Refereed Proceedings

The 13th International Conference on Fluidization - New Paradigm in Fluidization Engineering

Engineering Conferences International — *Year* 2010

FLUIDIZATION TECHNOLOGY FOR STABLE STARTUP OF COMMERCIAL FCC UNIT

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ABSTRACT

Conditions for maintaining good fluidization in the start-up of FCC have been determined. Catalyst defluidization and consequent catalyst losses from reactor cyclone are mainly affected by catalyst properties and stripper operating condition based on previous commercial startup experiences. Effect of fine catalyst contents on bed fluidity was determined. Bed fluidity in stripper was analyzed with slip velocity. Finally new startup guide was proposed and it was successfully applied to commercial FCC process of SK energy, Korea.

INTRODUCTION

Fluid catalytic cracking (FCC) is an industrial process that converts high molecular-weight hydrocarbons to lower molecular-weight products of high value. A modern FCC unit consists of three major parts: riser, stripper and regenerator. The FCC utilizes a circulation system whereby heavy oil contacts hot circulating catalyst and is lifted up a riser in which catalytic reaction occurs. The catalyst and reactor vapor products exit the reactor vessel and are sent for further processing. The catalyst passes through a steam stripping zone then enters a standpipe and is transported to the regenerator which burns off the coke on the catalyst and thus reactivates the catalyst. The heat from the combustion of the coke raised the catalyst temperature and the catalyst is transported down the standpipe to meet again the fresh oil feed. This completes the catalyst circulation loop.

FCC process has turn-around time every 2 or 3 years and following start-up time of about 5 days. The FCC unit experiences different situations in the start-up by variations of temperature, pressure and feed before reaching steady state compared to normal condition. Fluidization is of prime importance in the FCC unit since all phases of the process are performed in fluidized beds at all times as it circulates through the reactor/regenerator system. Therefore, lack of fluidization in the start-up with various conditions can lead to catalyst defluidization, or worse, shut-down of unit.

Many Companies that own FCC unit have experienced troubles with catalyst carryover from reactor cyclone to main column during the catalyst circulation step of startup. Recently, studies about poor fluidization in deep fluidized beds of group A particles have been reported with large cold model tests (1-3). However, studies about commercial FCC reactors are relatively sparse in open literature.

In this study, troubles with catalyst carryover in startup of FCC unit are analyzed in viewpoint of fluidization with previous experiences. From the analysis, conditions for maintaining good fluidization in the start-up have been determined. A new startup procedure with successful application to FCC unit of SK energy is proposed.

PLANT DESCRIPTION

The FCC (or RFCC) Unit was originally designed by UOP in 1994 for a capacity of 50,000 BPSD in Ulsan Complex of SK energy, Korea. The unit has operated with residue feed rates near 57,000 BPSD since first start-up in 1996. The schematic diagram of the FCC is shown in Fig. 1. The reactor riser is 60 m long. The upper section is 35 m long with a diameter of 1.6 m ID and, the lower section is 25 m long with a diameter of 1.0 m ID. The riser utilizes a Suspended Catalyst Separation System (SCSS): a vented riser with two stages of cyclones directly connected to the riser. These direct connected cyclone systems are widely used because of the yield benefits by dipleg sealing of first cyclone for minimizing the amount of hydrocarbon which enters the stripper and is therefore exposed to long residence time which results in overcracking to coke and light gases. The unit has six sets of two stage cyclones inside the reactor.

The stripper has a diameter of 4.0 m ID and a tangent length of 12 m. Steam is introduced at bottom, middle and top regions of the stripper through pipe grids. It mostly rises up countercurrent to the downwardly flowing stripper bed. The stripper has ring-donut type baffles in order to achieve efficient use of steam.

