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Cyclone Collection Efficiency Optimization by improving Dimensions, Inlet and Vortex Finder Design: An Application on TCD Texas Cyclone 1D3D Design

Amar Missoum[1]

[1] **Shenyang Aerospace University, 08 Daoyi Road, Shenbei, Shenyang, China**

Email amar@samtechuas.com URL www.en.sau.edu.cn

ABSTRACT

Cyclones have often been regarded as low-efficiency collectors. However, efficiency varies greatly with many variables such as particle size, density, cyclone design, velocity…etc. Advanced design work can greatly improve cyclone performance. This paper has discussed the design parameters required to construct a high performing cyclone through the application of Texas cyclone design, since it is widely approved as a high efficiency device. The approach is to remodel the cyclone by optimizing the inlet design, the vortex finder and the overall sizing.

The software's CATIA V5 (CAD) and ANSYS Fluent 14 were used to simulate the field flow, and the Reynolds Stress model was chosen for its major suitability in simulating cyclonic effects

The results are highly promising where the efficiency of the new design cyclone (named AMSIE cyclone for the sake of ease the reading of this paper) where the collection efficiency increased dramatically, reaching 100% collection efficiency for particles >2.5 microns from Fluent simulation, and these results were confirmed from practical tests.

1. INTRODUCTION

Cyclone separators are in most cases used as precleaners to separate particulate matter from polluting the atmosphere. The world has come to value clean air in this present day like never before. One of the measures put in place is pollution control. This particular effort employs mechanical means to engineer the control of pollution (i.e. treatment of fumes as they are formed). Cyclones have been one of the mechanical means owing to the fact that they have no moving part, suitable for high temperature working conditions and require little or no maintenance at all.

Cyclone is a gas cleaning device that utilizes the centrifugal force created by spinning gas stream to separate particles from a gas. The inlet gas is brought tangentially into a cylindrical body, a strong vortex is created inside and the middle of the cyclone and any particles denser than the carrier gas are subjected to centrifugal forces. The centrifugal force moves particle radially outwards towards the inside cyclone surface onto which the solids deposit and eventually will be collected at the bottom.

So as an effort to improve the collection efficiency of a cyclone separator, this research took the opportunity of the available rig (Coal fire boiler rig) which will produce a measurable amount of flue gas and lab measuring instruments and condition, to design a new pollution control system for the outlet flue gas in order to remove even further the ash and other VOC compound.

Advantages of cyclones:

- ✓ Low capital cost (few parts, easy to assemble)
- ✓ Ability to operate at high temperatures (all metal parts)
- ✓ Low maintenance requirements (no moving parts).

Disadvantages of cyclones:

- ✓ Low collection efficiencies (especially for very small particles)
- ✓ Cyclones are used almost exclusively for particles > 5 μm.

- ✓ High operating costs (power required to overcome large pressure drop).

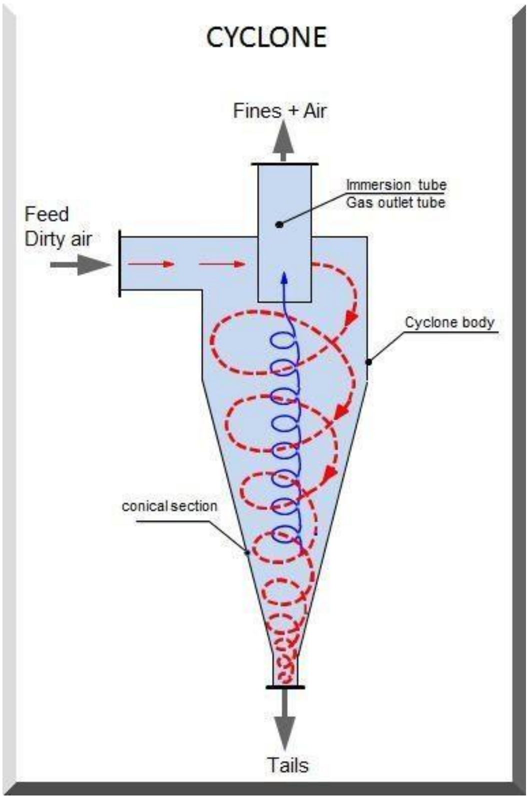


Figure 1: Diagram of a Cyclone

Previous researches (Nazaroff et al 1999) summarized the pros and cons of cyclone separator as fellow However, these disadvantages are not exclusive since much research was done in this field and the performance of cyclone separators are improving year by year (and this will be shown through this paper)

The cyclone design procedure outlined in Cooper and Alley (2002), hereafter referred to as the classical cyclone design (CCD) process, was developed by Lapple in the early 1950s. The CCD process (the Lapple model) is perceived as a standard method and has been considered by some engineers to be acceptable. However, there are several problems associated with this design procedure. First of all. The CCD process does not consider the cyclone inlet velocity in developing cyclone dimensions. It was reported (Parnell, 1996) that there is an "ideal" inlet velocity for the different cyclone designs for optimum cyclone performance. Secondly, the CCD does not predict the correct number of turns for different types of cyclones. The overall efficiency predicted by the CCD process is incorrect because of the inaccurate fractional efficiency curve generated by the CCD process (Kasper et al. 1993).

