on the Bi-Gas pilot plant at Homer City, Pennsylvania. The operating parameters (pressure, temperature and flowrate) specified in the Parson's Report on the Oil/Gas Complex were used in this study.

Since the reduced concentration of fixed carbon, decreases the product yield, conversion efficiency of the gasification reaction is reduced by using "dirty" coal.

Procedure

The proposed design was evaluated on the basis of its overall energy efficiency. The overall energy efficiency is calculated as the energy ultimately derived from the system divided by the heating value of the coal feed to the system. The coal type used throughout the analysis was "Illinois No. 6" because the Oil/Gas Complex was designed to process this coal type[2]. The specific analysis for this coal is shown in Table 1. The fraction of coal recovered from the specific gravity separation, and the composition of the "clean" and "dirty" splits are computed by extrapolating washability data compiled by the Bureau of Mines[9]. Figures 2 through 5 were generated from this data and relate the coal recovery rate to the sulfur, ash, carbon content, and heating value of the clean coal.

At a specified recovery rate the composition of the clean coal is set, and can be obtained from the curves. A mass balance is done to obtain the composition of the dirty coal. These newly determined compositions are used in the subsequent efficiency calculations.

The clean coal heating value is obtained from Figure 5. This enhanced heating value is used in all boiler calculations. A boiler efficiency of 85% is assumed in the calculation of the clean coal contribution to the total energy output. The treatment of the stack gases by FGD entails an energy penalty of 8% of the heating value of the feed coal[6]. This penalty is applied in proportion to the percentage of stack gas requiring treatment to meet EPA emission standards. This percentage is found by comparing the EPA standard of 1.2 lbs SO_2

Table I

Proximate Analysis of Illinois No. 6 Coal

Item	Wt %
Moisture	2.7
Ash	11.8
Volatile Matter	39.7
Fixed Carbon	45.8
	100.00

Ultimate Analysis of Illinois No. 6 Coal

Element	Wt %
C	70.69
H	4.98
N	1.35
O	8.19
S	3.51
Trace Minerals*	11.28
	100.00

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*A detailed analysis of all trace components is shown in Appendix B.

