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Economic Evaluation of Mixed $C_{4's}$ Upgrading Processes. (Raslanuf Ethylene Plant as a Case Study)

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ABSTRACT

Reducing the operating cost (opex) is a method implemented by Ethylene producers to keep ethylene prices from expensive feedstock more competitive in comparison with cheaper feed stocks like ethane. Alternatively economics maybe improved by upgrading the mixed C4 stream which is produced from ethylene plant and contains valuable unsaturated C4s such as butadiene, isobutylene, butene-1, and butene-2. There are different processing options available to recover these components or turn them into final products. These processing options or routes are combination of different chemical processes such as Total hydrogenation, Butadiene extraction, MTBE production form butylenes, Butane-1 recovery and other processes. Several upgrading options have been proposed and evaluated for Raslanuf ethylene plant c4 feed of about 130000 tonne/y. Internal rate of return IRR , payback time or period PBP, and the net present value NPV, all have been estimated for options which can be implemented at the site; butadiene extraction and metathesis.

Because base case results were not definitive, sensitivity analysis was performed. The parameters investigated are sales prices; feed cost, construction time and total investment. .The results suggest butadiene extraction is the best processing option for processing Raslanuf mixed C4 stream.

Keywords: *Ethylene, the upgrading of mixed C4,butadiene extraction, internal rate of return, sensitivity analysis.*

1. Introduction.

Ethylene is produced from steam cracker with different feeds tocks like ethane, LPG, gas oil and naphtha.

The gross profit margin, which is determined mainly by the difference between the products revenues and feedstock costs, made the ethylene produced by ethane (from natural gas) more profitable and competitive in comparison with ethylene from naphtha. Steam crackers, which depend on naphtha, faced a huge challenge in the ethylene market, and the need to reduce the cost of production issue appeared among petrochemical analysts.

Recent decline in crude prices have eroded much the massive cost advantage previously enjoyed by ethane over naphtha, This issue will not remain forever in the volatile oil markets , and many are forecasting oil prices to climb up by the end of 2016 [1]. The permanent solution to tackle the issue of higher feedstock and higher operating costs is to find the most economical upgrading route for one of the main products of ethylene such as pyrolysis gasoline (Py Gas)or the Mixed C4 s hydrocarbons.

This can be accomplished by converting relatively low valuable product to more valuable products. The title “mixed C4 upgrading routes or schemes “appeared in many articles [2] and some textbooks [3].

Raslanuf complex (Rasco) ethylene plantwith capacity (330000 ton/year) faced this challenge because its feedstock was naphtha produced in the nearby Rasco®refinery. It is considered as an old plant that needs upgrading.

The present paper investigated the different available technologies (routes) to upgrade locally mixed c4 produced by Rasco® to more valuable products. The data used in this case study is primarilyproducts capacity data obtained from previous published paper and website of the company [1,11].

The final choice of the best scheme was based on techno – economic profitability analysis using different parameters and taking into consideration the age of the plant, site constraints and its sensitivity to market fluctuations.

2. Processing routes or schemes available

Six upgrading schemes are identified and as follows:

2.1. Total Hydrogenation

Total hydrogenation process provides saturation of olefin, diolefin, and acetylene compounds in C4 stream. This process hydrogenates unsaturated hydrocarbons inside a single fixed-bed reactor system at mild operating conditions.

Product from the unit is mainly LPG, which can be recycled back to the ethylene plant to the cracking heater. The process called cocracking. The option of recycling back LPG will reduce naphtha feed and reduce the operating costs indirectly. It was not considered in this study because the prices of naphtha and LPG are almost the same [4].

2.2. Butadiene extraction

A typical butadiene extraction process consists of two stages of extractive distillation (Extractive distillation is necessary because the similarities in volatilities between the products in the C4 stream).

Products from this process are mainly a raffinate containing butenes from the first stage overhead and a crude butadiene product from the second stage. The solvent, for example in BASF butadiene process is N-methylpyrrolidinone (NMP).

2.3. Metathesis

Metathesis utilizes two chemical reactions to combine2-butenes with ethylene to produce propylene. The second reaction isomerizes butene-1 to butene-2 as the latter is consumed in the metathesis reaction. Economics suggest that it can be also selectively hydrogenated to produce additional butylenes feed for the metathesis reactor. The selective hydrogenation unit offers a highly selective catalyst for the hydrogenation of butadiene to butenes [5,6].

2.4. MTBE

Methyl tertiary butyl ether (MTBE) is an oxygenate used worldwide as gasoline octane booster, although the use of MTBE as octane booster has been declining due to problems with groundwater contamination. New type of octane booster ETBE is used instead. MTBE process converts isobutylene by using of methanol [6]

2.5. Other processes.

Other process schemes or routes are available and it is developed through the combination of the previously mentioned main routes.

