



Optimization of Propylene Production Process from Fluid Catalytic Cracking Unit

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ABSTRACT

This study explored the flexibility of FCC unit of a typical Refinery, in Optimizing Propylene, a feedstock for the petrochemical industry. This was achieved using Aspen Hysys (version 7.1), a chemical process software to systematically manipulate the reactor's temperature, pressure and catalyst activity variables in the FCCU. Result from the simulation showed that increase in temperature, pressure and ZSM-5 additive increases the propylene product yield and also enhances the MON and RON of gasoline. It is observed also that, there is a drastic rise in olefin product yield as the temperature rises and an increase in ZSM-5 catalyst additive. The product yield variation at a catalyst additive of 0.196 of a gradual increase in the temperature, it is seen that the reactor would only operate at an optimum temperature range of 520 – 540°C

Key words: Propylene, Optimization, FCCU, ZSM-5 zeolite

INTRODUCTION

Refineries also produce petrochemicals in addition to fuels. Petroleum refining processes generate light olefins as well as aromatics (especially benzene, toluene, and xylenes). In periods of high gasoline demand, refining operations tend to be optimized to maximize production of fuels; chemical co-production mode is not emphasized. In the future scenarios, there will be opportunities to shift from fuels emphasis to increased chemical production [5]. In addition to recovering chemical products co-produced in the refinery, transitional streams can be channelled to chemical production facilities such as steam crackers for ethylene and propylene production, and naphtha reformers for aromatics production. Again, disposition of intermediate refinery streams to chemical production facilities will become more advantageous as refinery fuel product demand is impacted by the new trends [5]. A large proportion of propylene is produced by steam cracking of light naphtha and during the fluid catalytic cracking process. Maximization of propylene production has become the focus of most refineries because it is in high demand and there is a supply shortage from modern steam crackers, which now produce relatively less propylene [1]. The flexibility of the fluid catalytic cracking (FCC) to various reaction conditions make it possible as one of the means to close the gap between supply and demand. The appropriate modification of the FCC process is accomplished by the synergistic integration of the catalyst, temperature, reaction-residence time, coke make, and hydrocarbon partial pressure [1].

Propylene is second in importance to ethylene as a raw material for petrochemical manufacture. The largest source of petrochemical propylene is that produced as the primary byproduct of ethylene manufacture. Ethylene plants charging liquid feedstock typically produce about 15 wt% propylene and provide almost 70 percent of the propylene consumed by the petrochemical industry [4]. Since Steam crackers produce more ethylene than propylene, and its construction is tied to the demand for ethylene, there is need to create more channels for the production of propylene. One of such is FCC produced propylene. This will help in meeting with the increase in demand in propylene and bridge gap in future. Also, since the construction of FCC units is driven by the demand for gasoline instead of propylene, most of the increased propylene supply will have to come from proper utilization of FCC flexibility towards increasing propylene.

LITERATURE REVIEW

Fluid Catalytic Cracking development started in the 1930's. From different findings, under proper conditions, finely divided solids could be made to flow like liquids. Such small particles offered advantages in heat transfer and mass diffusion over the large catalyst pellets used in other processes. For catalytic cracking, fluid phase seemed to be very advantageous also from the point of view of very quick heat transfer because of strong endothermic effect during cracking of feed and strong exothermic effect in the coke-burning regeneration [3].

A major breakthrough in catalyst technology occurred in the mid-1960s with the development of zeolite catalysts. These sieve catalysts demonstrated vastly superior activity, gasoline selectivity, and stability characteristics compared to the amorphous silica-alumina catalysts then in use. The availability of zeolite catalysts served as the basis for most of the process innovations that have been developed in recent years [2]. The continuing development, first in catalyst activity and then in process design led to achieving more product within the dilute phase of the riser, or riser cracking as it is commonly called. In 1971, UOP commercialized a new design based on this riser cracking concept, which was then quickly extended to revamps of many of the existing units. Commercial results confirmed the advantages of this system compared to the older designs. Riser cracking provided a higher selectivity to gasoline and reduced gas and coke production that indicated a reduction in secondary cracking to undesirable products [2] Although the mechanical configuration of individual FCC units may differ, their common objective is to upgrade low value feedstock to more valuable products.

