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Filtration of Water Based Coolants Using Hydrocyclone Separator

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ABSTRACT: Developments in distinctive industries are resulting in increase of small particles in commercial waste water. Fine particle grading, separation, and recycling contain many problems, and the separation efficiency is directly attached to the financial advantages and environmental effects. This paper discusses the hydrocyclone performance related to the solids particle separation (metal swarfs resulted from machining) from water based coolants like MUSCLECOOL 744, Tectyl 296 AM, Polyclean MT 218, etc used in the Cummins Industry for machining processes. The solid separation efficiency in the hydrocyclone will be illustrated. A separate trolley is being made to carry the hydrocyclone along with the centrifugal pump for pumping the coolant from the sump tank of the machine and passing it to the hydrocyclone where the solid particles gets separated into the sludge pod of the hydrocyclone and the clean coolant goes forward to the onboard tank from where it is again pumped to the sump tank of the machine for further use. In this study, a hydrocyclone with a nominal diameter of 0.1 m was designed and tested for the separation of particles from coolant in the industry. Hydrocyclones have been used in various processes in industries for over a century. They are a simple and efficient device, but still widely misunderstood in the oil and gas industry. Hydrocyclones are generally used in numerous separation applications, overcoming conventional technical and economic operating problems. Hydrocyclone is a simple mechanical device which has no moving parts, where solid particles are separated from liquid with a minimum head loss. As its name suggests, it uses a cyclone or tangential injection flow process which results in the centrifugal forces and moving solids outwards. The scattered particles, move downwards in a spiral path into an underflow sludge pod, while clean liquid move upwards to the center of the spiral, towards the top outlet. Results of pressure, particle separation efficiency and fluid separation efficiency are presented and evaluated. From the study of results it is observed that the separation efficiency increases with the increase in the fluid flow velocity at the inlet of the hydrocyclone.

KEYWORDS: Hydrocyclone, Commercial, Spiral, Sump Tank, Sludge Pod.

I. INTRODUCTION

In the second half of the nineteenth century, the hydrocyclone was used as a solid-liquid separator to remove sand particles from river water. Then the cyclone-shaped hydroelectric power plant is also introduced under the name gravitational water vortex power plant. A typical hydrocyclone includes a cylindrical section, a conical section, a lower flow cylinder section, and a particle collection basket. Separation is based on the difference in density between liquid and substance to be separated. The law of centrifugal separation is used to remove solid particles from a liquid according to the size, shape and density of the particles.[3]

A typical hydrocyclone consists of a cylindrical section with a central tube connected to a conical section with a discharge tube. An inlet tube is attached to the top section of the cylinder. The fluid being injected tangentially into hydrocyclone causes swirling flow and thus generates centrifugal force within the device. This centrifugal force field brings about a rapid classification of particulate material from the medium in which it is suspended.

