Design Optimization of Filter using CFD for Energy Conservation

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***Abstract*— The Research studies on filtration shows, over 70 Percentage of hydraulic systems failures are due to contamination or poor liquid conditions. Therefore filters are necessary in modern hydraulic systems to provide specified level of cleanliness, reliability, the hydraulic efficiency and the performance of the filters needs to be ensured the real life working conditions. For efficient operation of any pumping system, appropriate selection of associated pump is highly essential which in turn needs correct estimation of head losses of various elements specials of the pumping system including valves, filters, bends, piping etc. Since electric energy required for pumping reduces with reduction in head loss in pumping system. A need for minimum loss of head across the filters is required in pumping systems. On this background the selection of filter for a certain application is often based not solely on the filtration efficiency and dirt capacity but also low head across the filter.**

The paper highlights the improvisations effected in design of Y type filter through research undertaken at CWPRS for achieving percentage reduction in head loss with original design by using CFD simulation and experimentation. The reduction in head loss to such an extent had achieved huge saving in recurring expenditure towards power charges for pumping purpose.

Keywords*— *Y type filters; flow calibration circuit; CFD simulation; pressure drop; system resistance.

I. INTRODUCTION

Filtration is one of the most important areas in hydraulic system design and maintenance, but one that frequently contributes to downtime also. The purpose of the hydraulic filter is to control the cleanliness level of hydraulic fluid so that the reliably target of the whole system can be achieved. So in hydraulic systems, filters must be properly designed, installed and maintained. Also for initial design, it requires reliable data of the filter performance under real like conditions Further, the selection of filter for a certain application is not only based solely on the filtration efficiency and the dirt removal capacity but also depends on factors of flow rate handling capacity, pressure drop and service interval recommended etc.

R.H. Warring (1983) has shown that the relationship between pressure drop and flow rate is largely determined by the design and size of the complete filter, not the element and by the fluid viscosity performance curve are vary for each filter type and size .RT. H. Peery and Cecil H. Chilton (1990) studied about the flow through a filter screen can be considered as flow through a number of orifices in parallel.T. Christopher Dickenson (1997) indicated that in real hydraulic systems the filters are often exposed to highly variable flow, which decreases the filter performance. Hence the pressure drop test is most important when filters are operating on high flow rate. For efficient operation of any pumping system, appropriate selection of associated pump is highly essential which in turn needs correct estimation of head losses of various elements / specials of the pumping system including valves, filters, bends, piping etc. Since electric energy required for pumping reduces with reduction in head loss in pumping system. Gary S. Logsdon (2002) found that when a filter operated at a constant flow rate, head loss gradually increases throughout the run as the particles, which are to be removed from the liquid, are trapped within the filter screens. As such, to assess in advance the extent of increase in head loss due to clogging of filter elements and thereby increase in total head on pump, the new filters are also tested by simulation 50% clogged condition and to ascertain the extent of increase in head loss(Kumar et.al. 2016). Considering the findings of various researchers it is therefore considered necessary that filters are tested to assess the actual pressure drop across the filter with 100% clean condition and assess whether it is within limits of design values and also to establish the performance curves of the particular filter with 50% clogged conditions in order to set warning indication to safeguard the system against breakdown.

II. IMPORTANCE OF SPECIAL TYPE FILTERS

The selection of the perfect filtration solution contributes significantly for preventing damage caused by contamination besides ensuring availability of the system with minimum down time for cleaning of filter so as to achieve increase in the productivity. Further improper design and high head loss across the suction filters leads to reduction in available net positive suction head (NPSH) for the pump if installed in pump suction lines. This in turn can lead to occurrence of cavitation in pumps, which in turn will lead to impairing the pump performance and may result in sudden failure of pumps.

On the other hand, if pressure filters are fitted after the pump those need to be sized and designed for the system pressure and the flow rate of the pressure line in which they are installed. Wrong design and high head loss of pressure filters will have impact on the reduction in system efficiency. Where continuous operation of plant is essential, duplex filters/strainers are used as in an integral unit with one filter element in operation and other can be simultaneously cleaned. In this type of filter there is a provision to isolate one element at a time for cleaning with two changeover valves. This arrangement is used in the system to enable rapid changeover without interruption in operation of plant.

