COMBINED POWER CYCLE USING LOW BTU GAS PRODUCED FROM THE KELLOGG MOLTEN SALT COAL GASIFICATION PROCESS

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INTRODUCTION

In recent years, it has become increasingly important to look for alternate sources of energy on a commercially feasible basis. In the midst of the present energy crisis, coal remains the most abundant source of energy in this country. However, the time honored techniques used to convert coal into electrical power no longer satisfy the needs of the power industry. Also, the public and the industry alike have grown to be ecology conscious; there is an ever increasing emphasis on burning "clean" fuel. A direction now established for increasing the economics of power generation is to exploit the use of a combined gas turbine-steam turbine power cycle. The relatively inexpensive gas turbine extends operation into the higher temperature range (presently 1950°F) and the temperature limit on gas turbine development has yet to be established. However, the gas turbine requires a clean fuel, natural gas or clean liquids. Low Btu fuel obtained from The M.W. Kellogg Molten Salt Coal Gasification Process, currently under development, when used in conjunction with a gas turbine-steam turbine combined power cycle system provides for an efficient method of generating electrical power from high sulfur, high ash coal while minimizing environmental pollution.

DISCUSSION

Gasification of coal using Kellogg's Molten Salt Process has been described in detail elsewhere (1, 2, 3). The overall process converts the heating value of high sulfur coal to fuel gas with a lower heating value of 100 to 150 Btu/SCF at a conversion efficiency of around 90% with most of the sulfur retained by the melt. The gasifier is set to operate at 260 psia and 1700°F and compressed air is used to partially burn coal to produce the fuel gas at these conditions.

The work to develop the Kellogg Molten Salt Coal Gasification Process for SNG (Substitute Natural Gas) has been modified to develop a process that is compatible with the combined cycle concept. (See Figure 1.)

There are four systems in the process:

1. Gasifier --a single pressure vessel where molten sodium carbonate catalyzes the partial oxidation of coal by air to produce a raw fuel gas. A typical composition is shown in Table 1.

2. Coal and Carbonate Feed --supply coal and make-up sodium carbonate at pressure to the gasifier.

3. Gas Conditioning --a series of heat exchanges and gas washes make the raw gas compatible with a gas turbine.

4. Carbonate Recycle --the stream which purges ash from the gasifier is approxi-

mately 70% sodium carbonate and 8% sodium sulfide. The system recovers the sodium for recycling to the gasifier.

COMBINED POWER CYCLE

The overall efficiency of a combined cycle power plant buring low Btu gas produced from the Kellogg process is dependent on the coal gasification efficiency--including the salt cleanup and regeneration--and the temperature-pressure conditions in the steam generation system. Salt recovery technique thus is one of the key features in the performance of this cycle. The sensible heat from the melt purge (@ 1700°F) is used to preheat the air supply to the gasifier (to 990°F). (See Figure 2.) Most of the salt is recovered by evaporation as carbonate for recycle and the heat for evaporation is provided from the gas turbine exhaust. Sulfur retained by the melt is converted to hydrogen sulfide by carbonation and then recovered as elemental sulfur in a nearby Claus plant.

The fuel gas leaving the gasifier is cooled in a series of heat exchangers to a temperature of around 175°F before being sent to a scrubber. The major part of this heat is utilized for the production of steam and BFW heat for the steam system (2400 psia/1000°F/1000°F) as well as for reheating the scrubbed fuel gas back to 500°F before being sent into the gas turbine. The scrubbing operation provides the CO_2 needed for carbonation of the salt, while scrubbing with water eliminates sodium. The only fixed nitrogen in the fuel is a trace of NH_3 and thus the fuel gas produced is quite clean. Also, sodium carbonate being a catalyst gasifies coal completely without the production of associated coal distillates. For example, using Ohio Clarion High Sulfur (4.65%) Coal in the Kellogg process, it has been determined that more than 90% of sulfur is retained by melt for recovery later. This results in 0.78 lb SO_2/MMBtu in the flue gas without any scrubbing to remove SO_2.

The gasification system distributes the heating value of the coal into four parts. (See Table 2.)

The sensible heat in the fuel gas is available at various temperature levels. This requires a close integration with the steam system of the combined cycle so that it is used in the most efficient manner.

The number and type of interfaces just described mean that the gasifier and combined cycle must be tightly integrated if the overall system is to be very efficient.

Figure 2 shows the result of just such an integration. A commercially available gas turbine with 1950°F inlet temperature and a 2400 psia/1000°F/1000°F steam cycle were used. The match up between the steam cycle and sensible heat, both in the fuel gas and flue gas, is shown in Figure 3.

