Development of a Software for Design of Cyclone Separator: CySep

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ABSTRACT: Cyclone separator is a widely used industrial equipment for separation of solid and gas mixture. Process design of the cyclone affects the separation efficiency to greater extent. Design of cyclone based on Stairmand's cyclone is an iterative procedure. Software developed on user friendly platform can reduce human effort and increase efficiency. In current study, user friendly software 'CySep' is developed to calculate separation efficiency of cyclone separator. Moreover, results obtained from the 'CySep' is compared and found very accurate with already published literature.

1 INTRODUCTION

Cyclone separator is widely used as a gas-solid separator in process industries. Due to stringent environment regulations, it is now mandatory to separate dust particles from exhaust gases. It is also used in industries for the separation of catalyst particles laden with process gas. No moving parts and easy construction makes cyclone separator an economically viable option as a good gas-solid separator (Elsayed et. al. 2010, Funk et.al. 2014, Safikhani et. al. 2011). Cyclone separator separates gas-solid using centrifugal force. Gas-solid mixture enters into the cyclone tangentially, which creates swirling motion, due to which heavy solid particles are directed towards wall of the cyclone and moves downwards (Cortes et. al. 2007). As gas moves further downward more and more solid particles are separated. In cyclone separator, there are two vortices namely inner vortex and outer vortex. Gas-solid mixture, first directed in outer vortex and moves downwards after reaching to the bottom of cyclone gas take inner vortex path as it provides least resistance for gas and relatively pure gas is collected from the top of cyclone separator. Solid particles are collected from the bottom of the cyclone separator which provides least resistance path for solids.

Process design of cyclone separator is relatively easy, but iterative procedure of designing makes it quite cumbersome and less accurate. Design of cyclone is dependent on various factors like, particle size distribution of solids, desired efficiency, as well as pressure drop. Smaller size particles are difficult to separate compared to larger size particles and presence of smaller particles reduces efficiency of cyclone separator. It is recommended to use cyclone above particle size of more than 5 μm as efficiency is better with larger size particles (Elsayed et. al. 2010, Sinnot et. al. 2005). In order to achieve higher efficiency in less number of cyclones, one can not neglect pressure drop aspect. Actual pressure drop within the cyclone, must be less than or equal to maximum allowable pressure drop set by process constraints. By developing user friendly software, we can reduce human efforts and enhance accuracy. For this purpose, Java platform has been selected for programming language. Designer can use this software for designing and simulation. The design of software is based on Stairmand's standard cyclones. In present study, we have limited our focus to efficiency calculation.

2 METHODOLOGY

Designing and simulation is based on Stairmand's standard cyclone. Stairmand has developed effciciency curves for (i) High efficiency and (ii) High throughput cyclones. Design conditions for standards cyclones are tabulated in Table 1, while dimensions of standard cyclones in terms of diameter of cyclone (D_c) are tabulated in Table 2. Diameter for both standard cyclones (High efficiency and High throughput) is 203 mm. Actual design of cyclone is based on these standard cyclones. Scaling Factor (SF) determines deviation from standard cyclone. If SF is near to one, then design is near to standard design. Higher SF values indicate larger deviation from standard (Sinnot et. al. 2005).

In present study, we have taken different data points for efficiency curve manually from elsewhere (Sinnot et. al. 2005) and using Excel as a computation tool, curve fitting is done.

Table 1. Design conditions for Stairmand's standard High efficiency and High throughput cyclones (Sinnot et. al. 2005).

Sr. No.	Design conditions	High efficiency cyclone	High throughput cyclone
1	Test fluid	Air	Air
2	Density difference between gas and solids	2000 kg/m^3	2000 kg/m^3
3	Temperature	20 °C	20 °C
4	Pressure	1 atm	1 atm
5	Volumetric flowrate of gas	223 m^3/h	669 m^3/h
6	Viscosity of test fluid	0.018 mNs/m^2	0.018 mNs/m^2

Table 2. Dimensions of Standard Starimand's cyclones (Sinnot et. al. 2005).

