KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	KLM Technology Group www.klmtechgroup.com	Page : 1 of 98 Rev: 01 Rev 01- February 2017
KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru	Kolmetz Handbook Of Process Equipment Design REFINERY FLUIDIZED CATALYTIC CRACKING DESIGN, SIZING AND TROUBLESHOOTING (ENGINEERING DESIGN GUIDELINE)	Co Author: Rev 01 – Yulis Sutianingsih Editor / Author Karl Kolmetz

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These design guidelines are believed to be as accurate as possible, but are very general and not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

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INTRODUCTION

The fluid catalytic cracking process (FCC) is defined as a process for the conversion of feedstock like straight-run atmospheric gas oils, vacuum gas oils, and heavy stocks into high-octane gasoline, light fuel oils, and olefin-rich light gases. In the late 1950's, catalytic cracking was more than 60 per cent from all refingin cracking capacity. The features of FCC process are reliable operations and the ability to adjust the products.

Catalytic cracking process is typically applied on distilled gas-oil charge stocks with average yields about 40 – 45 % of gasoline. The process widey applied due to the minimal product yields of residual fuel oil compare to other process such as thermal cracking. Large volumes of olefinic production could be produced with good gas recovery, purification systems and further conversion to salable products like gasoline derivatives.

The goal of this refinery fluidize catalytic cracking gudieleine is to review the technical aspects of how a fluid catalytic cracking unt is designed and operates. Starting whih the history of fluid catalytic cracking technology, and how it has been improved for decades, what are the factors which influenced the process and how it corresponded to economical considerations.

History

The History of the catalytic cracking process is divided into minimal of four classes, including :

1. *Fixed-bed,*

   Houdry and cyclo-version catalytic cracking employed a series of chambers (Figure 1). Molten salt is circulated through tubes in Houdry cases and Houdry converters functioned as heat-exchanging agent, cooling during regeneration and heating during cracking reaction. After 9 – 15 minutes used, the activity of Houdry catalyst decreased signifincatly whilst cyclo-version catalyst could endure last longer of many hours.

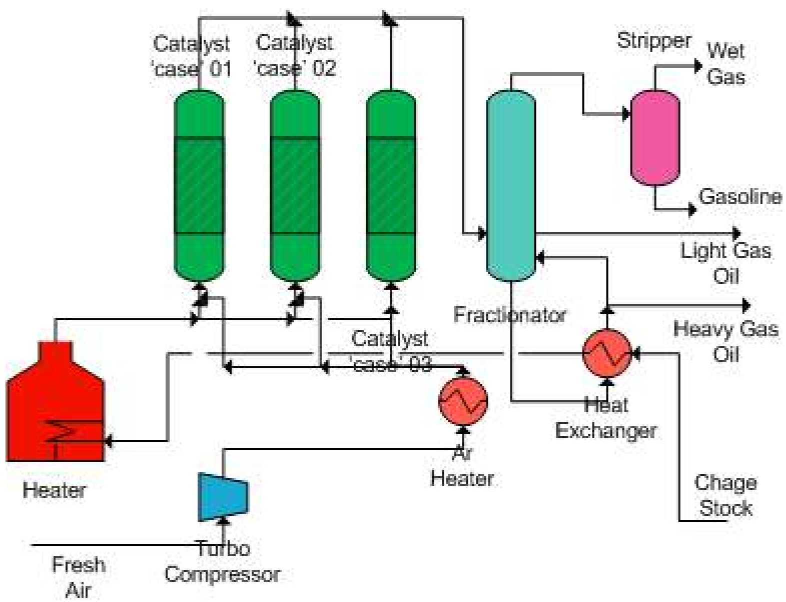

Figure 1. Fixed-bed process.

Although fixed-bed catalytic cracking units have been out of dated, they became a learning lesson of chemical engineering commercial development. The unit incorporated fully automatic instrumentation which provided a short time reaction, regeneration, purging cycle, a ovel molten salt heat transfer heat system, and an expander for recovering power to drive regeneration air compressor.

