4 OPTIMIZATION OF REFINERY CONFIGURATIONS

The initial study effort focused on evaluation of potential processing configurations for MOIN refinery modernization in Costa Rica.

The configurations definition is described in section 3. A linear programming (LP) model is used to evaluate and compare each of the configurations. For each potential configuration, a distinct LP model is assembled and used to evaluate and compare each of the configurations defined. The models include ISBL investment costs for all of the new refinery processes that might be stated in each configuration. The models also include investment costs for the utility systems that are determined to be required, as well as an estimate of tank cost requirements.

The LP model is mathematically driven to maximize profits and minimize costs, utilizing prices of feeds and products, investment costs, and any other cost defined in the model to calculate the optimum solution. The model is constrained only by limitations on the available quantity of feeds, product minimum and/or maximum production requirements, product specifications, and process system capacity limitations that may be imposed.

Crude assay data, feed and product definition, feed and product prices and product specifications used in the LP model are as defined in Section3. The following sections present the basis for the development of the LP model, the results of the initial refinery configuration analysis, and finally the results of the optimization effort associated with four configurations preferred by SERESCO.

4.1 Basis for LP Model Development (Initial Configuration Analysis)

As noted in the preceding section, crude and product prices, assay data, and product specification utilized in the preparation of the LP model were defined in Section 4 of the report. Additional factors used in establishing the LP model are as follows:

4.1.1 Miscellaneous

Besides the need to input feed and product prices, assay data, and other design basis data as described in Section 3, Table 4.1-1 summarizes other miscellaneous data used in the LP model.

Table4.1-1 Miscellaneous Data Used In LP Model

Feed and Product Pricing Basis Year	2015
LP Model Platform	RPMS
Model Basis (Volume or Weight)	Weight (Process Unit Yields)
Stream Day Factor	8400 hours/year for all processes unit(350days/a)
Feed Purchase Basis (Volume or Weight)	Volume
Product Sale Basis (Volume or Weight)	Volume/Weight
Feed / Product Volume Units	Barrels per Day
Product Weight Units	Metric Tons per Year
Utilities Reporting Basis	Units/h (e.g., Power = KW-HR/h)
Process Unit Capacities Units	Metric Tons per Year except as indicated

4.1.2 Process Units

Table 4.1-2 summarizes the refinery process units that are included in the LP model. Although, all of these units are included in the LP model, the solutions for each case may exclude certain process units. The table also provides a summary of the alternate operating modes (if required) that were incorporated into the LP Model. The technical information used in the LP model are from HQCEC design experience database and some operational databases from CNPC and Sinopec, two of the largest refining companies in China with top world refining capacity.

Table4.1-2 Refinery Processes Included In LP Model

Refinery Process	Notes
Crude Unit	New and existing crude units are included in the model. The crude unit can process 60,000 BPD of crude. Crude slates can range from sweet crude to sour crude, from heavy crude to medium, including one kind of crude with higher TAN.
Vacuum Unit	One vacuum unit, processing all crude unit bottoms, is included in the model.
Saturates Gas Plant	Modeled as a single unit SGP, processing all saturated gas and wild naphtha from most of the processes producing saturated gases.
Gas/LPG Desulphurization	Sweetening units (and corresponding investments) are included for saturate LPG, unsaturated LPG.

Refinery Process	Notes
Naphtha Hydrotreater	Unit processes full range straight run naphtha from the crude unit as well as coker naphtha and naphtha from other processes when applicable. This unit includes a naphtha splitter.
CCR Reformer	Unit processes heavy refined naphtha from NHT and/or heavy HCU naphtha from the hydrocracker. This unit is designed to produce 102 RON reformate and used to produce 98 RON reformate for reducing aromatics content in gasoline pool. A C_6 fraction hydro-treater is included for reducing benzene content.
C_5/C_6 Isomerization	Once through C_5/C_6 isomerization unit producing C_5/C_6 isomerate.
FCC	Defined as a FCC unit Processes VGO MHC bottoms. The unit operates in a maximum gasoline and LPG mode. FCC feed sulfur content initially is limited to 500 wppm to eliminate the need for a wet gas scrubber and a FCC gasoline post-treater. Unsaturated gas is processed in FCC unit.
Distillate Hydrotreater (or Mild hydrocracking)	Processes straight-run distillates from the crude units, naphtha and LCGO from the coker, LCO from the FCC/RFCC unit and diesel from the LC-Fining unit. Distillate MHC is used to upgrade the cetane number of diesel and main property of Jet in some cases.
VGO Hydrocracker/Mild hydrocracker	Processes VGO from the vacuum units and CGO from the coker. The hydrocracker with conversion levels of 98% has yield pattern that maximizes diesel and Jet. VGO MHC will supply FCC feed for clean production and good feed.
Delayed Coker	Processes vaccum residue from the vacuum units; including a gas plant for recovery of coker offgas, LPG and coker naphtha.
Flexi-coking	Like the combination of delayed coker and RFCC catalyst continuous regeneration section to produce syngas with low BTU and avoid solid coke
LC-Fining(Vacuum Residue Hydrocracker)	Ebullated bed residue hydrocracker processes vacuum residue and slurry oil diluents. The naphtha and distillate products are hydro-treated in their respective hydro-treaters. VGO is processed in the FCC unit or hydro-cracking and then processed in the FCC. VRHC bottoms are blended into fuel oil.
Hydrogen Purification	Pressure swing adsorption unit (PSA) processing hydrogen rich purge gas from hydro processing units producing high purity (>99.9%) hydrogen.
Sulfur Recovery Complex Including: Amine Regeneration Unit Sour Water Stripping	Modeled as a single unit in the LP. In reality, two SWS and amine trains will be included in the refinery: One for the hydro-processing units and one for other processing units. Includes a tail gas treating unit. The unit consumes a small quantity of H2.
Hydrogen Generation	This option is based on processing refinery fuel gas or saturated LPG or possible naphtha in a conventional steam reforming plant. The plant is designed to produce high purity hydrogen (99.9% min. by volume).

4.1.3 Utility/Offsite Systems

Table 4.1-3 summarizes the utility and offsite systems that are included in the LP model.

Table4.1-3 Utility and Offsite Systems in LP Model

Utility or Offsite System	NOTES
Power Supply	The power is from local national grid.
Steam Generation	In addition to process steam generation, a steam system using fuel oil/fuel gas will be considered
Cooling Water System	A new circulation system will be included and capability will be consider of consumption of existing units and new unit.
Condensate Recovery	New condensate recovery systems modeled with steam system
Waste Water Treatment	A new waste water treatment plant was modeled as a single unit. The capacity considered of discharge to existing units and new units
Tank Farm	Capacity Considered supporting the crude oil process capacity

The LP model includes refinery fuel gas and refinery fuel oil pools to satisfy the internal energy requirements of the refinery and utility systems. The LP model identifies the process units that consume refinery fuel oil and the process units that can only consume refinery fuel gas. The utility consumption and production table in the LP model gives an outline of the fuel type and disposition in detail.