Since the start-up of the first commercial FCC unit in 1942, many improvements have been made. These improvements have enhanced the unit's mechanical reliability and its ability to crack heavier, lower value feedstock. The FCC has a remarkable history of adapting to continual changes in market demands [6]. This trend has continued throughout the years as process designs emphasize greater selectivity to desired primary products and a reduction of secondary by-products.

Description of FCC Unit of a Typical Refinery

The purpose of the Fluid Catalytic Cracking (FCC) process of any refinery is to convert feed, heavy oil to lower boiling, high value products, primarily C3-C4 LPG, gasoline and light cycle oil. This is achieved using vapor phase chemical reactions in the presence of specialized FCC cracking catalyst during which the long molecular chain of the feed is cracked into shorter chain molecules. Heat for the cracking process is supplied by the hot regenerated catalyst which vaporizes the finely atomized oil feed and sets the stage for the rapid and selective cracking process. The vaporization and cracking reactions occur in the reactor riser. As by-product of the reaction, fuel gas, slurry oil, and coke are also generated in the reactor riser. The reaction section of this unit particularly includes reactor, catalyst regenerator and product separation.

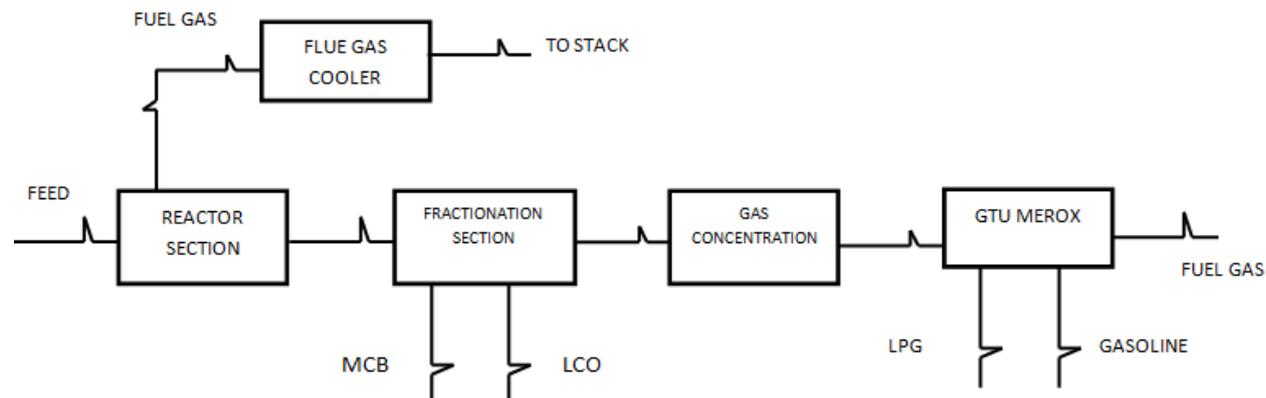


Fig. 1 FCC Unit Block Flow Diagram Of Typical Refinery

IMPORTANT DESIGN FEATURES OF FCC UNIT

Feed Nozzles

The feed (VGO, HDO and Steam) enters the Riser through the distributor nozzles at the Riser base and meets hot regenerated catalyst.

Reactor Riser

The cracking reactions take place during the residence time in the riser as the reaction mixture (composed of the feed and the catalyst) accelerates toward the Riser 'tee' Separator System at the top of the riser. Riser design allows reaction to take place in selective environment; maximizes catalytic reactions while minimizing thermal reactions.

Riser Terminal

'Tee' shaped outlet replaced the riser cyclones giving a good catalyst oil separation and lower equipment cost.

