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Optimizing Catalyst Loading for Improved Quality of SF-05 in Hydrocracker Reactor C-3-03B at HCU RU V Balikpapan

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ABSTRACT

PT Kilang Pertamina Internasional RU V Balikpapan innovated the Unibon Hydrocracker unit to increase the production of Smooth Fluid (SF-05), a high-quality base oil for drilling mud. Because the catalyst was approaching the end of run and the product did not yet meet specifications, the catalyst (Change of Catalyst - COC) was replaced with a new configuration in Reactor I C-3-03B. This research aims to optimize the hydrocracking process by changing catalyst loading and operating settings for the C-3-16B fractionation column. It is hoped that this effort will produce high-quality SF-05, meet market demand, and increase efficiency and environmental friendliness. The research results show that the Smooth Fluid SF-05 product meets all specifications with an average hydrogen consumption of 231,649 Nm3/m3 (purity 94.83%) in the HCU Train B reactor. This condition helps improve the quality of products that are more competitive in the market, thus having a positive impact on increasing company profits. Hydrogen consumption is influenced by various process variables and increases with changes in hydrogen partial pressure, CFR, H_2/HC ratio, conversion rate, WABT, and LHSV. All process variables are still within the specified operating design range.

1. Introduction

Hydrocracking is a petroleum processing process that aims to break down heavy hydrocarbon molecules into lighter hydrocarbons with the help of hydrogen gas (H_2). Hydrogen gas plays an important role in this process. The main function of hydrogen gas is to stabilize the molecular structure formed from the breakdown of hydrocarbon chains, prevent the formation of undesirable unsaturated compounds, and increase the production of light hydrocarbons that have higher economic value. A high enough amount and purity of hydrogen gas is very important to ensure the reaction runs well, thereby producing oil products according to the expected specifications. The process of breaking down hydrocarbon molecules takes place in a reactor which is part of the hydrocracker process unit. In addition, the hydrocracking process also helps reduce sulfur and nitrogen content in the final product, producing cleaner and environmentally friendly fuel [1–3].

In order to support the efficiency of the hydrocracking process, one of the key factors that affects reactor performance is the arrangement of catalyst loading. Configuring optimal catalyst loading is very important, because it can increase reaction efficiency and produce better quality products. According to research conducted by [4] shows that changing the catalyst loading configuration in a hydrocracking reactor can increase feedstock conversion and selectivity to desired products, such as lubricating oil.

As one of the largest oil refineries in Indonesia, PT Kilang Petroleum Internasional RU V Balikpapan produces various types of fuel oil and petrochemical products. One of its main products is Smooth Fluid (SF-05), a high-quality lubricant used for motor vehicle engines. Maintaining the quality of SF-05 products is essential to meet market demand and maintain customer satisfaction [5].

In order to support the production of SF-05 and maintain its quality, the company needs to focus on providing safe, reliable, efficient, and environmentally friendly fuel and non-fuel products. Continuous innovation and improvement are the keys to facing the challenges of Pertamina's head office in achieving high-quality product targets. In particular, Smooth Fluid (SF-05) functions as a base oil in a mixture of drilling activities using oil-based mud (Oil Base Mud/OBM), which must have the best performance and be environmentally friendly, and is produced from the diesel oil fraction [6]**.**

In the SF-05 production process, one of the crucial stages is the hydrocracking reaction which takes place in reactor I C-3-03B Unibon Hydrocracker. This reaction involves the use of a catalyst to convert heavy oil raw materials into lighter and better quality products, such as lubricating oil [7]. However, over time, catalyst performance may decrease, which can impact the quality of the SF-05 product produced.

To overcome this performance decline and improve the quality of SF-05 products, one approach that can be taken is to change the catalyst loading settings in the Unibon Hydrocracker I C-3-03B reactor. By making this configuration change, the expected catalyst performance can be optimized, so that the efficiency of the hydrocracking reaction also increases and produces SF-05 with better quality [4], [8].

Based on previous studies, it is known that changes in the catalyst loading configuration in the hydrocracking reactor can increase feed conversion, selectivity to the desired product, and the quality of the lubricating oil product [9], [10]. Therefore, the step of optimizing the catalyst loading configuration in the Unibon Hydrocracker I C-3-03B reactor is very important to ensure an increase in the quality of SF-05 products at PT Kilang Petroleum Internasional RU V Balikpapan.