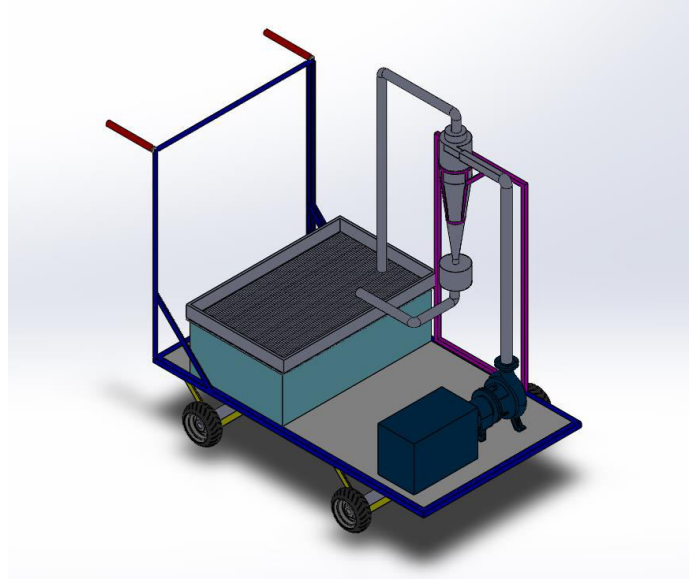


Fig 1. Prototype Design of Hydrocyclone Filtration System

The centrifugal field generated by the high circulating velocities creates an air core on the axis that usually extends on the underflow opening at the bottom of the conical section through the vortex finder to the overflow at the top. In order for this to occur the centrifugal force field must be several times larger than the gravitational one. Particles that experience this centrifugal field will tend to move outwards relative to the carrier fluid because of their relatively greater density. The larger, heavier particles will migrate rapidly to the outside walls of the cylindrical section and will then be forced to move downward to the inside of the conical wall. Small particles will, on the other hand, be dragged inward by the fluid as it moves towards the vortex finder. The flow in a hydrocyclone is very complicated with the presence of swirling turbulence, air core and segregation, and involves multi phases: gas, liquid, solid particles of different sizes. [8]

The hydrocyclone performance is determined by its internal flow field characteristics. Despite the simple structure of a hydrocyclone, its inner hydrodynamic behaviour is complex, involving highly conserved vorticity, broken vortices, and counterflow. Some defects in the separation process cannot be avoided because of the essential flow field characteristics (short-circuit flow, cycle flow, and airflow) of a common hydrocyclone. As a result, the separation efficiency and precision are unsatisfactory. The relationship between the structure and performance of hydrocyclones have been extensively investigated. Designing of the model is being done on Solidworks and the analysis and simulation is done on ANSYS Fluent. We found that attaching a sludge pod increases the efficiency of the filtration from 64 – 65% to above 95% approximately. This study is exclusively done for 50 microns particles. We aim to develop a system for the filtration of water based coolant like musclecool 744, Polyclean MT 218, Tectyl 296 AM. We plan to use hydrocyclone filter for the same because of its structural simplicity, robust separation devices with no moving part, small size of the unit, as well as low installation and maintenance costs and its proven efficiency. Typically the particle range in the company that we aim to address is 50 microns and we plan to separate these from the water based coolants using the hydrocyclone filtration technique. [9]

II. LITERATURE REVIEW

Hydrocyclone separation is a typical centrifugal separation technique widely used for particle separation, classification, and thickening in many solid–liquid processes. Hydrocyclone separation has the advantages of structural simplicity, robust separation devices with no moving part, small size of the unit, as well as low installation and maintenance costs. This separation technology is the predominant method used for solid particle removal, recycling applications, etc., and has thus become a research hotspot. In particular, researchers have focused on expanding its application scope from the mineral industry to many novel fields. [4]

In our project we aim to use a hydro cyclone filter for the filtration process of water based coolants used in the industries. Hydrocyclones have been widely used to separate fine particles by size in many industries. Their flows are complicated by the presence of swirling flow, turbulence, air core and segregation, and involve multiple phases: liquid, gas, and particles of different sizes and densities. The systematic studies for better designing and controlling of the hydrocyclone process are few and the fundamentals governing the complicated liquid-gas-solid flow in a hydrocyclone are still poorly understood, particularly at different feed solids concentrations and particle densities though being extremely important in practice. On the other hand, lack of comprehensive studies of the flows and performance in hydrocyclones of different geometrical configurations under wide range of feed solids concentrations is indisputable.[5]

III. IDENTIFICATION OF PROBLEM STATEMENT

Cummins India Ltd. is a large manufacturer of engines, generators and power systems. Hence, being such a heavy producer requires large machining operations. This kind of extensive machining requires around thousands of litres of coolant. Water-based coolants, synthetic coolants, oil based coolants etc. various kinds of coolants are used according to the requirement. It has been observed that these coolants, specially water-based coolants are discarded after their work cycle is completed. These work cycles generally depend and vary according to various machining operations. Though this discarded coolant can be reused if filtered properly using filtration techniques. But due to the complexity in operation of the existing sump cleaner the filtration of the used coolant is not done and hence they are discarded without being reused. Instead timely cleaning of the tank is carried out by emptying the tank to dry, and then cleaning it by manual means.[10]

