Comparative Research on Series and Parallel Hydrocyclones using Computational Fluid Dynamics

[1]Vimal A, [2]Herlin Mathura Rosary J A, [3]Jeeva Bharathi S, [4]Naresh P and [5]Naveen Kumar K
[1,2,3,4,5]Department of Mechanical Engineering, Sri Eshwar College of Engineering, Coimbatore, Tamil Nadu, India.
[1]vimal.a@sece.ac.in, [2]herlinmathurarosaryja2019mech@sece.ac.in, [3]jeevabharathi.smechlateral2020@sece.ac.in, [4]naresh.p2020lateralmech@sece.ac.in, [5]naveenkumar.kmechlateral2020@sece.ac.in.

Article Info
S. Venkatesh et al. (eds.), *1st International Conference on Emerging Trends in Mechanical Sciences for Sustainable Technologies,* Advances in Computational Intelligence in Materials Science.
Doi: https://doi.org/10.53759/acims/978-9914-9946-6-7_15

Abstract - Hydrocyclone are separating devices which work on the principle of centrifugal force. The Hydrocyclones finds its application in petroleum, chemical, textile, mining and paper industries. It is used for separating the solid suspended particles in the liquid. Performance of the Hydrocyclone is greatly influenced by the geometrical parameters and pressure drop. In this present work an overview has been made for arranging the two Hydrocyclone in parallel and series manner for enhancing the performance. The optimization of geometrical parameters is essential to reduce energy consumption and improve the performance of the hydro cyclone. The performance of the parallel and series Hydrocyclone is determined by the recovery efficiency of the industry Hydrocyclone. The energy consumption of the multi Hydrocyclone is reduced as two Hydrocyclone (parallel and series) were operated using a single pump. Numerical solution for the fluid flow is obtained by Computational Fluid Dynamics (CFD) by adapting k- Epsilon techniques.

Keywords - Parallel and Series Hydrocyclone, CFD, K- Epsilon Model.

I. INTRODUCTION

A mini hydro cyclone group with a u type parallel configuration. The results of two-phase studies showed that for 1.6 micron particles, the average separation efficiency was 79.4% and that it declined over the axial direction. [1] We created a discrete model of a ZZ, UU, and UZ type UZ type micro multi hydro cyclone. The output velocity of the manifold typically had more uniformity and the pressure drop had less uniformity with a bigger head loss or flow distribution coefficient. With identical geometrical conditions and operating characteristics, the micro hydro cyclone group has fewer than the other arrangements [2].While maximum fluctuations of 7.2% and 3.6% produced a pressure drop and flow distribution with a rather uniform pressure drop and flow distribution, the pressure drop and flow distribution with the lowest degree of non-uniformity in single-phase tests [7] Several cyclones in series are still largely unexplored in this regard, despite the fact that many geometry optimization researches on single cyclone designs have been documented [8].

The multi parallel Hydrocyclones are frequently employed in a parallel connection to enhance sewage treatment. They serve to remove very small dust from of the sewage. Based on a collection of mini-Hydrocyclone configured in parallel in the u type Wen-jieLv, et al, [1]. A 300 times bigger parallel component of such a small Hydrocyclone were made and utilised in pure sine wave tests to analyse the dispersion of loss of pressure and circulation. While in fluid second test, and to evaluate the results of separating. The pressure loss and circulation inside the single stage test were roughly equal in the enclosing axis but decreased in the axially, which really is line with the theoretical estimates. Yu-long Chang et al, [2] architectural integrity or lack of moving components, tiny hydro cyclones are frequently utilised as highly precise isolation. These were arranged in parallel, and then for big industrial uses, their capacities and output may both greatly improve. Its efficiency of a separator is highly correlated with stream homogeneity. We created a discrete model of the a UZ type small multi hydro cyclone with ZZ, UU, and UZ type configurations for this investigation. The outcomes of a discretization was contrasted with the outcomes of the test. And it was discovered that a lesser proportion splitting or even a smaller intake header height might produce a greater stream homogeneity.Its output velocities of a manifolds typically had more consistency as well as the differential pressure had much less consistency with a bigger head loss or flow diffusion coefficients.

