BOILER DESIGNS FOR LOW BTU GAS FIRING

by
Phillip J. Hunt, Manager
Performance Design Engineering

RILEY STOKER CORPORATION
WORCESTER, MASSACHUSETTS

Presented at
ASME ENERGY TECHNOLOGY CONFERENCE
Houston, Texas
January 30 - February 3, 1983

RST-16

INTRODUCTION

Industrial boiler owners have become much more sensitive to unit operating costs and overall plant efficiency than they have been in years past. This is obviously the result of rapidly escalating fuel and purchased energy costs which has resulted in the movement by many industrial plants to utilize more effectively rather than discarding fuels in industrial boilers to supply all or part of the heat input necessary for design output.

Three such companies which Riley Stoker Corporation has contracted for boiler orders during the past two years are:

1. Phillips Petroleum
   Units No. 29 & 40
   Borger, Texas

2. ANG Coal Gasification Company
   Great Plains Project
   Mercer County, N. Dakota

3. Exxon Company
   Baytown Refinery
   Baytown, Texas

These units all fully utilize the energy benefits of various waste fuels available from external processes. This paper will discuss specific boiler design features of each installation which allows this to happen.

PHILLIPS PETROLEUM - Units No. 29 & 40

Figure 1 describes in front and sectional views the units supplied Phillips Petroleum at Borger, Texas.

The boilers are rated at 450,000 Lbs steam per hour, 725 psig outlet pressure and 750°F outlet temperature when firing refinery gas (similar to natural gas) and oil.

When firing waste "CO" gas, the unit output is 350,000 Lbs steam per hour at 600 psig outlet pressure and 750°F final steam temperature. The boiler is supplied with feedwater at 298°F to a backend economizer whose heat recovery raises the incoming feed to 460°F before entering the boiler drum.

The boiler is designed to burn three fuels, individually or in combination. As mentioned previously, the fuels are oil, refinery gas and "CO" gas. Figure 2 describes the individual constituents of these fuels as well as an expected range from the process "CO" gas. The "CO" gas for this boiler is a by-product from the regenerators of the Fluid Catalytic Crackers at this refinery. Approximately 117,000 SCFM of this gas is available when the cracker is at maximum output. Thirty (30) to one hundred (100) Lbs/HR of catalyst dust are entrained in the "CO" gas. This results in a grain loading of about 0.034 grains/ACF passing through the boiler at full load. This compares to 0.6 grains/ACF present with a typical pulverized coal fired industrial installation.

The furnace design selected on Phillips is the Riley Turbo Furnace. This furnace utilizes downward firing main burners (directional flame) together with a slot/intertube type "CO" gas burner near the furnace floor. The turbo furnace has a characteristic venturi type furnace throat which aids in uniform combustion and successful fuel burnout.

Figure 3 describes the Riley Directional Flame Burner, while Figure 4 shows the Riley "CO" Gas Burner design.

The furnace on this contract is sized for a volumetric heat release of 28,500 $BTU/HR/FT^3$ and an area heat release of 122,000 $BTU/HR/FT^2$ when firing refinery gas at maximum continuous rating (MCR).

This boiler is a bottom supported two drum design. It utilizes two passes, one containing a single section of convection superheater surface and the other containing baffled boiler bank (generating) surface. Heat recovery is accomplished by a bare tube external economizer.

Figure 5 is a tabulation of key steam, water and flue gas characteristics when firing oil, refinery gas and "CO" gas. Note, that when firing "CO" gas at 350,000 lbs steam per hour output, 27% of the total heat input is supplied by the "CO" gas. At this load, if "CO" gas were not available for heat input, and additional 7030 Lbs of oil per hour or 5750 Lbs of refinery gas per hour would be necessary. If one were to make a series of assumptions on load factor, oil and refinery gas costs, the "CO" gas consumption could amount to five million dollars in oil cost savings or 3 million dollars from savings in refinery gas over a one-year period. (Assumptions - 75% load factor; Oil - $\$6/10^6$ BTU; Refinery Gas - $\$3.50/10^6$ BTU.)

"CO" gas is available to the boiler at a limited pressure (15.0 iwg.). This pressure must be capable of forcing the "CO" gas from the burner inlet through to the unit stack. It is, therefore, necessary to keep gas side velocities low throughout the heating surface bundles to preclude the use of expensive booster fan capabilities for the "CO" gas. For the Phillips design, maximum gas velocities through the unit were 65 FT/SEC.

The steam temperature control range for this unit is as depicted in Figure 6. The control of steam temperature is by means of spray water introduced at the superheater outlet.

NOx emissions control is essentially through the use of the turbo furnace and directional flame burners. The type of combustion achieved with this combination historically has proven low emissions without a need for more complicated and expensive features, such as off-stoichiometric firing or gas recirculation. NOx emissions for this contract are predicted to be 0.14 $Lbs/10^6$ BTU on refinery gas, 0.16 $Lbs/10^6$ BTU on oil and 0.10 $Lbs/10^6$ BTU on combination firing with "CO" gas.

ANG COAL GASIFICATION COMPANY

Figure 7 shows the sectional elevation view of our design as supplied to ANG Company. Three identical units were purchased.

The boilers are rated at 500,000 Lbs steam per hour at 1200 psig and 890°F superheater outlet. The unit is capable of combusting a wide range of synthetic, waste and natural fuels. These fuels run the range from low, to medium to high BTU gases and liquid tars, tar oils, phenols and naptha.

Feedwater is supplied to the boiler at 306°F. A bare tube external exonomizer heats the incoming feed to 480°F before entering the main steam drum.

Typical fuels capable of being combusted are shown in Figure 8. Sustaining high BTU gas or liquid fuels are used with low and medium BTU gases in order to achieve the industry accepted 1800°F minimum adiabatic gas temperature at the combustion zone.

As was the Phillips design, ANG utilizes a Riley Turbo Furnace with six directional flame burners for combustion of the medium to high BTU gases and liquid fuels.

The low BTU gas is introduced through the lower front and rear furnace walls in a burner design as indicated in Figure 4. The furnace was sized for a volumetric heat release of 22,900 $BTU/HR/FT^3$ and a furnace area heat release of 77,300 $BTU/HR/FT^2$, at maximum continuous boiler rating.

This boiler is a top-supported, two-drum baffleless boiler bank design. It operates under balanced draft furnace conditions and utilizes radiant and convective superheat sections for relatively flat steam temperature control characteristics as a function of steam load.

Superheat steam temperature is controlled through spray water introduction between the primary superheater outlet and the radiant superheater inlet. The steam temperature control characteristics as a function of boiler load with various fuels is shown on Figure 9.