The LP model also identifies tank requirements for all feed and product streams. The days of storage requirement are input into the LP model. Intermediate tanks are excluded in the LP model, but are included during the detailed project definition phase.

4.1.4 Investment Costs

As a preliminary cost investment, investment costs are calculated in the LP model for the new process units and utility systems using scale factor based on reference investment of similar unit according to the following formula:

$$\text{Investment Cost} = \text{Reference cost} \left(\text{New Capacity} / \text{Reference Capacity}\right)^{\text{scale factor}}$$

Reference investment costs are capital costs of the existing and similar unit. Scale factor vary depending on the vary unit, but are typically 0.65 – 0.8. Initial catalyst filling is also included in unit investment. The investment costs for those systems that were not specifically identified in the LP model (e.g. interconnecting piping, firefighting system, waster water treatment system, flares, buildings, warehouses, spare parts, auxiliary facilities, intermediate tank yard, etc.) were represented separately in the model, all-in cost defined as “other” within the LP model. This all-in cost was assumed to be around 60-80% of the calculated investment cost. The investment of each case is shown in the Tables of Preliminary Investment and

Economic Analysis.

4.1.5 Financial Analysis

In financial analysis, sales revenue and cost have been calculated to obtain the net profit and cash flow. The Internal Return Rate (IRR) and the Net Present Value (NPV) have been calculated using cash flow analysis, and the NPV has been determined at a discount rate of 12%

4.2 Initial Optimization Study Results (20 Configurations evaluated)

This section presents the results of the initial optimization screening analysis. The purpose of this analysis was to evaluate each of the refinery configurations defined based on result of market research and crude oil recommended by SORESCO, five crudes and about 4 types of configurations will be evaluated in the initial screening process. All 20 cases are shown in Table 4.2-1.

Table4.2-1 Process Configuration Case List

CASE	Crude Slate	Configuration
CASE1	MESA	Coker+MHC/FCC
CASE2	VASCONIA	Coker+MHC/FCC
CASE3	MARLIM LIGHT	Coker+MHC/FCC
CASE4	CASTILLA	Coker+MHC/FCC
CASE5	1/3PENNINGTON and 2/3VASCONIA	Coker+MHC/FCC
CASE6	MESA	Coker+HCU
CASE7	VASCONIA	Coker+HCU
CASE8	MARLIM LIGHT	Coker+HCU
CASE9	CASTILLA	Coker+HCU
CASE10	1/3PENNINGTON and 2/3VASCONIA	Coker+HCU
CASE11	MESA	Flexi-Coking +HCU
CASE12	VASCONIA	Flexi-Coking +HCU
CASE13	MARLIM LIGHT	Flexi-Coking +HCU
CASE14	CASTILLA	Flexi-Coking +HCU
CASE15	MESA	LC-fining +HCU
CASE16	VASCONIA	LC-fining +HCU
CASE17	MARLIM LIGHT	LC-fining +HCU
CASE18	CASTILLA	LC-fining +HCU
CASE19	PENNINGTON	RFCC(AR as feed)
CASE20	MESA	VISBREAKING

In Case 19, only PENNINGTON crude with low sulfur and metal content is used and its crude distillation bottom can be directly converted into light fuel by residue fluid catalytic cracking. Its process configuration is very short and its economic return is very good, but sweet crude resource is limited and the price is comparatively higher in the world market; it is also produced in Nigeria which is far from Coast Rica. At the same time, sour crude production is increasing, so we hope to balance the economic return, investment, environmental protection, crude resource and price. Especially since the existing refinery has been in operation for many years and some equipments may need to be replaced. Above all, we suggest using PENNINGTON crude to meet existing refinery needs with limited revamp along with sour crude for new expansion in our study.

In Case 20, the vacuum bottom is used to produce some fuel oil with low price by visbreaking. The light oil produced is not enough for the local market supply.

4.2.1 Case A (COKER + HCU) Configuration / Analysis

Case A's configuration analysis was based on using a coker and hydro-cracking unit with high conversion. This operation level produces enough Jet and diesel with good quality for local market demand. A block flow diagram showing the results of Case A configuration analysis is provided in Figure 4.2.1. The configuration comparisons of 4 crudes are listed in Table 4.2-2 and Table 4.2-3.

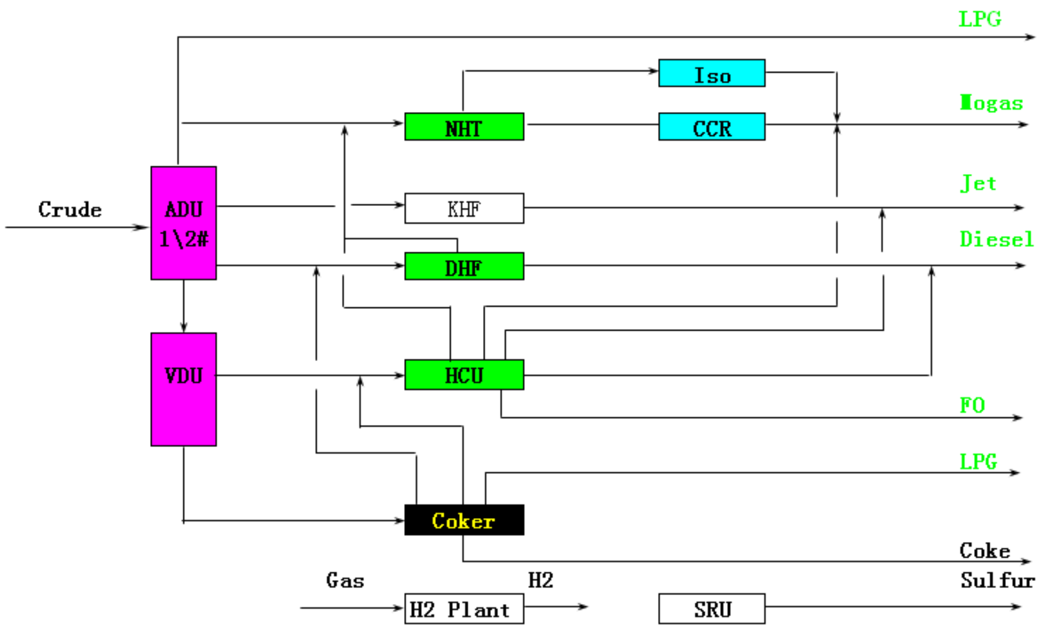

Figure 4.2.1Case A Block Flow Diagram

4.2.1.1 Process Units Capacity Comparison

Table4.2-2 Process units and capacity of Case A Unit:kt/a

No	Process Unit	Case6	Case7	Case8	Case9	Case10	Notes
1	1#ADU	1200	1200	1200	1200	1200	Existing
2	1#VDU	100	100	100	100	100	Existing
3	Visbreaking	230	230	230	230	230	Existing
4	KHF	140	140	140	140	140	Existing
5	Reformer	60	60	60	60	60	Existing
6	2#ADU	2000	2000	3000	2100	2000	New
7	2#VDU	1500	1800	2000	2150	1500	New
8	Coker	700	900	1000	1100	700	New
9	HCU	900	1100	1200	1200	900	New
10	NHT	550	450	400	450	500	New
11	DHT	1200	1200	1250	800	1300	New
12	CCR reformer	500	500	450	500	500	New
13	H_2 Plant	25	25	30	30	25	New
14	SRU Complex	25	25	20	40	20	New
15	Gas/LPG Desulphurization	80/70	90/70	90/80	100/90	80/40	New
16	Isomerization	150	120	110	120	140	New