Cong Huang a et al, [3]. Throughout numerical methods have been employed to anticipate that pressure difference and flows dispersal over different flow speed with structural configurations.The findings demonstrated that uniform flow distribution could be adjusted with the help of the inlet-pressure. At 0.10MPa, it was discovered that experimental data and

There was small variation between the calculated fluid flow with diffusion pattern. About the concentration of outflow and the concentration of pressure drop, the relative error percentages were less than 5% and less than 8%, respectively. Cong Huang a et al,[4] Theoretical study was used to investigate the uniform distribution of parallel multi -hydro cyclones of the UU type further in this paper. In order to achieve huge segregation, the linear Number of cyclones, which are described as potential machinery for highly accurate splitting, need to be developed more. Wen-jieLva et al, [5] Minimal olefins are produced using methanol which is derived either non - renewable sources via a chemical reaction catalysed It really has altered the nature of reduced alkynes depending on oil splitting and provided an alternative way to make them. The MTO process's wastewater, on the other hand, is difficult to manage. Counting up the mini Hydrocyclone is widely utilised to boost its throughput of sewage disposal that whenever a compact is utilized for oil water segregation with in methanol-to-olefin phase. A single mini Hydrocyclone efficiency and pressure drop distribution were investigated in the laboratory for this paper. Wen-jieLva et al, [6]to increase separation precision in industrial settings, multiple mini-hydro cyclones are frequently used in parallel. The mini-hydro cyclone group's low pressure drop and uniform flow distribution become significant challenges.

Whenever determining if gas solid cyclone separators are effective, the pressure loss and collection effectiveness are typically the most important factors. The best potential balance between both the pressure loss and the efficiency is found using mathematical cyclone models in optimization techniques according to design preferences. Several cyclones in series are still largely unexplored in this regard, despite the fact that many geometry optimization researches on single cyclone designs have been documented. Although more complex models are mentioned in the literature, because of the quicker computing times, researchers primarily utilise lower fidelity models Rafaello D. Luciano et al, [7]. If using increasingly complex models, the authors frequently use surrogate modelling techniques, which speed up computation but increase uncertainty. Moreover, a number of writers have improved the pressure drop or the efficiency, often by putting a restriction on the other parameter. In contrast, we demonstrate in this article how three cyclones were optimised for many objectives using high-fidelity computational fluid dynamic (CFD) cyclone modelling. It indicates that the optimization processes directly employ the outcomes of the CFD simulations. According to the results, the improved cyclone trios outperform the traditional Steinman high efficiency and Lapple moderate pressure drop designs. Jong Hwa Son et al, [10-14] The reason why the samples' extraction efficiency varied was a result of differences inside this size as well as surface area of the dirt and waste objects. The sewage and murky seawater were cleaned up by the multiHydrocyclone central functions at a consistent cleaning rate of roughly 500 tonnes per day. The findings indicate that the multiHydrocyclone platform provides an efficient, chemical-free, environmentally acceptable technique of water pre-treatment.

This present work involves the investigation on two 100 mm hydrocyclone connected in series and connected in parallel conditions. Using Discrete Phase Model technique, the particle distribution in both series and parallel arrangement were going to be studied.

II. REFERENCE MODEL

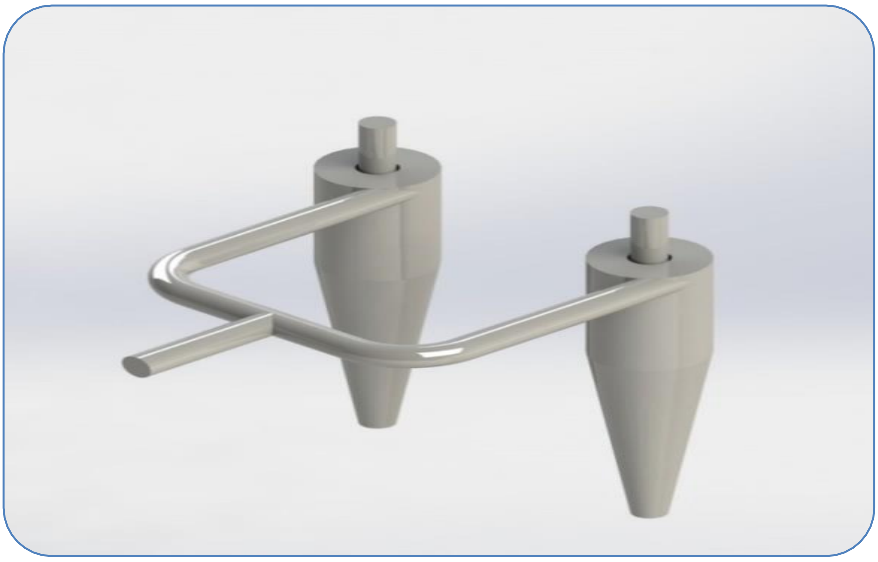

Fig 1. 3D Model of Parallel Multi Hydrocyclone.

