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Design Optimization of Filters for Energy Conservation

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Abstract - *Every hydraulic system needs a filter since the majority of hydraulic system failures are caused by pollution, dirt, and unclean water. Filters must maintain pump efficiency and flow rate in addition to filtering water Consequently, when headloss is decreased, this is possible. Head loss is essentially the loss from water obstruction caused by filter mesh, filter parts etc. Energy use and head loss are directly correlated. Consequently, the goal of this study is to determine the ideal location and suitable filter for the maximum energy conservation and minimal head loss. Real filters are tested in a virtual environment using CFD and simulation. saving money, energy, and other resources. This also prevents failure of filters in real world In this research with help of cfd simulation using of filters with minimum energy consumption is aimed In order to save energy and increase the effectiveness of hydraulic systems, it is essential to do research on the design optimisation of filters using computational fluid dynamics (CFD). This work attempts to reduce energy losses and pressure drops in the filter by optimising the design of a filter for hydraulic systems using CFD simulations. The shape, size, and flow channel of the filter are changed during the optimisation process, and the ensuing flow behaviour and pressure drop are examined. The identification of areas of flow separation, turbulence, and pressure losses within the filter is made possible by the CFD simulations. Design changes are done based on the CFD data to lower the pressure drop and improve the filter's efficiency.*

Key Words: **CFD, Energy Conservation, Head Loss, Convergence, Divergence**

1.INTRODUCTION

The design and upkeep of hydraulic systems depend heavily on filtration. To achieve dependable system operation, it is vital to regulate the degree of purity of hydraulic fluid. Without adequate filtration, pollutants like moisture, dirt, and debris can harm hydraulic parts and lead to system failure. Therefore, for optimum performance and to prevent downtime, correct filter design, installation, and maintenance are crucial.

It is essential to obtain accurate data on filter performance in real-world settings in order to build an effective filter for a hydraulic system. Using this knowledge, engineers may select the best filter for the job at hand and maximize its design specifications, including the filter medium, pore size, and geometry. By doing this, they can reduce pressure drop and service intervals while achieving the appropriate level of filtering efficiency and dirt removal capacity.

However, filtration effectiveness and dirt-removal capability are not the only factors to consider when choosing a filter for a given application. It is also necessary to consider additional elements like pressure drop and flow rate handling capabilities. For instance, if the filter's flow rate is too low, pressure may build up and the system's effectiveness may suffer. However, if the flow rate of the filter is too high, it may result in turbulence and lower filtration effectiveness. Furthermore, the pressure drop must be taken into account because it has an impact on the amount of effort needed to drive the hydraulic fluid through the filter. High-pressure drop filters have a tendency to use more energy and have higher running expenses.

In conclusion, careful consideration of a number of elements, including filter performance, flow rate handling capacity, pressure drop, and service intervals, is necessary when building an effective filtration system for a hydraulic system. Engineers can guarantee that the system runs dependably and efficiently while reducing downtime and maintenance costs by optimising these parameters.

Recent years have seen a substantial increase in interest in the use of conical filters for energy conservation in hydraulic systems. Conical filters have been optimised in several research to increase performance and decrease energy losses.

One study by Zhang et al. (2021) investigated the effect of conical filter geometries on pressure drop and filtration performance. The study found that increasing the cone angle of the filter increased the pressure drop, while decreasing the cone angle improved the filter's filtration efficiency. The optimal cone angle was found to be between 25-30 degrees, which provided a balance between pressure drop and filtration performance.

K. S. Kansara and K. H. Wu presented an optimization method for hydraulic filter design, taking into account factors such as filtration efficiency, pressure drop, and dirt holding capacity, and applies the method to a conical filter design for heavy-duty off-highway applications.

J. R. Younce and T. L. Simonson presented an experimental investigation of the effect of different geometric parameters of conical filter elements on their performance in terms of filtration efficiency and pressure drop.

