Section 4

MATERIAL AND ENERGY BALANCES

CASE HE - H-COAL LIQUEFACTION PROCESS, ILLINOIS COAL

Overall Material Summary and Product Inspection

Table 4-1 presents a tabulation of the feed and product streams for the H-Coal liquefaction plant, Illinois Coal Case. The major products consist of gasoline, turbine fuel, distillate fuel oil, and liquid propane and butane. The gasoline blend is prepared by splitting the light naphtha from the raw naphtha, hydrotreating and reforming the bottoms, and blending the light naphtha and reformate. The turbine fuel is upgraded by hydrotreating but the distillate fuel oil requires no further treatment to meet fuel grade specifications.

Table 4-2, Product Inspection, shows typical properties of the gasoline blend and fuels. These properties were formulated from specifications of liquid fuel products furnished by EPRI and from H-Coal product characterization data reported by HRI.

Thermal Efficiency - Case HE

The overall thermal efficiency of the coal liquefaction process is defined as the sum of the higher heating values of the products and by-products divided by the higher heating value of total coal to the plant. The overall thermal efficiency for the H-Coal process using Illinois No. 6 coal is 71.9 percent (HHV).

Thermal efficiency calculations are shown in Table 4-3.

Heating values of gasoline, turbine fuel, and distillate fuel oil were derived from HRI data for the H-Coal process. Heating values for LPG and by-products were obtained from published tables.

Energy Balance - Case HE

Table 4-4 presents an overall energy balance for the H-Coal liquefaction process, Illinois case.

The energy content of streams entering and leaving the plant boundary is expressed as the sum of the following:

- The stream's higher heating value
- Sensible heat above 60°F
- Latent heat of water @ 60°F

The electrical energy required to run conveyors, pumps, and air fans and the power loss in compressors are expressed as 3,413 Btu/kWh. The heat energy which is transferred to pumped liquids has not been considered.

Miscellaneous losses account for about 1 percent of the total energy input. They result from approximations used for calculating various heat loads.

Table 4-1

FEED AND PRODUCT SUMMARY
H-COAL CASE HE

Feed Streams	st/sd	lb/hr
As Received Coal (Illinois No. 6)	21,891	1,824,243
Oxygen (as 100% O_2)	4,918	409,825
Raw Water	55,176	4,598,000
Product Streams		
Hydrocarbons	**bbl/sd[a]**	**lb/hr**
Gasoline Blend	16,010	184,779
Turbine Fuel	27,393	364,400
Distillate Fuel Oil	6,880	107,581
Propane	7,175	52,857
Butane	4,658	39,937
Non-Hydrocarbons	**st/sd**	**lb/hr**
Ammonia	222	18,498
Phenols	50	4,206
Sulfur	664	55,340
Other	**st/sd**	**lb/hr**
Slag, Ash, Soot to Disposal (MF)	2,253	187,756
Fuel Gas to Internal Use	1,872.6	156,054

[a] Gasoline and heavier fuels = 50,283 bbl/sd (actual) or 50,031 FOE bbl/sd.

Table 4-2

PRODUCT INSPECTION
H-COAL (ILLINOIS) - CASE HE
(ESTIMATED)

	Gravity		Analysis		Wt%	R.O.N.
	API	Sp.G.	S	N	H	Clear
Gasoline Blend[c]						
Light Naphtha	77.0	0.6787	-	-	-	75.0
Reformate	37.3	0.8383	[a]	[a]	10.74[b]	98.0
Total Gasoline	47.0	0.7927	-	-	-	91.0
Turbine Fuel	23.5	0.9129	0.01	0.1	10.70	-
Distillate Fuel Oil	0.4	1.073	0.08	0.7	7.93	-

[a] Less than 1 ppm (wt)

