Prasanna et al. 2017. *Int. J. Vehicle Structures & Systems*, 9(1), 36-40
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.9.1.08

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Comparative Analysis of Various CFBC Cyclone Separator REPDS Profiles

N. Prasanna[a,b], R. Shanmuga Prakash[c] and M. Vijayakumar[c,d]

[a]*Dept. of Mech. Engg., Kongu Engg. College, Perundurai, Erode, India*
[b]*Corresponding Author, Email:bemethermal@gmail.com*
[c]*Dept. of Mech. Engg., M. Kumarasamy College of Engg., Karur, India*
[d]*Email:vijithermal@gmail.com*

ABSTRACT:

In the last decade research on CFBC (Circulating Fluidized Bed Combustion Boiler) has been increased but research on cyclone separator has not been paid well attention. All the existing designs of cyclone separator were mainly concentrating on a single parameter that is collection efficiency. But this work mainly concentrates on other parameters like pressure drop and denudation rate. Previous works related to cyclone separator having REPDS (Reduced Pressure Drop Stick) suggest that 50% REPDS in the vortex finder gives the optimum results for all the existing cyclone models. Existing REPDS profile is only circular; we attempted to change the REPDS profile to polygon shapes like square, hexagonal. All the cyclone separators with different REPDS profile have been designed for flow rate of 500m3/hr with operating velocity of 15m/s. CFD (Computational Fluid Dynamics) analysis has been done with operating velocity ranging from 15m/s to 30m/s, using K-€ turbulence model. The results obtained in CFD analysis reveal that there is no much variation in pressure drop, but there is a drastic change in the denudation rate while operating CFBC cyclone separator twice the designed velocity. Thus REPDS can be included in vortex finder of cyclone separator with any polygon profiles as mentioned above.

KEYWORDS:

CFBC; CFD; Cyclone separator; Denudation rate; Pressure drop; REPDS profile

CITATION:

N. Prasanna, R.S. Prakash and M. Vijayakumar. 2017. Comparative Analysis of Various CFBC Cyclone Separator REPDS Profiles, *Int. J. Vehicle Structures & Systems*, 9(1), 36-40. doi:10.4273/ijvss.9.1.08.

1. Introduction

In recent years, Circulating Fluidized Bed Combustion (CFBC) Boiler has revolutionized coal combustion predominantly in the field of power generation. Power generation industry prefers CFBC boilers because of reduced SOx and NOx emissions, high combustion efficiency, any type of solid fuel can be admitted for the combustion, which holds promise for low grade coals. CFBC boiler setup comprises of two segments namely, pre-combustion segment and post-combustion segment. Pre-combustion segment consists of furnace or fast fluidized bed, gas-solid separator (cyclone separator), solid recycle system (loop seal or L-valve), and external heat exchanger (optional). The furnace enclosure of a CFBC boiler is generally made of water tubes as in conventional boilers and the heat generated in furnace is absorbed by these heat transferring tubes. The post-combustion segment comprises of re-heater, super heater, economizer and air pre-heater surfaces which are used to recover the remaining heat of the flue gas from the furnace in order to increase the overall efficiency of CFBC Boiler.

Cyclone separator helps to separate the flue gas from coarse particles of limestone (sorbent) and partially burnt char with the help of centrifugal force and the influence of gravity. Then the collected solids are sent back to CFBC boiler bed (above the distributor plate). Usually upper half of cyclone separator is cylindrical in shape and the lower half is conical. Cyclone separator has tangential inlet at the cylindrical section which carries both solid and flue gas. Two vertical outlets, one at the conical section to expel solid particles and the other at the top of the cylindrical section for flue gas to vent out of cyclone separator. The second vertical outlet for flue gas at the cylindrical section is termed as vortex finder which helps to generate eddies inside the cyclone separator for effective gas solid separation. Solid particles sized less than 20 μm are not captured in cyclone separator, but they are collected either by bag house filter or electrostatic precipitator before entering into chimney. Collection efficiency depends on particle size, for particles less than 20 μm collection efficiency is less and vice-versa. Cyclone separator doesn't need any external source to separate solid and gas.

