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Research Article

Catalyst Losses and Air Flow Rate Effect on Cyclone Efficiency at Residue Fluidized Catalytic Cracking Unit

Pengaruh Kehilangan Katalis dan Laju Aliran Udara Terhadap Efisiensi Cyclone pada Residue Fluidized Catalytic Cracking Unit

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Abstract

Residue Fluidized Catalytic Cracking Unit (RFCCU) in the oil and gas industry is equipped with a regenerator that uses a cyclone to separate solid catalyst from reaction gases. Oxidation gases rise to the top of the regenerator before entering the cyclone stage. The cyclone inlet velocity depends on factors such as Main Air Blower (MAB) flow, dilute phase temperature, and dense bed temperature. Therefore, this study aimed to determine the effect of catalyst losses and combustion air flow rate on cyclone efficiency of RFCCU. The efficiency was determined simply by calculating catalyst losses compared to the catalyst inlet. The results showed that the dilute phase and dense bed temperature parameters had an indirect influence on cyclone inlet velocity. Furthermore, the separation efficiency of the device was 88% with 12 % catalyst loss by limiting the combustion air flow rate to a maximum value of 1,559 t/d. These limits should be met to prevent cavitation and reduce cyclone efficiency.

Keywords: air flowrate; catalyst losses; cyclone; regenerator; Residue Fluidized Catalytic Cracking Unit (RFCCU)

Abstrak

Residue Fluidized Catalytic Cracking Unit (RFCCU) pada industry minyak dan gas memiliki regenerator untuk proses regenerasi katalis. Regenerator tersebut memiliki siklon yang digunakan untuk memisahkan katalis padat dari gas reaksi. Gas oksidasi akan bergerak ke bagian atas regenerator dan kemudian masuk ke tahap Siklon. Kecepatan masuk siklon dipengaruhi oleh beberapa faktor seperti aliran Main Air Blower (MAB), temperatur pada fasa ringan, temperatur bed padat. Tujuan dari penelitian ini adalah untuk mengetahui pengaruh kehilangan katalis dan laju aliran udara pembakaran terhadap efisiensi siklon RFCCU. Efisiensi siklon dapat diketahui secara sederhana dengan menghitung kehilangan katalis dibandingkan dengan katalis masuknya. Parameter temperatur pada fasa ringan dan temperatur bed padat memiliki pengaruh tidak langsung terhadap nilai kecepatan masuk siklon. Efisiensi pemisahan alat tersebut sebesar 88% dengan 12 % kehilangan katalis dengan cara membatasi laju aliran udara pembakaran dengan nilai maksimum 1.559 t/d. Batasan ini harus dipenuhi untuk mencegah kavitasi dan penurunan efisiensi cyclone.

***Kata kunci**: cyclone; kehilangan katalis; laju aliran udara; regenerator; Unit Perengkahan Katalitik Terfluidisasi Residu*

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1. Introduction

Residue Fluid Catalytic Cracking (RFCC) unit in the oil and gas industry is designed to use a feedstock consisting of a mixture of Medium-High Vacuum Gas Oil. The FCC unit serves as the primary conversion center for transforming low-quality, heavy hydrocarbons into more valuable and lighter molecules [1]. Based on observation, the molecules are essential components of transportation fuels such as gasoline, jet fuel, and diesel. The FCC process is highly complex [2] and divided into several sections, including feed preheat, converter (reactor-regenerator), flue gas heat and pressure recovery schemes, main fractionator and gas plant, as well as treating facilities [3].

RFCC unit in the oil and natural gas industry adopts the cracking of long hydrocarbons into shorter chains using catalysts and heat in the reactor [4]. During the process, coke forms on the catalyst surface, reducing the number of active sites by causing blockage [5]. The catalyst in this state is referred to as spent, typically containing 0.9-1.3%-wt.

The regeneration of catalysts is conducted by fluidizing and continuously flowing into regenerator using adjustments effected on Control Air Blower (CAB) and Spent Side Valve [2]. In the regenerator, the coke is subjected to a combustion process through the oxygen supplied by Main Air Blower (MAB). The combustion process produces regenerated catalysts, CO, CO_2, and H_2O. Catalyst is then recirculated into the reactor using the riser for further reactions (coke content of 0.3–0.5%-wt). The oxidation products, in the form of gases, move to the upper part of the regenerator and enter a two-stage cyclone. In this context, cyclone is used to recover solid catalyst particles transported by the gases through centrifugal force [6]. After passing through the device, the gas exits from the top of the regenerator at a temperature of 676°C and is utilized to generate steam in Waste Heat Recovery Unit.

