EFFECT OF DESIGN AND OPERATING PARAMETERS ON MEASURED AND PREDICTED PRESSURE DROP IN CYCLONE

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ABSTRACT

In this study, many design parameters in cyclone such as cone height (30, 50 and 70 cm), vortex finder length (0, 10, 20, 30 and 40 cm) and dipleg length (25, 40 and 55 cm) were investigated under operating parameters via inlet air velocity (14, 16, 18 and 20 m/s) to find out the pressure drop (ΔP) of the cyclone empirically and predictively. The ΔP between inlet and outlet of the cyclone was measured experimentally by differential inclined manometer, while some mathematical models were used to predict ΔP of cyclone based on ***Shepherd and Lapple (1939), Barth (1956), Casal and Martinez-Benet (1983), Dirgo (1988) and Coker (1993)****. Some statistical indicators were used to compare and validate the measured with predicted results. As a result of this experiment, the maximum empirical ∆P were 161.3, 181.7 and 250.8 Pa recorded at inlet air velocity of 20 m/s, cone heights of 30, 50 and 70 cm under vortex finder lengths of 40, 40 and 0 cm and dipleg lengths of 55, 25 and 25 cm, respectively. Meanwhile, the minimum ∆P were 60.2, 63,6 and 80.6 Pa recorded at inlet air velocity of 14 m/s, cone heights of 30, 50 and 70 cm under vortex finder lengths of 10, 30 and 40 cm and dipleg lengths of 25, 55 and 55 cm, respectively. Furthermore, the best models to predict the pressure drop were* ***Shepherd & Lapple, Coker*** *and* ***Dirgo****, respectively. The* ***Shepherd & Lapple*** *model was more validation with cone heights of 50, 30 and 70 cm, respectively. Meanwhile, the predicted model* ***Coker*** *was more validation with cone heights of 30, 50 and 70 cm, respectively. While,* ***Dirgo*** *model was more validation to experimental data at vortex finder length of 20 cm then 30 and 10 cm, respectively.*

Key words: *Cyclone, Pressure drop, Inlet air velocity, Cone height, Vortex finder length, dipleg length.*

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NOMENCLATURE

a	: cyclone inlet height, m.
A	: cross-sectional areas of the inlet, m^2.
b	: cyclone inlet width, m.
c_o	: mass ratio of dust feeding the cyclone to the gas flow rate, dimensionless.
D	: cyclone vortex finder (exit pipe) diameter, m.
D_b	: cyclone cone-tip or dust outlet or dipleg diameter, m.
D_c	: cyclone body (cylindrical part) diameter, m.
Eu	: Euler number, dimensionless.
f	: friction factor (f = 0.05).
g	: gravity acceleration 9.81 m/ sec^2.
h_1	: cyclone cylindrical part (body) height, m.
h_2	: cyclone conical part height, m.
h_3	: cyclone dust outlet (dipleg) length, m.
H_{CS}	: height of the control surface extending from the bottom of the vortex finder to the cyclone bottom or core length, as shown in Fig. (3), m.
H_t	: cyclone total height (total height), m.
H_v	: inlet velocity heads, m.
k	: cyclone pressure drop constant, dimensionless.
K	: The vortex finder entrance factor (K = 4.4).
n	: number of measurements (statistics).
P_1	: pressure at air inlet, Pascal.
P_2	: pressure at air outlet, Pascal.
P_{si}	: static pressure at inlet, N/m^2.
P_{so}	: static pressure in outlet, N/m^2.
Q	: gas volume flow rate, m^3/h or m^3/s.
q	: term in Stairmands pressure drop model.
R	: cyclone radius ($D_c/2$), m.
R_{in}	: radial position of the center of the inlet for a slot inlet as shown in Fig (3), m.
R_x	: radius of vortex finder (D/2), m.
S	: cyclone vortex finder or gas outlet length, m.
v_i	: average air velocity at the cyclone inlet, m/sec.
v_x	: mean axial velocity in the vortex.
$v_{\theta cs}$	: tangential velocity at the control surface CS.
x	: experimental value.
x_1	: distance movement of liquid (water) in above inclined tube, m.
x_2	: distance movement of liquid (water) in below inclined tube, m.
y	: predicted value.
y_1	: vertical distance corresponding to x1, m.
y_2	: vertical distance corresponding to x2, m.
Z	: pressure head (difference in water levels), m.
α	: manometer inclined angle, degree.
ΔP	: pressure drop in the cyclone, N/m^2.
ΔP_{body}	: loss the pressure in the cyclone body, N/m^2.
ξ_c	: pressure drop coefficient, dimensionless.
ρ_g	: gas density (air) 1.18, Kg/m^3.
ρ_w	: density of water, 1000 kg/m^3.
φ	: constant, dimensionless.
▼	: reference level.

INTRODUCTION

The cyclone is one of the most important air purifiers and separation of solids from the air stream and most common in many agricultural processing industries and post-harvest operations. It is simple to install, low manufacturing and maintenance costs, no moving parts and the ability to operate under difficult operating conditions such as high temperature and pressure. In spite of the simplicity of install, the prediction of pressure drop inside the cyclone is very complex due to the interaction between designs and operating parameters. A great number of research projects have been dedicated to investigation of these parameters for distinct cyclone shapes under various operating conditions **(Hoffmann *et al.*, 1992)**.

It is desirable to operate at the lowest flow rate possible for which the collection efficiency of the cyclone is acceptable in order to reduce operating costs of the cyclone, which are a function of both inlet velocity and pressure drop. Thereby, the optimal design and operating parameters will be evaluated based on collection efficiency and pressure drop (**Faulkner and Shaw, 2006**).

The pressure drop across the cyclone is directly related to the inlet air velocity required to operate a cyclone device. **Schnell and Brown (2002)** presented that, inlet air velocity is a prime factor affecting the pressure drop and hence the cyclone efficiency. Efficiency increases with an increase inlet velocity as centrifugal force increases, but this also increases the pressure drop which is not favorable. While, **Chuah *et al.* (2003)** concluded that pressure drop is a function of the square of inlet velocity, so too high a velocity will cause excessive pressure drop. On the other hand, too low a velocity would cause a low efficiency. A very high inlet velocity would decrease the collection efficiency because of increased turbulence and re-entrainment of particles. Generally, it was found that the optimum operating velocity was around 18 m/s. Furthermore, **Abdel-Hadi (2014**) reported that the optimum practicable cyclone inlet velocity was 18.5 m/s.

