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Sensitivity Analysis of Process Parameters for Polyurethane Based Panel Air Filters

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Abstract**:** *The polyurethane processing for panel air filters (flexible foam)for high yield (free of all defects) is very critical and sensitive on account of Polyurethane making chemistry, short reaction times, process conditions, ambient temperature and humidity , equipment dispensing-mixing precision and moulds' surface quality, moulds' temperature and uniformity impacting the defects in filters like pin holes, short filling, over filling or growth, skin damage, loose skin, voids, hardness variations, shrink marks, knit lines etc. Research is conducted to study and establish a correlation between various parameters so that process settings can be altered to ensure minimum variation to output in spite of variation in inputs and noise to the system.*

Keywords**:** *Cell, Gel time, ISO Ratio, Nucleation.*

Cell-A single small cavity surrounded partially or completely by walls
Gel Time-For polyurethanes, the interval of time between mixing together the Polyol and the di-isocyanate and the formation of the non flowing, semisolid jelly like system
ISO ratio-The selected ratio by weight of Isocyanate with Polyol as 100
Nucleation- Process of forcing in air particles as bubbles in the Polyol molecules.

I. INTRODUCTION

THE market in India for polyurethane panel air filters is growing in line with the automotive growth in 4 wheelers and two wheelers with an additional volume for the after sales market generally with one to two filters per year per vehicle.

The challenge for the organized sector, manufacturing these filters as suppliers to the OEMs is high productivity coupled with high yield.

Typically the limiting process for productivity in the filter production will be the floor to floor time at the dispensing station which can be called as the constraint or bottleneck of the production line.

The low yield is on account of a process which is too sensitive to Polyurethane making chemistry, short reaction times, process conditions, ambient temperature and humidity , equipment dispensing-mixing precision and moulds' surface quality, moulds' temperature and uniformity impacting the defects in filters like pin holes, short filling, over filling or growth, skin damage, loose skin, voids, hardness variations, shrink marks, knit lines etc. The current defects' percentage is about 35% for a medium size rectangular filter on account of above defects.

To improve the overall productivity coupled with high yield, a research is conducted to study the correlation of various parameters on the presence of defects or the extent of defects.

The research is mainly being done in the following area-

a) Three-dimensional topographical analysis of foam surface texture, cream time changes and hardness as a function of mould temperature and its uniformity within the mould.

b) The surface hardness of the foam at various points on the product as a function of mixing ratio and controlled growth through varying grammage for definite inputs of raw materials.

c) The density and hardness of the foam as a function of the nucleation of Polyol.

d) The texture of the molded foam surface as a function of the type, concentration, spread and application process of mould release agent.

Currently the results of various experiments and observations are directing in making concrete hypothesis leading towards defining processes to make the panel filters free of various defects.

We hope to draw conclusions in the above research areas by and proving the same over a new production line which is expected to run with a production speed of about 600 filters per hour.

II. EXPERIMENTS AND OBSERVATIONS

The material and set up used for experimentation is as follows
Polyol (A component) Bayer grade---UASH 007592
Brookfield Viscocity---11.53Stokes, Density---1026 kg/m^3
Temperature of Polyol at mixing point- 25 ^{0}C
Isocyanate (B component) Bayer grade--- P4DB000389
Viscosity---1.28 Stokes, Density---1218 kg/m^3
Temperature of ISO at mixing point-25 ^{0}C
Standard mixing ratio-100:38
Polyol is well mixed before taking it in the day tank.
Polyol is stirred adequately in the day tank.
Line pressures-
A component- 9.5 N/m^2. B component—8.8 N/m^2

It is necessary for the experiments to be carried out , a precise system which will have accuracy of dispensing, Polyol-ISO ratio maintenance, capability of maintaining set temperatures of A and B components, capability of maintaining set line pressures, capability to dispense at set mould temperature, measurement of nucleation. A dispensing system with all the above capabilities is used and process capabilities of A and B components at 20 grams per second with 1 % and 2 % tolerance on mean dispense weight was calculated as shown in table I. The dispensing process capabilities are quite high and hence it is good to think that the results (output) of the various experiments should be quite precise.

