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Research Article

Numerical Simulation of Clearance Effect between Impeller and Volute Casing for Centrifugal Blower

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Abstract: In this paper, flow analysis of backward-curved single stage centrifugal blower has been carried out. In the present study, the blower with a design speed and flow rate of 3800 rpm and 1.2m^3/s respectively are chosen. The operating range is 0.4 m^3/s to 3.6 m^3/s. The impeller outlet diameter is maintained at 600 mm. The volute casing inlet diameter and outlet diameter have 600 mm and 960 mm. And then, the volute casing was optimized by reducing and increasing the volute clearances from 5-15%. The optimum blade exit angle (β_2 = 45°) is chosen and also analyzed with reducing the clearances effect 5%, 10% and 15%. The simulation is done for various volume flow rates (0.4 to 3.6 m^3/s) and clearance effects of 5%, 10% and 15% respectively. The required input power to blower is 16 kW and overall efficiency is 83%. The number of vanes is 12. In this study, numerical investigation of fluid flow inside the centrifugal blower is conducted. Therefore, Blade Modeler tool is used to build three dimensional geometry for analysis by using ANSYS-CFX Workbench. Centrifugal blower is aimed to analyze the pressure and velocity distribution within the impeller passage and volute casing. Effect of clearances between impeller and volute casing is varied during analysis, and its effect on efficiency, velocity and pressure of the blower is investigated.

In this study, backward-curved centrifugal blower was numerically simulated using ANSYS-CFX Software by drawing a performance curve for clearance effect of impeller and volute casing. In the present study numerical investigation of fluid field inside the centrifugal blower is done. And then, Blade Modeler tool is used to build 3D geometry for analysis by using ANSYS-CFX Workbench.

Keywords: centrifugal blower, numerical simulation, impeller and volute casing, clearance effect between impeller and volute casng, ANSYS-CFX Software.

I. Introduction

A centrifugal blower consists essentially of one or more impeller equipped with vanes, mounted on a rotating shaft and enclosed by a casing. Air enters the impeller axially near the shaft and has energy, kinetic and potential, imparted to it by the vanes. As the air leaves the impeller at a relatively high velocity, it is collected in a volute or series of diffusing passages which transforms the kinetic energy into pressure energy. This is accompanied by a decrease in the velocity. After the conversion is accomplished, the air is discharged from the machine. Air enters the impeller axially through the inlet nozzle which provides slight acceleration to the air before its entry to the impeller. The action of the impeller swings the air from a smaller to a larger radius and delivers the air at a high pressure and velocity to the casing. The centrifugal energy also contributes to the stage pressure rise. The flow from the impeller blades is collected by a spirally-shaped casing known as scroll or volute. It delivers the air to the exit of the blower. The scroll casing can further increase the static pressure of air. Impeller is the most important part of the blower components because of the fact that its performance inadvertently determines the blower's performance. An impeller is essentially a disk shaped structure with vanes that create the actual suction in a blower. Centrifugal blowers, which are capable of providing moderate to high-pressure rise and flow rates, are widely used in different industrial applications, such as air-conditioning systems in buildings and blowers in automotive cooling units, among others. Centrifugal blowers are composed of two main parts, namely, the casing and impeller as shown in Figure 1.

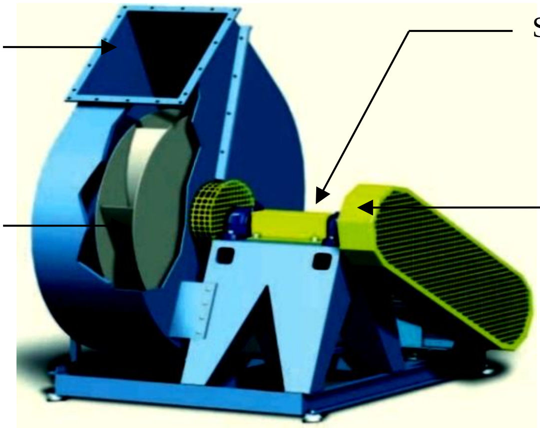


Figure 1. Single-stage Centrifugal Blower

II. Numerical Simulation of Clearance Effect between Impeller and Volute Casing

A. Effect of Clearances between Impeller and Volute Casing

In the present study, the blower with a design speed and flow rate of 3800 rpm and 1.2m^3/s respectively are chosen. The operating range is 0.4 m^3/s to 3.6 m^3/s. The impeller outlet diameter is maintained at 600 mm. And then, the volute casing was optimized by reducing the volute clearance 5-15%. The simulation is done for various volume flow rates (0.4 to 3.6 m^3/s) and clearance effects of 5%, 10% and 15% respectively. When the clearance is 32.7 mm, the base circle radius is 332.7 mm for the design as shown in Figure 2.