Demir *et al.* (2016) used the nine modifications of Stairmand High-Efficiency type cyclone (Stairmand HE) with various cylindrical and conical heights to investigate their effects on pressure drop and flow field within cyclones. The experimental results indicated that, the designer should be aware of that the body and conical heights have significant effects on cyclone pressure drop. For a body height of less than 1.5D_c and a conical height of less than 2.5D_c, pressure drop is more sensitive to conical height. On the other hand, body height is more effective on pressure drop when conical height is less than 2.5D_c and body height is greater than 1.5D_c. Therefore, increasing both body and conical heights together leads to reduced pressure drops with higher costs of construction. The pressure drop in a cyclone is the difference of static pressure between the inlet and outlet, which can be written as follows according to (**Chen and Shi, 2007**):

$$\Delta P = P_{si} - P_{so} \qquad (1)$$

The static pressure at the inlet cross-section is uniformly distributed because there is no swirling motion. It can be easily measured with a pressure tapping on the wall. But the static pressure at the wall outlet is quite different from its cross- sectional average due to the strong swirling flow. The dynamic pressure stored in the swirling motion can be significant. The determination of the static pressure downstream of a cyclone, hence the pressure drop becomes more complicated and difficult. There are two steps to calculate of cyclone pressure drop. The first step is to calculate the pressure drop in the number of inlet velocity heads (H_v) then calculate the pressure drop (**Shepherd & Lapple, 1939** and **Kanshio, 2015**).

$$H_v = k\frac{ab}{D} \qquad (2)$$

$$\Delta P = H_v \rho_g \frac{v_i^2}{2} \qquad (3)$$

The main objective of this study was to investigate the effect of cyclone design (cone height, cyclone total height, vortex finder length, dipleg length) and operating parameter (inlet air velocity) on the pressure drop to determine the appropriate design of the cyclone with inlet velocity. Moreover, to assess the predictive validity of some literature correlations in comparison with the measured pressure drop to the better use with the existing theories.

MATERIALS AND METHODS

Experimental Unit

The experimental unit was fabricated from galvanized steel sheet of 1.5 mm thickness; cutting and welding were by laser technology. The dimension and specification of the experimental unit are tabulated in Table (1) and the overview of cyclone annexed to the inclined water-manometer for measuring experimental pressure drop shown in Fig. (1).

Table (1): Dimension and specification of the experimental unit.

Parameter	Description	Values	Unit
D_c	Cyclone body diameter	30	cm
h_1	Cyclone cylindrical part height	50	cm
b	Cyclone inlet width	7.2	cm
a	Cyclone inlet height	7.2	cm
D	Vortex finder diameter	9.2	cm
D_b	Dipleg diameter	7.7	cm

1	Set of input dust.	5	Cyclone conical part.
2	Air supply unit.	6	Cyclone cylindrical part.
3	Inclined differential manometer.	7	Cyclone air and dust inlet.
4	Dipleg (dust outlet).	8	Vortex finder (air outlet).

Fig. (1): The overview of cyclone annexed to the inclined water-manometer.

Table (2) explains the parameters under study to determine the suitable cyclone design and inlet air velocity.

Table (2): The experimental parameters under study.

Parameter	Description	Values	Unit
h_2	Cyclone conical part height	30, 50 and 70	cm
h_3	Dipleg length	25, 40 and 55	cm
H_t	Cyclone total height	80, 100 and 120	cm
S	Vortex finder length	0, 10, 20, 30 and 40	cm
v_i	Inlet air velocity	14, 16, 18 and 20	m/s

Pressure Drop Measurements

The cyclone static pressure drop (ΔP) is usually calculated as the pressure difference between the inlet and the pressure across the vortex finder exit (**Hoekstra, 2000**). To get the best accuracy (resolution) the differential inclined manometer was used for measurement the pressure drop. The differential inclined manometer made from the silicone tube internal and external diameter of 6.5 and 9.5 mm, respectively, and filled with gage fluid (water). It was set at an angle 10^o (α) to the horizontal and annexed between the air inlet and outlet (vortex finder) as shown as in Fig. (1 and 2).

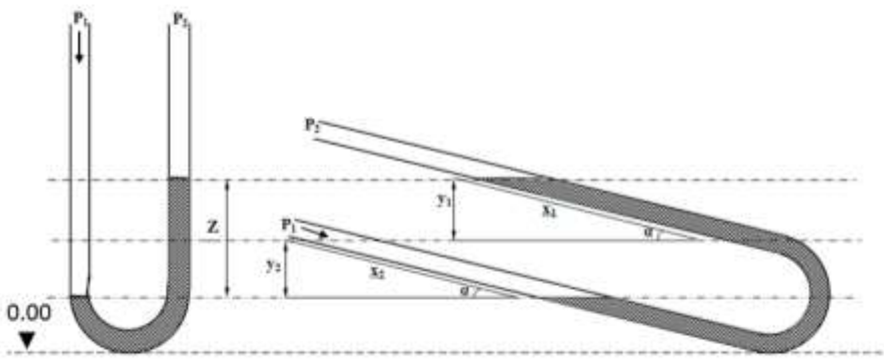

Fig. (2): The differential inclined manometer (Clifford *et al.*, 2009).