4.2.1.2 Overall Material Balance Comparison

Table4.2-3 Comparison of overall material balance for Case A Unit:kt/a

No.	Name	COKE+HCU				
		Case6	Case7	Case8	Case9	Case10
1	**Feed structure**					
1.1	MESA 30	2953.00				
1.2	VASCONIA		3054.00			2010.00
1.3	PENNINGTON					948.00
1.4	MARLIN LIGHT			3049.00		
1.5	CASTILLA				3137.00	
1.6	ETHANOL	77.43	69.99	67.67	69.91	73.69
1.7	Purchase fuel	99.16	109.39	119.57	114.42	97.12
	Subtotal	3129.60	3233.38	3236.23	3321.34	3128.81
2	**Product structure**					

No.	Name	COKE+HCU				
		Case6	Case7	Case8	Case9	Case10
2.1	Gasoline	750.75	671.56	651.02	671.13	714.14
2.2	Kerosene	327.90	368.46	285.57	398.88	340.74
2.3	Diesel	1525.65	1576.86	1711.21	1327.40	1588.37
2.4	LPG	79.85	90.00	87.24	100.11	71.86
2.5	Coke	210.10	268.66	240.21	536.45	187.97
2.6	Sulfur	24.35	23.37	18.80	37.85	16.21
2.7	Refinery fuel	116.90	134.24	147.54	144.10	116.42
2.8	Refinery gas	51.53	44.48	38.29	42.19	52.07
2.9	Loss	42.58	55.75	56.35	63.23	41.03
2.10	Subtotal	3129.59	3233.38	3236.23	3321.34	3128.81

4.2.1.3 Preliminary Investment and Economic Analysis Comparison

Table4.2-4 Preliminary investment and economic analysis for Case A   Unit:kUS$

No.	Name	COKER+HCU				
		Case6	Case7	Case8	Case9	Case10
1	Investment					
1.1	Revamp Investment	11090	11090	3370	11090	11090
1.2	2#CDU	49050	49050	84805	51002	49050
1.3	2#VDU	31170	36065	49045	41573	31170
1.4	Delayed coking	134780	164794	179286	193491	134780
1.5	Hydro-cracking	115230	135296	145050	145050	115230
1.6	NHT	11827	10277	9464	10277	11064
1.7	DHT	81642	81642	84009	61468	86347
1.8	CCR Reformer	132985	132985	123530	132985	132985
1.9	H_2 Plant	57770	57770	65634	65634	57770
1.10	Gas/LPG Desulfurization	6710	7066	7417	8107	5613
1.11	Sulfur complex	45963	45963	38449	66943	38449
1.12	Isomerization	29198	24976	23500	24976	27821
1.13	Subtotal	707416	756974	813558	812597	701369
1.14	Other	565932	605579	650847	650077	561095
1.15	Construction Investment	1273348	1362552	1464405	1462674	1262464
1.16	Working Capital	250925	240006	241648	237491	244576

No.	Name	COKER+HCU				
		Case6	Case7	Case8	Case9	Case10
1.17	Interest during construction period	89134	95379	102508	102387	88373
	Total Investment	1613407	1697937	1808561	1802552	1595413
2	Financial analysis					
2.1	Sales	2673492	2698812	2717746	2530846	2698114
2.2	Crude Oil Purchases cost	-2419613	-2303560	-2317617	-2273743	-2356982
2.3	Operation cost	-28432	-32622	-31931	-34286	-27905
2.4	Fixed Operation cost	-76401	-81753	-87864	-87760	-75748
2.5	Salary & welfare and Overhead	-23000	-23000	-23000	-23000	-23000
2.6	Maintenance Cost	-38200	-40877	-43932	-43880	-37874
2.7	Net Operation Revenue	87845	217001	213401	68176	176605
3	Financial Index					
3.1	IRR	8.19%	15.08%	14.26%	6.45%	13.60%
3.2	NPV (12% of discounted rate)	-319723	305225	235458	-506752	144810
3.3	Payback Period (Year)	12.58	8.66	8.96	14.20	9.27

In all, the five cases with the same configuration mode each processing different crude have different investment and internal return rates. The IRR of Case 7, Case 8 and Case10 are better than others. From the standpoint of investment, Case10's investment is lower than Case7 and Case8.

4.2.2 Case B (COKER + MHC + FCC) Configuration / Analysis

Case B's configuration analysis was based on using a coker and MHC/FCC with high conversion. MHC+FCC were placed in the configuration instead of hydro-cracking for more gasoline and LPG. This operation level produces enough LPG for the local market demand. In order to improve the diesel and Jet property, a distillate MHC is needed. A block flow diagram showing the results of Case B configuration analysis is provided in Figure 4.2.2. The configuration comparisons of 5 crudes are listed in Table 4.2-5 and Table 4.2-6.