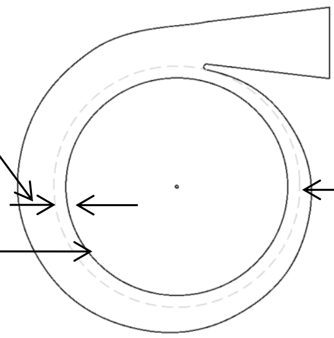


Figure 2. Geometry of Volute Casing

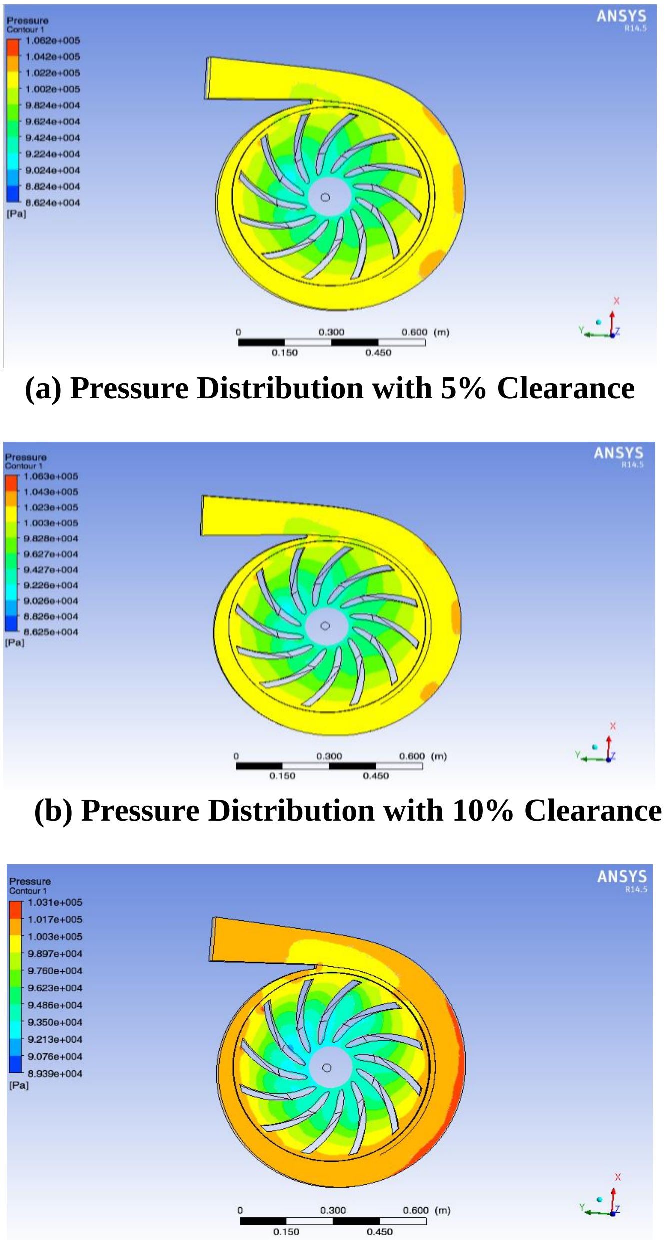
III. Simulation Results

After the post-processing of simulation results, the pressure distribution, and velocity distribution of the centrifugal blower are shown from Figure 3 to Figure 4.

A. Flow Distribution in the Centrifugal Blower

It is evident that the existence of a clearance between the impeller and volute casing will make the flow patterns much more complex. Figures 3 illustrate the flow fields in three different blowers. In order to reveal the impact of the clearance on the formation of flow field in each blower, three cases at which clearance takes its 5%, 10% and 15% values are presented.

In Figure 3(a), low pressure was observed at the impeller inlet and has higher pressure at the volute casing outlet. According to Figure 3(b), pressure decreases at the impeller inlet and gradually increases at the volute casing outlet. Pressure gradually increases from impeller inlet to volute casing outlet in Figure 3(c).