The practically differential pressure (pressure drop, ΔP) between the inlet and outlet corresponding to a vertical difference of levels y_1 and y_2 gives move of the meniscus $x_1$and x_2 along the slope. To calculate a vertical difference of levels y_1 and y_2 used the following equations according to **(Clifford *et al.*, 2009**).

$$y_1 = x_1 \sin\alpha \quad (4)$$
$$y_2 = x_2 \sin\alpha \quad (5)$$
$$Z = y_1 + y_2 \quad (6)$$
$$\Delta P = P_1 - P_2 = Z \times g \times (\rho_w - \rho_g) \quad (7)$$

Dewil *et al.* (2008) reported that, the static pressure drop (ΔP) between the gas inlet and outlet of a cyclone is proportional to the square of the flow rate (Q), with a proportionality resistance coefficient (ξ_c) defined on the basis of the inlet velocity (v_i = Q/ab), thus:

$$\Delta P = \xi_c \frac{\rho_g v_i^2}{2} \quad (8)$$

Table (3) summarized the models equations which descripted the inlet velocity heads (H_v) or pressure drop coefficient (ξ_c) of empirical and theoretical models according to **(Cortés and Gil, 2007).**

Table (3): The pressure drop coefficient (ξ_c) models according to (Cortés and Gil, 2007).

Reference	Equation	Remarks
	Empirical models	
Shepherd & Lapple (1939)	$\xi_c = Eu = \left(\frac{16A}{D^2}\right)$	(9)
Coker (1993)	$\xi_c = Eu = 9.47\left(\frac{A}{D^2}\right)$	(10)
Casal and Martinez-Benet (1983)	$\xi_c = Eu = 11.3\left(\frac{A}{D^2}\right)^2 + 3.33$	(11)
	Theoretical model	
Dirgo (1988)	$\xi_c = Eu = 20\left(\frac{A}{D^2}\right)\left(\frac{S/D_c}{(H_t/D_c)(h_1/D_c)(D_b/D_c)}\right)^{\frac{1}{3}}$	(12)

Barth (1956) suggested another theoretical model of (ξ_c) based on the equilibrium-orbit model and divided the pressure drop in the cyclone into three consists:

1- Loss the pressure at the inlet (this loss could be avoided by good design).

2- Loss the pressure in the cyclone body (ΔP_{body}), it can be estimated as the following:

$$\Delta P_{body} = \frac{\rho_g v_x^2 D}{2\, D_c}\left[\frac{1}{\left(\frac{v_x}{v_{\theta cs}} - \frac{H_t - S}{0.5\, D}\, f\right)^2} - \left(\frac{v_{\theta cs}}{v_x}\right)^2\right] \quad (13)$$

Where:

$$v_x = \frac{Q}{\pi\, R_x^2} \quad (14)$$

$$v_{\theta cs} = \frac{\pi\, R_{in}\, R_x\, v_x}{a\, b\, \varphi + H_{cs}\, \pi\, f\, R_{in}} \quad (15)$$

$$R_{in} = R - \frac{b}{2} \quad (16)$$

$$R_x = \frac{D}{2} \quad (17)$$

$$\varphi = 1 - 0.4\left(\frac{b}{R}\right)^{0.5} \quad (18)$$

3- Loss the pressure in the vortex finder (ΔP_x), can be estimated using a semi- empirical approach as following:

$$\Delta P_x = \left[0.5 \rho_g v_x^2\right]\left[\left(\frac{v_{\theta cs}}{v_x}\right)^2 + K\left(\frac{v_{\theta cs}}{v_x}\right)^{\frac{4}{3}}\right] \quad (19)$$

Therefore the total pressure drop is calculated as:

$$\Delta P = \Delta P_{body} + \Delta P_x \quad (20)$$

Hoffmann & Stein (2008) explained the item the height of control surface (H_{cs}) according to the equilibrium-orbit theory in the following Fig. (3)

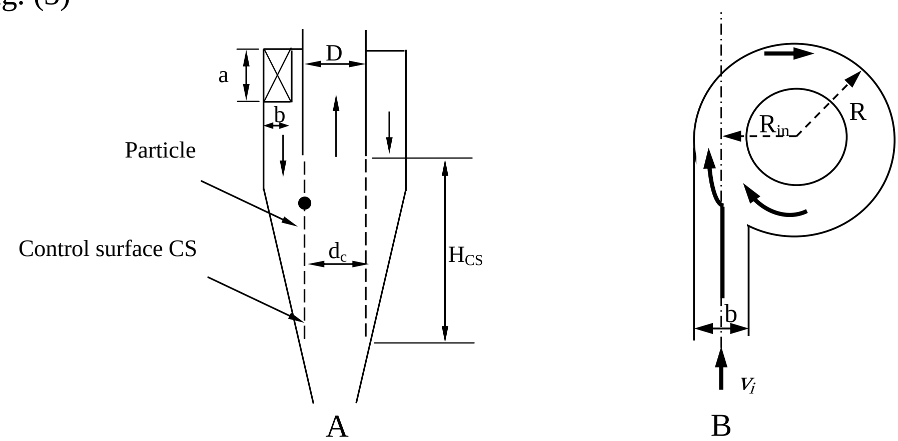

Fig. (3): A- The control surface concept in the equilibrium-orbit model and B- the inlet flow pattern for tangential inlet cyclone (B) according to (Hoffmann and Stein, 2008).

Statistical indicators for empirical models

The models validation parameters were used to assess the measured data of pressure drop in comparison with predictive validity of some literature correlations to put the data into better use with the existing theories. Four general statistical indicators for empirical models were chosen to evaluate the prediction ability of the pressure drop predicted models. These indicators are mean relative deviation (MRD, %), a relative standard error of prediction (RSEP, %), root mean square error (RMSE) and Pearson correlation coefficient (r), respectively.

- Mean relative deviation (MRD, %) (**Chen and Morey, 1989**).

$$\mathrm{MRD}(\%) = \left[\sum_{j=1}^{n} \frac{|x-y|}{x}\right] \times \frac{100}{n} \tag{21}$$

The mean relative deviation modulus (MRD, %) is widely adopted throughout the literature with a minimum value indicative of a good fit for predicting models (**Van den Berg *et al.*, 1981**).

- Relative standard error of prediction (RSEP, %) (**Ghasemi and Niazi, 2005**).

$$\mathrm{RSEP}\ (\%) = 100 \times \sqrt{\frac{\sum_{j=1}^{n}(x-y)^2}{\sum_{j=1}^{n} x^2}} \tag{22}$$

Model accuracy is considered excellent when (RSEP) < 10 %, good if 10 % < (RSEP) < 20 %, fair if 20 % < (RSEP) < 30 % and poor if (RSEP) > 30 % (**Li *et al.*, 2013**).