The process started by preheating feedstocks and blended it with reactor effluent and the vaporize them to temperature of 800°F. Heavier components separated before the rest of feed flew through the bottom of the upflow bed. The catalyst consisted of a pelletized natural silica-alumina (Si-Al). The case of reactor about 11 ft diameter (inside) and 38 ft height for a typical production of 15,000 bbl/d. Cracked products the passed the preheat exchanger to regain heat and then fractionated. Operating condition of reactor is about 30 lb/in^2gauge and 900°F

The reaction cycle of a single reactor was about 10 minutes, after that the feed would automatically switched to a second reactor that had been regenerated. First reactor was steam purged for 5 minutes for regeneration. Regeneration air was conducting under close control and carbon was burnt off at rate at which the bed could be controlled by recirculating molten salt steam.

The steam contained a mixtures of KNO_3 and $NaNO_2$. 10 minutes is total time for one cycle of reactor regeneration. Finally, the regenerated bed being purged of oxygen and automatically cut back into normal operation. Multiple parallel reactors were used to approach steady-state process. Reactor bed temperature varied widely during reaction and regeneration periods.

Catalyst regeneration normally provided by steam injection followerd by vacuum process to evacuating the last of oil vapor. Carbon burned from catalyst could be controlled by adjusting of hot air, flue gas, and also steam.

2. *Moving-bed,*

Thermofor cracking with bucket elevators (T.C.C, Thermofor Catalytic Cracking) and Houdriflow air-lift processes. The catalyst moves through the oil zone to react. Through regeneration zone where air continuously burnt the coke deposits upon catalyst's surface. The catalyst motion upward influenced by air or by bucket elevators reaching destined high and downward by gravity through the reaction and regeneration zones.

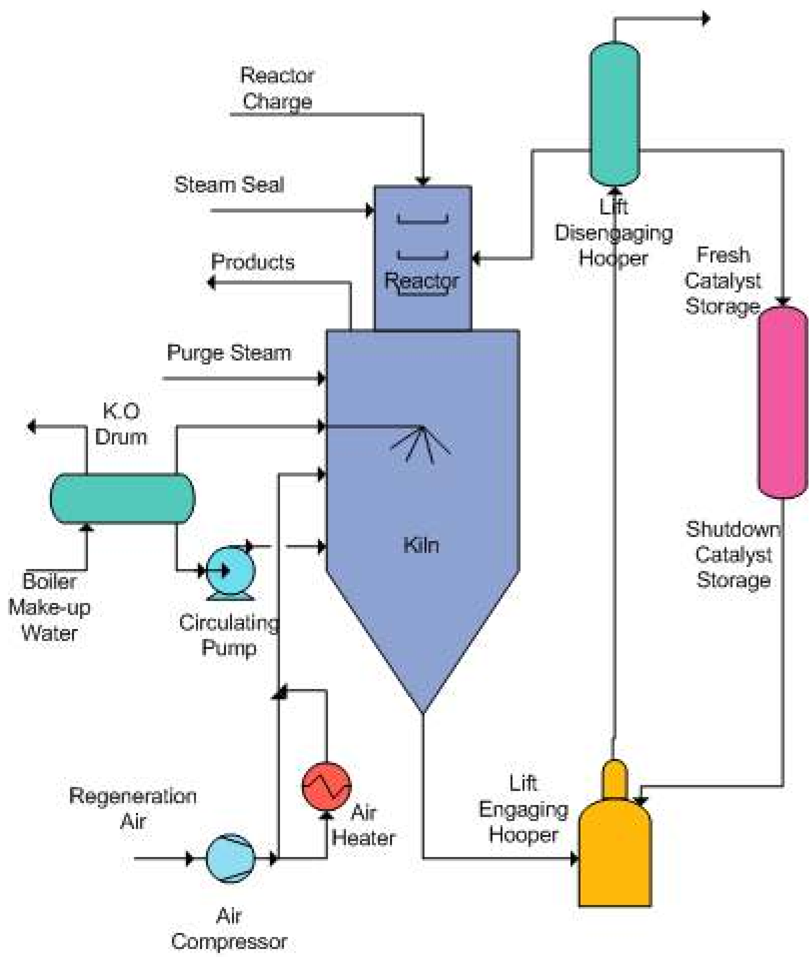

Figure 2. Moving Bed Process.