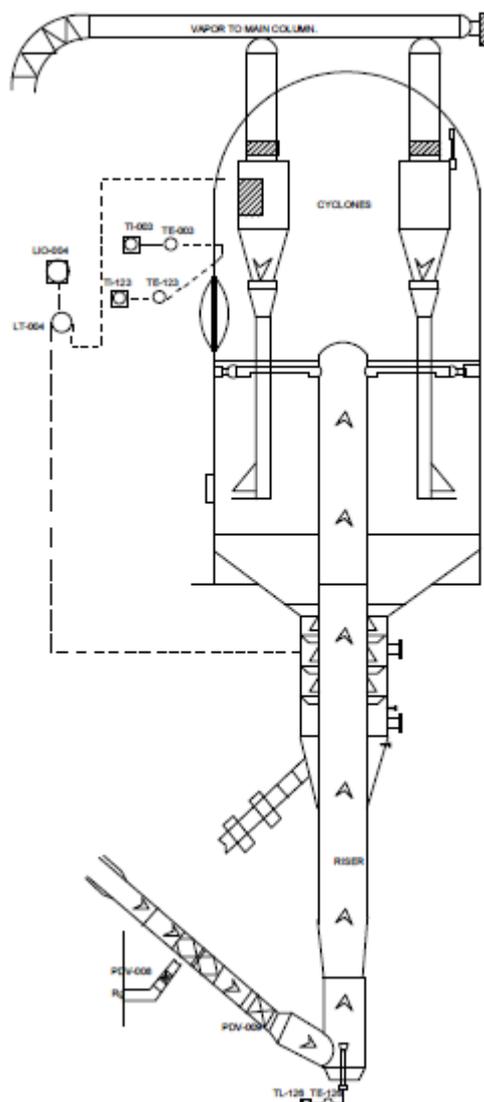


Fig. 2 Riser Reactor

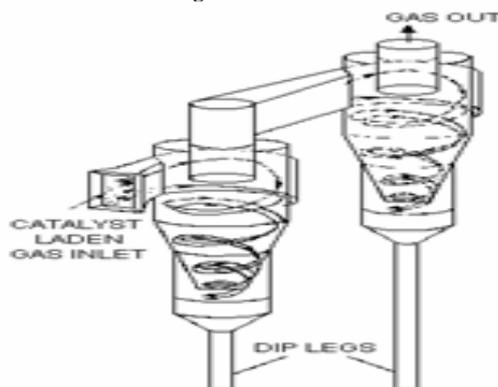


Fig. 3 Cyclone System

Reactor/Regenerator Cyclones

The vapor/flue gas leaving the Reactor/Regenerator will carry off the smaller catalyst particles with it. The cyclones are used to remove most of the catalyst particles from the Reactor/Regenerator vapor/flue gas. The larger particles are removed through inertial forces, which tend to keep the particle moving in a straight line to collide with the wall, and centrifugal forces, which tend to throw the particle outward to collide with the wall. The collisions slow the speed of the particle and it tends to fall into the cyclones dip legs and return to bed. The drag forces of the gas will tend to carry the catalyst particles with it, but only the smaller ones are light enough to stay with the gas, because the inertial and centrifugal forces acting on them are small. The catalyst carry over must be max. 1000 wt. ppm in MCB.

Disengager

The reactor in this case can be called 'Disengager' as very little reaction takes place here.

Slide Valves

Slide valves are used to control catalyst/flue gas flow. All are gate valves provided with independent hydraulic oil system to ensure a reliable and stable operation. There are Regenerated Catalyst S/V and Spent Catalyst S/V.

Reactor Stripper

The steam to the stripping section is distributed through a number of small holes in the chest. A rate of 1-2 kg /1.000 kg catalyst is normal. It allows efficient contact between the catalyst and steam to displace the volatile hydrocarbons contained on and in the catalyst particles before they enter the regenerator, where coke will be burnt off. The displaced hydrocarbon vapors and most of the steam go up.

Plenum Chamber

The plenum chamber is a dome shape design which receives the flue gas from all the six pairs of regenerator cyclones. The Flue Gas leaving the Plenum Chamber enters the Orifice Chamber.

Regenerator Air grid

The Air Grid is Dome shape design with about 900 nozzles. The Air Grid distributes the combustion air evenly across the bed in the regenerator. A well distributed source of combustion air is essential for good, evenly distributed catalyst regeneration without after burn. The Air Grid is designed to operate satisfactorily at the minimum turndown design for the unit. The pressure drop across the grid is kept above 0.07 Kg/cm² at turndown to maintain adequate distribution and prevent intrusion of catalyst below the Air Grid and avoid associated erosion.

