Numerical study of canister filters with alternatives filter cap configurations

A N Mohammed¹, A R Daud¹, K Abdullah¹, S M Seri¹, M A Razali¹, M F Hushim² and A Khalid²

¹ Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia
² Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia
E-mail: akmaln@uthm.edu.my

Abstract. Air filtration system and filters play an important role in getting good quality air into turbo machinery such as gas turbine. The filtration system and filters improve the quality of air and protect the gas turbine part from contaminants which could bring damage. During separation of contaminants from the air, pressure drop cannot be avoided but it can be minimized to help reduce the intake losses of the engine. This study is focused on the configuration of the filter in order to obtain the minimal pressure drop along the filter. The configuration used is the basic filter geometry provided by Salutary Avenue Manufacturing Sdn Bhd. and two modified canister filter caps which were designed based on the basic filter model. The geometries of the filter were generated by using SOLIDWORKS software, and Computational Fluid Dynamics (CFD) software was used to analyse and simulate the flow through the filter. In this study, the parameters of the inlet velocity are 0.032 m/s, 0.063 m/s, 0.094 m/s and 0.126 m/s. The total pressure drop produced by the basic, the modified filter 1 and the modified filter 2 are 292.3 Pa, 251.11 Pa and 274.7 Pa respectively. The pressure drop reduction for the modified filter 1 is 41.19 Pa and is 14.1% lower compared to the basic filter, whilst the pressure drop reduction for modified filter 2 is 17.6 Pa and is 6.02% lower compared to the basic filter. The pressure drops for the basic filter are slightly different with the Salutary Avenue filter due to limited data and experiment details. Indeed the CFD software is very reliable in running simulations as an alternative to producing prototypes and conducting experiments, thus reducing overall time and cost in this study.

1. Introduction
A top quality gas turbine system is rated by their high availability and reliability, low maintenance cost and low performance degradation [1, 2]. The gas turbine is known as the engine that acts as the heart of the power plant that provides electric current. Gas turbine is a machine that has the ability to convert natural gas to mechanical energy. The energy produced is then supplied into generators that will produce electrical energy. This kind of energy is supplied to buildings and houses via power lines and also used for military purposes [3]. Operation of a gas turbine uses huge amount of air during its operation [4], thus the quality of air that enters the system is crucial as it influences the life cycle and performance of the gas turbine. Air is sucked into the combustion chamber using a compressor. In the combustion chamber, fuel is sprayed into the air thus resulting in an ignition and generates a high-temperature flow.
Air filtration system plays a crucial role in achieving low maintenance cost and high performance gas turbines [2]. It helps to capture liquids, sub-micron particles and dissolved contaminants such as water-borne salt from entering the engine. Designers reconstructed, optimized and rebuild the pleat geometry thus leading to a filter that has high particle collection efficiency [5]. If a filtering system is not applied before the air enters the engine, it can lead to severe problems such as blade erosion, compressor fouling and hot gas fouling which can reduce the efficiency and become a threat to the turbine [6]. Any particle that has a size larger than 10μm in size can cause an erosion threat towards the internal gas turbine parts. Currently, no treatment can be applied to the damaged part due to erosion; these turbine parts need to be replaced with the new ones thus increasing operational cost.

Fouling is the abrasive removal of material from the flow path by hard particles impinging on flow surfaces. The compressor usually is the most affected component by this kind of defect. Fouling of compressor blades is an important mechanism leading to performance deterioration in gas turbines over time. Particles that cause fouling are typically smaller than 2 to 10μm. Compressor fouling is due to the size, amount, and chemical nature of the aerosols in the inlet air flow, dust, insects, and organic matter such as seeds from trees, rust or scale from the inlet ductwork. Deposits from dissolved solids in a water spray inlet cooling system, oil from leaky compressor bearing seals, ingestion of the stack gas or plumes from nearby cooling towers also can lead to fouling. The effect of fouling is that it can increase surface roughness, decreasing the flow passage area, change in air foil shape of the turbine blade and overall performance degradation [6]. Fouling can be removed by off line water washing and slowed down by online water washing. Theoretically, the engine can be kept at a very small degradation level at all times, if it is frequently washed on-line, and the cost of shutting the engine down for off-line washing (typically a half day) is carried. The decision to shut the engine down for off-line washing is a balance between lost productions due to the lower power vs. the lost production for shutting the engine down for a certain amount of time.