Parallel Hydrocyclone

- Height h1H1 = 505mm
- Height h2H2 = 505mm
- Dimension D1= 100mm
- Distance between H1 and H2 (A) = 250mm

- H1 is the primary Hydrocyclone in parallel Hydrocyclone.
- H1 is the Secondary Hydrocyclone in parallel Hydrocyclone.
- h1 is the height of the primary Hydrocyclone.
- h2 is the height of the secondary Hydrocyclone.
- D1 is the dimension of primary and secondary Hydrocyclone.
- A is the distance in-between the both Hydrocyclone.

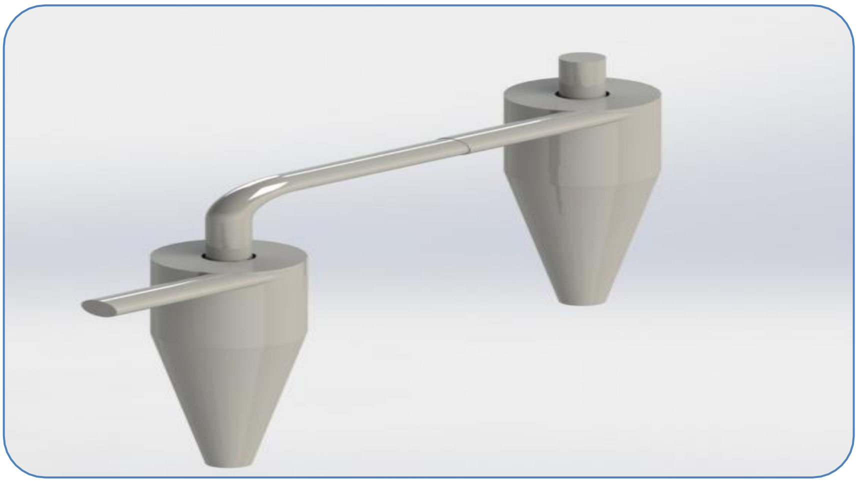

Fig 2. 3D Model of Series Multi Hydrocyclone.

Series Hydrocyclone

- Height h1H1 = 505mm
- Height h2H2 = 505mm
- Dimension D1= 100mm
- Distance between H1 and H2 (A) = 300 mm
- H1 is the primary Hydrocyclone in seriesHydrocyclone
- H1 is the Secondary Hydrocyclone in series Hydrocyclone
- h1 is the height of the primary Hydrocyclone
- h2 is the height of the secondary Hydrocyclone
- D1 is the dimension of primary and secondary Hydrocyclone
- A is the distance in-between the both Hydrocyclones

This is the reference model for both parallel and series Hydrocyclone [9]

The impurities particles, we were used the silicon sand (less than 0.4 mm, 0.5 mm , 0.7 mm and more than 0.7mm) Throughout the analysis of Hydrocyclone, the K-epsilon turbulence model has been created specifically for modeling swirling, centrifugal flow. **Fig 1** shows 13D Model of Parallel Multi Hydrocyclone**. Fig 2** shows 23D Model of Series Multi Hydrocyclone.

III. CFD ANALYSIS

Geometry

Open ansys workbench and select fluid flow (fluent) in tool box. In that right click the geometry files and select the import external geometry file and select the model and open. Click generate and select the inlet pipe face and right click then select the named selection name it inlet1 & inlet 2. Select the outlet pipes face and right click then select the named selection name it outlet1 & outlet2. Select the bin pipes face and right click then select the named selection name it bin1 & bin2. Go back to ansys workbench tab.

Mesh

Double click on the mesh and select the mesh in model tree and then sizing change it to fine. In smoothing change it to high. In assembly meshing method change it as tetrahedrons and then update. Go back to ansys work bench tab.

Setup

Double click the setup in the dialog box enable the double precision and click ok. In general enable the gravity and change y = - 9.81. In models double click the viscous select the k-epsilon (2 eqn) and click ok. Models double click the discrete phase in max no. of. Steps change it as 50000 and then click injections select create and change the injection type to surface.

