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Catalyst attrition in ebullated-bed hydrotreator operations

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Abstract

The catalyst level of the ebullated-bed is an important process indicator in operating the H-oil hydrotreating unit in Shuaiba Refinery, Kuwait National Petroleum Company (KNPC). In an attempt to use mixed hydrotreating catalysts in one of the H-oil reactors, the catalyst bed expanded more than usual, and the level was very unstable. Moreover, a reduced unit performance and unstable operations were resulted, which led to the unit shut down and process time loss. In a joint study between the Petroleum Technology Department at Kuwait Institute for Scientific Research (KISR) and KNPC, the hydrodynamics of the mixed and individual catalysts in a cold flow ebullated-bed reactor (EBR) were found to be very different, though the two catalysts had similar physical properties. Further study revealed that catalyst attrition was a very important factor in contributing such reactor behaviours. © 2001 Published by Elsevier Science B.V.

Keywords: Catalyst attrition; Hydrotreating catalyst; Ebullated-bed

1. Introduction

Catalysts play a vital role in heavy residue refining processes. Increased availability of heavy, sour crudes and tighter environmental protection regulations have made residue oil conversion processes increasingly important. The H-oil process, a multiphase residual conversion unit developed in the 1960s by the Hydrocarbon Research Incorporation (HRI), now acquired by the Institut Francais Du Petrole (IFP), employed a unique technology of using a bed of ebullated catalysts instead of the conventional fixed-bed. The ebullation technology offers several advantages, such as the online addition and withdrawal of catalyst, equilibrium activity catalyst, lower pressure drop, and near-isothermal reaction conditions.

The H-oil unit in the Shuaiba Refinery of KNPC, one of the three oldest working processes, was commissioned in 1968 [1]. It comprises two single rector and separator trains, and a common fractionation section. Fig. 1 shows a simplified diagram of the H-oil EBR in Shuaiba Refinery. The unit was originally designed for a vacuum residue feed of 28 000 BPD. After several in-house modifications and revamps, it is now processing about 56 000 BPD of Kuwaiti vacuum residue [2].

Throughout the past years of operation, the refinery used only catalysts recommended by the licenser, and only a single type of catalyst was used at one time. Recently, the refinery had used mixed catalysts in one of the H-oil unit trains. During start-up, both fresh and spent of the recommended catalysts (A) were loaded in the H-oil EBR. However, during the daily catalyst addition, a small amount of other catalyst (B) was added. Although B was restricted to a predetermined ratio with A, lower reactor performance was observed and details will be discussed in the later session. Some of the H-oil process data in the period using mixed catalysts are shown in Table 1.

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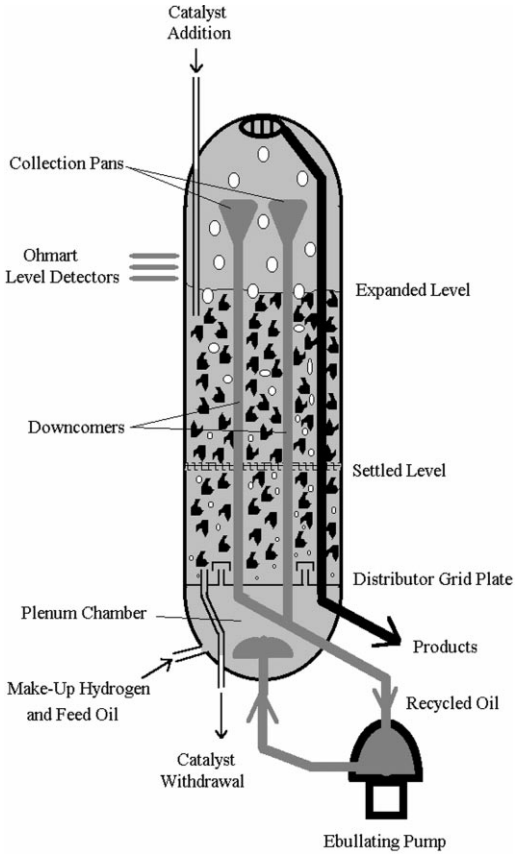

Fig. 1. A simplified diagram of the H-oil EBR in Shuaiba Refinery, KNPC.

