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A Numerical Investigation on Affecting Parameter of the Wind Turbine Blade to Recover Waste Energy

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ABSTRACT

The research isassociated with a concept of the waste energy recovery from the air which isexhausted at high speed in process industries. A numerical simulation is performed to calculate the power which is responsible for the rotation of theblades. Here in cement plant, air which is exhaustedfrom bag filter with a velocity in the range of 16-25 m/s is to be utilized. Concept of air strike on blade is usedto utilized the waste energyfor the production of electricity for the domestic lightning purpose, which is simply going to the atmosphere. So design of blade plays the important role to make the system efficient. Hence the parameter like no. of blade on rotor, deflection angle, shape of curvature of blade profile, blade thickness etc. are considered, which give clear idea for the efficient system.

Keywords :- Wind Turbine, Exhaust duct, high velocity air, Waste energy recovery,

I.INTRODUCTION

In process industries like in cement, fertilizer,Bulk-drug pharmaceuticals,Textiles etc.The air is used to process the material like drying, purging to reduce emission etc. and after the completion of its function air is expelled into the atmosphere. The aim of the paper is to utilize this exhaust air for the power production for domestic lightening purpose. Recently the wind turbine plays an important role for generation of electricity but because of the size of the blade of the turbine creates a difficulty to use wind turbine in the research. Apart from this natural wind turbine is mainly dependent on geographical condition due to that its utilization factor is also very low in the range of 18 to 24%. Hence a new concept for the generation is needed. From the literature and the theory, concept of Pelton wheel gives an idea to prepare a model which can produce the same results as in the case of water as a working fluid.

In Cement industries emissions of air pollutants has to be controlled under NESHAP (National Emission Standards for Hazardous Air Pollutants) regulations.Polluted air is purged from various location in material flow path. Suction port is allocated at probable dusting location, from such point air is sucked by means of centrifugal fan. This air passes through house of no. of bag, where dust particle is separated from polluted air. At the end of this process high velocity clean air is exhausted to atmosphere. Present paper is focused on small duct as a pilot model having rectangular duct of 250mm×300mm, from which air is exhausting at 16m/s with the atmospheric pressure of 40mm of H_2O.

This paper introduces designing procedure followed for wind turbine of artificial air. Air divergence is examined to study the flow behaviour and its effect at various distance on thrust force of the blade. Selection of blade is carried to check its compatibility for this specific purpose. Selection of suitable thickness of acrylic plate is carried out to predict its feasibility for designed wind turbine. Optimized blade size and deflection angle is selected by performing numerical analysis in ANSYS software. No. of analysis has been carried out to select optimum no. of blade for the wind turbine. Mesh independency test has been also carried out to optimize the calculation time and proper utilization of resources. Numerical analysis has carried out in ANSYS software using standard $k - \epsilon$ equation as it validates well actual flow behaviour.

II.LITERATURE SURVEY

Small scale wind turbine is widely used for house hold application at remote location. From literature review it has been found that savonius wind turbine is one of the simplest and widely used to utilized natural wind source. Savonius wind turbine is drag based type wind turbine. From no. of research paper, it has been found that helical savonius rotor having two scoop is one of the most efficient turbine[1]. Tip Speed Ratio(TSR) is the ratio of the velocity of tip of the blade and velocity of wind, Konrad Kacprzak et al. [2]found power is maximum at 0.81 TSR. Zhenzhou Zhao et al. [3] found in result of numerical analysis that power coefficient is 0.165 and 0.12 for two and three blade rotors respectively at TSR = 0.8. which also validated by U.K. Saha et al. [4] and Mohammed Ali et al. [5]. M.A. Kamoji et al. [6] found in experiment that, aspect ratio of 0.88 have maximum coefficient power of 0.165 at TSR of 0.7 for a helical Savonius rotor with a 90º twist at a Reynolds number of 120,000. Jae-Hoon Lee et al. [7] and M.A. Kamoji et al. [6] had also concluded that conventional rotor has higher fluctuation of torque whereas rotor having helix angle is more stable. Overlap ratio can be defining as ratio center gap and diameter of the rotor, which is found advantageous as it also gives thrust force to the downwind blade. Akwa et al. [8] has concluded rotor having overlap ratio of 0.15 gives averaged power coefficient equals to 0.3161 in CFD analysis.

