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Computational Fluid Dynamics Analysis on Cylindrical Brimmed Diffuser

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Abstract:
The objective of the present study is to evaluate the influence of brim thickness and also the diameter of the diffuser on the enhancement of wind speeds in the shrouded diffuser region. In the present study only the shrouded diffuser with the brim is considered without the wind turbine for simulation purpose.

Introduction:
The study of the flow around diffuser which is used for small wind turbines has great importance in enhancing the velocity and in turn the power output of the wind turbine. The diffuser is an innovation that has many researchers for possible use in generating energy more efficiently, due to the considerable increase in power extracted from the kinetic energy due to motion of the fluid.

The power in wind is well known to be proportional to the cubic power of the wind velocity, approaching

$P = ½ \rho A v^3 C_P(W)$ i.e., $\mathbf{P \propto v^3}$

The wind turbine This means that even a small amount of acceleration gives a large increase in the energy output. Therefore, many research groups have tried to find a way to accelerate the approaching wind effectively.

Shrouded Wind turbine:
Wind energy technologies have been developed rapidly and are about to play a big role in a new energy field. However, in comparison with the overall wind power potential available, the scale of wind power generation is still small. Apart from the wind farm regions where large wind turbines are generally installed, the untapped potential includes region of small intensities of wind speeds where the small power output even in areas where lower intensity of wind speeds and complex wind patterns are expected is strongly desired.

The power generation is proportional to the cube of wind speed. Increase in wind power output can be by slight increase in the velocity of the approaching flow. By enhancing wind speed locally, the power output of a small wind turbine can be increased substantially.

In the present study, the concept of accelerating the wind speed locally by using shrouded diffusers with brims is considered

The Figure illustrates an overview of shrouded small wind turbine with the diffuser and brim. The brim generates a large separation of flow behind it, where a very low-pressure region appears to draw more wind

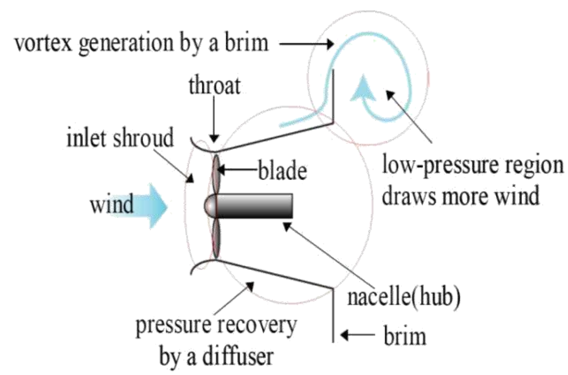

Fig.1 Principle of Cylindrical Brimmed Diffuser Wind turbine

Objective of the Project:
The scope of the present study includes analysis of the variation of the free stream velocity and determines an efficient dimension set up of the shrouded wind turbine by establishing 2D CFD models of shrouded wind turbine with the varying Brim width as 25mm, 75mm, and 100mm which is initially fixed in the Reference model as 50mm for the following two cases;

By varying the thickness of the brim in the Rear Face and Front Face of Brim and maintaining all the other dimensions of the model constant. Diffuser height (Outlet) as 35mm, 40mm, 45mm where the initial height has been 30mm

Below is the image of the Reference model with 50mm thickness and brim height as 200 mm

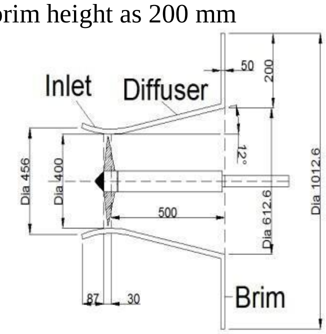

Fig 2. Reference model with thickness 50mm and brim height 200mm

Fig.3 Cylindrical Brimmed Diffuser Wind Turbine (Small Wind Turbines)

Modelling of the Cylindrical Brimmed Diffuser :