Table 2
Physical properties of catalysts A and B

Property	Catalyst A	Catalyst B
Mean particle length (mm)	5.2	4.7
Fine content (<40 mesh) (wt.%)	0.03	0.03
Particle diameter (mm)	0.97	1.038
Bulk density (compacted) (kg/m^3)	0.447	0.453
Average crush strength (kg/mm)	0.95	0.86
Attrition loss (wt.%)	0.9	0.9
Surface area (m^2/g)	310.0	289.0
Pore volume (H_2O adsorption) (cm^3/g)	0.81	0.81

Both catalysts A and B were screened by a series of tests: chemical contents, particle size distribution, surface area, bulk density, average crush strength, pore volume, pore size distribution, average oil penetration, and catalyst activity test in a fixed-bed reactor. Table 2 shows some physical properties of A and B obtained from the manufacturer, and confirmed by two international catalyst testing laboratories. No significant differences were observed. Nevertheless, the complexities of the ebullation phenomena have caused unexpected operation problems to control and stabilise the expanded catalyst bed level in the EBR at a predetermined oil-to-gas ratio. The adequacy of the present catalyst characterisation analyses for catalysts meant for EBR operation is in doubt. This issue has already been raised by Kam et al. [3], since catalyst stratification [4,5] and attrition [6–8] can play an important part in the hydrodynamic behaviours. Kam et al. [5,9] also reported some effects of catalyst stratification from ebullation in a cold-flow EBR

Table 1
Process conditions using mixed catalysts

Process time (day)	Normalised vacuum residue feed	Normalised diluent feed	Normalised catalyst addition rate	Normalised CAT	950°F$^+$ Conversion (%)
1	Base	Base	Base[a]	Base	56
2	0.96	1	0.110A + 0.028B	0.991	53
3	0.96	1	0.147A + 0.037B	0.991	42
4	0.96	1	0.093A + 0.026B	0.991	42
5	0.96	1	0.093A + 0.026B	0.997	42
6	0.96	1	0.110A + 0.028B	0.991	49
7	0.96	1	0.110A + 0.028B	0.997	49
8	0.96	0.667	0.093A + 0.026B	1.001	52
9	1	0.667	0.092A + 0.023B	1.001	50
10	1.04	1	0.093A + 0.026B	1.003	49
11	1.04	1	0.093A + 0.026B	1.003	49
12	1.04	1	0.093A + 0.026B	1.009	49

[a] The base for catalyst loading during start-up is 50% fresh 50% fresh + 50% spent of catalyst A.

of catalyst A, and of mixed catalysts of A and B, respectively. In this paper, the catalyst attrition in the cold-flow EBR due to ebullation at the refinery gas-to-oil ratio will be discussed.

1.1. Catalyst attrition

Attrition occurs when solid particles are transported in fluid media, in which the particles collide with the container wall or with each other. The nature of attrition depends on the angle of contact, contact stresses and masses, relative velocities and the particle shapes, sizes and strength. The realisation of catalyst attrition causing the reduction in reactor efficiency was observed by Forsythe and Hertwig [6] in the early development of the fluid catalyst cracking process. Similar observations were also reported by Wei et al. [7]. However, the main stream of attrition studies is in fluidised-bed combustors [10–12] or particle comminution [13,14]. There are relatively few investigations published on the multiphase EBRs, which are now becoming commercially important because of their flexibility in dealing with most types of heavy feedstock and are attractive because of the ease with catalyst replacement during operation [15].

The ebullation in EBRs is basically a suspension of catalyst particles in a turbulent liquid medium and agitation with hydrogen gas bubbles, which result in homogeneous mixing and maintain a uniform reactor temperature. The continuous settling and rising of catalysts in the ebullated-bed, interparticle impacts, fracture and abrasion cause attrition with the consequent production of fines. The fines produced affect the hydrodynamic characteristics and foul the process instrument and equipment.

2. Qualitative analysis of the H-oil unit operation problems

In the period when mixed A and B catalysts were used in one of Shuaiba Refinery's H-oil EBRs, operations were unstable and performance was lower. The major operational problems experienced were the higher catalyst addition rate, higher hydrogen consumption, higher catalyst spread temperature and higher catalyst exotherms. In addition, the catalyst level in the EBR was constantly unstable and the $975^{\circ}F^{+}$ conversion was lower. Foaming occurred in the preflash vessel. Moreover, a considerable amount of small catalyst particles and fines were found in the downstream flow circuits and equipment. Lower efficiencies in the process equipment such as the hydrogen gas preheater, ebullation pump, and recycle hydrogen compressor were also noted.

Some operation problems could be explained from the information of the commercial EBR process conditions, and findings from our hydrodynamic study of mixed hydrotreating catalysts in a cold-flow EBR [9]. These experimental observations were the following:

1. Catalysts A and B do not mix evenly in the expanded ebullated-bed.
2. Catalyst B is more sensitive to the liquid and gas flows than A.
3. Catalyst bed expansion is higher even with only a small amount of B in A.