Along with the increasing demand for high-quality SF-05 products, the condition of the catalyst used in the hydrocracker unit (HCU) reactor is increasingly critical, because it is approaching the end of its service life (EOR). In addition, the reaction temperature setting in the reactor bed has exceeded the maximum limit set, so that the SF-05 product produced still does not meet the expected specifications. Increasing the reaction temperature can accelerate the formation of coke on the catalyst surface, which has a negative impact on reactor performance. Therefore, to ensure that the SF-05 produced is in accordance with the specifications and has high quality, it is necessary to place a new catalyst (Change of Catalyst/COC) by changing the catalyst loading configuration in Reactor I C-3-03B.

Therefore, this research aims to examine the effect of changes in catalyst loading settings in Reactor I C-3-03B hydrocracking unit as well as changes in the way of regulating operating conditions in the C-3-16B fractionation column for diesel oil fraction products on improving the quality of SF-05 products that will be generated.

2. Research Methodology

2.1. Materials

The research to be conducted requires software equipment in the form of: Reactor and Fractionation Column: the main equipment in the research to observe and analyze operating conditions directly in the field. Distributed Control System (DCS): a computerized system used to monitor, control and regulate operating conditions automatically. To see the changes that occur, Statistical Product and Service Solutions (SPSS) is used: software used for statistical analysis and data management as well as design simulation and analysis processes to test the normality of the operating condition data of the C-3-03B reactor and fractionation column. Microsoft Excel 365: a spreadsheet application that functions for data processing, analysis, and visualization to create data and tables and initial calculations which are then used as input for Aspen HYSYS.

The type of material is research data which consists of primary data types and secondary data types obtained from Pertamina RU V Balikpapan HCC Unit, certain references or literature, literature studies, and company data or documents used to support primary data

2.2. Procedures

To conduct research correctly and in accordance with the expected goals, there are several stages that must be carried out. These stages include:

2.2.1. Preparation Stages

First, initial research was carried out regarding the operating conditions of the reactor and fractionator columns. Second, reactor I C-3-03B and Fractionator Column C-3-16B HCC units were determined as research subjects. Third, supporting software in the form of DCS, SPSS, MS Excel needs to be prepared. Fourth, the specified research time is August - October 2023. Next, data related to equipment operating conditions must be prepared (data sheet), Then, a procedure for loading and unloading the catalyst in the reactor must be created. Finally, create a procedure for setting operating conditions in the fractionation section during SF-05 production.

2.2.2. Reseach Stages

In conducting this research, there are several steps that need to be taken. First, record the operating parameters in the form of fresh feed flow rate, Recycle Feed flow rate, Unconverted Oil product flow rate, gas flow rate, gas purity, operating temperature, and property data from catalyst. Second, measure additional operating parameters that are not included in routine monitoring. Third, carry out a normality test of operating condition data to obtain certainty whether or not it is appropriate as input for changes to the catalyst loading configuration. Fourth, carry out calculations and manage data related to operating conditions in accordance with the operating variable calculation formula. Fifth, determine the independent operating variable in this research, namely setting the temperature for withdrawing diesel oil products in the C-3-16B fractionation column. Finally, the procedure for setting operating conditions in the fractionator section during SF-05 production is made in the form of a Standard Operating Procedure (SOP).

3. Results and Discussion

3.1. Process Description

PT. Kilang Pertamina Internasional RU V Balikpapan Refinery, especially the Hydrocracker Unit Train B, has a processing capacity of 27,500 barrels/day and functions to carry out conversion through a cracking process in the reactor with Fresh Feed (FF), namely High Vacum Gas Oil (HVGO). from the High Vacum Unit (HVU) plant and storage tank with a ratio of around 45% and 55%. HVGO is converted into lighter products with high selling value, such as Liquified Petroleum Gas (LPG), Light and Heavy Naphta, Light and Heavy Kerosene, and Gasoil, apart from that, also special products high quality, namely Smoot Fluid (SF-05) which will be discussed in this research. The HVGO feed design data can be seen in table 1.