The process inside cyclone includes separating catalyst and gas through the principle of centrifugal force. In the process, the force can be utilized to enhance particle collection by several hundredfold. The design of cyclone separators for solid removal is treated as for catalyst regenerator process [7]. The centrifugal force drives catalyst particles to collide with cyclone walls, allowing solid catalysts to settle as shown in Figure 1.

According to the industrial investigation by Song et al 8, catalyst loss faults of cyclone separator were closely related to FCC operating conditions (such as the gas flow rate, solids' loading, operating pressure, catalyst properties) as well as equipment performance and integrity. In equilibrium catalyst sample analysis, fines less than 40 µm typically lose approximately 16.3% in the normal range.

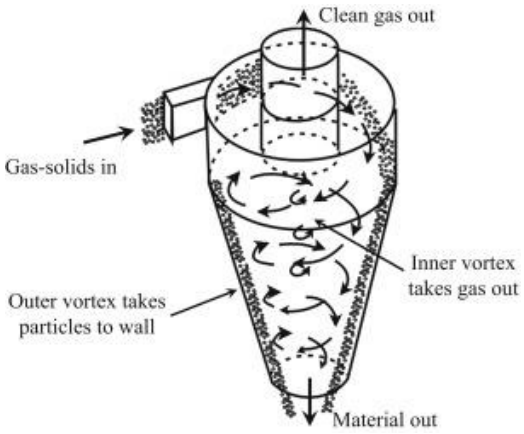

Figure 1. The shape of the gas flow that enters and exits the cyclone [8]

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A high-velocity inlet improves particulate removal efficiency in a cyclone [9]. High inlet velocity of cyclone affects solid catalyst separation efficiency because it enhances the effectiveness in capturing particulates [10]. The effect of the air mass flow rate on flow properties was investigated by Tang et al [11]. The results showed that with an increase in superficial air velocity from 0.65 m/s to 1.03 m/s, the total flow rate of catalysts through cyclones increase linearly. These walls are defined as non-slip boundary conditions for both the solid and gas phases. In the system model, the catalyst passing through the device is defined in such a way that 100% of the material returns to the regenerator, but this is not verified in industrial practice. Catalyst losses, or unseparated catalysts in cyclone, were parameters used to calculate efficiency.

This study observed the flowrate air blower effect on catalyst losses, which provides the deficiencies of cyclone efficiency. The novelty lies in the identification of cyclone efficiency as a catalyst separator unit by measuring catalyst loss and the velocity of air blower in industry with lower losses. It is urgent to identify the optimization process and maintenance of cyclone efficiency.

2. Research Methods

Existing data from the Process Engineer was described using calculations. The composition of the flue gas is known based on the analysis by Gas Industry Laboratories. Observation data were obtained in the Digital Control System from 11 to 24 June 2024. The parameters used to analyze cyclone performance were measurement data on the system, including MAB flow, CAB, dilute phase temperature, dense bed temperature, and catalyst losses.

Equation 1 was adopted as the basis for how much air enters the regenerator. Equation 2 was used to calculate combustion air corrected to a dry basis with the data obtained, namely saturation vapor (lb/hr), moisture content (lb/hr), wet air (lb/hr), dry air (lb/hr), and water in the air (lb/hr). Subsequently, the flue gas rate (lb mol/hr) in equation 3 was calculated. Equation 4 was applied to determine the total wet flue gas rate by summing the dry flue gas (lb mol/hr), water from air (lb mol/hr), and water from H_2 in coke.

$$Total\ Air\ to\ RG = MAB\ to\ RG + CAB\ to\ J - Bend \quad ..(1)$$

$$\text{Dry Air} = Wet\ air\ x\ \frac{1}{(1 + moisture\ content)} \quad ..(2)$$

$$Dry\ flue\ gas\ rate = \frac{\text{N}_{2\text{ in Dry air}}}{\%\text{mol}\frac{(\text{N}_2 + \text{Ar})}{100}} \quad ..(3)$$

$$TWFGR = Dry\ Flue\ Gas + water\ from\ air + water\ from\ \text{H2}\ in\ Coke \quad ..(4)$$