In the moving-bed processes (Figure 2), the catalyst is pelletized into 1/8 in diameter beads. Forced by gravitation, the beads moved downward through a seal zone to reactor that operated at 10 lb/in^2.gauge and about 900°F. After that, beads continue moved through another sealing and countercurrent stripping zone which operates at atmospheric pressure.

Table 1. T.C.C Yield

	Value
Operating Conditions	
Feed (bbl/d)	5775
Temperature (°F)	950
Throughput ratio	1.33
Conversion (% vol)	72.6
Catalyst	
Make- up (tons/d)	0.35
Purity (%)	50
Yields	
Fuel Gas (% wt)	6.4
Poly feed (% vol)	17.5
C5+ gasoline (% vol)	57.3
Light cycle oil (% vol)	18.0
Decant oil (% vol)	7.0
Coke (% wt)	7.0
RON	93.6

Regeneration air injected near the center of bed and moved upward and downward. Upward gas purposes to burn minimal 60% of coke. Meanwhile, downward gas aimed to complete burning process where catalyst temperature reach up to 1250°F. Two or three cooling water coils provided in bed for temperature control. Finally, the catalyst moved to the last seal zone where beads were recirculated to the top of column. Typical operation and yield cracking of feedstock with 26°API, 11.9 CF on zeolite catalyst proposed in Table 1.

3. *Fluidized-bed*

In the widely used fluid catalytic cracking (F.C.C), a very fine powdered catalyst is lifted into reaction zone within the incoming oil to the reaction which immediately vaporizes upon contact with catalyst. After the reaction complete, the catalyst is lifted into regeneration zone by air.

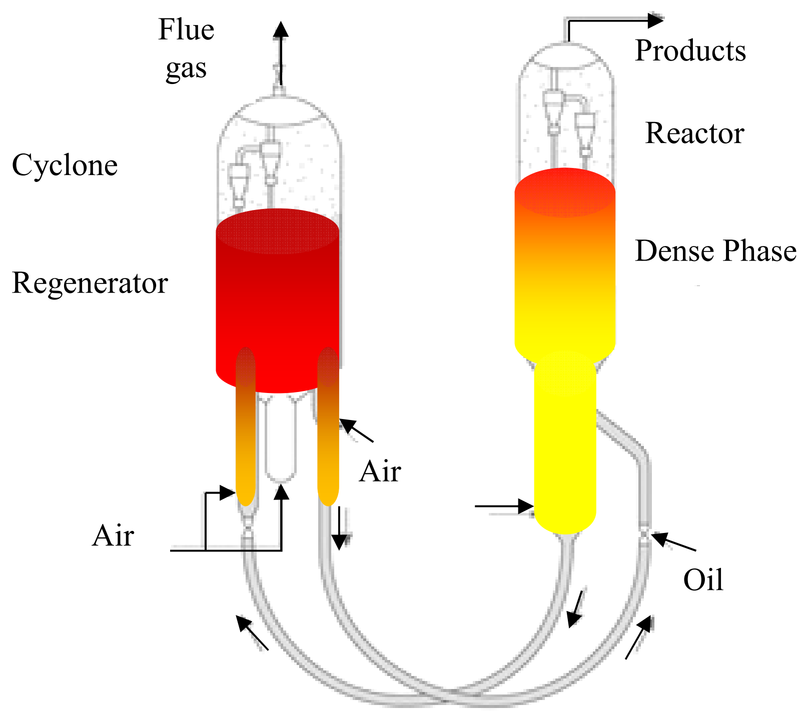

Figure 3. Fluidized Bed Process

Both in the reaction and regeneration zones, the catalyst is held in a suspended state by the passage gases through the catalyst dust and small amount of catalyst moved from the reactor to the regenerator and vice versa. Oil tends to saturate the enormous volume of pulverized catalyst in the reactor and hence the catalyst shall be carefully stripped by steam before it enters the regenerator.

