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FLUIDIZED-BED CATALYTIC CRACKING UNITS EMULATION IN PILOT PLANT

EMULACION DE UNIDADES DE DESINTEGRACION CATALITICA DE LECHO FLUIDIZED EN PLANTA PILOTO

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Abstract

Due to necessity to predict accurately the performance of fluidized-bed catalytic cracking (FCC) industrial units, after feedstock or catalyst is changed, use of pilot plant as emulation devices has been increasing. Among these pilot plants, the Recirculation Catalyst Pilot Plant is the small-scale simulator that closer matches the behaviour of industrial units. This kind of pilot plants consists of riser, stripper, regenerator and separation column that perform duties similar to those of industrial units. Additionally, this pilot plant is able to operate using a descendant flow reactor (downer) in order to emulate several technological trends; which operation mode promises better selectivity. FCC process involves many variables interconnected in complex way, making a difficult task to predict its performance when operating far from original design conditions. Nevertheless, using the same catalyst, the same feedstock and the same main operating conditions of industrial units, it is possible to emulate the performance of industrial units in pilot plant. In this work, the characteristic relationship between pilot plant and industrial units is shown with examples of emulation, establishing its importance in research and support of technical services. Scale-up problems are addressed and solutions that *mimic* operating data from an industrial plant are found. Conversion results are shown graphically to easily assess industrial potential benefits that can be drawn from pilot plant emulation.

Keywords: catalytic cracking, emulation, pilot plant, reactors.

Resumen

Debido a la necesidad de predecir con precisión el desempeño de unidades industriales de desintegración catalítica en lecho fluidizado (FCC) después de un cambio de carga o de catalizador, el uso de plantas piloto como dispositivos para emulación se ha incrementado. Entre estas plantas, la de recirculación de catalizador es la que logra emular más cercanamente el desempeño de unidades industriales. Este tipo de plantas consiste de riser, agotador, regenerador y columna de separación, tal que desempeña tareas similares a aquellas de las unidades industriales. Además, esta planta es capaz de operar en flujo descendente (downer), a fin de emular diversas tendencias tecnológicas; operación que promete mejores selectividades. El proceso FCC involucra muchas variables interconectadas de manera compleja, haciendo difícil predecir su desempeño cuando operan lejos de las condiciones originales de diseño. Sin embargo, utilizando el mismo catalizador, la misma carga y las mismas condiciones de operación que en las unidades industriales, es posible emular la operación de estas unidades en la planta piloto. En este trabajo, se muestran las relaciones características entre la planta piloto y las unidades industriales, a través de ejemplos de emulación, estableciendo su importancia en investigación y soporte de servicios técnicos. Se tratan problemas de escalamiento y encontrando soluciones que *imitan* resultados de operación industrial. Los resultados para la conversión se muestran gráficamente a fin de visualizar fácilmente beneficios potenciales industriales utilizando la emulación en planta piloto.

Palabras clave: desintegración catalítica, emulación, planta piloto, reactores.

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1. Introduction

Fluidized Catalytic Cracking (FCC) is a very complex process combining a reaction stage (riser) with a continuous catalyst regeneration stage. Both stages strongly interact, particularly in energy balance. Catalyst regeneration severity and capacity highly influences riser behaviour. There are several factors that complicate FCC operation, among them feed composition is probably the main one, since it is a complex mixture of hydrocarbons with different chemical reactivity (Mariaca-Domínguez *et al*., 2003). The second important fact is the big number of simultaneous reactions in the riser. Thirdly, the decaying catalytic activity coming from coke formation and catalyst deactivation produced by feed contaminants and regeneration severity. Least but not lest is the important effect from equipment design.

Pilot plant studies are a support tool in research and development activities, as well as the platform for providing technical services and improvements. These plants are strategic bases for deciding about feedstock and catalyst, through evaluation of yields and quality of products. They are also important studies in feasibility. For example, in refining petroleum industry, and particularly in FCC, it is observed a tendency to incorporate feedstock hydrotreatment because of the increasing supply of heavy oils. There is also a trend to develop better catalysts in order to look for optimal operating conditions.

Due to its high impact on the profitability of refineries, it is often unfeasible and/or impossible to try new feedstock or catalysts during FCC industrial operation. On the other hand, laboratory microactivity plants, like MAT and ACE units, give quick results that are not usable, directly, to model the industrial process performance (Boock & Zhao, 1998; Maya-Yescas *et al*., 2004).

So, pilot scale equipment offers advantages and fewer risks than laboratory equipment to scale up operating conditions and process performance, quickly generating enough quantities of products for more complete and detailed analysis (*e.g*. Prasad & Balaraman, 1995; Leuenberger *et al*., 1988). Pilot plants are considered, in general, as reduced versions of industrial units (Boock & Zhao, 1998); however, scale reduction has implications in design and operation of these pilot plants. Energy balance is the most important difference between industrial and pilot plants, resulting in differences in coke yields and catalyst-to-oil ratio (C/O) when the same conditions are chosen for both plants (Young *et al*., 1988).