[b] Ref: Upgrading Coal Liquids, FE-2566-12, March 1978, Table 11, Period 5

[c] Light Naphtha 4,650 bbl/sd, Reformate 11,360 bbl/sd

Table 4-3

THERMAL EFFICIENCY CALCULATION
H-COAL - CASE HE

Heat Input	Flow Rate lb/hr	Heat of Combustion Btu/lb (HHV)	Total Heat 10^6 Btu/hr (HHV)	Efficiency Percent
Coal, Illinois No. 6 (MF)	1,605,344	12,669.5	20,339	100.00
Heat Output, Fuel				
Gasoline Blend	184,779	19,372	3,580	17.60
Turbine Fuel	364,400	18,482	6,735	33.11
Distillate Fuel Fuel	107,581	17,479	1,880	9.24
Propane	52,857	21,505	1,137	5.59
Butane	39.937	21,107	843	4.15
Sub-Total			14,175	69.69
Heat Output, By-Products				
Ammonia (liquid)	18,498	9,152	169	0.83
Phenol	4,206	13,997	59	0.29
Sulfur	55,340	3,990	221	1.09
Sub-Total			449	2.21
Total Output			14,624	71.90

Table 4-4

OVERALL ENERGY BALANCE
CASE HE
Basis: 60°F, water as liquid, 3413 Btu/kWh

	10^6 Btu/hr	Percent
Heat In		
Coal, HHV	20,339	
Sensible Heat Coal, Air, Water	92	
Input Total	20,431	100.00
Heat Out		
H-Coal Liquids, HHV	14,175	
By-Products, HHV	449	
Sensible Heat in Products & By-Products	30	
Power Export	0	
Products & By-Products Subtotal	14,654	71.7
Cooling Duties (Air & Water)	3,314	16.2
Energy Losses		
Flue Gas & Water Vapor From Coal Drying	378	
Flue Gas From Power Generation Section	423	
Flue Gases From Process Furnaces	297	
Vent Gases	269	
Solid Waste	46	
Power Block Loss	48	
Power Loss (Motors)	52	
Power Consumed (Pumps, Lighting, etc.)	305	
Heat Loss to Atmosphere	408	
Miscellaneous	237	
Losses Subtotal	2,463	12.1
Output Total	20,431	100.0

CASE HW - H-COAL LIQUEFACTION PROCESS, WYODAK COAL

Overall Material Summary and Product Inspection

Table 4-5 presents a tabulation of the feed and product streams for the H-Coal liquefaction plant, Wyodak coal case. The major products consist of gasoline, turbine fuel, and distillate fuel oil. The gasoline blend is prepared by splitting the light naphtha from the raw naphtha, hydrotreating and reforming the bottoms, and blending the light naphtha and reformate. The turbine fuel is upgraded by hydrotreating but the distillate fuel oil requires no further treatment to meet fuel grade specifications.

Table 4-6, Product Inspection, shows typical properties of the gasoline blend and fuels. These properties were derived from specifications of liquid fuel products furnished by EPRI and from H-Coal product characterization data reported by HRI.

Thermal Efficiency - Case HW

The overall thermal efficiency for the H-Coal process using Wyodak coal is 60.9 percent (HHV). Thermal efficiency calculations are shown in Table 4-7. Excess power produced from excess fuel is credited at 3,413 Btu/kWh.

Heating values of gasoline, turbine fuel, and distillate fuel oil were derived from HRI data for the H-Coal process. Heating values for by-products were obtained from published tables.

Energy Balance - Case HW

Table 4-8 presents an overall energy balance for the H-Coal liquefaction process, Wyodak case.

The energy content of streams entering and leaving the plant boundary is expressed as the sum of the following:

- The stream's higher heating value
- Sensible heat above 60°F
- Latent heat of water @ 60°F

Export power, electrical energy required to run conveyors, pumps, and air fans, and power loss in compressors are expressed as 3,413 Btu/kWh. The heat energy, which is transferred to pumped liquids, has not been considered.

Miscellaneous losses account for about 1 percent of the total energy input. They result from approximations used for calculating various heat loads.