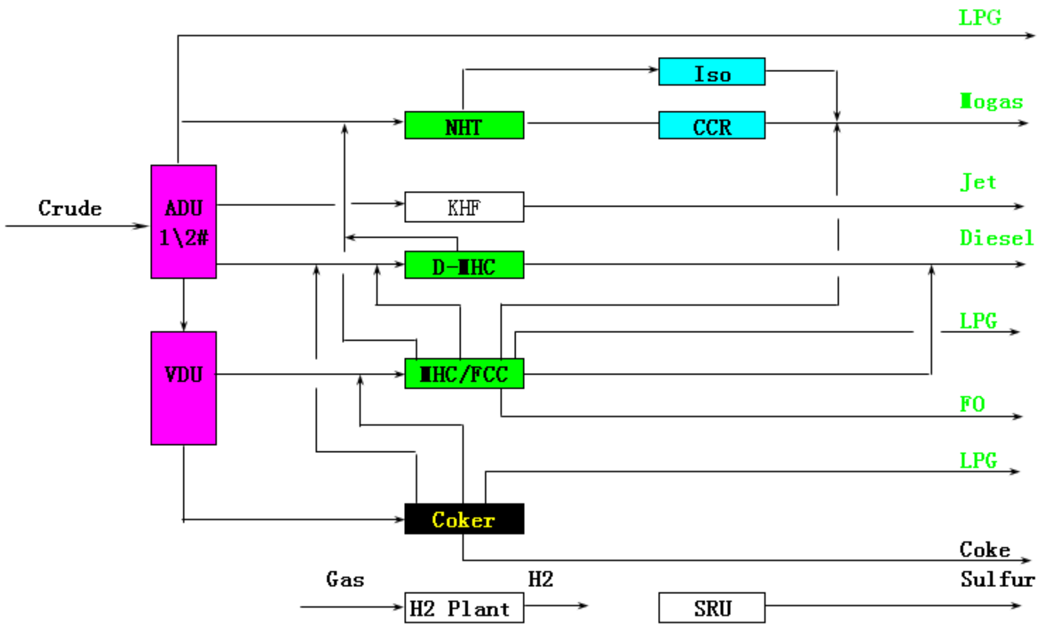

Figure 4.2.2Case B Block Flow Diagram

4.2.2.1 Process Units Capacity Comparison

Table4.2-5 Process units and capacity for Case B Unit:kt/a

No.	Process Unit	Case1	Case2	Case3	Case4	Case5	Notes
1	1#ADU	1200	1200	1200	1200	1200	Existing
2	1#VDU	100	100	100	100	1000	Existing
3	Visbreaking	230	230	230	230	230	Existing
4	KHF	140	140	140	140	140	Existing
5	Reformer	60	60	60	60	60	Existing
6	2#ADU	2000	2000	3000	2100	2000	New
7	2#VDU	1500	1800	2000	2150	1500	New
8	Coker	700	900	1000	1100	700	New
9	VGO MHC	900	1050	1200	1200	900	New
10	FCC	750	900	1000	1000	750	New
11	NHT	600	500	400	400	550	New
12	Distillate MHC	1500	1600	1700	1200	1600	New
13	CCR reformer	450	350	300	300	400	New
14	H_2 Plant	20	30	25	30	20	New
15	SRU Complex	25	25	20	40	20	New
16	Gas/LPG Desulphurization	90/140	110/160	110/180	120/190	90/130	New
17	Isomerization	160	140	120	130	160	New

4.2.2.2 Overall Material Balance Comparison

Table4.2-6 Comparison of overall material balance for Case B Unit:kt/a

No.	Name	COKE+MHC/FCC				
		Case1	Case2	Case3	Case4	Case5
1	Feed structure					
1.1	MESA	2953.00				
1.2	VASCONIA		3054.00			2010.00
1.3	PENNINGTON					948.00
1.4	MARLIM Light			3049.00		
1.5	CASTILLA				3137.00	
1.6	Ethanol	107.19	102.12	106.21	108.13	101.55
1.7	Purchase fuel	41.03	74.15	73.70	83.49	62.83
	Subtotal	3101.22	3230.27	3228.91	3328.61	3122.38
2	Product structure					
2.1	Gasoline	1020.35	970.94	1007.45	1043.59	974.47
2.2	Kerosene	283.74	302.60	205.15	263.54	340.85
2.3	Diesel	1178.67	1227.47	1307.81	961.67	1225.00
2.4	LPG	171.54	185.94	197.76	214.47	153.80
2.5	Coke	210.66	268.66	239.98	535.98	187.97
2.6	Sulfur	25.32	24.64	17.25	37.44	17.55
2.7	FCC coke	37.76	43.59	49.37	51.25	37.03
2.8	Refinery fuel	41.03	74.15	73.70	83.49	62.83
2.9	Refinery gas	95.61	73.42	72.18	67.01	77.65
2.10	Loss	36.54	58.86	58.24	70.18	45.12
	Subtotal	3101.22	3230.27	3228.91	3328.61	3122.27

4.2.2.3 Preliminary Investment and Economic Analysis Comparison

Table4.2-7 Preliminary investment and economic analysis for Case B Unit:kUS$

No.	Name	COKE+MHC/FCC				
		Case1	Case2	Case3	Case4	Case5
1	Investment					
1.1	Revamp Investment	11090	11090	3370	11090	11090

No.	Name	COKE+MHC/FCC				
		Case1	Case2	Case3	Case4	Case5
1.2	2#CDU	49050	49050	84805	51002	49050
1.3	2#VDU	31170	36065	49045	41573	31170
1.4	Delayed coking	134780	164794	179286	193491	134780
1.5	VGO MHC	58297	64940	71303	71303	58297
1.6	FCC	82790	94060	101259	101259	82790
1.7	NHT	12570	11064	9464	9464	11827
1.8	Distillate MHC	145231	152926	160526	121487	152926
1.9	Reformer	123530	103603	93005	93005	113754
1.10	H_2 Plant	49416	65634	57770	65634	49416
1.11	Gas/LPG desulfurization	9446	10419	11370	11683	9116
1.12	Sulfur complex	45963	45963	38449	66943	38449
1.13	Isomerization	30547	27821	24976	26415	30547
1.14	Subtotal	783880	837429	884628	864350	773212
1.15	other	627104	669943	707703	691480	618569
1.16	Construction Investment	1410984	1507372	1592331	1555831	1391781
1.17	Working Capital	250832	241504	243178	239771	245881
1.18	Interest during construction period	98769	105516	111463	108908	97425
	Total Investment	1760584	1854392	1946972	1904510	1735087
2	Financial analysis					
2.1	Sales	2659984	2692380	2715809	2529163	2690150
2.2	Crude Oil Purchases cost	-2409350	-2311074	-2324206	-2290095	-2360752
2.3	Operation cost	-33639	-35746	-36800	-37944	-33309
2.4	Fixed Operation cost	-84659	-90442	-95540	-93350	-83507
2.5	Salary& welfare and Overhead	-23000	-23000	-23000	-23000	-23000
2.6	Maintenance Cost	-42330	-45221	-47770	-46675	-41753
2.7	Net Operation Revenue	67007	186896	188494	38099	147829
3	Financial Index					
3.1	IRR	6.44%	12.75%	12.40%	4.36%	11.29%
3.2	NPV(12% of discounted rate)	-494689	78250	43500	-708478	-67572
3.3	Payback Period (Year)	14.26	9.61	9.76	16.96	10.38

In all, five cases with the same configuration mode each processing different crude have different investment and internal return rates. The trend of Case B is similar with Case A. The IRR of Case2, Case 3 and Case5 are better than others. From the investment standpoint, Case5's investment is lower than Case2 and Case3.