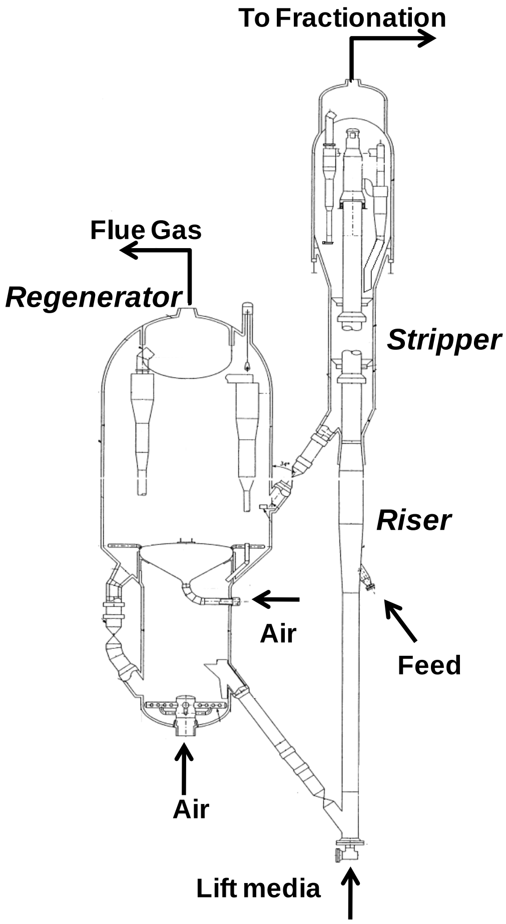

Fig. 1 Schematic diagram of FCC unit

The regenerator employs a two-stage regeneration system. The two-stage regenerator consists of an upper regenerator (1st stage) and a lower regenerator (2nd stage). The first stage regenerator has a diameter of 10.4 m ID and a tangent length of 13.7 m. The second stage regenerator has a diameter of 5.5 m ID and a tangent length of 10.5 m.

Normal Startup Procedure

Normal startup of the FCC unit part in plant can be divided into the following steps:

1. Steam out the reactor and main column, and heat up the catalyst section.
2. Load catalyst to the regenerator and heat catalyst.
3. Circulate heated catalyst between the reactor and regenerator.
4. Start oil to the riser.
5. Establish normal operating conditions.

Trouble Experiences

SK energy experienced two troubles with catalyst carry-over from reactor cyclone during the catalyst circulation step of startup attempts in 2005.

During the first startup attempt, catalyst was probably carried over to the Main Column due to issues with the first stage reactor cyclones. The reactor cyclones are not efficient at inlet velocity between 4 and 11 m/s and steps must be taken to minimize the period that velocities are within this critical range. It is conjectured that catalyst carryover can occur because the velocity is high enough to entrain catalyst in the vapor (steam), but still lower than required to collect efficiently particles.

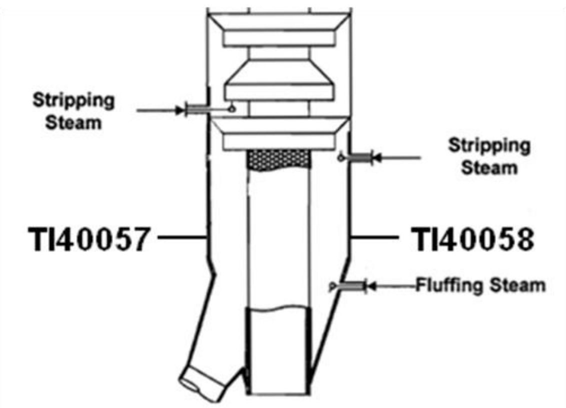

Fig. 2 Location of two thermocouples in bottom region of stripper

Meanwhile, a temperature divergence (up to 43°C) was observed within the Reactor Stripper. An increasing temperature differential (ΔT) between stripper TIs 40057 and 40058 as shown in Fig. 2 is not usual and indicates fluidization problems in the stripper. Temperatures in the stagnant region will lag behind the active side. It might be possible that the catalyst level in the first stage cyclone increases if one side of the stripper becomes stagnant and the first stage diplegs are sealed. If the cyclone catalyst level gets too close to the cyclone outlet tube, catalyst will be entrained and carried over to the second stage cyclones and to the main column. A rough estimate of catalyst mass carried to the Main Column was 67ton. History of these phenomena is shown in Fig. 3.

