

THE EFFECT OF EXTERNAL SUCTION AT THE DUST OUTLET OF A CYCLONE

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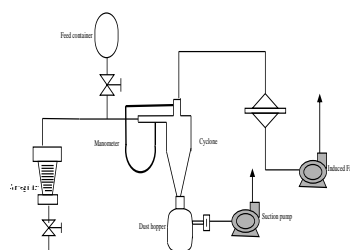
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Graphical abstract



Abstract

Cyclone is one of the most commonly used particulate dust collectors in industries. It employs centrifugal force generated by a spinning gas stream to separate the particulate matter from the carrier gas. However, cyclone is efficient to collect coarse rather than fine particulate size fraction. In this regard, a study was carried out to determine the effect of creating more negative pressure at the storage hopper of a 100 mm diameter laboratory scale cyclone. The negative pressure was created by drawing out a small portion of the gas stream by means of an air pump attached to the storage hopper. Results showed that there was exponentially related between the pressure drop (ΔP) and the amount of gas stream drawn at the storage hopper, but with an increment of 2.6% with suction compared to without. Interestingly, it was observed that more of the fine particulate matter was drawn from the gas stream as the suction flow rate increases. This is due to the suction velocity which exceeds the terminal falling velocities of the fine particles size range. There was a reduction by weight in the fine particle emitted from the cyclone ranging between 14% to 52% by introduction of the suction. The finding serves as a basis for future work in reducing fine particulates from a cyclone separator.

Keywords: Air pollution, cyclone, suction, increase efficiency, pressure drop

Abstrak

Siklon adalah salah satu daripada pengumpul debu zarah paling biasa digunakan dalam industri. Ia menggunakan daya emparan yang dihasilkan oleh putaran aliran gas untuk memisahkan bahan zarah dari gas pembawa. Walau bagaimanapun, siklon cekap untuk mengumpul zarah kasar berbanding saiz zarah yang halus. Dalam hal ini, satu kajian telah dijalankan untuk menentukan kesan mewujudkan tekanan yang lebih negatif pada corong penyimpanan berdiameter 100 mm siklon skala makmal. Tekanan negatif telah dicipta dengan mengeluarkan sebahagian kecil daripada aliran gas melalui pam udara yang diletakkan pada corong penyimpanan. Hasil kajian menunjukkan bahawa terdapat hubungan yang eksponen antara kejatuhan tekanan (ΔP) dan jumlah aliran gas terkeluar pada corong penyimpanan, tetapi dengan peningkatan yang sangat kecil sebanyak 2.6% dengan sedutan berbanding tanpanya. Menariknya, ia telah diperhatikan bahawa lebih banyak zarah halus dikeluarkan daripada aliran gas semasa kadar aliran sedutan meningkat. Ini adalah kerana halaju sedutan yang melebihi terminal halaju jatuh daripada rangkaian zarah bersaiz halus. Terdapat penurunan dalam pembebasan zarah halus dari siklon dalam lingkungan antara 14% hingga 52% dengan pengenalan sedutan. Penemuan ini berfungsi sebagai asas untuk kerja-kerja akan datang dalam mengurangkan partikel halus dari pemisah siklon.

Kata kunci: Pencemaran udara, siklon, sedutan, tingkatkan kecekapan, kejatuhan tekanan

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cyclone on the FP size fraction. In all cases, each of the experiment was repeated thrice and the average value was reported.

3.0 RESULTS AND DISCUSSION

3.1 General Observations on Pressure Drop of the Cyclone

Table 1 presents the pressure drop across the cyclone as a function of the inlet velocity obtained from this experiment compared to other theoretical pressure drop models where it is observed that the experimental pressure drop model was more conservative compared to the literatures.

The pressure drop was calculated based on Equation 1, [14].

$$\Delta P = \frac{1}{2} H_v V_i^2 \rho_g \quad \dots \text{Equation 1}$$

where H_v is pressure drop expressed in number of inlet velocity heads, V_i is inlet gas velocity (m/s) and ρ_g is gas density (kg/m³). The inlet velocity is determined from the volumetric flowrate divide by the cross section inlet area of the cyclone.