4.2.3 Case C (Flexi-coking + HCU) Configuration Analysis

Case C's configuration analysis was based on using a Flexi-coking and HCU with high conversion. Flexi-coking is placed in the configuration instead of coker to void solid coke production and sale with low price. But syngas, with low heating value of 128BTU/SCF, has much N_2 of 48 mol%. How to make use of syngas is a difficult problem in the world. More than 95% coker is delayed coker and there is less than 10 operating commercial process units. This is why the flexi-coking case is only used for study analysis.

A block flow diagram showing the results of Case C's configuration analysis is provided in Figure 4.2.3. The configuration comparisons of 5 crudes are listed in table 4.2-8 through table 4.2-9.

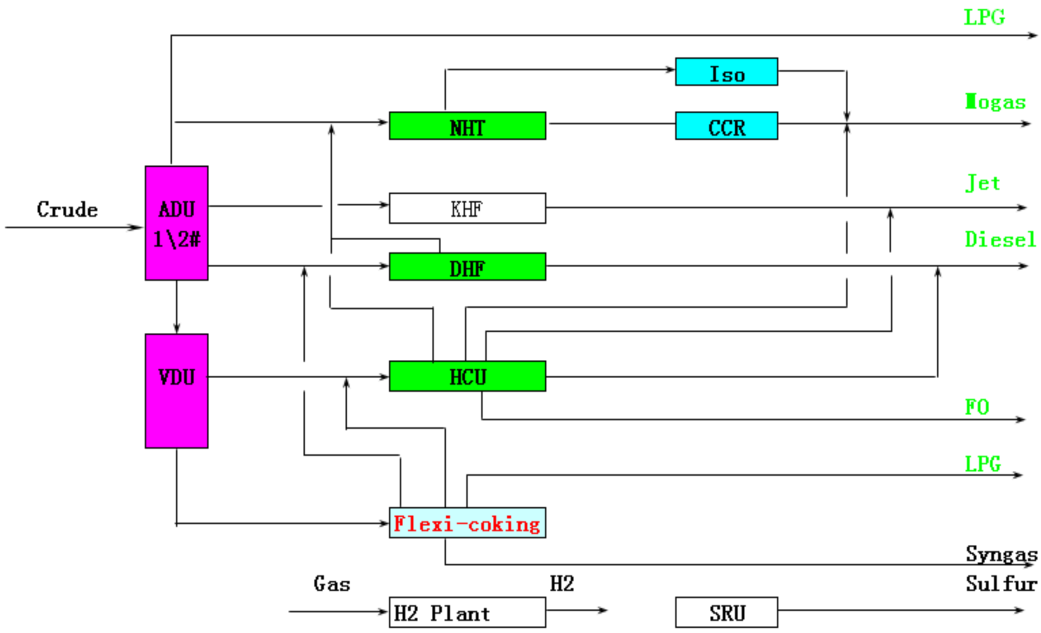

Figure 4.2.3 Case C Block Flow Diagram

4.2.3.1 Process Units Capacity Comparison

Table4.2-8 Process units and capacity for Case C Unit:kt/a

No	Process Unit	Case11	Case12	Case13	Case14	Notes
1	1#ADU	1200	1200	1200	1200	Existing
2	1#VDU	100	100	100	100	Existing
3	Visbreaking	230	230	230	230	Existing
4	KHF	140	140	140	140	Existing
5	Reformer	60	60	60	60	Existing
6	2#ADU	2000	2000	3000	2100	New

No	Process Unit	Case11	Case12	Case13	Case14	Notes
7	2#VDU	1500	1800	2000	2150	New
8	Flexi-Coking	700	900	1000	1100	New
9	HCU	900	1100	1200	1200	New
10	NHT	550	450	400	450	New
11	DHT	1200	1200	1250	800	New
12	CCR reformer	500	500	450	500	New
13	H_2 Plant	25	25	30	30	New
14	SRU Complex	35	30	25	60	New
15	Gas/LPG Desulphurization	70/70	80/70	90/80	100/80	New
16	Isomerization	150	120	110	120	New

4.2.3.2 Overall Material Balance Comparison

Table4.2-9 Comparison of overall material balance for Case C Unit:kt/a

No.	Name	Flexi-coking+HC			
		Case11	Case12	Case13	Case14
1	Feed structure				
1.1	MESA	2953.00			
1.2	VASCONIA		3054.00		
1.3	PENNINGTON				
1.4	MARLIM Light			3049.00	
1.5	CASTILLA				3137.00
1.6	Ethanol	79.42	70.20	64.87	69.35
1.7	Purchase fuel	152.58	156.54	162.54	210.51
1.8	Subtotal	3185.00	3280.74	3276.41	3416.86
2	Product structure				
2.1	Gasoline	753.79	674.13	644.53	672.27
2.2	Kerosene	330.45	369.76	286.08	399.98
2.3	Diesel	1531.07	1580.87	1715.93	1331.99
2.4	LPG	80.51	80.60	84.72	90.67
2.5	Sulfur	32.96	30.57	21.74	61.18
2.6	Synthetic gas	1214.38	1555.16	1390.98	3101.26
2.7	Refinery fuel	170.52	181.53	190.56	239.76
2.8	Refinery gas	35.74	44.38	37.45	43.72

No.	Name	Flexi-coking+HC			
		Case11	Case12	Case13	Case14
2.9	Loss	44.50	56.89	58.50	66.27
	Subtotal	4193.90	4573.89	4430.48	6007.10

4.2.3.3 Preliminary Investment and Economic Analysis Comparison

Table4.2-10 Preliminary investment and economic analysis for Case C Unit:kUS$

No.	Name	Flexi-coking+HC			
		Case11	Case12	Case13	Case14
1	Investment				
1.1	Revamp Investment	11090	11090	3370	11090
1.2	2#CDU	49050	49050	84805	51002
1.3	2#VDU	31170	36065	49045	41573
1.4	Flexi-coking	277423	329836	321929	461524
1.6	Hydro-cracking	115230	135296	145050	145050
1.7	NHT	11941	10277	9464	10277
1.8	DHT	81642	81642	84009	61468
1.9	CCR Reformer	132985	132985	123530	132985
1.10	H_2 Plant	57770	57770	65634	65634
1.11	Gas/LPG Desulfurization	5984	6710	7417	7764
1.12	Sulfur complex	41495	53181	45963	92593
1.13	Isomerization	29198	24976	23500	24976
1.14	Subtotal	844978	928878	963715	1105936
1.15	other	675982	743102	770972	884749
1.16	Construction Investment	1520960	1671980	1734688	1990685
1.17	Working Capital	255913	244590	245580	252661
1.18	Interest during construction period	106467	117039	121428	139348
1.19	Total Investment	1883340	2033608	2101695	2382694
2	Financial analysis				
2.1	Sales	2758729	2790460	2796878	2715302
2.2	Purchases cost	-2457634	-2335615	-2343923	-2399433
2.3	Operation cost	-32867	-37128	-36833	-44458
2.4	Fixed Operation cost	-91258	-100319	-104081	-119441
2.5	Salary & welfare and Overhead	-23000	-23000	-23000	-23000

No.	Name	Flexi-coking+HC			
		Case11	Case12	Case13	Case14
2.6	Maintenance cost	-45629	-50159	-52041	-59721
2.7	Net Operation Revenue	108342	244239	237000	69249
3	Financial Index				
3.1	IRR	8.57%	14.45%	13.82%	5.52%
3.2	NPV(12% of discounted rate)	-339763	289448	220726	-770866
3.3	Payback Period (Year)	12.20	8.86	9.11	15.19

In all, four cases with the same configuration mode each processing different crude have different investment and internal return rates. The IRR of Case12 and Case 13 are better than others. From the investment standpoint, Case13's investment is lower than Case12.

