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Fabrication and Experimentation of Diffuser Augmented Wind Turbine

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Abstract- Wind Energy is turning into a big supply of renewable energy throughout the globe. This ever increasing field can probably reach the limit of accessibility and utility with the wind energy facility sites and size of the turbine itself. Therefore, it's needed to develop wind capturing devices that may produce energy within the locations wherever typical horizontal axis wind turbines (HAWTs) are too unrealistic to put in and operate. A diffuser augmented wind turbine (DAWT) is one such invention. DAWTs increase the ability output of the rotor by increasing the wind speed into the rotor employing a duct. The main objective of the project is to analyze the flow through the diffuser by placing it in wind tunnel and further the results are compared with the computational results.

The purpose of investigating the flow through, the diffuser is to find out the behavior of wind flow at the throat region of the diffuser. Numerical analysis of diffuser is performed using the tool ANSYS FLUENT 15 and then by experimentation in wind tunnel.

Experiments were carried out for investigating the flow pattern inside the circular profile diffuser of radius 60mm, Throat diameter of 200mm, inlet and outlet diameter of diffuser is 320mm. Pitot tubes are inserted on the rake and then mount on the throat region of diffuser for flow measurement in that region. Differential pressure transducers which gives voltage output are used for sensing the pressures from Pitot tubes, static tubes which is mount on surface of test section of tunnel and PS tube which is used for reference velocity. Further obtained pressure will be converted to velocity and get the required result. After completion of computational and experimental work comparable results were obtained.

Keywords- DAWT, HAWT, VAWT, Wind energy

I. INTRODUCTION

Energy became the most important source for all living beings. Recently lot of renewable energy technology have been developed and now many researches is also going on the field of sustainable non-polluting alternative resources. But there are still 1.3 billion peoples are living without using any electrical energy resources [1]. Most of this population are depends on the kerosene, cooking stoves like fossil fuels to full fill their basic needs. These fuels are pollutant and it produces hazards gases it will badly effect the health of the human beings and the ecology of the environment also. And over use of the fossil fuels, it is depleting, due to these the cost of the fossil fuels increasing. Therefore, the development of the cost effective and non-pollutant resources is very important in future.

In recent day, the energy is derived from sustainable power sources is increased, for example, sunlight based energy, wind energy, hydro energy and so forth. The renewable energy that is available in huge amount, can be replaced and also they are non-hazardous. Conversion system or machine required to produce the electrical energy while using these renewable energy sources are expensive and difficult to manufacture.

The DAWT system is incorporated into the class of small scale wind turbine to capture more wind energy for increasing the power generation. The main aim of this wind energy concentrator to improve the life cycle economics of wind energy conversion systems.

A small increase in the velocity of approaching wind turbine can generate huge growth in the power yield. By using these concepts developed a wind energy concentration to capture and accelerate the approaching wind. According to betz hypothesis the most extreme power generated from the conventional wind turbine is 59.3%. However, in practical condition only the portion of kinetic energy will absorb by the wind turbine for producing power. Therefore, the efficiency is not more than Betz value which would be nearly 30 to 40%. So as to increase the power generated by the wind turbine and also to build up the wind turbine in economical way, diffuser augmented wind turbine is such type of innovation in the sector of wind turbines.

Diffuser augmented wind turbine is foremost wind energy concentrators and it is also the new technology in the field of small wind turbine. The velocity is the most important aspect which influences the efficiency of the wind turbine. For low density areas it is required to develop the wind energy capturing devices. The working guideline of DAWT is like that of the ordinary wind turbine with the expansion of diffuser being the difference.

Diffuser Augmented Wind Turbine Physics

The basic two power augmentation principle of the wind turbine is the 1st principle is to escalation the mass flow passing through the wind turbine and the second principle is to generating vortex behind the rotor by promoting the strong mixing of the turbulent flows. The figure shown in below can be explained the first principle of wind turbine.

