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Automation of FCC Centered Oil Refinery for Diesel Maximization

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Abstract: Oil refining is an industrial process which involves separation, conversion and finishing. FCC centered refinery uses Fluid Catalytic Cracking Unit (FCCU) has the major conversion unit. FCCU is responsible for the production of petrol, LPG and Light Cycle Oil (LCO). Diesel is the most important fuel used in automobiles because of its high efficiency. The global demand for diesel is increasing than petrol but many older refineries have optimised their plant for producing more petrol than diesel. LCO is the diesel boiling range material, which is produced in addition to gas and petrol in the FCCU. LCO is treated in the diesel hydrotreater (DHT) unit to produce low sulphur environment friendly diesel. In this paper, production of LCO is increased in the FCCU by employing medium conversion mode rather than using traditional low conversion mode. Low conversion mode will cause a loss of gas production, deteriorate petrol octane rating and also increase the production of low valued slurry oil. With medium conversion technique both gas quality and quantity is maintained and improves the petrol octane rating. Medium conversion mode also reduces the amount of low valued slurry oil. Slurry oil contains LCO boiling range material in it, hence a separate slurry oil stripping tower is employed to recover the LCO from slurry oil. The control of Fluid Catalytic Cracking Unit is complicated as it involves numerous parameters to be monitored and controlled. Hence Distributed Control Systems (DCS) is employed to automate the FCCU Process.

Keywords: Fluid Catalytic Cracking, LCO, Distributed Control Systems, Diesel Maximization.

I. INTRODUCTION

The worldwide demand for the diesel is expected to rise by 5million barrels per day. Consumption of ultra-low sulphur diesel is projected to increase at a rate faster than petrol over the next 10 years [13, 14]. As a result, refining companies are examining different cost effective techniques to increase the diesel yield. Diesel maximization is the term refers to increasing the amount of diesel extracted from the crude oil. Fluid catalytic cracking (FCC), a type of conversion unit, is primarily used in producing petrol in the refining process. Fluid catalytic cracking is a refinery process that is used to create petrol and other distillate fuels from larger molecules using catalyst. The catalyst is a solid zeolite material that is made fluid by the hot vapour and liquid is fed into the FCC. As the catalyst is fluidized due to heat, it can circulate between reactor and regenerator vessels. After the feed is cracked through contact with the catalyst, the resulting vapour is processed in fractionators, which separate the fractionator feed based on various boiling points into several intermediate products like lighter hydrocarbons, petrol, light cycle oil and slurry oil. The automation of fluid catalytic cracking process is done by identifying the important parameters to be measured and controlled and designing the control loops for the identified parameters.

In the fluid catalytic cracking unit, the important parameters are reactor temperature, feed flow rate, lift steam flow rate, hot regenerated catalyst temperature, spent catalyst temperature, feed temperature, reactor liquid level, regenerator temperature, regenerator air flow rate, light cycle oil flow rate, petrol flow rate, stripping steam flow rate and main fractionator top temperature. Using distributed control systems, transmitters and control valves are linked with the controllers. The control loops are designed using control drawing builder function present in the DCS software. Various operator windows like overview view, control group view and graphics view are designed to monitor and control the process effectively. Araromi et aldiscussed the performance of proportional integral controllers for the control of condenser liquid level in the condenser drum of Fluid catalytic cracking unit [1].Carla I.C. Pinheiro et al discussed about the FCC process, that converts gas oil into valuable products like petrol, light cycle oil. [2]. Hasan Sildir et al discussed about the importance of controlling regenerated catalyst flow rate, spent catalyst flow rate, regenerator air flow rate and regenerator temperature in FCCU [3,4]. Ilshat Sharafutdinov et aldiscussed the evaluation of increasing Euro V diesel production by increasing FCC LCO production. The FCC LCO production in the FCC conversion range between 60 and 79 wt. % is investigated in this paper [5].