Pilot plant size allows studying and simulating confidently the industrial unit behaviour with no risk for production. It is also possible to develop new catalysts formulations for each feedstock in long term tests and give recommendations for better operation aiming to optimize conditions and improve profitability. Besides, pilot plant information is essential for developing, adjusting and validating FCC simulation models. As data source for simulation, pilot plants give opportunities to explore broad ranges of process conditions, being useful to process research and development (Dienert *et al*., 1993).

Taking into account the aforementioned arguments and considering the high economic impact of FCC units in refineries, it is highly advisable to use pilot scale information to provide permanent technical services, in order to optimise industrial operation and to research and development efforts.

1.1. Pilot plant description

The typical arrangement of a pilot plant scheme is shown in Fig. 1. Feedstock is taken from a couple of storage vessels, connected to the control system. This couple of storage vessels allows normalising operation with a reference feedstock and then introducing a new one. A dosage pump with precision control is used to send the feed through the heater and nozzle. There is a system to control and register the flow. A nitrogen or vapour stream can be used as dispersant, feeding it through an independent heater. Feed vaporizes as soon as gets in touch with catalyst coming from regenerator and goes through the riser, as in the industrial unit. At the top of the riser, catalyst and products are separated using cyclones. Spent catalyst falls to a vertical column within a dense phase fluidized bed, in order to strip hydrocarbons from catalyst with vapour or nitrogen flowing counter current. A slide valve controls the flow of stripped catalyst to regenerator. Stripping temperature, bed height and vapour/nitrogen flows are controlled to adjust stripper efficiency.

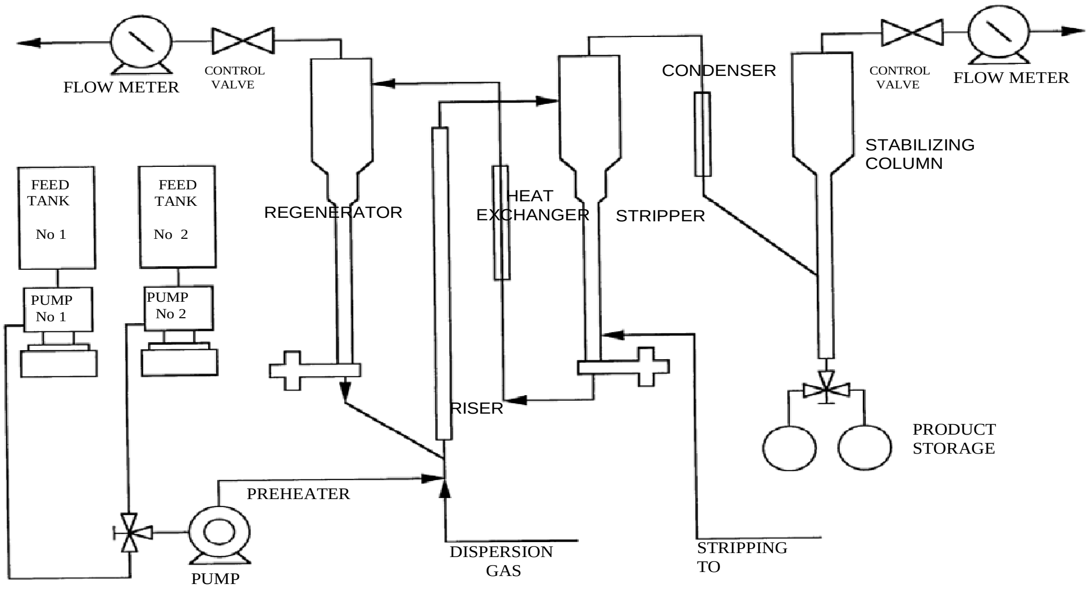

Fig. 1. FCC Pilot plant basic equipment.

Gaseous products go to a stabilizer column, to separate components heavier than C_5 & C_6; this liquid product is fractionated to obtain gasoline, LCO and HCO. Gas products at NTP conditions are analyzed using an online chromatograph. The spent catalyst is sent to the regenerator with a nitrogen or vapour line transfer, part of which is a double tube heat exchanger using air. Exchanger heat balance provides a reliable method for getting C/O ratios. During regeneration reactions, coke deposited on catalyst surface burns inside a fluidized bed using air, and generating flue gas. At exit of this flue gas, a control valve is used to maintain regenerator and stripper pressure. Regenerated catalyst goes through a slide valve to a return line with independent heating that fix the inlet temperature to riser.