2. Methodology
In this study, Computational Fluid Dynamics (CFD) is used to analyse the filter performance. The geometry of the filter is provided by Salutary Avenue Manufacturing Sdn. Bhd. The geometry of the filter is modelled using SolidWorks and imported into the ANSYS WORKBENCH. The simulation and analysis process is being run by using the fluid flow (CFX).

The parameters used for this study are also obtained from Salutary Avenue (SA) which is the air flow rate, surface area of the filter and pressure drop of the Salutary Avenue filter from the experiment. The filter classes that are used are F9 from European Standard 779:2002. Table 1 shows the data that are used in this simulation. The velocity is used as the inlet parameter of the simulations.

| Flow Rate (m³/s) | Pressure Drop (Pa) | Area (m²) | Inlet Velocity (m/s) |
|-----------------|-------------------|-----------|---------------------|
| 0.236           | 25.0              | 7.5       | 0.032               |
| 0.472           | 47.2              | 7.5       | 0.063               |
| 0.708           | 77.1              | 7.5       | 0.094               |
| 0.944           | 121.8             | 7.5       | 0.126               |

The three processes involved in CFX are pre-processing, solver, and post processing. The geometry of the filter is developed in the SolidWorks and then imported into the CFX design modeller. The surface of the filter is then named as inlet, enclosure, outlet, symmetry, porous and wall. Figure 1 shows the filter model imported into the design modeller. After assigning the surface names, meshing
Figure 1. Filter Model in Design Modeller.

Figure 2. Filter Model in Meshing.

takes place. In this part, the minimum and maximum are set up for the geometry which is 8mm and 11 mm. Inflation is set at the outlet of the filter with maximum 5 layers. Figure 2 shows the meshed filter model.

The next step in pre-processing is the setup where all the parameters of the filter are declared. There are two main domains set in setup which is the air and filter domain. Figure 3 shows the air and filter domain. Next, the boundary condition is assigned. The inlet and outlet boundary condition of the filter setting is shown in figure 4 and 5.

The inlet and outlet setting for the CFX setup have 2 different configurations. The first case applies the inlet velocities at 0.032 m/s, 0.064 m/s, 0.094 m/s and 0.126 m/s and using outlet pressure at 30 kPa. In the second case, the inlet velocities are set at 0 m/s and outlet pressure at -30 kPa.

Figure 3. Air and Filter Domain.

Figure 4. Inlet Boundary Setting.

Lastly, after setup processes completed, solver process takes place. In solver, the number of iteration is set at 1000 iteration and 0.0001 RMS value. This shows that the iteration will stop if the RMS value is converged even if the number if iteration did not reach 1000 iteration. Figure 6 shows the solver and output control setting.
Simulations are then ready to run and post-processing process takes place. This is where the result of the simulation is generated. From this section, graphs and contours such as pressure, velocity vector and velocity contour will be generated. Line location is also applied on the centre of the filter by placing the coordinates in order to determine the pressure along the filter as shown in figure 7.

Grid independent test is then conducted. The goal is to determine which sizing is to be used. In this test, basic filter is used as the benchmark model. The result obtained from different meshing sizes are then compared to the selected meshing size which is minimum at 8 mm and maximum at 11 mm. this size is selected because of the result are near to the smaller sizing. The selection is based on the number of nodes generated during meshing process and the time consumption by the software to generate the mesh and solves the simulation and the result is compared between the different sizing in the figure 8. Table 2 shows the number of nodes and elements at different sizing.
### Table 2. Nodes and element at different sizing.

| Grid Size (Min) | Grid Size (Max) | No of Nodes | No of Element |
|-----------------|-----------------|-------------|---------------|
| 8               | 13              | 207677      | 1118435       |
| 8               | 11              | 337697      | 1845530       |
| 7               | 10              | 445034      | 2451446       |

### 3. Results and discussion

In this section, the velocity, pressure vector and contour extracted from simulation is presented. The filtration assembly from Salutary Avenue (SA) is compared with the simulation of basic, modified 1 and modified 2 filters and discussed. Pressure drop is determined by calculating the pressure different at the inlet and outlet of the filter. The pressure drop is determined by using equation (1).

\[
\Delta P = P_{\text{inlet}} - P_{\text{outlet}}
\]  

(1)

Here, \( \Delta P = \) Pressure Drop, \( P_{\text{inlet}} = \) Pressure Inlet and \( P_{\text{outlet}} = \) Pressure Outlet.