TABLE I - PROCESS CAPABILITY OF THE POLYURETHANE DISPENSING MACHINE

Component	Grams /sec	Time	Weight	Tol +/-	Wt .Max	Wt. Min	Cp	Cpk
A	20	1	2.74	2%	2.74	2.75	12.84	12.77
A	20	2	8.23	1%	8.23	8.25	16.03	14.86
B	20	1	21.73	2%	21.74	21.71	3.3	3.16
B	20	2	7.43	1%	7.43	7.45	2.73	2.5

A.Effect of Nucleation Coupled with Mixing Speed on Density of Polyurethane

The effect of different levels of nucleation was done to study the effect on density of polyurethane and its hardness.

TABLE II- CORRELATION OF MIXING SPEED TO DENSITY OF POLYURETHANE FLEXIBLE FOAM

Sr.No.	Nucleation condition	Mixing speed	Density Kg/M3	Hardness after 24 hrs Shore A
1	Not done	2500	496	48
2	Not done	2500	497	47
3	Not done	3000	489	44
4	Not done	3000	486	44
5	Not done	3500	484	43
6	Not done	3500	483	42
7	Not done	4000	465	43
8	Not done	4000	468	42
1	Done	2500	398	32-33
2	Done	2500	398	
3	Done	3000	395	31-32
4	Done	3000	395	
5	Done	3500	393	31-32
6	Done	3500	393	
7	Done	4000	392	31-33
8	Done	4000	392	

The experiment above is done at various times and with different barrels of material to confirm the observations and trend. With no nucleation of Polyol the bubble formation is limited in size and the cell size remains small and the cell walls are quite strong. Hence the result on density is higher and the hardness too is higher. As the mixing speed is increased, under the standard day tank pressure, the entrapment of air shows higher volume which gives a little higher scope for the CO_2 gas in the blowing reaction to inflate the cell, making the PU cell structure of a lower density and lower hardness.

As the Polyol is nucleated to a reasonably mature scale, the entrapped air allows the CO_2 gas to enlarge the cell substantially lowering the density reasonably low at a lower hardness. It is also seen that the effect of mixing speed is negligible in a nucleated condition.

The foam microstructure is also studied under various experiment conditions and shows considerable change in the morphology and appearance.

B. Effect of Mould Temperature on the Hardness and Rise Time of Polyurethane

The moulds used for this experiment are plastic in Polypropylene. They are heated in a convection oven for the temperatures and then polyurethane is dispensed in it confirming the set mold temperatures for the specific grammage in the specific ratio.

The change in cream time and the change in hardness is noted. Each experiment repeated 5 times to check consistency and reduce measurement error. The higher mold temperature creates increased cell size and hence reduction in hardness.

TABLE III- CORRELATION OF MOULD TEMPERATURE TO RISE TIME OF POLYURETHANE IN MOULD CAVITY

Sr.No.	Sample No	Mould temp. (^{0}C)+/- 2 °	Mixing RPM	Nucleation	Gel time in Seconds	Hardness on Product Shore A
1	A1-A5	35	3000	Done	21	45-47
6	B1-B5	40	3000	Done	19	45-47
11	C1-C5	45	3000	Done	18	45-48
16	D1-D5	50	3000	Done	16	44-45
21	E1-E5	55	3000	Done	15	43-44
26	F1-F5	60	3000	Done	14	40-41
31	G1-G5	65	3000	Done	13	39-41

C. Effect of Variation in Mixing Ratio on Polyurethane Hardness

The mixing ratio was varied to see the effect on hardness. The observations were done on 5 samples at each value of mixing ratio. The hardness was measured in the free rise state after dispensing. Measurements of hardness were made after 30 minutes, 2 hours, 4 hours, 6 hours, 8 hours and 24 hours. The PU curing was done in ambient temperature. Generally the measurement position for each cup was considered at the same point. The changes in the hardness pattern above and below the 100:38 ratio position are studied carefully and related to the rate of reaction with respect to time. It is also interesting to see the changes in hardness along with density of foam at the specific ratio