Wear occurs in the inner walls of cyclone separator due to the impact of solid particles separated from the inlet charge and due to the influence of gravity it slides down the wall and gets collected at the bottom. So wear rate is a crucial factor in deciding the life time of cyclone separator. Wear rate can be calculated in two different ways either as erosion rate or denudation rate. Erosion rate indicates the mass of the material removed from the surface of the cyclone separator (kg/year), whereas the denudation rate is the average rate of reduction in thickness of the cyclone separator (μm/year). Prabir Basu [1] dealt with six different types of cyclone separator for different purposes namely high through put, high efficiency and general purpose. The cyclone separators studied in this research work were designed based on his design procedure. Amol S. Kinkar et al [2] performed a CFD analysis of CFBC boiler accounting the parameters like velocity and vorticity, of the cyclone separator and compared the parameters with the data provided by the equipment supplier. He drew a conclusion that region opposite to the inlet of cyclone separator experiences a maximum wear due to rise in velocity at this region to a value more than 30m/s. This maximum wearing region is termed as target region.

Chuah et al [3] mathematically studied the cyclone separator pressure drop of Casal & Martinez, Coker, Dirgo and Shepherd & Lapple models at different temperatures and velocities, and compared his results with experimental data. He found that Coker model is best suitable for varying temperature and Shepherd & Lapple model is best suitable for all possible velocities to predict pressure drop in cyclone separator. Ramachandran et al [4] developed a new empirical model by varying cyclone diameter, height and flow rate to predict pressure drop without accounting the effect of charge loading and optimization curves have been plotted. A design procedure is developed with the aid of optimization curves which show designer can choose a feasible parameter to obtain an optimal cyclone separator. Wang et al [5] observed that reduction in pressure drop can be achieved by inserting stick into a cyclone separator. In this work stick is placed at four different locations and pressure drop about 20% is achieved without any change in collection efficiency. Maximum of 50% pressure drop can be achieved by compensating collection efficiency upto 5% with stick.

Ramachandran et al [6] modified the height of vortex finder in the six existing cyclone separators for four different proportions with reduction in height which is compensated by Reduced Pressure Drop Stick (REPDS). CFD analysis has been carried out and 50% REPDS height has been found as optimal design. Gimbun et al [7] predicted and evaluated the importance of temperature and inlet velocity on pressure drop of cyclones using CFD simulations. Results of the CFD analysis suggest that it is one of the best methods to predict the operating pressure drop of cyclone. Chen et al [8] constructed a cold model of scale 20:1 of 100MW CFBC boiler having an edge-sloped vortex finder and compared the experimental results with existing cyclone model. Inlet velocity of cyclone is having strong influence on pressure drop. Raoufi et al [9] studied the effect of vortex finder shape and diameter of cyclone separator using Reynolds Stress Transport Model (RSTM) and Discrete Random Walk (DRW) turbulence models. His analysis concluded that increasing the divergent angle of vortex finder, collection efficiency decreases and pressure drop increases.

2. Design modification

This work mainly concerns on increasing the lifetime by reducing denudation rate and decreasing the pressure drop of cyclone separator using various REPDS profile. 50% REPDS height provides optimum result [6], hence 50% REPDS height is used in this study. Fig. 1(a) shows the existing vortex finder shape, and the varied cross section of REPDS are in three different profiles like circular (Fig. 1(b)), square (Fig. 2(a)) and hexagonal (Fig. 2(b)) for six existing cyclone separator designs [1].

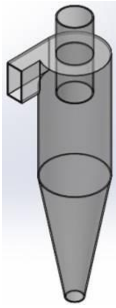


Fig. 1(a): Existing cyclone

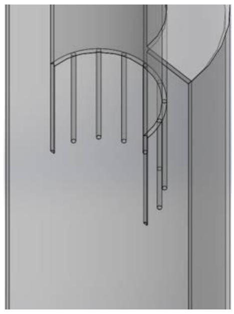


Fig. 1(b): Circular profile

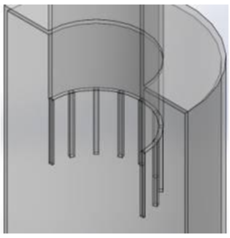


Fig. 2(a): Square profile

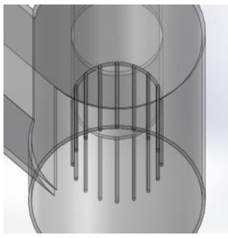


Fig. 2(b): Hexagonal profile

3. Software validation using Coker model

Six cyclone separators has been designed [1] for a flow rate of 500 m^3/hr. CFD analysis has been carried out using SOLIDWORKS 2014 flow simulation. Pressure drop of existing cyclone separator has been analyzed using CFD and compared with Coker model [3]. The following boundary conditions are used for analysis inlet flow rate 500m^3/hr and outlet pressure as environmental pressure. The equation goal has been setup for pressure drop contour as P2 – P1. Where P2 and P1 are the pressure at the outlet and inlet surface (mm of water column) respectively. An average value of pressure drop has been obtained by this equation goal. This pressure drop value has been compared with the values of Coker model predicted pressure drop. The comparison is shown in the following graph Fig. 3. There is a maximum deviation of 14% between CFD simulation results and Coker model results.