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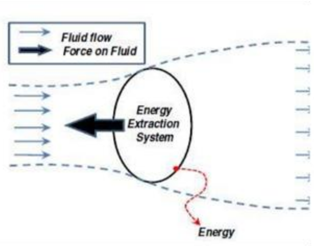

Figure 1a Conventional wind energy extraction.

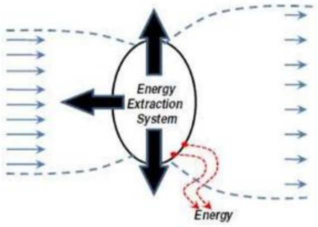

Figure 1b DAWT energy extraction scheme

Figure 1a indicating the principle of energy extracted from the conventional wind turbine. The conventional wind turbines are working on the basis of momentum theory. It is the theoretical approach developed by Betz. The conventional wind turbine is operating at the maximum betz limit 59.3%. Theoretically, the air flows through the conventional wind turbine is decelerated to 2/3 of the approaching wind velocity when it is attacking the rotor plane. The pressure will increase in front of the rotor deceleration of the flow of inward wind. It results fraction of mass being pushed side ways around the rotor. Because of the flow continuity and incompressibility is that the rotor effectively captures the kinetic energy confined in the wind from an effective surface that is 2/3 of the swept rotor surface [2].

The figure 1b shows [2] the approaching wind velocity extraction by using diffuser surrounded by the conventional wind turbine. By exerting the perpendicular force on the forthcoming wind can be increased the effective surface. To increase the perpendicular force on the wind turbine by placing the annular lifting devices, such as, diffuser surrounded by the rotor with its suction side pointing towards the center. From Newton's 3rd law it states that the counter acting force will generate the approaching air stream in order to establish the force in equilibrium. This counter acting force can only be exerted when the flow of air mass through the annular lifting device is sucked. So due to this the outward force will widen the stream tube, or catchment area, ahead of the rotor as depicted.

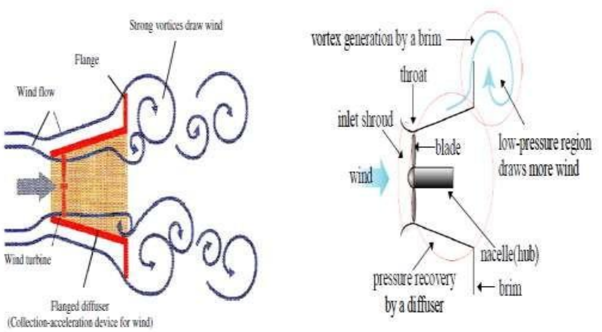

Figure 2 flow around a flanged diffuser.

The figure 2 shows the second principle [6], to generate the strong vortices behind the diffuser to create the negative pressure region outside of the diffuser to suck more mass flow rate of air. Due to the more turbulent mixing in the back side of the diffuser negative pressure created behind the diffuser and the free stream velocity approaching the diffuser inlet increases. Consequently, the power output increases, simultaneously coefficient of power also increases. That's why the DWAT is called the collecting accelerating devices for approaching wind.

In 1980 C.A. J Fletcher did an analysis on DWAT using blade element theory and results were compared with the experimental work performed by Igra and Gilbert. From the experimental results, it is concluded that the use of diffuser attachment on the outer periphery of the rotor blade reduces the total drag force acting on the rotor blade. The power output increases due to the use of DAWT. [3]

Ohya et al developed a shrouded wind turbine using a flanged diffuser [4]. The objective of the work is to gain a higher power yield of the shrouded wind turbine, the project team examined the finest form of the flanged diffuser. As a result, a shrouded wind turbine with a flanged diffuser has been developed, and validated power augmentation for a given turbine diameter and wind speed by a factor of about 4–5 compared to a standard (bare) wind turbine. The team came to know in a field experiment, i.e. using a model wind turbine with a flanged diffuser shroud, the output performance was as expected and make equal that of the wind tunnel experiment.