In the same topic Seyed et al, 2016 summarized different cyclone design models and efficiency where:

- Pant and Barth model under-predict the collection efficiency when the cyclone diameter is less than 15 cm.
- Energy dissipation model does not account for the change in collection efficiency with the change in cyclone diameter
- Lapple model follows empirical results but over-predicts the collection efficiency

WANG et al (2002) states that the Taxas University TCD approach to design cyclones was to initially determine optimum inlet velocities (design velocities) for different cyclone designs (1D3D,1D2D,2D2D). This design process allows an engineer to design the cyclone using a cyclone inlet velocity specific to the type of cyclone desired. Knowing the design inlet velocities, this model gives near reality performance and high collection efficiency. The TCD model will be chosen in this research as a base design; also knowing from this previous article that efficiency will increase with the increase of input velocity, in addition an Increase in the dust concentration thus the density will increase the efficiency.

2. THE CHOICE OF 1D3D CYCLONE

WANG et al (2002) reported that in the agricultural processing industry, 2D2D (Shepherd and Lapple, 1939) and 1D3D (Parnell and Davis, 1979) cyclone designs are the most commonly used as abatement devices for particulate matter control. The Ds in the 2D2D designations refer to the barrel diameter of the cyclone. The numbers preceding the Ds relate to the length of the barrel and cone sections, respectively. A 2D2D cyclone has barrel and cone lengths of two times the barrel diameter, whereas the 1D3D cyclones has a barrel length equal to the barrel diameter and a cone length of three times the barrel diameter of these two cyclone designs is shown in figure 2. Previous research (Wang, 2000) indicated that, compared to other cyclone designs, 1D3D and 2D2D are the most efficient cyclone collectors for fine dust (particle diameters less than 100 µm).

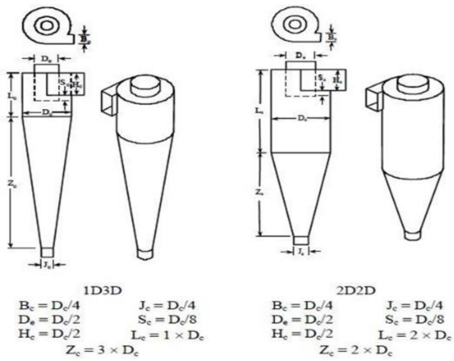


Figure 2. 1D3D and 2D2D cyclone configurations.

Mihalski et al (1993) reported "cycling lint" near the trash exit for the 1D3D and 2D2D cyclone designs when the PM in the inlet air stream contained lint fiber. a significant increase in the exit PM concentration for these high efficiency cyclone designs and attributed this to small balls of lint fiber "cycling" near the trash exit causing the fine PM that would normally be collected to be diverted to the clean air exit stream. Simpson and Parnell (1995) introduced a new low-pressure cyclone, called the 1D2D cyclones, for the cotton ginning industry to solve the cycling-lint problem. The 1D2D cyclones is a better design for high-lint content trash compared with 1D3D.

Since the AMSIE cyclone is going to be used for ash separation and eventually aerosols then it is obvious that we are left with two choices either 1D3D or 2D2D.

Wang et al 2002 summarized the performance of 1D3D and 2D2D cyclones and found that is highly dependent on the inlet air velocity and air density. Proposed cyclone design inlet velocities are:

- 16 m/s ± 2 m/s (3200 ft/min ± 400 ft/min) with air density at standard condition for 1D3D cyclones.
- 15 m/s ± 2 m/s (3000 ft/min ± 400 ft/min) with air density at standard condition for 2D2D cyclones.
- 12 m/s ± 2 m/s (2400 ft/min ± 400 ft/min) with air density at standard condition for 1D2D cyclones.

However, Faulkner and Shaw (2006) tested the TCD 1D3D at a different range of inlet velocities and demonstrated that when separating large aerosols from process air streams, cyclones may be operated at inlet velocities well below the TCD design specifications. The results of the research show that we can operate cyclones at lower inlet velocities and easily obtain collection efficiencies equal to those predicted by the TCD method.

These findings make it much less critical for these industries to maintain the narrow window of flow rates specified by the TCD method in order to be in regulatory compliance with federal and state permit guidelines. All treatments demonstrated collection efficiencies above 99% for the tested aerosols, regardless of the inlet velocity or cyclone.