Regenerator vessel can be heated to different temperatures. Flue gas and excess air are measured and analyzed continuously (O_2, CO, CO_2, SO_X and NO_X). Control system is based in flue gas composition to adjust the air quantity and keep the regeneration level required. Additionally, this pilot plant can be operated using a descendant flow reactor (downer) in order to study other technological trends. It has been presumed that this operation mode promises greater selectivities (Ikeda & Imo, 1999). Heat balance can be adjusted with two operation modes for flexibility: Adiabatic Mode and Heat Balance Mode

1.2. Adiabatic mode

In this operating mode, riser outlet temperature is fixed and controlled with hot catalyst flow coming from regenerator. This mode allows industrial emulation of conversion and product yields, by using the same temperatures for outlet riser, preheating and regeneration. It requires only to adjust the C/O ratio, fine-tuning with nitrogen or vapour flows and the desired temperature profile inside riser.

1.3. Heat balance mode

Typical FCC pilot plant operation cannot follow industrial operation in the control of an important parameter—regenerator temperature. In industrial units, regenerator temperature is determined from thermal balance existing in the steady state operation and is not controlled. Minor size in pilot plant means heat losses are comparatively more important than in the industrial case. Consequently, it is necessary to add heat to the pilot plant regenerator to obtain industrial temperatures. In the heat balance mode it is possible to fix regenerator temperature taking as a basis the coke yield. A correlation is used to calculate this parameter and use it in the control system to adjust the temperature of the catalyst at the riser inlet, forcing the pilot plant to react in a similar way to the industrial unit. By using this mode, calculations are made automatically by the control system of the pilot plant.

2. Methodology

Typical feedstock and equilibrium catalyst samples were taken from an industrial FCC unit; standard characterization variables were measured for feedstock (Table 1) and catalyst (Table 2); and some special tests were performed.

Table 1. Typical feedstock properties.

Density, kg / m^3	920.0
Conradson Carbon, % p	0.20
ASTM D-1160 distillation, ºC	
10% vol.	346
50% vol.	422
90% vol.	501
Metal content	
Nickel, ppm	380
Vanadium, ppm	440
Iron, ppm	750
Sodium, ppm	2.5

Table 2. Typical equilibrium catalyst properties.

Activity MAT, % p	70.0
Specific area, m^2 / g	158
Pore specific area, cm^3 / g	0.172
Coke on regenerated catalyst, g_{coke} / $g_{catalyst}$	0.066

In order to maintain catalyst properties, equilibrium catalyst was changed before every one of the 50+ experiments carried out. Outlet riser temperature was maintained at the industrial operation value. Feed preheating temperature values were chosen from a wide range (See Table 3), and operation was performed in adiabatic mode. For each operating point standard conversion was calculated by analyzing gas products (gas chromatography) and liquid products (simulated distillation); coke was estimated from the heat balance. Regenerator temperature was kept high in all experiments, in order to assure good regeneration, and keeping residual coke in catalyst (ω_{CRC}), below 0.05 wt. %.

Table 3. Base parameters in FCC pilot plant operation.

Variable	Range	Independent	Dependent
Outlet riser temperature, ºC	525	X	
Preheating temperature, ºC	100 - 350	X	
C/O Ratio	6.8 - 25.5		X
Conversion, wt. %	61 - 77		X
Yields, wt. %	-		X

3. Industrial emulation: results and discussion

Since standard conversion is the main dependent variable in FCC units, it was considered as response variable. Emulation experiments were designed to investigate conversion trend around the industrial value (73 % wt). It was decided to move the preheating temperature from 100 ºC to 350 ºC, maintaining constant the outlet riser temperature (525ºC) and keeping the regenerator temperature above 690 ºC, to see the way the pilot plant behaves. The results are shown in Fig. 2.

Results show the expected tendency, as FCC standard conversion is proportional to C/O ratio, taking an asymptotic behaviour. Upper limit is a function of feed and catalyst characteristics, within operation conditions range. The data dispersion shows the normal experimental error uncertainty. There is a general similar trend for each series, despite the fact that other variables could have additional effects. Among the obtained results, the experimental points that showed similar conversion to the industrial value were selected. Gasoline, LPG and Dry Gas yields were compared to industrial ones as shown in Fig. 3. It is evident that just small deviations were found, the biggest being in dry gas yields, making the emulation results acceptable.