K. Y. Chiu, K. W. Wang, and C. Y. Huang presented the design of a hydraulic filter element with a conical mesh structure, aimed at improving the filtration efficiency and dirt holding capacity compared to conventional flat mesh filters.

R.H. Warring (1983) demonstrated that the fluid viscosity performance curve varies for each filter type and size, and that the design and size of the overall filter—rather than the element—largely determines the relationship between pressure drop and flow rate.

RT. H. Peery and Cecil H. Chilton (1990) conducted research on the idea that the flow through a filter screen can be compared to the flow through a number of orifices simultaneously.

C. Contaldi, A. Maturo, and F. Oriani experimented on the performance of different hydraulic filter elements, including conical filters, in terms of filtration efficiency, pressure drop, and dirt holding capacity

A. V. Kozlov and A. N. Semenov presented a numerical solution for fluid flow in a conical filter element, analyzing the effect of different geometric parameters on the pressure drop and filtration efficiency.

Finally, it has been demonstrated that conical filters enhance energy conservation in hydraulic systems by lowering pressure drop and energy losses. Further study is required to optimise the conical filter design for energy conservation because the ideal filter shape, porosity, and mesh size can vary depending on the particular application.

2. IMPORTANCE OF SPECIAL TYPES OF FILTERS

Conical filters are of great importance in hydraulics due to their unique design and filtration capabilities. They have a conical shape, which enables a more uniform distribution of fluid flow across the filter's surface. This design reduces pressure drop and improves filtration efficiency, making them a highly effective choice for hydraulic systems.

One of the primary functions of conical filters is to remove contaminants from hydraulic fluid, such as dirt, debris, and moisture. Contaminants in the hydraulic fluid can cause significant damage to the system's components, leading to system failure and downtime. By effectively filtering out these contaminants, conical filters ensure that the hydraulic fluid remains clean and the system operates efficiently.

Conical filters are superior to other types of filters, such as cylindrical filters, in terms of their ability to filter as well as their capacity to hold more dirt. The frequency of filter changes and related downtime are reduced since they can hold more pollutants before needing replacement or maintenance.
Conical filters are also a reasonably priced option for hydraulic systems.

They are built differently than other types of filters, resulting in a reduced pressure drop, which lowers the energy needed to move hydraulic fluid through the system. Because of this energy efficiency, the system is more sustainable and has lower running expenses.

Overall, because of its distinctive design, filtration abilities, high dirt-holding capacity, and cost-effectiveness, conical filters are a crucial part of hydraulic systems.

They are essential in ensuring that hydraulic systems run dependably and effectively, with the least amount of downtime and maintenance expenses.

3. CONICAL FILTER CONSTRUCTION

The conical-type filter tested at CWPRS, Pune is a filtration system designed to remove contaminants from a fluid stream. This filter comprises of welded inclined plates, which are placed at a 5° angle with the axis passing through the center of the inlet. The filter is attached to a flat plate at a 90° angle. The fluid flow enters the conical-type filter through the inlet and then enters the filter element through the opening provided. As the fluid flows through the filter, the inclined plates cause the contaminants to separate from the fluid, allowing the clean fluid to pass through and the contaminants to be trapped. One important aspect of the conical-type filter is the flat plate that is attached to it. This plate acts as a resistance to the flow of fluid, thus decreasing the velocity of flow and increasing the pressure upstream of the flat plate. This increase in pressure helps to ensure that the fluid flow is maintained at a consistent rate, which is essential for the efficient operation of the filter.

Overall, the conical-type filter is an effective and reliable filtration system that can be used in a variety of applications to remove contaminants from fluid streams. Its unique design, which includes welded inclined plates and a flat plate, helps to ensure that the filter operates at peak efficiency, while also providing consistent and reliable performance over time.

Fig -1: Filter housing

4. TEST CIRCUIT

In order to calibrate flow metres and determine the performance characteristics of other flow elements, such as valves and filters, the calibration laboratory at CWPRS, Pune, is outfitted with a primary gravimetric standard (Figure 2). The principle used in the circuit for flow measurement is to precisely weigh the amount of water passing through the flow element being tested at a constant flow rate over a precisely timed period. The fundamental way to determine flow rate is the mass of water that has been diverted to time.