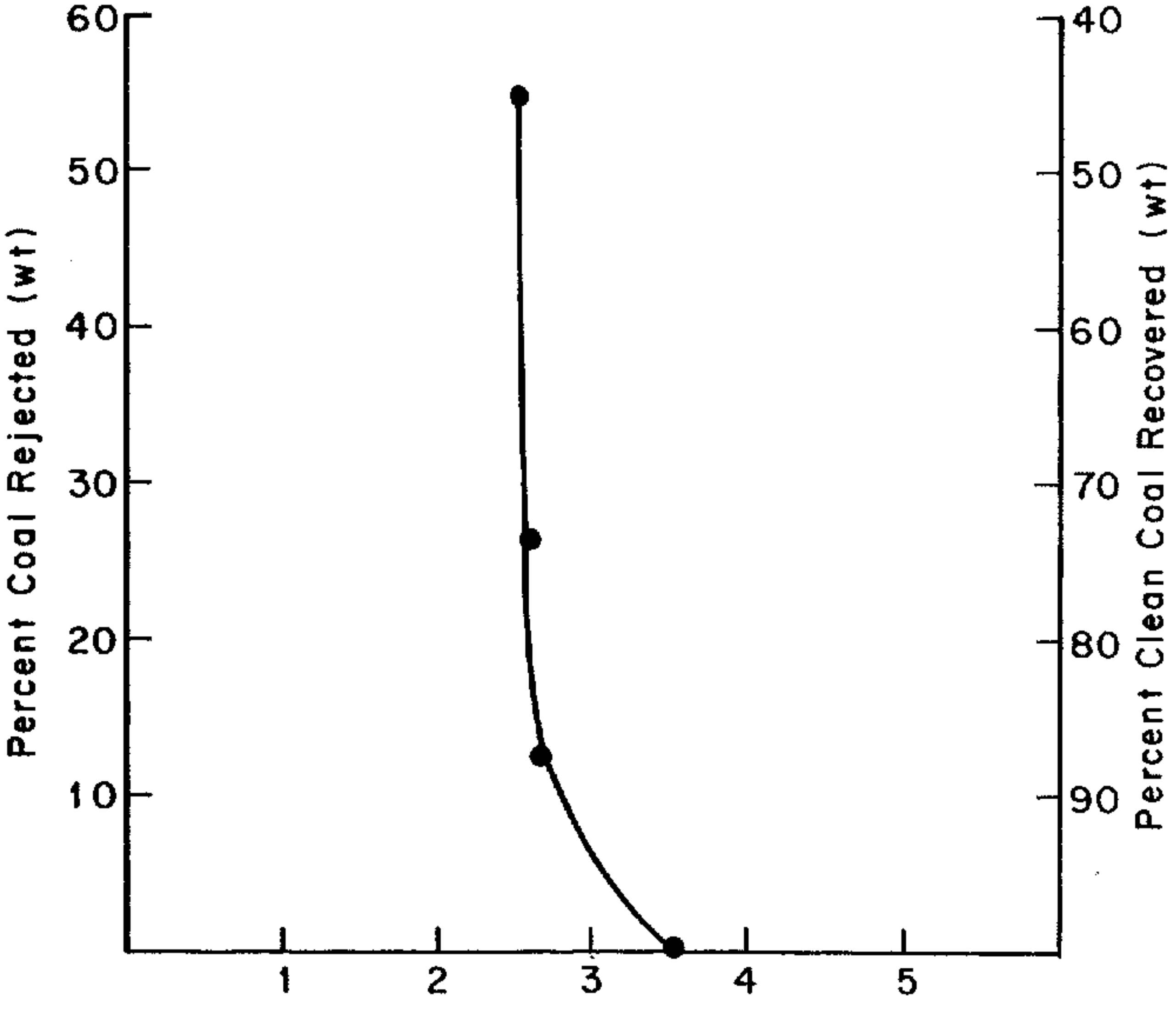

Figure 2a

Sulfur Content vs Coal Recovery During Clean-up

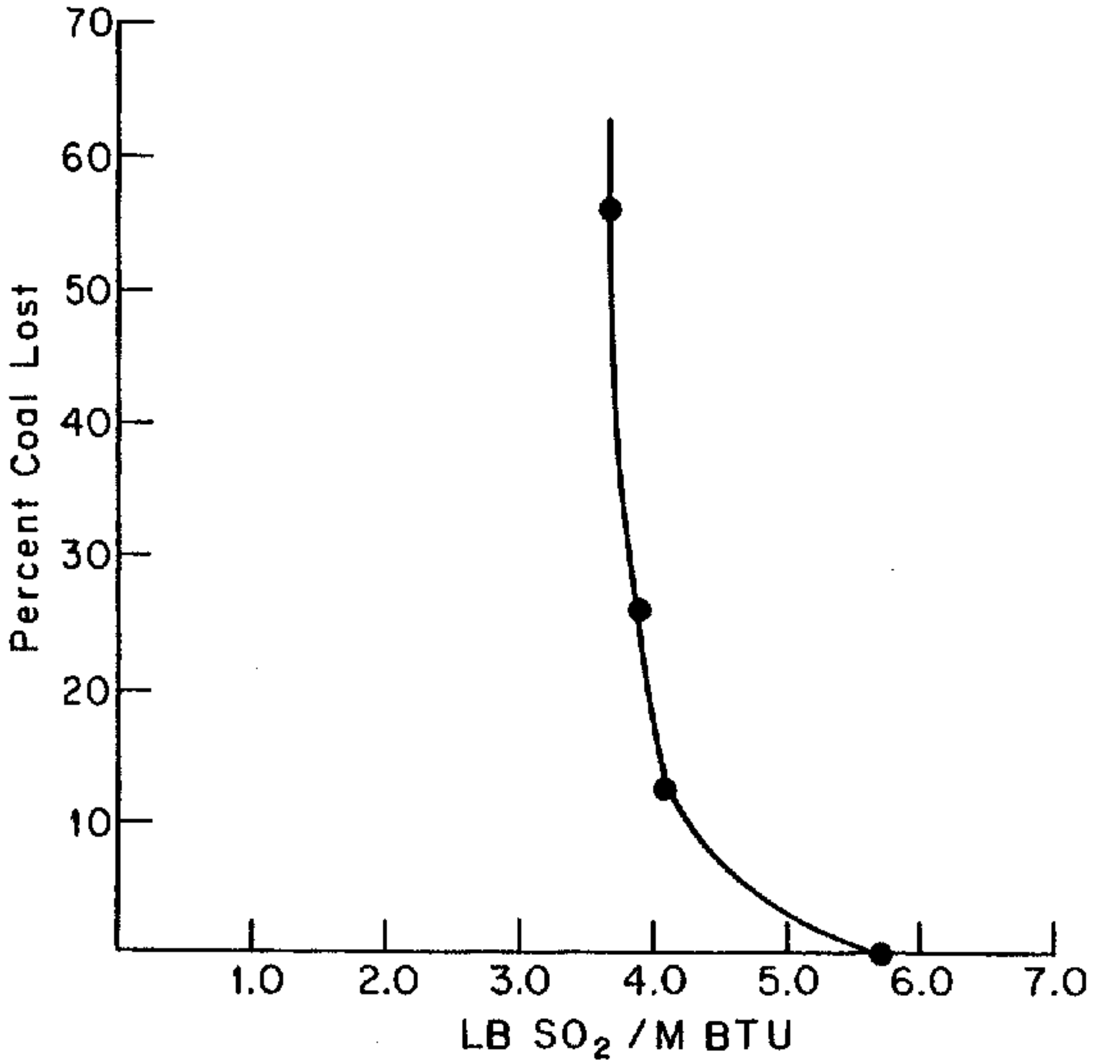

Figure 2b

Emissions vs Mass Losses of Coal During Clean-up

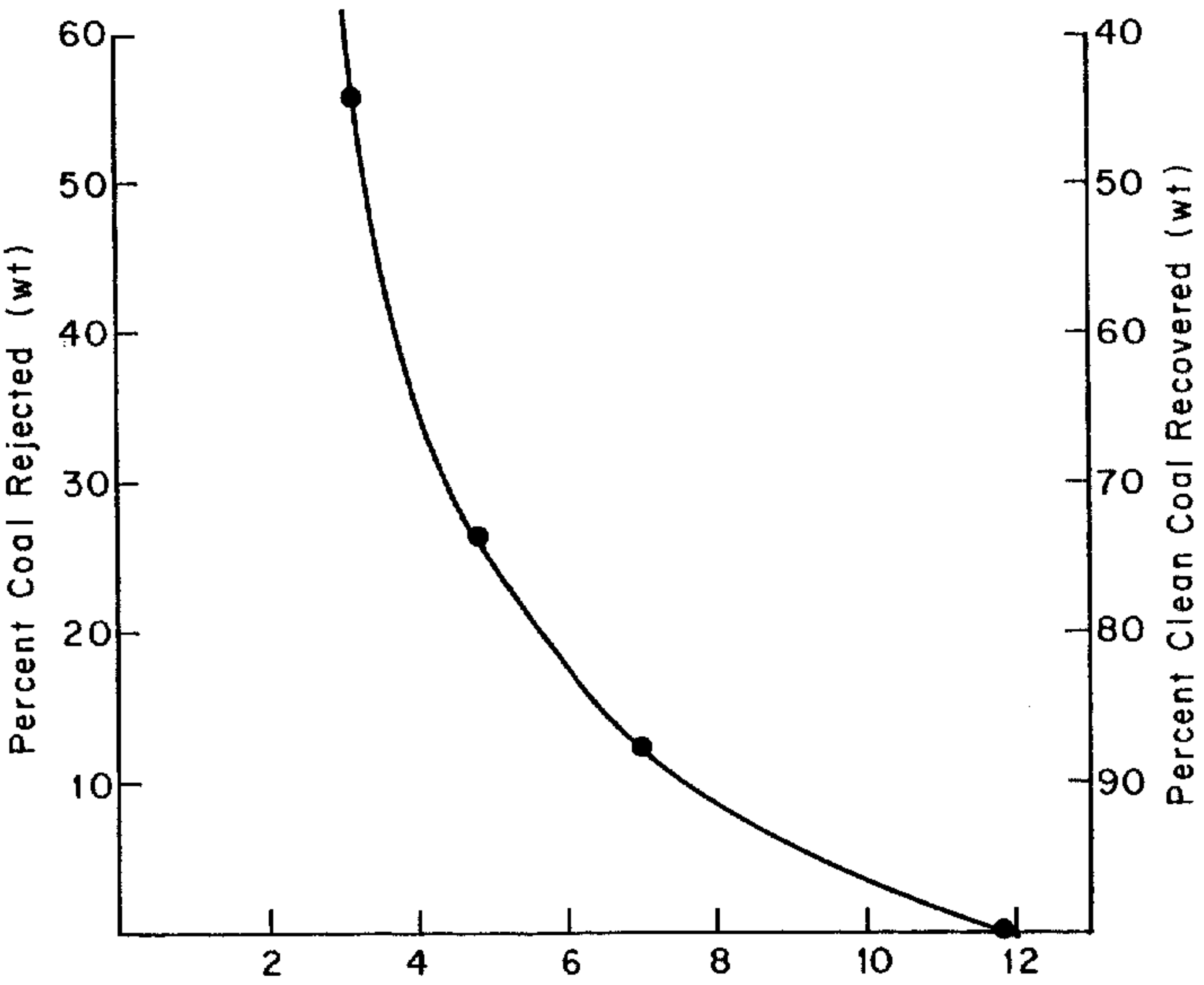

Figure 3

Ash Content vs Coal Recovery