In material select ash-solid. Go to the point properties enable the scale flow rate by face are & impact using face normal direction. After that, variable diameter = 5e-06m, velocity = 7m/s, total flow rate = 0.00001 kg/s. Go to turbulent dispersion enable the discrete random walk method and change the number of tries = 500 and click ok. In material select fluid and go to fluent database materials and then find the liquid-water & click copy. Go to cell zone conditions click edit in the material change that to liquid-water and then click ok. In boundary condition select inlet in that type select the velocity inlet dialog box will open in velocity magnitude = 7m/s, in specification method change to intensity and hydraulic diameter, diameter = 0.067m after that go to DPM change it as user-defined. Repeat the same procedure to inlet2. Come back to boundary conditions select outlet1 in that type select the pressure outlet dialog box will open change intensity and hydraulic diameter, diameter = 0.1m after that go to DPM change it as escape. Repeat the same procedure to outlet2. Come back to boundary conditions double click the wall dialog box will open in that go to DPM change it as reflect. Come back to boundary conditions double click the bin1 dialog box will open in that go to DPM change it as trap. Repeat the same procedure to bin2. In solution go to methods and then select change the turbulent kinetic energy in the direction of second order upwind and also change the turbulent dissipated rate to second order upwind. Go to initialization change it as standard initialize and select compute from as inlet and click initialize and go to patch and click zones to patch as solid and z velocity = -7m/s and click patch. In run calculation change number of iterations = 500 and calculate after compiling click ok. Go to graphics and animations double click the particle track and select release from the injection as injectio-0 and track. Go to file export click the particle history data and select injection and then click write. Go back to ansys workbench tab.

Boundary Conditions Settings Includes

1. Inlet velocity = 7 m/s
2. Pressure outlet = 1 atm pressure
3. Turbulence intensity = 5%
4. Water density = 998.2 kg/m^3
5. Viscosity = 0.001003 kg/ms
6. No of particles injected at inlet =
7. For discrete phase model
   - Overflow - Escape Condition
   - Underfloor- Trap Condition
   - Remaining walls - Reflected Condition
8. Mass flow rate of particles = 20g /s.

Results

Double click the results, the postCFD window will appear in the enable the wall-solid check box and double click it and change color and go to render option increase the transparency and click apply. Go to file import and select particle track file select the file that is saved in setup process. And select the fluent particle for ash-solid double click it go to color change it as variable and also select ash-solid id. And go to color map change it as rainbow. Go to symbol enable the show symbols check box increase the scale = 0.6 and apply. Save the output image to your device and then disenable the show track and click apply. Go to animations option select fluent particle for ash-solid and then go to options increase the symbol size = 0.6 and click ok enable the save movie option and click play the output will save in your device.

CFD Analysis of Particle Trajectory in Parallel Flow

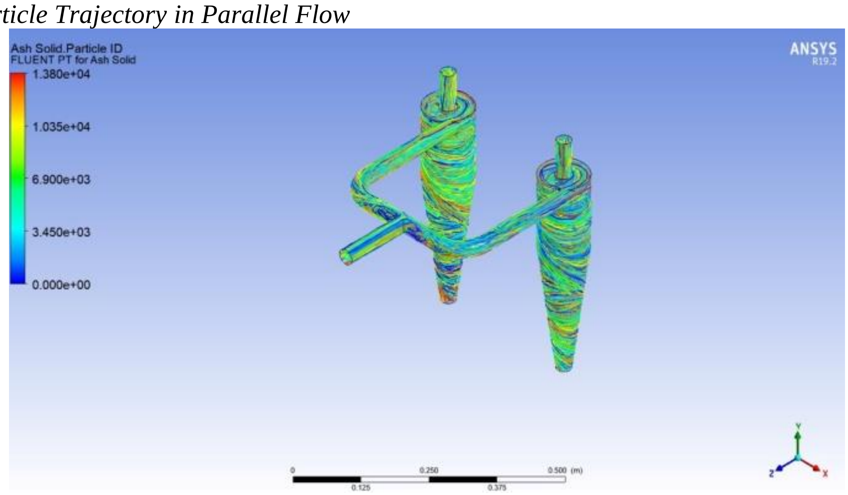

Fig 3. Particle Trajectory of Parallel Flow.

The minimum pressure of the parallel Hydrocyclone is 0.000e+00 and the maximum pressure is 1.380e+04. **Fig 3** Shows Particle Trajectory of Parallel Flow.

CFD Analysis of Particle Trajectory in Series flow

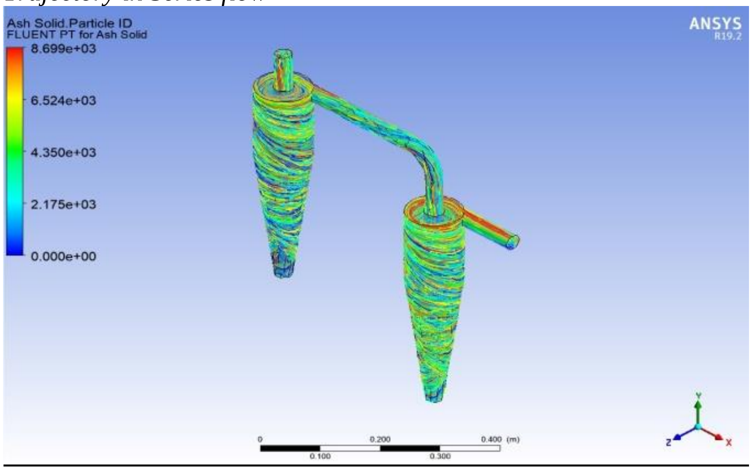

Fig 4. Particle Trajectory of Series Flow.