The H_v , pressure drop is calculated by the following Equation 2.

$$H_v = K \frac{HW}{D_e^2} \quad \dots \text{Equation 2}$$

where H is height (390 mm), W is width (100 mm), D_e is exit diameter (40 mm) and K is a constant taken as 16.

Table 1 Pressure drop equation cross cyclone of this experiment compared to other models from literatures

This study's experimental data	$\Delta P = 6.64v_i^2$
Sherperd and Lapple (1939)	$\Delta P = 6.12v_i^2$
First (1950)	$\Delta P = 5.38v_i^2$
Alexander (1949)	$\Delta P = 3.77v_i^2$
Stairmand (1949)	$\Delta P = 4.26v_i^2$

Figure 2 is the graphical presentation of Table 1 clearly showed that the pressure drop of the cyclone increases with increase of the cyclone's flowrates or inlet velocity [2, 12]. It clearly depicts the experimental model was nearest to Sherperd and Lapple pressure drop model with a difference of 18% and represents the highest pressure drop estimation compared to the other models.

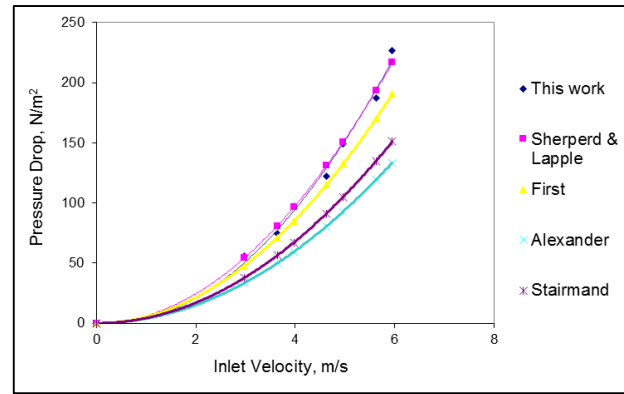


Figure 2 The theoretical and experimental pressure drop across cyclone with respect to cyclone's inlet velocity

3.2 General Observations on Pressure Drop of the Cyclone Upon Introducing External Suction

Table 2 presents the linear pressure drop equation for cyclone flow rates at varied external suction where notably it indicates the ascending order in magnitude of the gradient from low to a higher cyclone flow rate. At the highest cyclone flow rate of $Q=18 \text{ m}^3/\text{hr}$ the difference in the pressure drop with and without suction was 2.6%. As a comparison, this was only 0.9% for the lowest cyclone flow rate of $Q=9 \text{ m}^3/\text{hr}$. The difference was more pronounced for the higher cyclone flow rates.

Table 2 The linear pressure drop equation for cyclone flow rates at varied external suction

Cyclone Flow rate (m ³ /hr)	Equation	Gradient
18	$y_{18} = 6.54x + 229$	6.54
17	$y_{17} = 4.59x + 188$	4.59
14	$y_{14} = 4.22x + 122$	4.22
12	$y_{12} = 2.91x + 97$	2.91
11	$y_{11} = 2.49x + 76$	2.49
9	$y_9 = 0.54x + 54$	0.55

Note: $y = ax + b$ where y is pressure drop across the cyclone, x is the suction flow rate, a is the gradient and b is the intercept (when suction is zero)

Figure 3 presents the comparison between pressure drop across the cyclone with and without suction in the dust hopper, whereas stated earlier, there was a slight increase in the pressure drop by having the external suction in the system. This graph was generated by operating at condition of maximum suction i.e. at (0.9 m³/hr) and no external suction. This is probably due to the external suction that pulls out some portion of air from the dust hopper, which creates a suction zone-nearing vacuum in the dust hopper.

