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Design and development of high performance panel air filter with experimental evaluation and analysis of filter media pleats

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ABSTRACT
In automobile vehicles mostly plastic molded panel filters used for the purpose of engine air filtration. Fibrous structured cellulose media were being used with different permeability's according to requirement of rated air flow rate required for the engine. To optimize the filter pleat design of automotive panel air filter, it is important to study correlation of pressure drop, dust holding capacity & efficiency. The main role of a filter is to provide least pressure drop with high dust holding and efficiency. A channel made for the testing of different pleat designs. This research comprises of experimental design & evaluation of filter element with variable pleat depth and pleat density. This assessment offers the selection of pleat design according to the performance requirements.
***Keywords* -** Panel air filter, pressure drop, dust holding capacity, efficiency, pleat depth, number of pleats.

I. INTRODUCTION

In recent development of air filters, generally they contain cellulose filter media & have been folded with the help of pleating machine. Engine air filter can be used to protect the mechanical parts of engine from deteriorating; the air coming from the atmosphere to the intake should arrest fine particles with high efficiency. With the same time it should withstand low pressure drop & high service life i.e.; high dust holding capacity. To get these responses generally designer defines paper permeability, so that high permeability media gives low pressure drop but it should not able to give high efficiency.

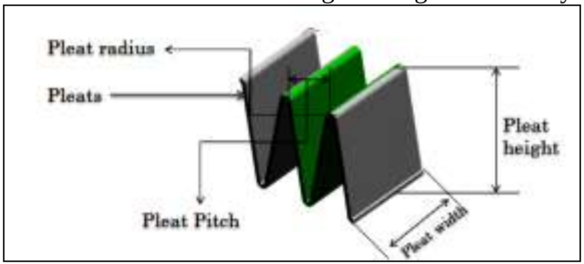

Figure 1 Pleat design configuration

Objective of this research is to investigate the effect of pleat depth & NOP (number of pleats) shown in figure.1 on pressure drop, dust holding capacity & efficiency, also detection of pleat design model at the optimal & minimal performance levels. The foremost purpose which makes this evaluation treasured that the experimental exploration of pleat design model, selection of design model with consideration of pleat depths & NOP according to the benchmark of automotive air filters, different trends of performance modes has evaluated.

II. PREVIOUS WORK

Previous work has been done for the evaluation of pressure drop of panel filters not for the efficiency and the dust holding capacity. Similar evaluation has done for the cylindrical type cartridge filters.

III. EXPERIMENTAL MODEL

A rectangular channel made for the experimentation of air filter testing. Rectangular channel given in fig.1 connected to the air filter test rig. This air filter testing set up contains dust ejection unit, Filter housing, mounting jig, Pressure sensor connecting points, absolute filter, controller, flow meter, flow rate adjusting valve & blower. Air flow rate of 0.4 cubic meters per minute set in the testing rig. This test rig runs at the same air flow rate. A standard frame of the filter made up of length 136mm & width 112mm. In rectangular channel length of inlet & outlet 100mm as shown in fig.1

Length of the dirty side of filter frame from the inlet & length clean side from the outlet is 200mm.

Height of the channel is 150mm and width of the channel is 125mm. An experimental model developed for the different pleat designs as shown in Table 1

Air flow rate (m3/min)	Run	Pleat depth (mm)	NOP (No's)	Filtration area (m^2)	Face velocity (m^3/min)
0.4	1	15	9	0.025	0.01
	2	15	29	0.082	0.03
	3	15	53	0.151	0.06
	4	30	9	0.051	0.02
	5	30	29	0.165	0.07
	6	30	53	0.302	0.12
	7	40	9	0.068	0.03
	8	40	29	0.220	0.09
	9	40	53	0.402	0.16

Table 2

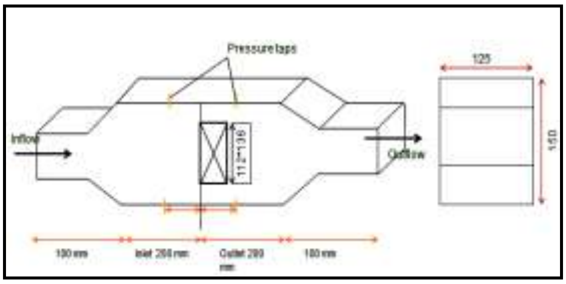

Figure 2 rectangular channel

Pleat depth & number of pleats is considered on three levels i.e.; pleat depth 15mm, 30mm & 40mm, NOP 9mm, 29mm & 53mm. According to this design models, paper pack of the variable pleat geometry fitted into the inside frame of rectangular channel with the help of hot melt. The pleat pitch also differs on three levels i.e.; 15mm, 5mm & 3 mm. This experimental design model runs on 9 levels.

