Appendix C

Case 3

Steam Reforming of Natural Gas

CASE 3

The following report gives a brief description of each of the units in the block flow diagram. All capital cost data in this report, except where otherwise specified, have been estimated from similar installations described in the Houston Area Medium-BTU Coal Gasification Project Final Report, published in June 1982 by Union Carbide [1] (All references to material in this report will be referred to as Houston, and all scaling exponents from the Houston report are 0.65). The plant consumes 1.2 billion standard cubic meters of natural gas per year and produces 0.50 million metric tons of mixed alcohols per year.

SYNGAS PRODUCTION FROM NATURAL GAS

Compressed natural gas (stream 14) and steam (stream 15) are reacted in the Steam Reformation Block. The cooled output gas (stream 17) goes to the Rectisol Block. The cost for this unit was estimated from data found for a hydrogen production facility, with a scaling exponent of 0.8 [2]. The fuel gas usage for this block is estimated to be 30% of the natural gas feed.

RECTISOL

The cooled gas stream (stream 17), nitrogen gas (stream 19) for methanol regeneration, and methanol make-up (stream 20) for vapor loss all enter the Rectisol Block. CO_2 levels are reduced to the ppm range. The clean syngas (stream 22) is sent to the alcohol synthesis loop. A CO_2-N_2 mixture (stream 24) and a CO_2 rich stream (stream 23) are produced as byproducts. Condensed water is also removed (stream 17A). This block is the same as Houston Plant 05. The cost for this plant was estimated by using exponential scaling.

PRESSURE SWING ADSORPTION

The clean syngas (stream 22) is sent to PSA for selective hydrogen removal and purification. The adjusted syngas (stream 22AA), which leaves the PSA unit at 200 kPa, is compressed and then sent on to the reactor. The purified excess hydrogen is then split into two streams. One stream (27A) sent to the plant battery limits for sale, if possible.

MoS_2 ALCOHOL SYNTHESIS LOOP

Clean syngas (stream 26) at 140 atmospheres enters the catalytic reactor along with the syngas recycle (stream 56B). The products (stream 26A) are taken to the separations block where the unreacted syngas is removed (stream 59). Part of this stream (stream 27) is sent to power generation while the rest (stream 56) is sent to CO_2 removal. The cost of this block was estimated from the cost of a methanol synthesis loop, with a scaling exponent of 0.565 [3].

CO_2 REMOVAL

This block is very similar to the Rectisol Block. Recycled gas from the alcohol separation block (stream 56) is the only feed. CO_2 free syngas (stream 56A) is then recompressed and sent back to the reactor. CO_2 is taken off as a product (stream 57). The cost of this block is calculated the same way as in the Rectisol block. The power requirement for this unit is included in the Rectisol block.

COMBUSTION GAS TURBINE

The light hydrocarbons extracted from the reactor recycle (stream 27) in the Alcohol Synthesis Loop are sent to a combustion gas turbine with hot gas heat recovery. The power from the combustion gas turbines is assumed to be 35% of the HHV of the fuel in stream 27. This is consistent with recent studies on IGCC plants using medium BTU synthesis gas [5]. The cost for this block was estimated from data taken from an EPRI report, where each train can produce up to 200 MW with a scaling exponent of 0.67 [6].

EXHAUST GAS HEAT RECOVERY

The hot exhaust gas stream from the Gas Turbine Block (stream 70) at 590°C and 101 kPa enters the Exhaust Gas Heat Recovery Block and is cooled against process boiler feed water at 25°C (stream 73). The exhaust gas stream exits at 200°C (stream 75), and the boiler feed exits as steam at 10,000 kPa and 535°C (stream 74). The cost for this block was estimated from data taken from an EPRI report, where each train can generate up to 425 tons of steam per hour with a scaling exponent of 0.67 [6]. This block also supplies the reheat between the high pressure and intermediate pressure steam turbines.

POWER GENERATION

The steam from the Exhaust Gas Heat Recovery Block is let down in the steam turbines for power production. The cost for this block was estimated from data taken from an EPRI report, where each train can produce up to 500 MW with a scaling exponent of 0.67 [6]. This is a 3-stage steam turbine system. The high pressure stage inlet is 535°C, 10,000 kPa steam. The exhaust at 3,000 kPa is reheated to 535°C before entering the intermediate pressure stage. The final stage exhausts to a surface condenser at 7.4 kPa. Each turbine has an assumed efficiency of 75%.