Table 3. Potential energy savings.

Cyclone	Inlet Velocity (m/s)	Flow Rate (m^3/s)	Pressure Drop (kPa)	Energy (kW)	% Energy Use v. TCD[a] (%)
1D3D	16.26	0.0425	1.03	0.44	100
	13.21	0.0345	0.62	0.22	49
	10.16	0.0265	0.32	0.09	20
2D2D	15.24	0.0398	1.18	0.47	100
	12.70	0.0332	0.73	0.24	52
	10.16	0.0265	0.41	0.10	23

[a] TCD = Texas A&M Cyclone Design.

Figure -3: Various inlet velocities applied on TCD 1D3D and 2D2D

In addition, the overall collection efficiencies between 1D3D and 2D2D cyclones at a velocity of 16 m/s shown in the table below.

Table 2. Overall efficiency

Cyclone	Lapple Model	Measured (Wang et. al, 2000)
1D2D	78.9 %	95 %
2D2D	86.6 %	96 %
1D3D	85.2 %	97 %

Figure-4: overall efficiency of 1D3D and 2D2D

As we can see that the 1D3D has a higher collection efficiency, thus in this research 1D3D is going to be chosen as base dimension for AMSIE cyclone. Now before we move to the inlet design, AMSIE cyclone is going to be based on TCD model and 1D3D design, we need to know at what particle size and density the cyclone is tested and/or simulated.

Particle size and density

Comparing densities, MMD (Mass Median Diameter (in m)) and the collection efficiency between Faulkner and Shaw (2006) and Wang et al (2000). And in the table below there is very useful data as a base measurement for AMSIE cyclone.

The common aerosol used by the two papers is Cornstarch, and from the table below (Faulkner and Shaw (2006) we can see the density of 1.5 g/cm3 and an MMD of 17.95m. For Wang et al (2000) experiments use cornstarch density 1.52 g/cm3 and an MMD of 19 µm So, for this paper we are going to use an MMD of 17 µm and a density of 1.5 g/cm3, however the simulation tests will be carried out on much less particle's diameter ranging from 1 m to 20 m, 1.5 gram/cubic centimeter = 1 500 kilogram/cubic meter

Table 1. Properties of experimental aerosols.

Aerosol	Particle Density (g/cm^3)	Shape Factor	MMD (AED[a]) (µm)	GSD
Cornstarch	1.5	1.00	17.95	1.41
Alumina	3.9	1.44[b]	9.96	1.42

[a] Aerodynamic equivalent diameter.
[b] Source: (Mark et al., 1985).

Figure-5: Faulkner and Shaw (2006) experimental aerosols.

Table 15. Traced cut-points (d_{50}) from measured efficiency and PSD for 1D3D and 2D2D cyclones

Dust	ρ_p	PSD MMD/GSD	1D3D measured η_{total}	1D3D Traced d_{50}	2D2D measured η_{total}	2D2D Traced d_{50}
A	1.77	20 / 2.0	99.7 %	3.00	99.6 %	3.20
B	1.82	21 / 1.9	99.3 %	4.30	98.9%	4.82
C	1.87	23 / 1.8	99.7 %	4.50	99.6 %	4.80
Cornstarch	1.52	19 / 1.4	99.3 %	8.25	99.2 %	8.50
Flyash	2.73	13 / 1.7	96.8%	4.85	95.5 %	5.25

- PSD: particle size distribution
- Dusts A, B, and C are fine cotton gin dusts from different ginning processing streams. The dusts had been passed through a screen with 100 µm openings.
- MMD: mass median diameter (µm) of PSD
- GSD: geometric standard deviation
- ρ_p: particle density (g/cm^3)
- Measured η_{total}: measured overall cyclone efficiency from previous research (Wang, 200).
- Traced d_{50}: d_{50} (µm) obtained from equation 67 by setting P (d) equal to the overall efficiency.

Figure-6: Wang et al (2000) experimental aerosols

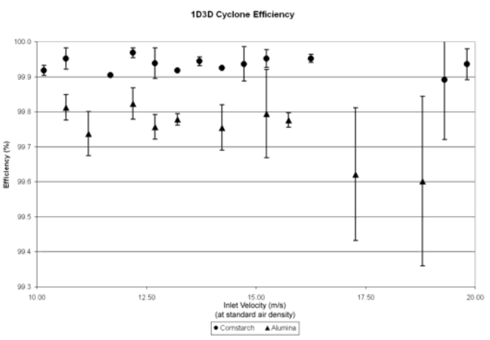


Figure-7: Collection efficiencies with 95% confidence intervals of the 1D3D cyclone for all replications at each inlet velocity and inlet loading rate combination. (Wang, 2000)

From the figure-7 above we can see the efficiency is higher for alumina and cornstarch aerosols for 1D3D cyclone at an inlet velocity of 15 to 16 m/s Thus, in this research we are going to test the cyclone at the optimal velocity of 15 m/s

Conclusion 2: in this research we are going to use a density of 1.5 g/cm3, with particles diameter ranging from 1 µm to 20 µm, and an inlet velocity of 15m/s.