The residual heat from the regenerated catalyst become a major source of heat for the incoming oil in the circulation process. The large amount of heat contained in the hot flue gases shall be recovered from regeneration zone by heat exchangers or waste-heat-boilers. The growth of fluid catalytic cracking process has continued and there are more than 10 million bbl/d of total capacity over the world

The basic U-bend unit was adapted to several differet process schemes (Figure 3). The hot, low molecular weight reactor products vaporized the lighter components of the atmospheric residuum up to 1100°F. The reactor and regenerator bed zones designed to run at 4 to 6 ft/s in a low bed densities. Both or reactor and regenerator colum were tapered a larger diameter at their topside to provide space of cyclone housing.

4. *Once-through process,*

The suspended catalytic cracking process once attracted attention. Once-through process (Figure 4) could also named as suspensoid process because of the state of catalyst and suspension mixture. The catalyst was within lubricating-oil clay and passes through the cracking furnace along with the oil and is removed from the fuel oil by an oliver precoat filter.

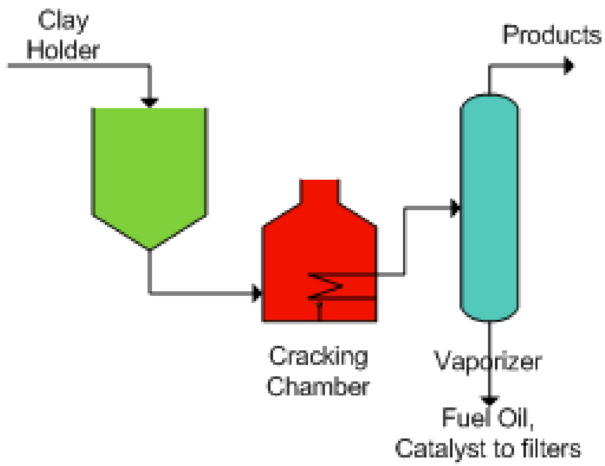

Figure 4. Once-through process (suspensoid system).

On a pilot plant project, once through process looked promising considering the effect of temperature to the process. Numbers of the C5+ gasoline increase as much as temperature increasing (Table 2).

Table 2. Effect of Temperature

	Average reactor temperature (°F)		
	850	**900**	**950**
Conversion (%)	55.1	55.1	55.1
Space velocity	0.8	1.3	2.0
Products (% wt)			
CH_4	0.71	0.85	1.20
C_2H_4	0.4	0.55	0.75
C_2H_6	0.6	0.75	1.05
C_3H_6	2.4	3.35	4.4
C_3H_8	2.1	2.15	2.15
C_4H_8	5.1	4.2	3.35
C_4H_{10} (normal)	1.4	1.3	1.25
C_4H_{10} (iso)	5.1	4.2	3.35

C_5^+ - gasoline	34.6	33.5	32.2
H_2 (% wt)	0.04	0.05	0.06
Light Fuel (% wt)	15.8	13.8	12.4
Heavy Fuel (% wt)	29.1	31.1	32.5
Coke (% wt)	4.85	4.2	3.7

In addition, Table 3 provides details of quality product from once-through process prior to temperature effect.

Table 3. Quality Product (once-through process)

	Average reactor temperature (°F)		
	850	**900**	**950**
RON (clear)	91.2	94	95
RON (+ 3 cc TEL)	97.6	98.6	99

Fluid Catalytic Cracking Development

Generally, fluid catalytic cracking process contained the following sections (Figure 5) :

1. *Reactor and Regenerator,*

   The feedstock is cracked in reactor to an efluent containing hydrocabons ranging from dry gases to highest-boiling material in the feedstock plus hydrogen (H_2) and hydrogen sulfide (H_2S). After that, the catalysts are circulating and recirculating in the regenerator to rejuvenated by burning deposited coke with high temperature air.

