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Original article

Analysis of Pressure Drop in Gas–Solids Cyclone Separators: An Experimental Approach

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ABSTRACT

In industrial operations, cyclone separators are essential for removing particles from gas streams. The performance and energy efficiency of these devices are greatly impacted by the pressure drop across them. Through experimental investigation, this paper examines the pressure decrease in gas-solids cyclone separators. The effect of many operational factors on the pressure drop was investigated, including gas velocity, particle size, and input design.The findings demonstrated that the pressure drop across the cyclone increases significantly with increasing inflow velocity and reduces with increasing cyclone size. Regardless of cyclone size, input velocity, or particle size, a strong direct correlation was found between the pressure drop for dusty air and that for clean air. Operating at moderate gas velocities was shown to significantly reduce pressure drop without compromising separation performance, whereas higher velocities necessitate advanced cyclone designs or secondary systems to mitigate the associated pressure increases

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INTRODUCTION

Cyclone separators, which are mostly used to separate solid particles from gas streams, are crucial equipment in a variety of sectors, including cement manufacturing, environmental management, and chemical processing. Cyclone separators are a popular option for particle separation in industrial settings due to its ease of design, robustness, cheap operating costs, and low maintenance requirements [1]. Nevertheless, despite these benefits, a crucial element influencing their effectiveness and running costs is the pressure drop, which is the pressure differential between the separator's input and exit. In addition to being a clear measure of energy usage, this pressure decrease is a crucial factor in assessing the general effectiveness of cyclone separators [2]. The resistance produced by the whirling flow necessary to push particles to the separator walls causes a pressure decrease in a cyclone separator. The energy required to sustain the separation process increases with the pressure decrease, which affects operational costs and efficiency. Therefore, it is crucial for research and practical application to optimize the design of cyclone separators to reduce pressure drop without sacrificing particle collecting efficiency [4].
Numerous research has looked at the variables that affect pressure drop in cyclone separators in recent years, including cyclone shape, intake velocity, and particle size. For example [4], investigated how input velocity influences energy losses in impact separators, while Fassani and Fassani (2022) examined the effects of solid loading on pressure drop [5].
Experimentally verified models that can forecast pressure loss under a variety of operating circumstances and design modifications are still lacking, nevertheless [6]. By experimentally investigating pressure drop in gas-solids cyclone separators and examining the effects of cyclone size, input velocity, and particle properties on pressure drop and separation performance, this work seeks to close this gap. By offering a thorough experimental examination of cyclone

separator pressure drop, this study adds to the body of literature already in existence and may help improve design and operating techniques for a range of industrial applications [7].

METHODS

Experimental Apparatus and Instrumentation:

An experimental facility that was expressly planned and constructed was used to perform experiments in order to gather the experimental data for this investigation. In Figure 1, the test rig's schematic perspective is displayed. Two blowers supply air with a volume flow between 14.5 and 114.5 m3/hr, which is drawn and monitored using a calibrated orifice meter [8]. This quantity of air is mixed with the injected particles in the cyclone's rectangular cross section intake and discharged tangentially to the cyclone being tested [9].

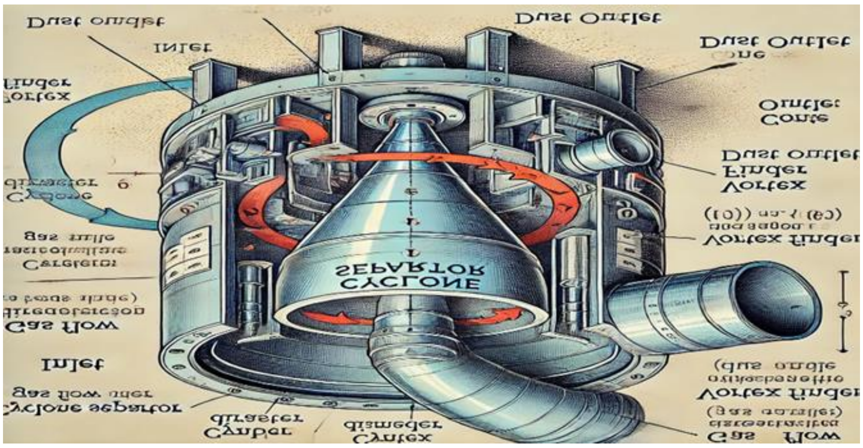

Figure 1. Illustration of the experimental test rig layout

The pressure drop across the cyclone and the orifice is tracked using a multi-tube manometer that is connected to pressure taps that are drilled normal to the wall and have an inner diameter of 1 mm. The hopper section collects the cyclone's deposited particles [10]. Various regulating valves are used to modify the air-particle combination [11]. The regulating valve and solids supply reservoir make up the solid feeding system (4). The solids supply has a conical end and a cylindrical form.