Yuji Ohya et al investigated Shrouded Wind Turbine [5]. In this work, researchers were developed a new wind turbine system that comprises of a diffuser shroud with a broad-ring brim at the exit periphery and a wind turbine inside it. The shrouded wind turbine with a brimmed diffuser has validated power augmentation by a factor of about 2–5 compared with a bare wind turbine, for a known turbine diameter and wind speed. They came to the conclusion from the experiment that, because a low pressure area, due to a strong vortex formation behind the broad brim, draws more mass flow to the wind turbine inside the diffuser shroud.

A Naustion et al [6] did a research work on Curvature Interior Profile for DWAT. In this research, the way was found to accelerate potential power augmentation obtainable by diffuser augmented wind turbine. For this, enhanced airfoil shape was used as the interior profile instead of original flat interior. Optimization of curvature interior profile program XFOIL 6.9 and CFD technique were used to find the velocity distribution across the curvature profile. From this analysis, it is concluded that the proposed optimized geometry here NACA 5807 airfoil to be used. They gave velocity enhancement of 65.5% in contrast to the diffuser with original flat interior.

II. METHODOLOGY

In recent years there has been a rapid growth in the wind power harvesting technologies where the challenge is to somehow to extract the maximum power output from the wind turbines. This work involves modelling of diffuser to perform fluid flow analysis on diffuser using fluid flow analysis package Ansys Fluent. Obtaining the velocity stream lines, velocity vector and pressure contours to understand the extreme velocity which develops in the diffuser.

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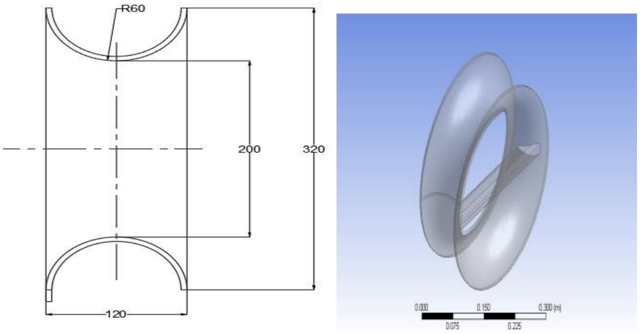
The model is fabricated after finalizing the design with diffuser rake setup, Pitot tubes were inserted in the rake for flow measurement in the throat region of diffuser. An arrangement is made for mounting the diffuser in wind tunnel. Pressure transducers are used for sensing the pressure from Pitot tubes and Pitot-static tube which gives the voltage output for differential pressure. Further obtained pressure values can be converted to velocity and required results may be acquired. Experimental work is carried out with the designed diffuser in the wind tunnel with different flow velocities obtained from the different rotational speed of the motor, of the wind tunnel and the values of pressure at different locations of the throat region of the diffuser are obtained. Comparison of results acquired from the numerical method and the experimental work.

A. Experimental Investigation

The basic two power augmentation principle of the wind turbine is the first principle is to rise the mass flow passing through the wind turbine and the second principle is to generating vortex behind the rotor by promoting the strong mixing of the turbulent flows. By doing the analysis of different radius of diffuser, decided to for fabrication of a diffuser centered on the result in Ansys. The dimension of diffuser is of Throat Diameter- 0.2 m, Inlet Diameter- 0.32 m, Outlet Diameter- 0.32 m & Length of 0.12 m