During the second attempted startup, Reactor cyclone velocity was more closely controlled but, catalyst was carried over to the main column. Though the unit was started up with the diplegs unsealed, radial ΔT in bottom region of stripper is drifted apart. The second attempt at circulation and startup resulted in 3 apparent catalyst loss events, one of which occurred when sealing the cyclone diplegs, one during transition from low to high velocity, and a final apparent loss just prior to and following introduction of feed to the riser. The possible cause of all three losses during the second attempted startup can probably be attributed to a local defluidization in the stripper and following catalysts accumulate in the cyclones.

For a couple of weeks afterwards, it was attempted to seal the cyclone diplegs by increasing the bed height of stripper. Finally, dipleg was sealed with minor catalyst carryover and the unit worked under normal operation.

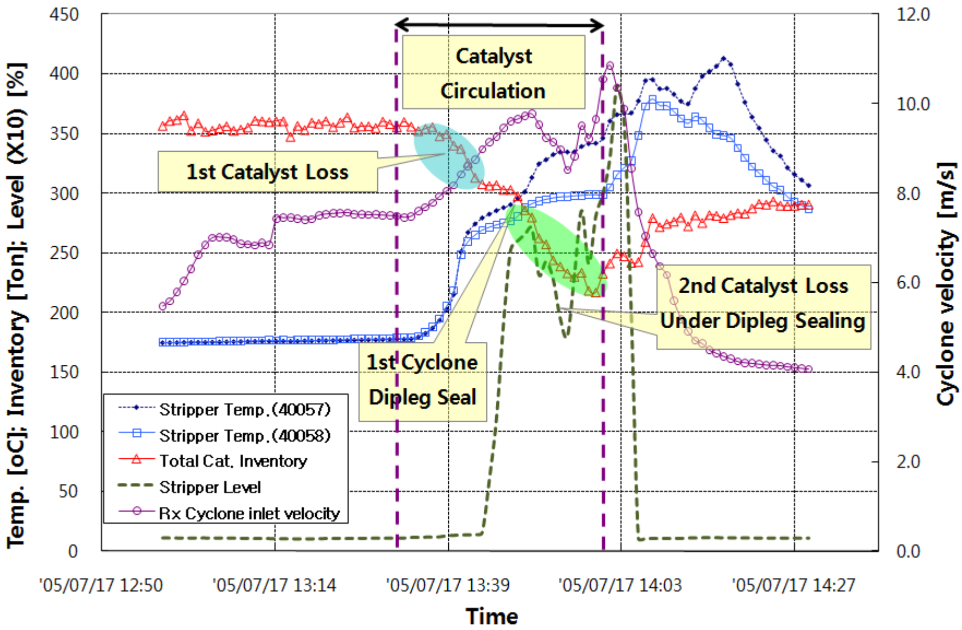

Fig. 3 History of catalysts carryover

RESULTS AND DISCUSSION

Root Cause Analysis

From root cause analysis, it is concluded that the main mechanism for carryover was more related to fluidization problems in stripper because any area with no gas flow or insufficient entrained gas can become defluidized and stagnant during the steps in startup. When this occurs under a primary cyclone dipleg, it partially or fully prevents flow of the catalyst separated in the cyclone from flowing to the stripper. In this case, once the catalyst flow from the primary cyclone is restricted, the second cyclone loading increases to the point where the second cyclone dipleg is overloaded. Finally, any catalyst amount greater than this will be carried out of the second cyclone to the main column.

However, it is noticed that the carryover occurred even though steam rate in stripper was same with normal operation before catalyst circulation. Also, stripper exhibits better fluidization characteristics at high catalyst flux rates in normal operation. These mean that operating conditions within normal or design ranges did not significantly affect fluidization in the stripper.

