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Review of Empirical Approach of Cyclone Separator Efficiency

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Abstract— This review critically assesses the empirical methodologies used to quantify the efficacy of cyclone separators in industrial settings. The study examines traditional empirical techniques to determine their efficacy and limitations in adequately depicting the complex fluid dynamics and particle behavior that take place within cyclones. This analysis emphasizes the importance of taking into account actual operational conditions and establishing standardized testing methods in order to obtain reliable and comparable results through a comprehensive examination of empirical approaches. Furthermore, it highlights the ability of developing technology to significantly improve the efficiency of cyclone separators.

I. INTRODUCTION

Cyclone separators are immobile apparatuses utilized to facilitate the segregation of denser substances from lighter components on the basis of density disparities. The apparatus makes use of the energy generated by centrifugal forces. The implementation of a constrained geometry promotes the formation of a robust vortex during the process of fluid and particle mingling. Cyclones are employed across various industries for the purpose of phase separation, dust extraction from vapors, and size-based classification of dense materials [1]. Larger particulates are propelled along the cyclone wall by the combined effects of gravity and increased peripheral velocity. Ultimately, as the peripheral velocity diminishes, these particulates are accumulated and deposited in the dustbin. Typically, the gaseous phase re-enters the cyclone through the bottom of the receptacle. Consequently, re-entrainment occurs when particles that were previously separated are reintroduced into the inner core vortex. This effect decreases the efficacy of separation [2]. Cyclone separators are indispensable devices that are widely employed in the field of multiphase flow separation. This device is primarily intended for the separation of gas from solid or liquid substances. There are numerous inlet configurations for the cyclone separator, including concurrent, axial, countercurrent, and tangential. The assessment of separator efficacy frequently hinges on the flow resistance and segregation efficiency, both of which are regarded as critical parameters. [3] In order to extract particulates from a fluid, cyclone separators employ the centrifugal force generated by a turbulent, whirling flow. Cyclone separators are essential particulate separators utilized in a variety of industries on account of their uncomplicated design, which consists of immobile components, low operating costs, and easy maintenance. Cyclone separators eradicate particles from a fluid by utilizing the centrifugal force produced by a turbulent, whirling flow. Cyclones are an essential particle separator employed across various industries due to their straightforward construction incorporating immobile components, economical operation, and user-friendly maintenance [4]. Particularly, allergies affecting the skin, lungs, and cardiovascular system are adversely affected by the emission of dust particles from industrial sources. In order to address and control these concerns, various sectors have developed inventive techniques for collecting all the particulate matter. They utilized an extensive array of machinery in order to collect particulate matter. Cyclone technology, which collects and purifies air to facilitate human inhalation by collecting microscopic particles, has been adopted by the majority of industries. Dust particles are gathered in an exceptional manner by the tornado separator. It is highly adaptable and can be utilized in a wide variety of contexts. It exhibits remarkable efficacy in collecting minuscule particles [5]

Table: 1. Indusrtrial application of cyclone separator

Sr.no	Author	Year of Publish	Type of industry	Usage
1	N. Prasanna, S. Ajay, T. Rajagopal	2021	Thermal power plant	Capturing fly ash that is present in the exhaust gas.
2	P. Katare A. Krupan A.Dewasthale	2021	Petroleum industries	To filtration of impure water through the elimination of catalyst from gases.

Sr.no	Author	Year of Publish	Type of industry	Usage
3	Anjun Li, Ziang Zhu, Peikun Liu Xiaoyu Li	2023	SOLAR POWER PLANT	Separation of supercritical water & S-CO_2
4	Haichao Zhao ,Mingpu Du, Conghui Gu, Jingyu Zhu, Kaiyuan Denvag, Yuan Liu	2023	N/A	Separation of dry bio-mass
5	Marek WASILEWSKI	2013	Cement Industry	Extraction of sizable particulate with the intention of regulating air pollution

II. EMPIRICAL MODELLING APPROACH OF CYCLONE SEPARATOR

The in-flow characteristics of a cyclone separator, such as the gaseous velocity and input dimension, are crucial factors to consider. Research has shown that the efficiency of collecting follows a pattern of increasing and then decreasing, while the pressure drop consistently increases with the velocity of the intake gas [7]. A simulation of the optimal-efficiency inlet velocity, sometimes referred to as the critical gas velocity, has been successfully achieved. The increase in cone length successfully compensated for the drop in pressure, resulting in a higher collecting efficiency. Furthermore, the turbulence strength reduced proportionally as the length of the cone increased [6]. Many empirical models have been adapted to incorporate the efficiency of cyclone separators. The models consist of these components:

a. Iozia and Leith Model

The model that was initially developed by Barth (1956) is the basis for the Iozia and Leith (1990) logistic model, which is a modified version of the model that is based on force balancing. The flow resistance and the centrifugal force are the two forces that are supposed to be experienced by a particle that is being carried by the vortex, as stated by the model. The collection efficiency η_i of particle diameter dpi can be calculated from

$$\eta_i = \frac{1}{1+(d_{pc}/\bar{d}_{pi})^{\beta}}$$

where d_{pc} is the 50% cut size given by Brath model.