Using a dial scale, the feeding control valve was adjusted to provide the required mass flow rate of feeding solids. Three of the four cyclone sizes that were utilized were made from metal sheets with varying cyclone diameters of 10, 14, and 16 cm. The fourth cyclone was made from Perspex and had a diameter of 7.5 cm to allow for visual monitoring of the flow inside the cyclone. The size ratios for the Stairmand cyclone design employed in this investigation are displayed in Fig. 2.

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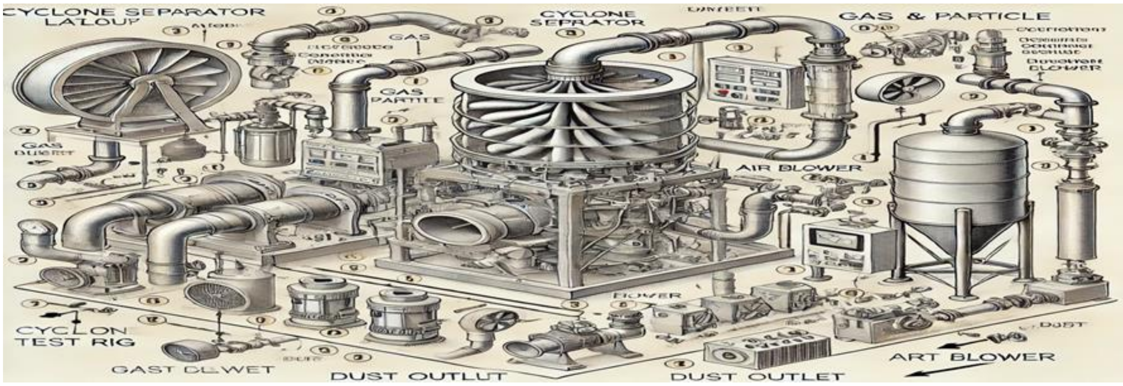

Figure 2. The dimension ratios for Stairmand cyclone design used in this study

Test Method

White cement and commercial sand were the two solids utilized in the trials to examine how particle size affected the cyclone pressure decrease. The solid particles are sand. Overall, the particle sizes were sand, with median diameters of 70,225,360, and 510 μm. Figure 3 displays the particle size distribution (PSD) and density, which is about 1400 kg/m3. White cement's physical characteristics include median widths of 70 μm and a density of around 1315 kg/m3.

Before being used, all solid samples were dried at 600 degrees Celsius in an oven. Nearly comparable air pressure and ambient temperature were used for the trials. More attention was paid to the experimental readings, which were then tallied and visually represented. The tests were conducted with intake velocities ranging from 5.3 to 16.77 m/s with dust loading values of 50, 80, 100, 125, 200, 275, and 350 gsolids/kgair. Before beginning the test, the forced and induced blowers were operated for a long enough period of time to achieve steady flow conditions. To provide the necessary flow rate, the delivery valve was opened to a certain position. A sample of solid particles (sand) with a specified particle diameter is added to the solid supply reservoir after being weighed on a scale to calculate its mass.

To provide the necessary solid flow rate, the calibrated solid control valve is opened to a certain position. The orifice meter's observations of the cyclone's pressure decrease in relation to the clean air condition were noted. The solid loading valve opened, and the air temperature in the orifice meter's inlet corresponding to the situation, the solid loading period, and the pressure decrease in the cyclone were all recorded. Over a certain amount of time, the cyclone gathered solid particles, which were then weighed using a scale to calculate its mass. For a wide range of potential flow rates, these measurements of dusty and clean air conditions were repeated, and the associated results were calculated.

Cyclone performance parameters

i. Pressure drop, $\Delta P = P_{si} - P_{so}$, uncertainty range 0.91 minimum and 3.36 maximum.
ii. Inlet velocity, $V_i = Q/A$ (m/s), uncertainty range 1.26 minimum and 4.7 maximum.
iii. Solid loading, $C_{si} = M_i/M_a$ (g_{solids}/kg_{air}), uncertainty range 0.026 minimum and 1.3 maximum.

RESULTS AND DISCUSION

Effect of Cyclone Size on the Pressure Drop

Both a local loss and a friction loss make up the pressure decrease across a cyclone. A contraction loss at the outlet tube entrance (also known as the vortex finder) results from an abrupt reduction of the flow area when air enters the outlet tube from the separation space of a cyclone. The expansion loss at the cyclone inlet is caused by the expansion of air flow axially and radially after entering the cyclone, resulting in a local expansion loss. The air flow in the exit tube is separated into two areas: an annular zone, where the axial velocity is equally distributed, and a core region, where the axial velocity is supposed to be extremely tiny, or insignificant. The air tangential velocity is nevertheless quite high in this area.