2. *Main Fractionator,*

   The effluent then is separated into varous products. The overhead products involving light material and gasoline whilst the heavier liquid products, heavier naphtha and cycle oils are separated as sidecuts and slurry oil is separated as a bottom proucts.

3. *Gas concentration unit,*

   The unstable gasoline and lighter proucts from overhead products are separated into fuel gas in unsaturated gas plant. Meanwhile, $C_3 – C_4$ for alkylation or polymerization and butanized gasoine that is essentially ready for use except for possible chemical treating.

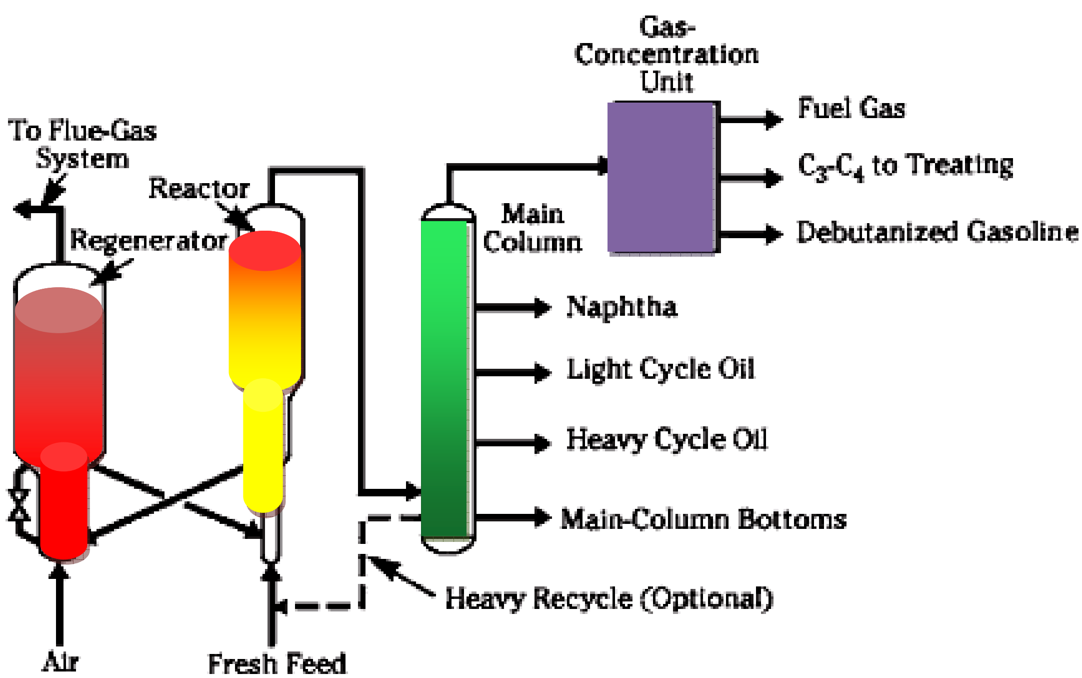

Figure 5. Generalized fluid catalytic cracking process

The process started when fresh feed which previously heated at 600 – 700°F lifts hot regenerated catalyst into the reactor as the feed rapidly vaporized. After that, cracked material leaves the reactor through cyclone separators and separated into several products. A kind of clay fines accumulated in a small amount at the bottom of vessel (0.5 lb/gallons) and they will return to the reactor. To maintained the catalyst, cyclone separators system or cottrell precipitators oftenly used.

Operating Conditions

As much as like any other chemical process run, fluid catalytic cracking process requires a specific operating condition to optimize desired products while also maintining feedstock handling. Every one of operating conditions has a correlation and influenced on one another. At special case, one variable could be limited or fixed by unit restrictions or heat balance requirement. The operating conditions group into two major classes :

1. *Dependent variables.*

   Aiming to parameters like catalyst-to-oil ratio, air regeneration rate, regeneration temperature and also conversion of the products. Although conversion aimed as dependent variable a description of general conversion effects is needed to understand the role of independent variables.