These curves show that the heat interchanges are arranged in such a fashion that minimum temperature differentials of around 40°F are observed at the pinch points. This, along with the fact that heat available at the gasifier level is limited to steam generation, has required that BFW heating and steam generation be done in more than one step. The distribution of power among various components for a 120 $_e$MW net plant is shown in Table 3.

It is estimated that integration of a gas turbine combined power cycle (with fully loading the gas turbine in conjunction with a 2400 psia/1000°F/1000°F steam system) with the Kellogg Molten Salt Coal Gasification process generates power at a net heat rate of around 9500 Btu/kw-hr or lower using available equipment (HHV).

UTILIZATION OF LOW ASH COAL

(e.g., Pittsburgh Seam Coal with 5.2% ash-1.3%S) Incorporating minor changes in the purge recycle and the power cycle discussed above, the molten salt process can be very effectively used with low ash coal. It is estimated that such a process would have a gasifier efficiency of over 95% with a 0.45 lb/MMBtu of SO_2 in the flue gas without any scrubbing. The overall efficiency of such a combined cycle power plant utilizing the low ash coal is estimated around 40% (8500 Btu/kwh based on HHV).

ECONOMICS

Any attempt at economic analysis in these days must be based more on underlying fundamentals of a system rather than on numbers.

However, in Table 4 is an attempt at a current analysis. This compares the cost of power generated by a conventional power plant equipped with a stack gas scrubber to the gasifier - combined cycle system. Both systems were considered to have an efficiency of 36%. Coal was assumed to be 20$/ton, the conventional plant to cost 400$/kw plus 55$/kw for a scrubber. The gasifier - combined cycle system was estimated to be 375$/kw. These parameters reflect the conditions at the end of 1974. Table 4 shows an 11% advantage for the gasifier - combined cycle system. This can be considered marginal since it is a system currently under development.

STATUS OF THE PROCESS

Extensive work has been done in testing the containment of the molten sodium carbonate bath for the production of high Btu pipeline quality gas (SNG). Basic data on the gasification process have been reported. Low Btu coal gasification is essentially an outcome of the Kellogg Molten Salt process for the production of SNG and as such most of the work done for the SNG process can easily be extended to the production of low Btu gas.

Thus, incorporating a combined cycle in conjunction with the Kellogg Molten Salt process, currently under development, for the production of low BTu gas, provides for a relatively easy way of obtaining power with the following advantages:

1. The Molten Salt gasifier will handle any type of coal including caking coals without pretreatment.

2. The catalytic action of the molten sodium carbonate promotes complete gasification of coal without the production of associated coal distillates, thus eliminating downstream fouling and some of the pollution control facilities that would otherwise be required.

3. The catalytic effect of sodium carbonate allows gasification at lower temperatures permitting higher gasification efficiency.

4. The system provides clean fuel gas for use in a gas turbine.

5. In the next five to ten years gas turbines possibly will be available with inlet temperatures of 2500°F and 3000°F. The power cycle efficiency in these cases are estimated to be 46% and 49%, respectively, based on HHV and low ash coal. And finally,

6. It is estimated that power plants using 3000°F inlet to gas turbine result in about 47% reduction in power costs compared to a conventional cycle (Table 4)

REFERENCES

1. Cover, A.E., W.C. Schreiner, and G.T. Skaperdas, "The Kellogg Coal Gasification Process", paper presented at American Chemical Society Meeting, Washington, D.C., Sept. 1971.

2. Cover, A.E., W.C. Schreiner, and G.T. Skaperdas, "Kellogg's Coal Gasification Process", Chemical Engineering Progress, March 1973.

3. Cover, A.E., and W.C. Schreiner, "The Kellogg Molten Salt Process", paper presented at the 4th Conference on Synthetic Fuels from Coal, Oklahoma State University, Stillwater, Oklahoma, May 1974.