4.2.4 Case D (LC-Fining + HCU) Configuration / Analysis

Case D's configuration analysis was based on using an LC-FINER with high conversion. Its built-in on-stream catalyst addition and withdrawal system eliminates the need to shut down for catalyst replacements. The LC-fining process is owned by Chevron Lummus Global (CLG), a joint venture between Chevron USA and Lummus Technology. This process has been used for desulfurization, demetallization, canradson carbon reduction, and hydro-treating of vacuum resides. Commercial designs and unit operations range from desulfurization at minimum conversion for production of high quality fuel oil, to nearly complete conversion of resid into low sulfur distillate products. Recent advances in its technology include new designs of the reactor internals that increase conversion and throughput. Current designs can process up to 50,000bpd of heavy vacuum resid in single train systems. An alternate option of operating the LC-FINER at lower conversion and thereby allowing production of an unconverted bottoms stream suitable for fuel oil product blending was considered. Although, LC-fining can crack most of its heavy bottom into light oil with no solid coke production, huge investment and much H2 consumption are needed. This limits LC-fining technology development and reduces the opportunity of process development and commercial use. Based on some information from TPIT, HQCEC's partner, the investment estimation of LC-fining with the capacity of 45,000BPSD is 0.7 billion EU dollar in EU. Now there are about 9 commercial operation units in the world.

Table4.2-11 LC-Fining Process Units List of CLG

User Name	Capacity, Million barrels / day	Time
BP-Amoco，USA	6	1984
synthetic crude oil companies，Canada	4	1988
Agip, Italy	2.5	1988
Oil company ,Slovak	2.3	2000
Canada company, Shell (2sets）	7.9	2003
Neste, Finland	4	2007
Canada company, Shell	4.73	2010
Northwest company, Canada	2.9	2010
Undisclosed	6	2011
Undisclosed	3.3	2011