The minimum pressure of the series Hydro cyclone is 0.000e+00 and the maximum pressure is 8.699e+03 Pa. **Fig 4** shows Particle Trajectory of Series Flow.

Grid Validation

Refinement ratio should be greater than 1.3. This present simulation has (13800) refinement ration. Hence the grid is validated.

IV. RESULTS AND DISCUSSION

CFD Analysis

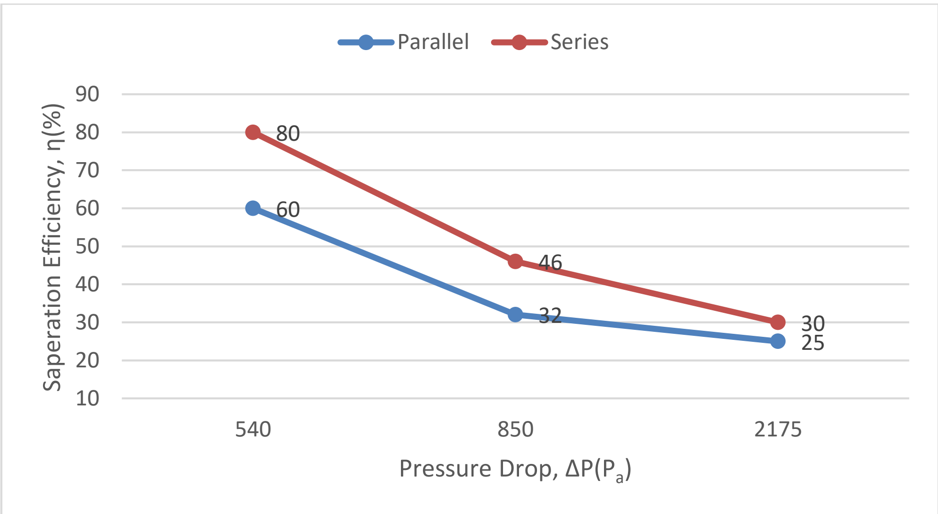

Fig 5. CFD Analysis.

While comparing the parallel and series of CFD Analysis. Series is more efficient (80%) compare to parallel (60%). While the Pressure Drop, ΔP is increasing Efficiency, η will reduce. **Fig 5** shows CFD Analysis.

V. EXPERIMENTAL VALIDATION

Hydro-Cyclones in Series

Initial mass of the particle (Silicon sand) is 1kg.Above the observation, the valve position when fully opening, particles collected at both the Hydrocyclone was 0.75kg and efficiency was high (75%) at valve when fully opened.

E = [$(H_1 + H_2)$ / Mass of the particles**]**x 100

Where, E= Efficiency

H_1= Particles collected at first hydro- cyclone
H_2= Particles collected at first hydro-cyclone
E_1 = [(0.35+ 0.40) / 1**]** x 100 = 75%
E_2 = [(0.20 + 0.20) / 1**]** x 100 = 40%
E_3 = [(0.10 + 0.10) / 1**]** x 100 = 20%
Where, E_1= Efficiency at valve was fully opened
E_2= Efficiency at valve was semi- opened
E_3= Efficiency at valve was partially opened

Table 1. Observation For Parallel Connected Hydrocyclones

S. No	Pressure Difference	H_1	H_2	$H=H_1+H_2$ (in kg)	E (%)
1.	Full open	0.25	0.30	0.55	55
2.	Semi open	0.10	0.15	0.25	25
3.	Partial open	0.05	0.10	0.15	15