Spray water is generated from a "sweet water" condenser. The condenser (heat exchanger) utilizes feedwater before it enters the economizer as a cooling medium for condensing saturated steam from the boiler drum. The heat exchanger has the capability of providing 70,000 Lbs of spray water per hour for steam temperature control, while heating the incoming boiler feedwater approximately 45°F.

A schematic of the sweet water condenser spray water generator is shown on Figure 10. Note this system does not require a spray booster pump, but in fact utilizes the differential pressure drop across the primary superheater (40 psi) as its driving head, since the spray water loop is a parallel path to the primary superheater. An important design consideration obviously, is to design enough pressure drop into the primary superheater to provide the desired pumping head in the spray water circuit.

Backend heat recovery on the ANG design is by bare tube economizer and regenerative airheater. At MCR with combination fuel firing, the economizer manages to recover heat corresponding in a 325°F gas temperature drop while the airheater reduces the gas temperature a further 160°F.

Figure 11 tabulates key, air, gas, water and steam performance characteristics at 400,000 Lbs steam per hour on liquid fuel only (MCR on liquid fuel) and 500,000 Lbs steam per hour on low and medium BTU gas in combination with liquid fuel.

It should be noted that at 500,000 Lbs steam per hour, 44% of the total unit heat input is supplied by waste gas. Using the same assumptions on load factor and fuel costs as were used on the Phillips contract, utilization of the waste gas rather than liquid fuel oil could realize savings of 13 million dollars in oil costs per year.

Since the fuels to be combusted result from the gasification of various coals, some particulate contamination of the fuels exists. To minimize erosion from these particles, gas velocities were not allowed to exceed 50 FT/SEC through any section of heating surface.

NOx emissions are essentially controlled through the application of the Riley Turbo Furnace and the directional flame burners. At 400,000 LB/HR steam output firing liquid fuels, NOx is predicted to be 0.35 LB/10^6 BTU. At 500,000 LB/HR steam output firing combination low and medium BTU gas with liquid fuels, NOx is predicted to be 0.25 Lb/10^6 BTU.

Steam purity is guaranteed on this contract not to exceed 0.1 ppm. To accomplish this, a system of steam drum internals as shown in Figure 12 were offered. The system uses two stages of mechanical separation equipment. The first are "cans" or centrifugal separators where 93% of the steam water separation occurs. The last stage of separation equipment are chevron driers where the remaining purification occurs. The maximum design loading for the steam purification equipment is 15,000 Lbs steam per foot of drum length.

EXXON COMPANY

Unit SG501C at the Baytown, Texas refinery is described on Figure 13. The boiler is rated at 319,000 Lbs steam per hour when firing "CO" gas turbine exhaust gas and sustaining fuel.

When firing oil or rich refinery gas with combustion air (no turbine exhaust gas) the boiler is capable of generating 425,000 Lbs steam per hour at 640 psig and 700°F final steam conditions.

This unit is distinct from the last two described in that it is designed to utilize the sensible heat and the oxygen content of gas turbine exhaust gases as a sole source of combustion air.

When at 319,000 Lbs steam per hour, 160,000 Lbs of turbine exhaust gas at 800°F and 16.17% O_2 by volume is sufficient to combust 430,000 LB/HR of "CO" gas and 4,000 LB/HR of sustaining refinery gas.

Figure 14 describes the fuels and turbine exhaust gas on which the design is based.

The furnace design selection for Exxon is the Riley Turbo Furnace with four directional flame burners. There are no separate "CO" gas burners on the unit as was used for Phillips and ANG. The CO burner is incorporated with the main directional flame burners. The lower furnace (hearth) is refractory lined so as to maintain near adiabatic conditions in the combustion zone. This enhances burner and combustion stability even when fuel and turbine exhaust conditions are periodically interrupted or changed as will occur because of external process influences.

The furnace waterwall refractory is a high alumina, high temperature, erosion and corrosion resisting compound which is gunnited to "Y" anchors that are welded to the waterwall fins. The refractory will be a minimum of 2" thick beyond the waterwall tube crown.

Because the lower furnace is maintained in such an intensely high combustion temperature condition, another NOx emission abatement technique in addition to the turbo furnace is needed. That is, overfire air is introduced above the turbo furnace throat through a series of air ports. This system is only needed when firing refinery gas or oil at 425,000 Lbs steam per hour, to keep NOx below 0.2 Lb/10^6 BTU on refinery gas and below 0.3 Lb/10^6 BTU on oil. The system is not needed for NOx control when firing waste fuels with turbine exhaust gas.

The furnace on this contract has been sized for an area heat release of 95,900 BTU/HR/FT^2 and a volumetric release rate of 27,450 BTU/HR/FT^3 when firing refinery gas at 425,000 Lbs steam per hour.

The unit is a pressurized design utilizing two differently sized forced draft fans. Because of the wide variance of volume and head requirements between the waste gas/turbine exhaust gas firing and refinery gas/normal combustion air requirement conditions, the two fans are necessary. This will ensure high fan efficiency for the wide range of operating conditions demanded and it will also avoid the potential requirement of operating in an unstable fan system demand region as might occur if one fan was selected with an attempt to satisfy all combustion air requirements.

The superheater and boiler bank heating surfaces are configured to allow a single passage of flue gas with a maximum gas side velocity of 70 FT/SEC.

Backend heat recovery is attained through the application of a bare tube economizer which heats incoming feedwater from 250°F to 365°F while reducing flue gas temperature from 670°F to 290°F when firing refinery gas as 425,000 Lbs steam per hour.

Figure 15 describes basic design operating criteria for the boiler.

When at 319,000 Lbs steam per hour 78% of the total heat input is provided by waste CO and turbine exhaust gas. If this heat had to be provided with refinery gas 14,400 Lbs of refinery gas/hr would need to be fired. Making the same assumptions as were used on Phillips and ANG, the waste gas would offset 7.6 million dollars in refinery gas consumption during a one year period.

Steam temperature is controlled on this boiler through the use of spray water. The spray water is generated using a sweet water condenser application similar to what was described on the ANG contract.

Figure 16 shows the variation of steam temperature with varying boiler load and fuel conditions.

SUMMARY

Riley Stoker Corporation has been furnishing unique boiler designs for low BTU gas utilization for thirty years. Their operating success is a matter of public record. The evolution of the Company's design concepts have reached a point where the three recent contracts described in the paper incorporate many years of design and operating experience. Our experience will be further enhanced when these three contracts are placed in service and their operation proven under extremely varying fuel combinations. We have great confidence in the turbo furnace design with directional flame burners and are optimistic that further operational flexibilities will be shown on these boilers so that even greater design capabilities can be achieved on future offerings.

