Air flow optimization for energy efficient blower of biosafety cabinet class II A2

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Abstract. An energy efficient Biosafety Cabinet (BSC) has become a big challenge for manufacturers to develop BSC with the highest level of protection. The objective of research is to increase air flow velocity discharge from centrifugal blower. An aerodynamic duct shape inspired by the shape of Peregrine Falcon's wing during diving flight is added to the end of the centrifugal blower. Investigation of air movement is determined by computational fluid dynamics (CFD) simulation. The results showed that air velocity can be increased by double compared to typical manufactured BSC and no air recirculation. As conclusion, a novel design of aerodynamic duct shape successfully developed and proved that air velocity can be increase naturally with same impeller speed. It can contribute in increasing energy efficiency of the centrifugal blower. It is vital to BSC manufacturer and can be apply to Heating, Air Ventilation and Air Conditioning (HVAC) industries.

1. Introduction

The World Health Organisation (WHO), the U.S. Centers For Disease Control and Prevention (CDC) and other organisation classified BSC into 3 classes. Each classes are distinguished in two ways; level of personal and environmental protection and level of product protection provided. This research focuses on BSC Class II Type A2. This is because it is commonly used due to their versatility and economic designs [1].

One of the important equipment inside BSC is the centrifugal blower. The purpose of this centrifugal blower is to maintain air circulation in certain air speed inflow to BSC and downflow to enclosure work area. Air flow movement generated by centrifugal blower needs to provide a non turbulent airflow distribution inside enclosure work area to ensure that the material inside the enclosure are undisturbed by air flow [2]. Generally, the best design of a BSC is the ones with a non-recirculated air flow. Recirculation of air flow at work area can cause concentrated of contaminate airborne. It will also increase pressure drop due to the increase of flow velocity. Recirculation normally happened caused by turbulent flow. Acceleration of air by centrifugal blower with very less turbulent flow is one of objective in this research. Normally, BSC uses forward curved centrifugal blower type that has high efficiency, low noise level and relatively small air flow with a high increase of static pressure [3].

A guideline from Air Movement and Control Association (AMCA) stated that each blower needs an extended length of ductwork specified as a 100 percent effective length for the velocity pressure to be fully converted to static pressure [4]. It should be long enough so that the air velocity becomes uniform across the face of the duct that is called static to regain its velocity pressure. Therefore, the design of the duct at the outlet has great effect on the system performance. Unfortunately, current BSC design in the market does not follow the guideline highlighted by AMCA. Centrifugal blowers are used without any duct connected at the end of the blower outlet and does not effectively convert velocity pressure to static pressure to gain uniform air velocity. Thus, a non-uniformed velocity pressure can cause chaos air flow and have potential to generate turbulent flow.

From another perspective, Ultra Low Particulate Air (ULPA) filter lifetime highly depends on the characteristic of the inlet velocity flow. A non-uniform velocity creates non-distributed air pressure towards filter inlet area. As a result, certain area in the BSC gains higher pressure while some areas gain lower pressure. Area which received higher pressure frequently has less filter effectiveness and shorter lifetime compared to area with lower pressure. The necessity to create a uniform distribution of air inlet velocity is important to extend longer lifespan for ULPA filters.

This research will focus on the development of a novel shape design of a duct outlet for forward-curved centrifugal blower of BSC in order to improve air flow performance with less turbulent, uniform velocity and less power usage for biosafety cabinet class II A2. Theoretically, surface modification at the outlet or any surfaces has potential to increase air flow velocity [5] and improve its aerodynamic characteristics.

Recent study areas mostly covered on chemical fume hood rather than biosafety cabinet. There is no research study on improvement of aerodynamic design of components of the biosafety cabinet itself. CFD software was used to analyze flow characteristic inside a chemical fumehood using k-ω turbulence model [6]. Then, risk management system was developed for high level biosafety laboratory in China due to outbreak of diseases such as foot and mouth disease, SARS, and highly pathogenic avian influenza [7]. Outcome from research showed that flow characteristic of air inside a biosafety cabinet is influenced by jet velocity, suction flow velocity and descending flow velocities [8]. A new way to conduct an airflow assessment was introduced in a biosafety building using CFD application [9]. Successful improvement of air flow for an enclosed work area with robotic equipment was conducted to provide an unidirectional air flow [2]. On the other hand, CFD application was used in order to improve performance test for chemical fume hood [10]. Aerodynamic design for chemical fume hood was studied by safety cabinet manufacturer, ESCO to show significant impact on air flow in minimizing reverse and turbulence flow [11]. This paper research will induce a novel research area by improving air movement and pattern inside biosafety cabinet from improvements of centrifugal blower performance.