3. INLET DESIGN

L. Svarovsky, (1983) and many other researchers and cyclone manufacturers agree on the fact that rectangular shape inlet yields a higher collection than the circular one, narrated by G. E. Kouba, (1996) as that the advantage of the rectangular jet over the circular jet is that the angular momentum generated by the incoming fluid is concentrated closer to the wall which should aid separation. As the result of this research, it will be focused on the rectangular inlet and the one question that needs to be solved is the dimensional ratio between the inlet height and the inlet width. Chia-Wei Hsu, et al (2014) conducted research on the effects of the inlet area and inlet aspect ratio on the cyclone performance and he concluded the following (see figure below)

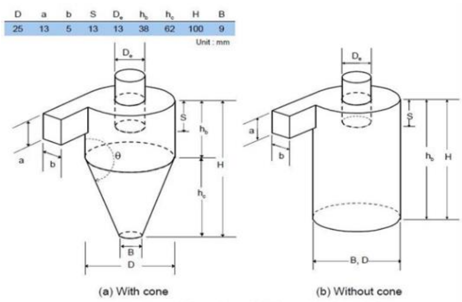


Figure-8 . Geometry and dimensions of Stairmand cyclone design.

Inlet Area (a × b) smaller inlet will lead to higher air flow resistance since the flow velocity rises as the inlet size decreases. Fig. 9(b) shows the penetration curves, and Fig. 9(c) records the 50% cut-off size and cyclone quality factor. 50% Cut point diameter (Cpd): The cut point diameter of a cyclone is the aerodynamic equivalent diameter (AED) of the particle collected with 50% efficiency. It influences the collection efficiency (Ce). Increase in Cpd will lead to decrease in Ce.

$$d = \left[\frac{9\mu}{2N - (\qquad)}\right]^{\frac{1}{2}}$$

Cpd = diameter of the smallest that will be collected by the cyclone

μ = gas viscosity (Kg/ms)

W = width of inlet duct (m)

N = Number of turns

V_i = inlet gas velocity (m/s)

Pp = Particle density (Kg/m^3)

Pg = gas(air) density (Kg/m^3)

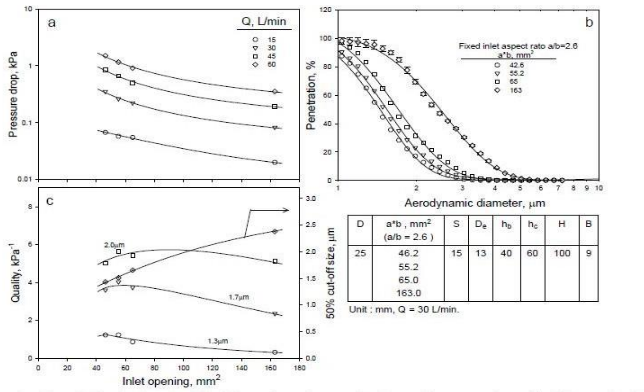


Fig. 9. The effect of inlet length and width (a:b) on the cyclone quality factor. (a) Pressure drop with different a:b. (b) Aerosol penetration as a function of particle size. (c) Quality and 50% cutoff size as a function of a:b.

The figures suggest that smaller inlets results in a smaller 50% cut-off size. Because the higher velocity caused by the smaller inlet will raise the inertial force of the particles, the particles will collide with the inner wall more often and hence be collected. This result agrees with many other studies (Dirgo and Leith, 1985; Iozia and Leith, 1990; Kim and Lee, 1990).

Inlet Aspect Ratio (a:b) Different inlet area will influence the inlet velocity as well as the tangential velocity.

Fig. 10(a) shows that as the aspect ratio of a/b grows, the airflow resistance increases. Larger inlet height (a) indicates that the airflow will have more friction with the inner wall, thus raising the airflow resistance. Fig. 10(b) shows the penetration curves, and Fig. 10(c) displays their 50% cut-off sizes.

They suggest that, under the same inlet area, larger inlet height leads to smaller 50% cut-off size since the airflow tends to have higher chance colliding with the inner wall through a narrower inlet, and hence be more efficiently collected. This result is supported by Lim et al. (2003) who verify that the proximity of the airflow to the wall has significant impact on the collection efficiency.

