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DESIGN AND ANALYSIS OF ONCE-THROUGH VENTILATION SYSTEM

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Abstract : In this paper a study of 2 HVAC duct systems is presented. One which is old and needs to be replaced and the other which is proposed to replace the existing system. Both the systems under consideration are analytically studied and the results of the proposed system are validated using software. All the calculations mainly revolve around the formula of discharge and the pressure loss in the duct due to friction. The results so obtained conclude that the proposed system is suitable to be implemented practically.

***IndexTerms* –** HVAC, Ducts, Simulation, Fluidflow

I. INTRODUCTION

HVAC stands for Heating, Ventilation and Air Conditioning which is the use of various technologies to control the temperature, humidity and purity of air in an enclosed space. The main goal of any such system is to provide thermal comfort and acceptable indoor air quality. It forms a critical part of any residential structure such as single-family homes, apartment buildings, hotels and senior living facilities and also large industrial and office buildings. A very vital component of any such system are ducts. These are basically conduits that supply warm or cool air to heat, ventilate and cool each room. These are generally connected to the unit which filters then heats to cools air before sending it off through the ducts. Ducts are generally of two types: Supply Duct and Return Ducts. Supply ducts blow warm or cool air to a particular area. These often have dampers to control the flow, which are installed near windows or doors to better counteract the loss of heat or cold. Return ducts extract air form the living spaces back to the HVAC unit, feeding either the furnace or AHU. The return vents are usually larger than supply vents. A filter is generally installed deep inside a return duct to protect the HVAC unit from impurities. The existing system under consideration in our present study mainly consists of 8 components: Pre-Filter, HEPA Filter , Air Handling Unit , Blowers , Plenum , Duct System , Dampers and grills. This current system caters to the need of 4 Rooms using a supply blower of 10,000 CMH capacity. But this system has been in use for over 20 years and now needs to be replaced. Our new system proposes the use of a blower of 17,000 CMH capacity in order to fulfil the cooling requirements of the 4 rooms and 2 more additional rooms which will cater to the need of radiopharmaceuticals. The results obtained by the analytical methods are then verified by using Fluidflow software and the obtained results are presented in this paper.

II. LITERATURE REVIEW

Research on duct system design has been done previously in different domains ranging from a fibreless based duct silencer to a new design to make AHU’s more energy efficient.[1] proposes an environment-friendly based silencer concept for noise control. Conventionally the silencer used are made of fibrous materials, which are unfavorable mainly due to the emission of harmful particles when exposed to media flow. In this study, a commercially available microperforated sheet metal panel was manufactured and an aluminum alloy was selected and implemented in the silencer design. Overall, one can see that the acoustic characteristics of the new silencer outbalance the average characteristics of the exiting silencers while being smaller in size and