N.H. Mahmoud et al. [9] has found higher torque in double stage rotor compared to single stage rotor. Tsutumo Hayashi et al. [10] had found in experimental analysis rotor having three stage have almost same torque coefficient TSR = 0.043 at a wind speed of 12 m/s. N. H. Mahmoud et al. [9] has found in experimental analysis that rotor having end plate have higher mechanical power.

Depending upon the generator, available wind speed at location, power generation varies for designparameter like aspect ratio, single stage or double stage, with plate and without plate, however in general it has been found that savonius rotor 0.88 aspect ratio with double stage and end plate is found one of the most suitable one.

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Pelton Wheel is one of the simplest and conventional method to convert kinetic energy of the fluid into mechanical energy the same concept is going to be utilized her to recover high velocity exhaust air.

III.TURBINE

Any of various types of machine in which the kinetic energy of a moving fluid is converted into mechanical energy by causing a bladed rotor to rotate is called turbine. The moving fluid may be water, steam, air, or combustion products of a fuel. In simplify way we may also define, a machine which converts kinetic energy of fluid into mechanical energy.

Here the concept of Savonius turbineand Pelton wheel is used to extract energy from exhausted air. Blade has been designed from the concept of the Savonius turbine. Aerodynamically, it is a drag-type device, consisting of three or four or six blade.

The effect of following parameter among the main parameters affect the performance of a Savonius Wind rotor.

1. Divergence of air in atmosphere
2. Types of blade
3. Thickness of plate
4. Effect of blade size
5. Deflection angle of blade
6. Selection of no. of blade
7. Grid Independency Test
8. Dynamic Analysis

1. Divergence of air in atmosphere

Before placing the model in front of the exhaust duct it is necessary to examine the divergence of the air flow in the domain because it creates the wake zone which will lead to the drastic change in the pressure profile.In Figure 1duct of size 250mm × 300mm is considered, where the air is ejected with velocity of 16m/s is analysed in the Ansys software. On examine the result from the analysis the exhaust air is having a maximum velocity in the mid-span which means that the air will strike the blade with high kinetic energy and that will lead to the rise of pressure at that point. Also it is observed that model should be placed in the optimum zone, otherwise the flow will not strike the blade with maximum energy.

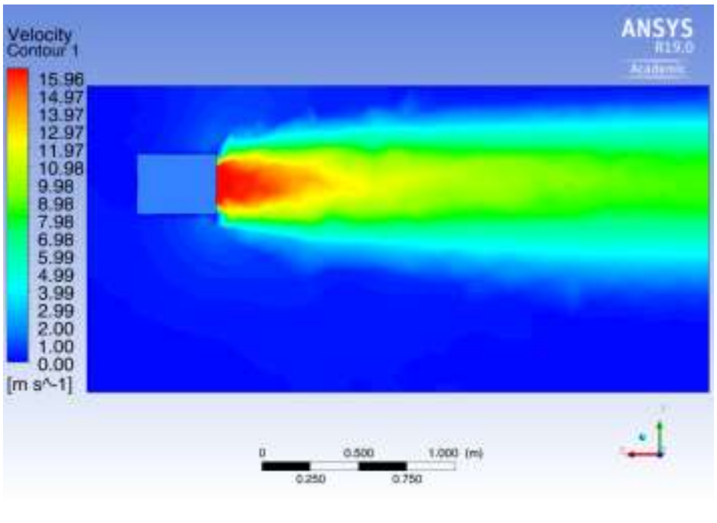

Figure 1 Divergence of air in atmosphere

The optimum zone depends on the length of the blade, as far as considering the 450 mmblade length the model should be placed in the range of 400 to 700 mm, otherwise the blade will strike the duct if the model is closer. From the Table 1the thrust force which is responsible for the rotation is maximum at a distance of 400 mm as distance decreases it is obvious that force will increases but considering geometrical point of view blade is placed at a distance of 550 mm gives the desired results without affecting the other parameters.