2. Methodology

Basic 3D model of biosafety cabinet was designed similar to an actual size with nominal width size of 1219 mm. Configuration of the biosafety cabinet are described in the figure 1.

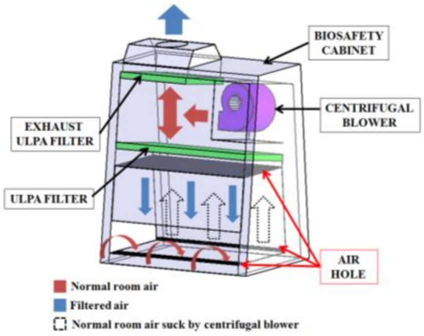

Figure 1. Basic 3D model of biosafety cabinet

Two types of biosafety cabinet configuration are simulated as can be seen in comparison from figure 2 and figure 3. The first configuration is configuration A with a ductless centrifugal blower outlet as can be seen from figure 2. This is a typical manufactured BSC configuration. Then, figure 3 shows duct after centrifugal blower.

Duct length was calculated complying to the guideline by Air Movement and Control Association (AMCA) [4]. Equation (1) was used to calculate hundred percent effective duct length, $L_{100\%}$ with flow rate less 12.7 m/s.

$$L_{100\%} = 2.5 \times D \tag{1}$$

Equivalent duct diameter, D is calculated using equation (2) with a and b are the width and the height of rectangular shape for outlet duct. The values were taken same as rectangular shape dimension for centrifugal blower outlet.

$$D = \sqrt{\frac{4ab}{\pi}} \tag{2}$$

By solving equation (1) and equation (2) with a = 287 mm and b = 141 mm, yields D = 227 mm and $L_{100\%}$ = 567mm. A 3D model for configuration B was drawn based on this length.

Simplified aerodynamic shape of Peregrine Falcon was applied at middle of duct for configuration B. This aerodynamic shape is a Cupped-Shape and V-Shape design as shown in figure 4 [12]. The authors previously designed geometries based on nature's inspired showed tremendous improvements in obtaining drastic results [13].

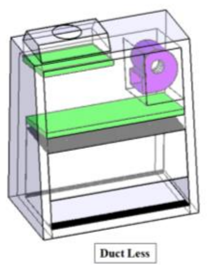

Figure 2. Centrifugal blower of configuration A

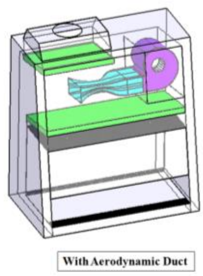

Figure 3. Centrifugal blower of configuration B

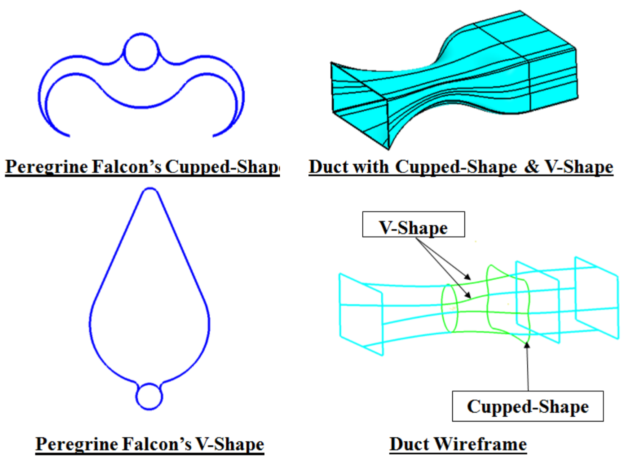

Figure 4. Peregrine Falcon's aerodynamic shape

Solid 3D of configuration A and B are imported to simulation software and mesh generated for each configuration contain approximately two million elements.

Numerical simulation using Fluid Flow (Fluent) analysis system with a standard of k-ε turbulence model has been used. Impeller rotational speed is being set to 66.9 rad/s for all configurations according to target of inflow air speed, V_i equal to 0.53 m/s as specified in BSC's catalog [14]. Concerning numerical simulation parameters, pressure outlet boundary conditions have been applied at outlet, respectively. A gauge pressure, P_o = 101325 Pa been applied to the environment. Simulation was conducted until achieved maximum residual value.