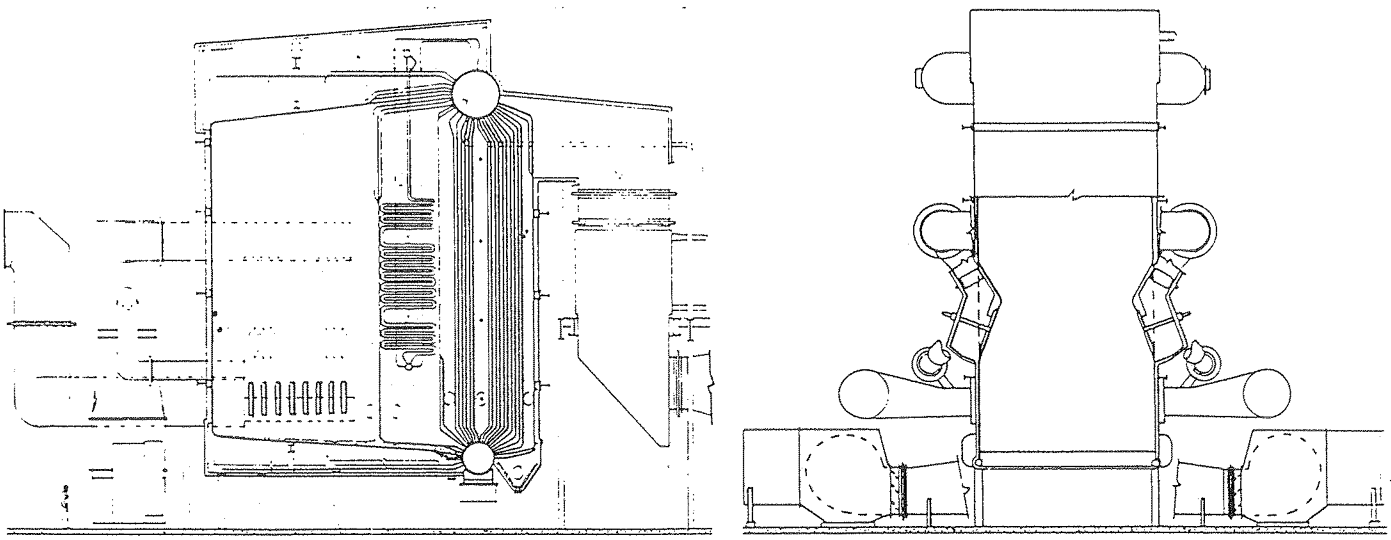


Figure 1 Phillips Petroleum - Units 29 and 40

NO. 6 OIL
% BY WEIGHT

H_2 - 10.27
C - 88.39
N_2 - 0.36
O_2 - 0.22
S - 0.72
Ash - 0.04
HHV -18,200 Btu/lb

REFINERY GAS
% BY VOLUME

CH_4 -19.71
C_2H_6 - 11.03
C_3H_8 - 2.11
C_4H_{10} - 0.84
C_5H_{12} - 1.68
C_2H_4 - 6.37
C_3H_6 - 2.61
C_4H_8 - 0.39
H_2S - 0.09
CO_2 - 0.58
H_2 - 48.76
N_2 - 5.83
HHV - 22,243 Btu/lb
HHV - 855 Btu/ft^3

"CO" GAS
%BY VOLUME

H_2O - 15.82
N_2 - 67.83
O_2 - 0.09
CO - 3.46
CO_2 - 12.8
Temp. - 440-540°F
HHV - 147 Btu/lb
11.1 Btu/ft^3
Sensible Heat - 242 Btu/lb
- 95 Btu/ft^3
Total HHV - 389 Btu/lb
- 106.1 Btu/ft^3