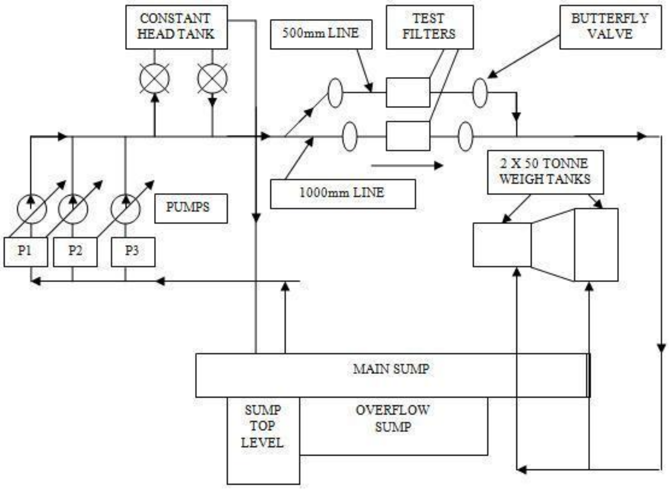

Fig -2: Test Circuit

The test circuit at CWPRS, where the filter was put through its paces, complies with ISO: 4185 and provided an 800 m3 capacity sump that served as a source of water for three parallel, variable-speed DC motor-driven pumps (700 LPS, 30 mwc), which feed water at a constant flow rate either into the Constant Head Tank (CHT) or directly into the flow metre line. Two 1000mm-sized throttling valves are offered for series operation, providing a fine control for controlling the flow rate through the test element. Pumps with variable speeds and a throttle valve on the bypass line that connects the pump delivery manifold and suction manifold are additional controls for adjusting flow rate.

After passing through one of the test filter's branches, the flow enters a set of diverters that directs it in one direction—to the sump—and in another—to the weigh tank. Additionally, it starts a high precision time counter that measures the length of time that water is diverted into a weighing system that consists of two weigh tanks, each with a capacity of 50 tonnes and mounted on load cells.

As a result, the time needed to gather the water in the weigh tank is measured with a one millisecond resolution. The net mass of water collected is the difference between the two mass measurements, or the original mass of the weigh tank before diversion of flow and the mass of the tank after diversion of flow.

5. INSTRUMENTATION

The details of instruments used and their accuracies are as follows:

Flow - + 0.3% by gravimetric method

Head - + 0.1% by precision manometer

Time - 0.001 second with digital timer

Flow stability of circuit- 0.001% of set flow rate

A five and half digit/time counter was used to measure the time of diversion into the measuring tank. By changing the speed of the pumps or by adjusting valves that were mounted on the test line downstream of the filter, the flow rate through the filter was adjusted to a desired value in the test range around the specified flow rate. The real flow rate was measured once the flow condition had stabilised. Near the rated flow rates as well as at different flow rate values, the pressure across the filter was monitored.

6. CFD MODEL

The CFD model was set up using Ansys Fluent. The k-epsilon model of turbulence was employed. The Reynoldsaveraged Navier-Stokes family of turbulence equations, which models all of turbulence's effects, includes the two-equation k-epsilon model.

Given that the model under consideration exhibits relatively small-scale flow phenomena and is predominantly characterized by straight flows, it can be inferred that the k-epsilon model is particularly well-suited for simulating such flows. This is because the k-epsilon model is known to perform well in cases where the turbulence is relatively simple and the flow can be approximated as being isotropic and homogeneous. In such scenarios, the k-epsilon model can effectively capture the dominant physical mechanisms responsible for turbulence and predict the fluid dynamics with a high degree of accuracy.