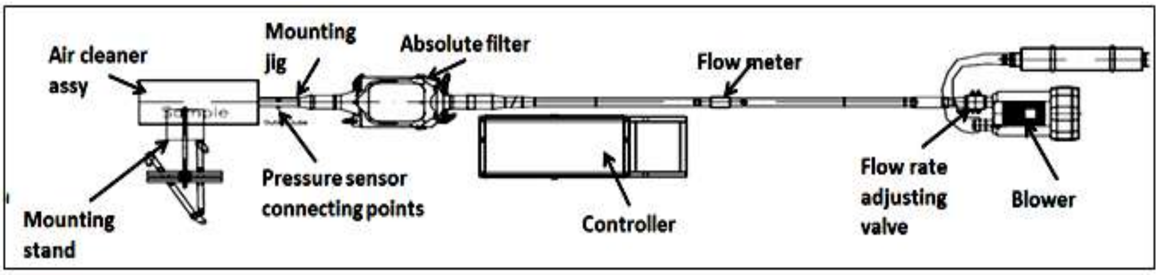

Figure 3 Air filter test set up

Outcome of this experiments are pressure drop, dust, holding capacity & efficiency.

Test dust A2 fine used as per ISO standard 12130-1. Dust particles were injected into the inlet of rectangular channel at the rate of 1gm /min as per the standard ISO 5011.Filter media of permeability 491in liter per square meter sec we kept constant.

IV. TESTING PROCEDURE

Outlet of rectangular channel is connected to the mounting jig. Rectangular channel is mounted on the stand so as it to match the level of dust feeder. For the assessment of pressure drop, we need to set the detection level at 50%, 75%, 100%, 125% & 150% of (0.4m3/min) rated air flow rate. We consider the pressure drop at 100% of rated air flow rate for evaluation. After testing of pressure drop next is dust holding capacity and efficiency measurement testing. We need to set rated air flow rate in the controller with the (1gm/min) dust flow rate. We terminate this test at final pressure drop; final pressure drop is initial pressure drop plus 100 mmaq of pressure. Weight of the filter housing and filter element has automatically been taken by the controller, as the controller is directly connected to the weighing balance. Dust fed through the dust feeder into the inlet of filter housing. Dust passed through the filter element will be collected into the absolute filter. After achieving the terminating condition we need to take the weight of filter housing & filter element to calculate the dust holding capacity. We need to take before after weight of absolute filter for the calculation of efficiency.

Formula to calculate efficiency:

$$E = \left(1 - \frac{G_1}{G_2}\right).100$$

Equation 1

Efficiency (E) can be defined by equation 1. Where G1 is an amount of penetrated particles (which haven´t been captured) and G2 is total amount of particles upstream. It is the ratio of particles captured by a filter over the total number of particles found in the air upstream of the filter. Filter efficiency can either be based on specific particle size ranges or based on the total number of particles of all sizes.

V. EXPERIMENTAL RESULTS

Experimental results of these design models categorized in two main categories. Dry media and their effect of pleat depth on pressure drop, DHC & efficiency. Similarly the effect of number of pleats on pressure drop, DHC & efficiency.

The pressure drop across cellulosic filter media found decreasing with increase in pleat depth as shown in figure.3 .NOP-9 sample is higher restriction than NOP-29 & NOP-53, while pressure drop of NOP-29 sample is showing increasing trend after 30mm pleat depth, pressure drop trend of NOP-53 is linearly decreasing.

The dust holding capacity across cellulosic filter media was found to increase with increase in pleat depth. NOP-53 sample is higher DHC than NOP-9 & NOP-29; NOP-9 sample is lower DHC than NOP -29 & NOP=-53.Graph plot of DHC shown in figure.4 is linearly increasing with increase in pleat depth.

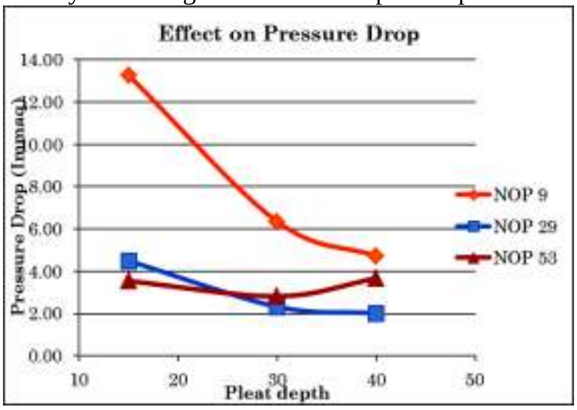

Figure 4 Effect of pleat depth on pressure drop

The efficiency across cellulosic filter media was found mix effect of linearly increasing and decreasing at variable pleat depth shown in figure.5. NOP 9 sample is showing down trend while increase in pleat depth. NOP 29 sample is showing in uptrend while increase in pleat depth. NOP 50 showing up trend up to 30 pleat depth and instant down trend up to 40 pleat depth.