$$Temp.Regen = \frac{T_{Dense\ bed\ phase} + T_{Dilute\ phase}}{2} \quad ..(5)$$

$$\text{ACFS}\ Regen = \frac{Total\ wet\ flue\ gas \times R \times T_{Regenerator}}{p_{Regenerator} \times 3600} \quad ..(6)$$

$$Superficial\ Velocity\ Regen = \frac{ACFS\ Regenerator}{A_{Regenerator}} \quad ..(7)$$

$$Cat_{Losses} = Cat_{Add} - Cat_{withdrawal} - \left((delta\ level\ stripper\ reactor) \times 0.42\right) \times (diameter\ vessel\ reactor) - \left((delta\ level\ Bed\ RG) \times 0.54\right) \quad ..(8)$$

$$Eficiency = \frac{Cat_{Add} - Cat_{Losses}}{Cat_{Add}} \times 100\% \quad ..(9)$$

The regenerator temperature in equation 5 was calculated using the dense bed (°C) and dilute phase temperatures (°C). Equation 6 applied the ideal gas law using the total wet flue gas rate (lb/mol/hr), ideal gas constant (Psia. ft^3/lb.mol.R), average regenerator temperature, and regenerator pressure. Equation 5 was used to calculate the actual cubic feet per second at the

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regenerator, 1st stage cyclone, and 2nd stage cyclone, with the only difference being the average temperature and pressure. Equation 7 was applied to determine superficial velocity using ACFS data (ft^3/s) and regenerator or cyclone cross-sectional area (ft^2).

Equation 8 calculated catalyst losses by subtracting catalyst out, reactor stripper delta level, and the regenerator bed delta level from catalysts in. Equation 9 calculated cyclone efficiency, where the difference between catalyst in and catalyst losses was proportional to catalyst in multiplied by 100%.

3. Results and Discussion

Cyclone inlet velocity can affect the ability to separate the solid catalyst from the flue gas in reducing losses. The velocity influenced the dissipation that occurs between the catalyst particles and the cyclone wall. High values of cyclone inlet velocity can, over time, damage cyclone. According to Kinkar et al, the higher the velocity of inlet cyclone, the greater the attrition force and the more pronounced the thinning of cyclone wall [12]. There is a need to limit the permitted speed to prevent the cyclone from thinning and to ensure the reliability of its performance. The optimum velocity entering the cyclone ranges from 15 m/s - 30 m/s [13].

3.1. The Effect of Catalyst Losses on Efficiency

The efficiency of separating catalyst particles from gas in a cyclone separator depends on several parameters, such as catalyst losses in the system. A good catalyst can convert raw materials into the desired product. Ndak et al identified the factors that affect the level of catalyst quality, which include morphology and particle size [14]. In this study, the size used was dominant at 69-78 µm, and as the catalyst is very small, it becomes lost. Higher losses in the system led to a lower cyclone efficiency value. In the catalyst mass balance, losses are integrated into the system. This implies that the loss of particles not separable by the cyclone leads to a decrease in the efficiency.

Based on Figure 2, the catalyst losses value of 0.37 t/d produced the highest efficiency value of 88%. The higher the value of catalyst losses, the lower the efficiency value. This is attributed to the lower delta value in the numerator lead. There is a sharp decline in catalyst losses of 1.65 t/d and 1.68 t/d. The more intense the reaction, the greater the amount of catalyst lost from the system.