TABLE 1
COAL AND FUEL GAS COMPOSITION

COAL PROXIMATE ANALYSIS

% ASH	16.87
% VOLATILE	39.44
% FIXED CARBON	43.69
	100.00
% SULFUR	4.65
% MOISTURE	3.43

HIGHER HEATING VALUE - 11273 BTU/LB

FUEL GAS ANALYSIS

	WGT. FRACTION
N_2	0.614
H_2O	.02
CO_2	.04
CO	.31
CH_4	.006
H_2	.01
H_2S	.0002
	1.00

HIGHER HEATING VALUE - 137 $\frac{BTU}{SCF}$

TABLE 2
DISTRIBUTION OF HIGHER HEATING VALUE
IN COAL AFTER GASIFICATION

1. FUEL GAS TO GAS TURBINE		
	HHV	72.5%
	NET SENSIBLE HEAT GAIN	1.8
2. STEAM GENERATED BY FUEL GAS		16.6
3. ASH PURGE LOSS		
	NET SENSIBLE HEAT LOSS	1.9
	COMBUSTIBLE (C, S)	6.7
4. SCRUBBER LOSS		0.5
		100%

GASIFIER EFFICIENCY (1) + (2) = 90.9%

TABLE 3
DISTRIBUTION OF POWER FOR 120 $_{e}$MW PLANT
(REFER TO FIG. 1)

GAS TURBINE	69.3
STEAM TURBINE	61.2
GROSS	130.5 $_{e}$MW
AUXILIARIES	6.5
BOOSTER COMPRESSOR	4.0
	10.5 $_{e}$MW

POWER OUT (NET) = 120 $_{e}$MW

OVERALL EFFICIENCY = 36%

TABLE 4
COMPARISON OF POWER COST FOR 480 MW CONVENTIONAL PLANT
WITH SCRUBBER VS. GASIFIER COMBINED CYCLE PLANT

	CONVENTIONAL WITH SCRUBBER		GASIFIER COMBINED CYCLE	
CAPITAL	15.8	MILLS/KWHR	13.0	MILLS/KWHR
LABOR	0.3		0.3	
OPERATING	10.6		10.7	
TOTAL	26.7		24.0	