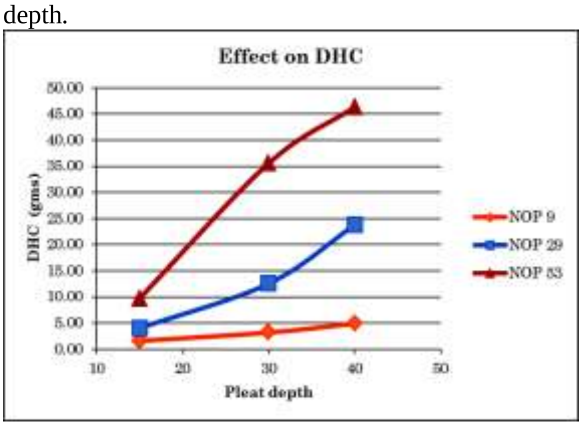

Figure 5Effect of pleat depth on DHC

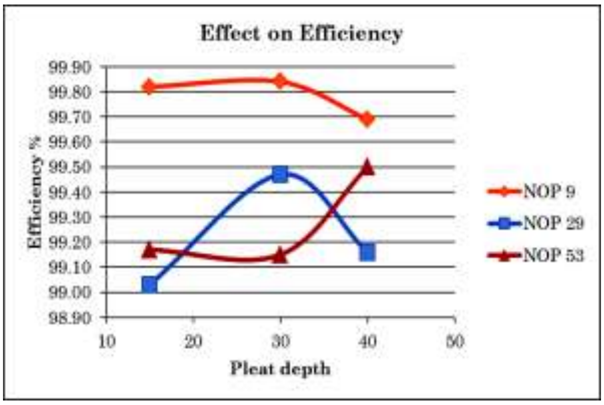

Figure 6 Effect of pleat depth on efficiency

Effect of NOP on Performance parameters as explained below. The pressure drop across cellulosic filter media was found to decrease with increase in pleat depth. Pleat depth-15 filter element is higher restriction than pleat depth-30 & pleat depth-40 as shown in figure.6.

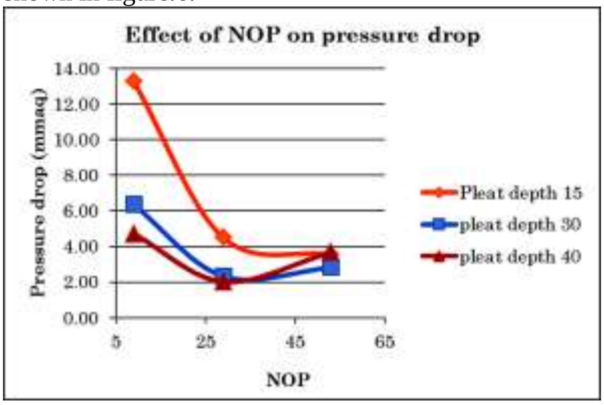

Figure 7 Effect of NOP on pressure drop

The dust holding capacity across cellulosic filter media was found to increase with increase in NOP. Pleat depth 40 sample is higher DHC than pleat depth 15 & pleat depth 30, pleat depth 15 sample is lower DHC than pleat depth 30 & pleat depth 40. Graph plot of DHC is linearly increasing with increase in NOP as shown in figure.7.

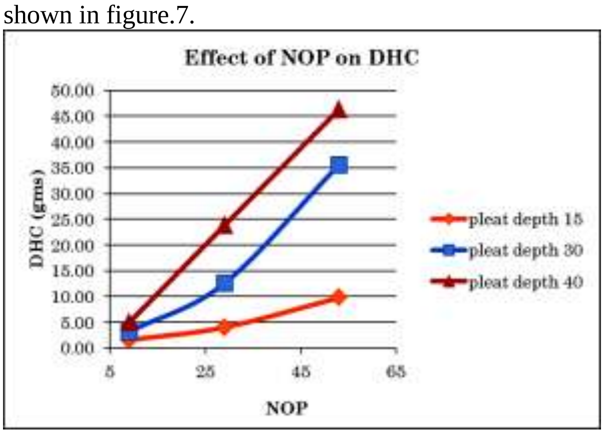

Figure 8 Effect of NOP on DHC (dust holding capacity)

The efficiency across cellulosic filter media was found mix effect of linearly increasing and decreasing at variable NOP, except pleat depth 30. Pleat depth 15 sample is showing higher efficiency at lower number of pleats, it is getting decreasing as increase in NOP up to 29 NOP & getting higher from 29 NOP. Pleat depth 30 sample is showing linear trend of decreasing efficiency while increase in number of pleats. Pleat depth 40 sample is showing higher efficiency at lower number of pleats, it get decreasing as increase in NOP up to 29 NOP & getting higher from 29 NOP as shown in figure.8.