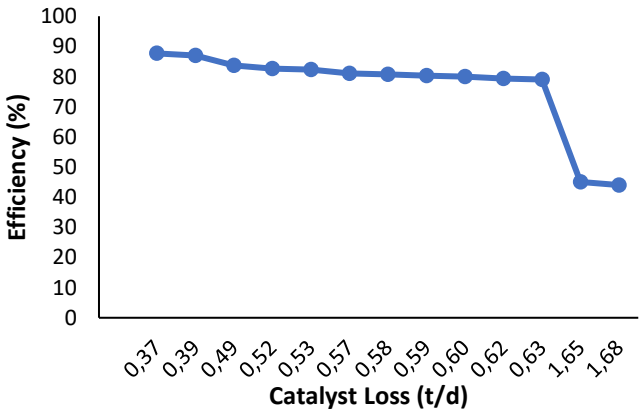

Figure 2. Catalyst separation efficiency based on the effect of catalyst loss

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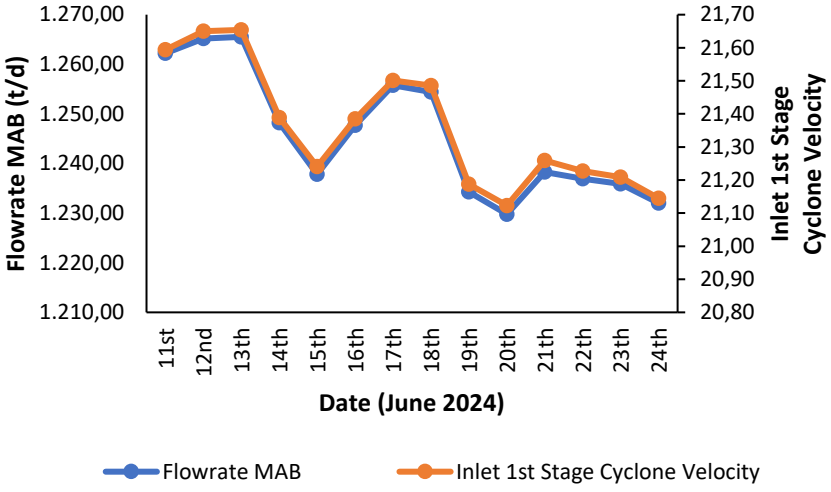

Figure 3. Graph of MAB flow and 1st stage cyclone inlet velocity on June 11-24, 2024

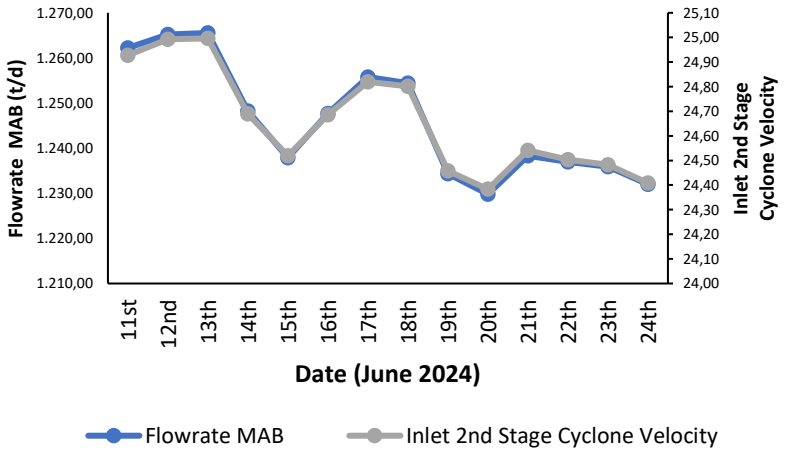

Figure 4. Graph of MAB flow and 2nd stage cyclone inlet velocity on June 11-24, 2024

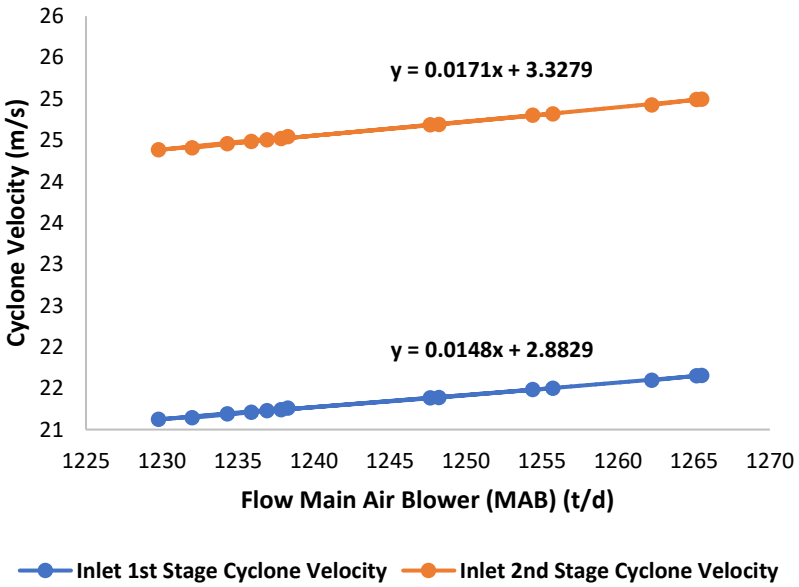

Figure 5. Effect of MAB flow and cyclone inlet velocity

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3.2. The Effect of Combustion Air Flow Rate

The combustion air flow rate, or MAB and CAB flow rates, is a factor that affects the value of cyclone inlet velocity. The value of MAB and CAB corresponds to the total volume of air supplied to the regenerator. The velocity of the regenerator is directly proportional to cyclone inlet velocity. Therefore, considering the factors that can affect the value of regenerator velocity is essential, as cyclone inlet velocity is also influenced. Figures 2 and 3 show the difference in the effect of MAB flow on the value of 1st and 2nd stage cyclone inlet velocity.