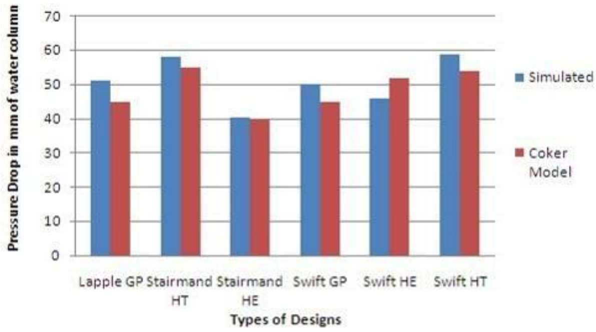


Fig. 3: Comparison between simulated and Coker models

4. Results and discussions

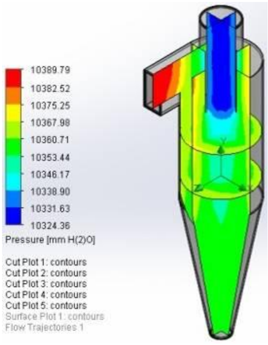
CFD analysis has been carried out for three REPDS profile in six designs of cyclone separator for various inlet velocities (15, 20, 25 and 30m/s) and results are compared. Two different analyses have been carried out, one is flow simulation and another is particle study. Flow simulation is used to predict the pressure drop. Particle study is done after flow simulation. Particles are injected at the inlet and analysis is made to compute denudation rate. Table 1 shows the parameters for flow analysis and Table 2 shows the parameters for particle study. The pressure contours of Lapple GP model has been shown in Figs. 4(a) to (d) for existing profile, circular REPDS, square REPDS, and hexagonal REPDS respectively.

Table 1: Parameters of flow simulation

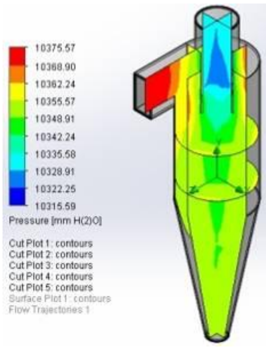
Initial Conditions	
Thermodynamic parameters	Static pressure: 10332.27 mm H(2)O Temperature: 20.05°C
Velocity parameters	Velocity vector Velocity in X direction: 0 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: 0 m/s
Turbulence parameters	Turbulence intensity and length: Intensity: 2.00% Length: 0.003 m
Material Settings	
Fluids	Air
Path	Gases pre-defined
Specific heat ratio (Cp/Cv):	1.399
Molecular mass:	0.0290 kg/mol
Boundary Conditions	
Inlet	
Type	Static pressure
Faces	Face<1>@LID4
Coordinate system	Face co-ordinate system
Reference axis	X
Thermodynamic parameters	Static pressure: 10370.16 mm H(2)O Temperature: 20.05°C
Turbulence parameters	Turbulence intensity and length: Intensity: 2.00% Length: 0.003 m
Boundary layer parameters	Boundary layer type: Turbulent
Outlet	
Type	Outlet volume flow
Faces	Face<2>@LID5
Coordinate system	Face co-ordinate system
Reference axis	X
Flow parameters	Flow vectors direction: Normal to face Volume flow rate: $0.1389 m^3/s$

Table 2: Parameters of particle study

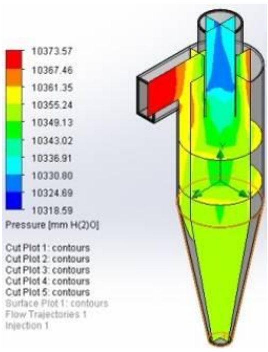
Erosion	Yes
Gravity	$X = 0 m/s^2$ $Y = -9.8 m/s^2$ $Z = 0 m/s^2$
Wall conditions	Ideal Reflection
Wall material density	$10000 kg/m^3$
Erosion co-efficient	$2x10^{-9}$
Function of particle diameter	1
Function of impact angle	1
Function of relative particle velocity	2.6
Number of particle injected	25
Particle diameter	20 micron
Particle nature	Gravel based soil
Mass feed Rate	1kg/s



