RESEARCH ARTICLE OPEN ACCESS

A numerical study on combined effect of deflector plate, twist angle of blades, and tip speed ration the performance of Savonius Hydrokinetic Turbine

[1]**B. SRINIVASA RAO,**
Gandhi Institute of Excellent Technocrats, Bhubaneswar, India

[2]**TRILOCHAN MAJHI,**
Eastern Academy of Science and Technology ,Bhubaneswar, Odisha, India

ABSTRACT
Savonius Hydrokinetic Turbine (SHT) is a small-scale renewable energy source that is a sustainable solution for remote areas andrural electrification. The current research work establishes a numerical study on combined effect of deflector plate (no deflector,deflector at 90°, deflector at 45°), twist angle of blades (0°, 12.5°, 25°), and tip speed ratio (0.5 to 1.5) on the performance ofturbine in terms of coefficient of power (Cp) using CFD simulation considering a realizable k-ε turbulence model. A total of 99simulationswereperformedconsideringalltheabovedifferentconditions.Tovalidatetheresults,simulationswerecomparedwith the results of a previous study having no deflector plate. It has been identified that SHT with blade twist angle of 12.5° anddeflector plate at 90° produces maximum coefficient of power as 0.364 at a tip speed ratio (TSR) of 0.9 for a 0.5 m/s watervelocity. It was observed that Cp increases by an average 15% for SHT having blade twist and deflector plate as compared to SHTwithoutblade twistanddeflector plate.
Keywords: Savonius hydrokinetic turbine, twisted blades, Computational Fluid Dynamics (CFD) simulation, power coefficient,deflectorplate, tip speedratio(TSR)

I. INTRODUCTION

In recent years, the growing global demand for energy, the increasing reliability and cost of fossil fuels, and the unforeseenenvironmental threats associated with the consumption of fossil fuels have significantly increased the demand for renewableenergy [1]. Global electricity demand increased by 81% from 13,152 TWh in 2000 to 23,845 TWh in 2019 and is anticipated toincrease by another 58% by 2040 [2]. Global CO2 emission has increased by 61% in 31 years from 20.5 Gt in 1990 to 33.0 Gt in2021 [3]. These crises have led researchers and scientists to search for new renewable sources to fulfill energy demand, reducedependency on fossil fuels, and reduce carbon emissions that harm the environment. Nonetheless, the global renewable energycapacity has shown substantial growth of more than 170% from 1135 GW in 2009 to 3064 GW by the end of 2021 [4].Hydropower, with an installed capacity of 1230 GW (40 percent), accounted for the highest proportion of worldwide total energycapacity, followed by solar and wind energy, with capacities of 849 GW (28 percent) and 825 GW (27 percent), respectively. Theremaining renewable energy sources were estimated at 160 GW (5%), consisting of bioenergy, geothermal, and marine energy [4].Among renewable energy sources, hydropower is ample, inexpensive, and has maximum potential for electricity production inworld [5]. However, conventional largescale hydropower systems are not considered environmentally friendly power generationsystems because they need construction of huge water reservoirs or dams, which may severely impact the environment andsurroundingecosystem[6].

Hydrokinetic turbine is a type of hydropower system that produces energy sustainably with less environmental effect. The HKTtechnology operates similarly to wind turbine, with the distinction of water as operational fluid. It creates power by directlycapturing the kinetic energy of water, obviating the need for penstock and dam. [7].A micro hydrokinetic turbine can act as asmall-scalerenewableenergysourcewhichisapracticalandsustainablesolutionforruralandremoteareaelectrificationwhichare unconnected to the power grid where the load requirement is less than 5kW [8]. We can find streams or canals with low or nowaterheadnearruralareas.Insuchawaterflow,installingatraditionalhydroelectricplantisimpractical.However,ahydrokineticenergysystemcanutilise the energyofflowingwaterwithlowor no head[9].
Hydrokinetic technology can provide an appealing non-polluting source of energy to decrease the necessity of fossil fuels andfulfill the electricity requirement. Hydrokinetic technology is seen asan

affordable and environmentally friendly option forelectrification in rural and off-grid areas [9]. The design and construction of a traditional Savonius rotor is basic, with an 'S' shaperotor consisting two semi-circular blades [10]. It works on the principle of difference in drag forces that exist between theadvancing and returning blades. Savonius hydrokinetic turbine was invented in 1931 by Finnish inventor Sigurd J. Savonius toharness wind energy [11]. In direction of fluid flow, a concave surface is provided on the advancing blade while a convex surfaceis on the returning blade, theformer captures avolume of fluidwhile later disperses the volume of fluid. The drag force onconcave surface is greater than the drag force on the convex surface, which results in a net positive torque. due to blade geometry.Sincemoretheflowingfluidiscollectedontheconcaveportion,thepressureonthatportionrises,movingtherotorwithanet force and positive net torque. The performance of the rotor can be affected by various parameters such as the number of blades,blade shape, tip speed ratio (TSR), end plate, aspect ratio, overlap ratio, rotor angle, multi-staging, Reynolds number, installationparameters,andaugmentationtechniques[10,12].