All Dimensions in mm

Figure 3a –2D Cad and 3D model of Diffuser

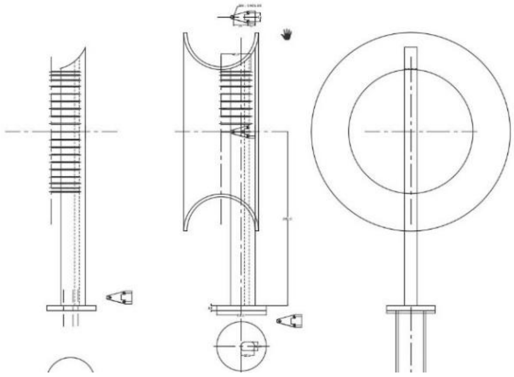


Figure 3b - 2D drawing of diffuser with pitot tubes

B. Computation fluid Dynamics:

ANSYS FLUENT 15.0 is used for the analysis and to find wind flow inside the diffuser. This software offers the wide physical modelling abilities required to model flow, turbulence and heat transfer. [7].

In this simulation, it was anticipated to be a symmetric incompressible steady flow with the following boundary conditions: initial wind velocity 10 m/s as velocity inlet at the front boundary diffuser; inlet pressure surrounding the diffuser was set to atmospheric pressure; pressure inlet with 0 pressure input; diffuser wall was as stationary wall [8]. Surface meshing setting was 50 number of division for diffuser and 100 division for domain.

III. RESULTS AND DISCUSSIONS

A. Experimental Study

The figure 4a shows the variation of velocity with respect to Pitot tube position radially outwards at the diffuser throat for a free stream velocity of 10 m/s. It is observed that the velocity radially increases from diffuser center to radially outwards towards the diffuser wall.

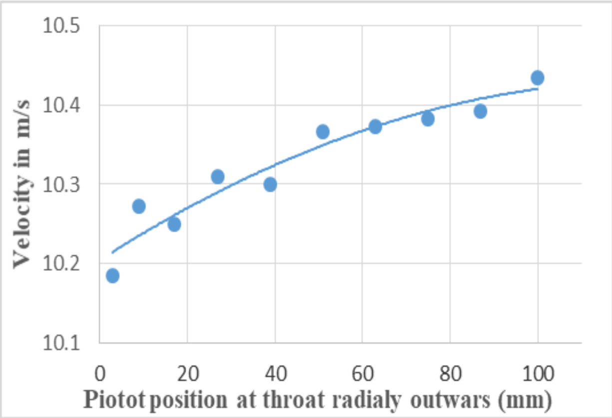


Figure 4a- Velocity vs Pitot tube location at the diffuser throat radially outwards for the inlet stream velocity of 10 m/s

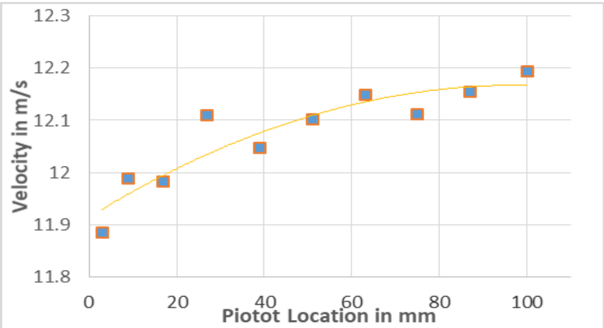


Figure 4b- Velocity vs Pitot tube location at the diffuser throat radially outwards for the inlet stream velocity of 11.7 m/s

The figure 4b shows the variation of velocity with respect to Pitot tube position radially outwards at the diffuser throat for a free stream velocity of 11.7 m/s. It is observed that the velocity radially increases from diffuser center to radially outwards towards the diffuser wall.

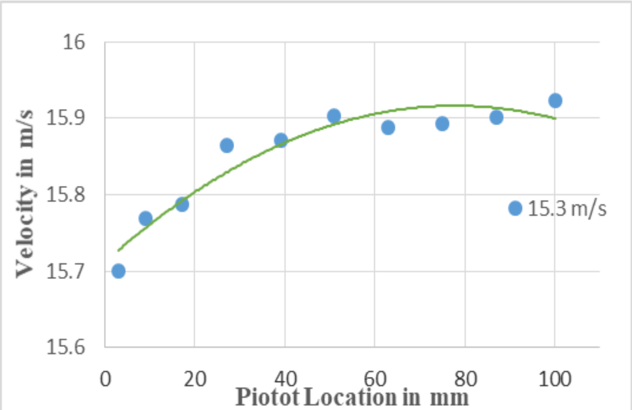


Figure 4c-Velocity vs Pitot tube location along throat for inlet free stream velocity 15.3 m/s