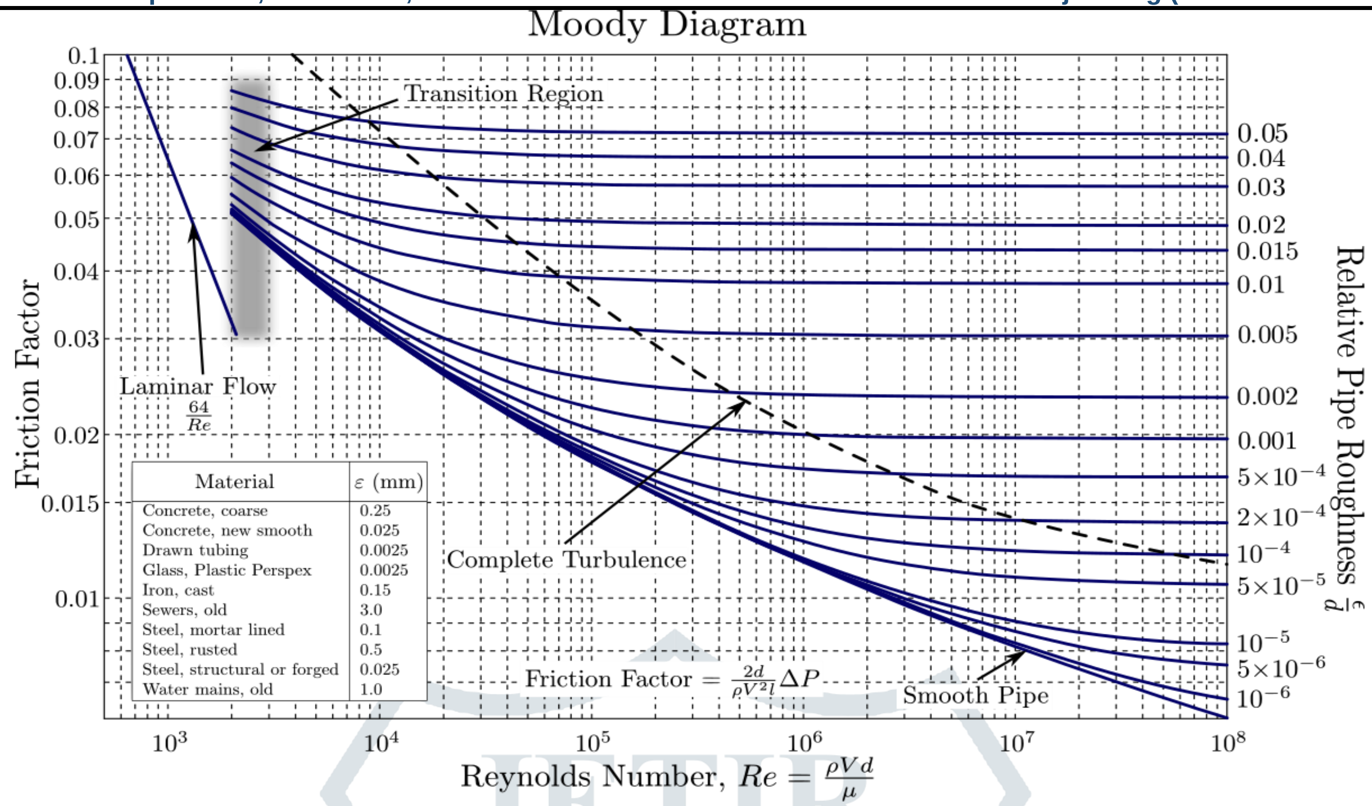

Figure 1: Moody Chart (S Beck and R Collins , Wikipedia , 2012)

having an environment friendly design.[2] mainly discusses the experience of orifice-plate based flow measuring systems for evaluation of air leakages in air conditioning equipment's. The magnitude of leaked air has a direct effect on energy use and the indoor air quality. Recent studies show that about 10-30% of conditioned air escapes from an average central air conditioning system. In the present investigation, three orifice plate-based leak-test setups were designed and setup.. From the results, it was found that a second-order fit was inadequate to relate the pressure drop and flow rate in all the cases. While a third-order polynomial was adequate for the first two units, a sixth- order was necessary for the other two.[3] proposes a novel design consisting of 2 heat recovery units in order to diminish the energy demand of air handling units. In the proposed design the exhaust air exergy is recycled using the primary heat exchanger whereas the energy from the returned air is recovered using the secondary heat exchanger. Due to the incorporation of the primary heat exchanger, the cooling coil load decreased. The coldness from the exhaust air has been recovered to the fresh air in the primary heat exchanger, due to this, the cooling coil power decreased from 78.52 to 61.52 kW (21.65% reduction). [4] proposes a digital twin maintenance framework to overcome the limitations of facility maintenance management. In this study, 3 models are implemented namely, operating fault detection using APAR method, condition prediction using ML technologies and maintenance planning. As per the study, this method has proven to be both functional and beneficial. The system has a high success rate even though it detects wide variety of different problems and a variety of different AHU's. [5] has examined the effectiveness and durability of filters used in plasma arc cutting of metals. The removal efficiency for a cutting operation carried out in a cutting chamber decreases from over 99 to below 93% at 2 mm after 20 times of reuse. This study has shown that HEPA filters have the lowest filtration efficiency in an MPPS region, and filter efficiency continues to decrease as the number of filter usages increase.[6] investigates the function of nano-treating filters with silver and titanium dioxide nanoparticles (Ag/TiO2 NPs) to identify contamination of SARS-CoV-2 in high-efficiency particulate air (HEPA) filters within hospital isolation rooms of confirmed COVID-19 patients. In the intensive care unit, which has strict aerosolization control protocols, two samples obtained from the HEPA filter air exhaust outlets before nano-treatment tested positive for SARS-CoV-2 RNA. This finding suggests that tiny virus-laden droplets may be dispersed by airflow..[7] has examined Pressure drop across a HEPA filter which has been measured as a function of solid particle mass loading using three materials. Sodium chloride, ammonium chloride and aluminum oxide particles in several different size distributions. In all cases, specific resistance of the filter cake increased as the mass median particle diameter decreased.[8] examines the friction coefficient for both laminar and turbulent flow in rectangular channels theoretically and empirically. Three rectangular ducts with theoretical aspect ratios of 1:1, 5:1, and 10:1 were used to monitor the local pressure decrease. To get Reynolds numbers starting in the lower laminar range and extending through the transition area to the turbulent regime for each duct, the flow rate was changed. The results were that at aspect ratios less than 5:1, the predicted values of the friction factors were lower than the experimental data, with a maximum difference of 12 per cent evident for the square duct.[9] here the author is examining frictional pressure decrease in rectangular ducts. Results on turbulent flow for smooth rectangular ducts and smooth circular tubes were compared using consistency between theory and experiment in laminar flow as a basis for accepting published data. It has been demonstrated, in agreement with the work of other investigators, that the hydraulic diameter is inappropriate for accurate estimation of turbulent friction factor in rectangular ducts.[10] This paper presents general equations for pressure drop calculations for developed and developing laminar flow in ducts of the arbitrary cross-section. The Equations have been evaluated for the calculation of total pressure drop in laminar flow for ducts with arbitrary cross-sectional shapes. It is shown that the given equations compare very well with the theoretical values.