Earlier this sump cleaner was in use but there were several issues. The sump cleaner is very large in size and hence it is difficult to move around carrying the sump cleaner to each and every machine where machining operations are performed. Also even if we somehow managed to try and clean the coolant tank with the help of sump cleaner, frequent choking of the mesh filter used was observed. Due to all these difficulties in operation, the sump cleaner is not considered effective for cleaning and filtration of the coolant tank. Filtration and reuse of these already used coolants can result in numerous advantages. But instead, discarding it affects the cost effectiveness and various financial parameters of the industry. All this coolant is considered waste whereas it can be reused and its working life cycle can be increased. Traditional manual tank cleaning technique requires the machine to stop while cleaning the tank. This affects the production rate and increases downtime. This situation is not ideal for any manufacturer.

Proper filtration technique needs to be employed to overcome these disadvantages. Time to time cleaning of coolant tank and filtration and reuse of the coolant is required to minimize these effects. For this purpose, different types of tank cleaners and various filtration processes are available in the market. Different types of sump cleaners are designed such that they are compact, portable and easy to handle. Mainly there are two methods used. First one is sump cleaners with a diaphragm pump. Diaphragm is a positive displacement pump. It is also called as membrane pump. This pump works by using a blend of reciprocating action of a rubber, teflon diaphragm otherwise thermoplastic and appropriate valves on any face of the diaphragm to push the liquid. These pumps are self-priming and are not expensive because the working fluid does not come in contact with the internal parts of the pump. [1]

Another type of filtration system is filtration using hydrocyclone filters. Hydrocyclone separators are effective in removing suspended particles from any flow stream of a medium where the specific gravity of the impurity particles is heavier than the medium it is in. The more significant the difference in the gravity between the water and the particle, the greater the efficiency of the removal process. Depending on the specific gravity of the particle and the viscosity of the flow stream, very small and denser particles can be removed using this filter. Hydrocyclone filters can be used effectively for filtration of water-based coolants as the metal impurities have higher density than the coolant. These filters need to be combined with a pump at inlet to provide the tangential entry to the impure coolants. This system outperforms the existing sump cleaner system in working efficiency as well as the performance parameters. Choking issue of the filter does not arise because there is no actual strainer or mesh is required for the filtration. Downtime is also reduced as this system is faster compared to tradition manual cleaning as well as existing sump cleaner.



IV. METHODOLOGY

In hydrocyclone unit must be installed vertically with sludge pod under the hydrocyclone. Conical shape accelerates the velocity of the water increasing centrifugal forces and maximizing separation. It's easy to operate and maintain with no moving parts or screens. There is no head loss build-up or clogging during separation.

There are various design parameters of hydrocyclone which are as follows:

Cone angle:

For design purpose, 11.8° cone angle is chosen. The larger the hydrocyclone diameter, the coarser the separation.

Cone section length:

The length of cone depends upon the underflow cylinder diameter and cone angle and for this project we made it 0.319 m.

Inlet and overflow section diameters:

The inlet dimensions are 0.0225*0.0145 and overflow pipe diameter value is fixed at 0.03m, respectively for a flow rate of 1.95 l/s. To increase the intake capacity of a hydrocyclone, its inlet diameter has to be increased.

Cylinder section diameter:

Cylinder diameter is selected as 0.100m for this model.

Cylinder section length:

The length of the cylinder section is selected as 0.14 m.

Vortex finder design:

Vortex finder takes the clean water and delivers it to the outlet. If the length of vortex finder increases, it is likely to disturb the vortex and result in coarser separation of particles. So, the length of the vortex finder should be optimum and is found by a trial and error method. In this model, the length of the vortex finder was kept at 0.072m.

Height of hydrocyclone:

The height from the top of the outflow pipe to the end of the underflow cylinder section is referred to as total height of hydrocyclone and for this project the total height of the hydrocyclone is 0.581m.

Pump:

The centrifugal slurry pump chosen for our model is of 2 litre/sec flowrate.

Clean coolant tank:

An onboard coolant tank of 0.65*0.4*0.2m (52 litres) is provided for the clean coolant from the overflow of the hydrocyclone to settle in until it is been pumped back to use.