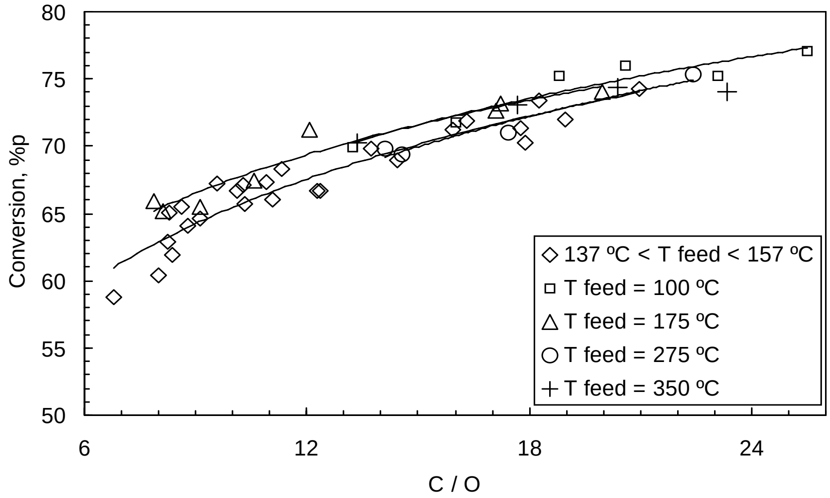

Fig. 2. Operating region for 525 ºC outlet riser temperature.

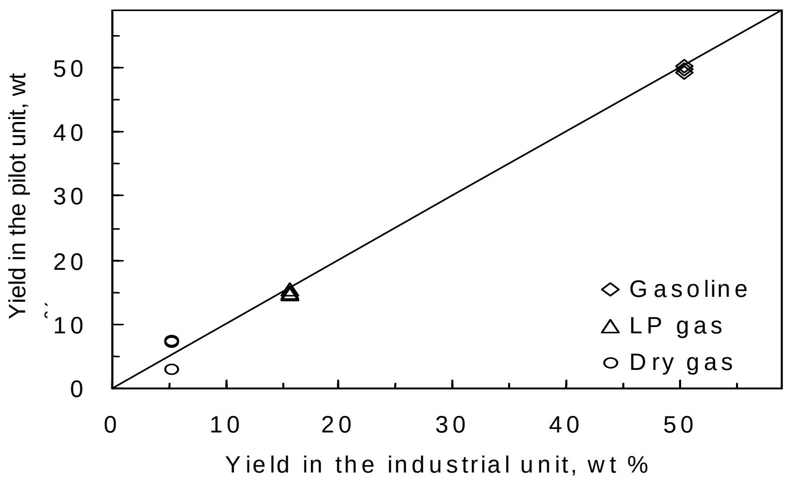

Fig. 3.Pilot plant results vs. industrial data.

Table 4. Gas composition comparison (wt. %).

Product	Component	Pilot Plant	Industrial Unit
Dry Gas		2.70	3.73
	Hydrogen	0.11	0.09
	Methane	0.98	1.34
	Ethylene	0.83	1.01
	Ethane	0.77	1.30
LPG		15.78	14.09
	Propane	1.65	1.31
	Propylene	6.38	3.45
	i-Butane	3.51	3.18
	n-Butane	0.79	1.26
	Propadiene	0.03	N.A.
	1-Butene	0.85	1.19
	i-Butylene	0.89	1.36
	t-Butene	0.98	1.29
	c-Butene	0.68	1.04

Scaling problems seem to explain the differences in yields. The emulation of industrial operation can be fine-tuned by moving around some other variables. For specific emulations, it is possible to adjust temperature profile along the riser, move the regenerator temperatures and/or make runs with different dispersion flows in such a way to minimize deviations. Yield and gas composition were obtained and compared with industrial data. A sample of one of the aforementioned cases is shown in Table 4. The composition is not quite similar, these data need to be studied under the frame kinetic models in order to use them for complete emulation. As it was mentioned before, pilot plant parameters can be tested beyond standard industrial conditions. In this particular case it was possible to obtain values for C/O ratio in a broad range, with values as high as 25. These values are not exhibited by industrial units, but they could be useful to evaluate the behaviour during heavy feeds cracking, or to explore the maximum conversion attainable for a catalyst-feedstock system.

Conclusions

Emulation of the behaviour of an industrial FCC unit was explored using a pilot plant. The standard conversion was emulated for different C/O ratios, by setting different feed temperature, at constant temperature at the riser outlet. In this region, unit operation could be oriented to maximize yield of either gasoline or olefins. The emulated operating region is specific for the catalyst and feedstock used, as well as operating conditions. It is interesting to note that parameters out of common operation regions are possible to obtain by manipulating variables. In this case C/O ratios greater than 25 were studied, which are not seen in commercial FCC units, but are useful to evaluate different combinations of feedstock and catalyst. Yields and composition of main products, gasoline and LPG, are well emulated, even if there is still room for fine-tuning by manipulating other variables. Emulation is specific for each commercial unit and catalyst-feedstock system. Finally, it should be noted that despite the similarity between pilot and commercial units, there are some scale-up problems to solve.

Acknowledgments

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