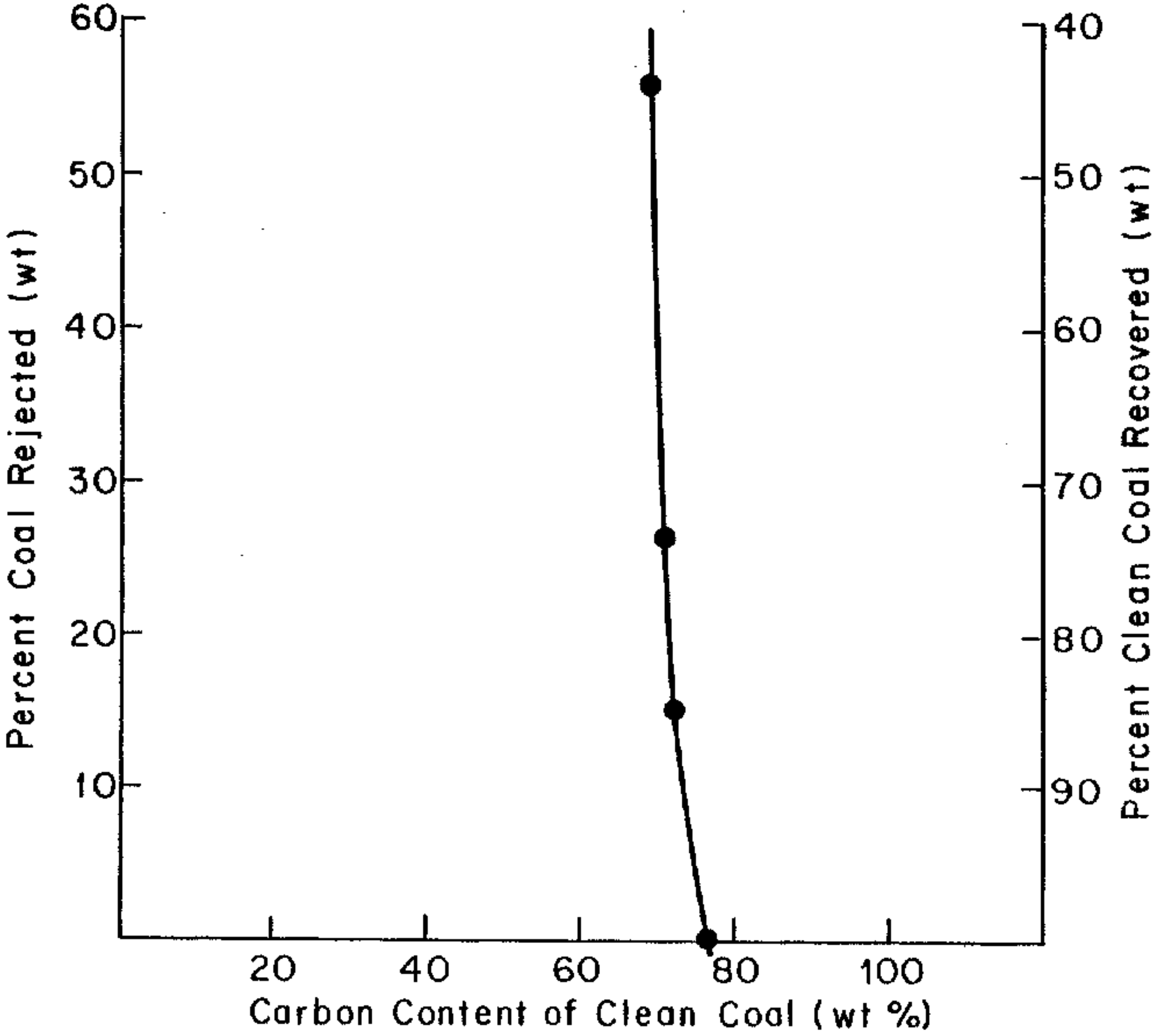

Figure 4

Carbon Content vs Coal Recovery

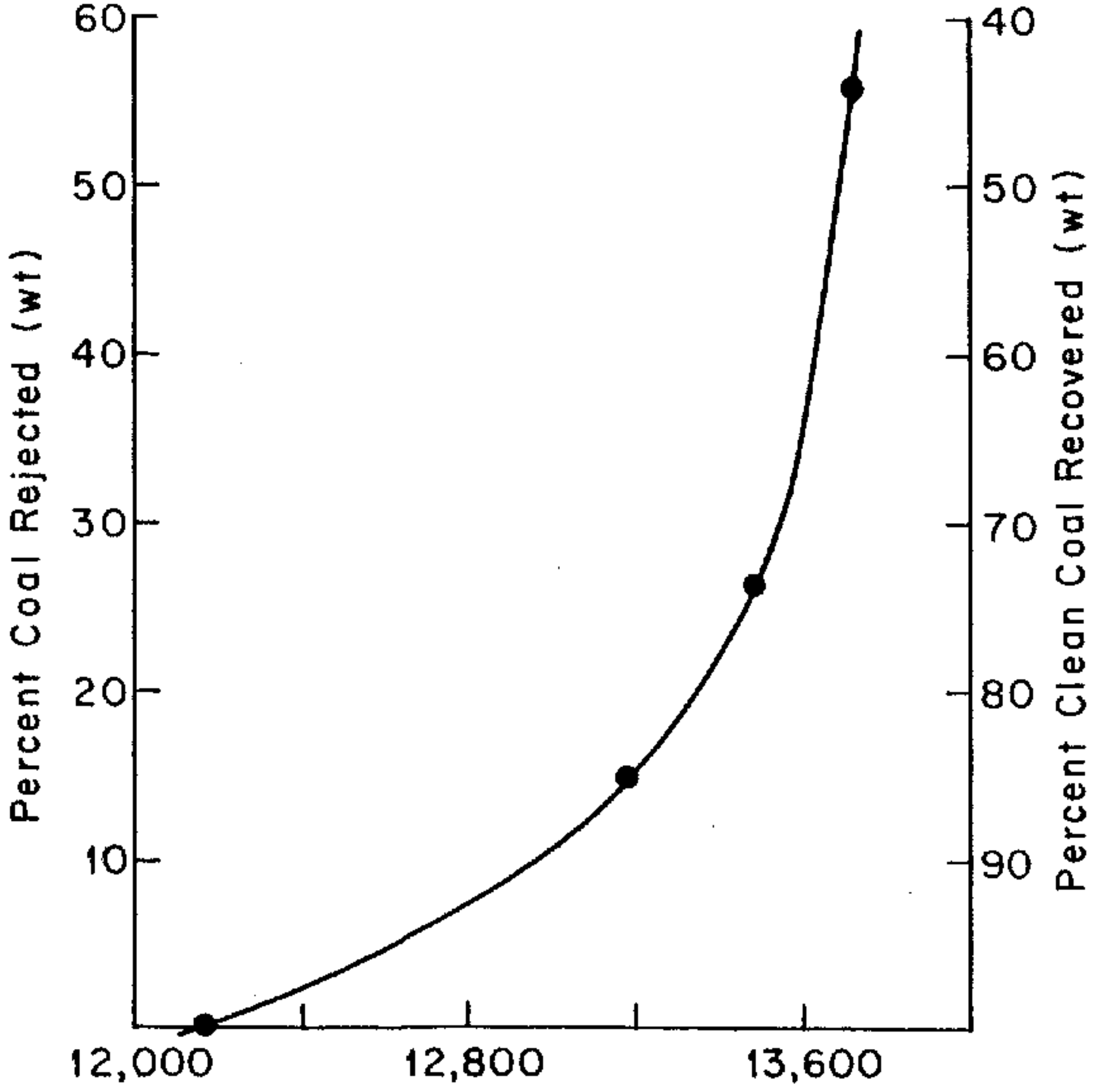

Figure 5

Higher Heating Value vs Coal Recovery

per MMBtu with the content of SO_2 in the stack gases. The specific amount of treatment was found in accordance with reference 7. (See sample calculations for details, Appendix A.) The following equation is used in determining the boiler unit's contribution to the production of useful energy.

$$\text{Boiler Energy} = \text{HHV}\ (.85 - .08\ [\text{fraction FGD Treatment}])$$

The effect of gasifying dirty coal was also considered in this analysis. With the aid of the computer program: "Equilibrium Model of Gasification", the efficiency of the gasifier, operating at 1700°F and 1000 psi with the dirty coal was obtained(8).