Figure 2 Design Fuels - Phillips Petroleum

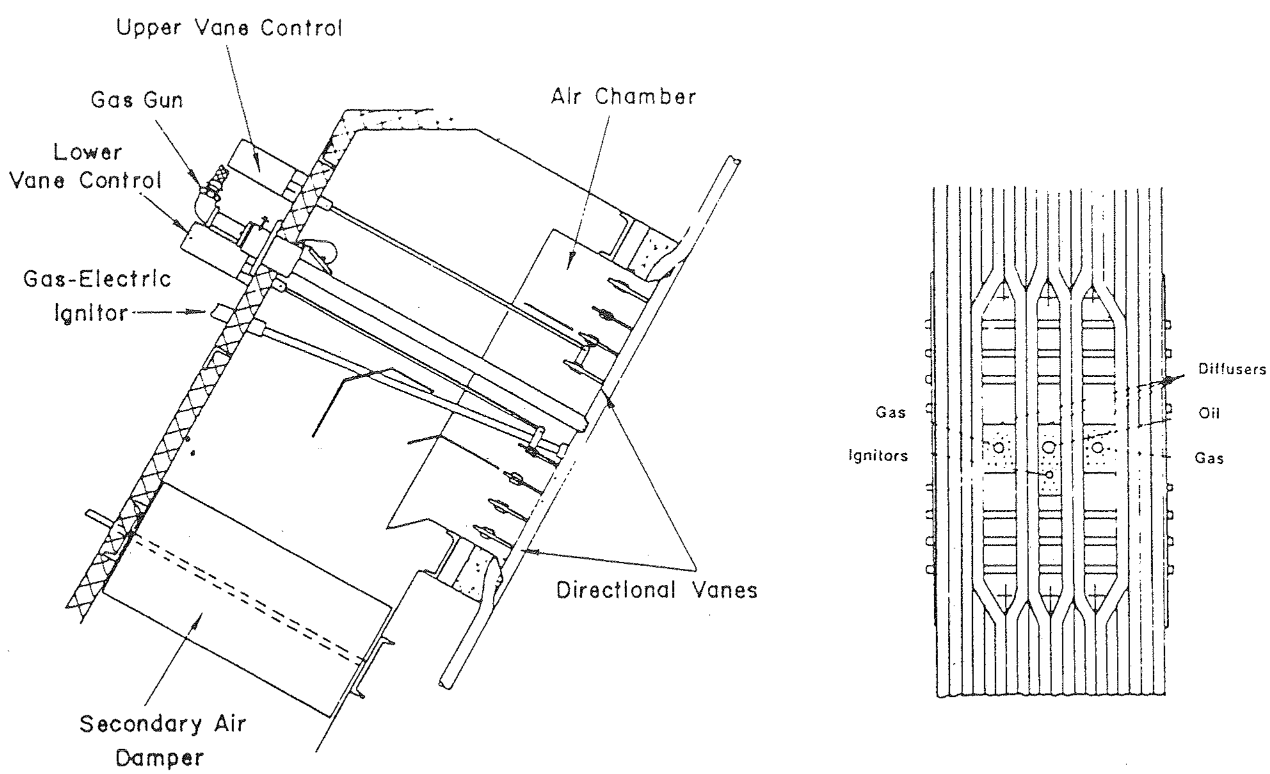


Figure 3 Riley Directional Flame Burner

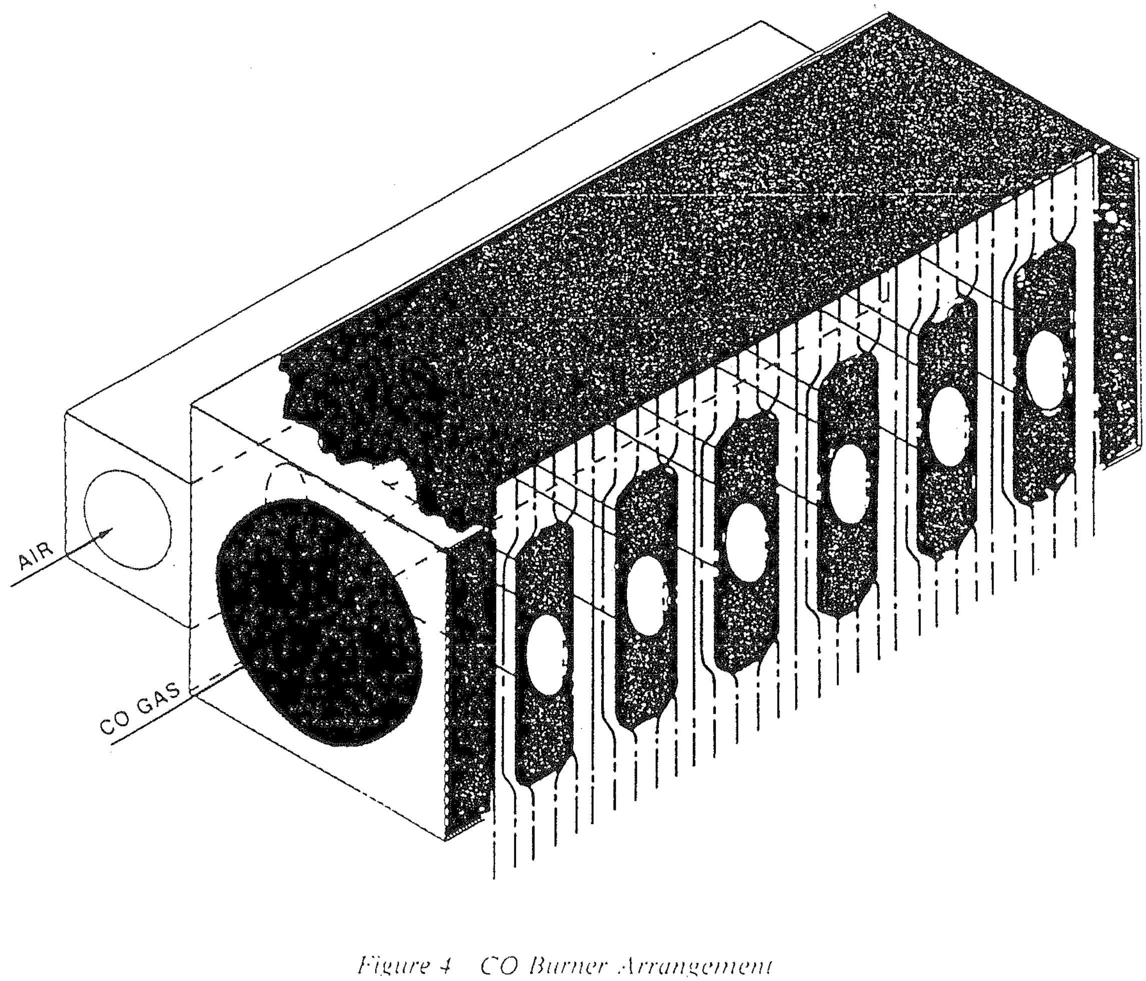


Figure 4 CO Burner Arrangement

	REFINERY GAS	OIL	REFINERY GAS AND CO GAS
1. Steam Output #/hr	450,000	450,000	350,000
2. Steam Temperature °F	750	750	750
3. Gas Temperature Leaving Boiler Bank °F	550	520	530
4. Gas Temperature Leaving Economizer °F	320	310	305
5. Feedwater to Economizer °F	298	298	298
6. Feedwater Leaving Economizer °F	450	448	442
7. Boiler Efficiency %	84.26	87.93	79.41