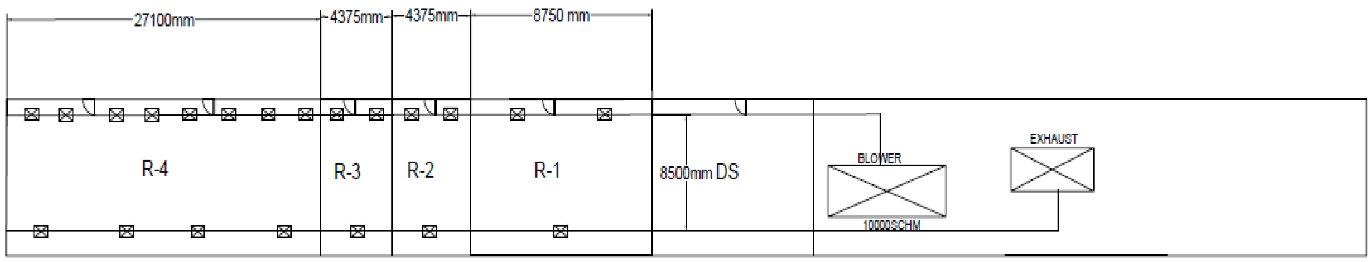

Figure 2: Layout of the Existing System

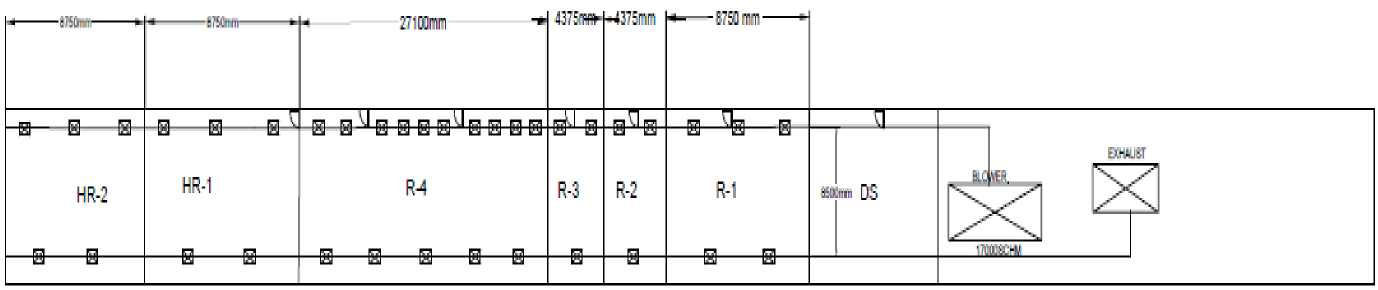

Figure 3: Layout of the Proposed System

III. ANALYTICAL APPROACH

In the proposed system , a blower of 17000 CMH capacity is used which will distribute air to the 6 rooms. In order to do so , the calculations will consist mainly of 2 parameters , firstly the discharge left after every grill and secondly the velocity of the air after every grill. In order to calculate the velocity:

$$v = Q/A \qquad (1)$$

In this equation ,the Area of the duct has been taken from Page no. 4 of the Bureau Of Indian Standards (BIS) IS 655:2006 catalogue and discharge at the start of the system is known, using the velocity of the air at the start of every room and after each and every grill is calculated. This is calculated mainly to maintain the velocity of the air within the specified range of 6-10 m/s. After these calculations are verified, the next step would be to calculate the pressure loss due to friction. Firstly, the hydraulic mean diameter is calculated:

$$d = 4A/P \qquad (2)$$

The Area and the Perimeter is calculated using BIS catalogue as shown previously. Once , the hydraulic mean diameter is calculated , the next step is to calculate the relative roughness:

$$\text{Roughness} = € /d \qquad (3)$$

Here , the value of € is taken as 0.15 mm as the material used for the ducts is Galvanized Iron Steel (GIS) and d is
calculated previously. Next step is to calculate the Reynolds Number:

$Re = \rho vd/\mu$ (4)

Density and viscosity of the air is known, the values of v and d are taken as the maximum velocity and mean diameter of that cross-section respectively. Using the values of Reynolds number and roughness, one can calculate the value of friction factor using the Moody Chart as shown in Figure 1. Using the values of friction factor, the Head Loss due to friction is calculated by substituting the values in the Darcy-Weisbach Equation:

$h_f = flv^2/2gd$ (5)

Length and velocity are taken pertaining to a particular cross-section of the duct. Finally one can calculate the pressure drop using the Bernoulli's equation and assuming the change in velocity head to be negligible :

$\Delta P = \rho g h_f$ (6)

The calculations for both the existing and the proposed system are performed using the above approach, the only difference being that in the existing system , the duct dimensions are known , whereas for the proposed system , the values will be taken from the standards.

Table 1: Analytical Results of the Supply Side of the Existing System

Cross-Section (in mm)	Pressure Loss (in Pa)	Reynolds Number
625x750	4.24	296888
625x625	4.646	284160
625x500	4.97	260237.7
500x500	5.56	233544
500x375	6.65	199264.6
500x250	8.89	153556

Table 2: Analytical Results of the Exhaust Side of the Existing System

Cross-Section (in mm)	Pressure Loss (in Pa)	Reynolds Number
750x450	12.114	258907.5
650x450	9.13	161487.5

Table 3: Analytical Results of the Supply Side of the Proposed System

Cross-Section (in mm)	Pressure Loss (in Pa)	Reynolds Number
800x800	7.87	430000
800x600	10.81	393000
800x400	16.75	335000
700x300	10.082	255000
500x300	9.106	204000
400x200	15.215	173000

IV. EXPERIMENTATION

4.1Existing System

This is the current system which is in use in the industry. It mainly consists of 8 components: Pre-filter, Air Handling Unit, Blowers, Plenum, Duct System, Dampers and Grills. Fresh air is taken in and passed firstly though the pre-filter. This basically perform the function of capturing pollen, dirt,dust, moisture, bacteria, and virus. The Air Handling Units (AHU) consist of a coil through which cold water is circulated, outside air passes through it and cools down and gives its energy to the cold water. This chilled air is then transferred to the plenum using a blower of 10000 CMH capacity. Once in the plenum, the air is distributed to the various rooms using duct system. The duct system consists of dampers to control the flow rate passing through the grills. The grills are the actual opening of air into the room. The air circulates in the room, gains temperature and is removed from the room using the exhaust duct from where it is released back to the atmosphere. The current layout consists of 4 rooms: Room 1,2,3 and 4 as shown in figure 2.

4.2 Proposed System

The components of the proposed system remain the same, with the only difference being the addition of HEPA filter at the supply side and the use of a blower of 17000 CMH capacity. This is mainly done to cater to the needs radiopharmaceuticals, which will be present in the 2 additional rooms in the proposed system and the increase in
capacity. The rooms are: Room 1,2,3,4,Hypothetical Room No. 1 and Hypothetical Room No. 2. The layout of the same is shown in Figure 3.

4.3 Input for Simulation

In order to verify the calculations done for the proposed system , simulation is performed. This is done on fluidflow software which offers a complete design environment for the hydraulic design, analysis and troubleshooting of fluid systems The inputs provided were mainly:
1) Length of the duct
2) Geometry of the duct
3) Dimension of the duct
4) Roughness Index of the material
5)Velocity of the air flowing through the duct
As the cross-section of the duct throughout the supply side and exhaust side is varying, these inputs are specific to a particular cross-section of the duct. The value of the pressure loss due to friction is validated and compared with the analytical values using this tool.