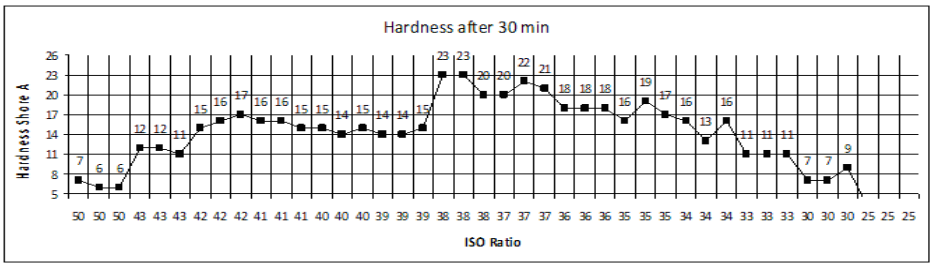

Fig. 1 Graph between 'ISO Ratio' vs. 'Hardness Shore A' after 30min.

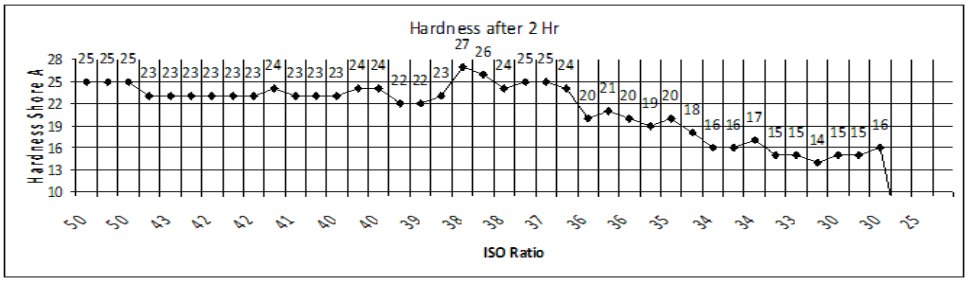

Fig. 2 Graph between 'ISO Ratio' vs. 'Hardness Shore A' after 2 Hrs.

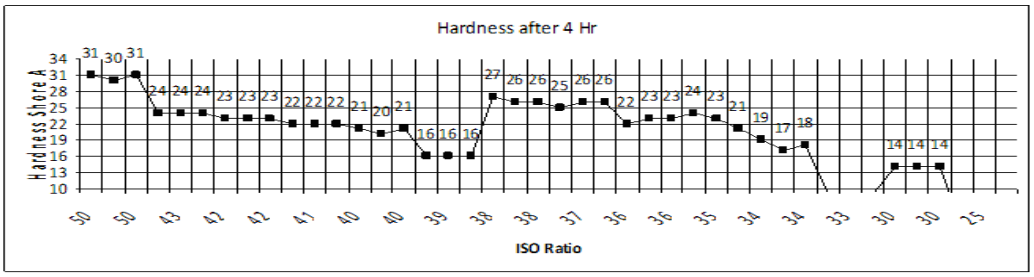

Fig. 3 Graph between 'ISO Ratio' vs. 'Hardness Shore A' after 4 Hrs.

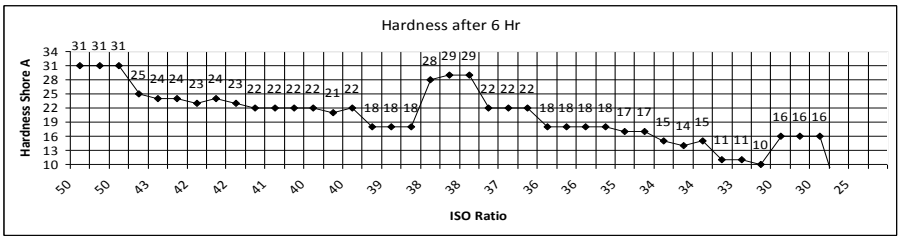

Fig. 4 Graph between 'ISO Ratio' vs. 'Hardness Shore A' after 6 Hrs.