A dissipation of the air dynamic energy in the outlet and a whirling loss resulting from the air's friction with the cyclone wall owing to its viscosity are both included in the friction loss. As a result, the pressure drop in cyclones is strongly influenced by their magnitude. Figures 4 through 7 show the experimental findings of the fluctuation of pressure drop in four different cyclone sizes at varying solid loadings, ranging from 50 to 350 gsolids/kgair, with a constant mean inflow velocity of 10.3 m/s.

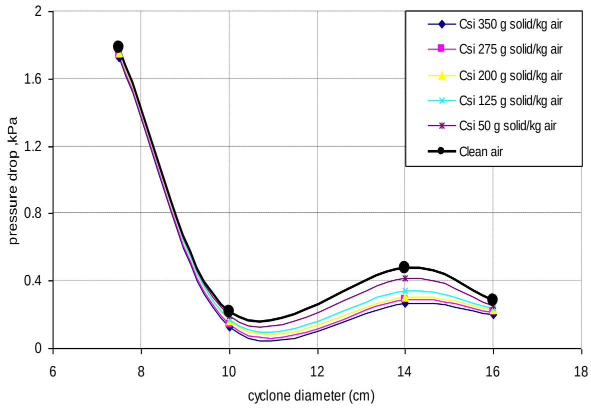

Figure 3. Pressure drop variation with cyclone diameter for 225 μm particle size with varying solid loading at a constant 10.3 m/s input velocity.

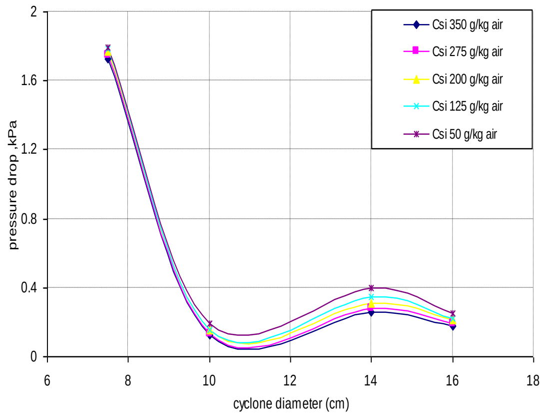

Figure 4. Pressure drop variation with cyclone diameter for particle size (360 m) with varying solid loading at constant input velocity of 10.3 m/s is seen in Fig. 5.

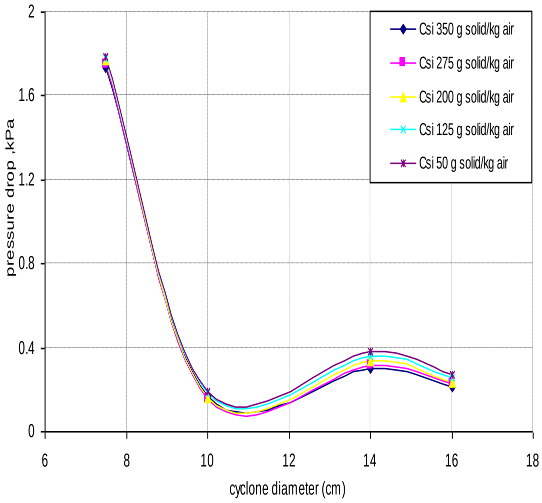

Figure 5. Changes in pressure drop with cyclone diameter for 510 μm particles with varying solid loading at a constant 10.3 m/s input velocity.

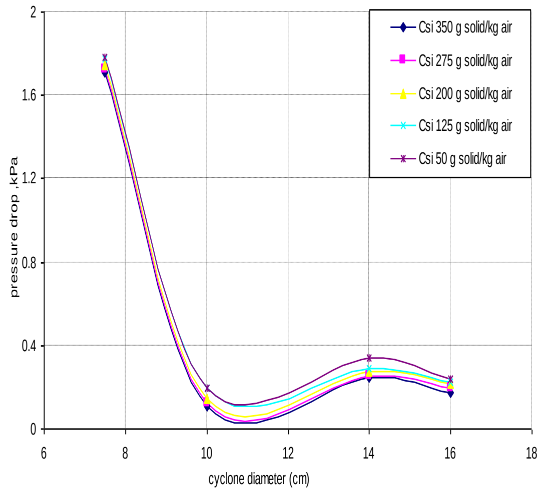

Figure 6. shows how the pressure loss changes with cyclone diameter for general particle size under various solid loading conditions at a constant input velocity of 10.3 m/s.

According to these figures, the pressure drop across a cyclone generally decreases as its size increases, with a notable abrupt decline observed when the cyclone size increases from 7.5 to 10 cm. This feature can be explained by the fact that the rectangular inlet area, the outlet tube area, and the total area of the contact surfaces between the air flow and the cyclone wall (the sum of the top cover area and the cyclone barrel and cone area) all grew larger as the cyclone size increased at constant inlet velocity. The outflow tube (dissipation loss of air dynamic energy) and the cyclone's walls experience the majority of pressure losses.
Because the cyclone's internal hydraulic diameter and velocity vary as the area grows, the pressure drop is affected. This lowers the Reynolds number, which in turn lowers the wall friction coefficient and reduces losses in the separation gap. Nevertheless, the vortex finder experiences fewer losses as a result of the tangential velocity's drop in magnitude. According to published data by EL and Batsh et al. [7], the pressure drops decreases as cyclone size increases.