The figure 4b shows the variation of velocity with respect to Pitot tube position radially outwards at the diffuser throat for a free stream velocity of 11.7 m/s. It is observed that the velocity radially increases from diffuser center to radially outwards towards the diffuser wall. .

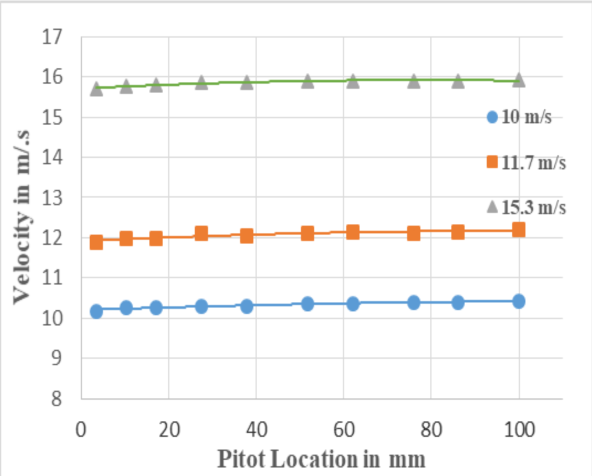


Figure 5-Comparison for different inlet free stream velocity

The figure 5 shows the comparison on different free stream velocity, what are the variation of velocity with respect to different Pitot tube locations at throat in the vertical direction from centre of the diffuser towards the surface. It is observed that the values of velocity obtained at 15.7 m/s of free stream velocity is higher than the other 2 velocities and it is observed that for all 3 free stream velocity, the velocity radially increase from diffuser center i.e. throat region to the surface of the diffuser.

C. Computational study

Case 1- Diffuser with Rake setup

Ansys Fluent-15 is used for the flow analysis in the diffuser. Domain is created as per the reference [9] depends on the diffuser dimension and Inlet free stream velocity of 10m/s.

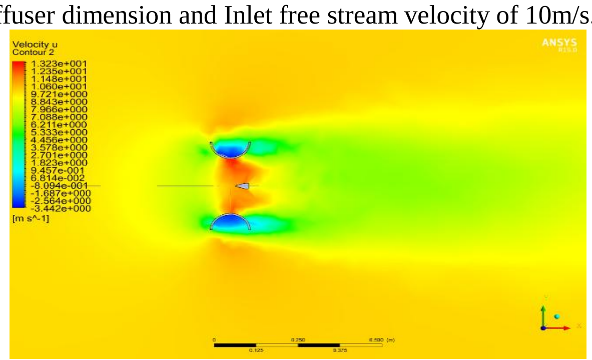


Figure 6a- Velocity contour

The figure 6a shows the variation of velocity with respect to various region of diffuser for the free stream velocity of 10 m/s. It is observed that the velocity continuously increases from the center of diffuser towards the surface. Flow features like flow separation, vortices formation can also be seen from the figure.

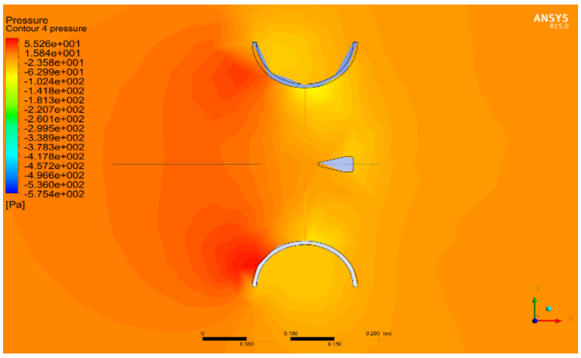


Figure 6b - Pressure contour

The figure 6b shows the variation of pressure with respect to various region of diffuser for the inlet velocity of 10 m/s. It is perceived that the pressure is maximum at inlet region and further it is continuously decreases from the diffuser inlet towards the throat.