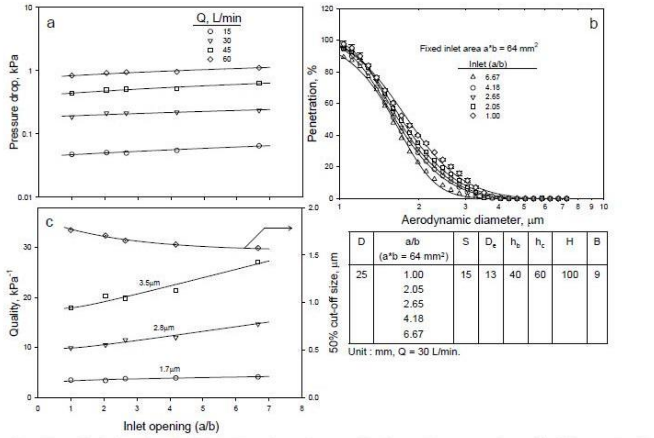


Fig. 10. The effect of inlet length and width (a:b) on the cyclone quality factor. (a) Pressure drop with different a:b. (b) Aerosol penetration as a function of particle size. (c) Quality and 50% cutoff size as a function of a:b

From Fig. 10(c), we may also conclude that higher aspect ratio of a to b results in higher cyclone performance. The optimal inlet aspect ratio might be correlated to other sizes of the cyclone, such as hb and/or S. Searching for the ultimate optimal inlet aspect ratio can be complex and will take more experiments to clarify.

An-Ni Huang et al (2017) states that the relationship between the pressure drops across the cyclone and the inlet gas velocity for the conventional cyclone and cyclone with the laminarizer are shown in Fig. 3 together with empirical correlations developed for conventional cyclones (J. Casal et al, 1983 & Lapple, 1939). The pressure drops across the cyclone increased with the inlet gas velocity in the range studied. When the inlet gas velocity increased, so did the turbulent swirling flow. The energy dissipation by the turbulent swirling flow caused greater pressure to drop across the cyclone (J. Gimbun et al, 2005). The Coker's correlation of the pressure drops across the cyclone (A.K. Coker, 1993) was closest results

Khairy Elsayed (2011) conducted research on five different inlet width and height which have been simulated, using the Reynolds stress model (RSM), to study the effect of cyclone inlet dimensions on the cyclone separator performance and flow pattern.

The following conclusions have been obtained.

- The maximum tangential velocity in the cyclone decreases with increasing both the cyclone inlet width and height.

- No acceleration occurs in the cyclone space (the maximum tangential velocity is nearly constant throughout the cyclone). The axial variation of both the static pressure and axial velocity is very limited.
- Increasing the cyclone inlet width or height decreases the pressure drop at the cost of increasing the cut-off diameter. So, an optimization procedure is needed to estimate the optimum value of inlet dimensions.
- Wider inlet cyclones (b/D) gap between the cyclone barrel and the vortex finder are not preferred.
- The effect of changing the inlet width on the cut-off diameter is more significant in comparison with that of the inlet height.
- The optimum ratio of the inlet width to the inlet height b/a is from 0.5 to 0.7.

Conclusions from this analysis

From above literature review we can conclude that the higher the inlet the better efficiency and if we combine that with the optimum ratio of the inlet width to the inlet height b/a that should from 0.5 to 0.7, we can easily deduce that the suitable inlet ratio is 0.7, and this is going to be chosen to calculate the dimensions of the inlet in this paper.

Our laboratory coal boiler rig (as you can see from the pictures bellow) has already a small cyclone separator at the outlet of the furnace and the intention of this research is to replace this later with the new AMSIE cyclone (Figure-11a), which will give us the opportunity to compare the performance of both, also the plan was to add another AMSIE cyclone to the outlet of the induced fan (Figure-11b).

Figure 11a: Picture of the induced fan, where the bigger AMSIE cyclone should be mounted at the 60 mm diameter outlet

Figure 11b: Picture of the small cyclone connected to the boiler outlet, which should be replaced by the AMSIE small cyclone for testing

Figure-11

Thus, there is a need to design two cyclones and adjust the inlet and the outlet to the piping connections which are already there. In this case we can see it as an advantage, the only issue is we have the new cyclone with a rectangular inlet and the original connections are circular, which means we just need to keep the same area so that the flow rate wouldn't be disturbed.

4. INLET DESIGN IMPROVEMENT

The manufacturer (heumannenviro.com) established the advantages of using an involute inlet which add to the performance and the collection efficiency of a cyclone separator.