Figure 5 Design Performance - Phillips Petroleum

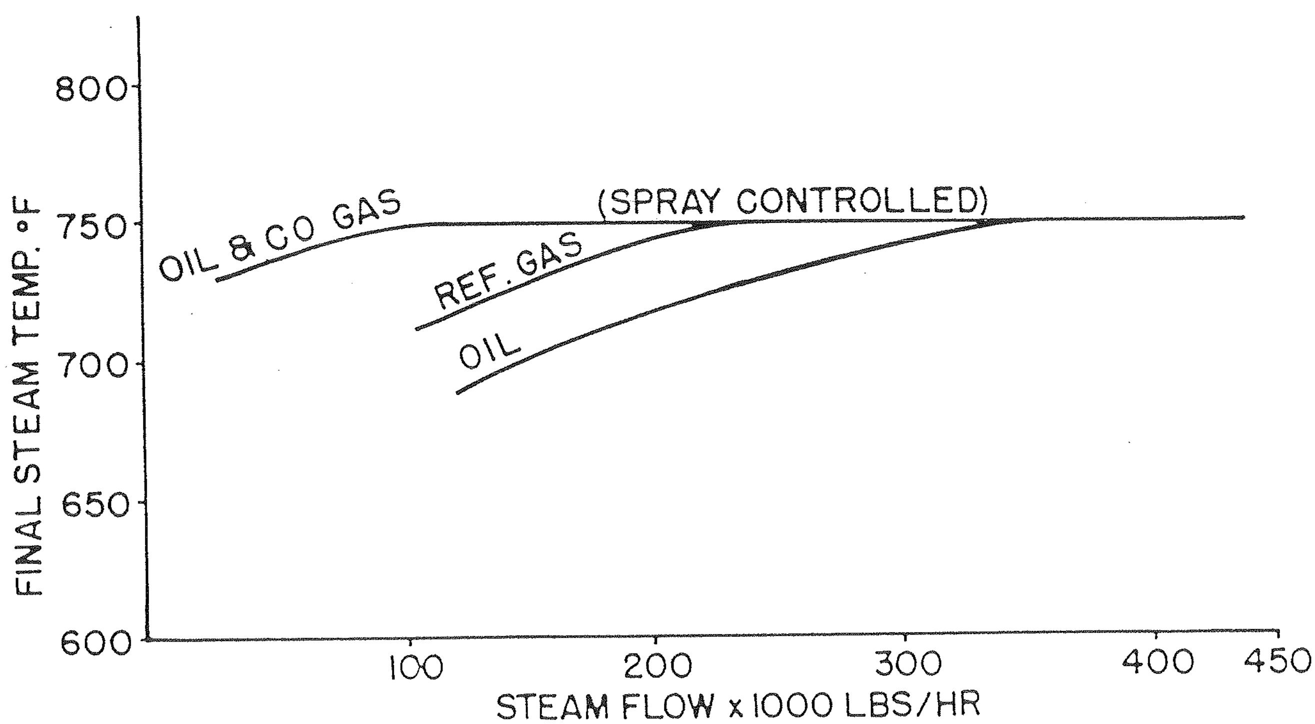


Figure 6 Final Steam Temperature Characteristics
Phillips Petroleum

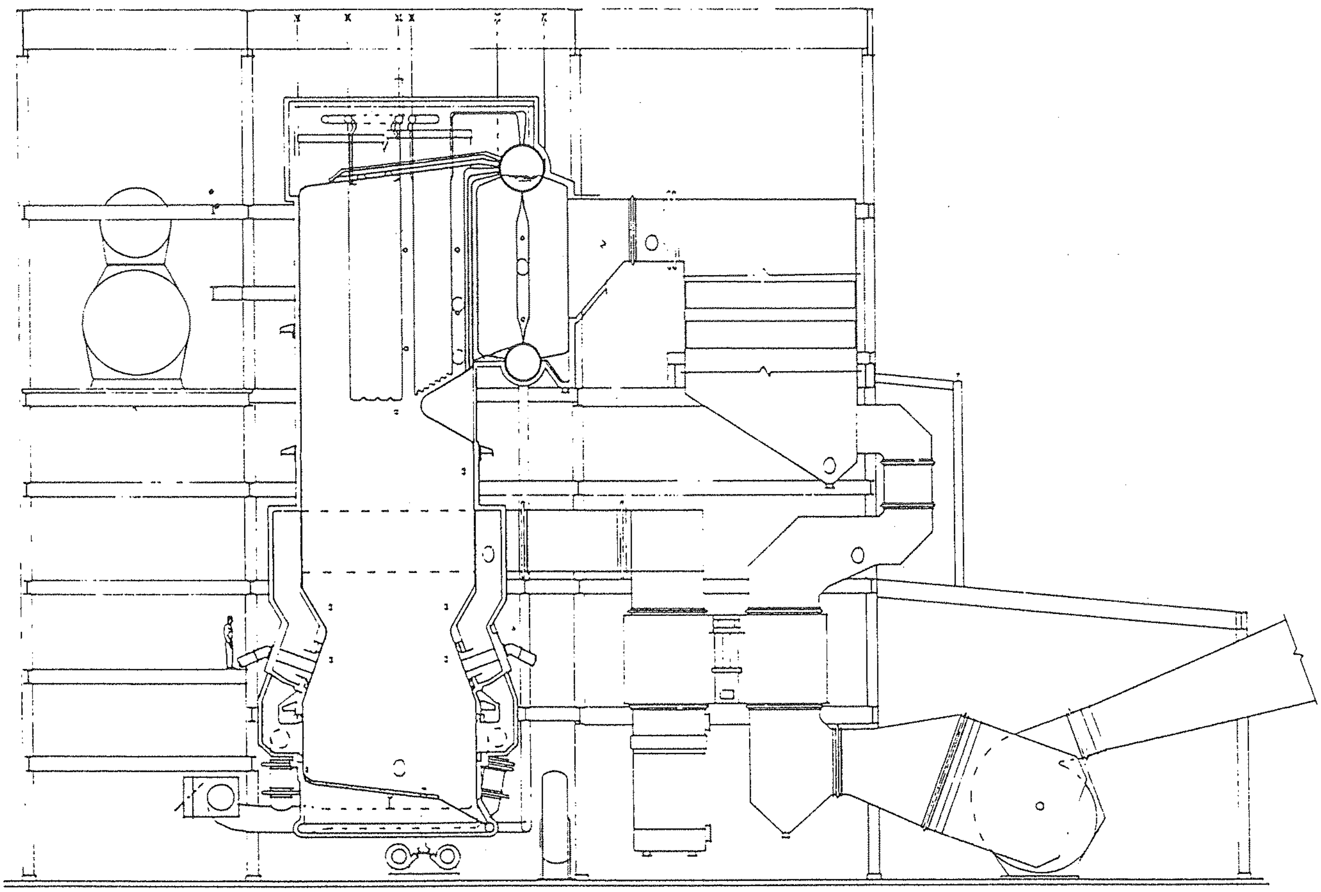


Figure 7 ANG Coal Gasification Company

WASTE GAS % BY VOLUME	LOCK GAS % BY VOLUME	LIQUID FUEL TAR AND TAR OIL % BY WEIGHT
CH_4 - 0.897	CH_4 - 11.10	C - 80.11
C_2H_6 - 0.695	C_2H_6 - 1.00	S - 0.54
C_3H_8 - 0.241	CO - 15.5	N - 0.71
C_4H_{10} - 0.174	CO_2 - 31.4	H - 8.43
C_6H_{12} - 0.012	H_20 - 2.60	O - 7.05
C_2H_4 - 0.060	H_2 - 38.4	H_2O - 3.09
C_3H_6 - 0.123	HHV - 5,364 Btu/lb	Ash - 0.07
C_4H_8 - 0.124	HHV - 307 Btu/ft^3	HHV - 16,453 Btu/lb
H_2S - 0.010		
CO - 0.145		
CO_2 - 91.971		
H_2O - 5.168		
N_2 - 0.112		
H_2 - 0.268		
HHV - 400 Btu/lb		
HHV - 44.5 Btu/ft^3		