Table 1 Effect of distance

Sr. No.	Distance of blade from duct (mm)	Thrust force (N)
1	400	15.60
2	450	15.58
3	500	15.33
4	550	15.28
5	600	15.23
6	650	14.90
7	700	14.80

2. Types of blade

From the literature three types of blades:forward, radial and backward are available and the research for considering the blade are analyzed in the ANSYS software. With the help of pressure analysis it can be observed that pressure is maximum at the center point of the blade, which is mainly responsible for the thrust force. As shown in Figure 3, Figure 2 and Figure 4forward blade have high drag force of 15.6394N while radial and backward have 9.2979N and 7.57N respectively based upon that redial blade is selected.

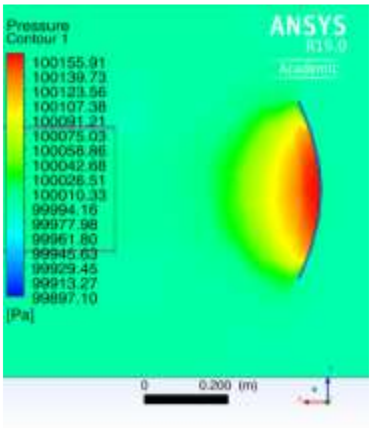

Figure 2Forward blade

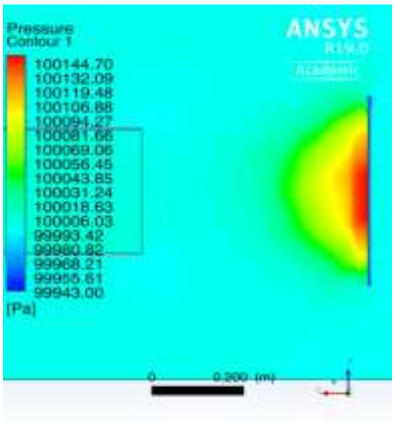

Figure 3Radial blade

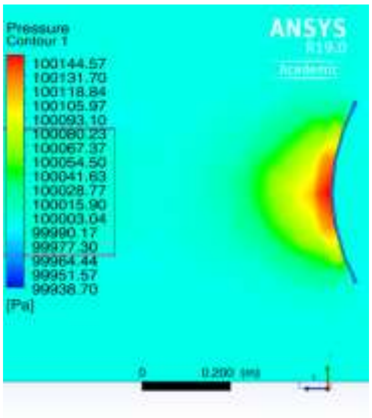

Figure 4 Backward Blade

3. Thickness of blade

While designing the geometry the consideration of the thickness of the blade plays significant role that leads to the rise of the weight of the blade. Hence the stress analysis has been carried out with acrylic material in the range of 3mm to 4mm thickness. Acrylic plate is used as its having good formability to manufacture blade. Acrylic plate is mounted on fabricated structure as shown in Figure 5, Structural analysis is shown in Figure 6 Figure 7 and Figure 8, maximum deformation is found at the corner of the blade. Acrylic plate having thickness of 3.5 mm is selected based on required strength.

Table 2 Material property of acrylic plate

Sr. No.	Property	Value
1	Density	1550 kg/m^3
2	Young Modulus	2800 MPa
3	Poisson's Ratio	0.37
4	Tensile Yield Strength	210
5	Compressive Yield Strength	120
6	Tensile Ultimate Strength	220