Approaches

There are two major factors on fluidization in stripper. First, the catalyst in the unit must remain in a fluidized state at all times. Second, the flow of catalyst and gas should have uniformity in entire stripper. From two view points, practical approaches are proposed

1) Particle Size Distribution (PSD)

Catalyst properties have the greatest effect of fluidization characteristics, especially the PSD. If the amount of fines contents (less than 45 μm) gets low, FCC unit has fluidization problems in a bubbling bed.

In this study, fluidity (U_{mb}/U_{mf}) which is one of fluidization index was measured to get a base for good fluidization quality. Catalysts, namely equilibrium catalysts (E-cat), were obtained from FCC unit in normal operation and fine content was controlled by adding or removing the fine in E-cat. To get the fluidity, U_{mb} and U_{mf} were measured in a cold model reactor (0.05 m id.) with air. Experimental results are summarized in Table 1.

Table 1 Experimental results of U_{mf}, U_{mb} and fluidity

Particles	d_p [mm]	F_{45} [wt.%]	U_{mf} [m/s]	U_{mb} [m/s]	U_{mb}/U_{mf} [m/s]
No fines	61.2	0.20	0.0040	0.0065	1.63
Fines case I	60.35	5.00	0.0035	0.0067	1.91
E-cat	60.1	6.58	0.0033	0.0066	2.00
Fines case II	59.9	7.98	0.0032	0.0068	2.13

Effect of fines contents in FCC catalysts on fluidity is shown in Fig. 4. The fluidity increases with increasing the fines content. The increment of 1 wt.% of fines increases 0.057 of fluidity. It indicates that a certain loss of fines could make poor fluidization in some region like near the wall of the stripper because Group A materials with high fines contents retain air longer than Group A materials with low fines (2). From previous experiences, it is noticed that most of the catalyst fines were carried over to the main column during the prior catalyst loss incident like passage of critical range of cyclone inlet gas velocity. Also, fines loss usually occurs from the regenerator during the catalyst heatup period at relative low pressure even though regenerator was filled up with equilibrium catalyst of high fines contents before solid circulation.

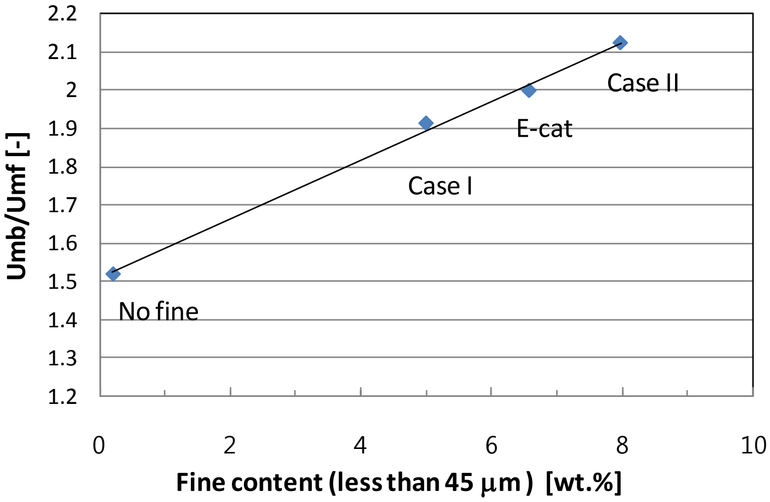

Fig. 4 Effect of fine content on catalyst fluidity

In this study, a guiding equation for fines makeup to E-cat bed has been proposed. Even Abrahamsen and Geldart(5)'s equation for prediction of fluidity has been widely used, it covers wide range of Geldart A particles, so that it is not enough for exact prediction in urgent decision. Measured fluidities for FCC catalysts with various fines contents have been correlated with gas and particle properties based on Abrahamsen and Geldart study (5).

$$\frac{U_{mb}}{U_{mf}} = \frac{2466\rho_g^{\ 0.13}\mu_g^{\ 0.52}\exp[1.00F_{45}]}{d_P^{\ 0.80}g^{0.934}[\rho_P-\rho_g]^{0.934}} \qquad (1)$$

Eq. (1) can provide PSD management guide for fluidized bed quality in the unit by informing desired PSD of fresh catalyst for make-up. Also, a unit startup guideline of fines contents more than 6 wt. % is added in new procedure based on fines contents in normal operation with good fluidity.