II. PROCESS DESCRIPTION

In fluid catalytic cracking, the hot oil feed is contacted with the catalyst in the feed riser line of the reactor. As the cracking reaction starts, the catalyst is deactivated by the formation of coke on the surface of the catalyst. The spent catalyst and effluent vapours are separated before the catalyst enters the regenerator. The spent catalyst enters the regenerator and the coke is burned using the oxygen in the air. The oil vapours are taken to the overhead of the fractionation tower for to separate into streams having different boiling range [2]. The feed to an FCC is usually the High Vacuum Gas Oil which has the initial boiling point of 340C having the molecular weight of 600 or higher as shown in Fig.1. The FCC unit vaporizes the feed and catalyst mixture and breaks the long chain molecules into short chain molecules. The catalyst in the form of fluid is circulated continuously between the reactor and regenerator to ensure enough amount of catalyst is present in the reactor for proper reaction.

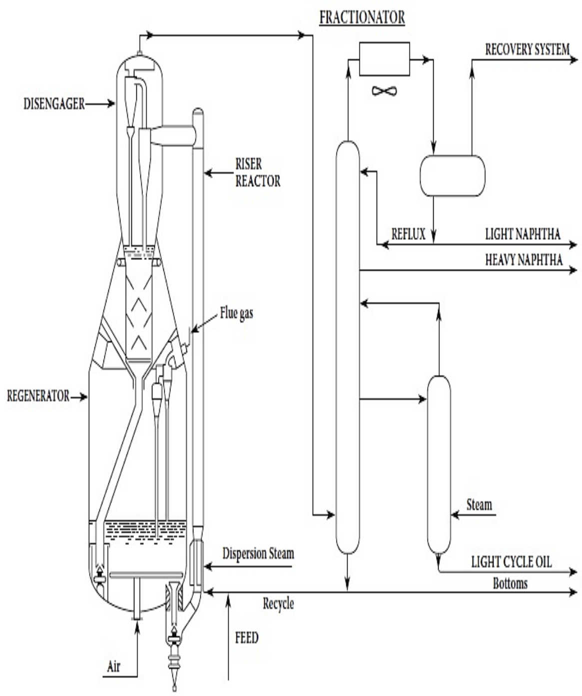

Fig. 1. Various sections of FCC Unit.

III. DISTRIBUTED CONTROL SYSTEM

A Distributed Control System (DCS) is control scheme for a plant, wherein control components are distributed throughout the system. A DCS uses custom processors as controllers and uses both proprietary and standard communication technologies. Input, output & communication cards form the components of the DCS. The processor gets information from input cards and sends information to output cards based on the calculation performed by processor. The input cards receive information from input instruments in the process (or field) and the output cards transmit instructions to the output instruments in the field. The inputs and outputs can be either analog signal or digital signals. DCS used in this paper is YOKOGAWA CENTUM VP DCS. Distributed control system has decentralised control function but the monitoring is centralised. The basic components of a DCS are Field Control Station (FCS), Engineering/Operator Station (ENG/HIS) & Communication Bus. FCS is the system where all the control functions are executed. The operator controls the plant from operator station. The same component can be used to do the configuration changes. The operator station is called the Human Interface Station (HIS) in CENTUM VP system. The component used for configuration is called the Engineering station (ENG). Both these components can reside in one hardware. The FCS and HIS are connected via a real time network called VNet/IP bus. This communicates all the parameters to and from the FCS to the HIS. Centum VP software is used to configure the input output cards, control loops and graphics for plant. This is also used to link the input / output cards with the controller. Graphics views are used by the operator to monitor and control the plant easily.

IV. IMPLEMENTATION

Control loops for reactor, regenerator, FCC main fractionator, FCC overhead section and FCC main fractionator stripping section are designed and implemented in the DCS. The fresh feed and recycle feed flow control loop controls the amount of feed that can be processed in the plant. Reactor temperature control loop is used to maintain the temperature of the reactor. Lift mediumis used to mix and rise the catalyst and feed to the riser zone. In the reactor, steam is used as lift medium. Hence the PID controller is employed to control the lift steam. Fig. 2 represents the reactor section control using the distributed control system. The pressure between the reactor and regenerator is regulated using slide valve present in the regenerator zone. Air provides oxygen for the combustion of this coke and is supplied by one or more air blowers. Air blower provides sufficient velocity and pressure to maintain the catalyst bed in a fluidized state. Cascade control is employed to operate air flow control valve. Primary controller measures the regenerator temperature and its setpoint is provided by the operator and secondary controller measures air flow and uses the setpoint provided by primary controller to control the air flow to the regenerator. Fig. 3 depicts the control of reactor section using the distributed control system.