Average air velocity output, V_o are determined at the end of discharge area for configuration A and B. Then, the percentage of air velocity increment, η is determined using equation (3).

$$\eta = \left(\frac{V_o - V_i}{V_i}\right) \times 100 \quad (3)$$

Velocity uniformity between both configurations also to be analyzed as determined from this research objective.

Air flow pattern at top compartment and work area compartment was observed to check the degree of severity of recirculation of air. Besides, the pressure at two inlet surface of ULPA filter was determined in order to confirm the pressure distribution towards the ULPA filter.

3. Results and Discussions

Results of simulation shown in figure 5 and figure 6 shows that is the discharge area with duct has positive impact on air velocity pattern. The theory and numerical prediction converged as the result of Configuration A had a non-uniform velocity at discharge area. High air velocity at bottom region appeared compared to top region with a less velocity distribution. Configuration B with the duct successfully converts the non uniform velocity to a uniformed velocity pressure. Figure 5 and figure 6 below shown velocity comparison contour for both configurations.

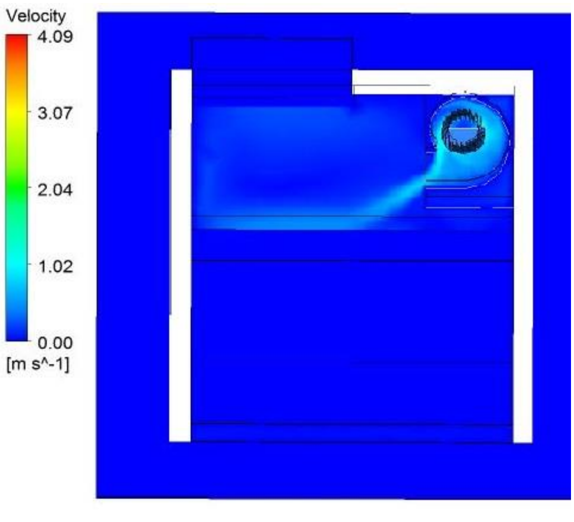

Figure 5. Velocity contour for configuration A

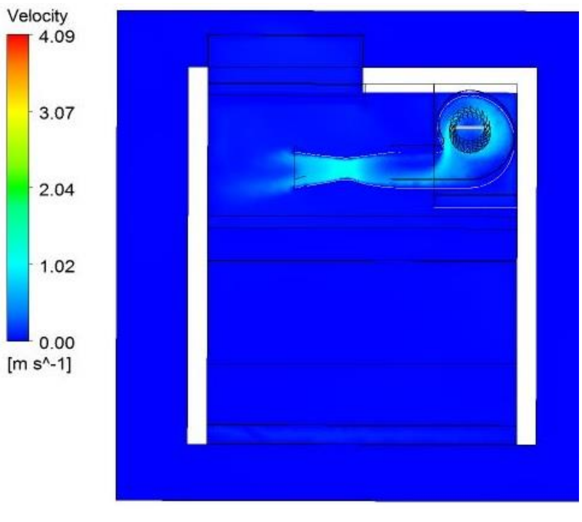

Figure 6. Velocity contour for configuration B

Furthermore, configuration B had greater average velocity value at duct discharge area compared to configuration A. The average velocity for configuration A is 0.32 m/s and configuration B is 0.77 m/s. Configuration A is set as a reference value as shown in Table 1 for comparison in percentage. It is because Peregrine Falcon shape at middle of duct for configuration B increased about 3 times of air average velocity from 0.32 m/s to 1.07 m/s. This supports the fact that air velocity accelerated naturally in configuration B was formed when air passes through the aerodynamic duct shape.

Figure 7 below shows bad air recirculation happened at the top compartment of configuration A caused by non-uniform velocity output from ductless centrifugal blower. Compared to configuration B the air flow had a smooth movement and less air recirculation can be seen from figure 8.

Local pressure distribution at inlet ULPA filter for configuration B was almost distributed evenly as can be seen from figure 10 below. While for configuration A as can be seen from figure 9, had higher concentrated pressure at one area, promoting backflow and recirculation inside the work area.