The optimum velocity entering the cyclone ranges from 15 m/s - 30 m/s [13]. Based on Figure 2, from June 11-24, 2024, the value of the 1st stage cyclone inlet velocity (orange curve) was below the maximum limit of 30 m/s and above the minimum limit of 15 m/s. This signified that the velocity value obtained had a velocity within the predetermined limits, as presented in Figure 3. From June 11-24, 2024, the value of the 2nd stage cyclone inlet velocity is in the appropriate limit range. Based on Figures 3 and 4, the value of MAB flow had a direct proportional effect on cyclone inlet velocity. The maximum limit of MAB flow needs to be reviewed in such a way that cyclone inlet velocity remains in accordance with the predetermined standard.

The dilute phase and dense bed temperatures are directly proportional to the value of regenerator velocity [15]. This description shows several variables influencing cyclone inlet velocity, including MAB flow, dilute phase temperature, and dense bed temperature. The dilute phase and dense bed temperatures were influenced by other variables that are not reviewed in this study, such as the oxygen content contained in MAB flow and the amount of coke in the catalyst.

Table 1 shows the effect of the relationship between dilute phase and dense bed temperatures on regenerator and cyclone inlet velocities. The value of regenerator velocity is directly proportional to cyclone inlet velocity. The factors that influence these variables need to be considered. Dilute phase and dense bed temperatures were observed to affect regenerator velocity.

Table 1. Temperature of the dense and dilute phases with cyclone velocity

Temperature (°C)		Cyclone Velocity (m/s)	
Dense Phase	**Dilute Phase**	**Inlet 1st Stage**	**Inlet 2nd Stage**
654.46	677.00	21.65	25.00
654.46	675.00	21.65	24.99
654.84	679.00	21.59	24.93
666.66	680.00	21.39	24.69
670.18	675.00	21.38	24.69
662.76	672.00	21.49	24.80
665.11	672.00	21.26	24.50
673.80	680.00	21.24	24.52
664.07	666.00	21.50	24.82
664.87	670.00	21.19	24.46
663.40	674.00	21.23	24.50
662.89	673.00	21.21	24.48
663.79	672.00	21.14	24.41

Figure 5 shows the relationship between MAB flow in the range of 1,224-1,272 t/d and cyclone inlet velocity in the range of 21-26 m/s. A linear regression was performed, and an equation for the relationship between MAB flow and cyclone inlet velocity was obtained. The 1st stage equation was y1 = 0.0148x + 2.8829, while the 2nd stage equation was y2 = 0.0171x + 3.3279. By imposing the limitation of the maximum value of cyclone inlet velocity (y_1 and y_2), the values x_1 =

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1,832 and x_2 = 1,559 will be obtained. The maximum limit for MAB flow was determined by selecting the lowest value due to safety factors. The flow that can be injected into the regenerator is a maximum of 1,559 t/d. Based on the calculation, the efficiency is 88%, while the standard value of efficiency cyclone in a plant is 75%-99%. The performance of this equipment is in the standard range and remains good.

4. Conclusion

In conclusion, higher losses decreased the efficiency of the cyclone in separating gas and catalyst. The maximum efficiency, with a value of 88%, showed that the amount of saturation or losses of the catalyst is related to the low concentration of gas. The combustion air flow rate was directly proportional to cyclone inlet velocity. A restriction on the combustion air flow rate was required at a maximum of 1,559 t/d; hence, the inlet velocity value did not exceed the specified limit. Dilute phase and dense bed temperatures had an indirect influence on the value of cyclone inlet velocity. This was because the variables affect regenerator velocity.

Recommendations for further studies include the combustion air flow rate in the regenerator. The value is expected to be below the maximum limit that has been determined to keep the cyclone from potential erosion and damage. Catalyst losses are to avoid adding an excess, thereby optimizing efficiency and recycle catalyst. The separation that occurs in a cyclone can take place efficiently.

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