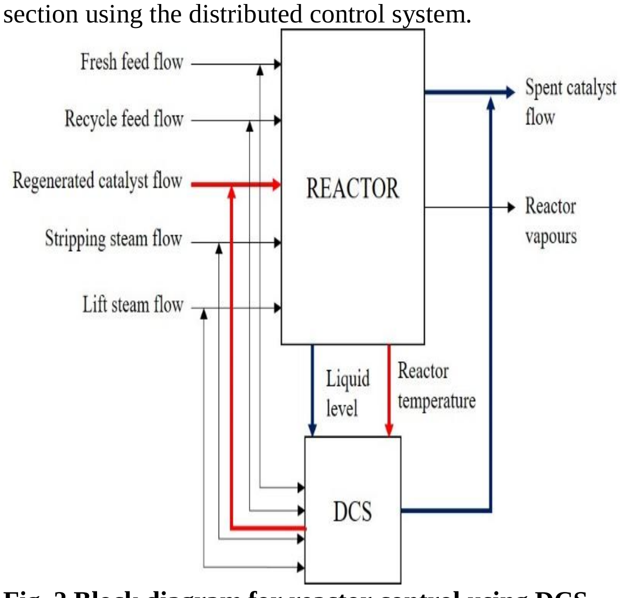

Fig. 2.Block diagram for reactor control using DCS.

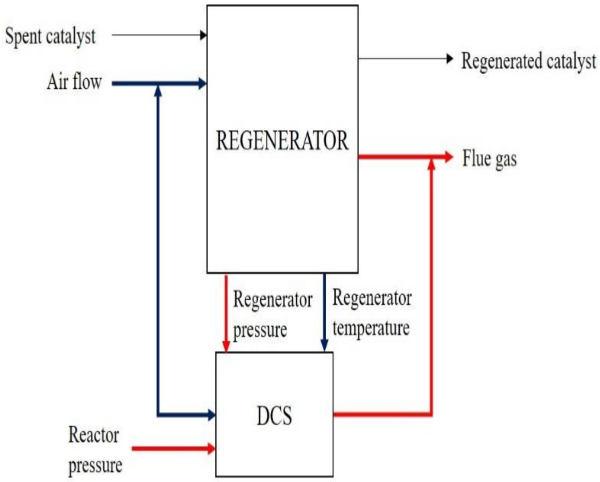

Fig. 3.Block diagram for regenerator control using DCS.

FCC main fractionator top temperature is controlled by temperature control loop to ensure that materials having boiling range below the petrol end point are sent to condenser drum. Fig.4. The vapours from the top of the FCC Main fractionator is cooled by passing the vapours through condensers. The condensed liquids are collected in the reflux drum. Some part of the condensed liquids are recycled back to the FCC main fractionator to increase vapour/liquid interface. The liquid level of the reflux drum is maintained at 50% to ensure enough amount of liquid is pumped backed to the fractionator.

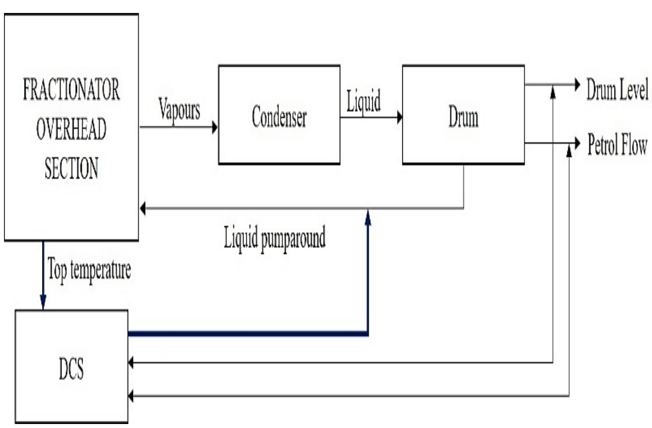

Fig.4. Block diagram for fractionator overhead control using DCS.