Effect of Particle Size on the Pressure Drop

The cyclone pressure loss with varying dust loadings and particle sizes at constant mean cyclone input velocity is shown in Figures 8.11 to 11.

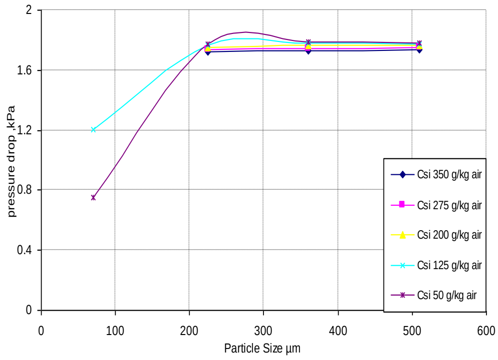

Figure 7. Variation of pressure drop with particle size for cyclone diameter (7.5 cm) with different solid loading at constant inlet velocity of 10.28m/s.

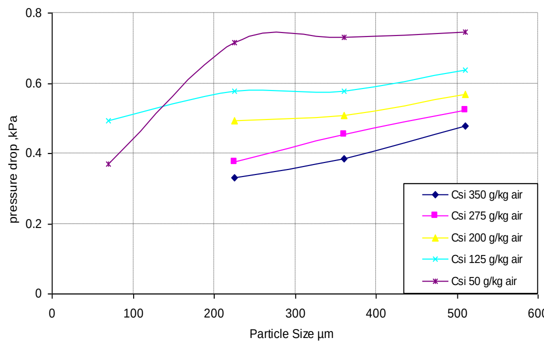

Figure 8. Variation of pressure drop with particle size for cyclone diameter (10 cm) with different solid loading at constant inlet velocity of 17.66 m/s.

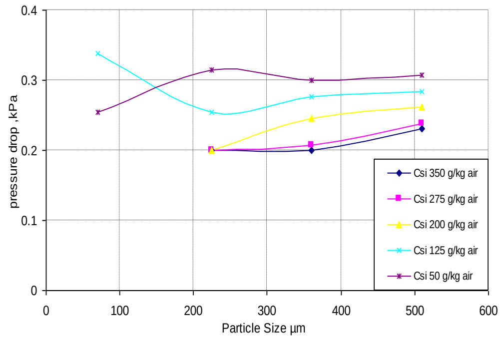

Figure 9. Variation of pressure drop with particle size for cyclone diameter (14 cm) with different solid loading at constant inlet velocity of 9.478 m/s.

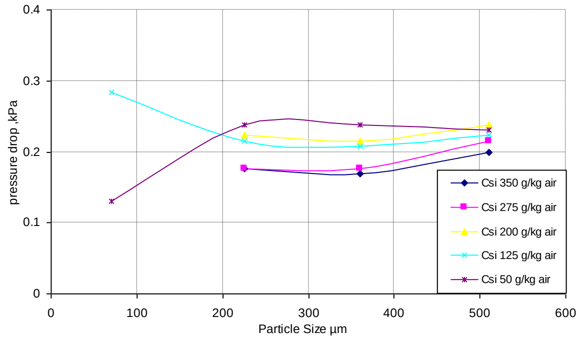

Figure 10. Variation of pressure drop with particle size for cyclone diameter (16 cm) with different solid loading at constant inlet velocity of 9.936 m/s.

These figures demonstrate that as particle size rises, so do the cyclone pressure reductions. According to the general trends of pressure drop at different particle size curves, the pressure drop increases quickly from 70 to 225 µm and then gradually at a low slope from 225 to 510 µm. The data make it abundantly evident that there is no distinct pattern in the way that particle size affects pressure drop. Generally speaking, the centrifugal force will rise as particle size increases..

Effect of Inlet Velocity on the Pressure Drop

Figs. 12 to 27 illustrate how entrance velocity affects cyclone pressure decreases at different particle sizes and dust loading for every cyclone that is employed.

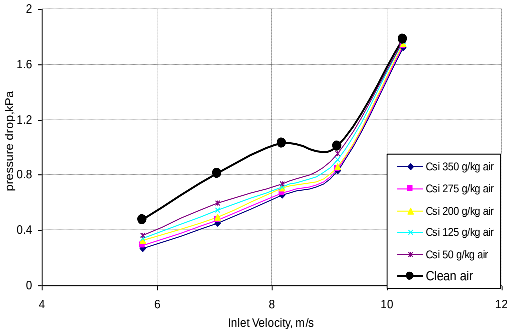

Figure 11. Variation of pressure drop with inlet velocity for cyclone diameter (7.5 cm) at and particle size (225µm) with different solid loading.