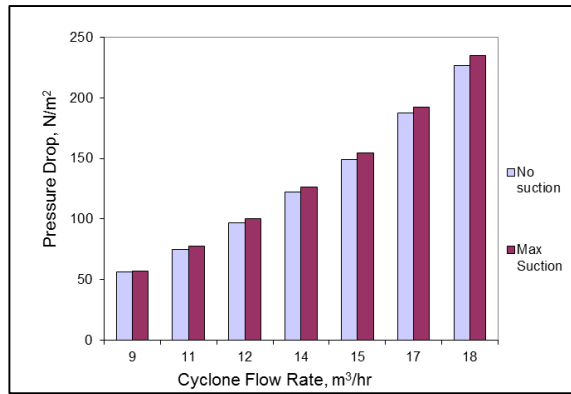


Figure 3 Pressure drop versus cyclone flow rate with and without suction

It is found that there was a difference in pressure drop across the cyclone between the results with and without the external suction. In this case, the plot of the experiments with external suction fits a quadratic equation as presented in $\Delta P = 6.89V_i^2$, which has a slightly higher gradient compared to the one without suction $\Delta P = 6.64V_i^2$. The finding suggests that there was an increment in the pressure drop across the cyclone by introducing an external suction.

3.3 The Overall Collection Efficiency Without Suction

The overall collection efficiency of the cyclone was investigated under both conditions, with and without external suction at the dust hopper of the cyclone. Sample of coarse particle (CP), and a mixture of coarse and fine particle (FP) were introduced under various cyclone flow rates. The collection efficiency was determined using Equation 3

$$\eta = \frac{m_{\text{collected}}}{m_{\text{feed}}} \times 100\% \quad \dots \text{Equation 3}$$

where $m_{\text{collected}}$ is referring to mass collected in the dust hopper after the experiment, meanwhile m_{feed} is the amount of mass fed into the cyclone before the commencement of the experiment. Some presentation of data was done in amount of mass collected in the dust hopper, which also reflect the collection efficiency, where the higher the mass of samples collected, the higher the collection efficiency.

Figure 4 shows the amount of particle collected in the dust hopper under various cyclone flow rates and the amount of CP fed into the system which shows that the amount of particle collected (i.e. collection efficiency) increases with cyclone flow rates as similarly reported by others [15-17]. The increase in the amount of the particle collected by the cyclone with the increase in the volumetric flow rate, the latter being influenced by the inlet velocity. Increased volumetric flow rate, increases the inlet velocity which in turn increases in the speed of vortex rotation, thus

contributing to a higher cyclone collection efficiency [16].

Also as in Figure 4, a higher loading of sample introduced contributes to a higher collection efficiency of the cyclone which is due to the particle collision in the cyclone as reported in literatures [18-22].

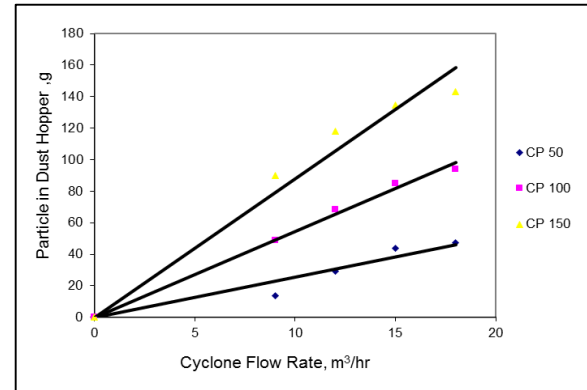


Figure 4 Particle collected in the cyclone dust hopper versus cyclone flow rate Q , with various mass of coarse particle

Figure 5 shows cyclone collection efficiency versus cyclone flow rate for various percentages of fine particles in the total amount of 100 g of the sample, where similar to the trend reported previously, the collection efficiency increases with the cyclone flow rate. As expected, the collection efficiency of the cyclone is higher for a mixture of sample with a lower percentage of fine particles (i.e. higher percentage of coarse particle in the admixture).