**Figure 9.** Basic Filter Case 1 Streamline.

**Figure 10.** Basic Filter Case 2 Streamline.

**Figure 11.** Modified Filter 1 Case 1.

**Figure 12.** Modified Filter 1 Case 2.
For the case 1, figures 9, 10 and 11 shows the velocity streamline for basic, modified filter 1 and 2 at 0.032 m/s. The streamline figure is show how the air is flows around and inside the filter. From the figure air is flows through filter near the outlet section due to suction pressure. For the modified filters, it can be seen that air is flow in the front side of filter compare to the basic filter.

For the case 2, which are using 0 m/s as inlet velocity and suction pressure at -30 Kpa. Figure 15, 16 and 17 shows the velocity streamline for basic, modified filter 1 and 2. The streamline figure shows how the air is flows around and inside the filter. From the figure, the basic filter shows that air cannot flows through the filter through the inlet. This is because, in that particular location, it has a solid structure and does not allow air to flow through it. For the modified filters, it can be seen that air is flow in the front side of filter compare to the basic filter.

The comparison between Salutary Avenue (SA) filter and simulation of the basic filter is conducted. For the Salutary Avenue filter, the results is based from the experiment that conducted by the industry. Figure 18 shows the graph of pressure drop versus velocity for both of the filter. It can be seen that the pressure different for both filter is increased as the inlet velocity increasing. The pressure drop for both filters is not same with each other. The total pressure drop for basic filter is much higher compare to the Salutary Avenue filter. The pressure drop for basic filter at the lower velocity which is 0.032 and 0.063 m/s is lower than Salutary Avenue and for the last two velocities the pressure drop for basic filter become higher than Salutary Avenue filter.

There is different between the pressures drop of the both filter due to some experimental data from Salutary Avenue that is not fully revealed which is confidential for the company such as the pressure on the outlet, data measurement of the pressure, enclosure details and air that is used for the experiment. Thus, the assumption is been made which lead to the differences of the results. Even the pressure drop is different between those two filters the data is still between the ranges with the Salutary Avenue filter.

From the figure 19, it is clearly can be seen that as the inlet velocity increase the pressure drop also will increase for the filters. Modified filter 1 recorded better pressure drop compare to the basic and modified 2 filter. According to the theory, the lower pressure drop is much better for filtration systems. The modified filter 1 and 2 produce the lower pressure drop due to the geometry factor where the cap is been modified and allow air to flow through the filter from the front side.

The improvement of the pressure drop for the modified filter 1 are from 11.47% to 14.82%, compared to the basic filter at the inlet velocity from 0.032 to 0.126 m/s. The total pressure drop produce by basic filter is 292.3 Pa and 251.11 Pa for modified filter 1. The pressure drop reduction is 41.19 Pa and 14.1% from basic filter. The total pressure drop for the modified filter 2 model is 274.7 Pa which is higher than pressure drop in modified filter 1 but lower than basic filter. The pressure drop reduction compared to the basic filter is 17.6 Pa and 6.02% lower.

Figure 20 show the pressure drop for four of the filters which are Salutary Avenue (SA), basic, modified 1 and modified 2 filter. According to the total pressure drop the basic filter produce the
higher total pressure drop which is 292.3 Pa then follow by modified 2, modified 1 and Salutary Avenue (SA) which 274.7 Pa, 251.11 Pa and 270.9 Pa respectively. From the figure, at 0.032 m/s to 0.063 m/s, the lowest pressure drop is from the modified 1 filter compare to other filters while at 0.094 m/s to 0.126 m/s, the lowest pressure drop is from the salutary avenue filter.