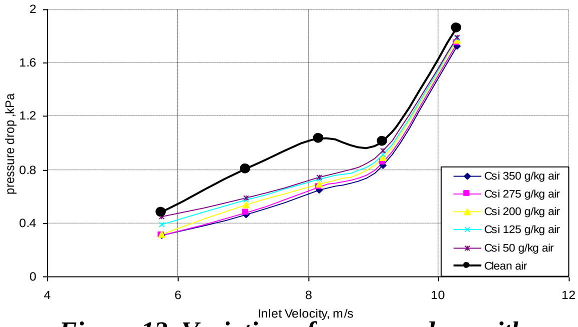

Figure 12. Variation of pressure drop with inlet velocity for cyclone diameter (7.5 cm) at and particle size (360µm) with different solid loading.

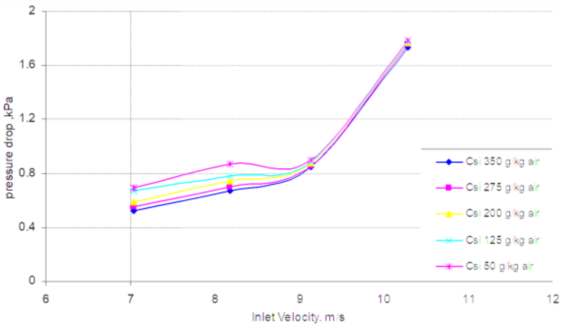

Figure 13. Variation of pressure drop with inlet velocity for cyclone diameter (7.5 cm) **at and particle size (510µm) with different solid loading.**

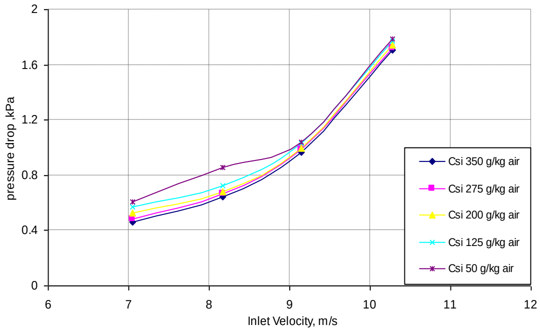

Figure 14. Variation of pressure drop with inlet velocity for cyclone diameter (7.5 cm) at and particle size (overall) with different solid loading.

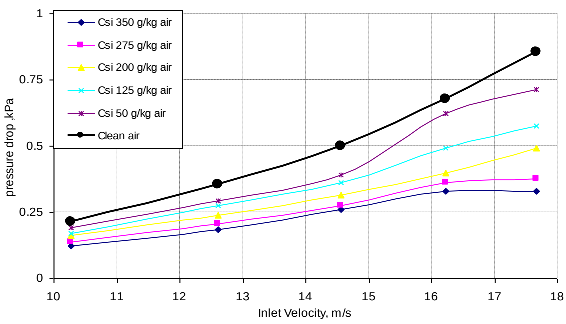

Figure 15. Variation of pressure drop with inlet velocity for cyclone diameter (10 cm) at and particle size (225µm) with different solid loading.

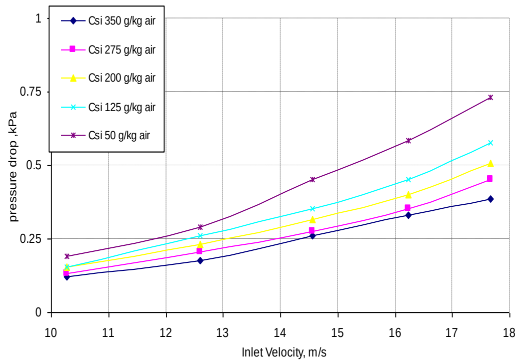

Figure 16. Variation of pressure drop with inlet velocity for cyclone diameter (10 cm) at and particle size (360µm) with different solid loading.

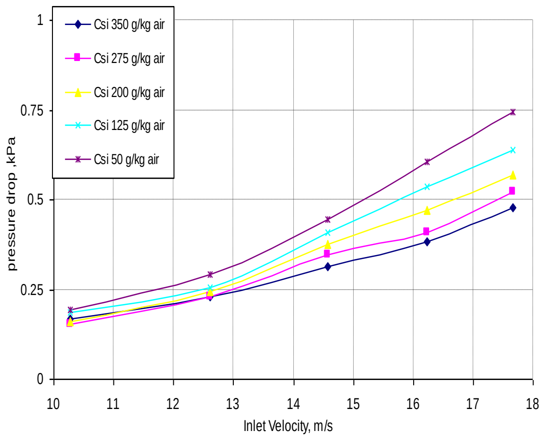

Figure 17 Variation of pressure drop with inlet velocity for cyclone diameter (10 cm) at and particle size (510μm) with different solid loading.