III. 'Y' Type Filter Construction

The Y type filter tested for NTPC Ltd at CWPRS, Pune comprises of welded flat plate, placed at an angle $60^o$with the axis passing through the centre of inlet as shown Figure1. The filter is attached to the flat plate at 90^o. The flow enters the Y type filter through the inlet and enters the filter element through the opening provided on the flat plate. Further, the flow gets filtered through the cylindrical filter element and leaving out into the Y shaped housing in the radial direction. The flat plate acts as a resistance to the flow of fluid, thus decreasing the velocity of flow and thereby increasing the pressure at the upstream of the flat plate. With a view to increase the head loss in the flow at the inlet of the filter element, a flat plate was welded in the filter shell. The manufacturer as per his design computations was anticipating head loss of 0.1bar across the filter at rated flow rate (488 m^3/hr) in clean condition and 0.15bar with 50% clogged condition. In order to access the real value of head loss with 100% clean and 50% chocked condition testing of filter was undertaken at CWPRS, in high precision facility with gravimetric method of flow measurement. The Y type filter was installed in the test circuit with above arrangement Fig1. to measure the flow rate through the filter.

Fig. 1. Y type filter testing at gravimetric calibration laboratory CWPRS, Pune

To adjust flow rate are, variable speed of pumps such that flow occurs, the Suitable pressure taps provided on the inlet and outlet of the filter was utilized for measurement of the upstream and downstream pressure.

IV. Test Circuit

The calibration facility at CWPRS, Pune, is equipped with a primary gravimetric standard (Figure2) wherein flow meters are calibrated and flow related performance factors of other flow elements like valves and filters are established. The principle employed in circuit for flow measurement is to accurately weigh the quantum of water passing at constant flow rate through the flow element under test in a precisely measured interval of time. The ratio of mass of diverted water to time is primary measure of flow rate.

The test circuit at CWPRS in which filter was tested is conforming to ISO: 4185 provided an 800 m3 capacity sump which acted as a source of water of the three variables speed-DC motor driven pumps (700 LPS, 30 mwc) operating in parallel which feed water at constant flow rate either into the Constant Head Tank (CHT) or directly in to the flow meter line. Two throttling valves of size 1000mm are provided to operate in series, which give a fine control for adjusting the flow rate through, test element. Additional controls to adjust flow rate are, variable speed of pumps and a throttle valve on bypass line connecting pump delivery manifold with suction manifold.

The flow after passing through one of the branches of the filter under test enters into diverters system, which diverts the flow to the sump in one position, and into the weigh tank in another. It also the triggers a high precision time counter used for measurement of time of diversion of water into weighing system; comprising of two weigh tanks, each of 50 Ton capacity installed on load cells.

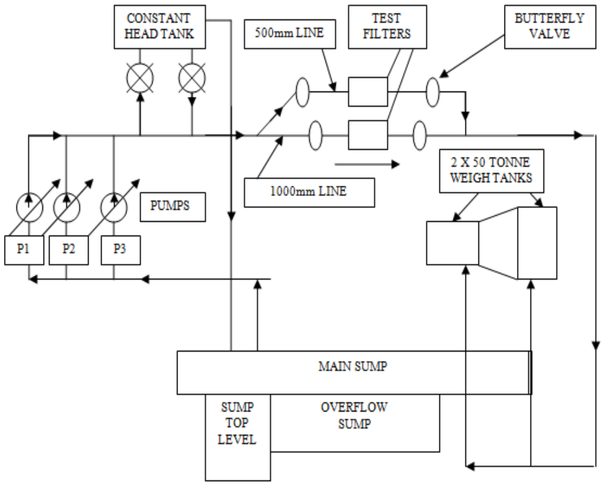

Fig. 2. Schematic diagram of gravimetric calibration circuit

Thus, the time taken for collection of water in the weigh tank is measured to a resolution of one millisecond. Difference of the two mass readings viz. initial mass of weigh tank before diversion of flow and mass of tank after diversion of flow is the net mass of water collected. The ratio of net mass to the collection time is the primary measure of flow rate.