The mathematical model for the k-epsilon method is given by:-

For turbulent kinetic energy k,

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right]+2\mu_t E_{ij}E_{ij}-\rho\varepsilon$$

For dissipation ε,

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}E_{ij}-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

Where,

u_i is the velocity component in corresponding direction.

E_{ij} is the component of the rate of deformation.

μ_t is the eddy viscosity

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon}$$

The rest values are constants and are predefined.

Various vectors were set up for the computational fluid dynamics. The vectors were derived by analysing the working conditions of the filter.

These velocity vectors represent the direction and magnitude of fluid flow at each point within the domain. Velocity vectors are used to track the movement of fluid particles and to identify regions of high or low flow.The velocity vector was set up in Z–axis and the rest axes were disabled.

Reynolds stress vectors describe the fluctuations in velocity within the fluid due to turbulence. Reynolds stress vectors are used to model the effects of turbulence and to determine the level of mixing within the flow. The vectors were set up for obtaining fluctuations in all 3 axes.

Vorticity vectors represent the local rotation of fluid particles within the domain. Vorticity vectors are often used to analyze the formation of eddies or vortices within the flow and to identify regions of high shear stress. The filter causes vortices in all 3 axes hence the respective vectors were set respectively.

4. RESULTS AND CONCLUSION

The tests conducted on the divergent and convergent conical filters involved a comprehensive analysis of their filtering efficiency under different conditions. Specifically, the filters were tested with 8 Mesh and 40 Mesh variations under both 100% clean and 50% clogged conditions. The purpose of these tests was to evaluate the performance of the filters in terms of their ability to remove contaminants and to determine whether there were any noticeable differences between the divergent and convergent configurations. To support the experimental result, results, CWPRS also conducted CFD simulations using Ansys Fluent. This approach allowed them to simulate the flow of fluids through the filters and to visualize the flow patterns under different conditions. The filter itself was designed using Creo Parametric, a powerful software package that is commonly used for engineering design and analysis.

Overall, the combination of experimental testing and CFD simulations provided a comprehensive picture of the performance of the divergent and convergent conical filters. These results can be used to inform the design and optimization of filtration systems in a range of industries, including water treatment, oil and gas, and pharmaceuticals.

To conduct the computational fluid dynamics (CFD) simulations, the filter assembly first meshed using Ansys Mesh. The housing of the filter was meshed using a quadrilateral mesh, while the filter itself was meshed using the tetrahedral meshing method. This combination of mesh types was chosen to ensure a high level of accuracy and efficiency in the simulations. Overall, the complete setup consisted of 17980 nodes, which were distributed across the various components of the filter assembly. The meshed components were then initialized and tested using Ansys Fluent, a widely used software package for CFD simulations. During the simulation process, the researchers monitored a range of variables, including pressure, velocity, and turbulence, to analyze the behavior of the fluid as it passed through the filter assembly. These data were then used to calculate the pressure drop across the filter in each configuration, as well as to evaluate the overall performance of the filter in terms of filtration efficiency and other key metrics. By using a combination of advanced meshing techniques and state-of-the-art simulation software, the CWPRS were able to gain valuable insights into the performance of the filter assembly and identify key factors that influence its behavior.