FUTURE PLANTS w/3000°F Inlet to Gas Turbine	
9.2	MILLS/KWHR
0.2	
8.8	
18.2	

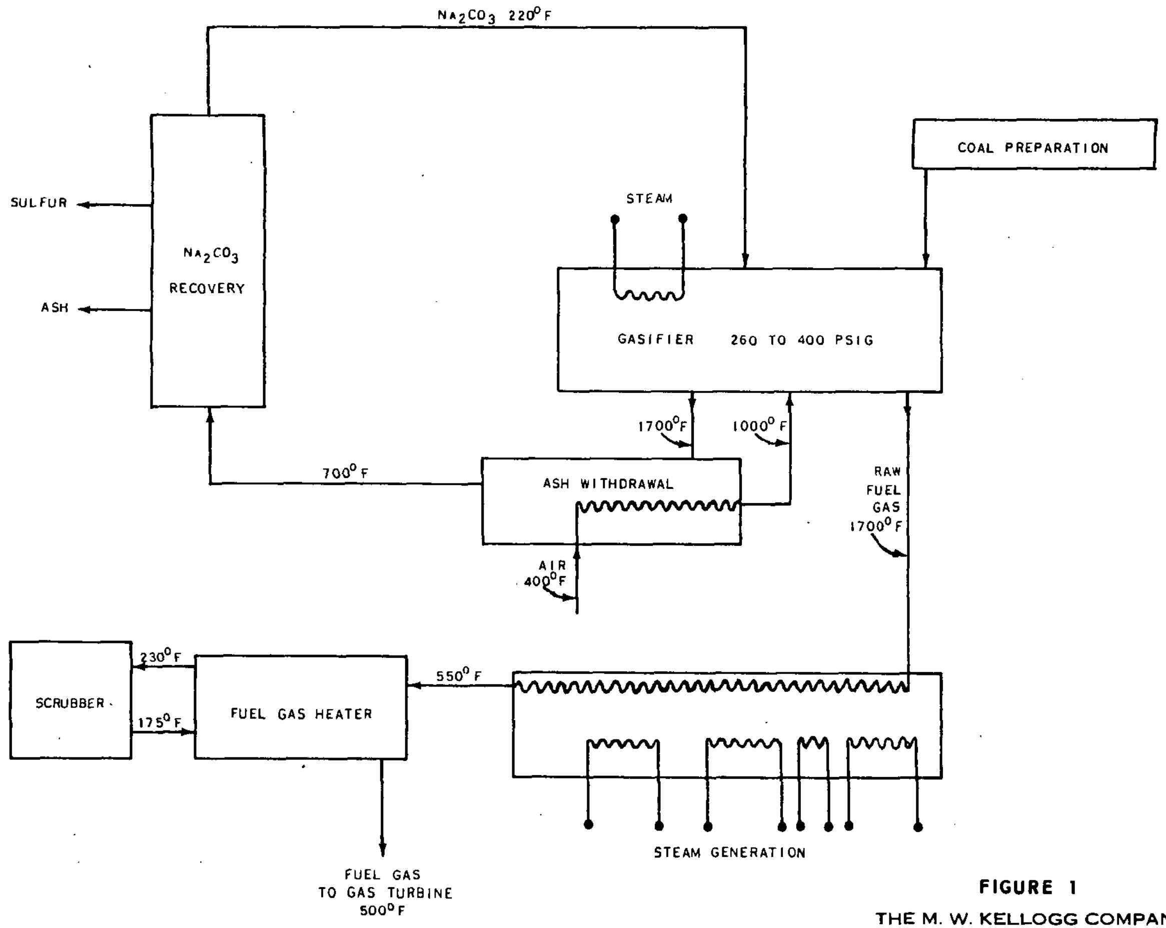

FIGURE 1

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MOLTON SALT COAL GASIFICATION