The summation of the energy generated from the boiler and the energy content of the gasifier product is made. This total energy from the system is divided by the heating value of the original coal input, yielding the overall energy efficiency.

The entire procedure was iterated from several recovery rates.

Results and Discussion

The overall energy efficiency over a range of coal recovery rates has been calculated for the proposed combustion/gasification system. Figure 6 summarized these results. No significant variation in efficiency exists among various recovery rates. The energy penalty of FGD had some influence on the results. A larger impact was felt from computed values for gasifier efficiency. These were higher and more stable at various feed compositions than originally believed.

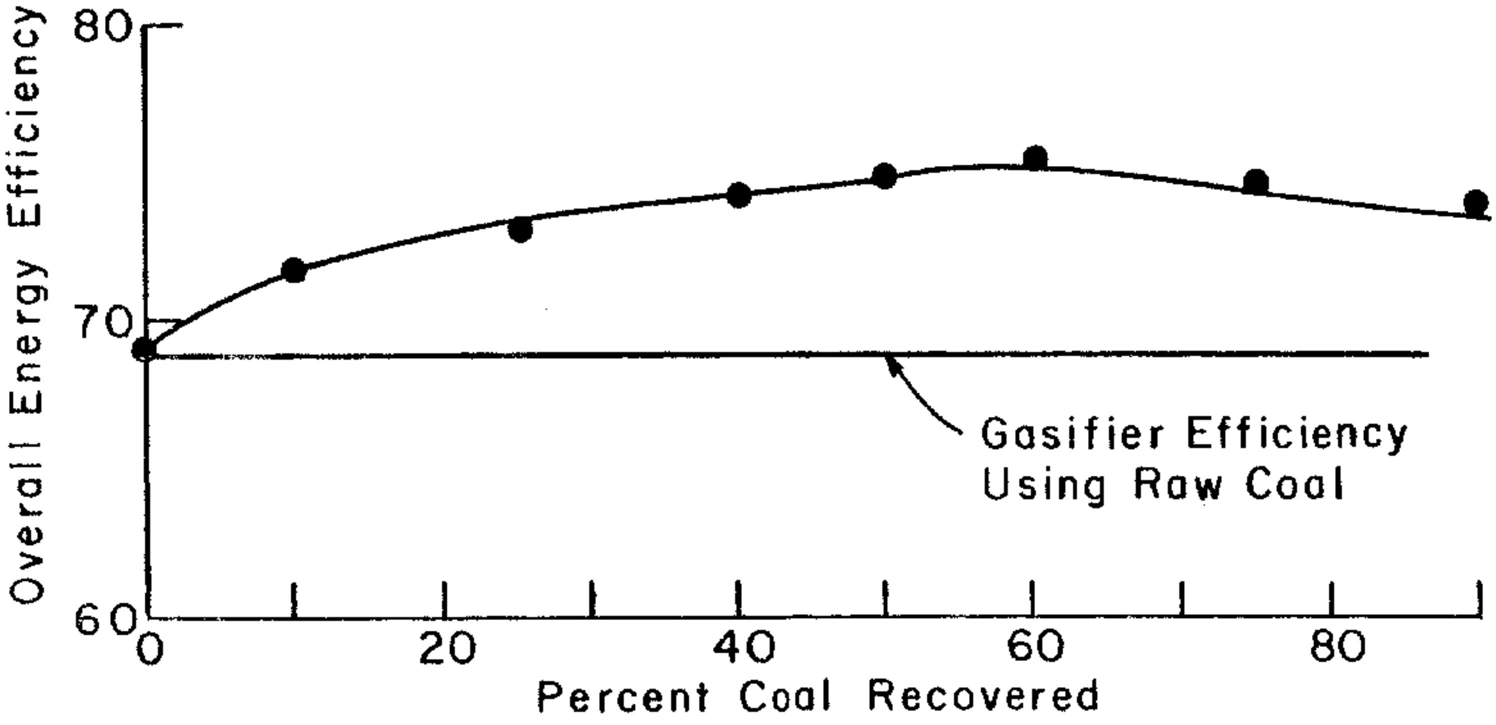

Figure 6

System Efficiency vs Coal Recovery

Figure 7 is a curve summarizing the effect of recovery rate (i.e., degree of cleaning) on the gasifier efficiency. The graph indicates that the gasification efficiency is insensitive to change in coal composition. This situation is rationalized if one observes the changing rate of steam and oxygen injection. The computer program used is an equilibrium model that optimizes these parameters for given feed compositions. Therefore, the gasification efficiency tends to be inelastic with respect to feed composition.