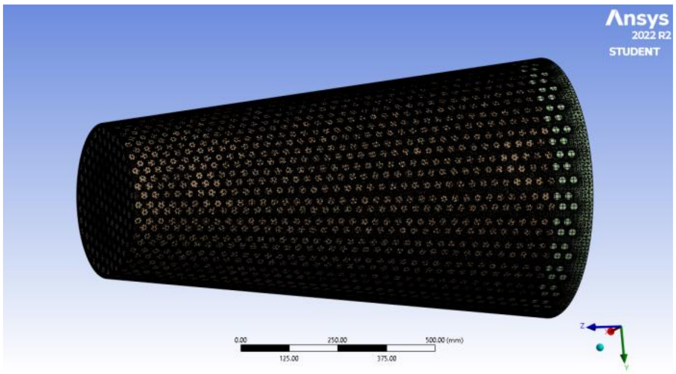

Fig -3: Meshing done on the filter

During the computational fluid dynamics (CFD) simulations, CWPRS observed a noticeable difference in the pressure drop between the divergence placement and the convergent arrangement. Specifically, the pressure drop was found to be greater in the divergence placement than in the convergent arrangement. These findings are supported by the data presented in Table-1, which clearly indicates the variations in pressure drop between the two configurations. It is worth noting that these results have important implications for the design and optimization of fluid systems, particularly in cases where minimizing pressure drop is critical to achieving optimal performance. Further research was conducted to explore the underlying causes of these observed differences and to develop more effective strategies for reducing pressure drop in the filter.

The pressure loss in the divergent and convergent configurations was found to be influenced by different components of the filter assembly. Specifically, in the divergent configuration, the base plate was identified as the main contributor to the pressure loss. This is likely due to the fact that the base plate provides a larger surface area for the fluid to pass through, which creates more friction and turbulence and ultimately results in a higher pressure drop.

On the other hand, in the convergent configuration, the conical plate was found to be the primary source of gradient pressure loss. The conical shape of this plate causes the fluid to accelerate as it passes through the narrowest point of the filter, which leads to a drop in pressure along the length of the plate.

The rim of the filter was found to contribute to the pressure loss in both the divergent and convergent configurations. This may be due to the fact that the rim provides a barrier that creates additional turbulence in the fluid flow, leading to increased friction and pressure drop.

Understanding the specific factors that contribute to pressure loss in different filter configurations is critical for optimizing filtration systems and ensuring their efficient operation. By identifying the sources of pressure loss, engineers and designers can develop strategies to minimize pressure drop and improve the overall performance of the filtration system.

In addition to identifying the specific components of the filter assembly that contribute to pressure loss, the researchers also explored the effect of various parameters on the performance of the divergent and convergent configurations. For example, they investigated the impact of mesh size and porosity on pressure drop and filtration efficiency.

Their findings indicated that a higher mesh size and porosity generally resulted in lower pressure drop and improved filtration efficiency. However, it is worth noting that there may be a trade-off between filtration efficiency and pressure drop, as increasing the mesh size and porosity can also lead to a reduction in filtering capacity.

Furthermore, CWPRS found that the orientation of the filter assembly can also have an impact on its performance. Specifically, they observed that changing the angle of the filter with respect to the flow direction can affect the distribution of flow and the resulting pressure drop.

Overall, these findings highlight the complex nature of filter performance and the need for a holistic approach to filtration system design and optimization. By considering a range of factors, including component design, mesh size and porosity, and filter orientation, engineers and designers can develop more effective filtration systems that achieve optimal performance while minimizing pressure drop and other undesirable effects.

Table -1: CFD Results for Convergent Filter

CONVERGENT				
FLOW RATE	100% CLEANED		50% CLOGGED	
	8 MESH	40 MESH	8 MESH	40 MESH
500	0.0182	0.2851	0.3732	0.5143

970	0.5938	0.6492	0.8934	1.287
1450	1.1847	1.7532	1.41	3.3794
1950	1.8324	3.1694	2.962	4.5321
2450	2.387	4.8563	4.7183	7.7493

In the studies conducted it was found out that, the base plate and rim play a crucial role in determining the pressure drop across the filter. The base plate is the solid surface on which the filter media is mounted, while the rim provides the seal to prevent the bypass of the fluid around the edges of the filter media.

Table 2 - For Divergent Filter

DIVERGENT				
FLOW RATE	100% CLEANED		50% CLOGGED	
	8 MESH	40 MESH	8 MESH	40 MESH
500	0.128	0.6512	0.5812	0.8641
970	1.4581	1.5829	1.3762	2.3361
1450	1.951	2.7513	2.3714	4.7612
1950	2.4371	4.5392	3.7491	5.9138
2450	4.1385	5.9142	5.3871	9.1628

In a divergent flow, the fluid flow is directly perpendicular to the base plate, which results in the highest pressure drop across the filter. This is because the fluid has to flow through the narrowest part of the filter media, and the resistance offered by the filter is at its maximum in this orientation. Therefore, the design of the filter should take into consideration the orientation of the fluid flow to ensure that the filter media is not overloaded and to minimize the pressure drop.