An involute Inlet where the outside edge of the inlet duct is positioned outside of the cyclone radius and is tapered into the body over some rotation

Advantages:

- ✓ Useful for making compact high-capacity designs.
- ✓ Reduce erosion when there is high particulate loading
- ✓ Methods of providing increased collection efficiency when increasing inlet or outlet velocity are not desirable

Disadvantages:

- ✓ More expensive and difficult to fabricate
- ✓ Increase pressure drop
- ✓ Less robust design if nozzle loadings are significant
- ✓ Can increase cone erosion if the particulate is abrasive

Also, it was noticed during CFD simulation as well as practical experiments, that for a normal tangential inlet cyclone design (Classical); there is a formation of a lower velocity or turbulent zone created at the opposite side of the inlet just behind the vortex finder (as you can see from the figure 1 below in dark blue color), and when simulating using an involute inlet design the flow is more laminar and the turbulent zone is not there anymore, evidently this will contribute to the reduction of eddy's and lowers the turbulent viscosity which in turn contribute in reducing the pressure drop and increase the efficiency.

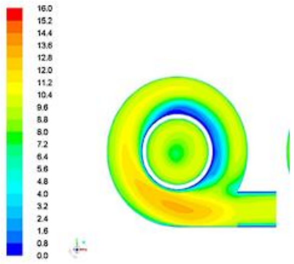


Figure 12a: top view- velocity profile of classical inlet design. Dark blue color zone represent very low velocity thus high turbulent zone (An-Ni Huang et al (2017))

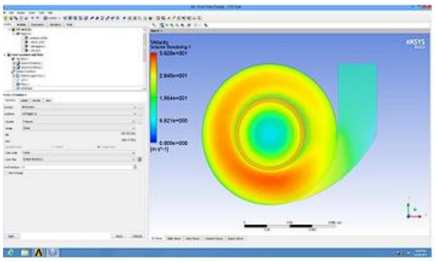


Figure 12b: top view of AMSIE cyclone, velocity profile of the Involute inlet design

The turbulent zone is dramatically reduced through this design as you can see the blue zone is practically inexistent.

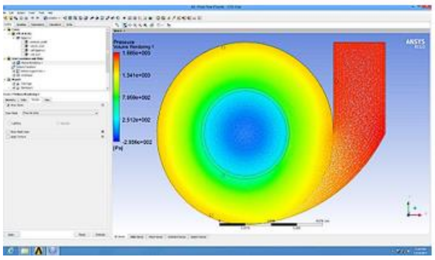


Figure 12c: top view of AMSIE cyclone, Pressure profile of the Involute inlet design.

Nice and smooth pressure distribution along the diameter of the cyclone

In contrary of the Heumann Environmental manufacturer who claim that the involute inlet will increase the pressure drop, from the above we proved the opposite, and this even supported by the pressure drop computation results, for example, the predicted TCD pressure drop (Wang et al, 2002) was 939 Pa, and the AMSIE cyclone pressure drop is 746 Pa, which is 193 Pa reduction.

Conclusion: use an involute inlet

Now we have another issue with the sink of the vortex finder or the length of exit pipe which sinks inside the cyclone, initially from TCD cyclone design the sink length is half of the cyclone diameter, however in this case the height of the inlet is higher than the sink length so, we will have the incoming aerosols escapes through easily, subsequently, as a solution we increased the length of the vortex finder to have the same as the inlet height.

5. CFD SIMULATION RESULTS AND DISCUSSION

5.1 The Choice of RSM as CFD simulation model

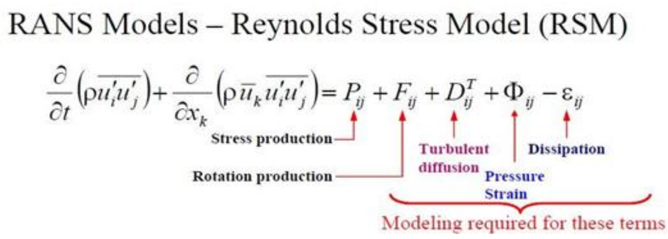
Gorton-Hüelgerth (1999) performed 3- dimensional calculations for a series of standard cyclones using the commercial computer package FLUENT (1997) with a built-in Reynolds stress turbulence model (RSM). Several different cyclone geometries (e.g. variation of the hopper entrance geometry) have been investigated. Numerical results for the gas velocity field showed very good agreement with their Laser Doppler Anemometer (LDA) measurements meaning simulating with RSM model the results correlate with the experiment results.

Shalaby et al. (2005) carried out numerical calculations at the apex cone and at various axial positions of a gas cyclone separator for industrial applications. Their work was based on the comparison between three turbulence models, RSM (Reynolds Stress Models) and LES.