TOTAL ESTIMATED CAPITAL INVESTMENT (MM$)

Pressure Swing Adsorption	15.1
Syngas Reforming	90.3
Rectisol	25.8
Gas Turbines	45.0
Steam Turbines	9.9
Exhaust Gas Heat Recovery	11.1
CO2 Removal	26.9
Other Compressors	57.5
Alcohol Synthesis Loop	47.2
TOTAL	328.8

(sum of individual block costs does not exactly equal the total due to round-off)

OVERALL ECONOMIC EVALUATION

The following table gives the totals and breakdowns for the yearly operating costs as well as the total installed cost for the plant, for Case 3A.

TOTAL ESTIMATED INSTALLED CAPITAL COST (MM$)		335.9
TOTAL ESTIMATED OPERATING COSTS (MM$/YR)		223.3
Natural Gas ($106/1000 cubic meters)	164.1	
Other Expenses	59.2	
TOTAL ESTIMATED CREDITS (EXCLUDING ALCOHOLS) (MM$/YR)		112.4
Hydrogen ($35.31/1000 cubic meters)	95.7	
Power ($0.05/kWh)	16.7	

The following table gives the totals and breakdowns for the yearly operating costs as well as the total installed cost for the plant, for Case 3B.

TOTAL ESTIMATED INSTALLED CAPITAL COST (MM$)		328.8
TOTAL ESTIMATED OPERATING COSTS (MM$/YR)		153.6
Natural Gas ($61.8/1000 cubic meters)	95.7	
Other Expenses	57.9	
TOTAL ESTIMATED CREDITS (EXCLUDING ALCOHOLS) (MM$/YR)		72.5
Hydrogen ($20.6/1000 cubic meters)	55.8	
Power ($0.05/kWh)	16.7	

Credits for nitrogen, argon, and other rare gases have not been included because prices were not available and potential markets have not yet been identified.

STAND ALONE COMPRESSORS AND POWER SUMMARY

There are 2 compressors that are not included in any of the blocks. Their inlet, outlet, pressure change, power rating, and installed capital cost are listed below. Following that is a summary of the total plant power output/input [4]. An efficiency of 70% is assumed for all compressors, with a maximum pressure ratio of 5 for a single stage of compression. Multiple compression stages with intercooling are used for services with pressure ratios greater than 5.

FUNCTION	INLET STREAM	P (kPa)	OUTLET STREAM	P (kPa)	POWER (MW)	COST (MM$)
Rxtr Prep	22AA	200	26	14000	-60.1	53.8
Recy Comp	56A	12666	56B	14000	-3.6	3.6
Total compressor needs					-63.6	
Other in plant needs					-1.4	
Total produced in steam and gas turbines					106.8	
Net power output					41.7	
Total installed compressor costs (1992 dollars)						57.5

REFERENCES

1. *Final Report on the Houston Area Medium-BTU Coal Gasification Project, Volumes 2 and 3.* Prepared by the Linde Division of Union Carbide Corporation, June 1982.

2. Baasel, William D., *Preliminary Chemical Engineering Plant Design, 2nd edition.* (Van Nostrand Reinhold, New York 1990), pp. 268-269.

3. Frank, "Methanol: Emerging Uses, New Syntheses," *Chemtech*, June 1982, pp. 358-362.

4. Baasel, pp. 529-530.

5. Report TR-101789, Houston Lighting and Power Company's Evaluation of Coal Gasification Coproduction Energy Facilities, EPRI Project 3226-04, 1992.

6. EPRI Report TR-100319, *Evaluation of a 510-MWe Destec GCC Power Plant Fueled With Illinois No. 6 Coal*, Prepared by Fluor Daniel, Inc., EPRI Project 2733-12, 1992.