In contrast, in a convergent flow, the fluid flow is subjected to the gradient of the filter, which reduces the pressure drop across the filter. This is because the fluid flow is gradually compressed as it passes through the filter media, which reduces the resistance offered by the filter. However, in convergent flow, the fluid flow eventually strikes the base plate, which can cause turbulence and result in an increase in pressure drop.

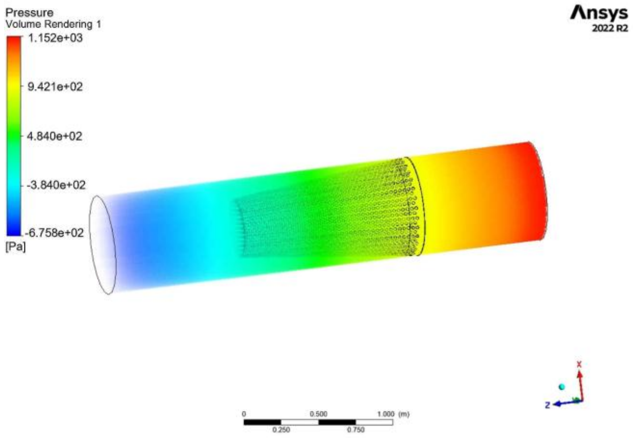

Fig -4: 100% Clean Condition

In summary, the base plate and rim of a filter play a critical role in determining the pressure drop across the filter. The orientation of the fluid flow with respect to the filter media must be considered in the design to ensure that the pressure drop is minimized, and that the efficiency of the filtration system is optimized. This is further highlighted in the CFD results.

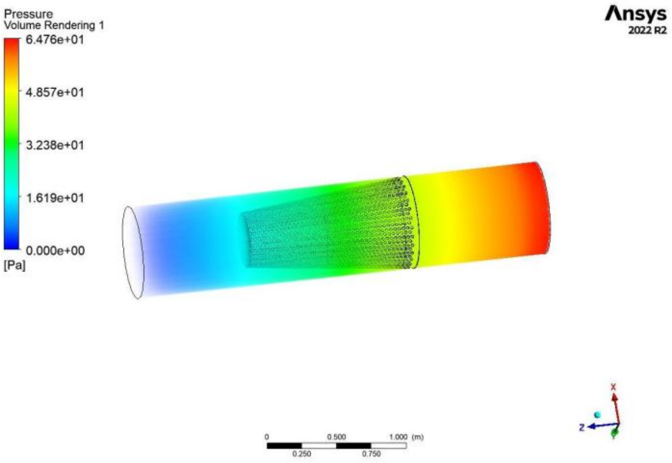

Fig -5: 50% Clogged Condition

When a filter is in a clogged condition, its performance can be severely impacted, and this is reflected in the pressure drop across the filter. In the case of a clogged filter, the pressure drop is least in the area where the filter is sealed. This is because the area that is sealed does not allow any flow to pass through, resulting in a lower pressure drop compared to the other parts of the filter.

RESULTS OBTAINED BY TESTING (Gravimetric Method)				
PRESSURE DROP				
FLOW RATE	100% CLEANED		50% CLOGGED	
	8 MESH	40 MESH	8 MESH	40 MESH
500	0.06	0.41	0.53	0.76
970	0.79	0.96	1.40	1.31
1450	1.55	2.00	2.91	1.84
1950	2.66	3.43	5.05	4.04
2450	4.13	4.45	7.81	6.35

The results obtained from CFD simulations can show the areas of the filter that are most affected by clogging. These areas may have higher pressure drops and may be more prone to damage or failure.

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