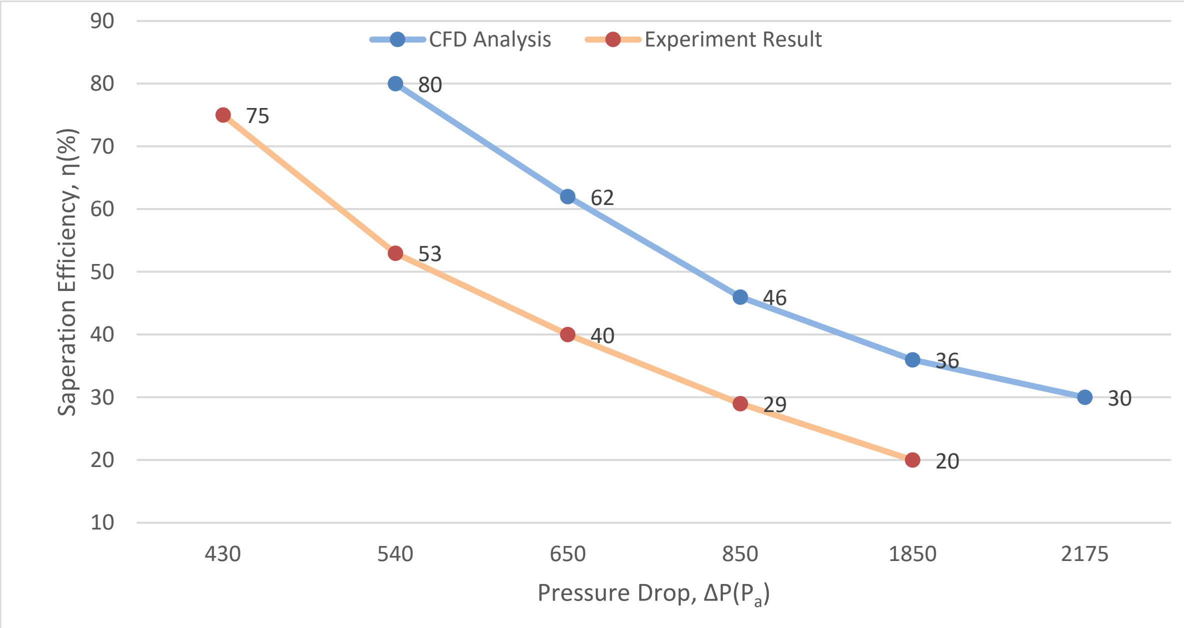

Fig 6. Validation Of CFD Analysis In Series Arrangement Using Experimental Setup.

Above the calculation we concluded that efficiency is high in when valve position artfully opened. **Fig 6** shows Validation of CFD Analysis in Series arrangement using Experimental setup. **Table 1** shows observation for parallel connected hydrocyclones

Hydro-cyclones in parallel

Initial mass of the particle (Silicon sand) is 1kg. Above the observation, the valve position when fully opening, particles collected at both the Hydro cyclone was 0.55kg and efficiency was high (55%) at valve when fully opened.

E = [(H_1 + H_2) / Mass of the particles**]**x 100
Where, E= Efficiency
H_1= Particles collected at first hydro- cyclone
H_2= Particles collected at first hydro-cyclone
E_1 = [(0.25+ 0.30) / 1**]** x 100 = 55%
E_2 = [(0.10 + 0.15) / 1**]** x 100 = 25%
E_3 = [(0.05 + 0.10) / 1**]** x 100 = 15%
Where, E_1= Efficiency at valve was fully opened
E_2= Efficiency at valve was semi- opened
E_3= Efficiency at valve was partially opened

According to the calculation, it is concluded that separation efficiency is higher in the series set up. The following graph shows that separation efficiency of two various set ups in multi hydro-cyclone.

Table 2. Observation for Series Connected Hydrocyclones

S. No	Pressure Drop	H_1	H_2	$H=H_1+H_2$ (in kg)	E (%)
1.	Full open	0.35	0.40	0.75	75
2.	Semi open	0.20	0.20	0.40	40
3.	Partial open	0.10	0.10	0.20	20