Sr. No.	Dimension	High efficiency cyclone	High throughput cyclone
1	Inlet height	0.5 D_c	0.75 D_c
2	Inlet width	0.2 D_c	0.375 D_c
3	Vortex finder diameter	0.5 D_c	0.75 D_c
4	Total cyclone height	4 D_c	4 D_c
5	Cylinder height	1.5 D_c	1.5 D_c
6	Vortex finder length	0.5 D_c	0.875 D_c
7	Cone tip diameter	0.375 D_c	0.375 D_c

3 DEVELOPMENT OF SOFTWARE

Graphic User Interface (GUI) is developed on the Java. There are two modes in CySep (i) Design and (ii) Simulate. In designing of cyclone, designer has to design equipment based on feed flowrate, particle size distribution, density of solids, density of gas and desired separation efficiency. So, these parameters will become inputs for designing and the final design will give dimension of cyclone and number of cyclones in parallel required to achieve desired efficiency. In simulation of cyclone, designer will get idea whether given number of cyclones would be able to separate solids from gas at desired efficiency at given process conditions or not. For illustration purpose, snapshot of GUI is shown in Figure 1. On left hand side of GUI for design mode, designer has to input variables like volumetric flow rate, density of solid particles, density of gas, required efficiency and particle size distribution. In simulate mode, designer has to input variables like volumetric flow rate, density of solid particles, density of gas, number of cyclone in parallel and particle size distribution. In design mode, 'CySep' will calculate the number of cyclones in parallel required to achieve desired efficiency, achieved efficiency and diameter of cyclone in design mode. While in simulate mode, 'CySep' will calculate achieved efficiency and diameter of cyclone for entered number of cyclones.

For comparison purpose, 'CySep' is compared with the solved example elsewhere (Sinnot et. al. 2005).

3.1 *Problem Statement*

Design a cyclone separator for separation of solid particles form gas stream. Particle size distribution in the inlet gas stream is tabulated in Table 3. Density of solid particles is 2500 kg/m^3. Gas is nitrogen at 150 °C. Operating pressure within the cyclone is 1 atm. Volumetric flowrate of gas is 4000 m^3/h and 80 percent recovery of solids is required. Comparative study of solved example from elsewhere (Sinnot et. al. 2005) and 'CySep' is tabulated in Table 4. Snapshots of results obtained through 'CySep' in design and simulate mode are shown in Figure 2 and 3 respectively.