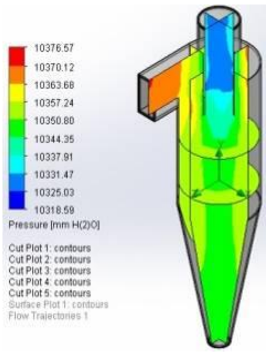
(a): Existing profile



(b): Circular profile



(c): Square profile



(d): Hexagonal profile

Fig. 4: Lapple GP models – Pressure contours

Three types of REPDS profiles attached to vortex finder of cyclone separator were studied. All the six kinds of cyclone separator were analyzed. The Coker model was used to find the pressure drop in each case. Simulation was done using solid works, and the comparison is made. Vortex finder attached with 50% REPDS is reducing the pressure drop and denudation rate drastically than the existing cyclone separator design because the intensity of eddies created inside the cyclone is reduced by REPDS. In cyclone separator the pressure energy available at the entry is converted into kinetic energy when the inlet feed is taking a tangential path. While the charges coming out of vortex finder this kinetic energy is not converted back to pressure energy in existing cyclone separator. This REPDS helps to reduce the conversion of pressure energy into kinetic energy so that outlet pressure energy is increased in turn the pressure drop is reduced. Since the kinetic energy is reduced the intensity of particle rubbing on the surface is also reduced so the denudation rate is less.

Flow simulation and particle analysis has been carried out for 3 REPDS profiles in six designs of cyclone separator. Figs. 5 to 13 show a comparison the pressure drop for three REPDS profile for various inlet velocities. There is only 2 to 3mm of water column pressure drop is observed from the above comparison charts. It portrays that REPDS profile doesn't play a major role in reducing the pressure drop. Figs. 11 to 14 show a comparison of the denudation rate for three REPDS profile for various inlet velocities. There is only significant change in denudation rate for 30m/s of velocity is observed. Cyclone Separator is designed to handle inlet flow rate of $500m^3/hr$, major variations are observed when cyclone separator is operated more than the designed flow rate.