The efficiency for gasifying raw coal (69%), is not significantly different from direct combustion efficiency (78 - 85%). Consequently, even at the optimal recovery rate (i.e., degree of cleaning), the system efficiency has no great advantage over the present gasification system. The optimal recovery rate is represented as the relative maxima in Figure 6. It is observed that 73% is not vastly different from the raw coal gasification efficiency of 69%, when one recognizes that error of approximately 10% is inherent in this study. Therefore, installation of the proposed system can not be recommended for commercial gasification projects.

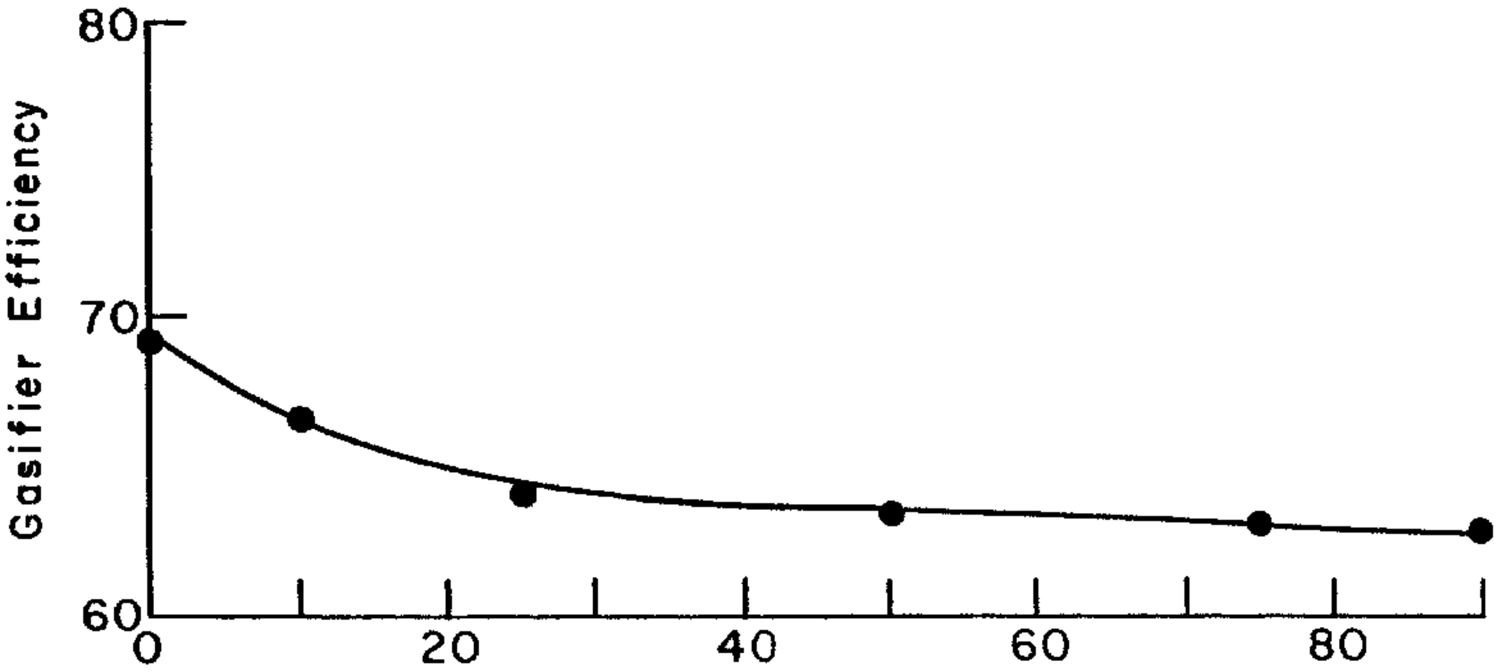

Figure 7

Gasifier Efficiency vs Coal Recovery

Accuracy and Sensitivity

Several sources of error can be identified within this study. Numerous assumptions and approximations were made. For convenience, these are listed below. The impact they have on the results of this investigation is considered as part of a sensitivity analysis which follows in Table 2.