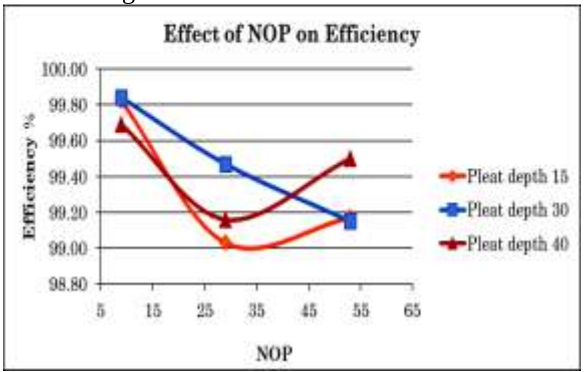

Figure 9 Effect of NOP on efficiency

We are using counter plot for the analysis of performance parameters, use of contour plot helps to visualize the response surface. Contour plots are useful for creating desirable response values and operating conditions. This plot shows how a response variable relates to two factors based on a model equation. Points that have the same response are connected to produce contour lines of constant responses. Because a contour plot shows only two factors at a time i.e.; pleat depth and NOP, while holding any other factors and covariates at a constant level.

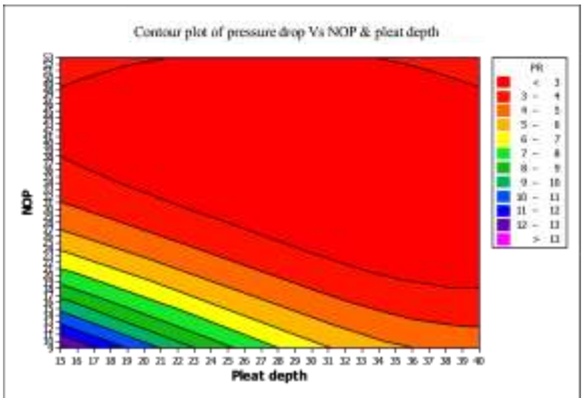

Figure 10 Contour plot of PD vs. NOP & pleat depth

Contour plot of pressure drop (PD) is showing linearly decreasing trend. We can plot exact values of pressure drop at specified NOP & pleat dept. Contour plot of DHC shows linear increasing trend .We can plot exact values of DHC at specified NOP & pleat depth. Contour plot of efficiency is showing linear increasing trend but it is independent on pleat depth, as the number of pleats increases efficiency also increases as shown in figure.10.

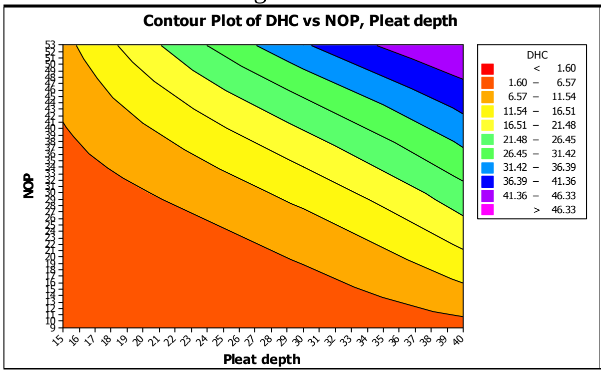

Figure 11 effect of DHC vs. NOP & pleat depth

Evaluation of effects of pressure drop with respect to face velocity, DHC & efficiency is very important. Figure.13 & figure.14 shows the contour plot of pressure drop verses DHC, efficiency & face velocity. Face velocity is the ratio of rated air flow rate and filtration area. Filtration area and face velocity of variable pleat designs has shown in table 1. In figure.13 contour plot showing the increment of DHC with increase in face velocity, Also the DHC is higher at lower pressure drop. In figure.14 efficiency decreases with increase in face velocity, also pressure drop will be higher at lower face velocities.