$$d_{pc}=\left[\frac{9\mu Q}{\pi P_p z_c v_{tmax}^2}\right]^{0.5}$$

η_i = Grade efficiency of particle size
d_{pc}= cut particle diameter collected with 50% efficiency (m)
d_{pi} = diameter of particle in size range i (m)
β = slope parameter
z_c = core length (m)
v_{tmax} = maximum tangential velocity (m/s)
Q = volumetric gas flow rate (m^3 /s)
μ = gas viscosity (m^2 /s)

b. Li and Wang Model

As part of their model, Li and Wang (1989) incorporated turbulent diffusion as well as particle re-entrainment or bounce at the cyclone wall. An analytical equation in two dimensions is developed in order to provide a representation of the dispersion of particles within the cyclone. During the construction of their model, Li and Wang made the following assumption: when uncollected particles are present in cyclones, the radial concentration profile and the radial particle velocity do not remain constant [8]. The collection efficiency for particle of size of this model is given by

$$\eta_i = 1 - \exp\{-\lambda\theta_1\}$$

where,

$$\theta_1 = 2\pi(S + L)/a$$

η_i = Grade efficiency of particle size
θ = angular coordinate
λ = characteristic value
S = cyclone gas outlet duct length (m)
L = natural length (m)
a = cyclone inlet height (m)

c. Koch and Licht Model

Koch and Licht formulated a collection theory in 1977. This theory considers the turbulent characteristics of cyclones and acknowledges the potential variability in gas retention lengths. Koch and Licht offer a more precise characterization of particle mobility in the entrance and collecting zones, based on the following assumption. According to their statement, the absence of tangential sliding between gas flows and particles is shown when their tangential velocities are equal [8]. G is a factor related to the configuration of the cyclone, n is related to the vortex and τ is the relaxation term. An equation on the particles collection yields the grade efficiency η_i

$$\eta_i = 1 - exp\left\{-2\left[\frac{G\tau_i Q}{D^3}(n+1)\right]^{0.5/(n+1)}\right\}$$

where,

$$G = \frac{8k_c}{k_a^2 k_b^2}$$

$$n = 1 - \left\{1 - \frac{(12D)^{0.14}}{2.5}\right\}\left\{\frac{T+460}{530}\right\}^{0.3}$$

$$\tau_i = \frac{\rho_p d_{pi}^2}{18\mu}$$

η_i = grade efficiency of particle size
ρ_p = particle mass density (kg/m^3)
μ = gas viscosity (m^2 /s)
d_{pi} = diameter of particle in size range i (m)
G = cyclone configuration factor
τ = relaxation time (s)
K_a = a/D
K_b = b/D
K_c = cyclone volume constant
a = cyclone inlet height (m)
b = cyclone inlet width (m)
D = cyclone body diameter (m)
T = absolute temperature (K)

d. Lapple Model

The Lapple (1951) model was developed without considering flow resistance, as it assumed the presence of force balance. Lapple assumed that the cyclone's input opening would evenly distribute particles as they entered the machine. A collecting efficiency of 50% is attained for particles that go down the cyclone wall from the entrance half-width. The efficiency of collection of any size of particle is given as

$$\eta_i = \frac{1}{1+(d_{pc}/\bar{d}_{pi})^2}$$

where,

$$d_{pc} = \left[\frac{9\mu b}{2\pi N_e v_i(\rho_p-\rho_g)}\right]$$

η_i = grade efficiency of particle size
N_e = Number of revolutions
d_{pc}= cut particle diameter collected with 50% efficiency (m)
d_{pi} = diameter of particle in size range i (m)
ρ_p = particle mass density (kg/m^3)
μ = gas viscosity (m^2 /s)
b = cyclone inlet width (m)
vi = inlet velocity (m/s)
ρ_g = gas density (kg/m^3)

III. DISCUSSION

The cyclone efficiency prophecy of the Li and Wang model is exceptional when operating at room temperature. When exceedingly high temperatures and pressures are combined, the Lapple model produces predictions of a satisfactory quality. The Koch and Licht model accurately predicts the efficiency of cyclones operating at high pressures. The Lapple model is demonstrated to be the most dependable. Depending on the particle size, the analytical or experimental method provides precise information regarding the type of cyclone separator required for material separation [8].

IV. CONCLUSION

This evaluation has elucidated the merits, drawbacks, and progressions associated with each methodology, underscoring the criticality of standardizing testing protocols and taking into account practical operational circumstances in order to guarantee dependable and resilient results. Implementing these strategies and capitalizing on emerging technologies will be essential in the future to maximize the efficiency of cyclone separators in a variety of industrial applications. Through the ongoing improvement of empirical methodologies and the adoption of technological advancements, practitioners in the fields of research, engineering, and industry can make significant contributions to the advancement of cyclonic separation systems that are both sustainable and efficient. This, in turn, will result in enhanced operational efficiency, product quality, and environmental compliance. This comprehensive review provides vital information for researchers, engineers, and practitioners involved in the design, functioning, and enhancement of cyclonic separation systems for various industrial uses.

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