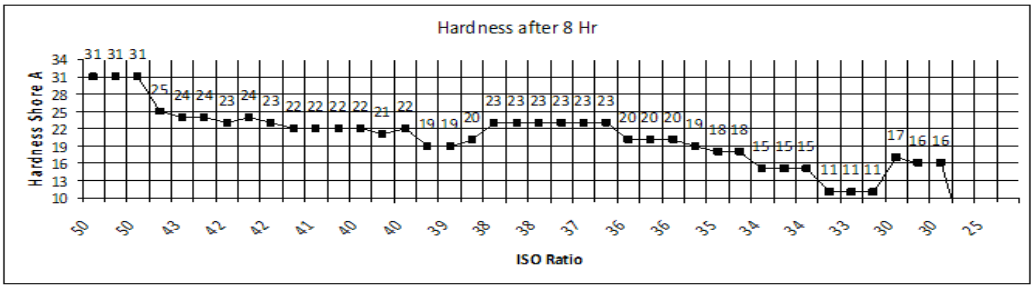

Fig. 5 Graph between' ISO Ratio' vs. 'Hardness Shore A' after 8 Hrs

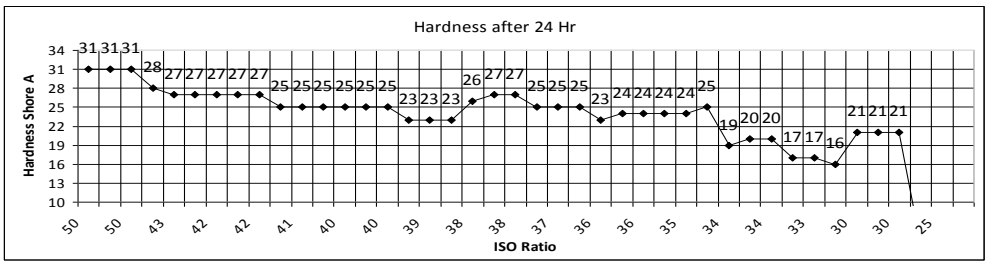

Fig. 6 Graph between 'ISO Ratio' vs. 'Hardness Shore A' after 24 Hrs

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D.Effect of Variation in Mixing Ratio on Polyurethane Density

The standard ratio is Polyol 100: ISO 38 by weight.

For the standard grammage output of polyurethane, the ratios are altered from 100:55 to 100:33 to see the change in density and also the microstructure of the polyurethane foam. All other parameters of processing are

kept the same

The change is density is plotted as shown below. The microstructure change is also noteworthy and not elaborated here due to space limitation

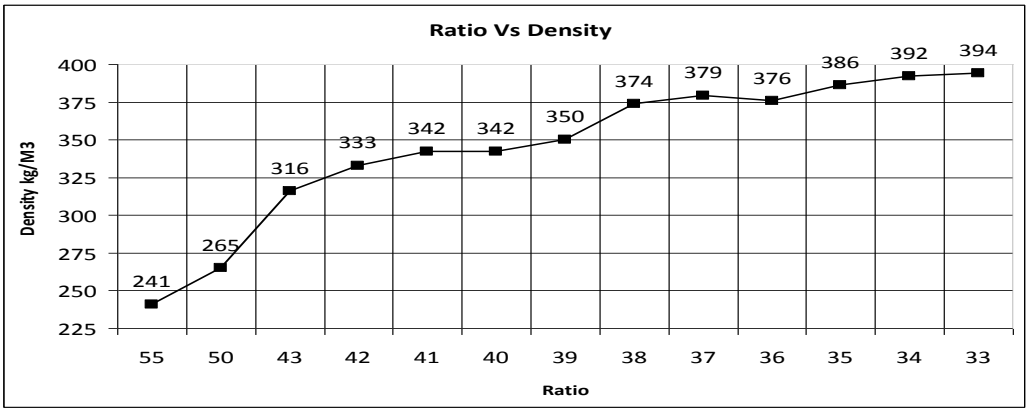

Fig. 7 Graph between Hardness Ratio vs. Density (Kg/m^3)

III. CONCLUSION

In Polyurethane processing, the process is very sensitive to various process parameters along with the basic materials to obtain necessary end results in terms of morphology and physical properties free of aesthetic defects. The experiments and the observations above have given a lot of insight.

The topographical analysis and the textural differences of the foam and the surface through photographs could not be attached due to limitation of space.

This research further aims to find correlations of material temperature variations, the shear rate effect due to stirring, the viscosity changes while dispensing, mould temperature on microstructure of PU, the skin thickness and the hardness/density variations in the cross section of the flexible foam.

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