The authors found that the application of LES reveals better qualitative agreement with the experimental data, but requires higher computer capacity and longer running times when compared to RSM calculations. (jullio.pe.kr/fluent6.1) reported that Reynolds stress model (RSM) embeds 07 equation and is the one most elaborate turbulence model that FLUENT provides. Abandoning the isotropic eddy-viscosity hypothesis, the RSM closes the Reynolds-averaged Navier-Stokes equations by solving transport equations for the Reynolds stresses, together with an equation for the dissipation rate. This means that five additional transport equations are required in 2D flows and seven additional transport equations must be solved in 3D.

Consequently, for this research RSM model will be chosen for the ANSYS_FLUENT simulation, Since the RSM accounts for the effects of streamline curvature, swirl, rotation, and rapid changes in strain rate in a more rigorous manner than one-equation and two-equation models, it has greater potential to give accurate predictions for complex flows.

However, the fidelity of RSM predictions is still limited by the closure assumptions employed to model various terms in the exact transport equations for the Reynolds stresses. This mean experiment needed to be carried out to validate the CFD results.



5.2 CATIA Design

The two AMSIE cyclones are designed using CATIA, and the actual sizes are used, both cyclones are very similar means the bigger cyclone is just a scale up of the small cyclone, as shown in the following pictures.

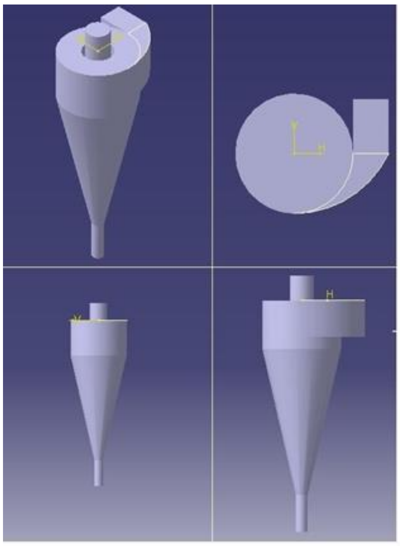


Figure-13: CAD CATIA design of the AMSIE small (inner) Cyclone, and bigger (Outer) cyclone. Just one picture is chosen because we won't notice the difference).

5.3 CFD simulation results and discussion

5.3.1 Fractional collection efficiency

The two models of AMSIE cyclones (Called big and small) CAD designs are imported to Ansys software with the actual real dimensions.

Meshing: Tetrahedral method used in meshing with very fine sizes, and the total cell was about 2 million for both models; in addition, the quality of mesh was relatively good according to the metrics spectrum with an Orthogonal Quality mesh 0.41. Simulation used RSM model with 300 iterations using first order upwind followed by 3000 iterations using second order upwind, the solution converged after about 5000 iterations. Using the discrete phase model for the injection of different diameter particles at the inlet combined with the specified gas flow density of 1500 kg/m3. The factional collection efficiency is calculated by using the following formula, for each participle diameter, and the results are summarized in the graph below.

$$\frac{N_r}{N_r - N_n}$$

Fractional collection efficiency of a particle:

N_r: Number of particles trapped

N_r: Number of particles tracked or injected

N_n: Number of incomplete particles

As we can see from the graph below Figure-14 the collection efficiency exceeds the ones obtained by Lapple, Barth, Dietz and Leith-Light for particles diameter between 0 and 8 m in addition, these results are higher than the ones reported for TCD cyclones at the minimum particle diameter of 10 m.

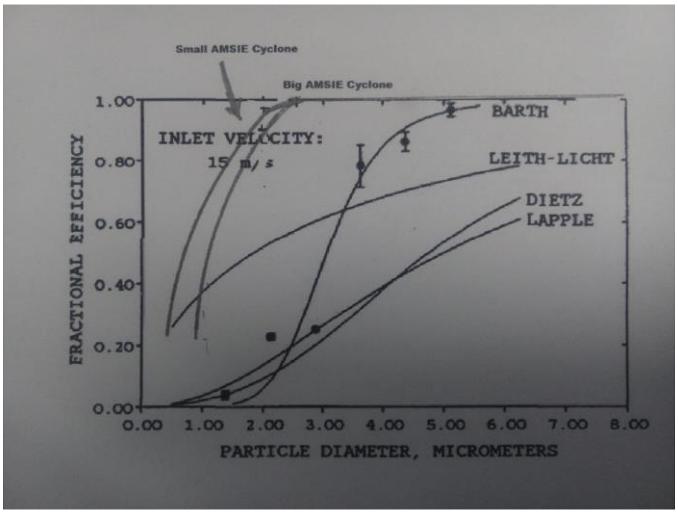


Figure-14: comparison of fractional efficiency of different Types of cyclones and AMSIE cyclones.