3. Economic evaluation for the proposed Mixed C4 upgrading schemes.

Before starting the economic evaluation by subjecting the different process to the different economic analysis methods, some consideration should be taken which will lead to dropping some options due to local condition or previous studies:

1- Option1 which is producing LPG by total hydrogenation scheme will be dropped from the evaluation for the following reasons:
- LPG is produced in the nearby refinery and can be utilized
- Previous studies showed clearly that the processing route1(total hydrogenation) has the least profit[2].

2- Options 4 and 5 were dropped from the economic evaluation because of the following:
- Raw materials for these options are not available on the site.
- Methanol procurement will be through several sea shipments per year thus increasing feed and operating costs.

Table 1: Material balance

t/y		Option 2	Option 3
Raw materials	Mixed C_4	130000	130000
	Ethylene	_	42000
	Hydrogen	_	2800
Products	Propylene	_	111872
	Butadiene	65000	_
	Raffinate	65000	62928

Therefore, only two process options (2 and 3) were subjected to economic evaluation .Table 1 illustrates the material balance required to carry out the economic evaluation for the base case study.

The feed for both schemes is 130000 t/y of mixed C4, also the products distribution in tons per year (t/y) are given in table 1. International sales prices of the different raw materials and products are for the August of year 2015 except for hydrogen price where the method of its equivalent fuel to calculate the price was used, as shown in Table 2. The Equipment costs are called the (inside battery limit) ISBL cost which is essential figure in the calculations was taken from old data found in previous studies. Escalation method was used to estimate the present value and location correction factor also used [7].

Table 2: Products and raw materials sales prices Aug.2015.

Raw material	$/T
Mixed C4	460
Ethylene	1100
Hydrogen	1000
Products	$/T
propylene	1000
Raffinate	411
Butadiene	900

The bases of the economic evaluation are given in Table3.Us Microsoft Excel® was used to calculate the annual cash flow, net present value NPV and IRR. The calculated economic parameters are presented in Table 4 for the two selected options. Payback period PBP was found for each case by calculating the cumulative cash flow column divided by plant lifetime[8].

Table 3: The basis of economic evaluation

Parameter	Value
Upgrading plant cap.	130000 t/y
Working days	330days
Plant life time	20 years
Plant construction time	2 years
On stream day	50% 3rd year, 100% (4-40)
Taxes	10%
Year of starting taxation	6th year
Maintenance	3% ISBL
Plant overhead	2% fixed investment

4. Discussion and results

Table 4 summarizes the results obtained for the two proposed processes. The economic indicators showed different rankings for the two options and both are economically feasible.

Table 4: The economic evaluation

option	2nd	3rd
Feed costs MM/y		
Mixed C 4	59.8	59.8
Hydrogen	_	2.8
Ethylene	_	46.2
Total feed cost MM/y	59.8	108.8
Product sales MM/y		
butadiene	58.5	_
Propylene	_	109.635
Raffinate	26.715	25.86
Total MM/y	85.215	135.495
Gross margin MM/y	25.415	26.695
Total utility cost MM/y	5.4	0.74
Total investment MM/y	32.2	36.59
Simple pay back PBP	2.14	2.32
NPV $ MM	76.4	79.3
IRR %	54	51

Option 2, which is the butadiene extraction, has the highest IRR (54%) and PBP of (2.14years) compared to 51% and 2.3 years for option 3-metathesis process. Based on the above results, which show very tight margin between the economic parameters, there is a need to see another method to evaluate the projects and guarantee the best selection.

5. Sensitivity analysis.

5.1. Importance of sensitivity analysis.

A sensitivity analysis is a way of investigating the effects of uncertainties in the different forecasts, which are due to the volatile market on the viability of a project. To perform this analysis the total investment and cash flows are calculated using what are considered the most probable values for the various factors; this establishes the base case for analysis. The cash flows and associated economic indicators are then calculated assuming a range of error for each of the factors that may affect profitability as measured by changes in NPV and IRR from base case. These are sales price, raw materials cost, total investment and construction time as shown in Table 5. The results of this analysis are depicted using tornado charts.

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Table 5: Sensitivity analysis parameters

Factor	Percent of base value
Sales price	-20 to +20
Feed cost	-10 to +30
Total investment	-20 to +50
Construction time	-6 months to +2years

5.2. Sensitivity analysis results with tornado charts.

A tornado diagram is a special type of bar chart which provides graphical representation of a comparative sensitivity analysis. It is a great tool for the decision makers to give them some insight into the uncertainties and their potential impact on the project under investigation. The x-axis of a tornado diagram is the value of the primary objective function e.g. (NPV). Parallel bars represent the objective function range from base case for each the sensitivity parameters. Each sensitivity analysis parameter in the model has its own bar, and the width of each bar shows how much impact that factor can have on NPV when varied through a range suggested for the study. In other words, it is a method to evaluate the risk associated with the project due to uncertainty in parameters, which affects the outcome [9].

5.3. Sensitivity analysis for 2nd option.

The sensitivity analysis has been performed for the various specified ranges of the input variable parameters depicted in Table 5.

Fig. 1: Tornado chart for 2nd optionwith NPV base 76 MM$.