(a) Pressure Distribution with 5% Clearance

(b) Pressure Distribution with 10% Clearance

(c) Pressure Distribution with 15% Clearance

Figure 3. Pressure Distribution at Different Clearances

The velocity distribution, in this part is represented by velocity contours. Figure 4 shows the velocity distribution of fluid around the volute casing and impeller vane for an inlet and outlet. In Figure 4(a), low velocity was observed within impeller passage and high pressure was found at the volute casing outlet. A high gradient of fluid velocity appears at the volute

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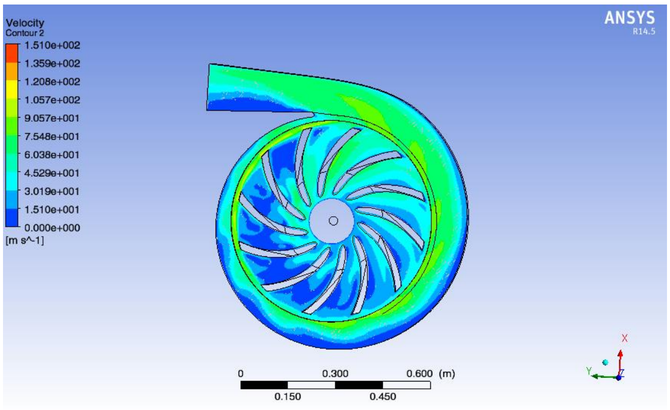
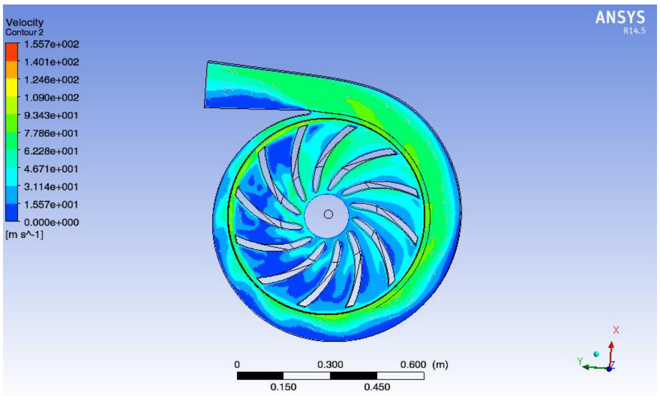
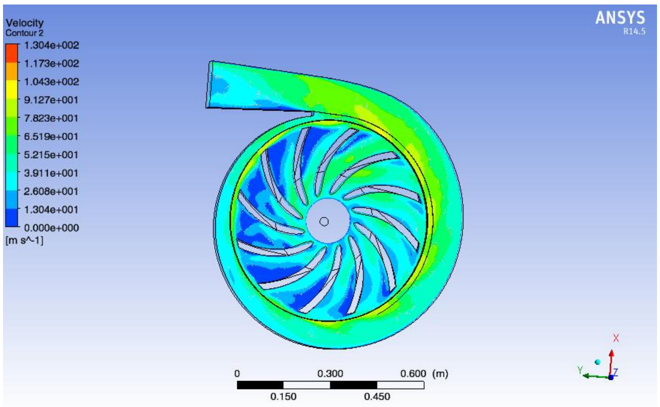
casing's outlet and low gradient of fluid velocity appears at impeller's inlet due to the change of clearance effect in Figure 4(b). According to Figure 4(c), high velocity was found at the volute casing inlet and decreased at the volute's wall.



(a) Velocity Distribution with 5% Clearance



(b) Velocity Distribution with 10% Clearance



(c) Velocity Distribution with 15% Clearance

Figure 4. Velocity Distribution at Different Clearances

B. Effect of Clearances between Impeller and Volute Casing on Overall Efficiency and Static Efficiency

The overall efficiency is plotted in Figure 5 by keeping rotational speed of impeller constant and varying;

1. Different clearance as 5%, 10% and 15%
2. Volume flow rate 0.4 to 3.6 m^3/s

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The results obtained from the CFD analysis of the centrifugal blower system with parametric optimization of different clearances are shown in Table 1, 2, 3, 4, 5 and 6. Table 1 shows effect of clearances between impeller and volute casing on overall efficiency for reducing with volume flow rate from 0.4m/s to 3.6m/s. Overall efficiency is taken as 83% and simulated result is observed 86.15% for centrifugal blower. The error between them is less 4% deviation which is in the range of acceptance and can validate the numerical result at design point. Overall efficiency is obtained 87.45% at 10% clearance and 89.21% at 15% clearance.