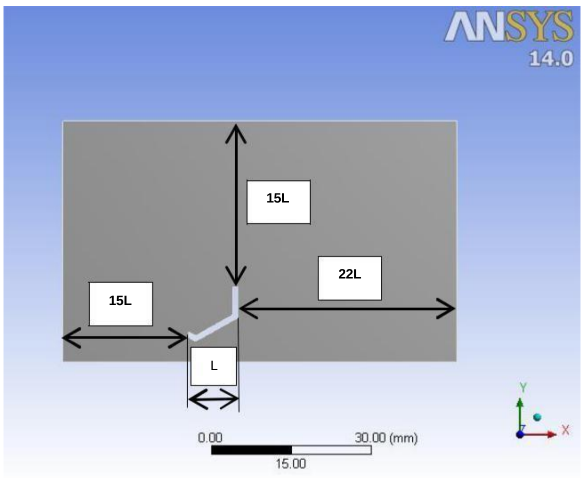

Fig.4 Boundary Plane Limits

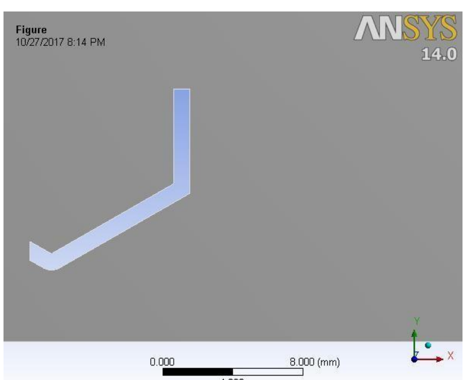

Fig.5: 2D Axisymmetric Model of Cylindrical Brimmed Diffuser

Boundary Plane Properties :

The boundary plane set keeping in mind the axis-symmetric feature. The five boundary conditions set in this modeling are as follows:

- ➢ Velocity Inlet Boundary Conditions
- ➢ Pressure Outlet Boundary Conditions
- ➢ Wall Boundary Conditions
- ➢ Symmetry Boundary Conditions
- Axis Boundary Conditions

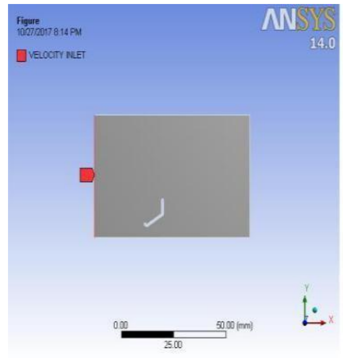

Fig.6 Velocity Inlet

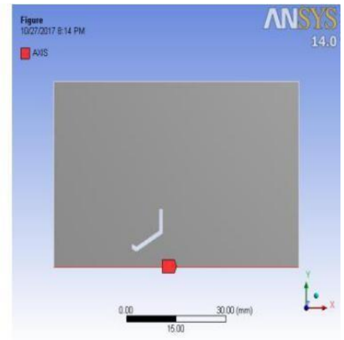

Fig.7 Pressure Outlet

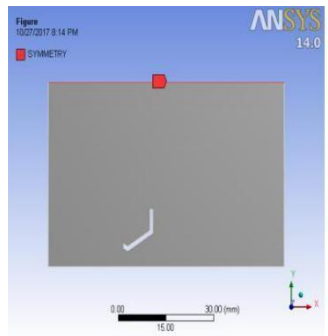

Fig.8 Symmetry

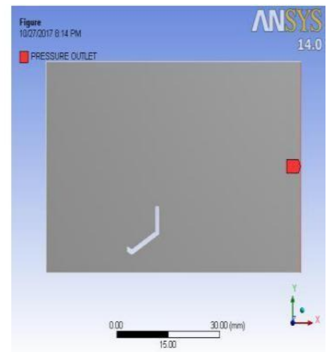

Fig.9 Axis

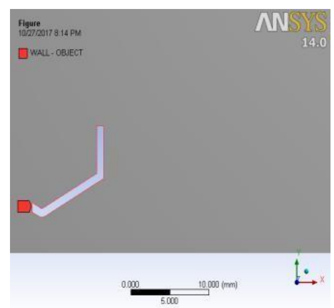

Fig.10 Model (Wall)