2.1. Higher catalyst addition rate

Catalyst B expanded more than A during ebullation even in a small amount. The loss of catalyst from the EBR due to catalyst carry-over should be more severe than A alone. Hence, more catalyst was needed to supplement the bigger loss. However, this explanation was not very satisfactory because the replacement was sometimes more than the total amount of B used in the daily catalyst addition.

2.2. Higher hydrogen consumption

From the mass balance on the purity of the recycle hydrogen, and the increase requirement of the make-up hydrogen, the gas was consumed more than usual. Since the hydrogen consumption depended mainly on the reaction kinetics and catalyst selectivity, no explanation would be offered from the present attrition study in a cold-flow EBR.

2.3. Higher bed-spread temperature

There are 18 temperature points in each H-oil EBR, and the bed-spread temperature is defined as the difference between the maximum and minimum bed temperatures. Since the selectivity and reactivity of catalysts A and B are different and the two catalysts are

not evenly mixed, the local bed temperatures, which depend on the exothermic factors of the appropriate catalytic reactions, will not be as homogeneous as that of an ebullated-bed using a single catalyst alone. And hence the higher bed-spread temperatures are resulted.

2.4. Higher catalyst exotherms

The catalyst exotherm is known as the difference between the reactor inlet temperature and catalyst average temperature (CAT). Since the bed-spread temperatures were higher, the CAT would be higher and hence the catalyst exotherms.

2.5. Unstable catalyst bed level

The catalyst bed level is one of the most important process indicators in the H-oil unit operation. It has to be kept lower than the permissible upper level (PUL) [2,16,17].

Since catalysts A and B do not mix evenly in the expanded ebullated-bed, catalyst B is more sensitive to the liquid and gas flows, and it also gives a higher bed expansion, the catalyst lost due to catalyst carry-over causes the reactor effluent density unevenly distributed. The commercial EBR level detectors, which can only sense the liquid density, pick up these signals from the density fluctuations. Evidently, more small catalyst particles and fines have been found in the downstream equipment during an unscheduled shutdown.

2.6. Lower 975°F^+ conversion

The higher bed-spread temperatures and catalyst exotherms provided favourable conditions for the reactions to produce light hydrocarbon gases. Although the hydrogen consumption was increased, the gas was used to hydrocrack the cracked products, instead of the residue.

The higher hydrogen consumption and lower 975°F^+ conversion in the commercial EBR indicated further hydrocracking of the cracked products, which were more exothermic than the hydrodesulphurisation (HDS) or hydrodemetallation (HDM). This was confirmed by performing a mass balance on the H-oil unit, its liquid product slate, and the gaseous product distribution, undertaken the Process Engineering Department of the refinery.

2.7. Foaming occurred in the preflash vessel

The increase in production of light hydrocarbon gases and the modification of surface tension and viscosity of the ebullated media due to catalyst attrition could facilitate foams formation in the free-board region of the EBR. The preflash vessel was the first separator after the EBR and the severity of foaming was mostly found in this vessel. In addition, the foams also affected the level control and indicator.

The foam formation was observed in the cold-flow EBR in the present catalyst attrition experiments at higher gas and liquid flow rates.

2.8. Catalyst particles and fines found in the downstream flow circuits

As discussed previously on the H-oil operational problems of the unstable catalyst level, catalyst B expanded more than A during ebullation. The smaller particles of B were carried out the EBR by the product effluents to downstream. To make the process conditions worse, the foams could carry away more small catalyst particles and fines. An examination on the scales removed from one of the residue feed preheaters reviewed that their major contents were catalyst fines of B.

2.9. Lower efficiencies in downstream equipment, such as the hydrogen gas preheater, ebullation pump, and recycle hydrogen compressor

The carry-over of catalyst particles and fines from the EBR deposited on the surfaces of the heat exchangers or other heat transfer equipment. These scales would increase the heat transfer resistance and reduced the flow areas. Hence, more energy were required to perform the same heat duty.

Both the ebullation pump and recycle hydrogen compressor were designed to provide momentum transfer for the fluids concerned. When solid particles were present in the transfer media, they would modify the equipment flow characteristics. In an extreme case, they could damage the equipment.