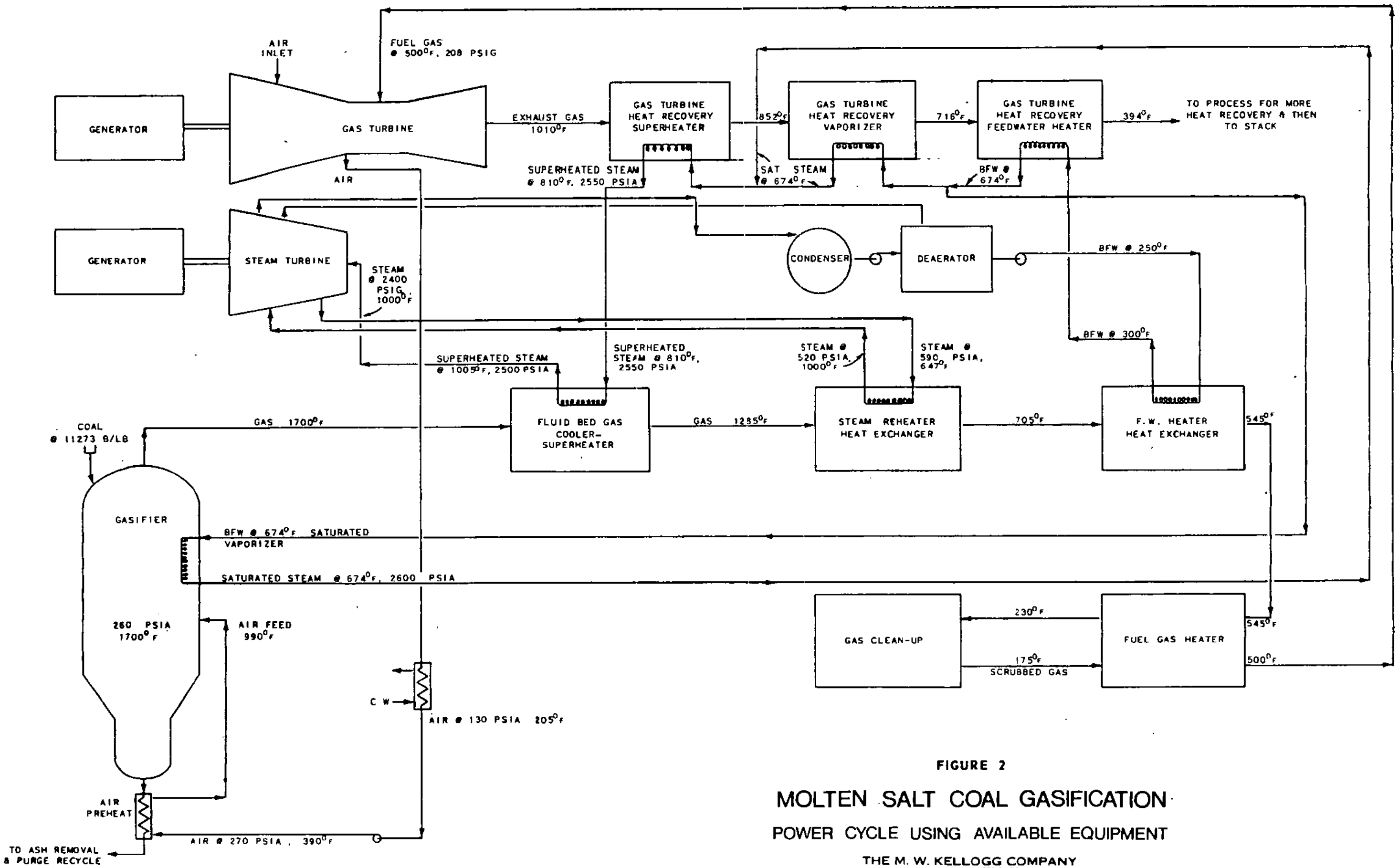

FIGURE 2

MOLTEN SALT COAL GASIFICATION

POWER CYCLE USING AVAILABLE EQUIPMENT

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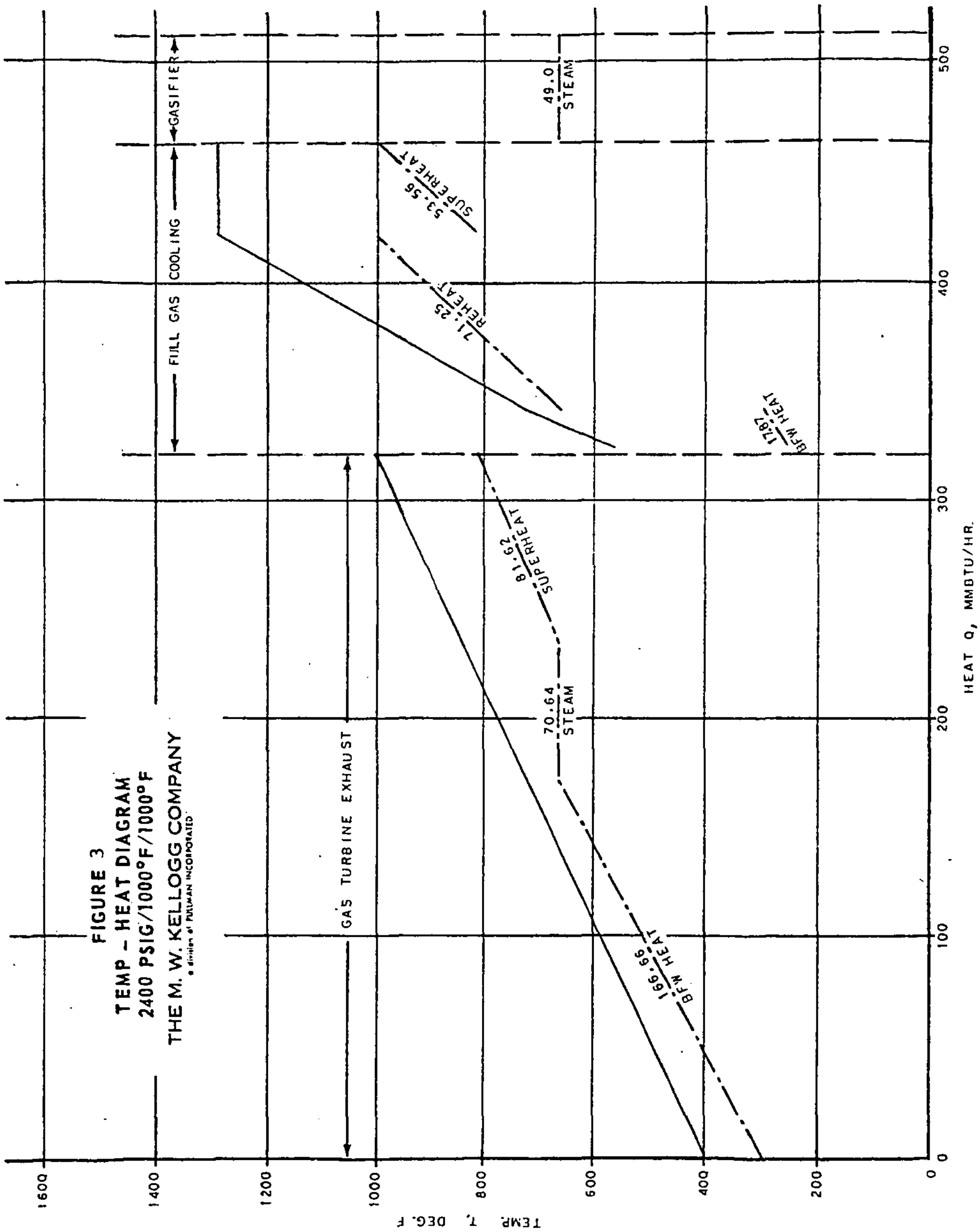

FIGURE 3
TEMP - HEAT DIAGRAM
2400 PSIG/1000°F/1000°F
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