- Root mean square error (RMSE) (**Jachner *et al.*, 2007**).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{j=1}^{n}\left(x_j-y_j\right)^2}{n}} \tag{23}$$

- Pearson correlation coefficient (r) according to (**Spatz, 2008**).

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{n\sum x^2-(\sum x)^2}\sqrt{n\sum y^2-(\sum y)^2}} \tag{24}$$

In general, maximum value of the Pearson correlation coefficient (r) is indicating a better fit of the predicted model. In other hand the minimum values of mean relative deviation (MRD, %), a relative standard error of prediction (RSEP, %) and root mean square error (RMSE) selected as a best fit model (**Tantar *et al.*, 2014**).

RESULTS AND DISCUSSION

Measured Pressure Drop

In general, in obtaining results the experimental ΔP increase with increase inlet air velocity and cone height and the results were agree with (**Chuah *et al.*, 2006** and **Juengcharoensukying *et al.*, 2017**). Fig. (4) illustrated the relationship between inlet air velocity and pressure drop under the different cone heights, vortex finder lengths and dipleg lengths.

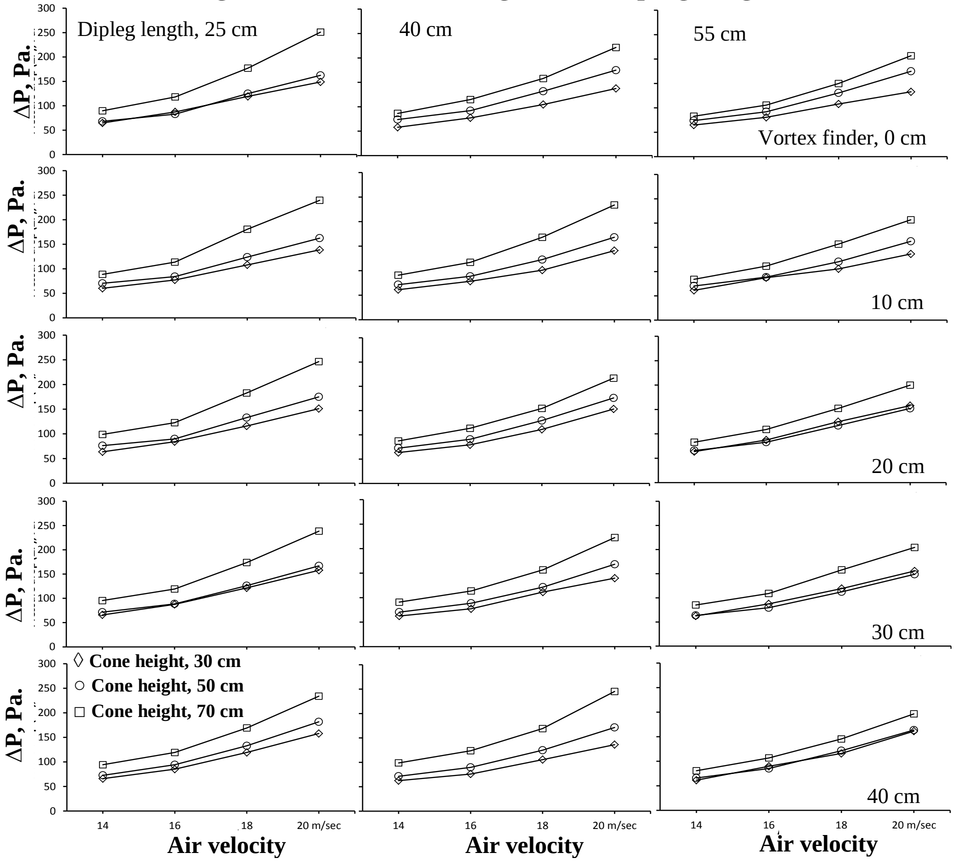

Fig. (4): Effect of inlet air velocity on measured pressure drop at different cone heights, vortex finder lengths and dipleg lengths.

The maximum ΔP were 161.3, 181.7 and 250.8 Pa recorded at inlet air velocity of 20 m/s, cone heights of 30, 50 and 70 cm under vortex finder lengths of 40, 40 and 0 cm and dipleg lengths of 55, 25 and 25 cm, respectively. Meanwhile, the minimum ΔP were 60.2, 63,6 and 80.6 Pa recorded at inlet air velocity of 14 m/s, cone heights of 30, 50 and 70 cm under vortex finder lengths of 10, 30 and 40 cm and dipleg lengths of 25, 55 and 55 cm, respectively. The results showed that the pressure drop was increased with increasing the cyclone size according to (**Azadi *et al.*, 2010**). Also the observed results showed that, the effect of both vortex finder length and dipleg length on ΔP was tiny effect and neglected, these results agree with (**Elsayed, 2011**).

Predicted Pressure Drop

The accurate prediction of cyclone ΔP is very important because it relates directly to operating costs and overall collection efficiency. The most widely used models for the pressure drop coefficient (ξ_c) are **Shepherd & Lapple (1939)**; **Barth (1956)**; **Casal & Martinez-Benet (1983)**; **Dirgo (1988)** and **Coker (1993)**. These five theories above-mentioned were applied in equation (8) to predict the ΔP according to (**Dewil *et al.*, 2008)** and validate them to the experimentally ΔP, which measured by the inclined differential manometer. Table (4) showed some statistical indicators to validate predicted with measured values of ΔP.

Table (4): Some statistical indicators to validate predicted with measured values of pressure drop.

Statistics parameters	Experiment	Shepherd & Lapple	Coker	Dirgo	Barth	Casal & Martinez
Mean	120.6	117.9	69.8	96.6	625.8	404.5
Std. deviation	46.4	30.6	18.1	59.3	162.5	105.0
R	-	**0.86260**	0.86260	0.33538	0.86151	0.86259
MRD, %	-	**15.4**	39.1	39.0	446.1	252.9
RSEP, %	-	**19.6**	46.5	51.2	402.8	226.2
RMSE	-	**25.4**	60.1	66.2	520.3	292.1

The **Barth** and **Casal & Martinez-Benet** models were given an extreme result comparing with measured ΔP because it has lower values of the Pearson correlation coefficient (r) and at the same time has the highest values of (MRD, %), (RSEP, %) and (RMSE) as shown in Table (4) according to (**Tantar *et al.*, 2014**).