Torch Oil Nozzles

During the start-up, torch oil is used to heat the catalyst to its operating temperature. The torch oil nozzles provide fine spray of heavy oil injected into the dense bed of air preheated catalyst when extra heat is needed. The torch oil is used when the temperature in lower Regenerator is above 400°C (ideal 415-430°C).

Expansion Joints

Expansion joints are critical equipment in FCC, an expansion joint is used to allow movement of the system as it heats up. The expansion joints at the Regenerator/Reactor stand pipes accommodate the relative expansion difference between the Regenerator and Reactor

Orifice Chamber

The orifice chamber is provided to reduce the pressure of the flue gas leaving the regenerator. The orifice chamber has six grids with different number of holes.

Flue Gas Cooler

The purpose of the Flue Gas Section is to recover thermal energy from the flue gas leaving the Regenerator. The energy is used to produce 42Kg/cm² superheated steam. Recovering this energy increase the efficiency of the unit.

Stack

The Stack is provided at the outlet of the Flue Gas Cooler and Incinerator to safely evacuate the flue gas to atmosphere.

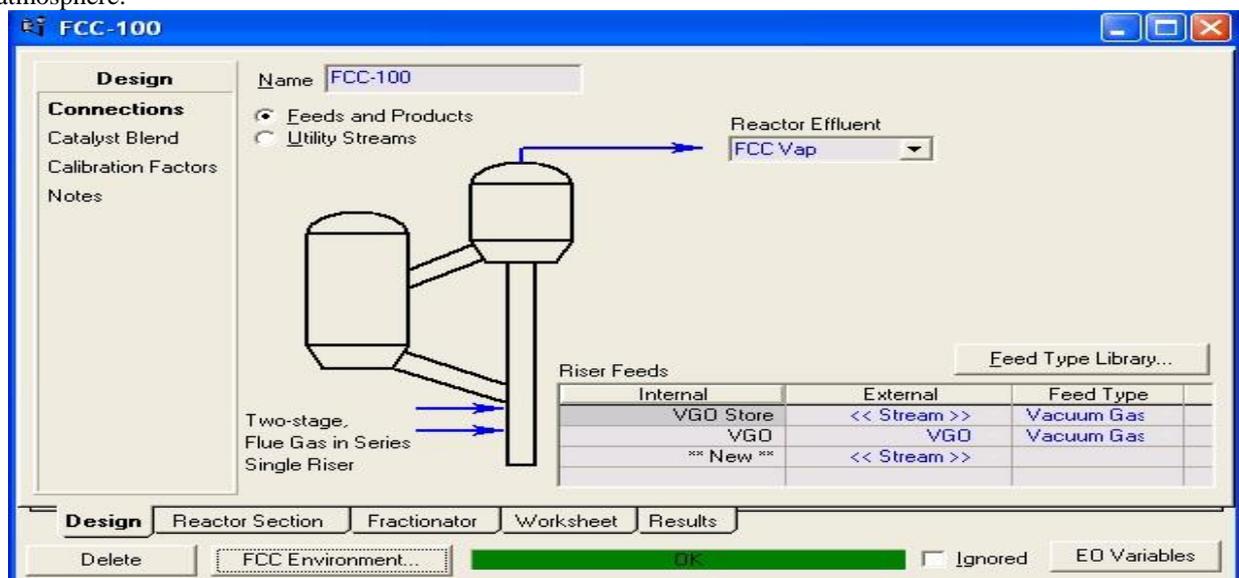


Fig. 4 FCC Design