V. DESIGN

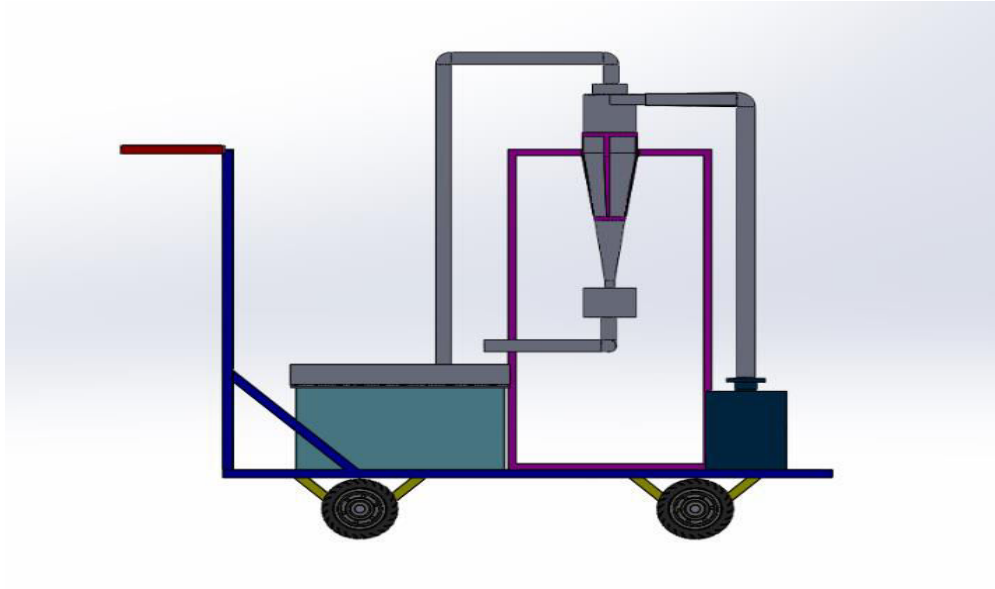


Fig 2. Side View

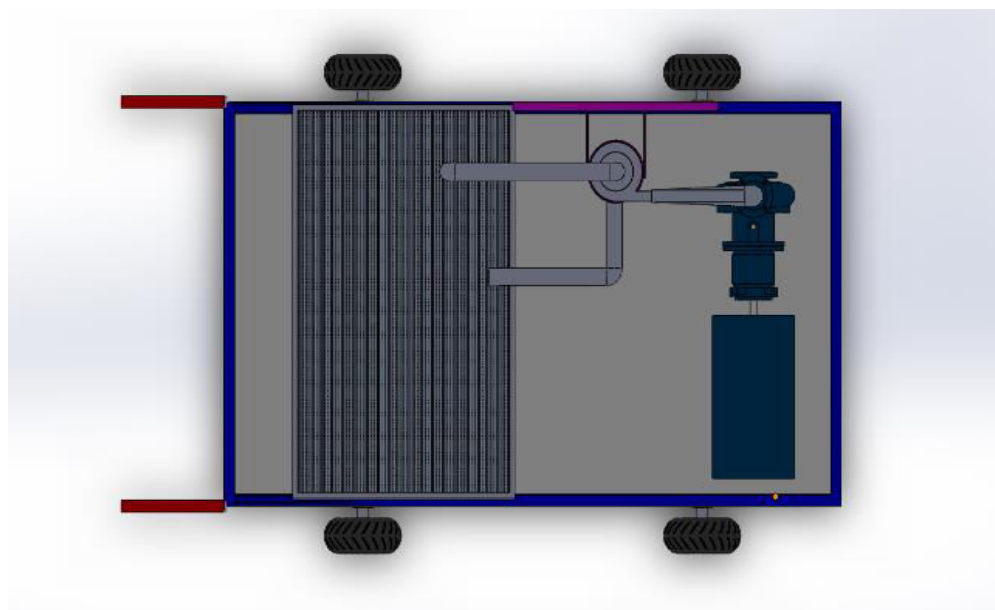


Fig 3. Top View

VI. COMPUTATIONAL ANALYSIS

We conducted the analysis of hydrocyclone using ANSYS Fluent software. The geometry of the model was imported from the Solidworks software. The meshing used was tetrahedron shaped and the element size of the mesh is selected as 0.005 m. The model used is viscous-standard k-epsilon with standard wall functions. The injection used is of 50 microns inert particles. The boundary conditions for the inlet is 6m/s as magnitude of velocity and specification method is intensity and hydraulic diameter. The solution method used is second order upwind.