![Figure 15. Filter Model in Design Modeller.](image1)

For the case 2, the pressure drops for modified 2 filter are lower compare to the basic and modified 1 filter. This is related to the shape of the inlet at modified 2 filter that is equipped with a bell-mouth shaped inlet which have the ability to help divert the surrounding air into the filter more efficiently. Pressure drop on modified 1 filter is lower than the basic filter because of the filter cap that helps to increase the area of filtration for the modified filter 1. Table 3 shows the pressure drop for Basic, modified 1 and Modified 2 Filter.

![Figure 16. Filter Model in Meshing.](image2)

![Figure 17. Filter Model in Design Modeller.](image3)

| Inlet Velocity (m/s) | Basic Filter | Modified 1 | Modified 2 |
|----------------------|--------------|------------|------------|
| 0.0                  | 34985.80     | 31265.89   | 30725.77   |
4. Conclusion

In conclusion, in case 1, modified filter 1 produce the minimal pressure drop compared to basic and modified filter 2. There were four values of inlet velocity used to obtain the pressure drop for each configuration which is 0.032 m/s, 0.063 m/s, 0.094 m/s and 0.126 m/s. The improvement of the pressure drop for the modified filter 1 are from 11.47% to 14.82% compared to the basic filter. On the other hand, improvement of pressure drop for modified filter 2 compared to basic filter were from 10.46% to 9.75% at the inlet velocity from 0.032 to 0.126 m/s, even though the modified filter 2 pressure drop were higher compared to the basic filter at slower inlet velocity. The total pressure drop produce by basic, modified filter 1 and 2 are 292.30 Pa, 251.11 and 274.70 Pa. The pressure drop reduction for the modified filter 1 is 41.19 Pa and 14.1% compared to basic filter and the pressure drop reduction for modified filter 2 is 17.6 Pa and 6.02% compared to the basic filter. The pressure drops for the basic filter are slightly different with the Salutary Avenue filter due to limited data and experiment details from the industry.

Based on the case 2, we can see that the lowest pressure drop recorded by the modified 2, modified 1 and the basic filter at 30725.77, 31265.89 and 34985.80 Pa. The velocity streamline also shows that there are higher rate of air entering the filter for the modified filters while the basic filter configuration did not allow air to flow through the front inlet of the filter.

The geometry of the filter is vital to minimize the pressure drop along the filters. The modified filter 1 and 2 are proved to be better at minimizing the pressure drop compared to the basic filter as they are designed to have more porous area that enable air to flow through them. The larger filtration area tends to helps in decreasing the velocity restriction thus producing lower pressure drop.

Acknowledgments

This research was made possible through funding from Universiti Tun Hussein Onn Malaysia (UTHM) IGSP Grant U413 and UTHM STG Grant U126. The authors would also like to acknowledge the contributions made by members of Flow Analysis, Simulation and Turbulence Research Group (FAST), the Centre for Energy and Industrial Environment Studies (CEIES) of UTHM, the Faculty of Mechanical and Manufacturing Engineering, and the Faculty of Engineering Technology at UTHM.

References

[1] Abam F I, Effiom S O and Ohunakin O S 2016 CFD evaluation of pressure drop across 3-D filter housing for industrial gas turbine plants. *Frontiers in Energy* 10(2) 192–202
[2] Orhon D, Hiner S D, Kurz R and Benson J 2015 Gas turbine air filtration systems for offshore applications *Turbosymposium* (Houston: Tutorial)
[3] Jansohn P 2013 *Overview of gas turbine types and applications* (Philadelphia: Woodhead Publishing Limited).
[4] Effiom S O, Abam F I, and Ohunakin O S 2015 Performance modelling of industrial gas turbines with inlet air filtration system. *Case Stud. Therm. Eng* 5 160–7.
[5] Fotovati S, Tafreshi H V and Pourdeyhimi B 2012 A macroscale model for simulating pressure drop and collection efficiency of pleated filters over time. *Sep. Purif. Technol.* 98 344–55
[6] Santini M, Marchetti G and Giuntini F 2008 Gas turbine high efficiency filtration systems *GE Oil & Gas*