1) Direct fired boiler efficiency of 85%.
2) Flue Gas Desulfurization energy requirements are 8% of the heat input to the boiler.
3) Energy required for coal grinding is negligible.
4) Gasification reaction approaches equilibrium conversion rate.
5) Downstream processing steps treating the gasifier effluent were unaffected.

Recognizing these limitations, an error of ± 10% can be expected in these calculations. It should be noted that Illinois No. 6 coal was used as a basis throughout this study. Other coal types may have characteristics that would alter the evaluation. Beneficial characteristics include ease of washability, high fixed carbon composition, and low sulfur and ash content.

The gasification program used to discern gasifier efficiency is an equilibrium model.[8] It does not exactly convey continuous operation results. The disparity here was believed to be small, however the surprisingly high gasifier efficiencies predicted by the model deserve some scrutiny. It is this factor which forced the retraction of the original

TABLE 2

Percent Efficiency Change for a 10% Change of an Individual Parameter

Parameter Name [10% Change]	Value	Change in System Efficiency
Boiler Efficiency	85%	1.2%
FGD Rate	8%	0.2%
Recovery Rate	60%	1.5%
Carbon Content of Gasified Coal	59%	0.4%
Gasifier Efficiency	69%	8.3%

The highest change of 8.3% on total system efficiency of 10% change in the assumed boiler efficiency indicates that this parameter has the most significant effect. On the contrary, the lowest change of .2% of the FGD energy consumption shows the negative sensitivity of this parameter.

hypothesis. Observing that the results are very sensitive to the gasifier efficiency, an error in these values could greatly influence the results of this entire evaluation.

Conclusions and Recommendations

1. The proposed combustion-gasification system should not be applied in commercial sized gasification designs.

2. Other coal types should be considered to evaluate the impact of coal characteristics on the system.

References

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3. Conversation with Kenneth Miller, Pittsburgh Energy Research Center, Bruceton, Pa.

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9. Op. Cit., Cavallaro, p. 61, 314.

10. Personal communication with Dr. Kun Lee, Professor, Chemical Engineering, Carnegie-Mellon University.

11. Miller, Kenneth J., Flotation of Pyrite from Coal: Pilot Plant Study, Pittsburgh Energy Research Center, Bureau of Mines RI 7822, 1973.

APPENDIX A

Sample Calculations

Following will be a sample of the calculations required to obtain a value for the overall efficiency of the proposed system. The case of 40% recovery of clean coal in the separation unit is used below. The procedure applies at any recovery rate.

1. Recovery rate of 40% is chosen.
2. From Figures 2 through 5 the composition of the clean coal is determined.

S - 2.5%
Ash - 3.1%
C - 67%
Heating Value - 13,650 BTU/lb

3. By mass balance the composition of the dirty coal is calculated. Initially the raw coal composition is given as:

S - 3.5%
Ash - 11.8%
C - 70.7%
HV - 12,172 BTU/lb

Choosing a basis of 100 lbs of raw coal, the dirty coal composition is easily derived.

$$S: \frac{.035 - .025(.40)}{.60} = .04$$

$$Ash: \frac{.118 - .031(.40)}{.60} = .18$$

$$C: \frac{.707 - .67(.40)}{.60} = .73$$

And via energy balance

$$HV: \frac{12{,}172 - 13{,}650(.40)}{.60} = 11{,}187$$

4. The boiler calculation is done assuming 85% efficiency and penalty of 8% for stack gas clean up. The amount of gas needing treatment must first be determined. From Figure 2b the coal directly fired at 40% recovery does not meet EPA emission standards. The amount of gas treated is calculated by:

$$STD = \frac{SO_2(1 - xn_s)}{Q\ Boiler}$$

where x = fraction of flue gas treated

STD = SO_2 emission regulation lb/10^6 BTU (1.2)

n_s = scrubber efficiency (80%)

SO_2 = lb of SO_2 in

5. The contribution to total energy from the boiler is found by the equation:

Boiler Energy = HHV (.85 - 0.8 [% FGD Treatment])

In this case

$$\text{Boiler Energy} = 13{,}650\ (.85 - .08[.45])$$
$$= 11{,}111$$

6. The contribution from the gasifier is computed by multiplying the given gasifier efficiency by the heating value of the dirty coal feed.

$$11{,}187 \times .66 = 7384$$

7. Overall Energy Efficiency

$$\frac{(11{,}111).40 + 7384(.60)}{12{,}172} = 73\%$$