Table 1. Effect of Clearances between Impeller and Volute Casing on Overall Efficiency for Reducing

Volume flow rate, Q	5% Clearance	10% Clearance	15% Clearance
0.4	0.6951	0.6893	0.7765
0.8	0.8139	0.8274	0.8829
1.2	0.8615	0.8745	0.8921
1.6	0.8776	0.8849	0.8806
2	0.8802	0.8614	0.8639
2.4	0.8398	0.8376	0.8361
2.8	0.7627	0.7694	0.7669
3.2	0.6489	0.6593	0.6417
3.6	0.4747	0.4729	0.4601

When the clearance effect is reduced, the maximum overall efficiency was obtained 89.21% at 15% clearance, which occurs at 0.047 flow coefficient in Figure 5. It is found that overall efficiency do not significantly differ from 0.036 to 0.106 flow coefficient at 5%, 10% and 15% clearances.

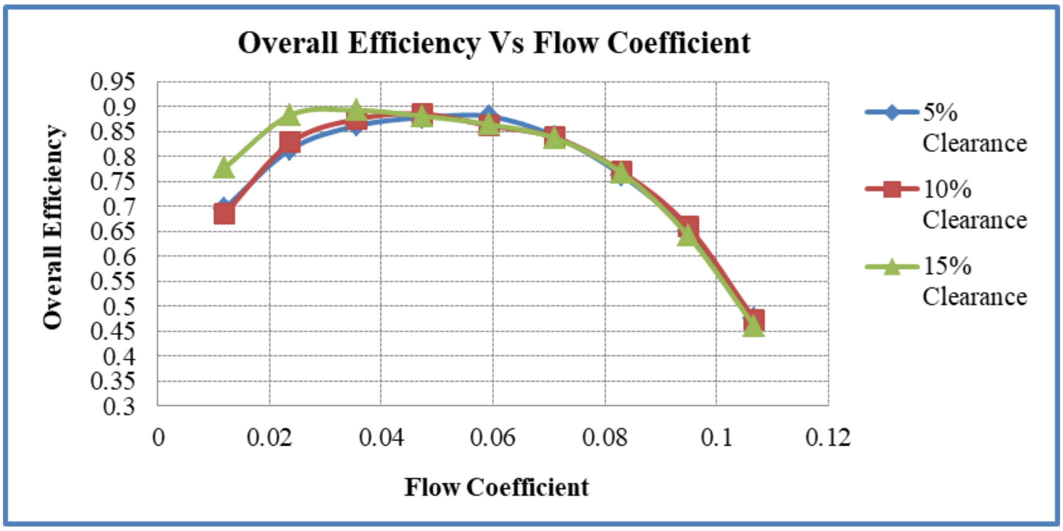

Figure 5. Performance Curves of Overall Efficiency Vs Flow Coefficient with Different Clearances for Reducing by Numerically

Table 2 shows effect of clearances between impeller and volute casing on static efficiency for reducing with volume flow rate from 0.4 m/s to 3.6 m/s. The static efficiency of the blower is observed 50% to be at 5% clearance and simulation result is occurred 53.22%. The static efficiency is obtained 53.29% at 10% clearance and 52.26% at 15% clearance.

Table 2. Effect of Clearances between Impeller and Volute Casing on Static Efficiency for Reducing

Volume flow rate, Q	5% Clearance	10% Clearance	15% Clearance
0.4	0.3548	0.3906	0.4072
0.8	0.4772	0.4965	0.5026
1.2	0.5322	0.5329	0.5226
1.6	0.5668	0.5484	0.5396
2.0	0.5972	0.5650	0.5501
2.4	0.5963	0.5605	0.5489
2.8	0.5675	0.5358	0.5242
3.2	0.5047	0.4678	0.4486
3.6	0.3962	0.3496	0.3277

The value of maximum static efficiency is observed 59.72 % at 5% clearance flow coefficient 0.059 in Figure 6. It is found that static efficiency was not affected between 0.01 and 0.036 flow coefficient. Different clearances are nearly the same from 0.07 to 0.106 flow coefficient.