As shown in Table (4) bold values refer to the more accurately model **Shepherd & Lapple** regarding particular indicator then **Coker** and **Dirgo**, respectively. The **Shepherd & Lapple** model has the highest value of (r) 0.86260 and the lowest value of MRD %, RSEP and RMSE, which were 15.4, 19.6 and 25.4, respectively. Figures (5, 6 and 7) illustrate the comparison between the best three models and the experimental results.

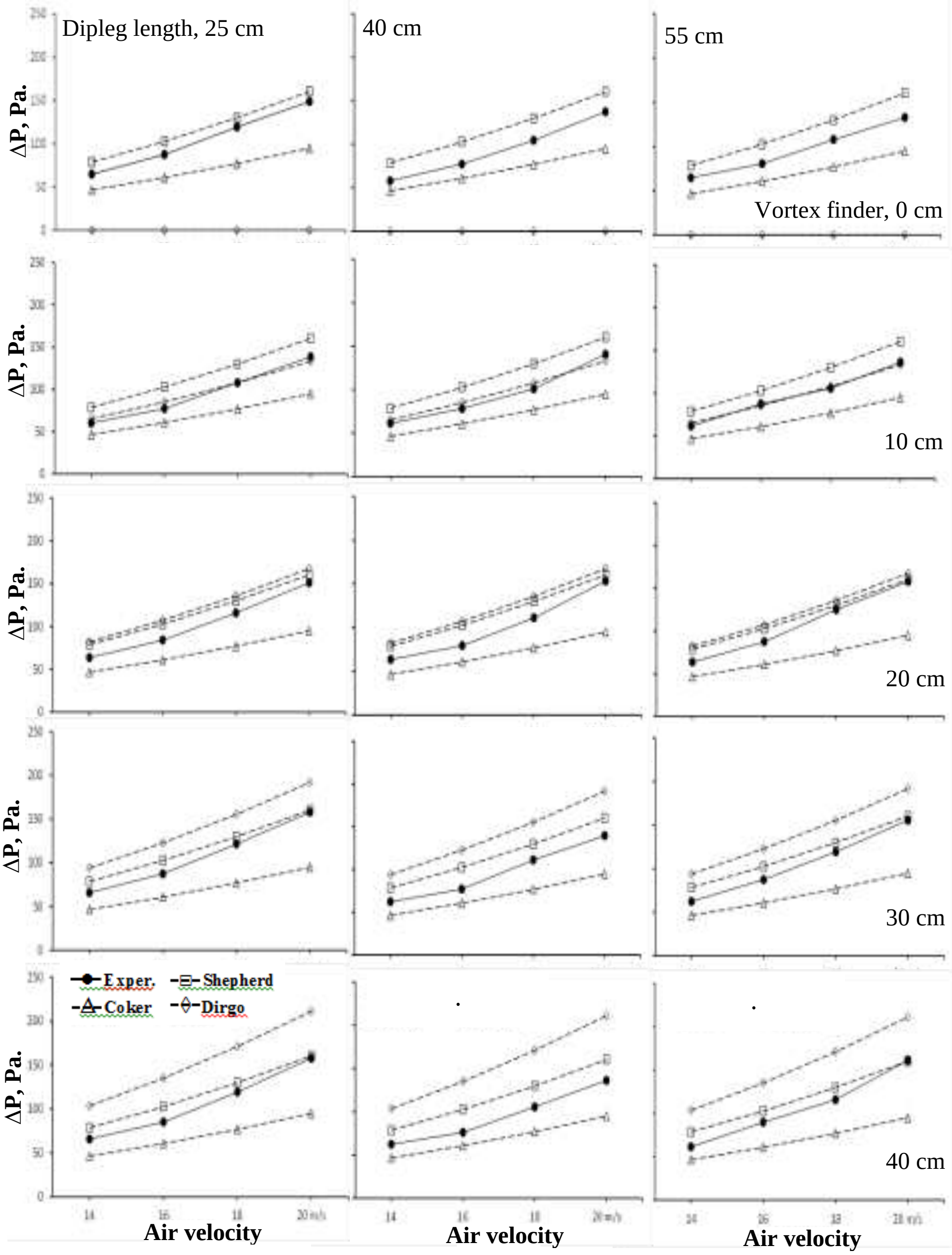

Fig. (5): The measured and predicted pressure drop at different coefficient models (ξ_c) under the cone height of 30 cm at different dipleg lengths and vortex finder lengths.

In general the ΔP of cyclone under cone heights of 30, 50 and 70 cm were increased with increasing the inlet air velocity. In Fig. (5) the measured values were closer to the **Shepherd & Lapple** model while, the **Dirgo** model was equal zero Pascal at vortex finder length zero cm because the model including the effect of vortex finder length. Meanwhile, increasing the vortex finder length lead to the increasing the predicted values of **Dirgo** model corresponding on measured ΔP at vortex finder length of 10 cm and corresponding on **Shepherd & Lapple** model at vortex finder length of 20 cm then rise above both measured ΔP and **Shepherd & Lapple** model under vortex finder lengths of 30 and 40 cm.

Fig. (6) illustrate the ΔP of cyclone under cone height of 50 cm. The experimental measured values were closer to the **Shepherd & Lapple** model especially at inlet air velocity of 18 m/s. While, the **Dirgo** model was equal zero Pascal at vortex finder length of zero cm and corresponding on **Shepherd & Lapple** model at vortex finder length of 20 cm. Generally, the predicted value of **Dirgo** model increasing with increase the vortex finder length.

Fig. (7) presented the ΔP of the cyclone under the cone height 70 cm. The experimental measured values were higher than the predicted values of all models and it was closer to **Shepherd & Lapple** model at inlet air velocities of 14 and 16 m/s after that, by increasing inlet air velocity from 16 to 20 m/s increasing the gap between the measured and predicted values. The values of **Shepherd & Lapple** model were closer to **Dirgo** model at vortex finder lengths of 20 and 30 cm at all inlet air velocity.