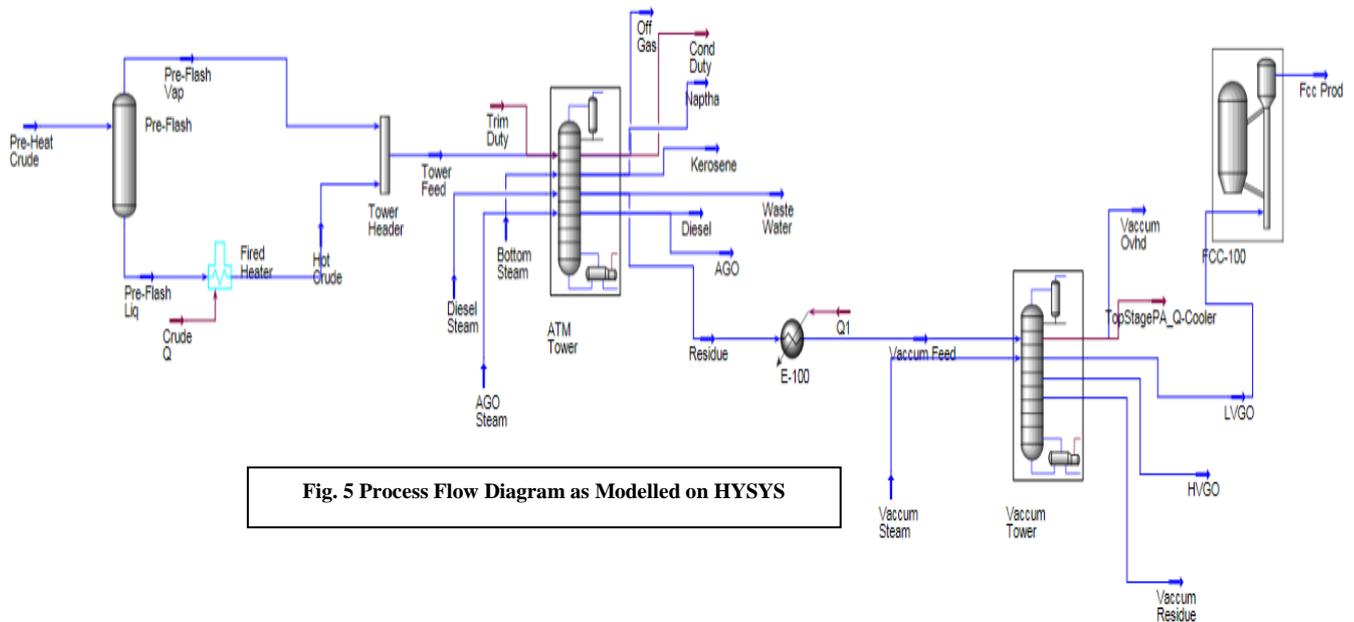


Fig. 5 Process Flow Diagram as Modelled on HYSYS

FCC-100				
Results				
Feed Blend				
Product Yields				
Product Properties				
Riser/Reactor				
Regenerator				
Fractionator				
Heat Balance				
Advanced				
Yields				
<input checked="" type="radio"/> Standard cut grouped <input type="radio"/> Standard cut detailed				
	Volume Flow [m ³ /h]	Mass Flow [kg/h]	Volume % [%]	Weight % [%]
H ₂ S		1632.4787		0.8722
Fuel Gas	7.2798	6197.8610	3.5747	3.3114
Propane	7.5165	3818.4547	3.6910	2.0401
Propylene	25.6681	13319.4608	12.6042	7.1163
nButane	4.6243	2701.6989	2.2708	1.4435
iButane	12.4625	7029.9623	6.1196	3.7560
Butenes	25.2268	15372.6228	12.3875	8.2133
Naphtha C5-430F	99.6623	76208.9138	48.9386	40.7168
LCO 430-650F	32.9135	29603.4326	16.1620	15.8165
Bottoms 650F+	16.2102	17845.7564	7.9599	9.5346
Coke Yield		13437.7056		7.1795
Total	224.2844	187168.3477	110.1334	100.0000
Conversion			75.8781	74.6489

Fig. 6 Product Yields From the FCC

PROCESS SIMULATION PROCEDURE

Collection of Data

Operating Data and Process flow Diagram of Fluid Catalytic Cracking Unit (FCC) were collected from a typical refinery and a model was developed with the data in a simulator, using Aspen Hysys (version 7.1)