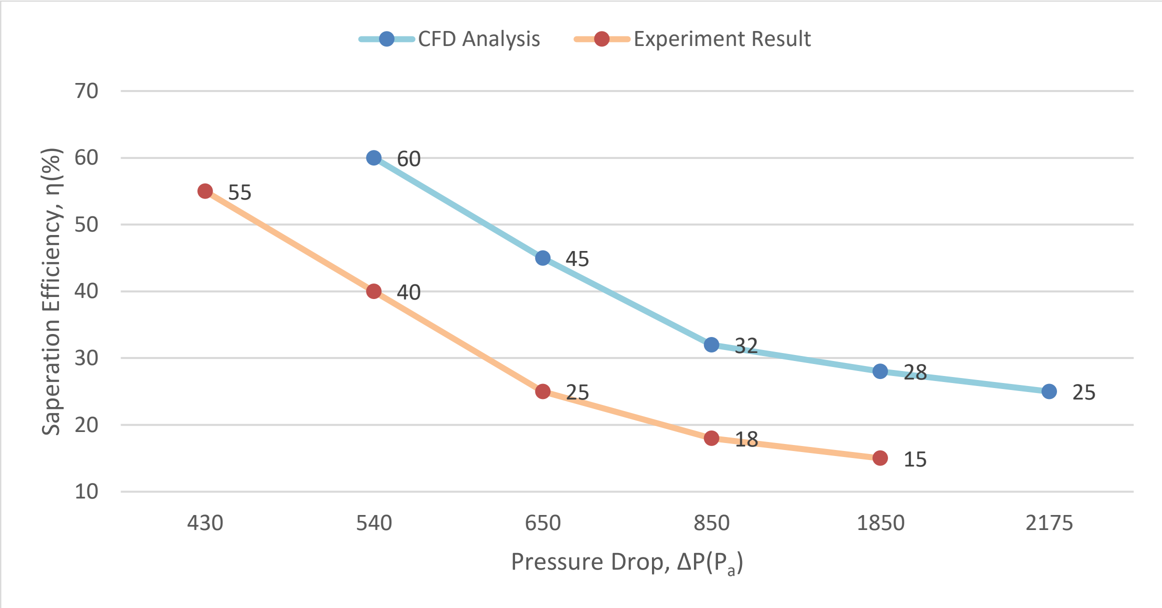

Fig 7. Validation Of CFD Analysis in Parallel Arrangement Using Experimental Setup.

While comparing the parallel and series Hydrocyclone CFD Analysis and Experimental results, Series Hydrocyclone is better than the parallel Hydrocyclone. **Fig 7** shows Validation of CFD Analysis in Parallel arrangement using Experimental setup. **Table 2** shows Observation for series connected hydrocyclones.

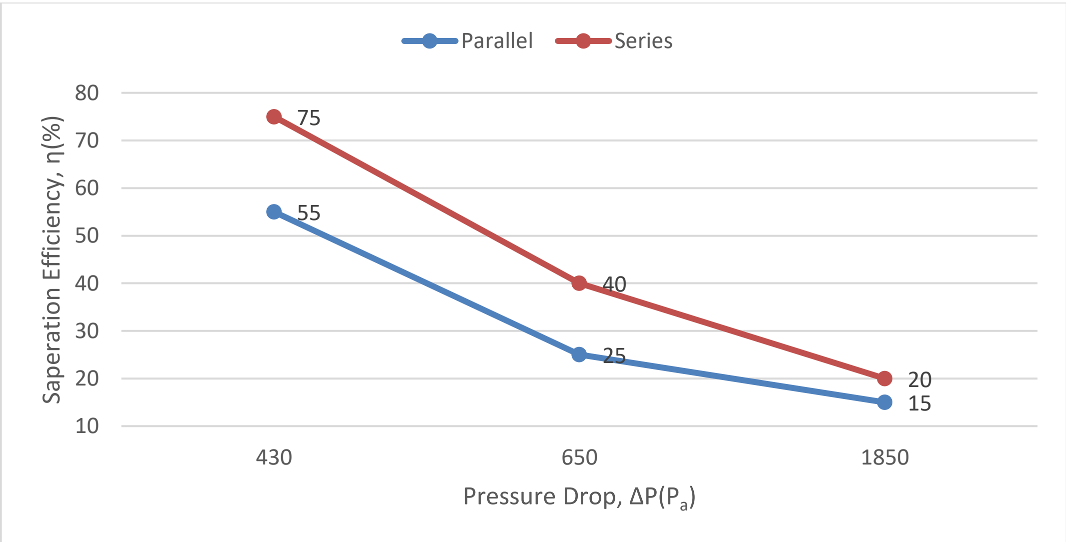

Fig 8. Experimental Setupvalidation.

While comparing the parallel and series of Experimental result. Series is more effective (75%) compare to parallel (55%). While the Pressure Drop, ΔP is increasing Efficiency, ηwill reduce. **Fig 8** shows Experimental setupvalidation

VI. CONCLUSION

In Multi Hydrocyclone are more effective for removing the dust particles compare to single Hydrocyclone. Because the inner diameter produces more centrifugal force, the longer length offers a longer exposure period. Improved dust particle segregation in multi Hydrocyclones is the outcome among these two aspects. Above the experiment, the efficiency in particle separation was high in series connection compare to the parallel connection. The parallel Hydrocyclone efficiency was 55% at valve when fully open end. The series Hydrocyclone efficiency was 75% at valve when fully open end.

VII. ACKNOWLEDGEMENT

The success of a project depends on a team and shared cooperation. We would want to take this occasion to express our gratitude to everyone who has helped us with this effort and to thank them. We appreciate the excellent facilities provided by the management and their continued support of this project.