To assess the effect of cone height on ΔP and put the data into better use; the data were validated with predicted ΔP models. Table (5 and 6) focused the comparison between the best predicted of ΔP models and experiment results under different cone heights and dipleg length, respectively.

Table (5) presented the correlation between the best predicted models and experimental ΔP under the cone heights of 30, 50 and 70 cm; the statistical values seem that the **Shepherd & Lapple** model was more validation comparing with other models. At the same time, this model was more validation with cone heights of 50, 30 and 70 cm, respectively. Meanwhile, the predicted model **Coker** was more validation with cone heights of 30, 50 and 70 cm, respectively, due to the high value of (r) and lowest value of (MRD, %), (RSEP, %) and (RMSE), respectively.

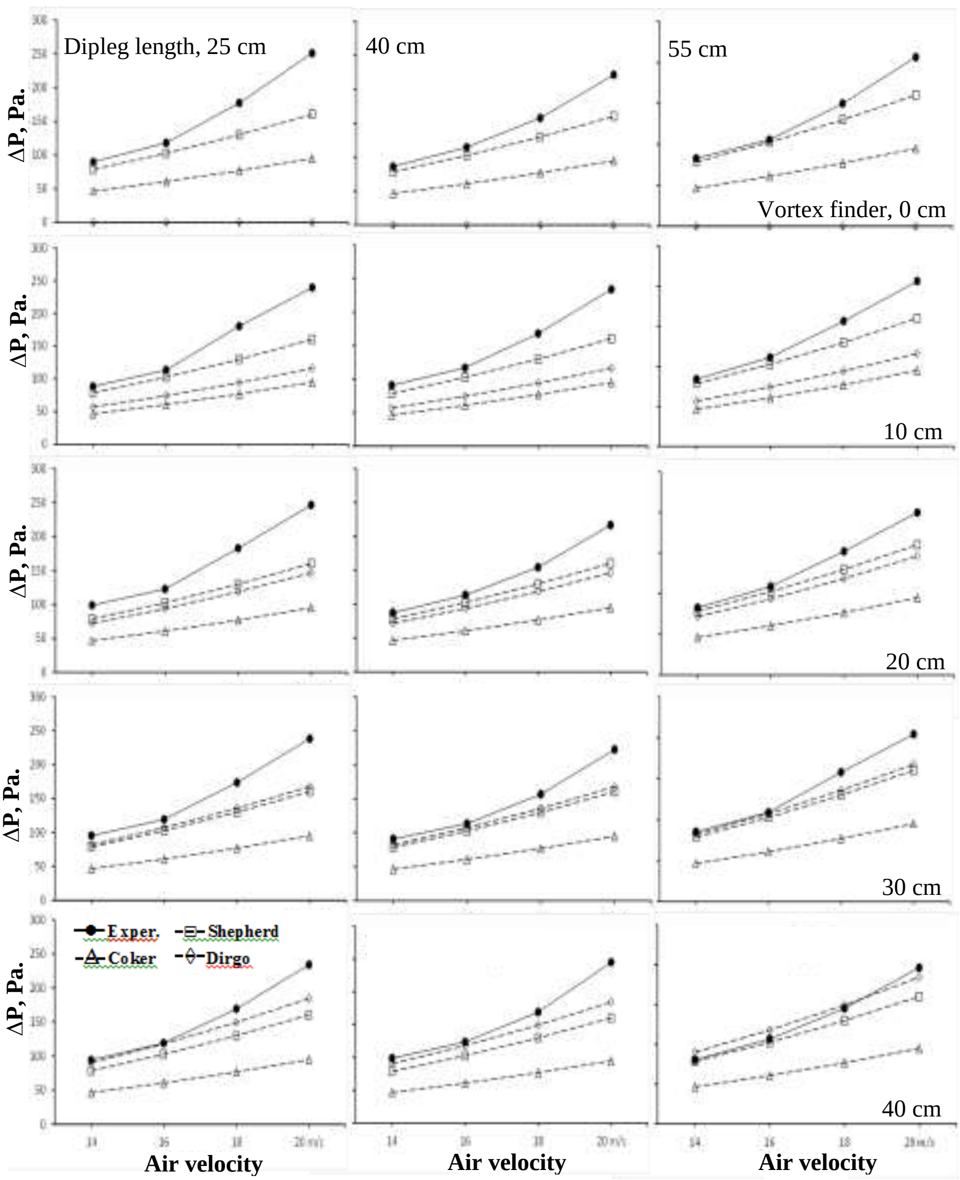

Fig. (6): The measured and predicted pressure drop at different coefficient models (ξ_c) under the cone height of 50 cm at different dipleg lengths and vortex finder lengths.