When we compare Savonius hydrokinetic turbine to the conventional hydropower turbine, it begins rotation at a much low waterspeed. Despite benefits such as high starting torque, low manufacturing costs, an easy construction, low rotational velocity,minimal noise emission, and direction independence of fluid, Savonius hydrokinetic turbines have low efficiency and substantialstatic torque fluctuation [13,14]. A lot of researches have been conducted in recent years to increase the performance of theSavonius rotor. These studies,which includedtheoretical,numerical,andexperimentalwork,aimedtoimprovegeometricparameters, blade profiles, and the employment of various augmentation techniques. Savonius rotors having twisted blades havebetter performance in terms of efficiency, smooth running, and starting ability than semicircular blade rotors [15]. Because of thelonger moment arm, a rotor with twisted blades yields more moment than a rotor with a semicircular profile. The highest forceoperates centrally (curvature center) and vertically in a semi-circular rotor, whereas the maximum force is located at the tip of theblade in the case of a twisted blade due to the twist in the blade. A twisted blade has a greater moment arm as result of thesechanges, and hence a larger power coefficient value [16]. Saha et al. [17] conducted experiments to investigate the effect of bladegeometry on rotor performance, they evaluated the performance of Savonius rotors with semi-circular and twisted blades (twistangle = 12.5°) and it was found that in all circumstances of single, two, and three-stage, the savonius rotor having twist showedimproved performance compared to rotor having no twist. To summarise, a two stage system with two blades with a blade twisthad the highest coefficient of power, CP=0.31. Kumar et al. [18] performed numerical analysis using CFD to optimize blade twistangle of Savonius hydrokinetic turbine and it was concluded that a Savonius hydrokinetic turbine with 12.5° blade twist angleprovidesamax.coefficientof power of0.39,leadingtoatipspeedratio (TSR)of0.9forwatervelocityof2m/s.

Since the inception of study on the Savonius rotor, researchers have been interested in the tip speed ratio (TSR).The mechanicaldesign of turbine, such as the rotor diameter and numberof blades, are important parameters that influence the ideal TSR. Ifturbine blade rotates at low velocity, they will not be able to capture the majority of the water and will travel through therotorwith less water. However, if the turbine blade rotates at high velocity, it will constantly pass-through turbulent waters. Thereshould be enough time between two rotors passing through the same area for adjacent water to flow in and be harnessed, ratherthan the used, turbulent water [19]. According to the study of Sheldahl et al. [20], the coefficient of power for two and three bladesof savonius wind turbine is optimal for TSR of 0.9 and 0.7, respectively. Zhao et al. [21] found that the maximum powercoefficients for a helical Savonius rotor at TSR of 0.81 and 0.55 for two and three-bladed turbines. Kailash et al. [22] performedanalysis of modified Savonius turbine and obtained a CP max of 0.15 at tip speed ratio of 0.7. According to Kamoji.et al. [23], atmaximumcoefficientofpower(CPmax),tipspeedratiowasdeterminedas0.69foramodifiedSavoniuswindturbine.Furthermore, Golecha et al.[24,25] put modified single-stage turbine having deflector plates on the returning blade and twodeflector plates on both blades to the test in a water-based environment, and found that the value of TSR at which maximumcoefficientofpower occursis 0.82forsingle deflectorplate and1.08 for two deflector plates.

Another performance enhancement technique of the Savonius turbine is to utilise deflector, they eventually prevent and divert thefluid flow from striking on the upstream of the returning blade of the rotor. This minimises the drag force on the returning blade,resulting in a large increase in power output [26]. A deflector can be a useful device for enhancing the efficiency in both water andwind applications, however it must be developed and combined with the turbine before it can be practically used. The deflectorplate anglemay be kept constant in case of hydrokineticapplications since thewaterflow stream in a river can be fairlyanticipatedascomparedwithwind.Airflow,onth eotherhand,canflowinanydirection,complicatingdesi gnintegration[27].Iioet al. [28] employeda flat plate deflector positioned upstream of a Savonius rotor design toimprove savonius rotor'scoefficientofpower.Theanalysisillustratedthat utilizingasingleflatdeflectorenhancedtheCPmax=0. 47by80%incomparison to a rotor with no deflector. Golecha [24] performed an experiment to examine how a single flat plate deflectorarrangement affects performance of Savonius hydrokinetic turbine, which Kamoji et al. [23] had previously investigated. In theirresearch,they examinedeightvariousdeflectorconfigurationsupstre amofthereturningbladeanddiscoveredthatpowercoef ficient of a modified single-stage Savonius rotor rose by 50% to CPmax=0.21 at TSR=0.82 when deflector plate angle was setto101°[24].