Table 4: Analytical Results of the Exhaust Side of the Proposed System

Cross-Section (in mm)	Pressure Loss (in Pa)	Reynolds Number
500x300	101.39	327375
500x400	27.457	341880
500x500	24.46	444000
600x600	16.64	480852

Table 5: Comparison of Analytical and Simulated Values of the Supply Side

Cross-Section (in mm)	Pressure Loss due to Friction (in Pa)		
	Analytical	Simulated	Error (%)
800x800	7.874	8.037	2.02
800x600	10.81	10.858	0.44
800x400	16.75	16.963	1.23
700x300	10.082	10.124	0.41
500x300	9.106	9.246	1.51
400 x 200	15.215	15.677	2.94

Table 6: Comparison of Analytical and Simulated Values of the Exhaust Side

Cross-Section (in mm)	Pressure Loss due to Friction (in Pa)		
	Analytical	Simulated	Error (%)
600 x 600	16.64	17.15	2.97
500 x 500	25.46	25.17	2.82
500 x 400	27.457	28.108	2.31
500 x 300	101.39	104.4	2.88

V. RESULTS AND DISCUSSION

The results of the analytical calculations of the existing system are shown in tables 1 and 2. These have been divided mainly into two parts one for the supply side and the other for the exhaust side. The dimensions of the ducts in the case of the existing system were already known and the calculation is done mainly to find Pressure Loss due to friction and Reynolds Number. Each of these hold some different significance in this research. Pressure Loss due to friction helps one to determine the difference in total pressure between two points in a duct. At the supply side, the pressure loss increases from 4.24 Pa in Room 1 to 8.89 Pa in Room No. 4. This can mainly be attributed to the increase in friction factor as one moves from blower towards the rooms. Also, the Reynolds number is decreasing from 296888 to a value of 153556. Similarly at the exhaust side the pressure loss decreases from

12.114 Pa to 9.13 Pa and the Reynolds Number from 258907.5 to 161487.5. The calculations of the proposed system are shown in tables 3 and 4. In this case , the dimensions have been taken from the BIS standards , the dimensions of the duct start from 800x800 mm and decrease to a value of 400 x 200 mm towards HR-2 at the supply side, this decrease can be attributed to the fact that in order to maintain the velocity within the range for the same discharge the area needs to be decreased. Whereas in the exhaust side as air is taken from the room , the discharge keeps on increasing as we move from start to finish of the system, hence the velocity keeps on increasing , as a result we need to increase the cross-section from 500 x 300 mm to 600 x 600 mm to maintain the velocity. Observing them more closely makes one identify that the trends is still the same with the pressure loss due to friction increasing from 7.87 Pa in Room No. 1 to a value of 15.215 Pa in Hypothetical Room No. 2 whereas the Reynolds number decreases as we move from the blower to the rooms. The major difference lies in the values of pressure loss and Reynolds number at the exhaust side , while the pressure loss decreases significantly from 101.39 Pa to 16.64 Pa , the Reynolds Number increases significantly from 327375 to a value of 480852.The change in Reynolds Number can be attributed mainly to the increase in length of the ducts in the proposed system to accommodate for the increase in the number of rooms. The comparison of the results of simulation and the analytical approach are as shown in tables 5 and 6, which have been depicted graphically in figures 4 and 5, observing the graphs and the tables, the values obtained by the analytical calculations are agreeing with the simulation to a certain extent. The maximum difference in values being 0.46 Pa at the supply side and 0.51 Pa at the exhaust side. Hence, the analytical calculations have been proved to be correct and these can be verified using the software as shown above.