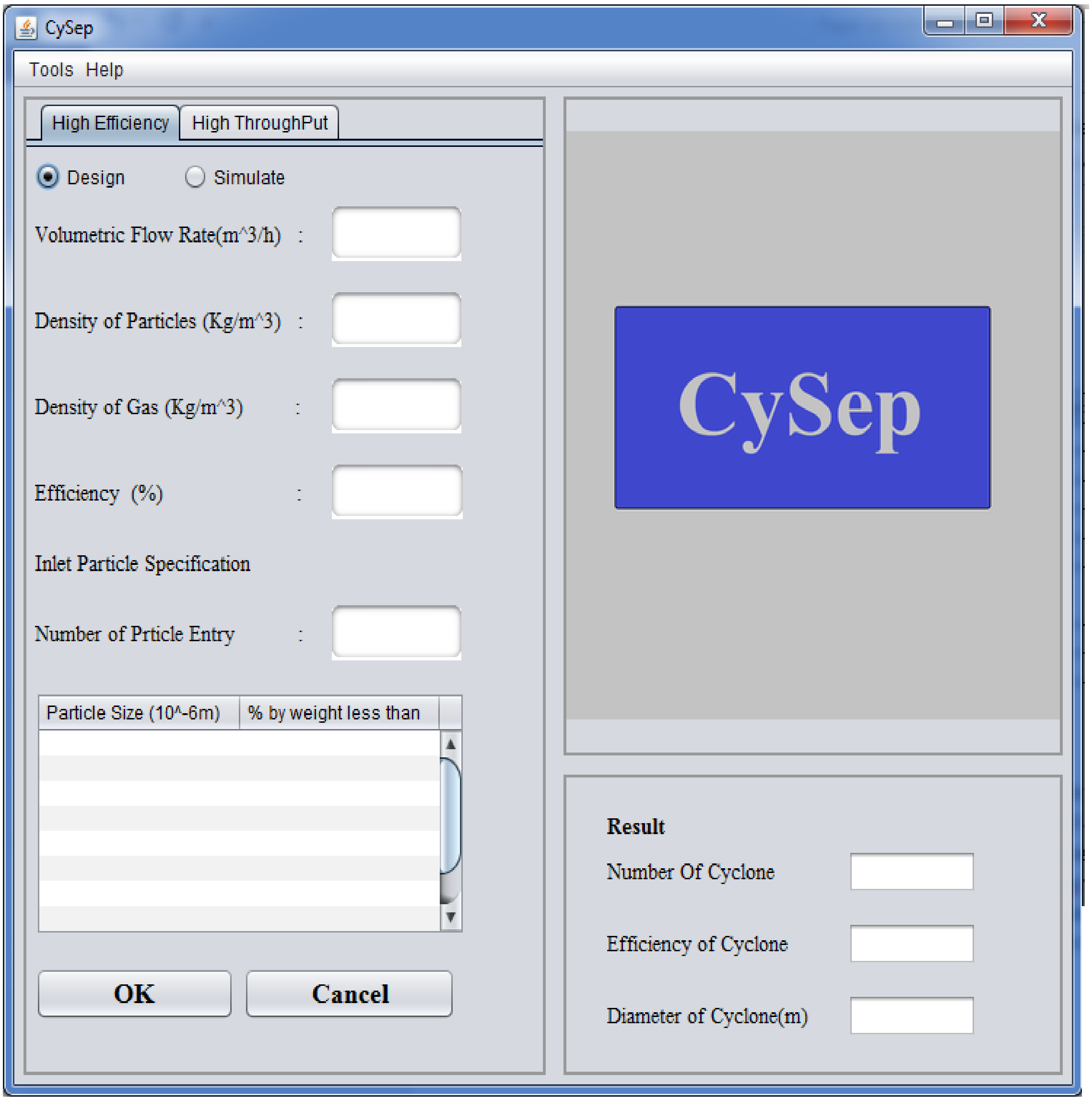

Figure 1. Snapshot of Graphic User Interface of 'CySep'.

Table 3. Particle size distribution of solids.

Sr. No.	Particle size, µm	Percentage by weight less than
1	50	90
2	40	75
3	30	65
4	20	55
5	10	30
6	5	10
7	2	4

In design mode, 'CySep' will start iteration with minimum number of cyclones i.e. one. It will initiate loop with the calculation of achieved efficiency with minimum number of cyclones. If desired efficiency has been achieved, then it will break the loop. Otherwise it will increase the number of cyclone by one and continue the iteration till the actual efficiency is equal to or more than the desired one. In the given problem, desired separation efficiency is 80 percent. As per the results obtained in design mode, using a single cyclone having diameter of 0.86 m separation efficiency of 82.649 percent can be achieved.