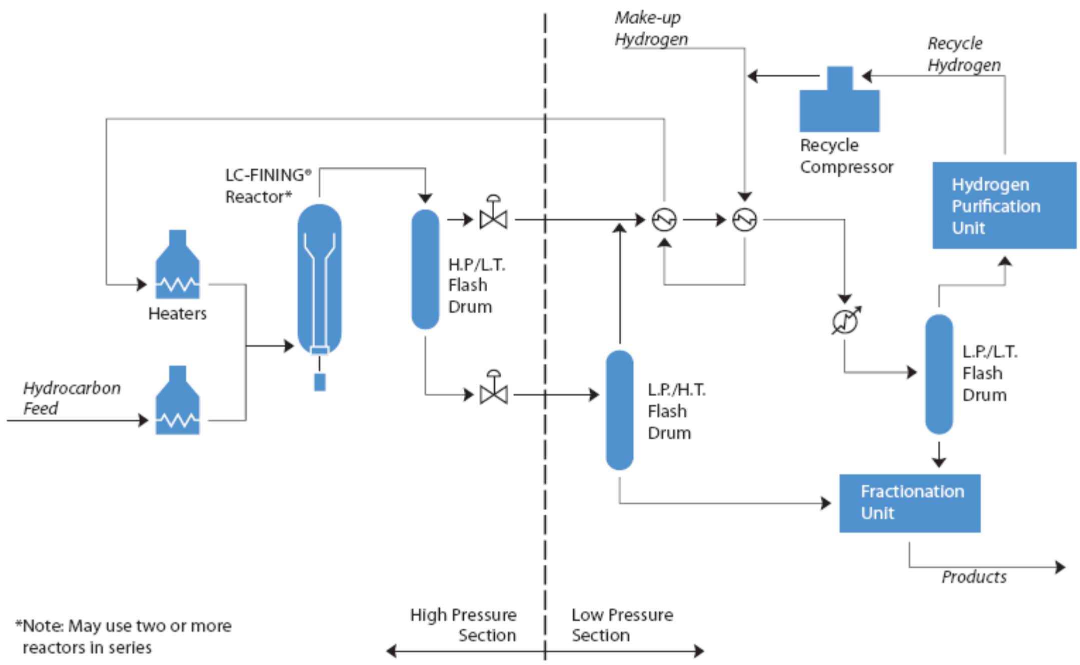

Figure 4.2.4a LC-fining Process Flow Diagram

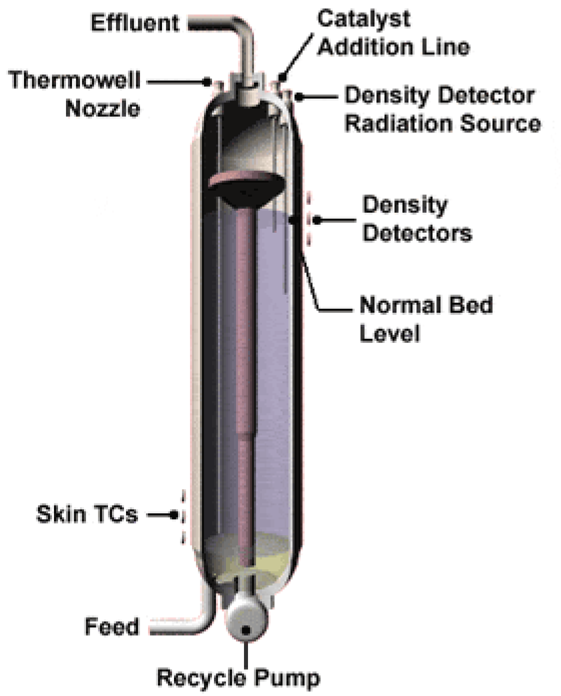

Figure 4.2.4b LC-fining Reactor Diagram

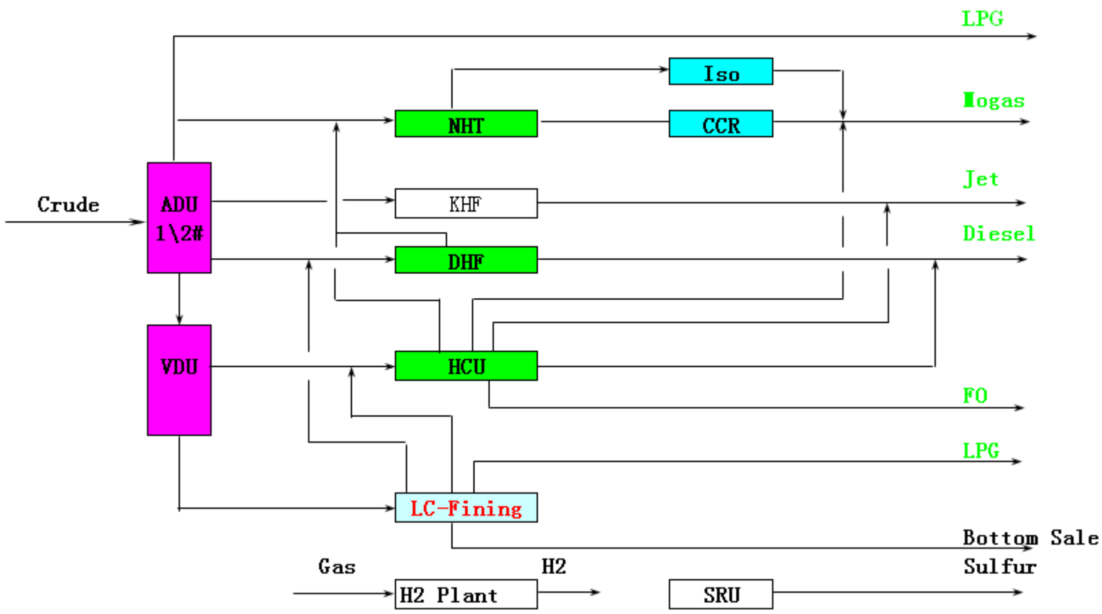

Figure 4.2.4c Case **D** Block Flow Diagram

4.2.4.2 Process Units Capacity Comparison

Table4.2-12 Process units and capacity for Case D Unit:kt/a

No.	Process Unit	Case15	Case16	Case17	Case18	Notes
1	1#ADU	1200	1200	1200	1200	Existing
2	VDU	100	100	100	100	Existing
3	Visbreaking	230	230	230	230	Existing
4	KHF	140	140	140	140	Existing
5	Reformer	60	60	60	60	Existing
6	2#ADU	2000	2000	3000	2100	New
7	VDU	1500	1800	2000	2150	New
8	LC-Fining	700	900	1000	1100	New
9	HCU	1000	1150	1250	1400	New
10	NHT	550	450	400	450	New
11	DHT	1200	1100	120	900	New
12	CCR reformer	500	500	450	500	New
13	H_2 Plant	40	45	55	60	New
14	SRU Complex	30	30	25	60	New
15	Gas/LPG Desulphurization	60/80	70/80	60/80	90/90	New
16	Isomerization	150	150	160	160	New

4.2.4.3 Overall Material Balance Comparison

Table4.2-13 Comparison of overall material balance for Case D Unit:kt/a

No.	Name	LC-Fining+HC			
		Case15	Case16	Case17	Case18
1	Feed structure				
1.1	MESA	2953.00			
1.2	VASCONIA		3054.00		
1.3	PENNINGTON				
1.4	MARLIM Light			3049.00	
1.5	CASTILLA				3137.00
1.6	Ethanol	77.15	69.29	65.07	71.58
1.7	Purchase fuel	162.29	177.08	179.17	207.32
2	Subtotal	3192.44	3300.37	3293.23	3415.90
2.1	Product structure				

No.	Name	LC-Fining+HC				
		Case15	Case16	Case17	Case18	
2.2	Gasoline	742.29	677.93	636.55	690.11	1017.26
2.3	Kerosene	351.31	395.45	306.81	431.86	384.11
2.4	Diesel	1554.08	1599.23	1726.74	1522.09	1227.61
2.5	LPG	66.74	52.21	21.16	31.74	158.41
2.6	Coke					
2.7	Fuel	191.00	243.60	267.33	307.88	
2.8	Sulfur	28.95	29.10	22.29	59.59	2.57
2.9	Refinery fuel	181.91	204.51	209.22	239.90	
2.10	Refinery gas	2.83	2.25	1.90	2.32	
2.11	Loss	73.34	96.09	101.22	130.42	
	Subtotal	3192.44	3300.37	3293.23	3415.90	

4.2.4.4 Preliminary Investment and Economic Analysis Comparison

Table4.2-14 Preliminary investment and economic analysis for Case D　　Unit:kUS$

No.	Name	LC-Fining+HC			
		Case15	Case16	Case17	Case18
1	Investment				
1.1	Revamp Investment	11090	11090	3370	11090
1.2	2#CDU	49050	49050	85934	51002
1.3	2#VDU	31170	36065	49045	41573
1.4	LC-fining	393727	457806	487681	516383
1.5	Hydro-cracking	125364	140194	149865	164087
1.6	NHT	11941	10277	9464	10277
1.7	DHT	81642	76818	81642	66751
1.8	CCR Reformer	132985	132985	123530	132985
1.9	H_2 Plant	80276	87175	100322	106623
1.10	Gas/LPG Desulfurization	6350	6710	6350	7764
1.11	Sulfur complex	53181	53181	45963	92593
1.12	Isomerization	29198	29198	30547	30547
1.14	Subtotal	1005973	1090549	1173714	1231676
1.15	other	804778	872439	938971	985340
1.16	Construction Investment	1810751	1962988	2112685	2217016

No.	Name	LC-Fining+HC			
		Case15	Case16	Case17	Case18
1.17	Working Capital	256458	245823	247033	246012
1.18	Interest during construction period	126753	137409	147888	155191
1.19	Total Investment	2193962	2346220	2507606	2618219
2	Financial analysis				
2.1	Sales	2807473	2849365	2824593	2849130
2.2	Purchases cost	-2461983	-2348572	-2355344	-2338117
2.3	Operation cost	-25277	-27765	-28602	-32488
2.4	Fixed Operation cost	-108645	-117779	-126761	-133021
2.5	Salary, welfare & Overhead	-23000	-23000	-23000	-23000
2.6	Maintenance Cost	-54323	-58890	-63381	-66510
2.7	Net Operation Revenue	134245	273359	227505	255993
3	Financial Index				
3.2	IRR	9.00%	14.16%	11.89%	12.53%
3.4	NPV (12% of discounted rate)	-350414	294319	-15741	79464
3.3	Payback Period (Year)	11.81	8.95	9.96	9.63

In all, four cases with the same configuration mode each processing different crude have different investment and internal return rates. The IRR of Case16, Case17 and Case 18 have reasonable internal return rate. From the investment, Case18's investment is lower than Case16 and Case17.