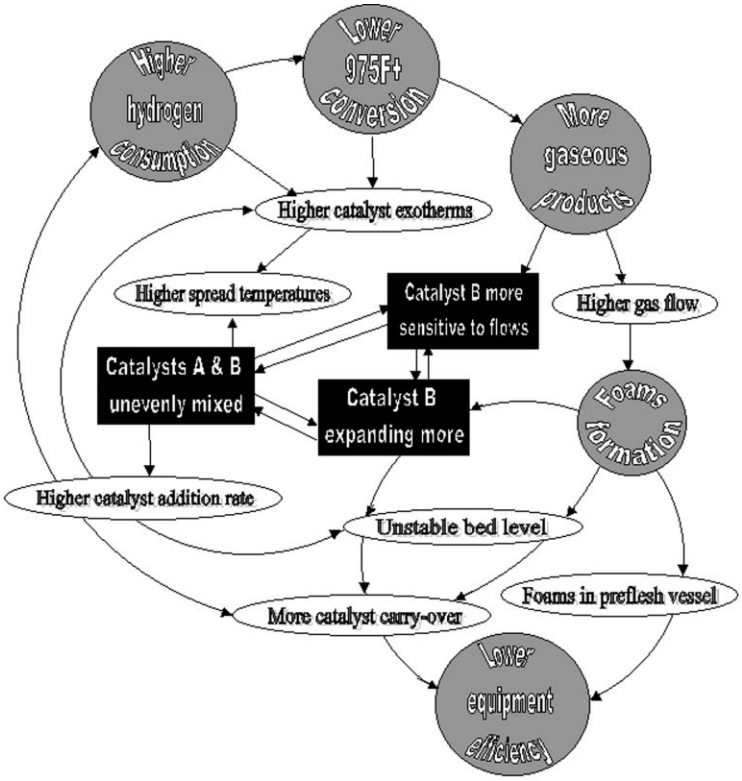

Fig. 2. Interactions of the operation problems and possible explanations in the H-oil unit in Shuaiba Refinery, KNPC.

2.10. Interactions of the H-oil operation problems

From the above analyses, it showed that all these operational problems were not isolated or occurred individually. They were highly interactive. One problem related to or affecting the others, and vice versa. A summary displaying the interactions between the operational problems (circles), process conditions (ellipses), and the experimental findings from the cold-flow EBR hydrodynamic study [3,9] (rectangles) is shown in Fig. 2. However, the above explanations did not provide a full picture of why only a small amount of catalyst B could upset the H-oil unit operation differently.

After reviewing the above discussions, it was decided to carry out catalyst attrition test experiments in the cold-flow EBR to examine the catalyst attrition characteristics, using the liquid velocity of the combined liquid feed, diluent and ebullation flows, while the gas velocity should be based on the refinery's gas-to-oil ratio.

3. Catalyst attrition study in the cold-flow EBR

Published studies on catalyst attrition in multiphase EBR are relatively limited. In our previous study of catalyst attrition in a cold-flow EBR at low oil-to-gas ratios [8], the employed multiphase system consisted heavy kerosene, hydrotreating catalyst particles and air. Under the experimental conditions, it was found that larger particles produced more fines but they gave a more stable catalyst level and in longer process time. In terms of particle shape, the maximum fines production was from the spherical particles, which were followed by the extrudates, and then cylindrical catalysts. This observation applied to the two particle sizes used in the study. The mechanical strength of the catalyst