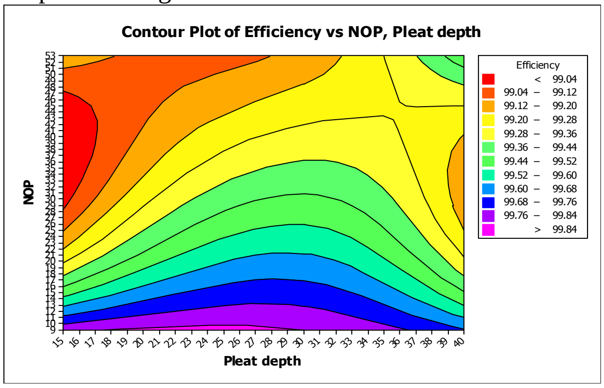

Figure 12 Effect of efficiency vs. NOP & pleat depth

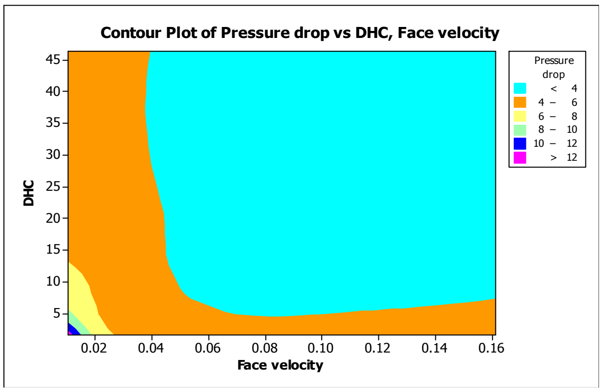

Figure 13 Contour plot of pressure drop vs. DHC & face velocity

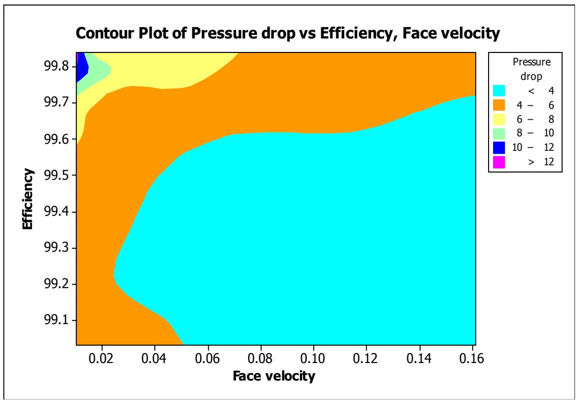

Figure 14 Contour plot of pressure drop vs. efficiency & face velocity

Figure.15 shows that air flow rate increases linearly with increase in pressure drop. All pleat deign models were plotted in the same graph so as to observe change in pressure drop with respect to air low rate.

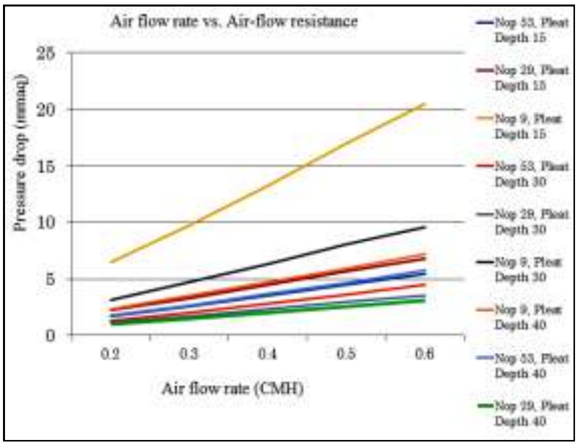

Figure 15 Graph plot of pressure drop vs. air flow rate.

VI. CONCLUSIONS

1. Performances effect of pleat depths shows design model NOP-53 & pleat depth-40 having lower pressure drop, higher DHC and higher efficiency.
2. Similarly performance effect of NOP shows enhanced effect at design model NOP-53 & pleat depth-40.
3. According to counter plot of pressure drop, decreasing in pressure drop with increase in pleat density and depth.
4. According to counter plot of DHC, it shows linear increasing effect with increase in filtration area.
5. According to counter plot of efficiency shows increasing effect with decrease in number of pleats, but it is independent on pleat depth.
6. Counter plot of pressure drop shown in figure 13 & figure 14 gives the directly proportional relation with face velocity. DHC increases with increase in face velocity at the same time decrease in pressure drop, It is opposite for the efficiency, increase in face velocity gives decrease in efficiency and pressure drop.
7. Pressure drop is linearly increasing with increase in flow rate, Figure 15 shows pressure drop readily decreasing with increase in pleat depth, influence of pleat depth more than NOP on pressure drop. Hence design model NOP-29 & pleat depth-40 shows lower pressure drop.

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