Figure C.1 : Block Flow Diagram for Case 3

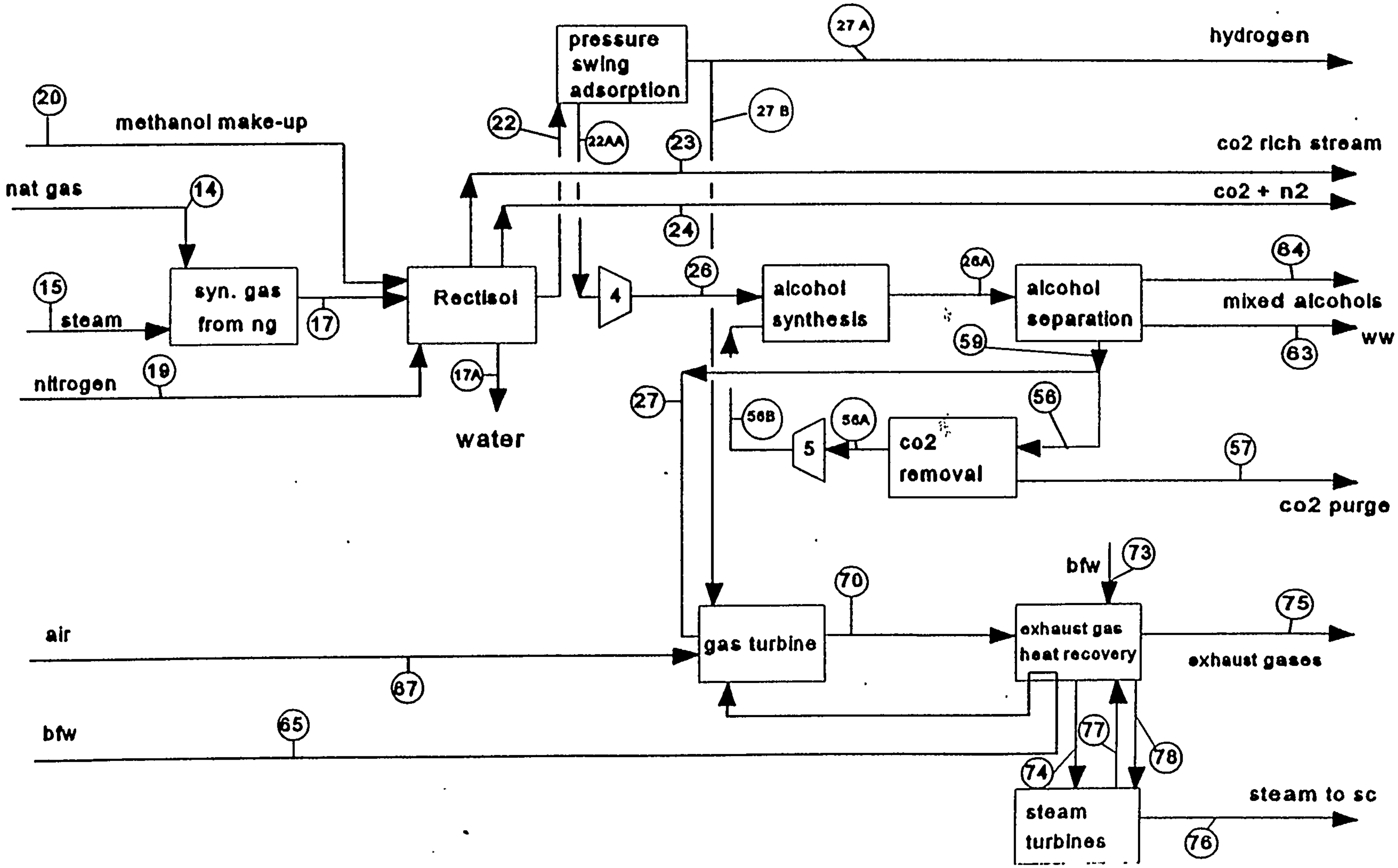

Table C.1 Case 3 Flow Table

	014	015	017	017A	019	020	022	022AA	023
Ar									
C									
CH3OH						0.6			
C2H5OH									
C3H7OH									
C4H9OH									
C5H11OH									
CO			5382.1				5382.1	5382.1	
CO2			1259.2						755.5
COS									
CaCO3									
H2			21183.2				21183.2	6057.1	
H2O		15708.1	7807.6	7807.6					
H2S									
N2					150.1				
NH3									
O2									
S									
Al2O3									
C3H6O2									
C4H8O2									
CH4	6646.5		5.2				5.2	5.2	
C2H6									
kmol/hr	6646.5	15708.1	35637.3	7807.6	150.1	0.6	26570.5	11444.4	755.5
kg/hr	106344.5	282745.6	389090.1	140536.0	4202.6	18.4	193148.7	162896.6	33243.2
Temp.(C)	25.0	300.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Press.(KPA)	1480.0	1480.0	1400.0	1400.0	1400.0	101.3	1400.0	200.0	1400.0