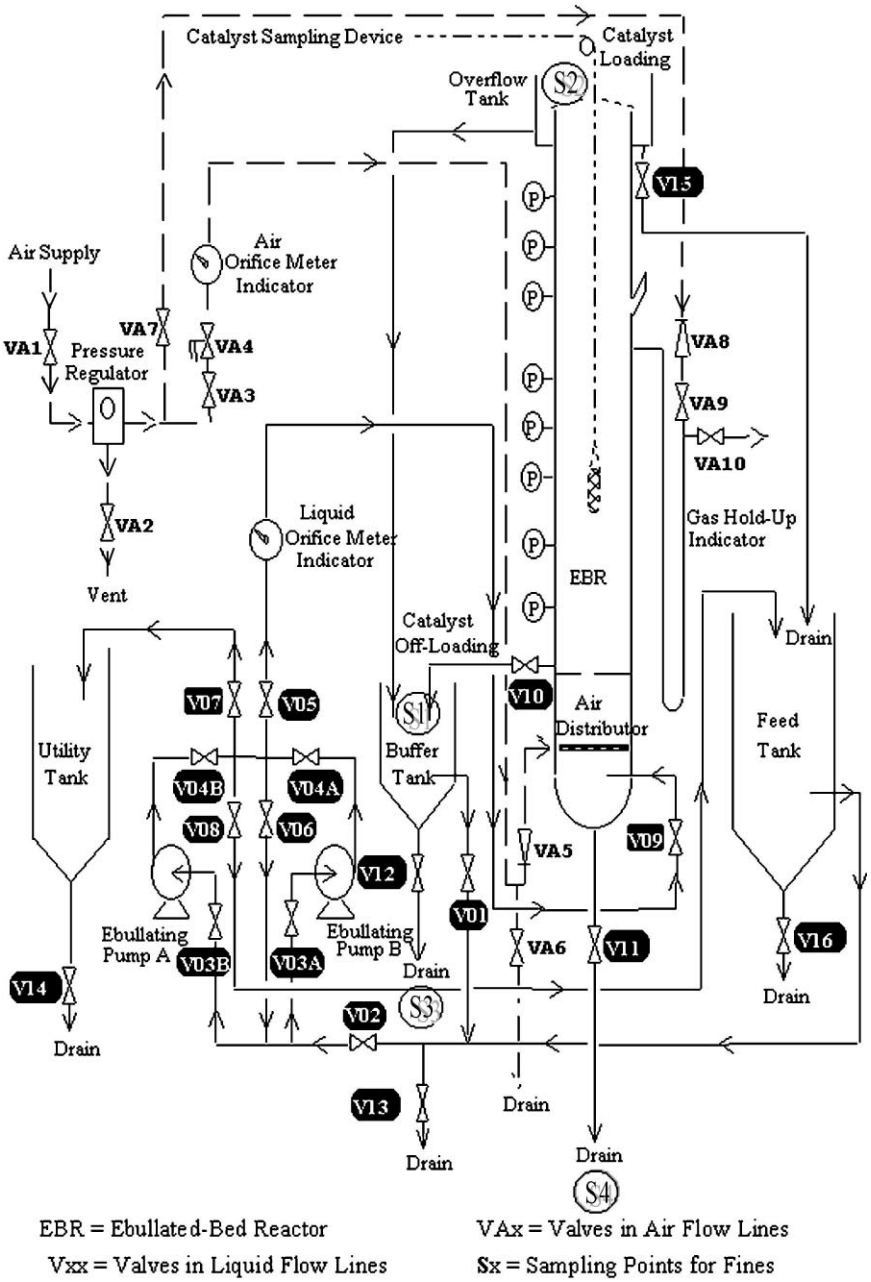

Fig. 3. A schematic diagram of the cold-flow EBR pilot plant at KISR — EBR: ebullated-bed reactor; V*xx*: valves in liquid flow lines; VA*x*: valves in air flow lines; S*x*: sampling points for fines.

supports was also an important indicator to determine the severity of attrition. A stronger side-crush strength catalyst support produced less fines. Soaking of catalyst particles could also reduce attrition. Catalyst particles were smoother after ebullation and caused a reduction in the bed expansion.

3.1. The cold-flow EBR

A schematic diagram of the cold-flow EBR used in the catalyst attrition study is shown in Fig. 3. The vertical EBR column is mainly made of glass and consists several long and short pieces, all are at an internal diameter at 0.15 m. Between the glass columns are metal spools with the same internal diameter for loading and off-loading catalysts. A total height of 4.5 m is accumulated. The gas and liquid inlets are at the low end of the EBR and below the catalyst grid support, which prevents catalyst particles dropping down and acts as an additional gas–liquid distributor. The gas and liquid flows are co-current and upward. Eight pressure taps, each connected to a pressure gauge, and located at 0.4 m interval on the column wall facilitate pressure measurements. The size of piping network for liquid flow is 0.0375 m. and that of the gas flow is 0.0125 m. Two pumps and a compressor are used for liquid and gas feeds transportation, and liquid ebullation. Air, hydrotreating catalysts and heavy kerosene are used as the gas, solid and liquid phase materials, respectively. Sampling points for the daily catalyst fines in suspension are located in the buffer tank and on the crown of the column, as marked in Fig. 3 as S1 and S2, respectively. The daily catalyst fines in sediments are sampled from the drain of the buffer tank, S3. Another sampling point, S4, is at the drain of the EBR. Only one sample from S4 is collected at the end of the experiment for an overall catalyst mass balance.

3.2. Process parameters

The process parameters that are directly affecting the hydrodynamics of EBRs are the flow rates of the liquid feed, gas feed and ebullation, as well as their respective transport properties. However, it is very important to maintain the gas-to-oil ratio to the predetermined value to avoid excess coke formation in the catalysts, reactor or downstream equipment. Its value depends on the properties of the feedstocks and catalysts, and process pressure and temperatures. The gas-to-oil ratio value from the commercial EBR cannot be applied directly to the cold-flow EBR simply because the ratio used in the commercial EBR is based only on the feed oil (residue and diluent) rate. In contrast, the liquid flow in the cold-flow EBR is in effect, the combined feed and ebullation rates. Hence, the value has to be adjusted with respect to the process temperature, pressure and flows. Table 3 shows some of the process parameters in both the commercial and cold-flow EBRs.