Reference

[1]. W. Lv, J. Chen, Y. Chang, H. Liu, and H. Wang, “UU-type parallel mini-hydrocyclone group separation of fine particles from methanol-to-olefin industrial wastewater,” Chemical Engineering and Processing - Process Intensification, vol. 131, pp. 34–42, Sep. 2018, doi: 10.1016/j.cep.2018.03.015.

[2]. Y. Chang, H. Wang, J. Jin, Z. Liu, and W. Lv, “Flow distribution and pressure drop in UZ-type mini-hydrocyclone group arranged in compact parallel manifolds,” Experimental Thermal and Fluid Science, vol. 100, pp. 114–123, Jan. 2019, doi: 10.1016/j.expthermflusci.2018.07.014.

[3]. C. Huang, W. Lv, J. Wang, J. Wang, and H. Wang, “Uniform distribution design and performance evaluation for UU-type parallel mini-hydrocyclones,” Separation and Purification Technology, vol. 125, pp. 194–201, Apr. 2014, doi: 10.1016/j.seppur.2014.01.057.

[4]. W. Lv, C. Huang, J. Chen, H. Liu, and H. Wang, “An experimental study of flow distribution and separation performance in a UU-type mini-hydrocyclone group,” Separation and Purification Technology, vol. 150, pp. 37–43, Aug. 2015, doi: 10.1016/j.seppur.2015.06.028.

[5]. W. Lv et al., “UU-type parallel mini-hydrocyclone group for oil-water separation in methanol-to-olefin industrial wastewater,” Chemical Engineering and Processing - Process Intensification, vol. 149, p. 107846, Mar. 2020, doi: 10.1016/j.cep.2020.107846.

[6]. R. D. Luciano, B. L. Silva, L. M. Rosa, and H. F. Meier, “Multi-objective optimization of cyclone separators in series based on computational fluid dynamics,” Powder Technology, vol. 325, pp. 452–466, Feb. 2018, doi: 10.1016/j.powtec.2017.11.043.

[7]. M. Durango-Cogollo, J. Garcia-Bravo, B. Newell, and A. Gonzalez-Mancera, “CFD Modeling of Hydrocyclones—A Study of Efficiency of Hydrodynamic Reservoirs,” Fluids, vol. 5, no. 3, p. 118, Jul. 2020, doi: 10.3390/fluids5030118.

[8]. K.-J. Hwang, S.-Y. Lyu, and Y. Nagase, “Particle separation efficiency in two 10-mm hydrocyclones in series,” Journal of the Taiwan Institute of Chemical Engineers, vol. 40, no. 3, pp. 313–319, May 2009, doi: 10.1016/j.jtice.2008.08.006.

[9]. S. Pasquier and J. J. Cilliers, “Sub-micron particle dewatering using hydrocyclones,” Chemical Engineering Journal, vol. 80, no. 1–3, pp. 283–288, Dec. 2000, doi: 10.1016/s1383-5866(00)00103-9.

[10]. J. H. Son, M. Hong, H. C. Yoo, Y. I. Kim, H. D. Kim, and J. T. Kim, “A multihydrocyclone water pretreatment system to reduce suspended solids and the chemical oxygen demand,” Desalination and Water Treatment, vol. 57, no. 7, pp. 2996–3001, Dec. 2014, doi: 10.1080/19443994.2014.987827.

[11]. W. Kraipech, W. Chen, T. Dyakowski, and A. Nowakowski, “The performance of the empirical models on industrial hydrocyclone design,” International Journal of Mineral Processing, vol. 80, no. 2–4, pp. 100–115, Sep. 2006, doi: 10.1016/j.minpro.2005.02.005.

[12]. L. Jiang, P. Liu, Y. Zhang, X. Yang, and H. Wang, “The Effect of Inlet Velocity on the Separation
 Performance of a Two-Stage Hydrocyclone,” Minerals, vol. 9, no. 4, p. 209, Mar. 2019, doi: 10.3390/min9040209.

[13]. K.-J. Hwang, Y.-W. Hwang, H. Yoshida, and K. Shigemori, “Improvement of particle separation efficiency by installing conical top-plate in hydrocyclone,” Powder Technology, vol. 232, pp. 41–48, Dec. 2012, doi: 10.1016/j.powtec.2012.07.059.

[14]. Y. Zhang et al., “Design of Hydrocyclone With Axial Inlet and its Performance Used in Wellbore,” Volume 5: Materials Technology; Petroleum Technology, Jun. 2014, doi: 10.1115/omae2014-23537.