4.2.5 Other Possible Configuration Cases

In order to compare other configurations, 2 short configurations with RFCC for processing sweet crude (case 19) and visbreaking (case 20) for producing fuel oil are studied.

4.2.5.1 Process Units Capacity Comparison on Case 19-20

Table4.2-15 Process units and capacity for Case 19-20 Unit:kt/a

No.	Process Unit	Case19	Case20	Notes
1	1#ADU	1200	1200	Existing
2	1#VDU	100	100	Existing
3	Visbreaking	230	230	Existing
4	KHF	140	140	Existing
5	Reformer	60	60	Existing

No.	Process Unit	Case19	Case20	Notes
6	2#ADU	2000	2000	New
7	2#VDU		1500	New
8	Visbreaking		900	New
9	FCC	900		New
10	HCU		800	New
11	NHT	600	550	New
12	DHF		900	New
13	DMHC	1600		New
14	FCC-NHT	400		New
15	CCR	500	500	New
16	H_2 Plant	10	20	New
17	SRU Complex	30	20	New
18	Gas/LPG Desulphurization	50/130	50/20	New
19	Isomerization	120	170	New

4.2.5.2 Overall Material Balance Comparison

Table4.2-16 Comparison of overall material balance for C19-20 Unit:kt/a

No.	Name	Case19	Case20
1	**Feed structure**		
1.1	MESA		2953.00
1.2	PENNINGTON	2844.00	
1.3	Ethanol	105.10	71.51
1.4	Purchase fuel	20.72	68.08
	Subtotal	2969.82	3092.59
2	**Product structure**		
2.1	Gasoline	1017.26	696.39
2.2	Kerosene	384.11	455.73
2.3	Diesel	1227.61	1083.56
2.4	LPG	158.41	57.60
2.5	Fuel		622.36
2.6	Sulfur	2.57	16.08
2.7	FCC coke	49.65	
2.8	Refinery fuel	36.45	89.36
2.9	Refinery gas	77.06	32.87

No.	Name	Case19	Case20
2.10	Loss	16.70	38.63
	Subtotal	2969.82	3092.59

4.2.5.3 Preliminary Investment and Economic Analysis Comparison on Case 19-20

Table4.2-17 Preliminary investment and economic analysis for Case 19-20 Unit:kUS$

No.	Name	ATM+FCC	Visbreaking
		Case19	Case20
1	Investment		
1.1	Revamp Investment	11090	11090
1.2	2#CDU	49050	49050
1.3	2#VDU		31170
1.4	Visbreaking		53664
1.5	FCC	85610	
1.6	Hydro-cracking		104868
1.7	NHT	12570	11941
1.8	DHT		66751
1.9	DMHC	152926	
1.10	FCC-NHT	7698	
1.11	CCR Reformer	132985	132985
1.12	H_2 Plant	30419	49416
1.13	Gas/LPG Desulfurization	7764	3647
1.14	Sulfur complex	53181	38449
1.15	Isomerization	24976	31872
1.16	Subtotal	568268	584901
1.17	other	454615	467921
1.18	Construction Investment	1022883	1052822
1.19	Working Capital	258139	246898
1.20	Interest during construction period	71602	73698
1.21	Total Investment	1352624	1373418
2	Financial analysis		
2.1	Sales	2765543	2669974
2.2	Purchases cost	-2506746	-2392842
2.3	Operation cost	-20960	-21556

No.	Name	ATM+FCC	Visbreaking
		Case19	Case20
2.4	Fixed Operation cost	-61373	-63169
2.5	Salary, welfare & Overhead	-23000	-23000
2.6	Maintenance Cost	-30686	-31585
2.7	Net Operation Revenue	122778	137823
3	Financial Index		
3.2	IRR	11.72%	12.63%
3.4	NPV (12% of discounted rate)	-20622	48108
3.3	Payback Period (Year)	10.26	9.77

4.3 Conclusion and Recommendations

The advantages and disadvantages analysis of all the cases are shown in the following table. All the cases can process 5 crudes with different conversion and different production. Case A and Case B have good processing flexibility, wide operating experience in the world, and reasonable investment with an economic internal return rate.

Table4.3-1 Advantage and Disadvantage Analysis of All Cases

Item	Advantages	Disadvantages
Case A	1) Good processing flexibility of sour crude with low API with max conversion 2) Provides good yield of light oil with good quality 3) Enough Jet and diesel for local market demand 4) To meet the balance of gasoline, Jet and diesel 5) reasonable investment and economic return 6) Widely used in processing sour crude in the world	1) Solid coke market 2) environmental impact of solid coke storage and transport 3) Some difficulty of blending gasoline with aromatics limit 4) Normal LPG production

Item	Advantages	Disadvantages
Case B	1)Good processing flexibility of sour crude with low API with max conversion 2)Provides good yield of light oil with good quality 3)Enough LPG and gasoline for local market demand 4) Reasonable investment and economic return 5)Widely used in processing sour crude in the world	1) Solid coke market 2) environmental impact of solid coke storage and transport 3) Crude property will limit Jet and diesel production with good quality 4) More gasoline and less diesel for local market
Case C	1)Avoid solid coke production and good processing flexibility of sour crude with low API with max conversion 2)Provides good yield of light oil with good quality 3) Good economic return	1)Higher investment 2)A few commercial process units is operated in the world 3)The use of Syngas with low BTU
Case D	1)Good processing flexibility of sour crude with low API 2)Provides good yield of light oil with good quality 3)Avoid solid coke production 4) Good economic return 5)Less environmental impact with all hydro-treating mode	1) Very higher investment 2) More H_2 consumption and much H2 feed needed 3)A few commercial process units is operated in the world

Based on the objectives of the feasibility study (maximum clean products production), technology experience, reasonable investment and good financial benefit, HQCEC had recommended Case A to be considered for further detailed analysis.

In case A, configurations with different crude have different process unit's size, investment and IRR. The IRR of Case 7, case 8 and Case 10 are better than Case 6 and Case 9. From the investment standpoint, Case10's investment is lower than Case7 and Case8.

Considering that Case 8 processes MARLIM with higher TAN, existing CDU unit has to be shutdown for acid erosion and a new CDU should be built, and it will result in higher investment costs.

The difference between Case7 and Case 10 is choosing different crude slates. Single crude oil has been processed in Case7 and two types of crude oil have been processed in Case10. Based on our experience, Case10 does not need to only rely on one type of crude oil; it also has better operating flexibility. Although the IRR of Case 10 is not the best one, there is less impact on existing refinery and it can be operated for supplying fuel during the expansion project construction period.

Balancing the investment, economic return rate, diversity of crude resource and operation flexibility, we suggest processing PENNINGTON crude to meet existing refinery needs with limited revamp along with processing sour crude within new expansion units, in our study. As a result, Case 10 will be evaluated in detail within the FSR.

5 Result of cases

Detail the result of cases are shown as attachment