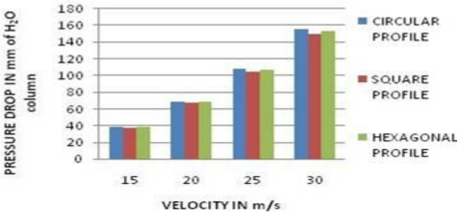


Fig. 5: Lapple GP pressure drop comparison

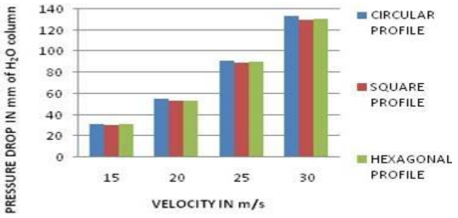


Fig. 6: Stairmand HE pressure drop comparison

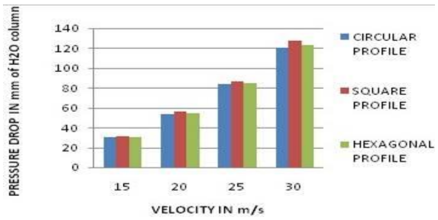


Fig. 7: Stairmand HT pressure drop comparison

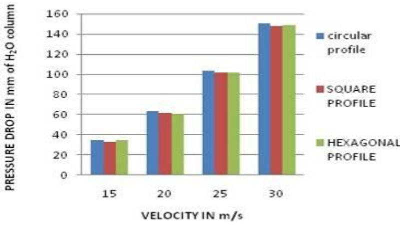


Fig. 8: Swift GP pressure drop comparison

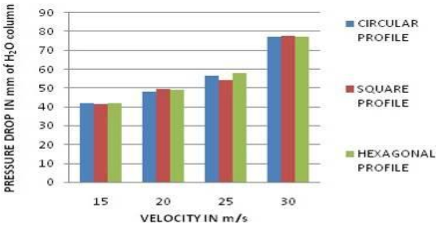


Fig. 9: Swift HE pressure drop comparison

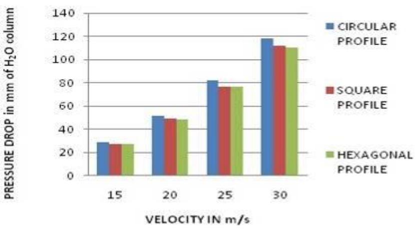


Fig. 10: Swift HT pressure drop comparison

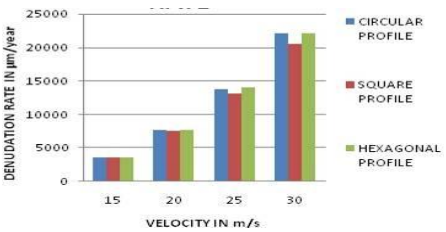


Fig. 11: Lapple GP denudation rate comparison

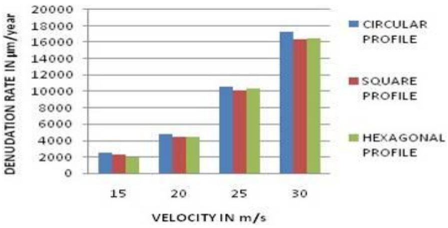


Fig. 12: Stairmand HE denudation rate comparison

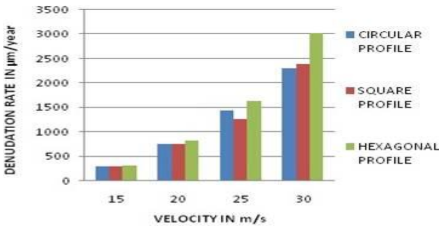


Fig. 13: Stairmand HT denudation rate comparison

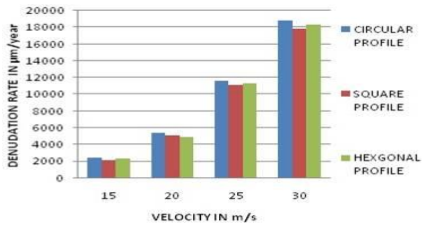


Fig. 14: Swift GP denudation rate comparison

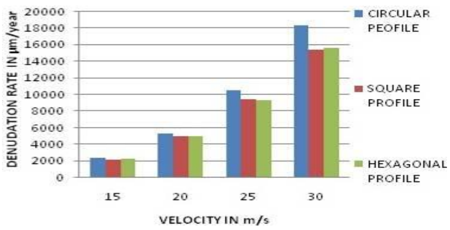


Fig. 15: Swift HE denudation rate comparison

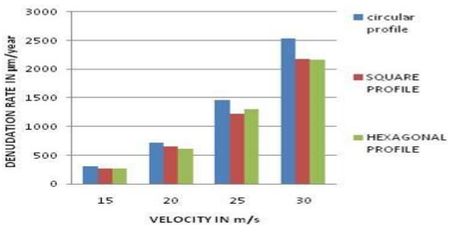


Fig. 16: Swift HT denudation rate comparison

5. Conclusion

Flow simulation and particle analysis has been carried out for three different REPDS profile in six designs of cyclone separator. It can be concluded indicate that REPDS is required to reduce the intensity of pressure drop and denudation rate. The REPDS profile should be of any polygon shape rather than circular.

REFERENCES:

[1] P. Basu. 2006. *Combustion and Gasification in Fluidized Bed*, CRC Press, 381-400. https://doi.org/10.1201/9781420005158.

[2] A.S. Kinkar, G.M. Dhote and R.R. Chokkar. 2015. CFD simulation on CFBC boiler, *Int. J. Sci. Technol. Res.*, 4(2), 34-39.

[3] J. Gimbun, T.G. Chuah, A. Fakhru and T.S.Y. Choong. 2005. The influence of temperature and inlet velocity on cyclone pressure drop : A CFD study, *Chem. Eng. Process*, 44, 7-12. https://doi.org/10.1016/j.cep.2004.03.005.

[4] G. Ramachandran, D. Leith, J. Dirgo and H. Feldman. 1991. Cyclone optimization based on new empirical model for pressure drop, *Aerosol Sci. Technol.*, 15, 135-148. https://doi.org/10.1080/02786829108959520.

[5] L. Wang and L. Ye. 2010. Reducing pressure drop in cyclones by a stick, *Aerosol Sci. Technol*., 31, 37-41.

[6] R. Ramachandran and P. Sivakumar. 2015. Design and development of cyclone separator interconnected CFBC, *J. Chem. Pharm. Sci*., 6, 207-211.

[7] T.G.C. Huah, J.O.G. Imbun, T.H.S.Y.C. Hoong and A.F.A.L.-R. Azi. 2003. Numerical prediction of cyclone pressure drop, *J. Chem. Eng. Environ.*, 2(2), 67-71.

[8] J. Chen, X. Lu, H. Liu and C. Yang. 2007. Effect of the bottom-contracted and edge-sloped vent-pipe on the cyclone separator performance, *Chem. Eng. J.*, 129, 85-90. https://doi.org/10.1016/j.cej.2006.11.005.

[9] A. Raoufi, M. Shams, M. Farzaneh, and R. Ebrahimi. 2008. Numerical simulation and optimization of fluid flow in cyclone vortex finder, *Chem. Eng. Process*, 47, 128-137. https://doi.org/10.1016/j.cep.2007.08.004.