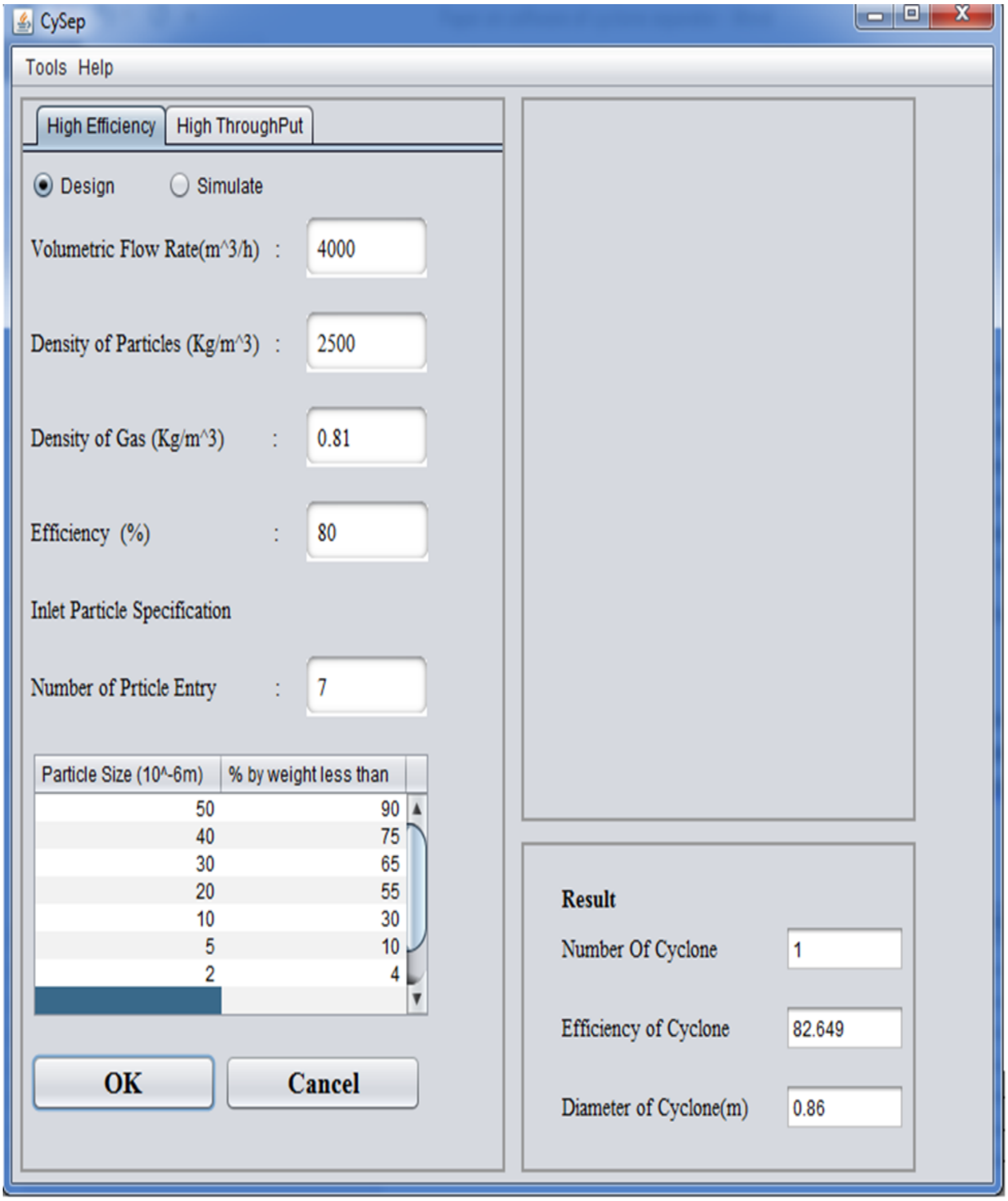

Figure 2. Snapshot of GUI in design mode.

In simulate mode, 'CySep' will calculate achieved efficiency for given number of cyclones. In simulate mode, software will not go for iteration. It will directly predict achieved efficiency for given number of cyclones. If we enter four number of cyclones in parallel, then as per the software achieved efficiency is 88.427 percent, which is quite close to already published literature.