5.3.2 AMSIE cyclones Velocity profiles

The tangential velocity increases from the cyclone center toward the wall to a maximum value and then decreases to figure-15 a and b. The position corresponding to the maximum tangential velocity has been reported to be around 0.5–1.0 of the vortex finder radius away from the cyclone center. In the present simulation, the position corresponding to the maximum tangential velocity was around 0.6–1.0 for the big cyclone and 0.7-1.0 for the small cyclone of the vortex finder radius away from the cyclone center. The simulation results agreed well with previous reports.

In the big cyclone the maximum tangential velocity reaches 40 m/s which corresponds to 746 Pa in pressure drop, which means that the average tangential velocity is decreased comparatively to the conventional cyclones and in the small cyclone the velocity reaches about 60m/s and this is due to its small size figure-15b.

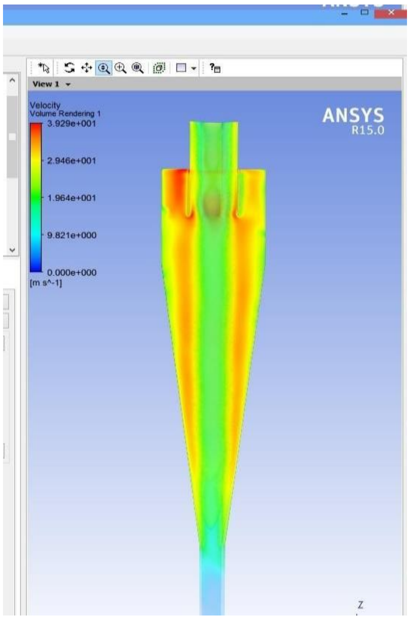


Figure-15a: AMSIE big Cyclone Velocity profile

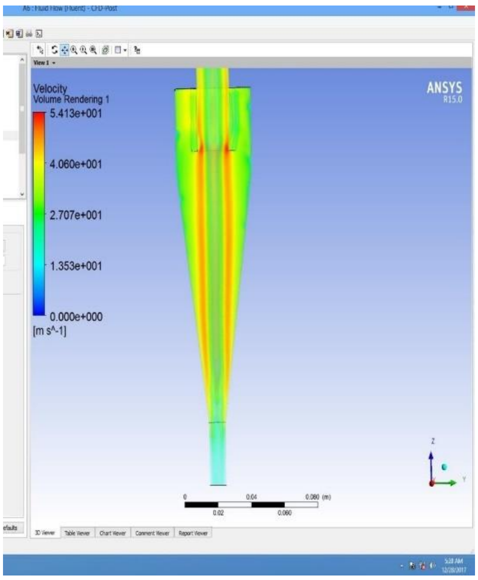
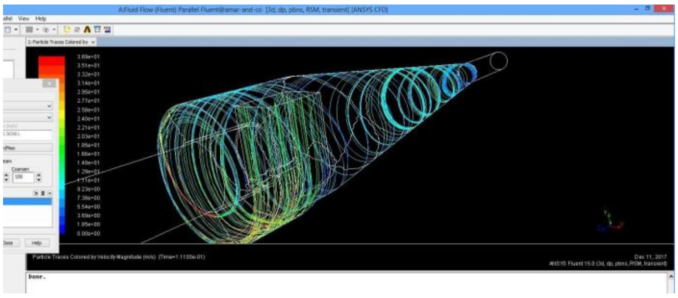


Figure-15b: AMSIE small Cyclone Velocity profile

From the Ansys_fluent simulation 885 particles were uniformly released at the inlet boundary of the entrance of AMSIE cyclones. The inlet boundary was one diameter size away from the cyclone center. The number of particles passing through each detection area was recorded until the total number of passing particles reached.

In the picture below we captured the 2.5 m particles diameter injection flow field in the big cyclone separator at 0.1 s of a time step.



6. CONCLUSIONS

The effect of the cyclone inlet dimensions on the performance and flow field pattern has been investigated computationally using the Reynolds stress turbulence model (RSM). The results show that the maximum tangential velocity in the cyclone decreases with increasing the cyclone inlet dimensions and the involute design decreases the pressure drop as well as the turbulence zone formed near the vortex finder.

Finally, and most importantly, there is a dramatic increase in the collection efficiency of the AMSIE cyclones. The effect of changing the inlet width and height especially had a great influence on the cyclone’s performance. where the collection efficiency increased dramatically, reaching 100% collection efficiency for particles >2.5 microns from Fluent simulation.

7. RECOMMENDATION FOR THE DESIGN

Practical tests needed to be carried out to validate the simulation results, so, the first step is to build two prototypes, one small cyclone need to be made from 3mm metal sheet to resist the high temperatures out of the boiler, and the second big cyclone can be made from plastic because it is going to be installed at the outlet of induced fan where the high temperature is not a big issue at this end.

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