LCO is withdrawn from the main column and routed to LCO stripper for flash control. Fig. 5 represents the control of LCO stripper using the distributed control system. Liquid level in the LCO stripper column must be maintained at 50% to ensure enough amount of liquid is pumped backed to the fractionator. The operation of LCO stripping steam control valve is controlled based on the LCO stripping steam flow rate. LCO stripping control uses the PID controller. Slurry is bottom product of the FCC main fractionator. As slurry contains the LCO boilng range material, it must be recovered to maximize LCO production. Fig. 6 represents the control of slurry stripper using DCS. FCC bottom product is fed to the slurry stripper, which is a steam stripper to recover the LCO boiling range material. Bottom products of the slurry stripper are recycled back to the reactor through slurry settler.The operation of slurry stripping steam control valve is controlled based on the slurry stripping steam flow rate.

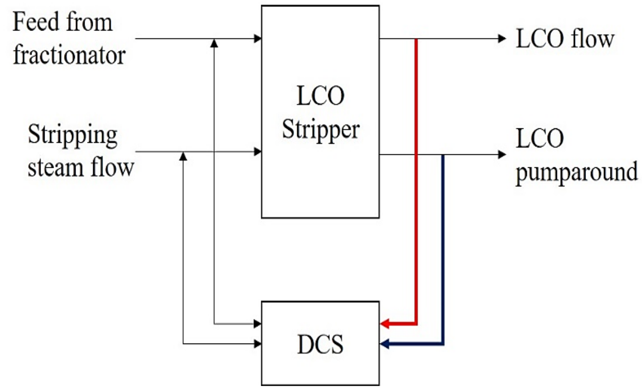

Fig.5. Block diagram for LCO stripper control using DCS.

All these control loops are implemented in the distributed control systems using the control drawing builder present in the Yokogawa Centum VP DCS.

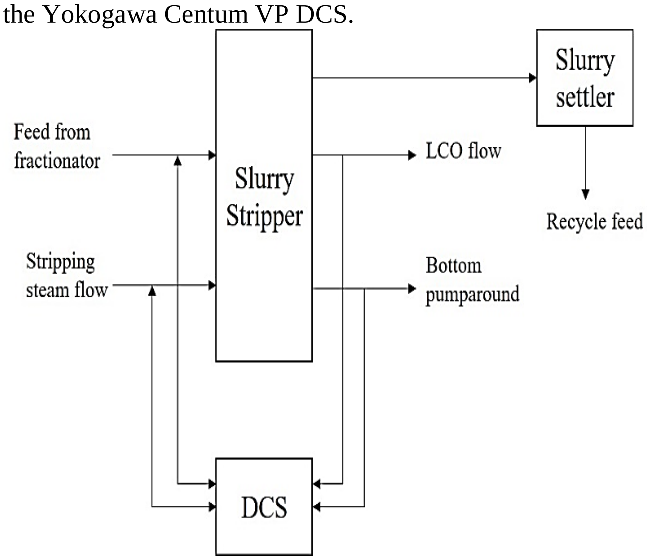

Fig.6. Block diagram for slurry stripper using DCS.

User defined windows are defined by the user based on the applications and display contents of the operation and monitoring. Graphic view display a graphical representation of the plant status, providing operation and monitoring environment. The concept of graphics view was introduced in the context of their applications to Piping and Instrumentation Diagrams. Fig. 7 displays the graphics view of the reactor regenerator section. Graphics view displays the current values of various transmitters, controllers and valves. With graphics view one can access the various instrument faceplates. Fig. 8 represents the FCC main fractionator section. This type of display helps an operator to maintain an accurate mental image of the effect that any control actions will have on the process, thereby minimizing errors in the plant operation.