Table 3
The process parameters of the H-oil and cold-flow EBRs (NA: not available)

Parameter	Commercial EBR	Cold-flow EBR
Gas and liquid flow rates		
Gas superficial velocity (total[a]) (m/s)	0.045	0.045
Liquid superficial velocity (total[a]) (m/s)	0.22	0.22
Catalyst inventory		
Initial catalyst loading (kg)	Base	5.00
Daily catalyst addition rate (kg)	1.65% × Base	0.00
Daily catalyst withdrawal (kg)	1.35% × Base	0.00
Static bed height (m)	4.00	0.19
Current gas-to-oil ratio		
Average process pressure (MPa)	17.06	0.10
Average process temperature (K)	715.00	295.00
gas-to-oil (feed) ratio (m^3/m^3)	11.00	NA
Gas-to-oil (total[a]) ratio (m^3/m^3)	2.00	2.00

[a] Total = feed + ebullation.

In this study, the pressure and temperature are kept in ambient conditions, and only one level of liquid flow rate, gas-to-oil ratio, and process temperature were used. The process parameters to be manipulated was the three levels of catalyst type A–C. The catalyst C was a commercial hydrotreating catalyst from another manufacturer. It was also an alumina based extrudate in similar size as A or B. Each test lasted around 26 days, depending on the attrition rate. Fresh catalysts and heavy kerosene were used in each new experiment. Details of the experimental procedures have been reported elsewhere [5,8,18] and are not repeated here.

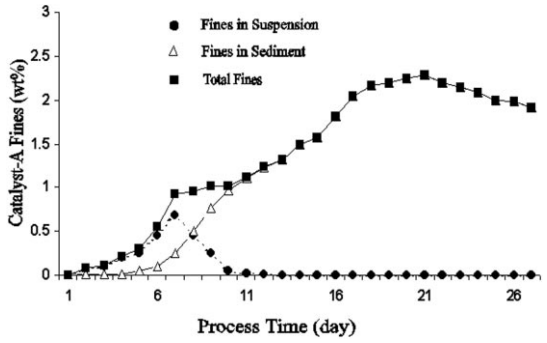

Fig. 4. Fines production of catalyst A with process time.

4. Results and discussion

The fines produced from ebullation are suspended in the heavy kerosene. The suspension is assumed to be a pseudo-homogeneous mixture as suggested by Kam and McGreavy [8]. This was confirmed by comparing the fines in the liquid samples taken simultaneously from the two sampling points and weighed after filtering treatment and drying. The maximum weight difference between the two samples was about 2% in a 0.005 kg sample. After each analysis, the liquid portion of samples was returned to the EBR to maintain the material balance of the system and minimise the loss of ebullated medium. The fines were comparatively small and could be discarded. However, once the suspension was saturated, sedimentation of fines commenced. Hence, a known volume of sample was also collected daily from the drain of the buffer tank for analysis of fines in the sediment and suspension. The concentration of fines in the suspension from this sample was in average, within 5% to those collected from the two designated sampling points. This evidently showed that the kerosene suspension was a homogeneous mixture. Moreover, the fine content in the sediment appeared not to withhold fines from the suspension. Again, only the heavy kerosene was returned to the EBR, though there was a trace of kerosene loss due to drying of the sediment samples. The fines from the sediments were not returned to the EBR because their accumulated mass would block the strainers and outlets of the buffer tank, and foul up the ebullation pump.

The total amount of fines produced was the sum of the fines from suspension and sediments, and was expressed in terms of the weight percent of the initial 5 kg catalyst loadings against the process time expressed in days. Fig. 4 shows the daily fines production of catalyst A due to attrition. The plot symbolised by the diamond shape depicted the daily fines content in the kerosene suspension. Fines production commenced as soon as the ebullation started, and increased continuously until the sixth day. From then on, the daily production of the fines in the kerosene suspension began to reduce. At the same time, fines in the sediments started to increase as shown by the curve in square symbols. After the ninth day, the kerosene suspension was saturated and no additional fines were detected thereafter. However, the fines contents in the sediments began to rise. The total daily fines production was indicated by the plot in triangular symbols.

The maximum suspension of catalyst fines that the heavy kerosene was able to hold before precipitation, could be determined from the accumulation of all the values of this plot. A value of 2.56 wt.%, i.e. 0.128 kg, was obtained.