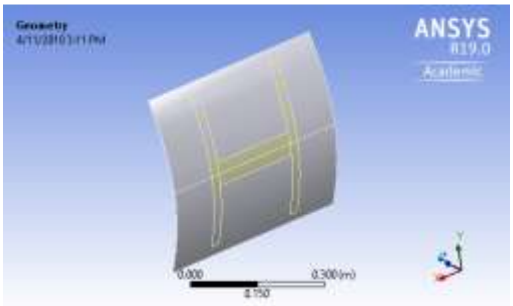

Figure 5 Fixed Surface

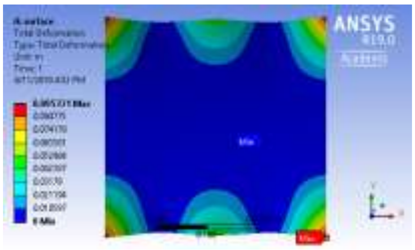

Figure 6 Deformation of 3mm thick plate

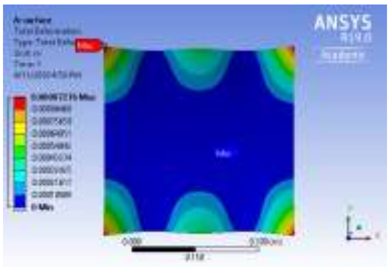

Figure 7 Deformation of 3.5mm thick plate

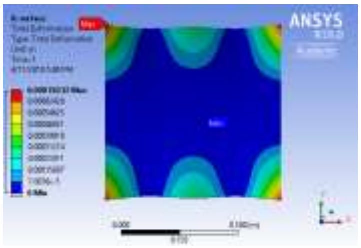

Figure 8 Deformation of 4mm thick plate

4. Effect of blade size

Numerical analysis in ANSYS software is carried out as shown in Table 3**,** which shows that rate of increase of thrust force after length of 422mm and width of 450mm is very less based upon that the same is considered for blade size.

Table 3 Effect of different blade size

Thrust Force (N)		Length (mm)		
		379	422	470
Width (mm)	350	15.6378	17.1405	18.1558
	400	17.1828	18.3455	19.6438
	450	18.0497	19.8562	21.0411

	500	19.0115	20.7965	21.9168
	550	19.3882	21.2485	22.1568

5. Defelction angle of blade

From the fig. of forward, radial and backward blade, there is conclusion that forward blade is more efficient. For energy conversion curve profile of the blades should such that air flow strikes and passed away without opposing upcoming air, the deflection angle with respect to the axis ranging from 90º to 180º are considered for the blade.From Table 4it can be concluded that the deflection angle with 155º curved blade profile directs the flow into the atmosphere in proper manner without creating any disturbamce in the flow.In this numerical analysisblade curve profile is formed by Bezier curve having 2nd order curve degree as shown in Fig. 9. In numerical analysis it has been found that having deflection angle of 155º gives maximum thrust of 15.63 N.

Table 4 Effect of deflection angle

Sr. No.	Blade Deflection Angle	Thrust force(N)
1	90	9.29793
2	95	10.1022
3	100	10.3059
4	105	10.9054
5	110	11.7039
6	115	12.1434
7	120	12.9814
8	125	13.4879
9	130	14.0403
10	135	14.5328
11	140	14.9003
12	145	15.2767
13	150	15.1869
14	155	15.6394
15	160	15.1238
16	165	14.9357
17	170	14.9088
18	175	14.7273
19	180	14.0719

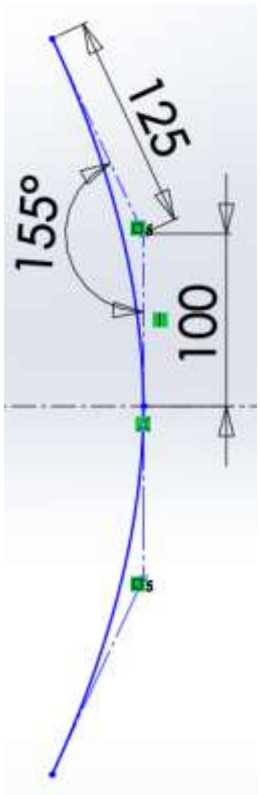

Figure 9 Blade curve profile

6. Selection of no. of Blade

In numerical analysis for no. of blade it can be conclude that 6 no. of blade is optimum for the selected application. As shown in fig.10 stream line shows that air particles passed away from side after striking on the blade, to constraint it and get higher impact force on blade this passage is enclosed from side and center, analysis for the same is carried out which gives negative result due to turbulence of the air inside.

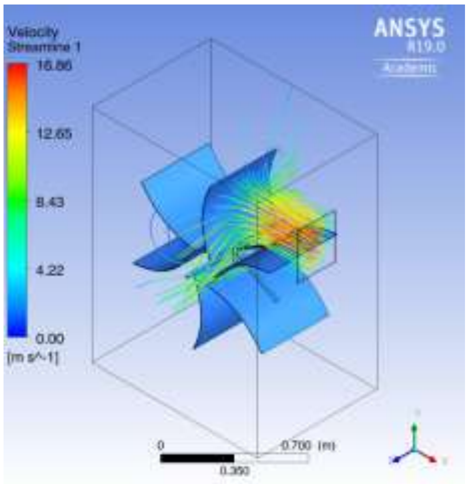

Figure 10 Stream flow of 6 blade wind turbine

Table 5 Effect of no. of blade

Sr. No.	No. of Blade	Torque (N·m)
1	3 blade	5.5945
2	4 blade	5.4690
3	6 blade	6.3950
4	6 blade turbine with end plate	6.2343
5	6 blade turbine with centre filled	5.4782
6	6 Blade Turbine with end plate and center filled	1.2353