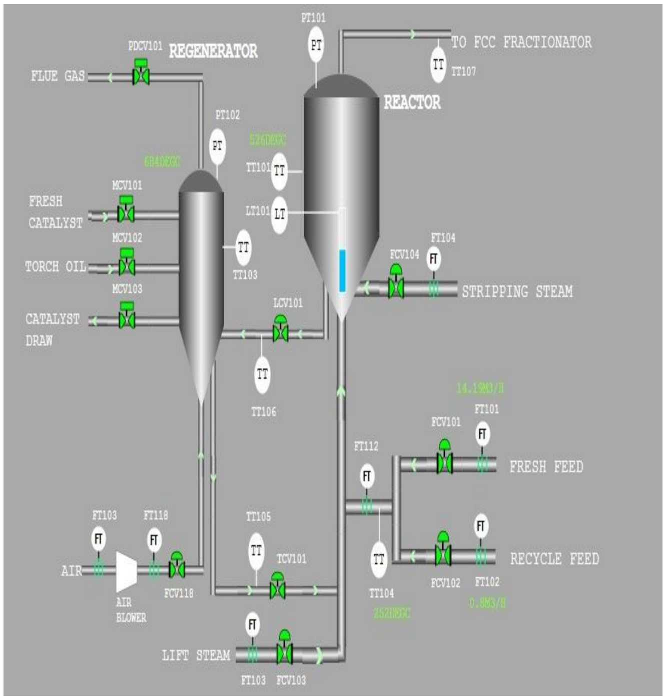

Fig. 7. Graphics view of reactor regenerator.

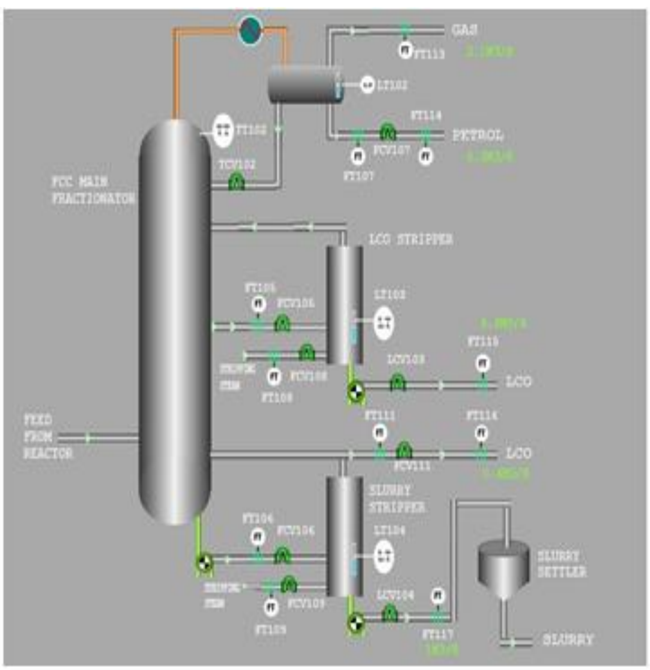

Fig. 8 Graphics view of FCC Main Fractionator.

IV. DIESEL MAXIMIZATION

LCO is the diesel boiling range material. Diesel is not made up of one single molecule, but rather a mixture of several different hydrocarbons. The major difference between LCO and diesel are the sulphur content and Cetane number.Combustion speed of the diesel is indicated by the Cetane Number. In a diesel engine, lower cetane fuels have longer ignition than higher cetane fuels. Table I tabulates the various countries diesel specifications compared with light cycle oil.

TABLE I: LCO VS. Diesel Specification

Property	Typical LCO	North America Diesel	Euro 5 Diesel
Sulphur, ppm	10000	≤15	≤10
Density, kg/m^3	900-960	875	820-845
Cetane Number	20-30	≥40	≥51
D-86 Distillation, °C	T_{90}≤345	T_{90}≤338	T_{95}≤360

Fluid Catalytic Cracking Unit is either operated in low or high conversion mode. Low conversion mode increases the amount of LCO production but octane rating of the petrol is reduced. Low conversion mode also increases the amount of low valued slurry oil. High conversion mode increase the amount of petrol and gas production but LCO quality and quantity is greatly reduced. To overcome the disadvantages of low and high conversion, medium conversion technique is employed. Medium conversion technique improves the quantity and quality of LCO without degrading the petrol octane rating.