V. 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. Flow rate through filter was adjusted to a desired value in the test range around rated flow rate by either speed variation of pumps or by maneuvering valves installed on the test line downstream of the filter. When flow condition was stabilized, the actual flow rate was measured. The pressure across the filter was measured near about the rated flow rates, as well as at variable flow rate values.

VI. Results And Conclusions

The tests were undertaken with the filter with original design. It was noticed that with 100% clean condition of filter the head loss across the filter was 0.18bar, which further increased to 0.190 bar with 50%, chocked condition. The test results (Table I) were deviating to a considerable extent from the values anticipated by the filter manufacturer. The filter design was also simulated by CFD Fluent analyser (Fig 3 &4). As such, when the design and construction of filter was reviewed by CWPRS, it was noticed that this increased head loss was owing to the following reasons:

-60°flat plate change in flow direction in header.

-Sudden contraction with 60°flat plat change in direction of flow manifold to 300 mm NB.

-Head loss through sharp bends downstream.

Considering all these aspects, CWPRS had undertaken actual head loss calculations for the entire filter system and it was observed that the estimated head loss was of the order of 0.18bar with presumption of smooth passage inside. The impingement plate was also contributing too much head loss since it was directly coming in the flow passage. The modified design was evolved in steps by smoothing these flow passages by avoiding sudden expansion, contraction, sudden sharp Y type shape, etc.

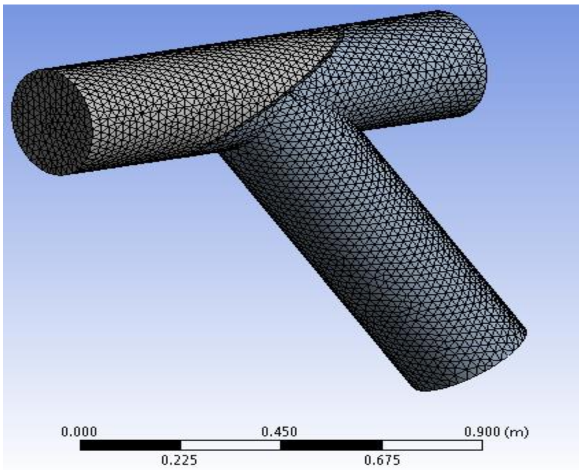

Fig. 3. Meshing Y Filter without Modified

The filter was tested for pressure loss under the variable flow range of 25% to 125% of rated flow. The head loss across the filter for rated flow rate viz. 488 m3/hr at different conditions is established. It was established that there impingement flat plate, the downstream bends were contributing significant resistance to flow. After the design modification of the each downstream bends, deflector flat plate assembly and expander assembly, it was identified that the filter assembly head loss at rated flow was 0.18 bar and 0.19 bar for 100% clean and 50% clogged conditions respectively.

These parameters are simulations on computational fluid dynamics ANSYS fluent approximation tool is used to simulate the head loss at real time condition for the filter at 100% clean condition head loss 0.14 bar for design flow rate of 488m3/hr. with mesh number of element 76135 and nodes 19406 using tetra Element.

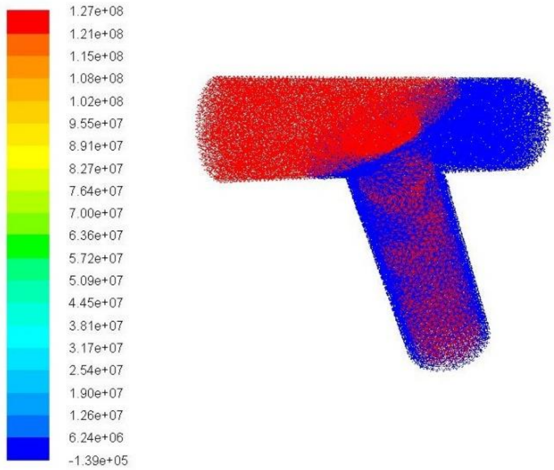

Fig. 4. Results CFD Fluent Pressure analysis of 100% clean condition without modified