Table 1. HVGO Bait Design Data

Property	HVGO	Test Method
Gravity, API	27.6	ASTM D-287
ASTM Dist. ºC	-	ASTMD-1160
IBP	352	-
10%	409	-
30%	423	-
50%	435	-
70%	452	-
90%	474	-
EP	516	-

Sulfur Content, Wt. %	0.09	UOP-380
Total Nitrogen, Wt. Ppm	360	UOP-384
Conradson Carbon, Wt. %	0.03	ASTM D-169
Heptane Insolubles, Wt. %max.	0.05	UOP-614
Metal (Ni+V), Wt. Ppm max	2	UOP-391 or 389
Color	4.0 max	ASTM D-1500

The SF-05 product that will be produced has critical parameters of density, aromatic content, viscosity, pour point, aniline point, sulfur content. SF-05 product specifications can be seen in table 2.

Table 2. SF-05 Product Specifications

Parameter	Unit	Method	Specification
Density @15ºC	-	ASTM D-1298	0.800 – 0.835
Flash Point PMCC	ºC	ASTM D-93	Min. 80
Aromatic content (BTX)	% m/m	GCMS	Max. 0.05
Viscosity @40ºC	cSt	ASTM D-445	3.0 – 3.7
Distilasi IBP	ºC	ASTM D-86	Min. 175
Pour point	ºC	ASTM D-97	Max. 3
Aniline point	ºC	ASTM D-611	Min. 80
Color ASTM	-	ASTM D-1500	Max. 1.5
Copper strip corrosion	-	ASTM D-130	Max. Class 1
Sulfur Content	ppmw	ASTM D-2622	Max. 40

The reactor in the hydrocracker unit uses a fixed bed reactor type using two different types of catalyst, namely the HC-215 LT (trilobe) catalyst which is used for the hydrotreating process and the DHC-8 (cylinder) catalyst, whose reaction orientation is hydrocracking.

3.2. Operating Condition

The operating conditions in the hydrocraking process will influence the progress of the conversion process. In addition, the operating variables that are regulated will affect the operating load (severity) of the reactor, quality and product quantity. These operating variables include: temperature, pressure, hydrogen consumption, conversion rate, H2/HC ratio, Combined Feed Ratio (CFR), Conversion per Pass (CPP), hydrogen partial pressure, Liquid Hourly Space Velocity (LHSV), Weight Average Bed Temperature (WABT). Operating conditions are obtained from direct observations in the field and data from the Distributed Control System (DCS). By using the formula for each operating condition, the following recapitulation data on the reactor evaluation results can be obtained which can be seen in Table 3.

Table 3. Recapitulation Data of Evaluation Results

Date	Variabel											
	Konsumsi	SG feed	Conversion	PP H2	LHSV	CFR	CPP	H2/HC	Reactor C-3-03B		Reactor C-3-04B	Reactor C-3-05B
									WABT			
	Nm3/Hr	-	%	Kg/cm2	1/Hr				C	C	C	C
01/08/23	234.42	0.893	91.56	150.57	0.55	1.7	53.76	1306.7	398.61	407.4	418.68	383.52
02/08/23	251.17	0.895	89.57	150.53	0.56	1.69	52.9	1241.31	397.19	406.1	417.7	384.39
03/08/23	218.61	0.894	88.88	150.66	0.56	1.7	52.25	1295.31	399.33	410.08	420.07	384.5
04/08/23	243.93	0.894	92.89	150.69	0.56	1.7	54.53	1258.09	396.8	407.78	420.38	384.99
05/08/23	244.36	0.897	94.37	151.14	0.57	1.7	55.53	1272.6	399.17	410.05	421.54	386.67
06/08/23	238.05	0.899	89.09	150.59	0.57	1.7	52.54	1245.77	398.13	408.75	420.36	386.69
07/08/23	224.73	0.897	93.02	150.33	0.58	1.7	54.68	1259.53	400.75	411.69	421.04	388.9
08/09/23	233	0.902	92.04	150.16	0.58	1.7	54.16	1231.81	401.33	411.44	421	389.06
09/09/23	220.26	0.901	90.64	146.57	0.58	1.69	53.74	1264.6	398.94	409.56	419.51	386.4
10/09/23	225.65	0.898	93.98	148.5	0.58	1.68	55.96	1251.89	398.46	408.39	420.1	385.9
11/09/23	229.93	0.899	91.28	149.92	0.58	1.68	54.37	1199.92	396.2	405.49	418.28	385.34
12/09/23	230.96	0.9	85.5	147.36	0.58	1.68	50.78	1177.85	396.6	405.58	416.72	388.7
13/09/23	231.58	0.902	89.45	147.24	0.58	1.7	52.77	1206.27	396.99	405.7	416.66	390.43
14/09/23	239.96	0.901	81.12	146.83	0.58	1.7	47.76	1116.59	397.99	405.73	414.12	391.2
15/10/23	224.72	0.901	92.67	149.43	0.59	1.7	54.45	1231.38	405.54	414.73	422.05	394.11
16/10/23	222.98	0.9	91.57	148.92	0.59	1.7	53.91	1229.65	406.18	417.15	421.73	391.3
17/10/23	223.72	0.901	92.47	149.47	0.59	1.7	54.47	1221.68	404.95	415.53	422.79	393.58