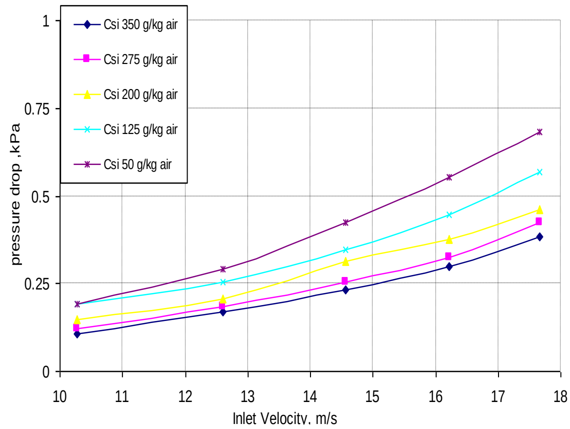

Figure 18. Variation of pressure drop with inlet velocity for cyclone diameter (10 cm) at and partcle size (overall) with different solid loading.

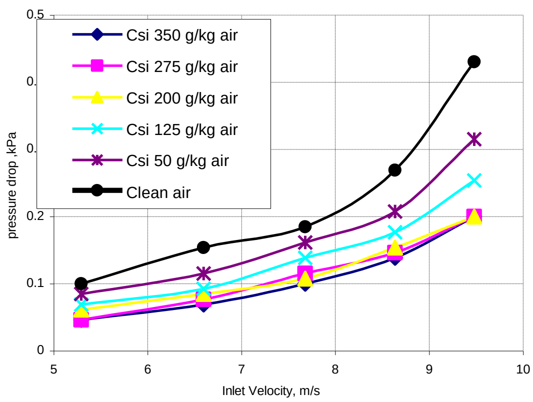

Figure 19. Variation of pressure drop with inlet velocity for cyclone diameter (14 cm) at and particle size (225μm) with different solid loading.

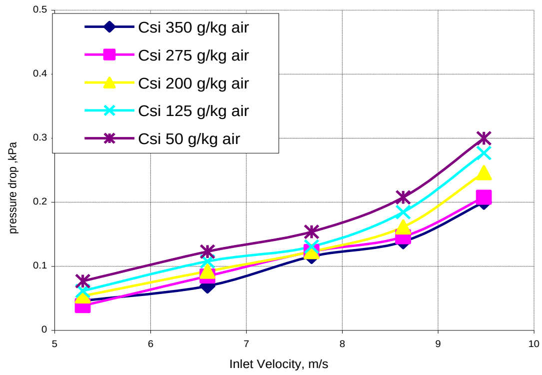

Figure. 20. Variation of pressure drop with inlet velocity for cyclone diameter (14 cm) at and particle size (360μm) with different solid loading.

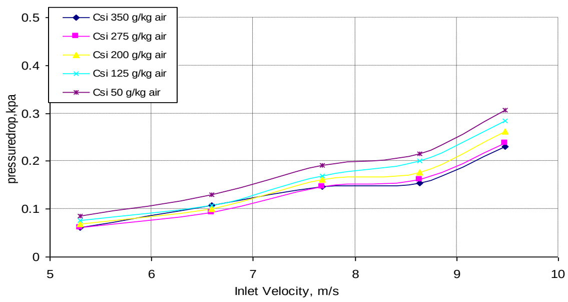

Figure 21. Variation of pressure drop with inlet velocity for cyclone diameter (14 cm) at and particle size (510μm) with different

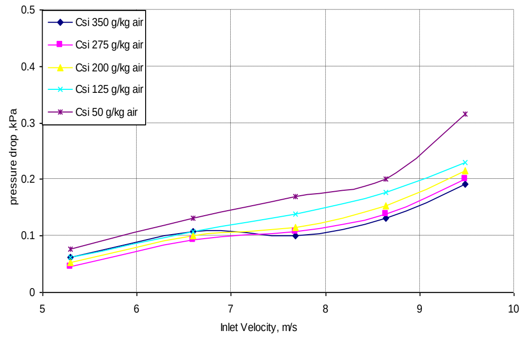

Figure 22. Variation of pressure drop with inlet velocity for cyclone diameter (14 cm) at and particle size (overall) with different solid loading.

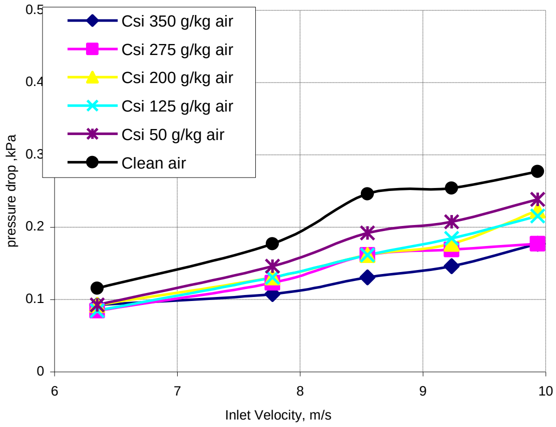

Figure 23. Variation of pressure drop with inlet velocity for cyclone diameter (16 cm) at and particle size (225μm) with different solid loading.