TABLE I. Result of Head Loss in Filter With Original Design

Actual	Pressure Gauge Reading	Pressure

FLOW RATE (CUM/HR)	(MWC)		GAUGE READING (BAR)
	UPSTREAM PRESSURE	DOWNSTREAM PRESSURE	
	100 % CLEAN CONDITION		
151.542	0.65142	0.63504	0.01638
245.719	0.66276	0.62118	0.04158
367.791	0.69174	0.60732	0.08442
487.303	0.73710	0.55314	0.18396
566.301	0.77112	0.51660	0.25452
	50 % CLOGGED CONDITION		
127.526	0.65016	0.63882	0.01134
253.877	0.6678	0.61866	0.04914
360.649	0.69174	0.59346	0.09828
467.331	0.72450	0.56070	0.16380
491.816	0.73584	0.54810	0.18774

After the modification, the initial design provided circular filter elements, it was resulting head losses at flat plate. These were replaced by circular filter element to sheet type element, also remove 60 deg flat plate in to the shell. To modified downstream sharp Y shape bend add smooth curve. All these modifications incorporated. Filter carried out using commercial ANSYS-Fluent software using Finite Element Mesh type tetra element 169808 and number of nodes 37338 is shown in figure 5&6

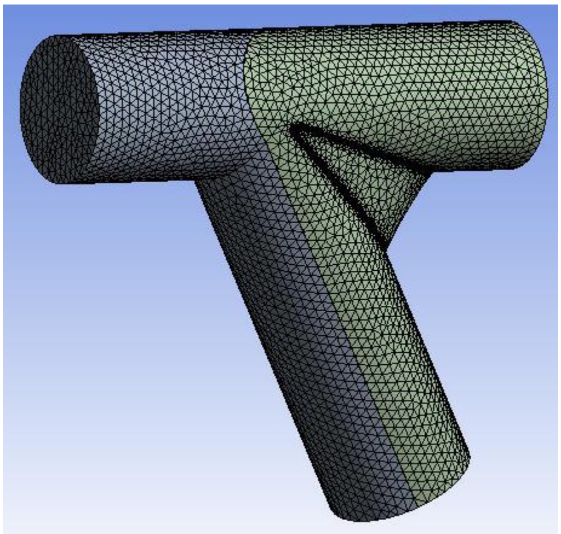

Fig. 5. Meshing Y Filter with Modified

filter. The Results obtained 50% clogged condition from CFD analysis 0.0496 bar and Experiments are compared and an accurate, CFD methodology to simulate filters (figure 6).

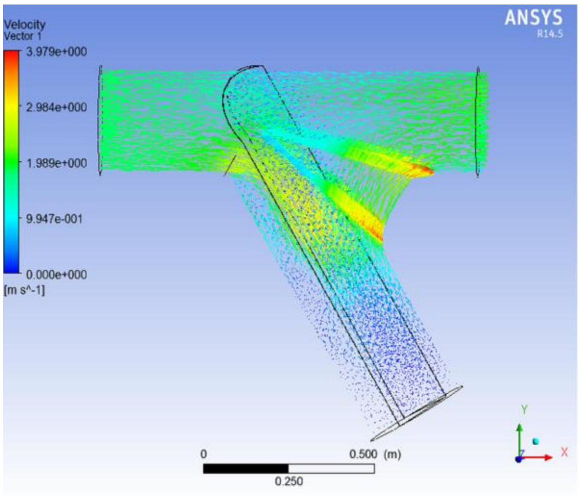

Fig. 6. Results CFD Fluent Pressure analysis of 50% clean condition with modified

The Pressure Drop obtained from CFD Simulation which is close the values anticipated by the filter manufacturer Then, experiments were repeated with 100% clean condition of filter and with 50% chocked condition in testing Lab, The head loss against the flow rate with the modifications are shown in table II.