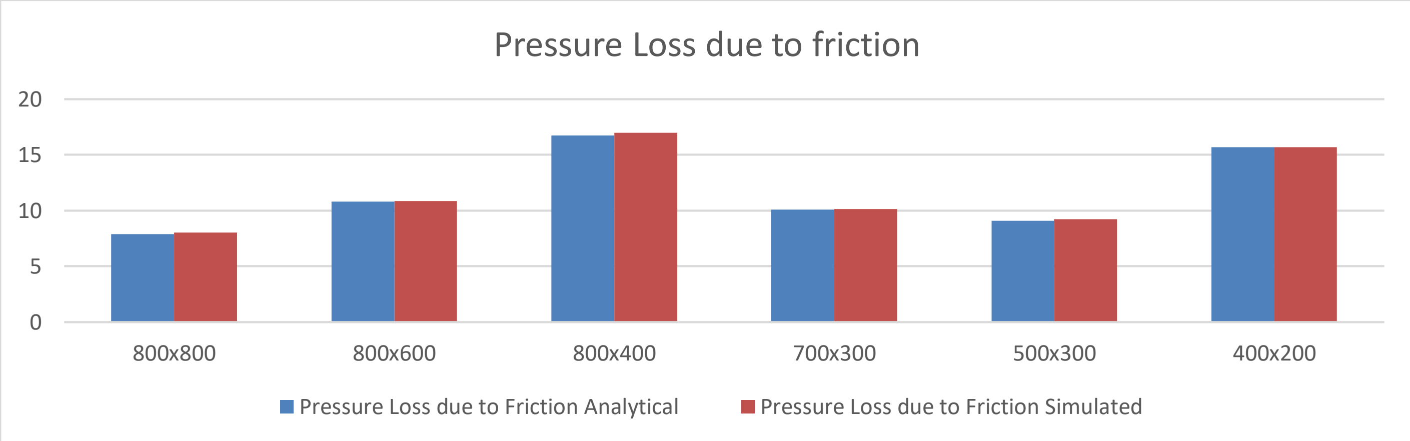

Figure 4: Graphical Representation of the Analytical and Simulated Values of the Supply Side

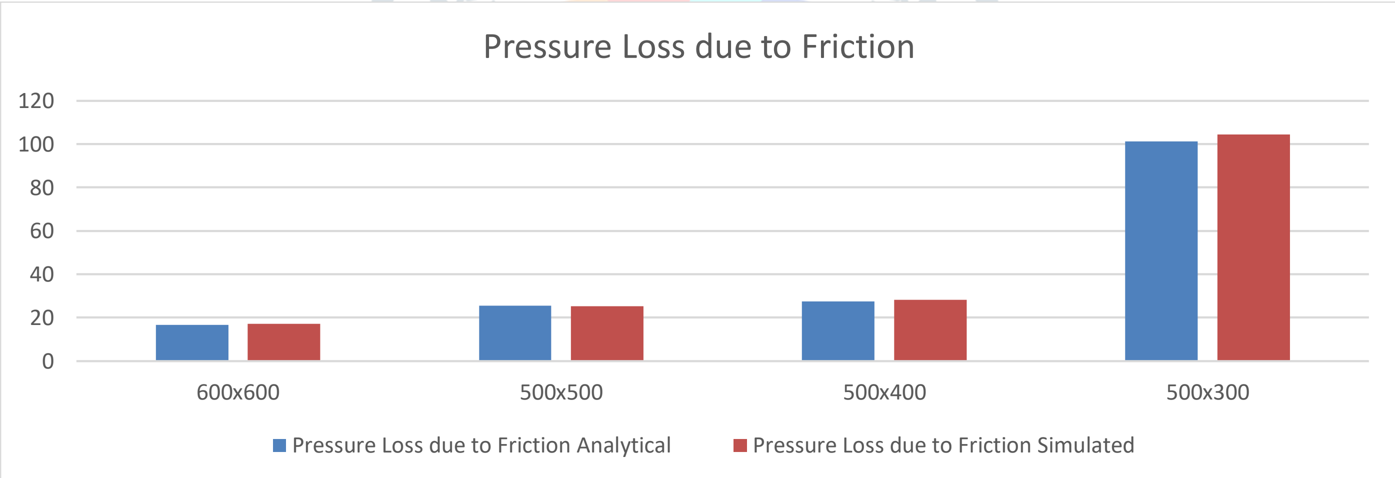

Figure 5: Graphical Representation of the Analytical and Simulated Values of the Exhaust Side

VI. CONCLUSION

This study has proposed a new duct system design to replace an existing system which was unable to cater to the needs of the new facility. The proposed system consists of 6 rooms , each of different dimensions. Out of these 6 , the last 2 rooms cater to the need of radiopharmaceuticals and hence , as a precautionary measure , HEPA filters have been utilized at the supply side in the proposed system. To cater to this increased capacity , a blower of 17000 CMH capacity is utilized in the new system, for which a new duct design is proposed with the main consideration being the need to maintain the air velocity within a specified range. Finally, using simulation the results have been validated and have been presented in this paper. Overall one can conclude that the approach taken for the design of the new system is correct and the system can be implemented practically.

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