Evaluation results show actual values based on operating condition data. If we average the calculation results of the reactor operating process variables including hydrogen consumption in the HCU train B reactor circuit, we can make a comparison between the calculation results and the design values for the existing operating conditions. Table 4 below is a comparison table data.

Table 4. Data Comparison of Calculation Results and Design Data

Variable	Unit	Evaluation	Desain	
			Min	Max
Consumption	Nm^3/m^3	231.649	168.5	337
Konversion	%	90.595	-	-
Hydrogen Partial Pressure	kg/cm^2g	149.347	111	170
LHSV	1/hr	0.575	0.8	
CFR	-	1.695	1.2	1.5
CPP	%	53.444	-	-
H2/HC Ratio	Nm^3/m^3	1235.938	1200	
WABT	-	-	-	-
Reactor 1 Bed I	°C	399.599		
Reactor 1 Bed II	°C	409.48	55 °C	454 °C (EOR)
Reactor II	°C	419.573		
Reactor III	°C	388.005		

An analysis can be carried out regarding the operating conditions of the reactor during operation to produce SF-05, namely:

- LHSV operates below design, because the amount of feed processed is currently also reduced according to processing targets. The increase in flow rate of processed feed will be directly proportional to the increase in operating LHSV, and vice versa.
- Combined Feed Ratio (CFR) is operated beyond the design limit, because more and more liquid recycle is returned to the recycle feed reactor. The aim is to reduce the severity of the fresh feed reactor and increase the conversion rate of the amount of feed into product.
- Hydrogen Partial Pressure is operated close to the design maximum with the aim of compensating for coke formation on the catalyst surface. Therefore, hydrogen partial pressure is an important parameter that must be monitored.
- In terms of temperature, the current peak temperature is 440 ^{o}C, from the permitted peak temperature limit of 454 ^{o}C. This indicates that the catalyst activity is still under normal operating conditions, and the SF-05 product as the main product is produced in accordance with the specified specifications.