Process Description

Fig 5 shows the process flow diagram as modeled using HYSYS version 7.1. The Simulations were performed using the data collected. The procedures for process simulation mainly involve defining chemical components (crude assay), selecting a thermodynamic model, choosing proper operating units and setting up input conditions (flow rate, temperature, pressure, catalyst information and other conditions). Data on most components, such as water, hydrocarbons, oxygen, CO, CO₂, NO₂, SO₂, is available in the HYSYS component library. To represent the refinery process and FCC unit in Aspen HYSYS, a process flow diagram (PFD) was built. In Simulation Basic Manager, a fluid package was selected along with the components which are to be in the input stream. In the process, Peng-Robinson was selected as the fluid package as it is able to handle hypothetical components (pseudo-components). Most of the heat utilities information was assumed in order to develop the model. The main processing units include riser reactor, Regenerator, Distillation Column, Vacuum Distillation column, Valves, Cooler and heaters. After the input information and operating unit models were set up, the process steady-state simulation was executed by Hysys. Mass and energy balances of each unit, as well as operating conditions and model of FCC was obtained. Fig 5.0 shows the FCC design on the simulator window.

Table -1 Simulation Result as Analyzed In an Excel Spreadsheet

Input Factors						Output Parameter				
Reactor/ Riser Temp(0c)	Reactor Pressure (Kpa)	ZSM-5 activity	Propylene (%)	Butenes (%)	Naphta (C5-430F)(%)	LCO (430-650)(%)	MON (C5-265)	MON (265-430F)	RON (C5-265F)	RON (265-430F)
530	340	0	4.61710732	6.17494898	45.9893284	15.90459288	94.4339326	92.6327056	83.5137382	80.7633724
530	340	0.02	5.1170526	6.58267848	44.9362021	15.88636928	94.8653922	93.0053071	83.9309656	81.1249196
530	340	0.04	5.61693061	6.99036744	43.8825284	15.8684183	95.29688	93.3777985	84.3481403	81.4863369
530	340	0.06	6.11674294	7.39801019	42.8282498	15.85076585	95.728396	93.750179	84.7652552	81.8476215
530	340	0.08	6.61649034	7.80559887	41.7732808	15.83345204	96.1599406	94.1224452	85.1823	82.208767
530	340	0.1	7.11617225	8.21312196	40.7174903	15.81653991	96.5915155	94.4945898	85.5992594	82.5697616
530	350	0	4.65638905	6.20961771	45.811058	15.92865423	94.4344504	92.6305939	83.5120241	80.7606847
530	360	0	4.69418269	6.24218105	45.619294	15.95916173	94.4354605	92.6264737	83.5086796	80.7554409
530	370	0	4.73042689	6.27285101	45.4224988	15.99126483	94.4366478	92.6216311	83.5047488	80.7492776
530	380	0	4.76516359	6.30181815	45.224937	16.02287551	94.4378706	92.6166439	83.5007005	80.7429302
530	390	0	4.79847774	6.32923447	45.0282475	16.05350709	94.4390888	92.6116752	83.4966673	80.7366064
530	400	0	4.83045672	6.3552153	44.8328069	16.08335588	94.4403068	92.6067076	83.492635	80.730284
520	340	0	4.26588037	5.80297106	45.7068598	16.86834591	93.5933542	90.9503488	83.4970105	79.3749182
530	340	0	4.61710732	6.17494898	45.9893284	15.90459288	94.4339326	92.6327056	83.5137382	80.7633724
540	340	0	5.18107187	6.71189614	44.9740829	14.91453477	95.28052	94.2905544	83.5105721	82.1206345
550	340	0	6.1165791	7.50294108	41.688036	13.96876107	96.1367077	95.9092469	83.4756217	83.4280613
560	340	0	7.60235802	8.60187633	35.0724516	13.17600639	97.0040576	97.4824165	83.4037185	84.6775496
570	340	0	9.73697153	9.97196762	24.5421887	12.59833162	97.8815365	99.0142724	83.2982801	85.874457