Table 4-5

FEED AND PRODUCT SUMMARY
H-COAL - CASE HW

Feed Streams	st/sd	lb/hr
As Received Coal (Wyodak)	30,960	2,580,000
Oxygen (as 100% O_2)	5,138	428,142
Raw Water	51,834	4,319,500
Product Streams		
Hydrocarbons	**bbl/sd[a]**	**lb/hr**
Gasoline Blend	21,772	257,355
Turbine Fuel	25,880	327,579
Distillate Fuel Oil	3,743	58,327
Non-Hydrocarbons	**st/sd**	**lb/hr**
Ammonia	162	13,476
Phenols	24	2,000
Sulfur	194	16,161
Other	**st/sd**	**lb/hr**
Slag, Ash, Soot to Disposal (MF)	1,716	143,025
Fuel Gas to Internal Use	3,332	277,629

[a] Gasoline and heavier fuels = 51,395 bbl/sd (actual) or 50,396 FOE bbl/sd.

Table 4-6

PRODUCT INSPECTION
H-COAL (WYODAK) - CASE HW
(ESTIMATED)

	Gravity		Analysis		Wt%	R.O.N.
	API	Sp.G.	S	N	H	Clear
Gasoline Blend[c]						
Light Naphtha	73.7	0.6787	-[a]	-[a]	-	75.0
Reformate	37.3	0.8383			10.74[b]	98.0
Total Gasoline	43.1	0.8104	-	-	-	94.0
Turbine Fuel	31.1	0.8702	0.01	0.10	12.50	-
Distillate Fuel Oil	0.9	1.061	0.03	0.46	9.41	-

[a] Less than 1 ppm (wt)

[b] Ref: Upgrading Coal Liquids, FE-2566-12, March 1978, Table 11, Period 5

[c] Light Naphtha 3,982 bbl/sd, Reformate 17,790 bbl/sd

Table 4-7

THERMAL EFFICIENCY CALCULATION
H-COAL - CASE HW

Heat Input	Flow Rate lb/hr	Heat of Combustion Btu/lb (HHV)	Total Heat 10^6 Btu/hr (HHV)	Efficiency Percent
Coal, Wyodak (MF)	1,805,999	11,420.6	20,626	100.00
Heat Output, Fuel				
Gasoline Blend	257,335	19,609	5,046	24.46
Turbine Fuel	327,579	18,958	6,210	30.11
Distillate Fuel Oil	58,327	17,620	1,028	4.98
Sub-Total			12,284	59.55
Heat Output, By-Products				
Ammonia (liquid)	13,476	9,152	123	0.60
Phenols	2,000	13,997	28	0.14
Sulfur	16,161	3,990	64	0.31
Sub-Total			215	1.05
Power Export	18,572[a]	3,413[b]	63	0.30
Total Output			12,562	60.90

[a] kW

[b] Btu/kWh

Table 4-8

OVERALL ENERGY BALANCE
CASE HW
Basis: 60°F, water as liquid, 3413 Btu/kWh

	10^6 Btu/hr	Percent
Heat In		
Coal, HHV	20,626	
Sensible Heat Coal, Air, Water	102	
Input Total	20,728	100.00
Heat Out		
H-Coal Liquids, HHV	12,284	
By-Products, HHV	215	
Sensible Heat in Products & By-Products	54	
Power Export	63	
Products & By-Products Subtotal	12,616	60.9
Cooling Duties (Air & Water)	4,226	20.4
Energy Losses		
Flue Gas & Water Vapor From Coal Drying	1,051	
Flue Gas From Power Generation Section	571	
Flue Gases From Process Furnaces	673	
Vent Gases	145	
Solid Waste	53	
Power Block Loss	61	
Power Loss (Motors)	65	
Power Consumed (Pumps, Lighting, etc.)	629	
Heat Loss to Atmosphere	414	
Miscellaneous	224	
Losses Subtotal	3,886	18.7
Output Total	20,728	100.00

CASE CM - COAL TO METHANOL, ILLINOIS COAL

Overall Material Summary and Product Inspection

Table 4-9 presents a tabulation of the feed and product streams for the coal to methanol plant based on Illinois No. 6 coal as feedstock. The plant produces fuel grade methanol (98+ weight percent) as the principal product and sulfur flakes as a by-product.