The inlet velocity of 10 m/s in the domain. After the convergence of the problem, the velocity is increased. i.e. the average velocity absorbed is 11.3 m/s.

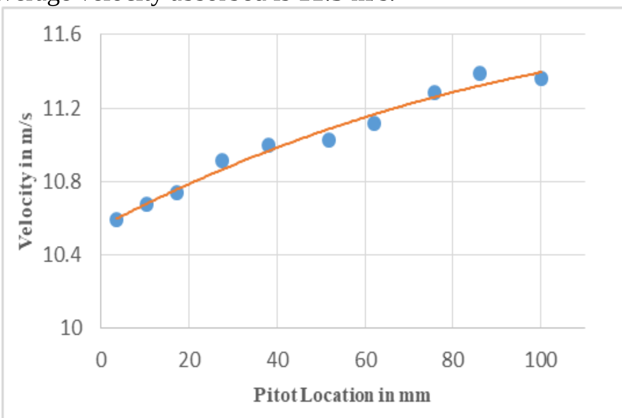


Figure 7a-Velocity at Z axis of throat

The figure 7a shows the increase of velocity with respect to different Pitot tube locations at throat in the vertical direction from centre of the diffuser towards the surface for Z axis of the throat. The result has a fluctuation because of existence of rake setup.

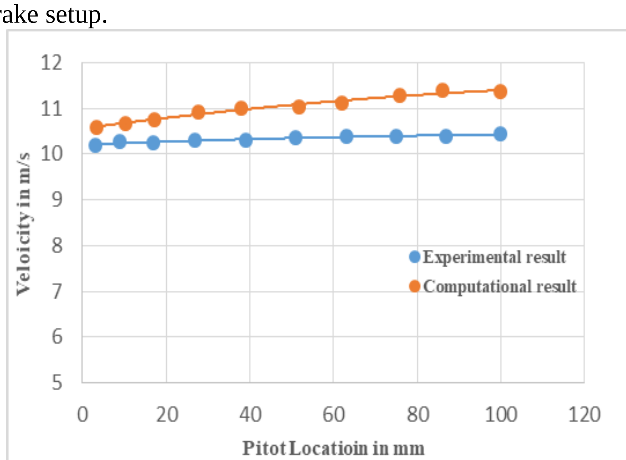


Figure 8-Comparison b/w Computational and experimental results

The figure 8 shows the comparison of computational and experimental results for the variation of velocity w.r.to the different locations of the Pitot tube for an approach velocity of 10 m/s in the wind tunnel.

In both the cases velocity continuously increases with respect to different Pitot tube locations at throat in the vertical direction from diffuser centre to surface of diffuser.

Case 2- Diffuser without rake

In real scenario, there is no presence of rake in throat region of diffuser. For flow measurement the rake is made and pitot tubes were mounted on it. By considering this factor, same analysis is done to the model which does not has the rake in it and both the results are compared.

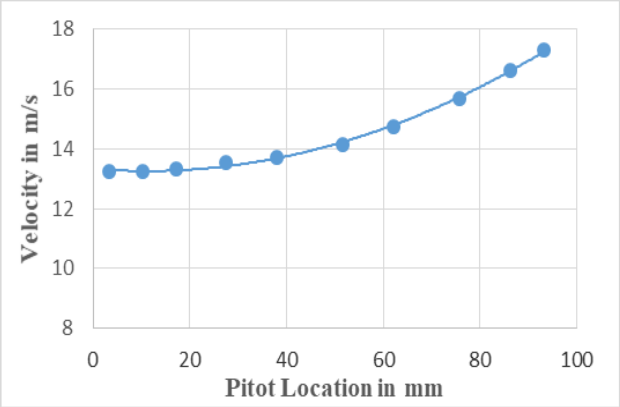


Figure9a-Velocity vs Pitot tube location along throat without rake for free stream velocity of 10 m/s