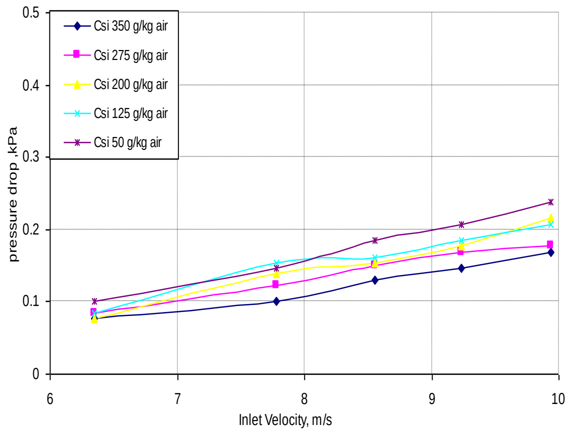

Figure 24. Variation of pressure drop with inlet velocity for cyclone diameter (16 cm) at and particle size (360μm) with different solid loading.

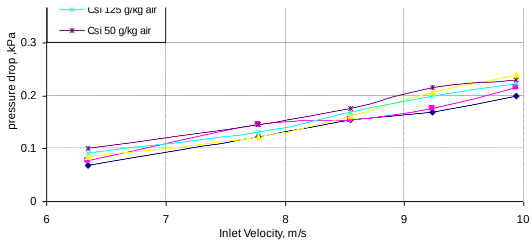

Figure 25. Variation of pressure drop with inlet velocity for cyclone diameter (16 cm) at and particle size (510μm) with different solid loading.

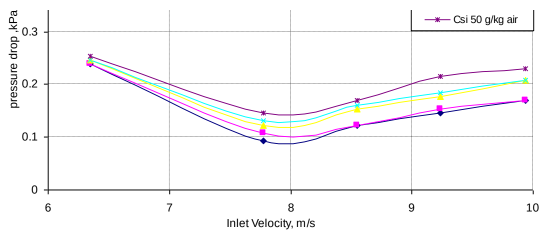

Figure 26. Variation of pressure drop with inlet velocity for cyclone diameter (16 cm) at and particle size (overall) with different solid loading.

These numbers show that the mean input velocity has a significant impact on the pressure drop under all test circumstances. According to the general trends, the pressure drop increases steadily up to 9.2 m/s as the inflow velocity increases, after which it increases abruptly.
This can be explained by the fact that the average entrance velocity exhibits varying impacts in various air cyclone wall contact flow regimes. In the vortex finder, viscous dissipation of this amount dominates pressure losses in cyclones. Since this dissipation is approximately proportional to the squared tangential velocity's (Vt2) absolute magnitude, every factor that tends to strengthen the vortex also increases losses. The tangential velocity rises with the inflow velocity, increasing the whirling loss and, consequently, the pressure decrease. De et al. [2], EL-Batsh et al. [7], and Chen et al. [8] all showed a similar pattern of the impact of input velocity on the pressure drop.

Relation between Clean Air and Dusty Air Pressure Drop
One of the crucial cyclone separator performance metrics is the pressure drop. Therefore, understanding the pressure drop is crucial for cyclone designers and users to ensure safe operation and appropriate design. Numerous academics have created various methods to calculate cyclone pressure. However, the majority of the methods are only appropriate for pure gases and are often unsatisfactory. Furthermore, a cyclone's pressure decrease in the presence of dusty gases is significant and differs much from that in the presence of pure gases. However, there is still no solution for reducing the pressure drop over a cyclone when dusty gases are present. The pressure drop is one of the most important cyclone separator performance parameters. For cyclone designers and users to guarantee safe functioning and suitable design, it is therefore essential to comprehend the pressure drop. Many scholars have developed a variety of techniques to determine cyclone pressure. Nevertheless, most of the techniques are frequently inadequate and only suitable for pure gases. Additionally, the pressure drop in a cyclone caused by dusty gases is substantial and very different from that caused by pure gases. Nevertheless, there is currently no way to lessen the pressure decrease over a cyclone in the presence of dusty gases.

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$$\Delta P_{s.d} = 1.452\left[\frac{[\Delta P_{s.c}{}^{1.2}}{C_{si}{}^{0.122}}\right]$$

The relationship's correlation coefficient is 0.9375. The intriguing aspect of this association is these findings. This appears to be a really helpful tool for forecasting the preThe relationship's correlation coefficient is 0.9375. The intriguing aspect of this association is these findings. It would appear that this is a very helpful tool for predicting the pressure reduction for dusty air.