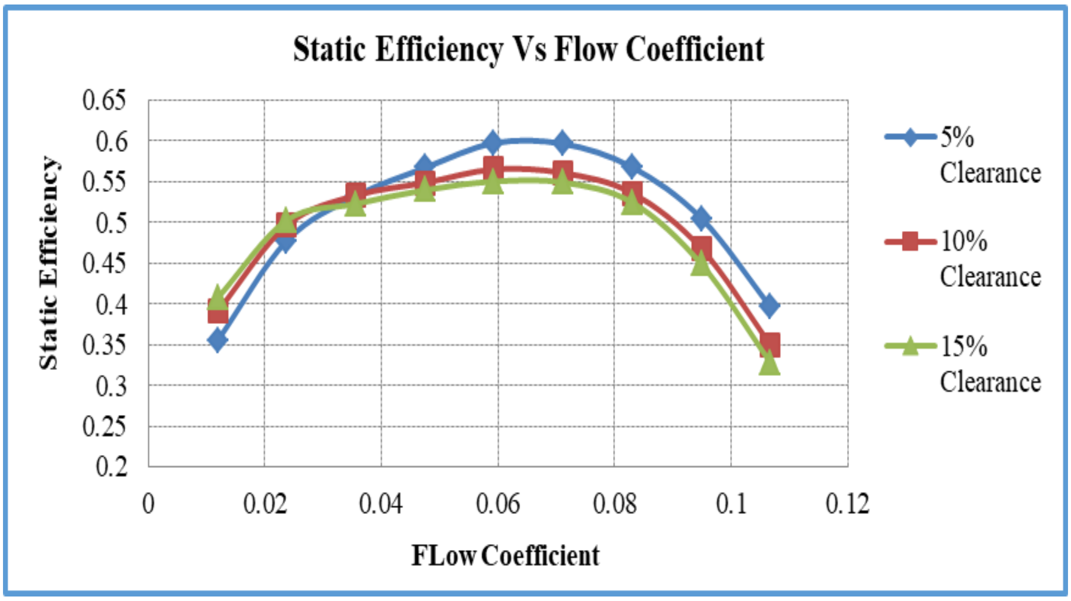

Figure 6. Performance Curves of Static Efficiency Vs Flow Coefficient with Different Clearances for Reducing by Numerically

Table 3 shows effect of clearances between impeller and volute casing on overall efficiency for increasing with volume flow rate from 0.4 m/s to 3.6 m/s. Overall efficiency is taken as 83% and simulated result was observed 87.18% for centrifugal blower.

The error between them is less 5% deviation which is in the range of acceptance and can validate the numerical result at design point. Overall efficiency is obtained 87.06% at 10% clearance and 88.24% at 15% clearance. When the clearance effect is increased, the maximum overall efficiency is obtained 88.24% at 5% clearance, which occurs at 0.036 flow coefficient in Figure 7.

It was gradually increased up to 0.036 flow coefficient at 5%, 10% and 15%. It is found that overall efficiency was not affected from 0.036 to 0.106 flow coefficient.

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Table 3. Effect of Clearances between Impeller and Volute Casing on Overall Efficiency for Increasing

Volume flow rate, Q	5% Clearance	10% Clearance	15% Clearance
0.4	0.6809	0.6751	0.7476
0.8	0.8237	0.8207	0.8689
1.2	0.8718	0.8706	0.8824
1.6	0.8806	0.8811	0.8714
2	0.8608	0.8601	0.8565
2.4	0.8351	0.8333	0.8324
2.8	0.7710	0.7709	0.7659
3.2	0.6588	0.6596	0.6422
3.6	0.4709	0.4791	0.4805