Figure 8 Design Fuels - ANG Company

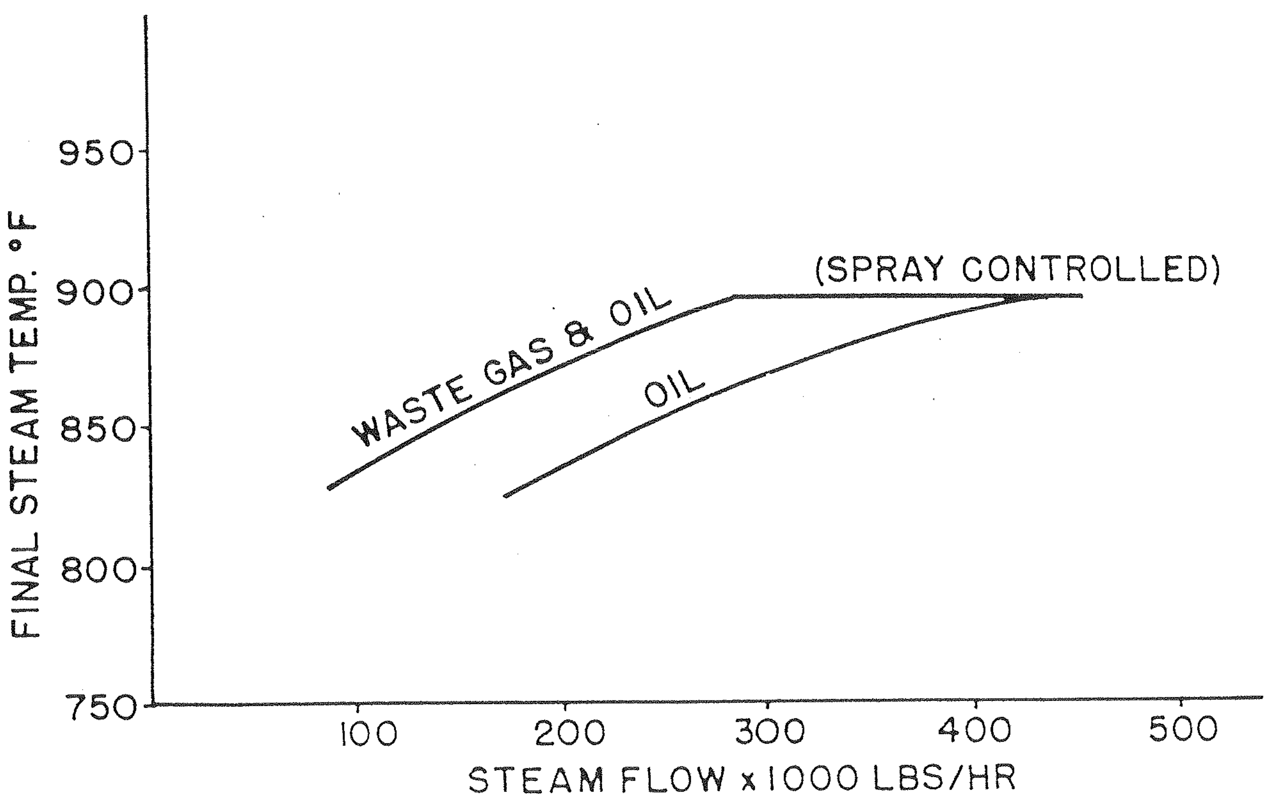


Figure 9 Final Steam Temperature Characteristics