Meshing:

Type : Free Quadrilateral Mapped mesh

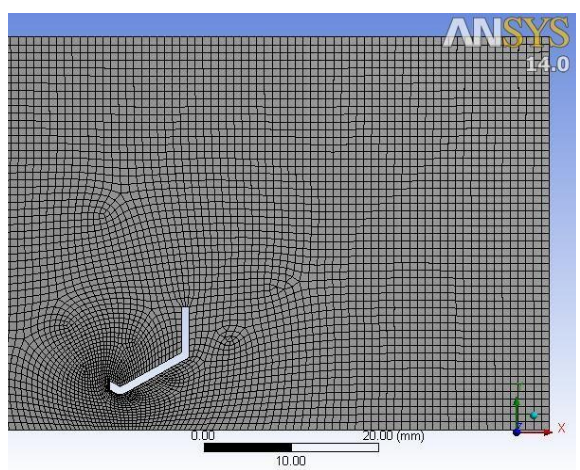

Fig.11 Quadrilateral Mapped Mesh

Solver Specifications and Fluid Properties

Table 1. Solver Specifications

Solver	Pressure Based
Formulation	Implicit
Time	Unsteady
Space	Axisymmetric
Velocity Formulation	Absolute
Porous Formulation	Physical Velocity
Gradient options	Green-Gauss Cell
Viscous Model	k-Ɛ

Table 2. Fluid Properties

Material Type	Fluid
Fluid	Air
Density	1.225 kg/m^3
Viscosity	1.7894 x 10^{-5} kg/ms
Pressure	101325 Pa
Velocity	4m/s

RESULTS:

Velocity Contours of Thickness increased in Rearface of Brim:

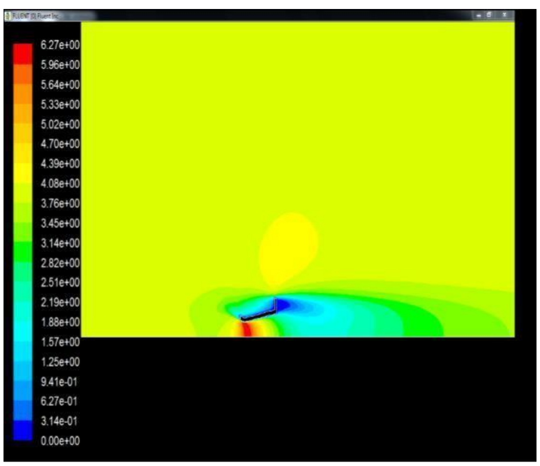

Fig.12 (a) 25mm Brim Thickness

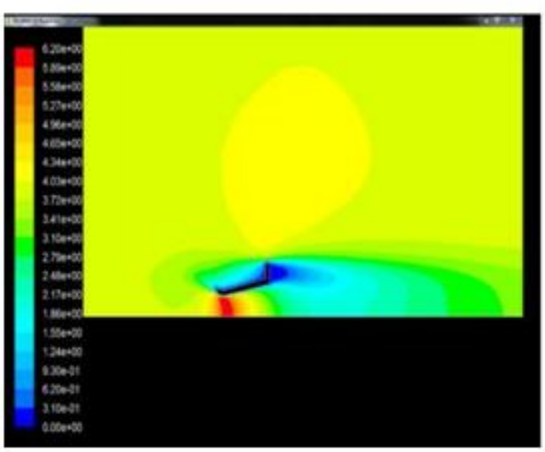

Fig.13 (b) 50mm Brim Thickness

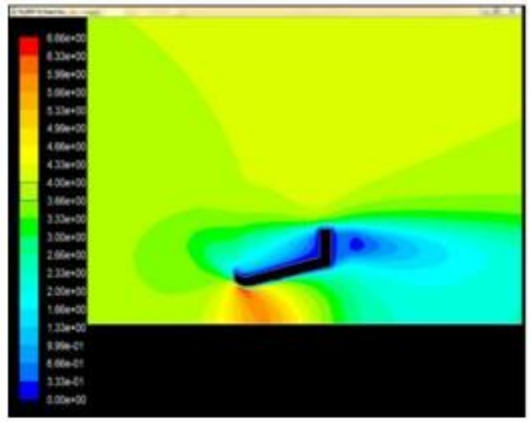

Fig.13 (c) 75mm Brim Thickness

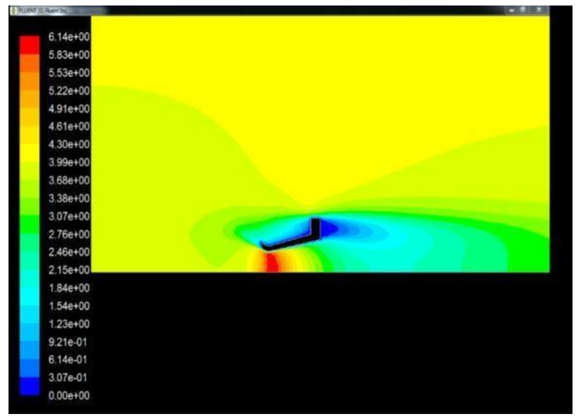

Fig.14 (d) 100mm Brim Thickness

Velocity Contours of Thickness increased in Frontface of Brim :