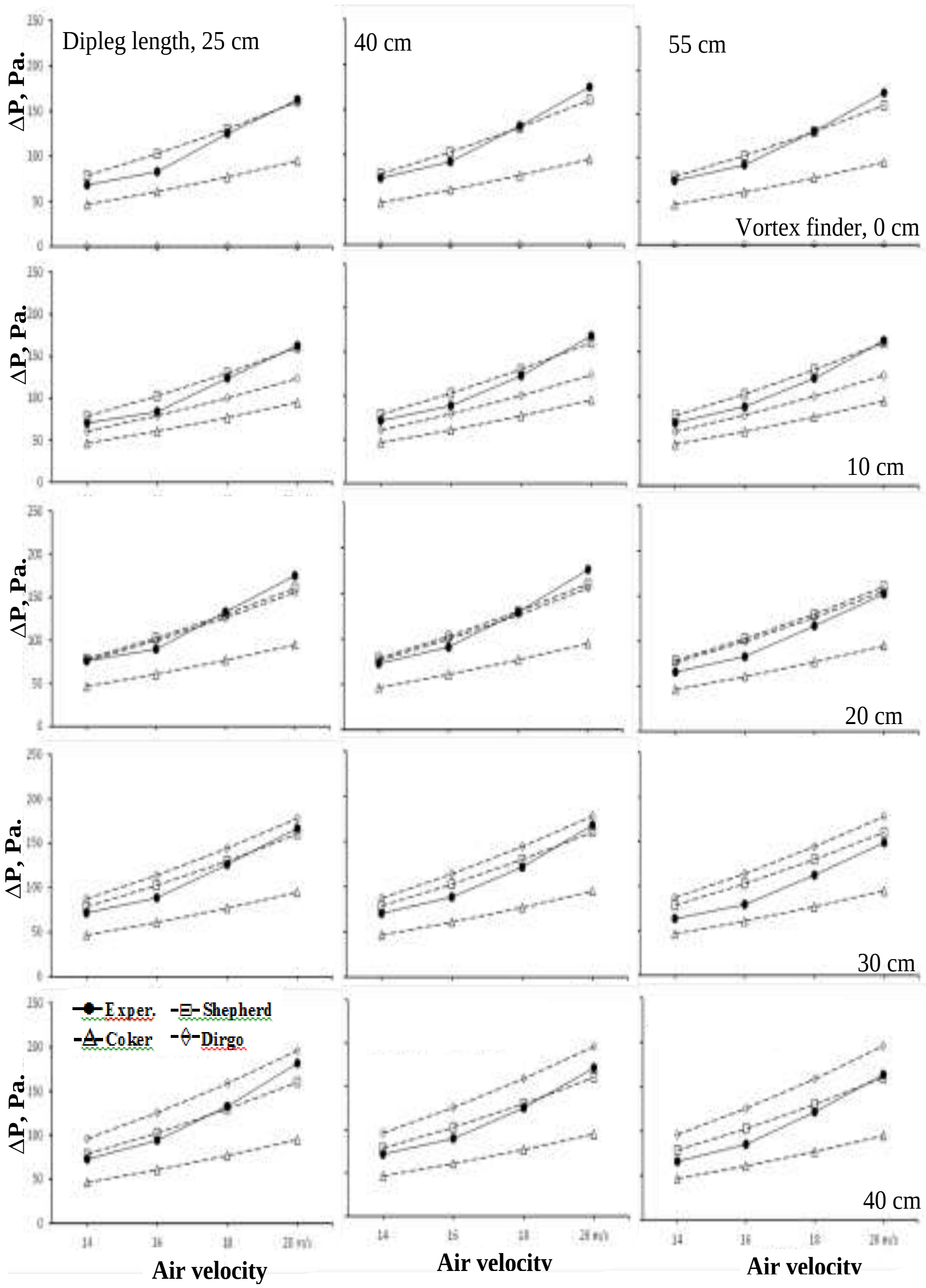

Fig. (7): The measured and predicted pressure drop at different coefficient models (ξ_c) under the cone height of 70 cm at different dipleg lengths and vortex finder lengths.

Table (5): Correlation between the best predicted pressure drop models and experimental results under different cone heights.

Validation parameters	Models	Cone height, cm		
		30	50	70
R	Shepherd & Lapple	0.97807	0.98023	0.96987
	Coker	0.97807	0.98023	0.96987
	Dirgo	0.48309	0.39186	0.41430
MRD, %	Shepherd & Lapple	18.8	9.9	17.5
	Coker	29.7	36.5	51.1
	Dirgo	43.8	35.4	36.9
RSEP, %	Shepherd & Lapple	16.8	9.3	24.6
	Coker	32.9	39.9	54.6
	Dirgo	51.9	48.9	52.2
RMSE	Shepherd & Lapple	17.9	11.1	38.6
	Coker	35.1	47.4	85.8
	Dirgo	55.2	58.2	81.9

Table (6) displaied the correlation between the **Shepherd & Lapple** model and experimental results under the best validation cone height of 50 cm as aforementioned at different dipleg lengths. The **Shepherd & Lapple** model was more validation to experimental data at dipleg lengths of 40, 25 and 55 cm, respectively, due to the high value of (r) and lowest value of (MRD, %), (RSEP, %) and (RMSE) respectively. In other word, the **Shepherd & Lapple** model was the best predicted model of ΔP especially under cone height of 50 cm and dipleg length of 40 cm.

Table (6): Correlation between the Shepherd & Lapple model and experimental results under different dipleg lengths at cone height 50 cm.

Validation parameters	Dipleg length, cm		
	25	40	55
R	0.98284	0.98870	0.97879
MRD, %	8.8	8.4	12.4
RSEP, %	8.8	8.0	11.1
RMSE	10.6	9.7	12.7

As observed from Table (5) the **Dirgo** model was less value of (r) and highest value of (MRD, %), (RSEP, %) and (RMSE), but Figures (5, 6 and 7) display that, the vortex finder length effect on ΔP in **Dirgo** model, where ΔP was increased with increase vortex finder length. Thus to determine the best correlation of **Dirgo** model under the vortex finder length the statistics values were focused in Table (7).

Table (7): Correlation between the predicted pressure drop of Dirgo model and experimental results under different vortex finder lengths.

Validation parameters	Vortex finder length, cm				
	0	**10**	**20**	**30**	**40**
r	-	0.00085	0.00094	0.00094	0.00090
MRD, %	100.0	20.8	17.9	25.2	31.2
RSEP, %	100.0	34.3	23.2	24.6	29.2
RMSE	128.9	43.8	30.2	31.5	38.1

Table (7) illustrated that, The **Dirgo** model was more validation to experimental data at vortex finder lengths of 20, 30 and 10 cm, respectively, due to it has the high value of (r) and lowest value of (MRD, %), (RSEP, %) and (RMSE), respectively. While the vortex finder 40 and zero cm were lowest validation to **Dirgo** model.

CONCLUSIONS

- The obtained results inducted that, the experimental pressure drop increased with increase inlet air velocity and cone height.
- The maximum ΔP were 161.3, 181.7 and 250.8 Pa recorded at inlet air velocity of 20 m/s, cone heights of 30, 50 and 70 cm under vortex finder lengths of 40, 40 and 0 cm and dipleg lengths of 55, 25 and 25 cm, respectively. Meanwhile, the minimum ΔP were 60.2, 63,6 and 80.6 Pa recorded at inlet air velocity of 14 m/s, cone heights of 30, 50 and 70 cm under vortex finder lengths of 10, 30 and 40 cm and dipleg lengths of 25, 55 and 55 cm, respectively.
- The observed results showed that, the effect of both vortex finder length and dipleg length on ΔP was tiny effect and neglected.
- The **Barth** and **Casal & Martinez-Benet** models were given an extreme result comparing with measured pressure drop.
- The best model to predict the pressure drop was **Shepherd & Lapple**, **Coker** and **Dirgo**, respectively. The **Shepherd & Lapple** model has

the highest value of (r) 0.86260 and lowest value of MRD, RSEP % and RMSE which are 15.4, 19.6 and 25.4, respectively.