ANG Company

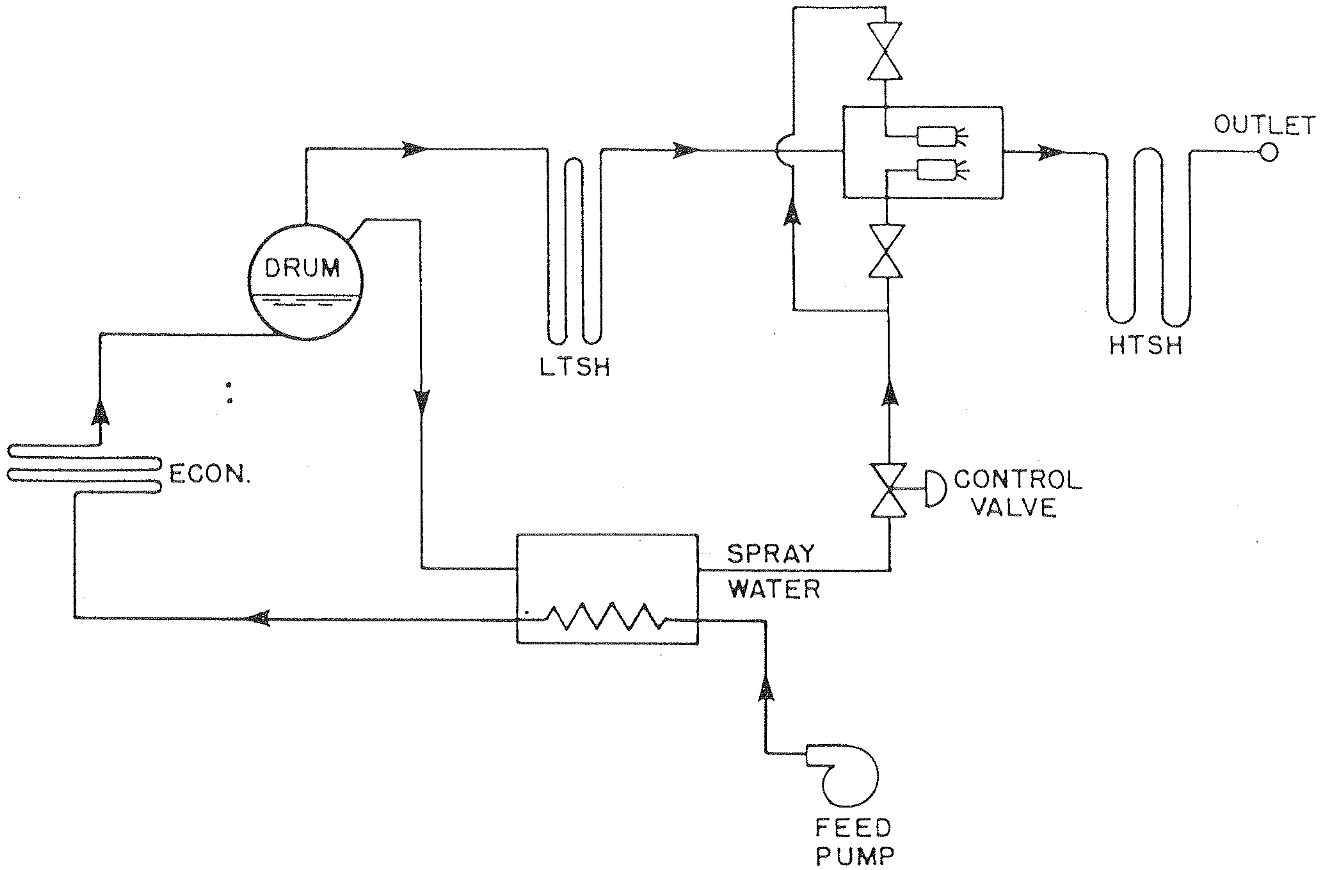
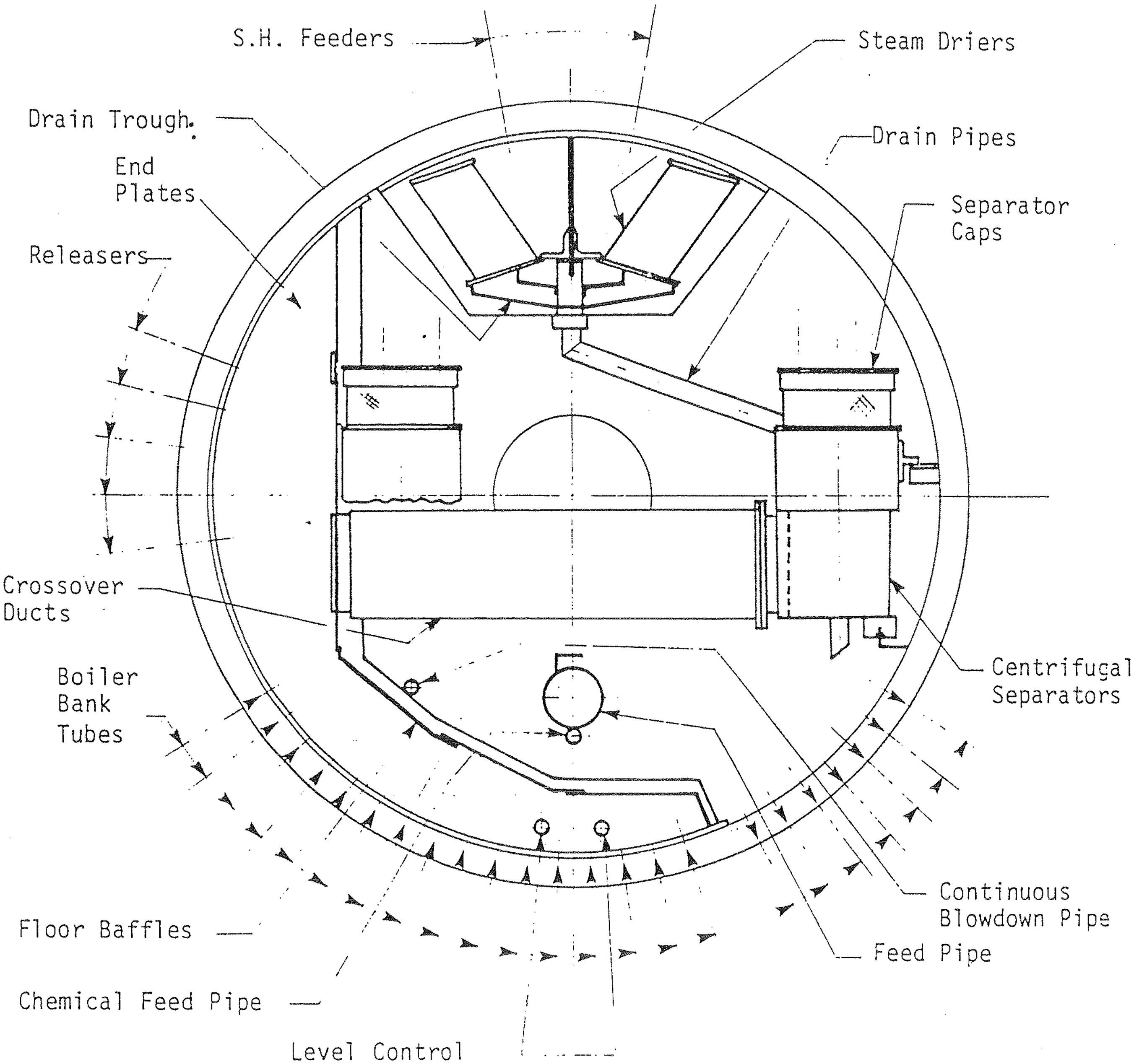