The figure 9a shows the variation of velocity with respect to various region of diffuser without rake for the inlet velocity of 10 m/s. It is observed that the velocity continuously increases from the diffuser center to radially away towards the diffuser surface. It is observed that the flow gets effected by the presence of diffuser, so the result of diffuser without rake is better compared to with rake.

Figure 9c and 9d shows the velocity and pressure contour of the without rake diffuser setup for a free stream velocity of 10m/s.

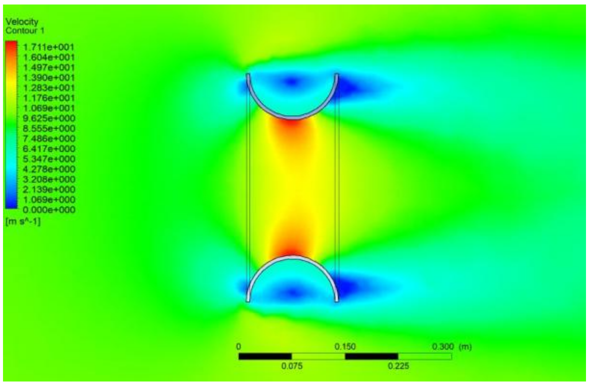


Figure 9c-Velocity contour

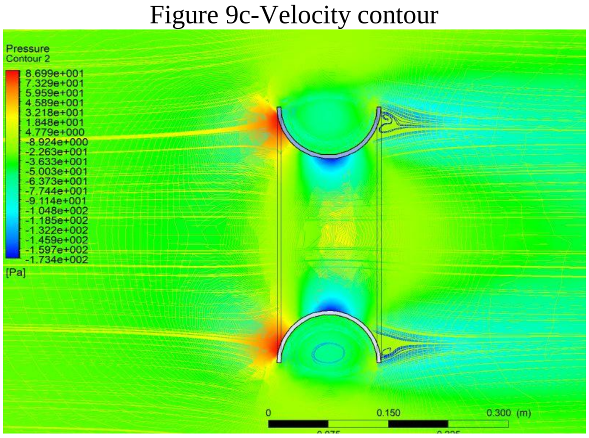


Figure9d-Pressure contour

The inlet velocity of 10 m/s in the domain. After the convergence of the problem, the velocity is increased by great amount i.e. the average velocity observed is 16.1 m/s.

IV. CONCLUSION

Experimental and computational investigations were carried out for flow fields of a diffuser. By processing the data obtained, characteristic values of the flow fields were estimated and compared with one another. The main conclusions derived from the study are as follows:

- The circular shape profile of 60mm radius was chosen for modelling the diffuser and numerical examination of the flow design around diffuser was done by utilizing ANSYS FLUENT 15.
- The diffuser is fabricated and tested in wind tunnel for performance test.
- From the both computational and experimental work come to know that, the velocity at the throat is more than the free stream velocity. The velocity at the diffuser throat section increases from diffuser axis to outer surface radially.
- From the present computational study there was around 60% improvement in the velocity for the selected diffuser geometry considering average wind speed at the diffuser throat section.
- For the both experimental and computation work the velocity vs pitot location graph is plotted and observed that, graph trend is same in both case.

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Santoshkumar Borkar has done BE in Mechanical Engineering from Visvesvaraya Technological University Belagavi Karnataka in the year 2017 has done BE project solar operated groundnut harvesting machine related to Agriculture field and also pursuing M.Tech in Thermal power engineering from VTU. His research interests are Thermal power generation, Advanced and computational fluid dynamics, thermodynamics, Air conditioning & Refrigeration system.

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