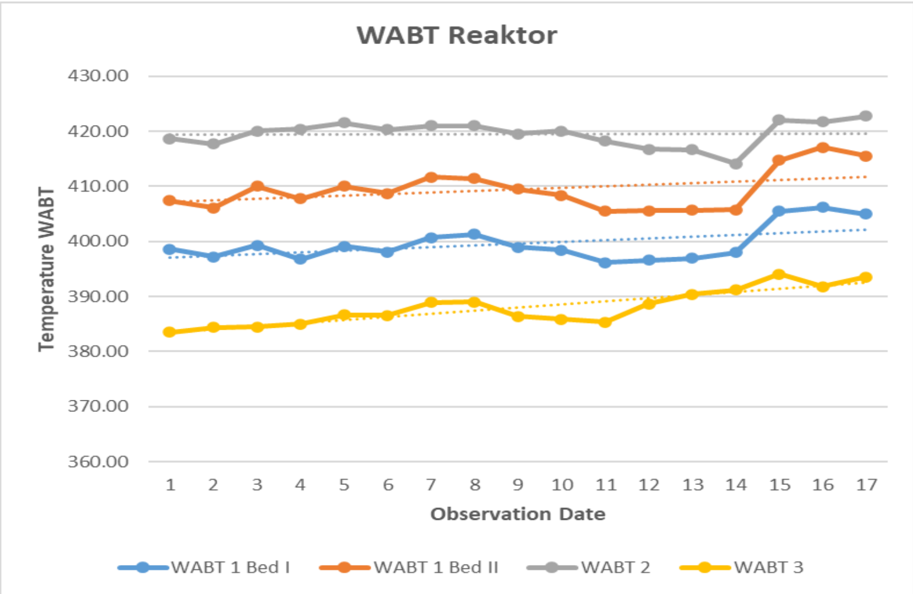

Fig. 1 Graph of WABT Reactor Condition

WABT calculation results are below design. This is because the required reaction temperature is smaller so WABT decreases. And it is shown by the decreasing slope on the WABT graph. If the reactant residence time is shorter, the frequency of the reaction will be lower, and vice versa. To overcome this, the action that needs to be taken is to increase the energy supply needed for the reaction, so that the frequency level that occurs can remain high even though the residence time of the reactants is relatively short. To increase the energy supply for reactions, appropriate actions need to be taken. This action is to increase the RIT (Reactor Inlet Temperature) value, which will have an effect on increasing WABT. The WABT calculation has been carried out in the previous sub-chapter, Figure 1 below shows the condition of the reactor WABT.

3.3. Correlation between Abtara Conversion and Product Yield

The amount of yield volume will vary greatly from one catalyst to another. This is because different types of catalysts will provide different cracking reactions. The type of catalyst will determine the level of cracking that occurs. Amorphous catalysts generally do not require a high conversion compared to zeolite to get the same product. However, zeolite catalysts generally have higher activity than amorphouse so they require lower temperatures. The volume of the main product will increase with increasing conversion. Product yield data produced by HCU train B includes Liquified Petroleum Gas (LPG), Light Naphta, Heavy Naphta, Light Kerosene, Heavy Kerosene, Diesel or SF-05, Net Bottom Fractionator (NBF) which can be seen in table 5.

Table 5. HCU Train B Product

Date	Product (m3/h)						
	LPG	**L Naphtha**	**H Naphtha**	**L Kerosine**	**H Kerosine**	**SF-05**	**NBF**
01/08/23	9.37	8.10	20.59	7.20	35.98	70.80	12.24
02/08/23	7.13	8.54	20.01	7.30	33.12	67.99	15.38
03/08/23	8.59	10.15	15.59	13.74	41.00	67.28	16.48
04/08/23	8.47	8.66	19.63	11.99	42.64	70.16	10.59
05/08/23	7.50	11.38	7.74	12.01	40.95	72.94	8.41
06/08/23	10.01	9.88	16.78	11.79	37.08	71.12	16.35
07/08/23	4.30	10.63	15.50	14.00	40.97	71.78	10.65
08/09/23	5.14	10.73	15.75	13.51	38.93	77.81	12.15
09/09/23	2.60	10.43	16.58	13.24	38.99	67.48	14.32
10/09/23	3.90	8.09	19.83	13.50	38.98	74.73	9.21
11/09/23	3.66	10.40	14.83	12.49	38.20	71.86	13.37
12/09/23	2.78	9.97	15.13	12.01	34.99	68.02	22.17
13/09/23	4.87	9.66	15.75	14.49	36.01	74.48	16.13
14/09/23	0.32	9.16	12.88	11.01	28.02	66.88	28.81
15/10/23	10.40	10.53	16.13	14.00	42.22	76.97	11.38
16/10/23	5.35	9.66	22.55	6.47	41.39	84.86	13.16
17/10/23	6.40	9.37	20.98	7.00	45.96	74.55	11.79

From Table 5 it can be seen that the number or quantity of SF-05 products has a higher percentage compared to other products, this indicates that the cracking process in the HCU reactor with the DHC-8 type catalyst is taking place optimally with the reaction direction to maximize the diesel fraction product. Apart from the quantity aspect, the quality analysis of the final product, especially the SF-05 product, is also strictly controlled so that it meets the specified specifications, which can be seen in Table 6.