The collecting forces developed in the cyclone are particularly effective on large particles where the swirling motion in the cyclone carries the coarse particles towards the inner wall of the cyclone creating collision that causes the particle to finally fall into the dust hopper. On the contrary, the fine particles will tend to follow the radially inward motion of the gas stream and escape out of the cyclone through the clean gas discharge outlet [3, 23]. Therefore, sample mixture with lowest amount of fine particles (i.e. 1%FP) will have higher collection efficiency compared to sample with highest percentage of fine particles (i.e. 5% FP) as depicted in Figure 5.

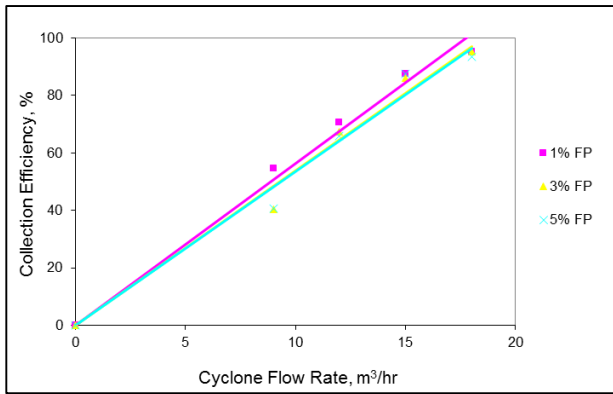


Figure 5 Collection efficiency versus cyclone flow rate for various percent of FP

3.4 The Overall Collection Efficiency with External Suction

Figure 6 presents the overall collection efficiency of the cyclone versus suction flow rate for 100 g of CP introduced into the cyclone which showed that there is an increase in the total amount (i.e. a sum of mass collected in the dust hopper and suction stream) of particles collected. However the increment seems to be marginal due to the fact that the applied suction flow rate was relatively small compared to the cyclone flow rate due to the limitation of the suction pump used. A similar trend was also observed for different amount of CP fed into the cyclone (i.e. 50 and 150 g) during the experiment.

Although the difference in the collection efficiency with and without suction was marginal (i.e. varied from 0.7 - 3%) the findings illustrate that applying suction enhances the overall collection efficiency of the cyclone. A more meaningful observation could have been obtained if a high percentage of suction for higher cyclone flow rates could have been experimented. It is anticipated that higher suction and at the higher cyclone flow rates would give a better result as the former further enhanced the total collection efficiency of the cyclone.

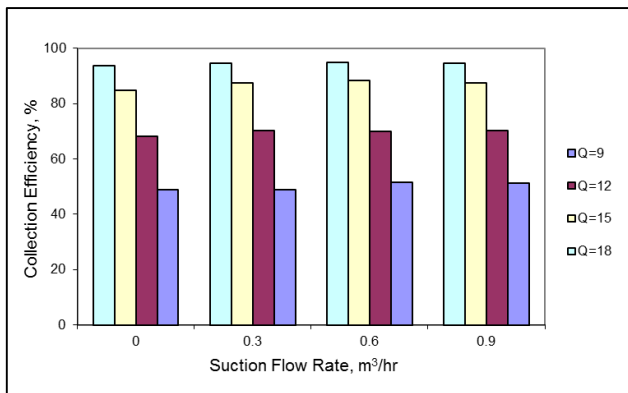


Figure 6 Collection efficiency versus suction flow rate under various cyclone flow rates, Q for 100 g of CP

Figure 7 presents the overall collection efficiency (i.e. weight in dust hopper and suction stream) of the cyclone versus suction flow rate for selected percentage of FP at fixed cyclone flow rate of 18 m³/hr which showed there is an increase in collection efficiency with suction flowrate. A similar trend was observed for all other cyclone flow rates (i.e. 9, 12 and 15 m³/hr). However, the overall collection efficiency is rather low as the FP percentage increases. This is as expected as cyclone is known to have less collection efficiency on fine particle [1, 24-27]. As in Figure 7, more of the FP size fraction was collected with the increase in suction flowrate illustrating enhancement of FP collection with the introduction of external suction at the dust hopper. In addition, as demonstrated in the figure, suction stream has the ability to be selectively collect fine particle rather than coarse particle size fraction.