Table 1. Comparison of percentage of average air velocity (configuration A as reference)

Configuration	Average air velocity outlet, V_o (m/s)	Percentage comparison to configuration A,η (%)
A	0.32	-
B	0.77	+ 141 %

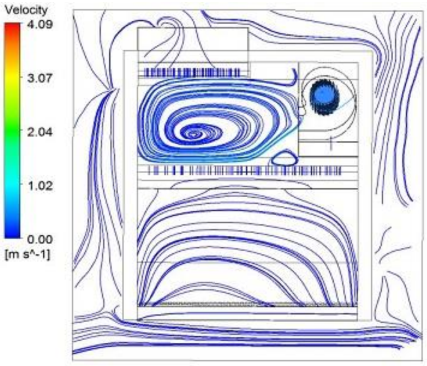

Figure 7. Streamline for configuration A

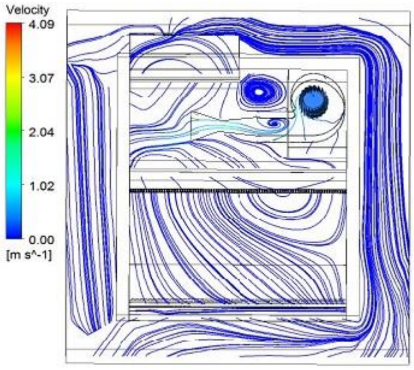

Figure 8. Streamline for configuration B

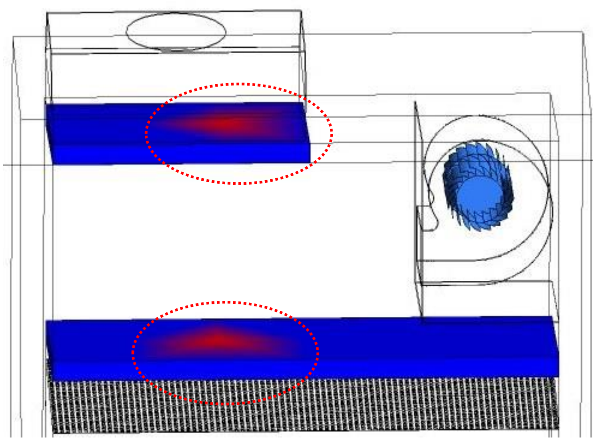

Figure 9. Pressure ditribution at ULPA filter for configuration A

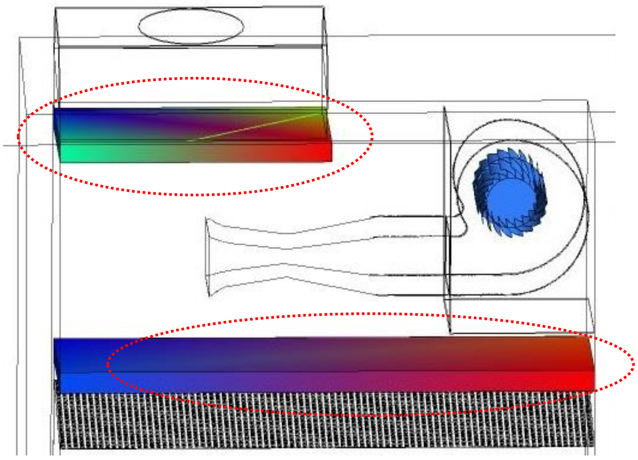

Figure 10. Pressure ditribution at ULPA filter for configuration B

Table 2 shows that the minimum and maximum pressure gauges inside BSC. Configuration B had greater pressure different on the maximum value compare to configuration A. It showed that air movement faster in configuration B instead of configuration A.

Table 2. Comparison of Pressure Gauge for configuration A and configuration B

Configuration	Min Pressure Gauge, ΔP_{min} (Pa)	Max Pressure Gauge, ΔP_{max} (Pa)
A	-1.32	0.89
B	-1.32	1.07

4. Conclusion

Biosafety cabinet with aerodynamic duct shape at discharge area had better performance compared to a ductless centrifugal blower. The study showed that uniform velocity generated manages to distribute pressure evenly to ULPA filter inlet area and less air recirculation happened. It also proved that an accelerated air can be introduced naturally without increase impeller rotational speed. As a result, rotational speed of impeller can be reduced to obtain similar performance and power consumption can be saved. It will help to reduce carbon emission by reducing power consumption as Kyoto Protocol requirement to reduce greenhouse gases emission. This research can be propose to all BSC manufacturer for create an energy efficient BSC.

Acknowledgments

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