7. Grid Independency Test

The grid independent study was carried out for the test section. The different meshing schemes were created and simulations were done on each grid for the same velocity to determine how mesh schemes affects the variables. For each case, the test section was created using unstructured tetrahedral cell. Evaluation of flow simulation focused on how mesh discretization altered flow behavior of the test section. The table 6 shows the comparison between the results for each mesh.

Table 6 Grid Independency test

Sr. No.	Node	Element	Torque	Deviation with previous result (%)
1	50845	282151	6.25702	-
2	60005	329381	6.47671	0.03392
3	61159	336374	6.46938	-0.00113303
4	66405	361557	6.47873	0.001443184
5	74227	402881	6.47408	-0.000718249
6	81474	441823	6.47217	-0.00029511

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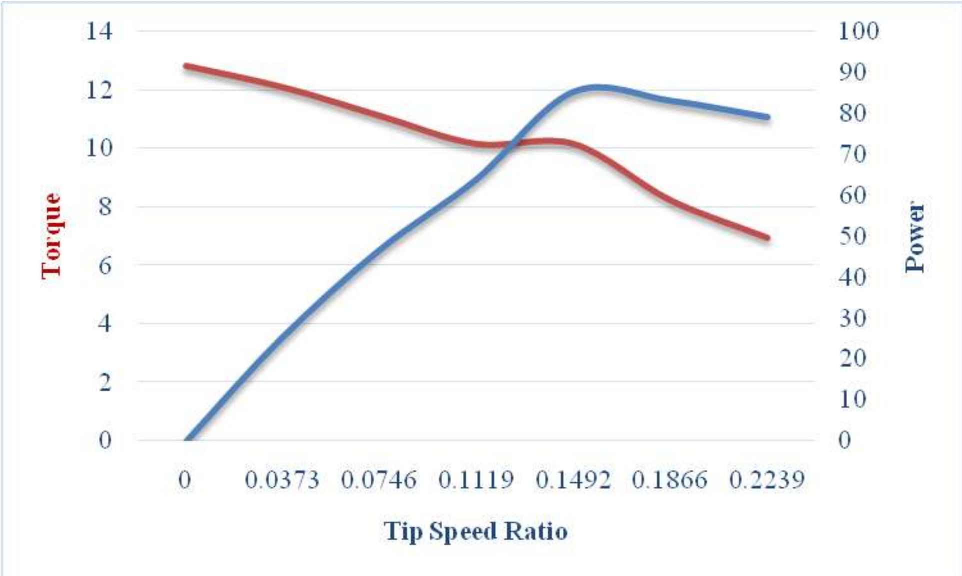
8. Dynamic Analysis

CFX analysis is carried out in ANSYS software, in which rotor has been rotated at different speed. According to rotation of wind turbine torque value changes eventually power output also as shown in fig. 11. Optimum amount of power has been found of 85.3414W at TSR of 0.149286 and 10.1827 N·m torque**.**

Figure 11Characteristic curve representing value of torque and power with respect to TSR



IV.CONCLUSION

On considering the various parameters which effects the performance of due system are analyzed. The study on 3 blade, 4 blade & 6 blade model predicts that the six blade model with forward blade profile are capable to produce the higher amount of power. The effect of deflection angle of the curvature of the blade profile helps the flows to leave the blade smoothly otherwise this will create the back flow on the blade, in order to rotate the model, the distance between the model and the duct also plays a role, as the distance increase, the force exerted will be lesser. Hence the system should place in such a manner that it should not strike the duct also striking force should be maximum at the center of the blade. As the no. of blade increases that will also increase the weight of the system. But the flow analysis depicts that the six blade model produce more torque and power. Finalized designed is capable of producing 85.3414W at TSR of 0.1492 with dynamic torque of 10.1827 N·m.

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