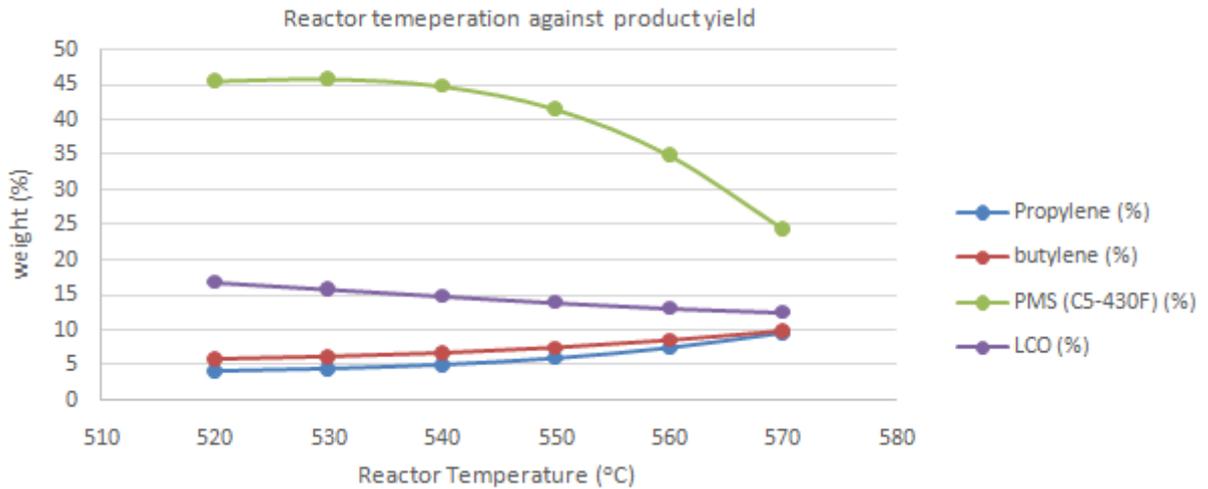


Fig. 7 Reactor Temperatures against Product Yield

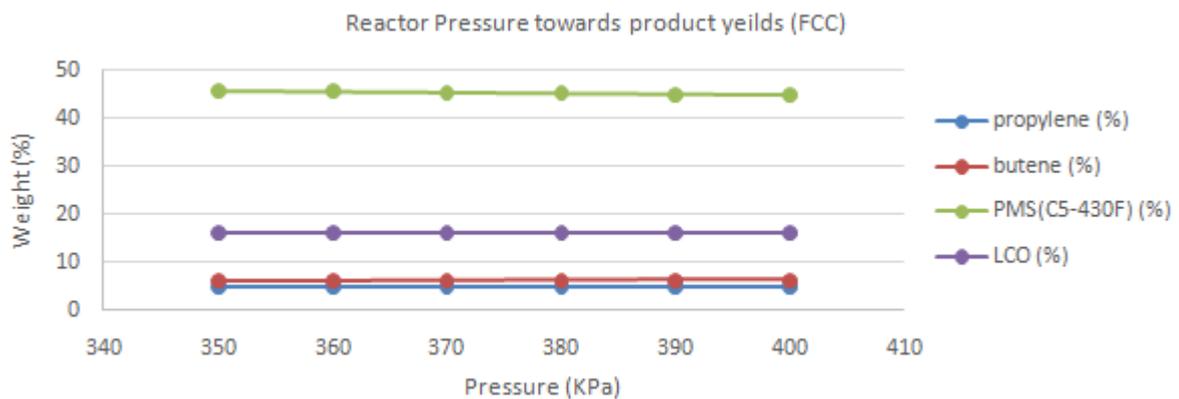


Fig. 8 Reactor Pressure against Product Yield

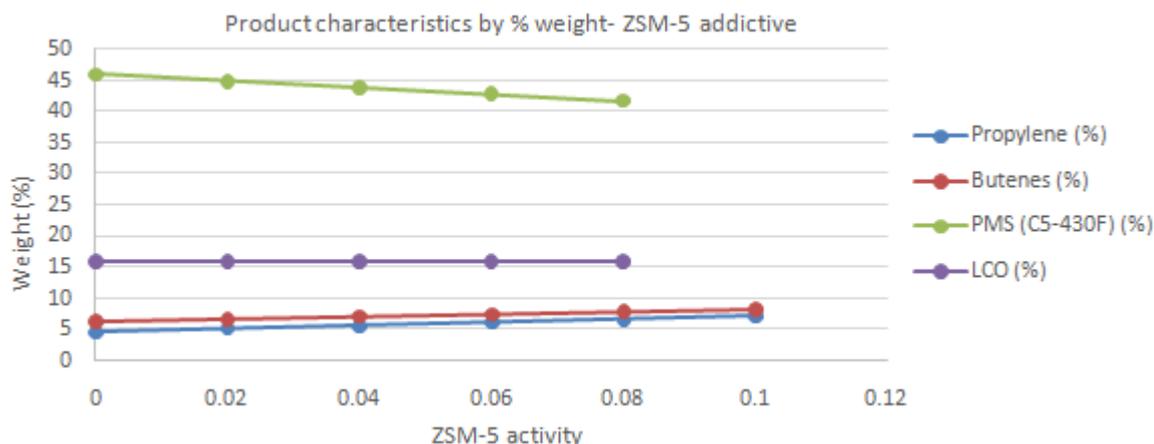


Fig. 9 Effect of Zsm-5 Activity on the Product Yield

Table- 2 Optimum Temperature Range for Optimization

Reactor / Riser Temp (Oc)	Reactor Pressure (KPa)	ZSM-5 activity	Propylene (%)	butenes (%)	Naphta (C5-430F)(%)	LCO (430-650)(%)
520	340	0.196	8.795880038	9.556082501	35.99234671	16.70227108
530	340	0.196	9.511785182	10.16218232	35.55409605	15.78327463
540	340	0.196	10.66524033	11.03901431	33.40036432	14.8454727

RESULT AND DISCUSSION

The result of the simulation was analyzed in an excel spreadsheet Table- 1, the product yield from the FCC unit is shown on fig 6.0. Process variables discussed in this section are, reactor temperature, reactor pressure, and Zsm-5 activity. From Fig 7, shows that increase in the reactors temperature, results to drastic drop in PMS production after 530°C, large drop in LCO Production, drastic Increase in Olefins production, Convergence of propylene and butylenes production having a larger % increase in butylenes yields. In Fig 8, an increase in the Reactor pressure, results in slight drop in PMS production, negligible drop in LCO Production, Slight Increase in Olefins production. In Fig 9, an increase in the ZSM-5 catalyst causes the drop in PMS production, slight drop in LCO Production, increase in Olefins production, Greater percentage increase in propylene than butylene production, and also it is observed that ZSM-5 additive truncates at 0.196% addition in the *HYSYS* simulation. Table -2 shows that at the optimum temperature range of 520 – 540°C and at catalyst activity of 0.196, there is increase in olefin production.