2) Catalyst and gas flow

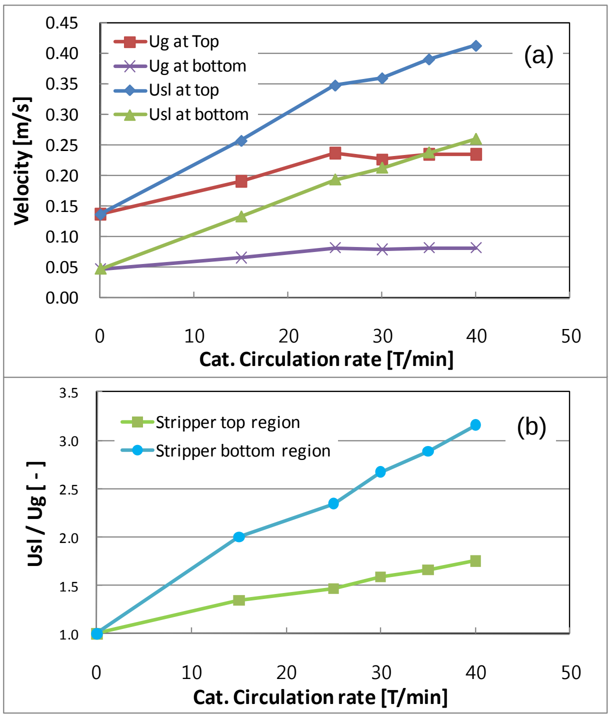

Fig. 5 (a) Effect of catalyst circulation rate on fluidizing velocity
(b) Effect of solid circulation rate on U_{sl}/U_g

Even though catalysts have good fluidity, identification of hydrodynamics in the stripper is important because many FCC have different design and its limitation in catalyst and gas flow. Flow problems encountered in commercial FCC stripper have been reported as bridging (1) or gas bypassing (2). These have been found in operating with deep beds of Group A particles (3). They are results of localized defluidization of the catalyst in areas where fluidizing gas does not properly reach the catalyst. Measurement of pressure fluctuation can give information about these problems at normal operation. However, it is not easy in startup steps because bed quality changes as time passes. To eliminate gas bypassing and bridging, FCC reactor licensor adopted baffle design inside of stripper. This eliminates stagnant areas of catalyst near the walls of the stripper resulting in a more uniform catalyst flux at normal condition, but did not work well in no or low catalyst flow range with showing radial temperature divergence like Fig. 3.

Hydrodynamics in stripper with baffles can be affected by not only gas flow rate but also catalyst flux. In this study, fluidizing velocity in stripper was analyzed with slip velocity(U_{sl}) like eq. (2).

$$U_{sl} = \frac{U_g}{\varepsilon} - U_s = \frac{U_g}{\varepsilon} - \frac{G_s}{[\rho_p(1-\varepsilon)]} \qquad (2)$$

Effect of catalyst circulation rate on fluidizing velocity is shown in Fig. 5(a). Before catalyst circulation, steam rate is set at about 4.4 ton/min. The steam velocity in

stripper increases 1.6 times at normal condition with increasing temperature by circulation of hot catalyst. However slip velocity increases 3-5 times with reaching normal catalyst circulation rate of 40 ton/min.
Effect of solid circulation rate on U_{sl}/U_g is shown in Fig. 5(b). U_{sl}/U_g is largely increased with solid circulation rate, especially in bottom region with relative low steam rate. It means that turbulence in bottom region of stripper is increased by catalyst flow and stagnant region could be depleted by the turbulence. Also, high catalyst flux is helpful for increase of gas velocity by increment of bed temperature. Another reason for the effectiveness of high catalyst flux in eliminating stagnant zone is that the downward solids flow pushes and separates the upward gas flow with preferential flow direction. This makes the gas flow redistributed. Also, the redistribution of gas flow exposes more catalyst surface area which allows the gas to permeate the solids and makes it easier to aerate the solids and prevent defluidization.