TABLE II. HEAD LOSS IN FILTER WITH MODIFIED RESULTS

ACTUAL FLOW RATE (CUM/HR)	PRESSURE GAUGE READING (MWC)		PRESSURE GAUGE READING (BAR)
	UPSTREAM PRESSURE	DOWNSTREAM PRESSURE	
	100 % CLEAN CONDITION		
331.114	0.65268	0.63504	0.01764
369.112	0.65520	0.63252	0.02268
475.823	0.66780	0.62496	0.04284
598.023	0.67032	0.61614	0.05418
641.936	0.67536	0.61236	0.06300
	50 % CLOGGED CONDITION		
309.799	0.65394	0.63126	0.02268
359.150	0.65898	0.62748	0.03150
425.220	0.66402	0.62118	0.04284
502.115	0.67410	0.61236	0.06174
587.331	0.68670	0.59724	0.08946
634.749	0.69300	0.59346	0.09954

Pressure drop across the filter is analyzed experimentally and Numerically, Results of CFD analysis is found good agreement with the experimental results of without and with modified filter. Effect of filter area and shell of filter body replace. It is observed that, pressure drop higher if the 60 Deg flat plate and shell shape. The above studies helps in designing the filter to reduce head-loss form 0.18 to 0.05 bar at rated flow of 488 m3/hr. This design up gradation enable to effect huge power saving of the order of 2 kW in turn leading to saving of Rs. 87,600/unit per year considering Rs.5 per electrical unit.

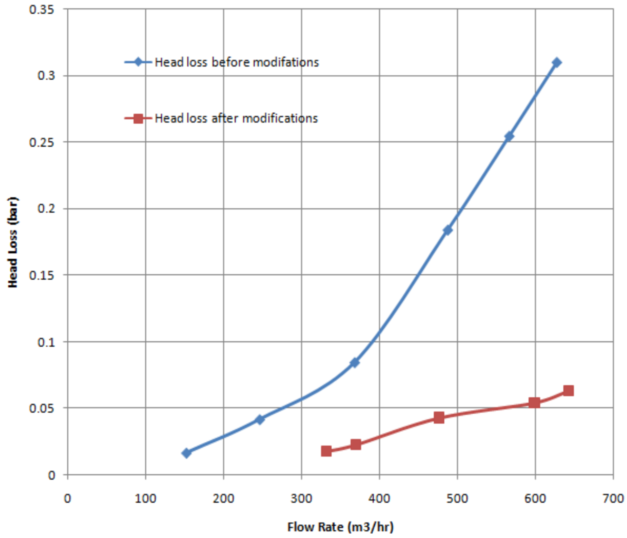

Fig. 7. Head loss Vs Flow Rate before and after modifications in 100 % clean condition

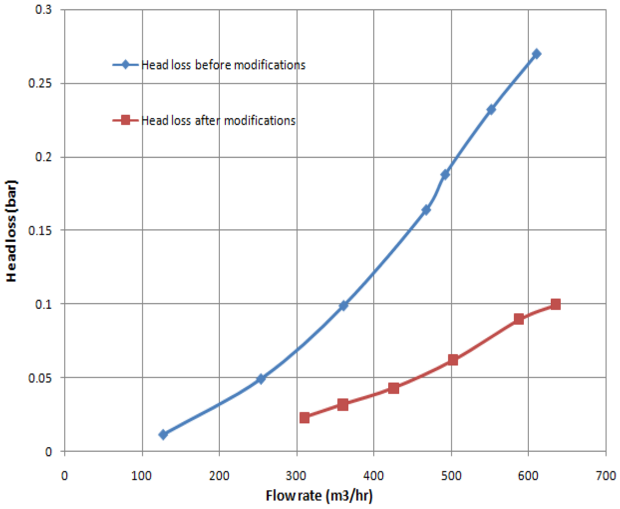

Fig. 8. Head loss Vs Flow Rate before and after modifications in 50 % clean condition

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