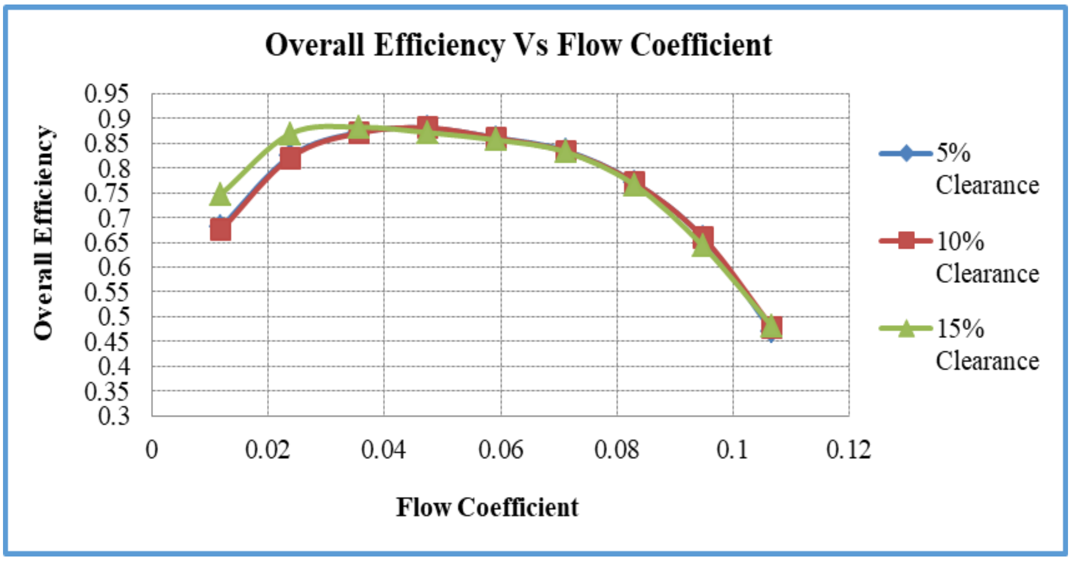

Figure 7. Performance Curves of Overall Efficiency Vs Flow Coefficient with Different Clearances for Increasing by Numerically

Effect of clearances between impeller and volute casing on static efficiency for increasing as shown in Table 4 with volume flow rate from 0.4 m/s to 3.6 m/s. The static efficiency of the blower is observed 50% to be at 5% clearance and simulation result is occured 53.67%. The static efficiency is obtained 53.86% at 10% clearance and 53.21% at 15% clearance.

Table 4. Effect of Clearances between Impeller and Volute Casing on Static Efficiency for Increasing

Volume flow rate, Q	5% Clearance	10% Clearance	15% Clearance
0.4	0.3888	0.3882	0.4252
0.8	0.4994	0.5002	0.5096
1.2	0.5367	0.5386	0.5321
1.6	0.5519	0.5537	0.5552
2.0	0.5701	0.5724	0.5663
2.4	0.5669	0.5696	0.5658
2.8	0.5459	0.5503	0.5487
3.2	0.4788	0.4841	0.4770
3.6	0.3631	0.3709	0.3771

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The value of maximum static efficiency is observed 57.24 % at 10% clearance flow coefficient 0.059 in Figure 8. It was found that static efficiency is gradually increased between 0.01 and 0.02 flow coefficient and decreased from 0.02 to 0.106. Different clearances are nearly the same from 0.07 to 0.106 flow coefficient.

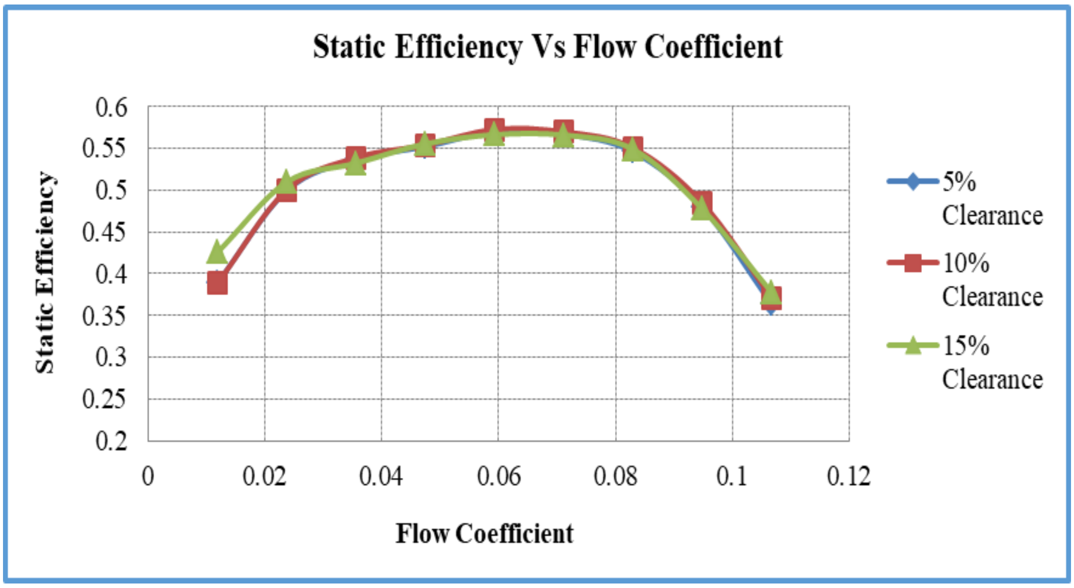

Figure 8. Performance Curves of Static Efficiency Vs Flow Coefficient with Different Clearances for Increasing by Numerically

Table 5 shows optimum blade exit angle and optimum clearances between impeller and volute casing on overall efficiency for reducing with volume flow rate from 0.4m/s to 3.6m/s.

Overall efficiency is taken as 83% and simulated result was observed 86.19% for centrifugal blower at design point. Overall efficiency was obtained 87.03% at 10% clearance and 90.16% at 15% clearance.