For solution initialization, standard initialization is used. 500 iterations were used for the calculation of the result. The solution converged at 120 iterations. The scaled residuals is represented below.

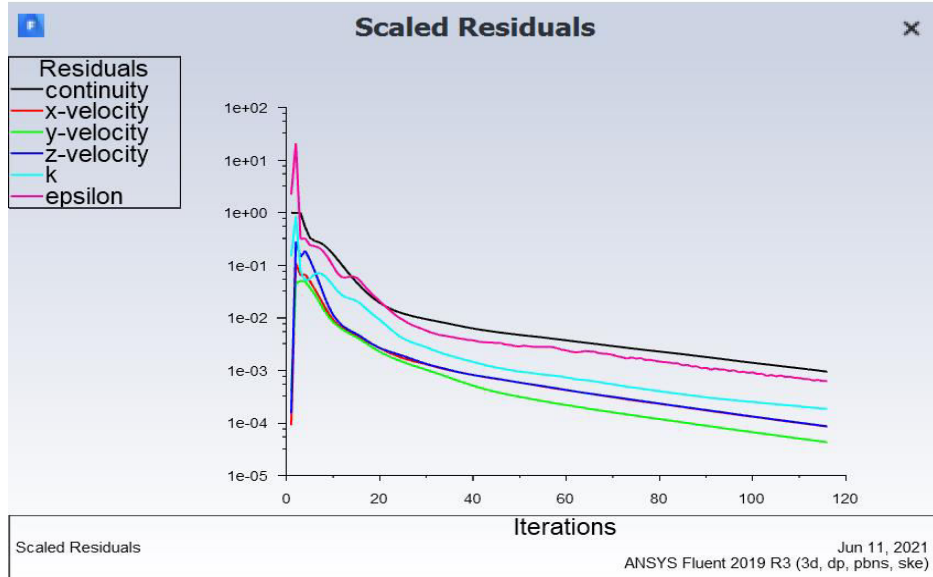


Fig 4. Scaled Residuals Graph

The net total pressure in the hydrocyclone is found to be 21242.55 pascal. The track history of 50 micron particles is number tracked = 360, escaped = 0, aborted = 0, trapped = 360, evaporated = 0, incomplete = 0, incompleteparallel = 0

From the above data the particle separation efficiency is,

$$\text{Particle separation efficiency} = \frac{\text{Trapped Particles}}{\text{Injected Particles} - \text{Incomplete particles}}$$

$$\text{Particle separation efficiency} = 100\%$$

Particle flow of 50 microns is represented below.