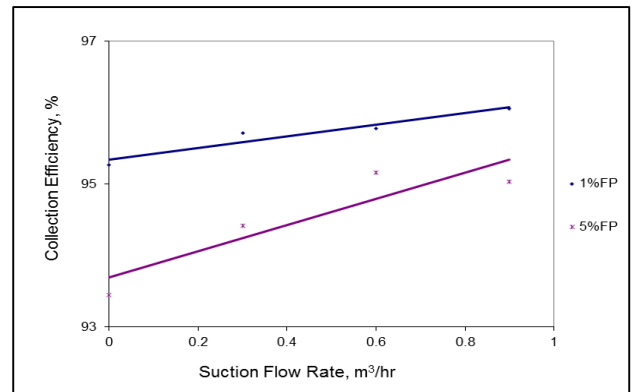


Figure 7 Overall collection efficiency versus suction flow rate for selected percentage of FP with fixed cyclone flow rate of Q, 18 m³/hr

3.5 Particle Collection on the Suction Filter Paper

Figure 8 presents the mass of particle collected in the suction stream at various cyclone flow rates (i.e. 9, 12, 15 and 18 m³/hr) for a fixed amount of 100 g CP sample, where it was observed that the cyclone flow rate influences the amount of sample collected in the suction stream. As previously stated, the amount of particles collected was higher at a higher cyclone flow rate. In addition, the mass of particles collected on the suction filter paper increases with the increase in suction for a fixed cyclone flow rate. It seems that more particles are carried into the cyclone at higher gas flow rate and with introduction of the suction stream at the dust hopper enhanced the amount of particles collected probably due to the pulling of the vortex further down into the hopper. Some of these free falling CP followed the suction stream and collected on the suction filter paper. A similar trend was observed for different amount of CP introduced into the cyclone (i.e. 50 and 150 g).

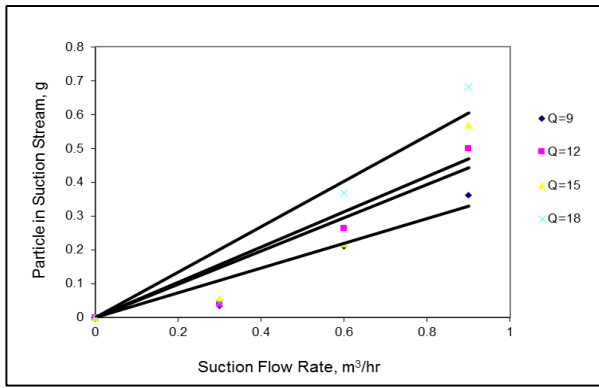


Figure 8 Particle collected in suction stream versus suction at various cyclone flow rates, Q

A similar observation was obtained when the experiments were repeated with mixture of FP and CP samples. As depicted in Figure 9, assuming a linear relationship between mass collected and suction flow rates, more particles were collected in the suction stream when more the FP was introduced in the sample for a fixed cyclone flow rate of 18 m³/hr. A similar trend was also observed for other cyclone flow rates. It was observed that more of the FP size fraction is collected with the increasing of the external suction which creates lower pressure that enables both the cyclone's inner and outer vortices to travel further down into the dust hopper. This creates disturbance in the vortices, consequently shedding off particles to fall freely at their terminal falling velocities into the hopper and suction stream.

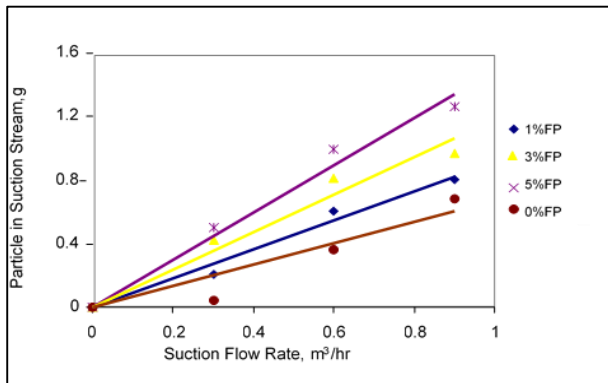


Figure 9 Particle collected in suction stream versus suction flow rate for various compositions of sample with fixed cyclone flow rate of Q, 18 m³/hr