2. *Independent variables.*

   Aiming to variables like reaction temperature, recycle of unprocessed feedstock, space velocity and contacted time, feed preheat temperature. Catalyst activity is an independent variable provided that the catalyst withdrawal and addition rates can be charged or that catalyst of differing activity could be used. Meanwhile, pressure and feed mole fraction has some limitation due to small range variations on an existing unit.

Such a common procedure is to develope the operating condition first and review the effects on products conversions, products yields, and also products quality in a pilot-plant or laboratorium scale. Nonetheless, when applied in real scale plant, the effects of operating variables are more complicated and require the 'net-effect' so it can be determine or estimated.

Typically, product conversion is influenced by catalyst-to-oil ratio, temperature, space velocity, and catalyst activity. If these factors increased, the severity of the reaction also raised. Detailed yields and quality products at a given conversion are varied upon particular combination of operating variables which will lead to observed conversion.

At high conversion levels, olefins secondary reaction become important, because olefins yield will recrease. Gasoline octane numbers increasing with conversion up to and past the maximum in yield whilst the quality credits are not sufficient to offset the debits because of low olefin yields, low gasoline yield and high coke production.

DEFINITIONS

Catalysis – A process in which to rearrange and manipulate compounds to become different structure without changing the number of carbon and hydrogen elements.

Crackability – An easiness feedstock to be converted in fluid catalytic cracking unit.

Dependent variables – A parameters in which has been fixed and dependable to other operating process.

Fixed-Bed – A kind of an first catalytic cracking process which employed a series of chambers

Fluidized-Bed – A last technology of catalytic cracking which most efficient and effective to be implied.

Fractionator - A mixture substance composed from hydrocarbon-rich gases.

Gas concentration unit – A unit in which unstable gasoline are separated into fuel gas and C_3 – C_4.

Independent variables – A variables that not correlated and dependable to other operating process.

Moving-Bed – A kind of next generation catalytic cracking process that consisted of Thermofor and Houdry air-lift process.

Octane Number – A number defines quality of gasoline

Once-through process – A kind of process which only applied on pilot plant scale.

Reactor – A vessel where main catalytic cracking reaction achieved.

Regenerator – A column where catalyst regenerated and recirculated.

NOMENCLATURE

A	: Area of port (in^2)
C	: Coke yield (% wt on catalyst)
D_o	: Hole area (in)
D_p	: Particle diameter (in)
e	: Void volume in standpipe, gas phase (ft^3/lb cat)
H	: Catalyst Holdup (tons)
l	: Length (ft)
P_1	: Upstream pressure (lb/in^2)
P_2	: Downstream pressure (lb/in^2)
Q	: Catalyst circulation rate (tons / min)
Q	: catalyst flow rate (lb/min)
S°	: Liquid space velocity. Vol/vol (hour)
T	: Standpipe temperature (°R)
T_B	: cubic average boiling point of the feedstock (°R).
t_c	: Catalyst residence time (hour)
v	: Vapor velocity (ft/s)
W_A	: Aeration steam (lb/h/ft of standpipe and aeration levels)
W_C	: Catalyst circulation rate (lb/min)
WHSV	: Weight Hourly Space Velocity (total feed basis)

SYMBOLS

α	: Decay velocity constant
ΔP	: Pressure drop (lb/in^2)
ε	: weight fraction comverted
θ	: Catalyst residence time (minutes)
θ	: Catalysti residence time (minutes)
λ	: extent of catalyst decay group
ρ	: Flowing density (lb/ft^3)
ρ_A	: Pressure of standpipe (lb.ft^2.ft of length)
ρ_B	: Bulk density of solids (lb/ft^3)
ρ_F	: Fluid density (lb/ft^3)
ρ_S	: Catalyst density (lb/ft^3)
	: Normalized time-on-stream.