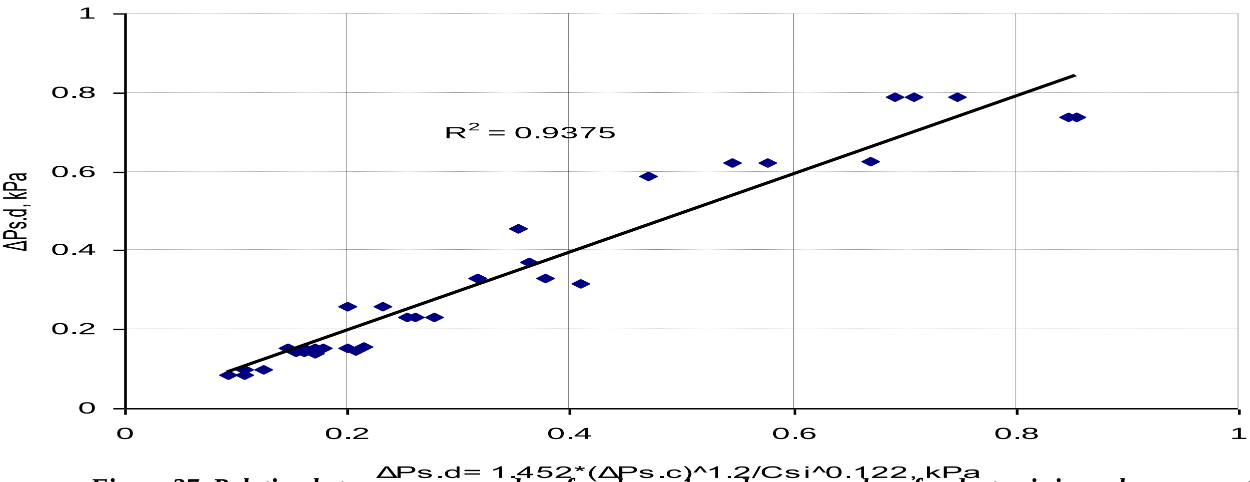

Figure 27. Relation between pressure drop for clean air and pressure drop for dusty air in cyclone separator.

CONCLUSION

As the size of the cyclone increased, the pressure drops across it decreased significantly, with a noticeable reduction observed as the size expanded from 7.5 cm to 10 cm. Regarding particle size, as it increased from 75 to 225 µm, the pressure drop rose dramatically, while from 225 to 510 µm, the increase in pressure drop was more gradual, exhibiting a lower slope. In terms of inflow velocity, the pressure drops steadily increased up to 9.2 m/s, beyond which it rose considerably. Regardless of cyclone size, input velocity, or particle size, a strong direct correlation was found between the pressure drop for dusty air and that for clean air. Operating at moderate gas velocities was shown to significantly reduce pressure drop without compromising separation performance, whereas higher velocities necessitate advanced cyclone designs or secondary systems to mitigate the associated pressure increases.

Conflict of interest. Nil

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تحليل انخفاض الضغط في فواصل الإعصار الغازية-الصلبة: منهج تجريبي

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قسم الهندسة الميكانيكية البحرية، كلية الموارد البحرية، الجامعة الأسمرية الإسلامية، زليتن، ليبيا

المستخلص

في العمليات الصناعية، تُعد فواصل الإعصار ضرورية لإزالة الجسيمات من تيارات الغاز. يتأثر أداء هذه الأجهزة وكفاءتها في استهلاك الطاقة بشكل كبير بانخفاض الضغط عبرها. من خلال التحقيق التجريبي، يبحث هذا البحث في انخفاض الضغط في فواصل الإعصار للغاز والمواد الصلبة. تم دراسة تأثير العديد من العوامل التشغيلية على انخفاض الضغط، بما في ذلك سرعة الغاز وحجم الجسيمات وتصميم المدخل. أظهرت النتائج أن انخفاض الضغط عبر الإعصار يزداد بشكل كبير مع زيادة سرعة التدفق الداخل ويقل مع زيادة حجم الإعصار. بغض النظر عن حجم الإعصار أو سرعة التدفق الداخل أو حجم الجسيمات، وُجدت علاقة مباشرة قوية بين انخفاض الضغط للهواء المحمل بالغبار وانخفاض الضغط للهواء النظيف. تبين أن التشغيل بسرعات غاز معتدلة يقلل بشكل كبير من انخفاض الضغط دون التأثير على أداء الفصل، في حين أن السرعات العالية تتطلب تصميمات إعصارية متقدمة أو أنظمة ثانوية للتخفيف من زيادات الضغط المرتبطة بذلك.

الكلمات الدالة. أجهزة فصل الأعاصير، فصل الغازات عن المواد الصلبة، انخفاض الضغط، التحليل التجريبي، ديناميكا الموائع.