However, major portion of falling FP are being extracted out from the dust hopper into the suction stream based on terminal falling velocity of a particle which is a function of density and size of the particle [14, 28]. Based on a micro pycnometer analysis, both the FP and CP have a similar density but with different particle size fraction of $\leq 75 \mu\text{m}$ and $\geq 150 \mu\text{m}$, respectively. Thus, FP that is categorized as a smaller

diameter has a smaller terminal falling velocity which is easier to be extracted and collected into the suction stream compared to CP.

3.6 Particle Collection on the Backup Filter Paper

To further support the previous findings, studies on the mass of particles that escaped from the clean gas discharge of the cyclone and collected on the backup filters were scrutinized. Figure 10 presents the mass of particles collected on the backup filter versus suction flow rates for various percentage of FP with a fixed cyclone flow rate which showed a decrease in FP collected onto the backup filter with increasing suction flow rate. This finding clearly indicates that the introduction of external suction flowrate helped to reduce fine particle emission from the cyclone.

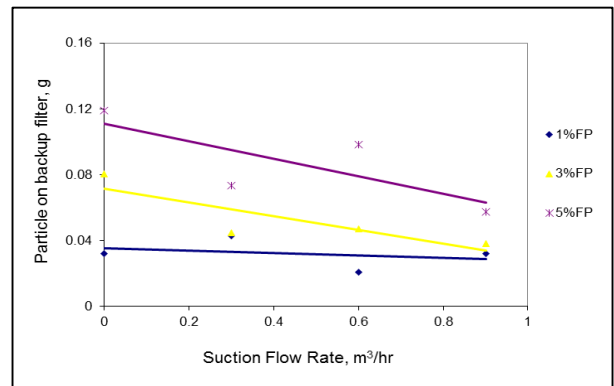


Figure 10 Mass particle collected on the backup filter versus suction flow rate for various composition of sample with fixed cyclone flow rate of Q = 18 m³/hr

Table 3 presents the percentage reduction of particulate mass on the backup filter with and without suction for 5% FP sample mixture which showed that there was a reduction on mass collected at the backup filter ranging from 13.6 up to 51.5% for cyclone flow rates between 9 to 18 m³/hr. Again this indicates that the cyclone flow rate under the influence of suction also play an important role in the reduction of the total particle emission. This finding suggests that the overall collection efficiency of a cyclone can be further enhanced by introducing external suction at the dust hopper.

Table 3 Percentage of reduction of particulate mass with and without suction on the backup filter

Cyclone flow rate (m³/hr)	Particle collected with no suction (g)	Particle collected with maximum suction (g)	% Reduction
18	0.119	0.0577	51.50
15	0.1211	0.0649	46.40
12	0.0723	0.0612	15.40
9	0.0562	0.0485	13.70

*with maximum suction of 0.9 m³/hr and sample of 5% FP mixture

4.0 CONCLUSION

The introduction of the suction stream in the dust hopper of a cyclone brings about a slight increase in pressure drop across the cyclone which also increase the performance of a cyclone. The study also showed that the increase in pressure drop was influenced not merely by the cyclone's flow rate but also by the suction flow rate applied at the dust hopper. The study found that there was a linear relationship between the suction flow rate and the mass of particle drawn by the suction stream. More of the fine particle size fraction was collected in the suction stream when a higher percentage of it was introduced into the cyclone. The study concludes that the suction stream has a higher 'selectivity' towards the fine rather than the coarse due to the difference in the terminal falling velocities of particles with respect to the suction flowrate. The introduction of the suction also plays an important role in the reduction of the total particulate mass emitting from the cyclone ranging from 14 to 52% compared to the one without any suction. This concludes that the introduction of suction reduces particulate released from a cyclone. Finally, this study serves as a basis for future research in increasing the performance of a cyclone in real plant situations to comply with the stringent particulate emission regulations.

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