- **Shepherd & Lapple** model was more validation comparing with other models. In the same time, the model was more validation with cone heights of 50, 30 and 70 cm, respectively. Meanwhile, the predicted model **Coker** was more validation with cone heights of 30, 50 and 70 cm, respectively.
- **Dirgo** model was more validation to experimental data at vortex finder length of 20 cm then 30 and 10 cm, respectively.

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الملخص العربى

تأثير العوامل التصميمية والتشغيلية على فرق الضغط المقاس والمتنبأ به داخل السيكلون

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يعتبر السيكلون من أهم أجهزة تنقية الهواء وفصل المواد الصلبة من تيار الهواء وأكثرها شيوعًا في العديد من الصناعات وعمليات ما بعد الحصاد. ويمتاز ببساطة التصنيع والتركيب وإنخفاض تكاليف الصيانة ويمكن تصنيعه من خامات بسيطة، ولا توجد به أجزاء متحركة، كما ان له القدرة على العمل في ظروف تشغيل صعبة مثل ارتفاع الضغط. وعلى الرغم من بساطة تركيبه، إلا أن التنبؤ بفرق الضغط داخل السيكلون يكون معقد للغاية نظراً لوجود العديد من العوامل التصميمية والتشغيلية المؤثرة على عملية التدفق وبالتالى فرق الضغط داخل السيكلون. ولا تزال هناك العديد من الدراسات التجريبية والنظرية حول السيكلون والتي تهدف إلى فهم وتوقع فرق الضغط (ΔP) فى السيكلون. وقد تم قياس ΔP بين مدخل ومخرج الهواء فى السيكلون بواسطة مانوميتر مائى فرقى تم تركيبه مائلاً بزاوية ١٠° على الأفقى وذلك لزيادة دقة القياس وهذ المانوميتر تم تصنيعه من أنبوب سيليكون قطره الداخلى والخارجى ٦,٥ و ٩,٥ مم على التوالى. وتمت دراسة بعض العوامل التشغيلية والتصميمية مثل سرعة دخول الهواء (١٤، ١٦، ١٨ و٢٠ م/ث)، أرتفاع الجزء المخروطى (٣٠، ٥٠ و ٧٠ سم)، طول الوصلة التليسكوبية لخروج الهواء (٠، ١٠، ٢٠، ٣٠ و ٤٠ سم) وطول فتحة خروج المواد المجمعة (٢٥، ٤٠ و ٥٥ سم). لتقييم فرق ضغط التشغيل (ΔP) فى الوحدة التجريبية. كما تم استخدام بعض النماذج الرياضية للتنبؤ ΔP وبعض المقاييس الإحصائية للمقارنة والتحقق مع النتائج المقاسة.

وقد توصلت الدراسة إلى النتائج التالية: -

- فرق الضغط المقاس يزداد مع زيادة سرعة دخول الهواء وارتفاع المخروط.
- أقصى قيمة لفرق الضغط (ΔP) كانت ١٦١,٣، ١٨١,٧ و ٢٥٠,٨ باسكال تم تسجيلها عند سرعة دخول الهواء ٢٠ م/ث، وأرتفاع المخروط ٣٠، ٥٠ و ٧٠ سم عند طول الوصلة التليسكوبية لخروج الهواء ٤٠، ٤٠ و صفر سم وطول فتحة خروج المواد المجمعة ٥٥، ٢٥ و ٢٥ سم، على التوالى. بينما، أقل قيمة لـ (ΔP) كانت ٦٠,٢ ، ٦٣,٦ و ٨٠,٦ باسكال تم تسجيلها عند سرعة دخول الهواء ١٤ م/ث، وأرتفاع المخروط ٣٠، ٥٠ و ٧٠ سم عند طول الوصلة التليسكوبية لخروج الهواء ١٠، ٣٠ و ٤٠ سم وطول فتحة خروج المواد المجمعة ٢٥، ٥٥ و ٥٥ سم، على التوالى.

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- كان تأثير كلاً من طول الوصلة التليسكوبية لخروج الهواء وطول فتحة خروج المواد المجمعة ضئيل ومهمل.
- أعطت نماذج **Barth** و **Casal & Martinez-Benet** نتائج متطرفة مقارنة بفرق الضغط المقاس.
- أفضل نموذج للتنبؤ بفرق الضغط داخل السيكلون هو نموذج **Shepherd & Lapple** و **Dirgo**، و **Coker** على التوالى. حيث أعطى نموذج **Shepherd & Lapple** أعلى قيمة للمقياس الإحصائى لمعامل الإرتباط (r) وهو ٠.٨٦٢٦٠ وأقل قيمة للمقايس الإحصائية الاخرى (MRD, %) ، (RSEP, %) و (RMSE) والتى كانت 15.4 ، 19.6 و 25.4 على التوالى.
- نموذج **Shepherd & Lapple** هو أكثر النماذج تحقيقاً للتنبؤ بفرق الضغط داخل السيكلون مقارنة بالنماذج الأخرى. وفى نفس الوقت كان هذا النموذج أكثر تحقيقاً للتنبؤ بفرق الضغطمع أرتفاع المخروط ٥٠ و ٣٠ و ٧٠ سم، على التوالى. بينما، نموذج **Coker** كان أكثر تحقيقاً للتنبؤ بفرق الضغط مع أرتفاع المخروط ٣٠ و ٥٠ و ٧٠ سم، على التوالى.
- نموذج **Dirgo** كان أكثر تحقيقاً للتنبؤ بالنتائج المقاسة عند طول الوصلة التليسكوبية لخروج الهواء ٢٠ ثم ٣٠ و ١٠ سم، على التوالى.