Table C.1 Case 3 Flow Table (cont'd)

	024	026	026A	027	27A	27B	056	056A	056B
Ar									
C									
CH3OH			628.3						
C2H5OH			655.4						
C3H7OH			145.0						
C4H9OH			36.5						
C5H11OH			15.2						
CO		5382.1	7001.9	714.2			6287.7	6287.7	6287.7
CO2	503.7		1493.7	152.4			1341.4		
COS									
CaCO3									
H2		6057.1	7880.0	803.8	15126.1		7076.3	7076.3	7076.3
H2O			140.1						
H2S									
N2	150.1								
NH3									
O2									
S									
Al2O3									
C3H6O2			18.0						
C4H8O2			11.9						
CH4		5.2	4375.8	446.3			3929.5	3929.5	3929.5
C2H6			171.6	17.5			154.1	154.1	154.1
kmol/hr	653.8	11444.4	22573.5	2134.1	15126.1		18788.9	17447.5	17447.5
kg/hr	26364.7	162896.6	420598.8	35975.2	30252.1		316722.5	257702.2	257702.2
Temp.(C)	25.0	240.0	310.0	25.0	25.0	25.0	25.0	25.0	45.0
Press.(KPA)	1400.0	14000.0	12666.0	12666.0	1400.0	1400.0	12666.0	12666.0	14000.0

Table C.1 Case 3 Flow Table (cont'd)

	057	059	063	064	065	067	070	073	074
Ar									
C									
CH3OH				628.3					
C2H5OH				655.4					
C3H7OH				145.0					
C4H9OH				36.5					
C5H11OH				15.2					
CO		7001.9							
CO2	1341.4	1493.7					1347.9		
COS									
CaCO3									
H2		7880.0							
H2O			140.1		955.8		2704.7	4298.2	4298.2
H2S									
N2						20181.9	20181.9		
NH3									
O2						5364.8	3651.9		
S									
Al2O3									
C3H6O2			18.0						
C4H8O2			11.9						
CH4		4375.8							
C2H6		171.6							
kmol/hr	1341.4	20923.0	170.1	1480.4	955.8	25546.7	27886.4	4298.2	4298.2
kg/hr	59020.4	352697.7	4905.1	62996.0	17204.2	736767.3	789946.7	77367.5	77367.5
Temp.(C)	25.0	25.0	25.0	25.0	25.0	25.0	590.0	25.0	535.0
Press.(KPA)	12666.0	12666.0	12666.0	12666.0	10000.0	101.3	101.3	10000.0	10000.0

Table C.1 Case 3 Flow Table (cont'd)

	075	076	077	078
Ar				
C				
CH3OH				
C2H5OH				
C3H7OH				
C4H9OH				
C5H11OH				
CO				
CO2	1347.9			
COS				
CaCO3				
H2				
H2O	2704.7	4298.2	4298.2	4298.2
H2S				
N2	20181.9			
NH3				
O2	3651.9			
S				
Al2O3				
C3H6O2				
C4H8O2				
CH4				
C2H6				
kmol/hr	27886.4	4298.2	4298.2	4298.2
kg/hr	789946.7	77367.5	77367.5	77367.5
Temp.(C)	200.0	40.0	380.0	535.0
Press.(KPA)	101.3	7.4	3000.0	3000.0

Table C.2 Case 3 Energy Analysis

ELECTRICITY		
Plant	Electricity Used (MW)	Electricity Produced (MW)
Rectisol Plant	1.4	0
Gas Turbine	0	80.7
Steam Turbine	0	26.1
Compressor 4	60.1	0
Compressor 5	3.6	0
Total	65.1	106.8