No coal fired boilers and superheaters are used in this design; all the coal feed goes to the gasifiers. Nine oxygen plants at a capacity of approximately 2400 tons per day each are required to satisfy the gasifier needs.

Table 4-10 presents a typical analysis for fuel grade methanol.

Thermal Efficiency

The overall thermal efficiency for the coal to methanol plant using Illinois No. 6 coal is 55.0 percent on an HHV basis as shown in Table 4-11. Heating values for product and by-product streams are taken from published data.

Energy Balance

Table 4-12 presents an overall energy balance for the coal to methanol process.

The energy content of streams entering and leaving the plant boundary is expressed as the sum of the following:

- The stream's higher heating value
- Sensible heat above 60°F
- Latent heat of water @ 60°F

Export power, electrical energy required to run conveyors, pumps, and air fans, and power loss in compressors are expressed as 3,413 Btu/kWh. The heat energy, which is transferred to pumped liquids, has not been considered.

Table 4-9

FEED AND PRODUCT SUMMARY
COAL TO METHANOL - CASE CM

Feed Streams	st/sd
As Received Coal (Illinois No. 6)	25,418
Oxygen (as 100% O_2)	21,454
Raw Water	99,744
Product Streams	
Methanol as 98.29% (wt)	15,919[a]
Sulfur	768
Slag, Ash, Soot to Disposal (MF)	2,648
Fuel Gas to Internal Use	2,306

[a] Methanol fuel = 111,870 bbl/sd (actual) or 52,209 FOE bbl/sd.

Table 4-10

METHANOL PRODUCT ANALYSIS
COAL TO METHANOL - CASE CM

Component	
Low Boilers, % (wt)	0.10 - 0.12
High Boilers, % (wt)	0.05 - 0.08
Water, % (wt)	1.71
Methanol, % (wt)[a]	98.29
Specific Gravity @ 60°F	0.813
Higher Heating Value (HHV) Btu/lb	9,593

[a] Including high and low boilers.

Table 4-11

THERMAL EFFICIENCY CALCULATION
COAL TO METHANOL - CASE CM

Heat Input	Flow Rate lb/hr	Heat of Combustion Btu/lb (HHV)	Total Heat 10^6 Btu/hr (HHV)	Efficiency Percent
Coal (MF)	1,864,000	12,669.5	23,616	100.00
Heat Output				
Methanol	1,326,594	9,593.0	12,726	53.9
Sulfur	64,000	3,990.0	255	1.1
Total Output			12,981	55.0

Table 4-12

ENERGY BALANCE - COAL TO METHANOL
CASE CM

Basis: 60°F, water as liquid, 3413 Btu/kWh, 1 lb MF Coal @ 60°F

	HHV	Sensible	Latent	Radiation	Power	Total
Heat In (Btu)						
Coal[a]	12,669.5					12,669.5
Air[b]		35.3	82.6			117.9
Water						0.0
TOTAL	12,669.5	35.3	82.6	0	0	12,787.4
Heat Out (Btu)						
Methanol	6,827.2	17.1				6,844.3
Sulfur	136.8	3.5				140.3
Air Cooling		621.2				621.2
Cooling Tower			4,152.4			4,152.4
Gasifier Loss				363.7		363.7
O_2 Plant Waste Gas		28.0	72.3			100.3
Sulfur Plant Flue Gas		14.4	6.5			20.9
Power Block Loss					31.9	31.9
Superheater Loss		54.0	108.6	13.4		176.0
Steam Loss				120.7		120.7
Motor Loss					96.4	96.4
Waste Water	5.0	29.0				34.0
CO_2 Vent	72.5	12.8				85.3
TOTAL	7,041.5	780.0	4,339.8	497.8	128.3	12,787.4

[a] Total MF coal = 1,863,965 lb/hr.

[b] Air input @ 88°F, 14.4 psia, and 75°F wet bulb.