Table 6. SF-05 Product Analysis Results after Configuration Changes

Product Analysis SF-05	Units	Limits	Date					
			01/08/23	**02/08/23**	**03/08/23**	**04/08/23**	**05/08/23**	**06/08/23**
Density @15 C	-	0.8 - 0.835	822.6	822.2	822.7	829.7	830.9	831.3
Flash Point	C	Min. 80	82	88	88	86	92	94
Aromatic Content (BTX)	% m/m	Max. 0.05	-	-	-	-	-	0.02
Viscosity @40 C	cSt	3.0 – 3.7	3.66	3.69	3.65	3.41	3.25	3.52

Distilasi (IBP)	C	Min. 175	206	201	194	193	208	208
Pour Point	C	Max. 3	0	0	-3	0	0	0
Aniline Point	C	Min. 80	87	88.2	89	83.6	82.9	82
Color ASTM	-	Max. 1.5	0.5	0.5	0.5	0.5	0.5	0.5
Copper Strip Corossion	-	Max. Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1
Sulfur Content	ppmw	Max. 40	6.2	8.7	6	7	7.8	7.7

Product Analysis SF-05	**Units**	**Limits**	**Date**					
			07/08/23	**08/09/23**	**09/09/23**	**10/09/23**	**11/09/23**	**12/09/23**
Density @15 C	-	0.8 –0.835	831.5	831.8	830.5	831.8	831.2	831.1
Flash Point	C	Min. 80	90	87	88	87	90	87
Aromatic Content (BTX)	% m/m	Max. 0.05	0.03	0.03	0.03	0.03	0.05	0.03
Viscosity @40 C	cSt	3.0 – 3.7	3.6	3.66	3.62	3.66	3.51	3.67
Distilasi (IBP)	C	Min. 175	203	206	195	206	205	200
Pour Point	C	Max. 3	0	0	-3	0	-3	-3
Aniline Point	C	Min. 80	83.1	81	83	81	84	82
Color ASTM	-	Max. 1.5	0.5	0.5	0.5	0.5	0.5	0.5
Copper Strip Corossion	-	Max. Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1
Sulfur Content	ppmw	Max. 40	8.3	8.6	18.2	8.6	14.1	20.1

Product Analysis SF-05	**Units**	**Limits**	**Date**					**Rata-Rata**
			13/09/23	**14/09/23**	**15/10/23**	**16/10/23**	**17/10/23**	
Density @15 C	-	0.8 –0.835	821.6	831.2	821.6	824.1	824.4	827.66
Flash Point	C	Min. 80	92	90	92	91	88	88.94
Aromatic Content (BTX)	% m/m	Max. 0.05	0.03	0.03	0.03	0.02	0.03	0.03
Viscosity @40 C	cSt	3.0 – 3.7	3.59	3.51	3.59	3.52	3.67	3.58
Distilasi (IBP)	C	Min. 175	200	205	200	205	208	202.53
Pour Point	C	Max. 3	-3	-3	-3	0	-3	-1.41
Aniline Point	C	Min. 80	88	84	88	88	87	84,81
Color ASTM	-	Max. 1.5	0.5	0.5	0.5	0.5	0.5	0.5
Copper Strip Corossion	-	Max. Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1
Sulfur Content	ppmw	Max. 40	7.4	14.1	7.4	8.1	3	9.49

4. Conclusion

From the research carried out, the resulting Smooth Fluid SF-05 product meets all the specified specification parameters. The average hydrogen consumption of the HCU Train B reactor circuit is 231,649 Nm3/m3 with a purity of 94.83%. This condition contributes to improving the quality of products that are more competitive in the market, thus having a positive impact on increasing the company's profits. Hydrogen consumption is related to various process variables such as fresh feed intake, feed SG, conversion, H2/HC ratio, hydrogen partial pressure, CFR, CPP LHSV, and WABT. Evaluation shows that hydrogen consumption increases with decreasing hydrogen partial pressure and CFR, as well as increasing H_2/HC ratio, conversion rate, and WABT. Hydrogen consumption also increases as LHSV decreases. The evaluation calculations of process variables related to hydrogen consumption are still within the specified operating design range.

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