Table 5. Optimum Blade Exit Angle (β_2 = 45°) and Optimum Clearances between Impeller and Volute Casing on Overall Efficiency for Reducing

Volume flow rate, Q	5% Clearance	10% Clearance	15% Clearance
0.4	0.6171	0.6725	0.7606
0.8	0.7973	0.8299	0.8722
1.2	0.8619	0.8703	0.9016
1.6	0.8791	0.8750	0.8724
2.0	0.8615	0.8706	0.8616
2.4	0.8540	0.8538	0.8329
2.8	0.7615	0.7615	0.7532
3.2	0.6422	0.6440	0.6303
3.6	0.4365	0.4609	0.4336

In this research, the optimum blade exit angle (β_2 = 45°) was chosen and analyzed with reducing the clearances (5%, 10% and 15%) as shown in Figure 9.

The maximum overall efficiency is observed 90.16% at 15% clearance and performance curves decrease between 0.047 and 0.106 flow coefficient. Therefore, optimum blade exit angle and optimum clearance effect were found 45° and 15% clearance.

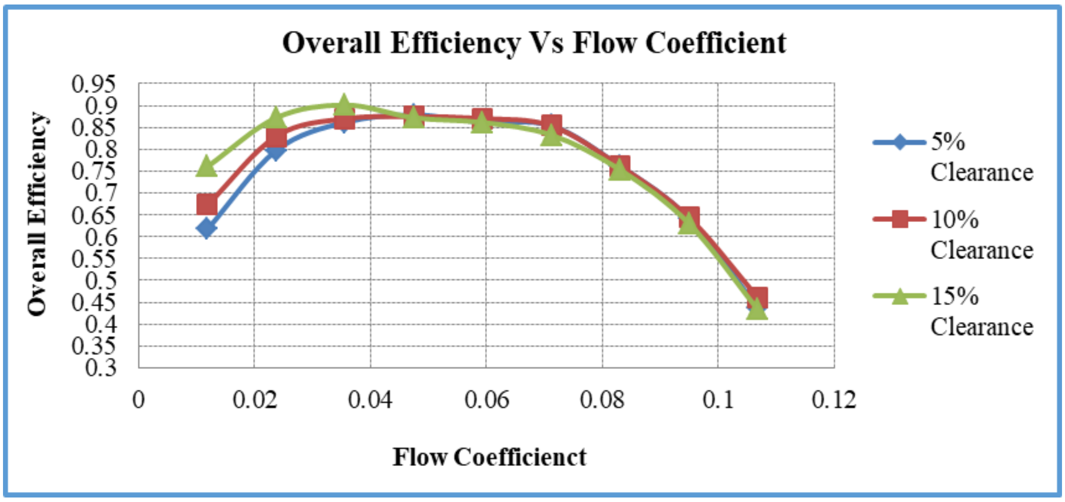

Figure 9. Performance Curves of Overall Efficiency Vs Flow Coefficient with Different Clearances at Blade Exit Angle 45 ° by Numerically

Table 6. Optimum Blade Exit Angle (β_2 = 45°) and Optimum Clearances between Impeller and Volute Casing on Static Efficiency for Reducing

Volume flow rate, Q	5% Clearance	10% Clearance	15% Clearance
0.4	0.3448	0.3903	0.3873
0.8	0.4714	0.5008	0.5013
1.2	0.5412	0.5414	0.5294
1.6	0.5891	0.5643	0.5492
2.0	0.6130	0.5812	0.5677
2.4	0.6369	0.6040	0.5834
2.8	0.6200	0.5725	0.5550
3.2	0.5709	0.5133	0.4935
3.6	0.4873	0.4037	0.3779