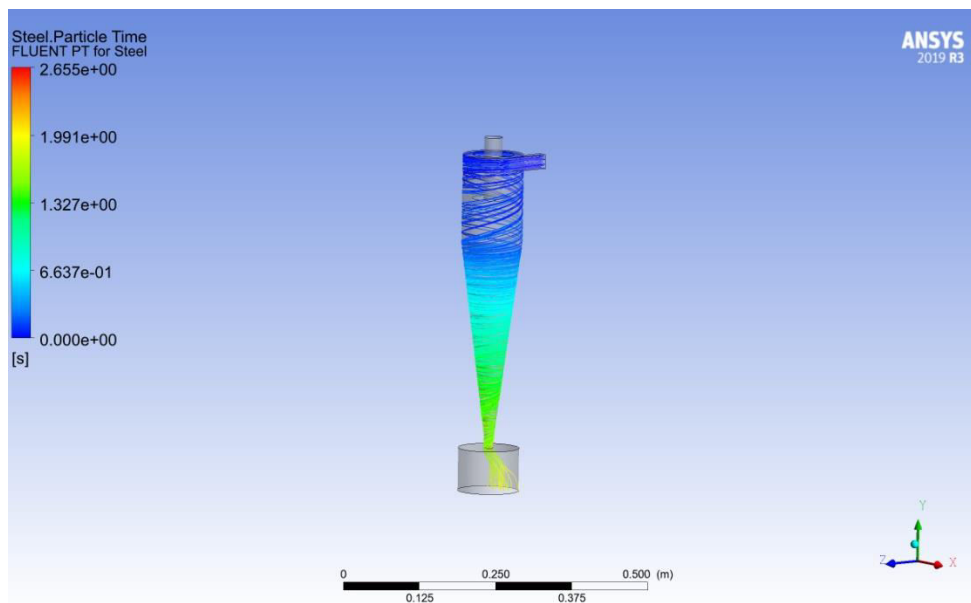


Fig 5. Flow of Particles Injected

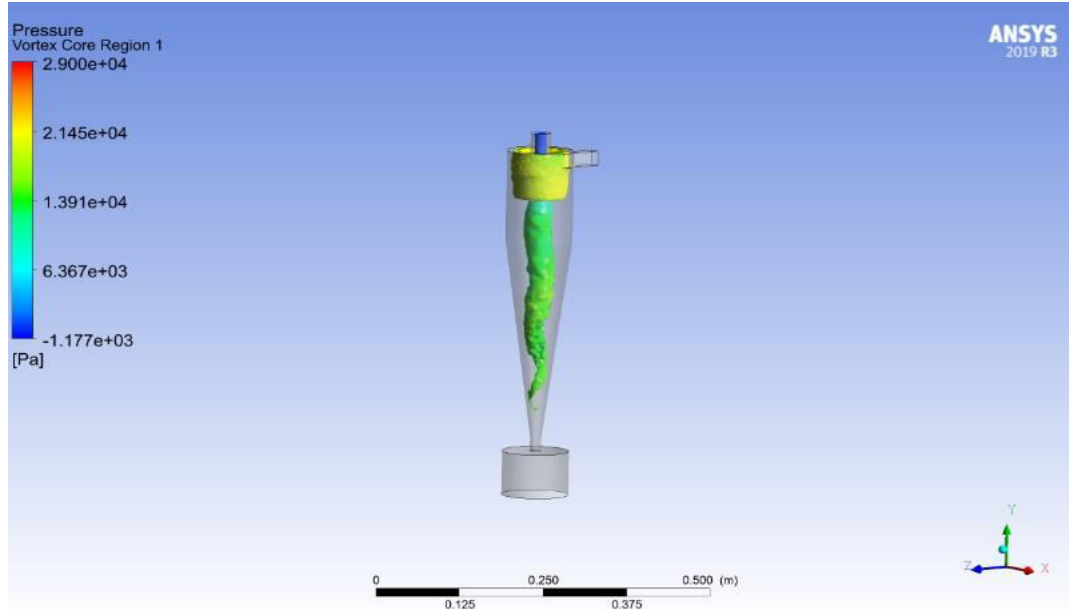


Fig 6. Representation of Vortex Core Region

The fluid flow efficiency obtained is stated below

$$\text{Fluid flow Efficiency} = (\text{Mass Flow Rate at Overflow} / \text{Mass Flow Rate at Inlet}) * 100$$

$$\text{Fluid flow Efficiency} = (1.95179 / 1.95398) * 100$$

$$\text{Fluid flow Efficiency} = 99.8\%$$

VII. CONCLUSION

- I. The Hydrocyclone filtration has a clear advantage over the existing sump cleaner. As the hydrocyclone has no moving parts, it is more durable and is also highly efficient.
- II. From the CFD analysis, it is found that the hydrocyclone is capable of filtering particles upto 50µm critical diameter with approximately 99% separation efficiency.
- III. This system is aimed to replace the existing sump cleaner where choking of filter and transportation of bulky system are the main problems.

VIII. ACKNOWLEDGEMENT

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