The output results, Figs (1 and 2) are arranged on tornado chart downward from largest width down to smallest width, and presented as tornado charts for the NPV and IRR.

- The factors associated with maximum change on NPV are the sales price, feed cost and to smaller extent is the construction time. The high feed cost and the low sales price may decrease NPV to a value less than the project investment which made the project unfeasible

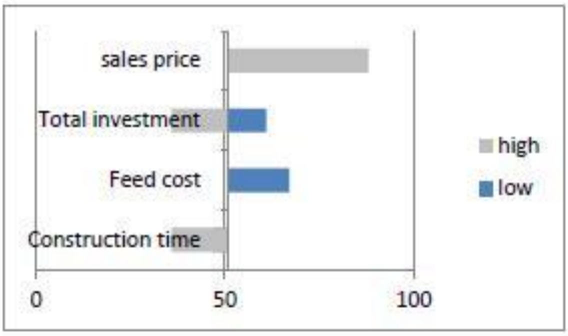

Fig. 2: Tornado chart for 2nd option with IRR base 54%.

- The factors associated with maximum change on IRR are the sales price, feed cost and to smaller extent is the construction time.
- It is clear that the sales price and feed cost are the most influential input parameter for both NPV and IRR, also it could be concluded even with the change in these parameters the 2ndoption still feasible and can withstand the volatile market, which is simulated, by these changes.

5.4. Sensitivity analysis for the 3rd option.

The sensitivity analysis has been performed for the various specified ranges of the input variable parameters shown in Table 5.

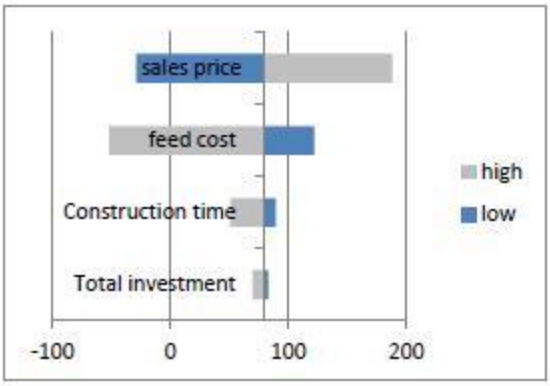

Fig. 3: Tornado chart for 3rd option with NPV base 79 MM$.

The output results, Figs (3 and 4) are arranged on tornado chart downward from largest width down to smallest width, and presented as tornado charts for the NPV and IRR and here are the results

- The factors associated with maximum change on NPV are the sales price, feed cost and to smaller extent is the construction time. The high feed cost or the low sales prices can make the project unfeasible

- The factors associated with maximum change on IRR are the sales price, feed cost and to smaller extent is the construction time. The parameters sales price and feed cost turned the NPV to negative, because of this, the IRR was not calculated, and the change in the magnitude was not shown on tornado chart either.

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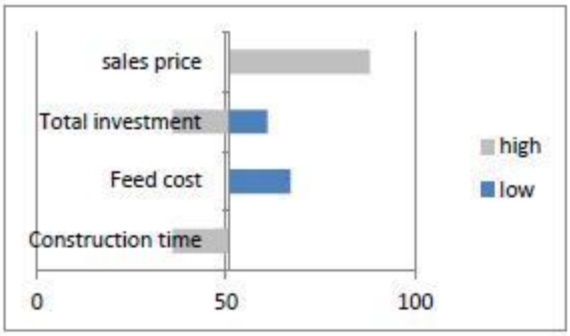

Fig. 4: Tornado chart for 3rd option with IRR base 51%.

6. Conclusions

In this study, four schemes regarding the upgrading of Mixed C4 stream from Raslanuf ethylene plant were studied. The cash flow method was used for the economic evaluation. The parameters, which were used, are net present value NPV, internal rate of return; IRR and simple payback period, all are evaluated for each case and the conclusion as follows:

- The 1st option was dropped because it will lead production of LPG, which is already available at Rasco refinery and can be used to reduce the consumption of naphtha feed to ethylene plant. This method were studied before in many literatures and was shown to be the least profitable [2].
- The 4thoption and the other process, which depend on the use of external raw material (Methanol),was also dropped because this study will focus on the raw materials that already available on site only.
- The two studied options (2 and 3) are profitable. Similar results have been reported [2, 4, and 10].
- The option that has the most attractive economic indicators is 2ndoption. Some of reasons behind this are the relatively low total investment in comparison to option 3.The feature that it consumes Mixed C_4 feed only, gives it advantage over option3, which consumes ethylene and small amount of hydrogen, which are considered as highly expensive raw materials.
- Sensitivity analysis was carried out because the margins between the economic parameters were tight to determine the most influential factor on the projects profitability as measured by NPV and IRR.
- Sensitivity analysis showed that the most influential parameters that affect the project are sales price and the feed cost.
- Tornado charts were used to illustrate the effect of each input parameter on the different economic indicators used in this study .These charts showed that option2 is less risky in comparison to option 3 and can withstand the expected global changes in prices better than option 3.

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