Startup with New procedure

New procedure for startup is based on a principle of keeping fluidization state all the time as discussed above. In management of particle properties, PSD and fine content are checked before shutdown for turn-around of unit because withdrawn catalysts are used for startup. In startup time, the PSD and fine content are carefully managed by eq. (1) which provides information of type (fine content) and makeup rate of fresh catalyst for makeup.
Some procedures are modified to get high catalyst circulation rate especially at cyclone dipleg sealing time. In previous procedure, regenerator temperature was kept at about 700℃, which means low catalyst circulation rate because the rate in FCC unit is controlled by temperature difference(ΔT) between regenerator and stripper. Use of a lower regenerator catalyst bed temperature is preferred for high circulation rate, as this requires more catalyst circulation flow to maintain the heat-up rate, thus more catalyst enters the cyclones and discharging from the reactor cyclone diplegs.
Based on previous operation data, it is found that about 30 ton/min of circulation rate shows better fluidization state with uniform radial ΔT, especially around catalyst discharge region from cyclone dipleg for stable stripper operation and the rate corresponds to slip velocity of 94 U_{mf} at the discharge region which is near terminal velocity of catalyst. To get the circulation rate, a control plan of the ΔT between regenerator and stripper is reflected in new procedure as shown in Fig. 6.

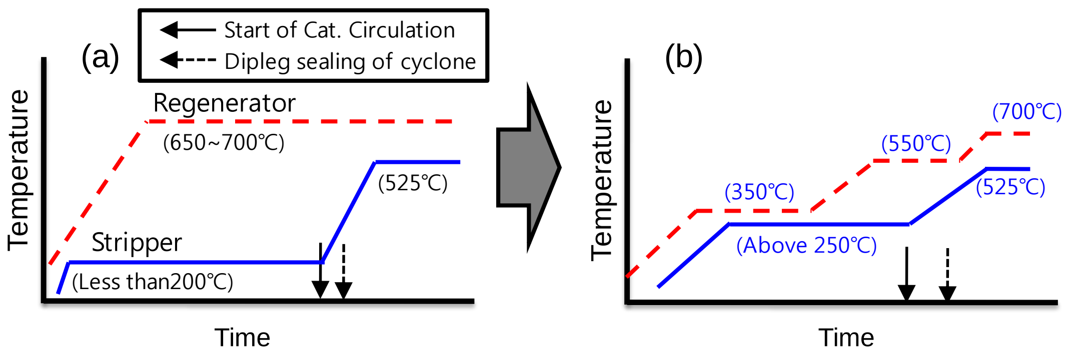

Fig. 6 Comparison of previous and new startup procedures

Finally, the new procedure was successfully applied to startup in 2008. It is proved to work well as keeping fluidity in stripper with showing uniform radial ΔT in stripper bottom (less than 2℃) and minimization of catalyst loss from unavoidable change with quick passage through critical region of reactor cyclone inlet velocity.

CONCLUSION

Conditions for maintaining good fluidization in the start-up of FCC have been determined. To prevent catalysts defluidization in stripper as main cause, catalyst properties and hydrodynamics for good fluidization state are identified based on normal condition. Effect of fine catalyst contents on bed fluidity was determined and, bed fluidity in stripper was analyzed with slip velocity. Finally new startup guide to keep good fluidity in start-up was proposed and the guide was successfully applied to startup of commercial FCC unit in 2008.

NOTATION

U_{mf} : Minimum Fluidization Velocity (m/s)
U_{mb} : Minimum Bubbling Velocity (m/s)
F_{45} : Fraction of Catalyst Below 45 μm
d_p : Mean Average Particle Diameter (m)
g : Gravity Acceleration (m/s^2)
ρ_p : Particle Density (Kg/ m^3)
ρ_g : Gas Density (Kg/m^3)
μ_g : Gas Viscosity (Kg/m Sec)

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