4.1. General observations

The flow regime under the present higher gas and liquid velocities was different than that observed before [5,8] when lower flow rates were used. Notably, there were two regions of ebullation and one free-board regime. The lower ebullation region was very dense with catalyst particles, but bubbles were smaller. The upper ebullation region was comparative dilute in the catalyst concentration. The particles were shorter in size, but the bubbles were larger. Foams were started to form in the upper ebullation region

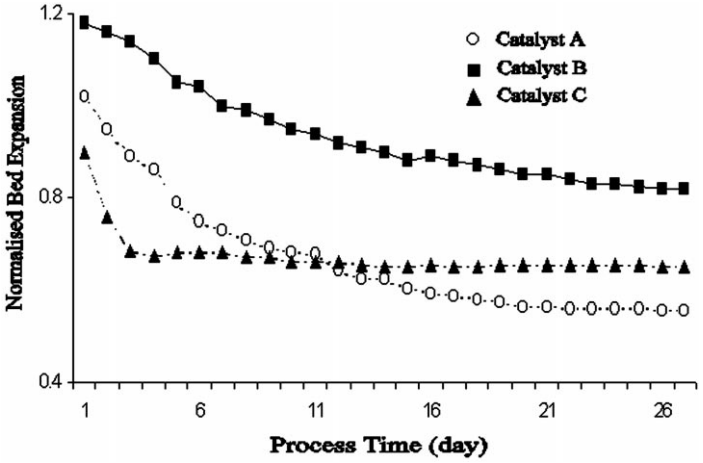

Fig. 5. Comparison of the normalised bed expansion of the three catalysts.

and continued in the free-board region. The foams were carried over to the overflow tank on the top of the EBR, see Fig. 3.

Fig. 5 shows the normalised bed expansion of the dense ebullation region plotting against the process time. Catalyst B provided the highest bed expansion. It was followed by catalyst A, and then C. The bed expansion of B higher than A was also observed at lower gas and liquid flow rates [3,9]. However, the bed expansion of both catalysts A and B reduced as process time increased. This did not apply to catalyst C, which kept almost constant throughout the test period after an initial rapid drop. From this plot, catalyst C appeared to be a very suitable hydrotreating catalyst for EBR because of its stable catalyst level. However, after analysing the fines production from attrition, its suitability was fully reduced.

4.2. Comparison of catalyst attrition

Before comparing the fines production between the three catalysts, it will be interested to see how the gas and liquid flow rates would affect the catalyst attrition. Fig. 6 shows the daily fines production of catalyst A for the two sets of gas and liquid flow rates. The plot symbolised by squares represented the total fines production at the higher flow rates. It was the same total fines production curve of A shown in Fig. 4. The take-off point for the heavier fines production started on the fifth day, which was sooner than that of the lower flow rates [5] on the eighth day. The maximum fines production at the higher flow rates was 2.33 wt.%, which was less than that at the low flow rates of 2.75 wt.%. However, the process time at which the maximum fines production occurred in both cases, was around 21 days.

Fig. 7 shows a comparison of fines production from catalysts attrition of A–C ebullated in the cold-flow EBR at the higher gas and liquid flow rates corresponding to that used in the commercial EBR. Catalyst A, represented by circles, produced the lowest fines while catalyst B, represented by squares, produced more fines than A. The characteristics of

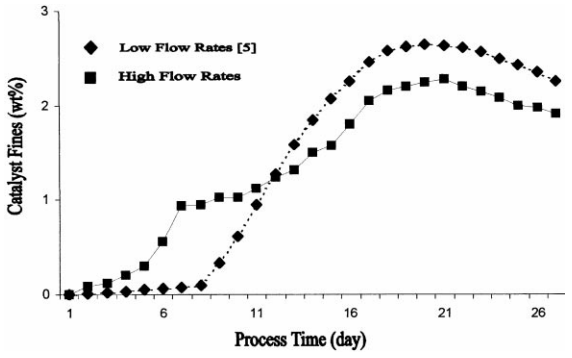

Fig. 6. Effect of gas and liquid flow rates on catalyst A fines production.