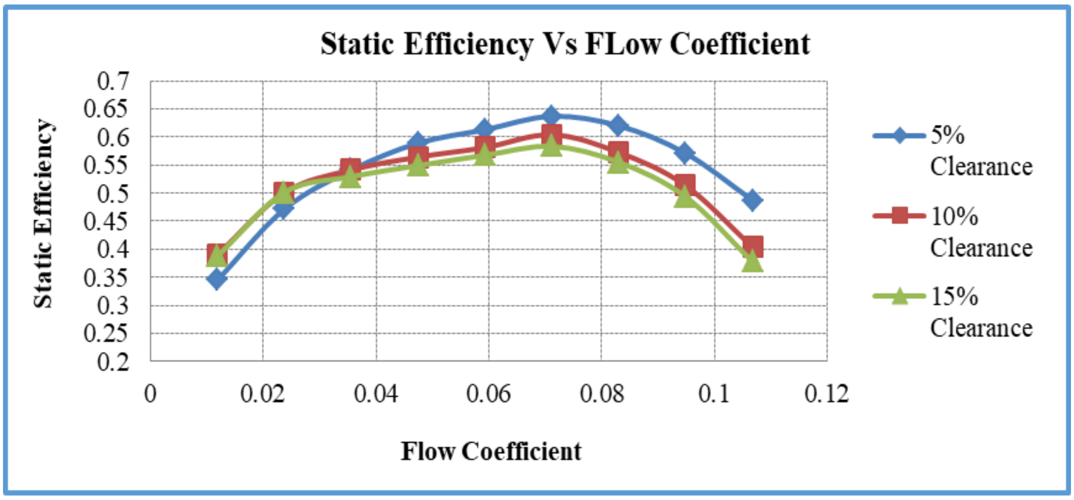

Figure 10. Performance Curves of Static Efficiency Vs Flow Coefficient with Different Clearances at Blade Exit Angle (45 °) by Numerically

Table 6 shows optimum blade exit angle and optimum clearances between impeller and volute casing on static efficiency for reducing with volume flow rate from 0.4m/s to 3.6m/s. The static efficiency of the blower was observed 50% to be at 5% clearance and simulation result was occurred 54.12%.

The static efficiency was obtained 54.14% at 10% clearance and 52.94% at 15% clearance. The value of maximum static efficiency was observed 63.69 % at 5% clearance flow coefficient 0.059 in Figure 10.

Different performance curves decrease gradually from 0.07 to 0.107 flow coefficient. And then, the volute casing was optimized by reducing and increasing the volute clearances from 5-15%. The optimum blade exit angle (β_2 = 45°) is chosen and also analyzed with reducing the clearances effect 5%, 10% and 15%. In the present work, centrifugal blower is aimed to analyze the pressure and velocity distribution within the impeller passage. Performance curves of the centrifugal blower are also drawn by using Excel Software.

IV. Discussions and Conclusion

In this paper, backward-curved blade is designed and analyzed for single stage centrifugal blower which is running with 3800 rpm counter-clockwise rotational speed. Centrifugal blower is very useful in many industries, farm machinery operations and air conditioning systems because this one is very simple and easiest way to support air supply for these applications. The capacity of this blower design is 1.2 m^3/s.

The design of the impeller has 600 mm outlet diameter. The number of vanes is 12. The volute casing inlet diameter and outlet diameter have 600 mm and 960 mm. The value of overall efficiency was 86.25% at blade exit angle β_2 = 45°. And then, the volute casing was optimized by reducing and increasing the volute clearances 5%, 10% and 15% with flow rate from 0.4 m^3/s to 3.6 m^3/s.

The optimum blade exit angle (β_2 = 45°) was chosen and also analyzed with reducing the clearances effect (5%, 10% and 15%). The maximum overall efficiency was observed 90.16% at 15% clearance and performance curves decrease between 0.047 and 0.106 flow coefficient. The value of maximum static efficiency was observed 63.69 % at 5% clearance flow coefficient 0.059. Different performance curves decrease gradually from 0.07 to 0.107 flow coefficient.

In this research, investigations on the effect of blade angles and effect of clearances of centrifugal blower on performance have been presented through CFD simulation. According to the design condition, overall efficiency is taken as 83% and simulated result was observed 85.71% for centrifugal blower.

The error between them is less 3% deviation which is in the range of acceptance and can validate the numerical result at design point. The maximum overall efficiency was obtained 88.93% at β_2 = 45°, which occurs at 0.047 flow coefficient. The static efficiency of the blower was observed 50% to be at blade exit angle of 50°and simulation result was obtained 52.81%. The results obtained are nearly equal theoretically.

When the clearance effect is reduced, the maximum overall efficiency was obtained 89.21% at 15% clearance. The static efficiency was obtained 53.22% at 5% clearance. When the clearance effect is increased, the maximum overall efficiency was obtained 88.24% at 5% clearance, which occurs at 0.036 flow coefficient. The static efficiency was observed 53.67% to be at the 5% clearance. The optimum blade exit angle (β_2 = 45°) was chosen and analyzed with reducing the clearances (5%, 10% and 15%). The maximum overall efficiency was observed 90.16% at 15% clearance. Therefore, optimum blade exit angle and optimum clearance effect were found 45° and 15% clearance.

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Conflicts of interest: There is no conflict of interest of any kind.

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