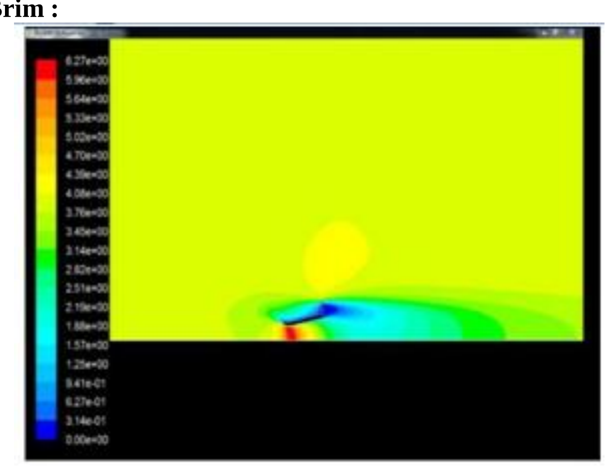

Fig.15 (e) 25mm Brim Thickness

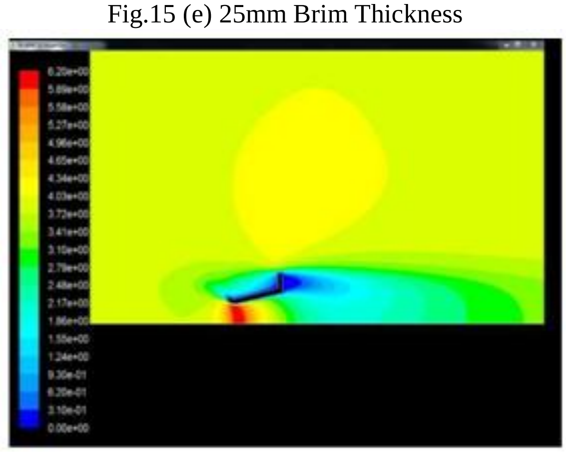

Fig.16 (f) 50mm Brim Thickness

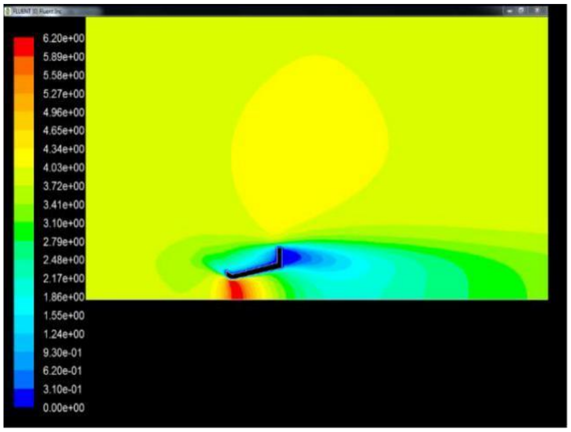

Fig.17 (g) 75mm Brim Thickness

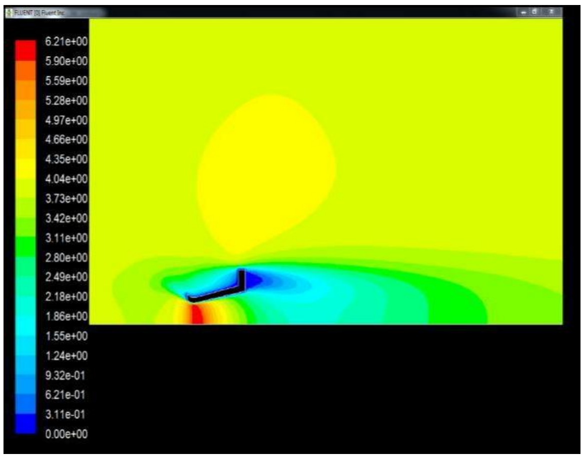

Fig.18 (h) 100mm Brim Thickness

8.3) Radius Increased in Diffuser Outlet:

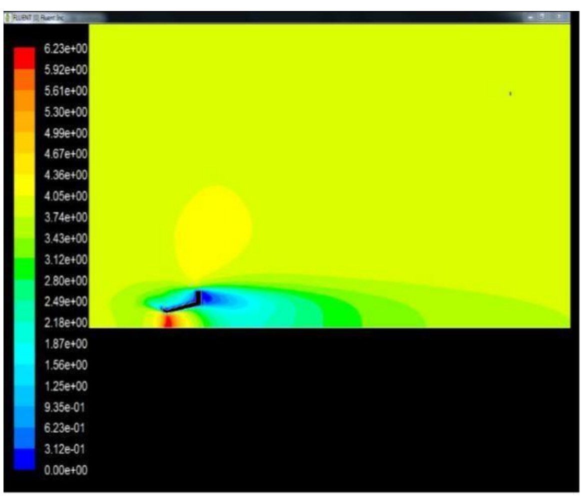

Fig.19 (i) Diffuser Outlet Radius = 300mm

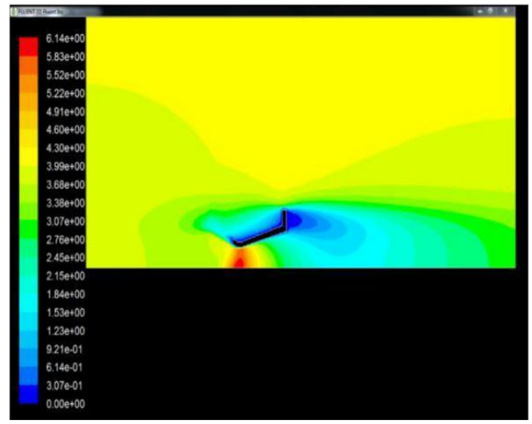

Fig.20(j) Diffuser Outlet Radius 350mm

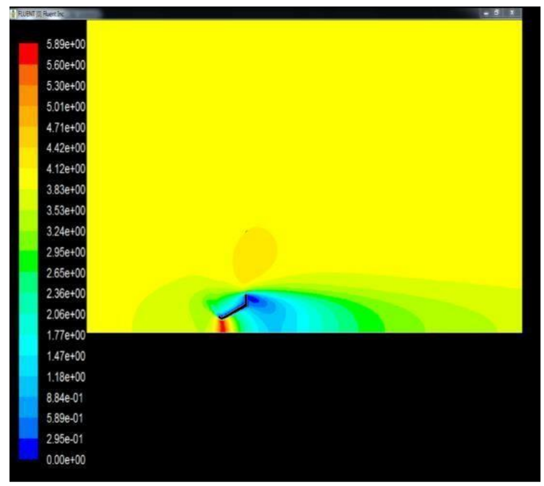

Fig.21(k) Diffuser Outlet Radius 400mm

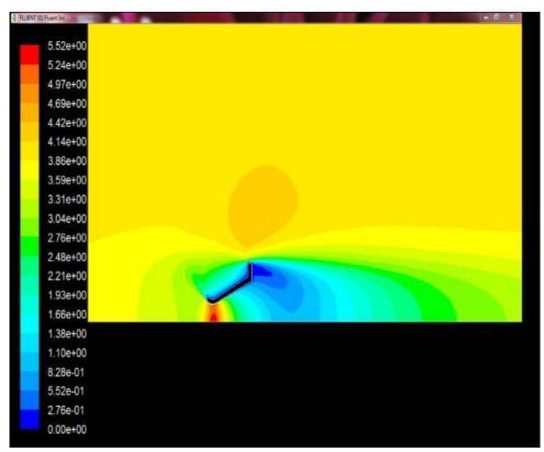

Fig.22(l) Diffuser Outlet Radius 450mm

RESULT AND DISCUSSION

Cylindrical Brimmed Diffuser for small wind turbines are being used to accelerate the wind velocity in the small wind regimes. Many experimental and numerical studies has been carried out on the shrouds to augment velocity/wind power and are available in the literature. At present, a parametric study has been carried using computational fluid dynamics on a cylindrical brimmed diffuser with the variations in geometric details of a diffuser 2-D axisymmetric model of only the brimmed diffuser with shroud (without modeling the wind turbine) is used in this study.The pre-processing and numerical simulation is carried out in ANSYS software 'Fluent' in Brim thickness in both Rear and Front face of Brim and variations in diffuser outlet radius at exit are the parameters used in this analysis.

Table 3. Velocity Comparison VInput = 4m/s

Case	Parameters	VAverage	Fastup Factor = VAverage / VInput
Thickness increasing in Rear Face of Brim	25mm	5.96	1.49
	50mm	5.89	1.47
	75mm	6.33	1.58
	100mm	5.83	1.45
Thickness increasing in Front Face of Brim	25mm	5.92	1.48
	50mm	5.89	1.47
	75mm	5.90	1.475
	100mm	5.92	1.48
Diffuser Outlet Radius	300mm	5.89	1.47
	350mm	5.83	1.46
	400mm	5.60	1.40
	450mm	5.24	1.31

Wind Turbine Power Calculation

The output power of single cylindrical brimmed diffuser wind turbine can be calculated by using this formula

$P = \frac{1}{2} \rho A v^3 C_P (W)$ i.e., $\mathbf{P \propto v^3}$

P - Output power (W)

ρ - Density of air (Kg/m^3) =1.225 Kg/m^3 r=L=Length of Blade (m) = 0.180m

A - Swept Area (m^2) = πr^2 (m^2) = 3.14 X $(0.180)^2$ = 0.101736 m^2

v - Wind velocity (m/s)

Cp - Power Coefficient (No unit) = 0.40 (Betz Limit)

Average velocity in Throat section (location of wind turbine blades) = v_{avg}
= 6.33m/s

P = 6.32 W

3D Design of Cylindrical Brimmed Diffuser:

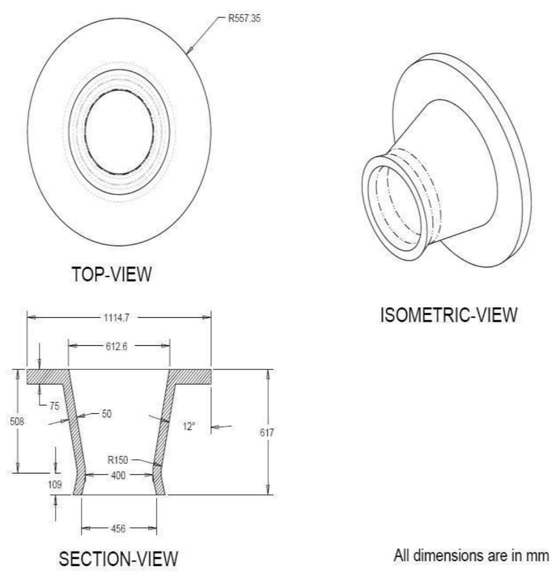

Fig.23 Orthographic views of Diffuser Model

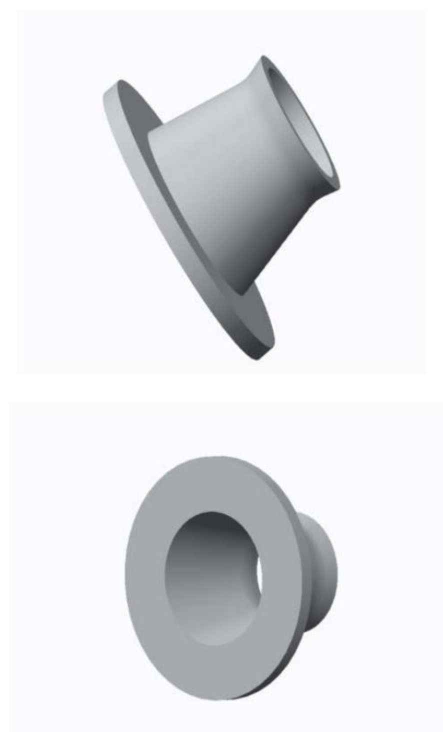

Fig.24 3D views of Cylidrical Brimmed Diffuser Model

Conclusion:

Based on the numerical simulation of flows with uniform and smooth approach velocity of 4m/s around the cylindrical brimmed diffuser wind turbine with the variations of brim thickness in both the Rear and Front face of Brim and diffuser outlet radius, the following conclusions have been made.

Comparison of the velocity of flow at different sections along the length of diffuser has been made both in Rear and Front face of Brim models.In the case of Rear face ,for throat section (at the location of wind turbine), the maximum average velocity of 6.33m/s is observed with an acceleration factor (or) speed up factor (ratio of average velocity to approach input velocity)of 1.58 for brim width of 75mm. However,there is no particular trend is observed to be negligible among these values.For Front face ,the shroud portion,the maximum average velocity of 5.92m/s is observed with an acceleration factor of 1.48 for brim thickness of 25mm and 100mm .

The average velocity values corresponding to shroud portion for different diffuser outlet radius values,viz.300mm, 350mm, 400mm and 450mm, are calculated and it can be observed that a maximum average velocity of 5.89m/s with an acceleration factor of
1.47 for diffuser outlet radius of 300mm .In general, the acceleration factor is observed to be decreasing with increase in diffuser outlet radius.The diffuser outlet radius of 300mm (reference model) is observed to have maximum value of 1.47among these values.

It is to be noted that this flow simulation is done for a two dimensional axisymmetric case of the model with steady state solution.
The studies are carried out for the cylindrical brimmed shrouded diffuser only (without the wind turbine).

The validation of the results obtained based on these simulation need to be done using windtunnel experiments. Hence, the results can be used quantitatively.

References:

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2. K.Abe, Y.Ohya An investigation of flow fields around flanged diffusers using CFD, J.Wind Engg. Indust.Aerodyn.92(2004) pp.315-330.

3. Leo Daiki Shinomiya, "Numerical Study of Flow around Diffusers With Different Geometry Using cfd Applied to hydrokinetics turbines design

4. Y.Ohya, T.Karasudani, A Shrouded Wind Turbine Generating High output Power with Wind-lens Technology, Energies Vol. 131, 2010.