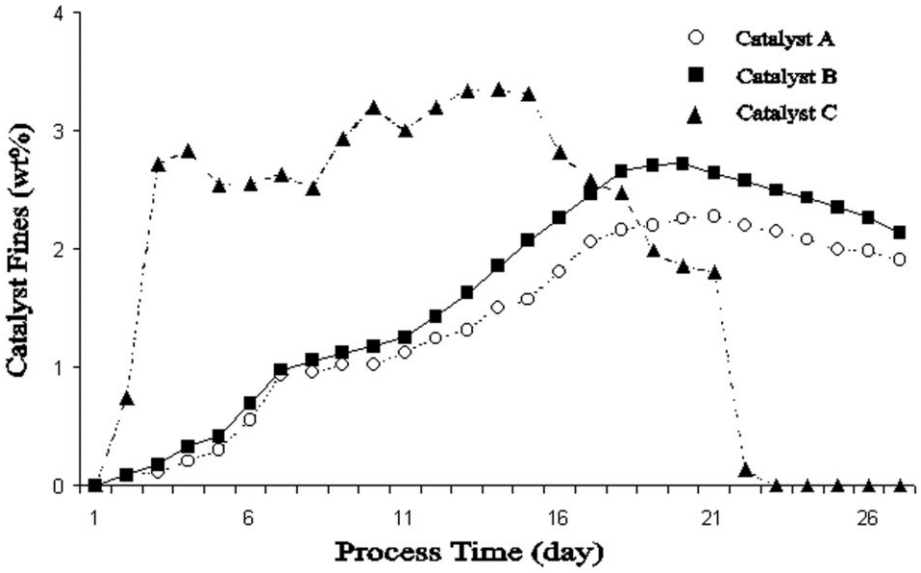

Fig. 7. Comparison of the total fines production with process time for the three catalysts.

fines productions for both A and B were similar. The take-off point for the heavier fines production started after ebullating for five days. The characteristic curve of catalyst C, represented by triangles, showed catalyst C produced the highest fines; and the rate of fines production was different than the others. The take-off point started on the first day of ebullation and finished after 21 days because no additional fines were detected from the drained sample. However, this was later discovered that a large quantity of fines had deposited around the strainer and blocking the outlets of the buffer tank, despite a sediment sample was off-loaded every day from its drain. Similar results were observed in the repeated run after clearing the buffer tank. From the characteristic curve of C, the blocking of the buffer tank outlet occurred from the 15th day, when the fines production in the sediments began to reduce. The blockage was completed on the 21st day. A summary of the mass balance of the three tested catalysts is given in Table 4. The loss in catalyst C, which was about 1 kg in the form of deposit in the buffer tank, was the major one among the three. As

Table 4
Mass balance of catalyst attrition on A–C

Mass balance	Catalyst A	Catalyst B	Catalyst C
Input			
Loading of fresh catalyst (kg)	5.000	5.000	5.000
Output			
Total fines from suspension (kg)	0.128	0.135	0.153
Total fines from sediment (kg)	1.723	2.063	1.946
Spent catalyst left in EBR (kg)	2.952	2.493	1.923
Loss			
Fines deposited in the Buffer Tank/Others (kg)	0.197[a]	0.309[b]	0.978

[a] Including 0.107 kg of small size (A) extrudate in the overflow tank.
[b] Including 0.214 kg of small size (B) extrudate in the overflow tank.

discussed previously, catalyst C was not really suitable for EBR hydrotreator operations because of its heavy fines production due to catalyst attrition from ebullation.

4.3. Further analysis of the H-oil unit operation problems

In view of the new findings on the attrition of catalysts A and B, better insights into the H-oil unit operation problems were obtained.

Since catalyst B produced higher catalyst fines, which moved along with the product effluents, either recycled with the ebullation flow or exited to the downstream separators. The fines could catalyse the hydrocracking reactions on the cracked products. Because of their very small particle sizes and homogeneously suspended in the product effluents, the mass and heat transfer resistance became negligible. Hence, the reaction rates of the catalyst fines were better than the extrudates of A or B. Therefore, more hydrogen gas was consumed for the reactions catalysed by the extra fines produced from B on the cracked products. Consequently, more gaseous products, lower residues conversion, and higher local temperatures, which could cause higher bed-spread temperatures and catalyst exotherms, were experienced. The higher local temperatures, the increased volume of gaseous products, and the extra fines of catalyst B would modify the density, surface tension and viscosity of the ebullation media, which would, in turn, exemplify the already unstable bed expansion and undesirable foams formation.

5. Conclusions

Attrition is an unavoidable phenomenon when catalysts are used in EBRs or fluidised-bed reactors. The fines produced from catalyst attrition will affect the stability of the reactor and modify the process performance.

From the attrition test, the ebullated media flow rates affect catalyst attrition rate. More catalyst fines are produced at high flow rates and hence the heavier fines production rate appears sooner than at low flow rates. Moreover, the maximum daily fines production at high flow rates is more. Nevertheless, a process time of around 21 days is required for both sets of media flow rates to reach the maximum fines production.

When comparing the attrition test results of the three commercial hydrotreating catalysts ebullated at high liquid and gas flow rates based on the refinery's gas-to-oil ratio, the suitability of catalysts to be used in an EBR hydrotreator can be determined. Though all three catalysts have similar catalyst characterisation properties, the suitability of B is not as good as A, while C is not recommended. It is because of the higher bed expansion and more fines produced from B during ebullation. In the case of C, the fines production is far too high for the cold-flow EBR to handle, in terms of only the hydrodynamics. When the reaction kinetics are included, more operation problems are anticipated. Subsequently, Shuaiba Refinery, KNPC has planned to adopt this testing procedure as an additional specification to select future EBR hydrotreating catalysts.

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