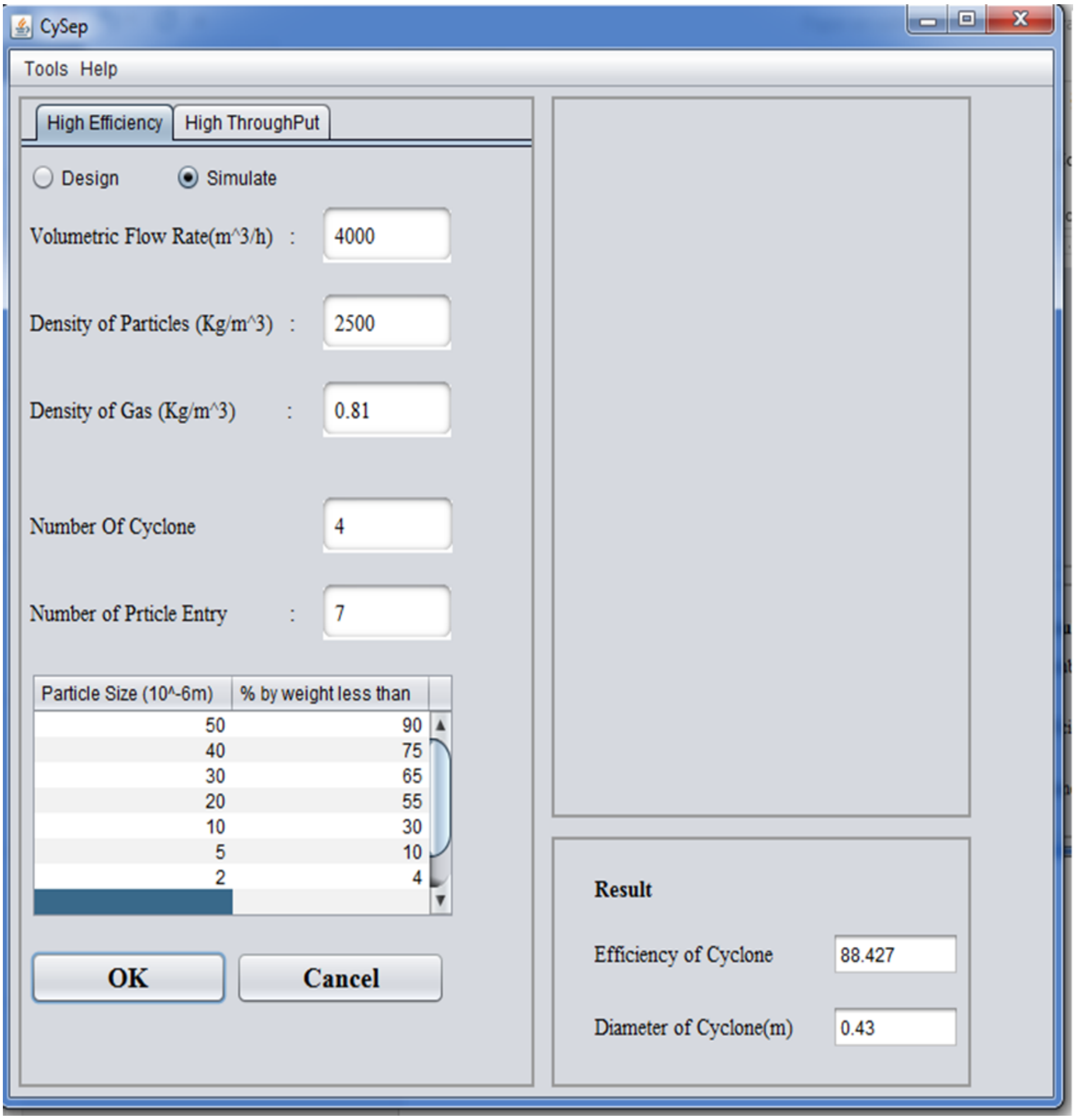

Figure 3. Snapshot of GUI in simulate mode.

Table 4. Comparative study

Sr. No.	Parameter	Results from (Sinnot et. al. 2005)	CySep Design mode	CySep Simulate mode
1	Achieved efficiency	88.7 %	82.649 %	88.427 %
2	Diameter of cyclone	0.42 m	0.86 m	0.43 m
3	Number of cyclone in parallel	4	1	4*

*Number of cyclones in parallel has to be entered by user in simulate mode

4 CONCLUSION

Results obtained on developed software ‘CySep’ are found to be quite accurate in terms of separation efficiency calculation. Software can reduce human efforts to considerable extent, as designing is an iterative procedure and can also increase accuarcy to many folds. Limitation of this software is that pressure drop calculations and other models have not been incorporated. Continuous efforts have been made to modify the software and obtain results which can be readily accepted by industries.

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