*Figure 10 "Sweet Water" Condenser Arrangement
ANG Company*

	LIQUID FUEL	COMBINATION OF FUELS Waste Gas Lock Gas Liquid Fuel
1. Steam Output #/hr	400,000	500,000
2. Steam Temperature °F	890	890
3. Gas Temp. Leaving Boiler Bank °F	697	860
4. Gas Temp. Leaving Economizer °F	413	535
5. Feedwater Temp. to Economizer °F	306	306
6. Feedwater Temp. Leaving Econ. °F	392	480
7. Boiler Efficiency %	89.15	78.93

Figure 11 Design Performance - ANG Company

STEAM DRUM INTERNALS
FOR 2 DRUM INDUSTRIAL BOILERS ABOVE 1000 PSIG
DOUBLE SIDED



NOTE:

Centrifugal separator requires use of 16" round doors.
Separator Skirts extend 1.5" below the normal water level.

Figure 12 Steam Drum Internals - ANG

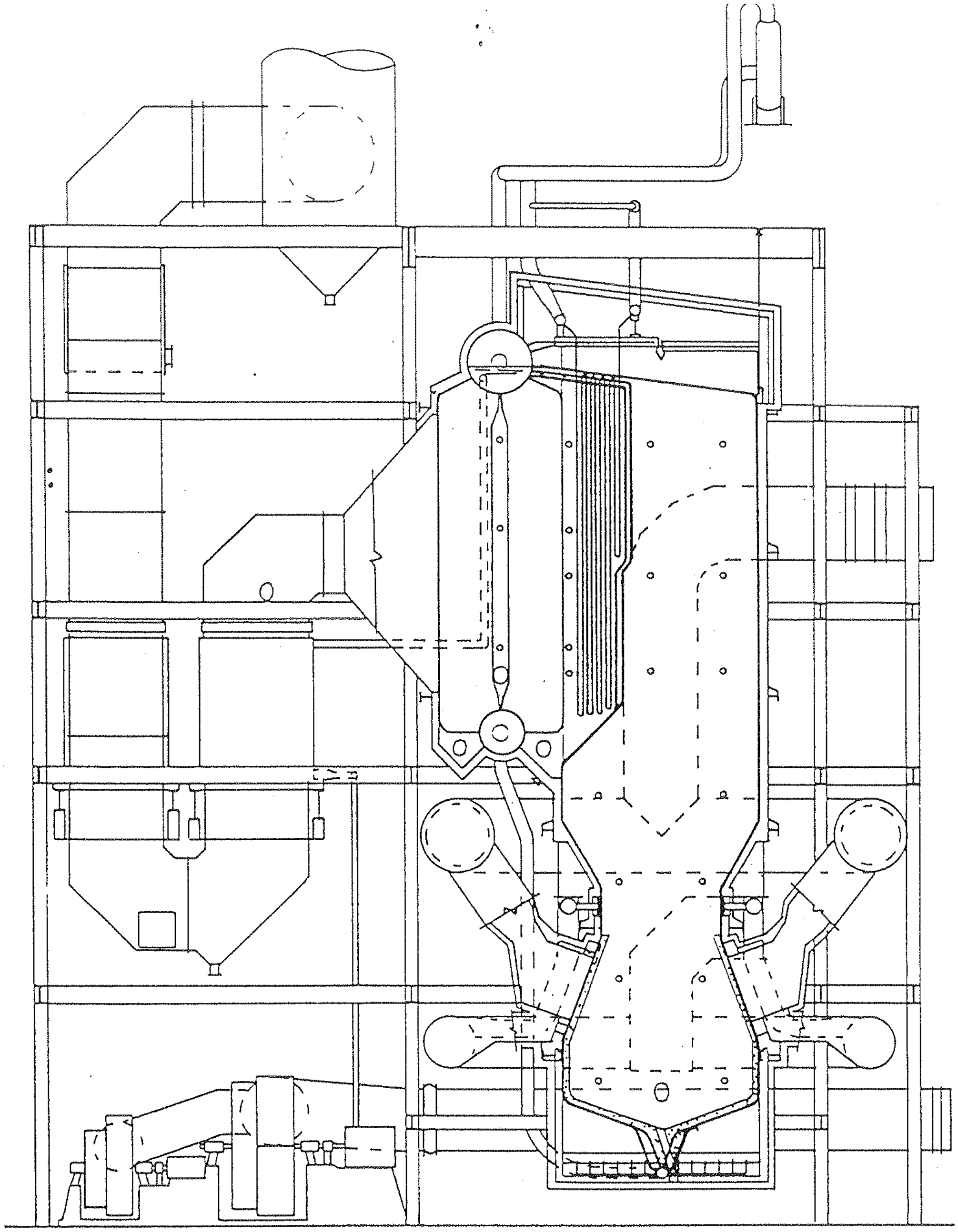


Figure 13 Exxon Company, Unit SG501C

REFINERY GAS % BY VOLUME	"CO" GAS	TURBINE EXHAUST GAS % BY VOLUME
CH_4 - 62.00	N_2 - 68.94	N_2 - 75.15
C_2H_6 - 2.00	H_2O - 13.51	H_2O - 6.75
C_3H_8 - 2.00	CO_2 - 9.46	CO_2 - 1.93
C_4H_{10} - 0.99	CO - 8.00	O - 16.17
CO - 3.00	O_2 - 0.09	Temperature - 800 °F
H_2 - 28.00	Temperature - 1350 °F	Sensible Heat - 187 Btu/lb
N_2 - 2.00	HHV - 344 Btu/lb	
H_2S - 0.01	Sensible Heat - 356 Btu/lb	
HHV - 22,935 Btu/lb	Total HHV - 700 Btu/lb	
HHV - 849 Btu/ft^3		

Figure 14 Design Fuels - Exxon Company

	WASTE FUEL	OIL	REFINERY GAS
1. Steam Output #hr	319,000	425,000	425,000
2. Steam Temperature °F	700	700	700
3. Gas Temperature Leaving Boiler Bank °F	665	675	670
4. Gas Temperature Leaving Economizer °F	335	290	295
5. Feedwater Temperature to Economizer °F	250	250	250
6. Feedwater Temperature Leaving Economizer °F	438	359	367
7. Boiler Efficiency %	85.38	88.05	83.89

Figure 15 Design Performance - Exxon Company

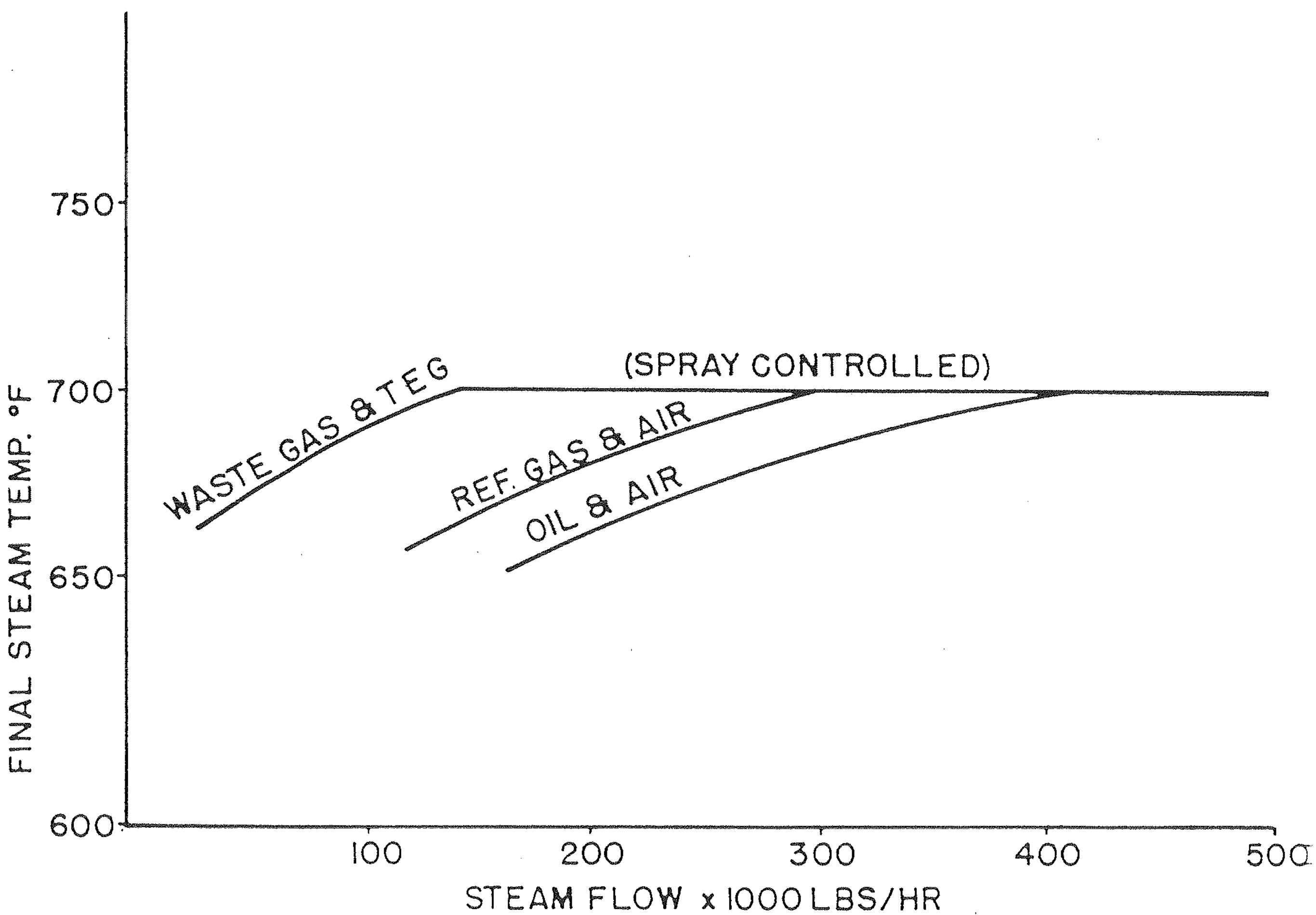


Figure 16 Final Steam Temperature Characteristics Exxon Company