TABLE II: Operating Conditions of FCCU

Operating Conditions	Conversion		
	Low	Medium	High
Riser Temperature (°C)	504	526	550
Feed Temperature (°C)	214	252	170
Catalyst to Oil Ratio wt/wt	6.6	6.7	11.4

Table II tabulates the various operating conditions of FCC. Fluid Catalytic Cracking Unit is operated in the medium conversion mode by changing the operating conditions of FCCU like riser temperature and regenerator temperature.

TABLE III: Product Yields of FCCU

Product Yields	Conversion		
	Low	Medium with Slurry stripping Tower	High
Gas (C3 + C4 + LPG), wt%	10.18	14.22	22.34
Petrol, wt%	43.21	41.95	46.00
LCO, wt%	27.42	29.5	16.01
Slurry, wt%	13.60	9.06	7.66
Coke, wt%	5.59	5.27	7.99
Conversion, wt%	58.98	61.44	76.33

As the FCCU is operated in the above condition the amount of LCO produced is increased to 29.5 % wt as shown in Fig.9. The amount of slurry produced is decreased to 9.06 % wt. when compared with the slurry produced in the low conversion mode. Table III tabulates the product yields of different conversion techniques. Table IV tabulates qualities of the different product from the FCC.FCCU product qualities are determined using the metrics like Petrol Research Octane Number (RON) / Motor Octane Number (MON) and API gravity.

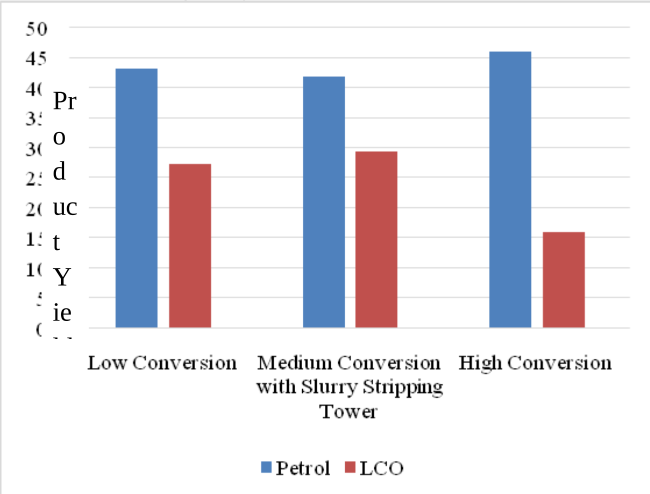

Fig.9. Petrol and LCO Yield.

TABLE IV: Product Qualities of FCCU

Product Qualities	Conversion		
	Low	Medium	High
Petrol RON/MON	90.7 / 80.5	93.9 / 82.6	95.6 / 84.4
LCO API Gravity, °API	22.2	17.0	11.3
LCO Hydrogen Content, wt%	10.7	9.9	8.8

The petrol RON/MON rating is improved in medium conversion when compared to low conversion mode. LCO API gravity is also improved in the medium conversion mode when compared with the high conversion mode. Based on the FCCU pilot plant data it is inferred that medium conversion technique produces the maximum amount of LCO with improved API Gravity. LCO API Gravity is improved in medium conversion technique when compared with high conversion technique.

V. CONCLUSION

This paper aims to maximize the LCO production in Fluid Catalytic Cracking unit and control the plant in a very effective way using Distributed Control Systems. The various components present in the FCCU along with their importance in running the FCCU efficiently are discussed. The result of this paper is to produce more quantity and quality LCO from FCCU without degrading the petrol octane rating using medium conversion technique and also to automate the complicated FCCU process by using DCS.

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