CONCLUSION

Based on this study it can be concluded that increase in riser reactor temperature, increases the yield of propylene in an FCC unit. There is sharp decrease in PMS and LCO yield when the temperature is increased. The MON and RON octane number are not affected with the increase in temperature. There is no significant effect of change in pressure on the product yield. Also increase in ZSM-5 additive results in greater %Increase in propylene production from FCC unit. There is a drop in PMS and LCO production with increase in ZSM-5 activity. ZSM-5 additive truncates at 0.196% addition in the hysys simulation and since there is a drastic rise in the olefin product yield as the temperature rises and also an increase in ZSM-5 catalyst additive, the product yield variation at a catalyst additive of 0.196 of a gradual increase in the temperature. Shows that the reactor would only operate normal at a temperature range of (520 – 540) °C

REFERENCES

- [1] AM Aaron, Maximizing Propylene Production via FCC Technology, *Appl Petrochem Res, Springerlink Publication*, USA, **2015**.
- [2] CL Helmer and FL Smith, *UOP Fluid Catalytic Cracking Process*, Chapter 3.3, UOP LLC Des Plaines, Illinois, **2004**.
- [3] P Hudec, FCC Catalyst- Key Element in Refinery, *45th International Petroleum Conference*, Bratislava, Slovak Republic, **2011**.
- [4] NM Philip, *Future Refinery- FCC Role in Refinery/Petrochemical Intergration*, Kellogg, Brown and Root Inc. Houston Texas, USA, **2001**.
- [5] P Ruzika, *Opportunities for Refinery and Petrochemical Plant Integration*, Carmagen Engineering Inc. New Jersey, **2014**.
- [6] R Sadeghbeigi, *Fluid Catalytic Cracking Handbook, Design, Operation and Troubleshooting of FCC Facilities, 2nd Edition*, Gulf Professional Publishing, USA, **2000**.