1. Research Methods2.1.Performanceparameter

TheSavoniusTurbine'sperformanceismeasuredbypo werandtorquecoefficientasmentionedbelow:

$TSR = \frac{\omega R}{V}$ (1)

$C_{Maverage}$

$C = \frac{T\omega}{}$

$= \frac{T}{0.5\rho A V^2 R}$

$\frac{\omega R}{}$

$= C$ (2)

$\times TSR$ (3)

$\frac{Paverage}{0.5\rho A V^3}$

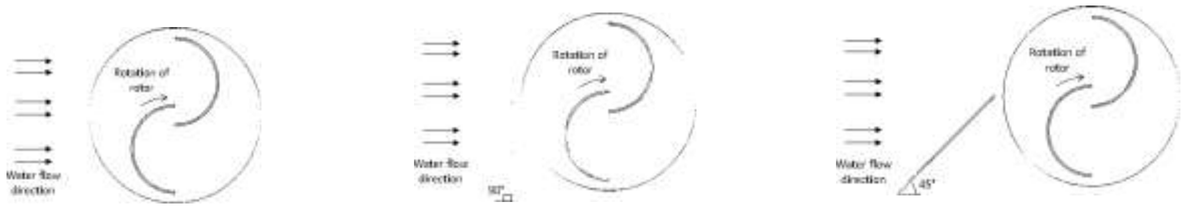
$0.5\rho A V^2 R \ V$

$Maverage$

whereρ=waterdensity[kg/m3],V=freestreamvelocit y[m/s],TSR=tipspeedratio,A=sweptareaofturbine[m 2],ω=rotationalspeed ofturbine[rad/s],R=radiusoftheturbine[m],T=averag emomentgenerated ontheturbine[Nm].

Configurationofdeflectorplate

Fig. 2 shows the 3 configurations of turbine and deflector plate used for analysis having 2 blades. First configuration design isconsidered without and deflector plate. Second design consists a deflector plate placed at 90˚ to the direction of liquid flow. Thirddesign consists a deflector plate placed at 45˚ to the direction of liquid flow. Further analysis has been done by increasing the twistangleofbladesviz. 0˚, 12.5˚ and25˚.



(a) (b) (c)

Fig1: Configurationsofturbineanddeflectorplatearrangement(a)withoutdeflectorplate(b)Withdeflectorplateat90˚(c)With deflector plate at 45˚

DesignParameters

Atwo-bladeSavoniusHTrotorwasdesignedusingSolidWork sconsideringvariousparametersviz.numberofblades =2,rotordiameter (D)= 0.16m, Rotorheight(H)=0.25 m,Aspectratio(H/D)=1.5625,Overlap ratio (e)=0.02m

Fig.3showsshowtheschematicdiagramofSavoniushy drokineticturbinedesignedinSolidWoks

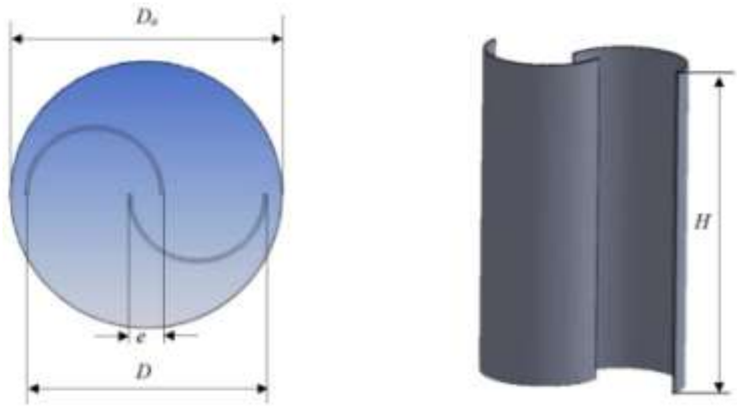


Fig3: DesignparametersofSavoniushydrokineticturbine

RotatingZone
Rotatingzoneisthevolumeintheproximityoftheturbinebladesinsidewhichrotationofbladetakesplace.Parametersconsidered for rotatingzoneare:rotordiameter (D)= 0.18 mandrotorheight(H)= 0.27 m

StatorZone
Statorzoneoropenchannelflowisthevolumewhereflowofwatertakesplace.Freestream velocityinwaterchannelconsideredin analysisis0.5m/s.Parametersforstatorzoneare:openchannellength=3m,openchannelheight=0.6m,openchannelwidth =0.6m,andblockageratio=13.5

BoundaryConditions
Table1showsthevariousboundarytypeandboundaryconditionstakenintoconsiderationinthisstudy,andalsodepictedinFig.4. The velocity inlet on the left side of the channel is set to free stream velocity of 0.5 m/s. The outflow condition has beenestablished at the extreme right border. The channel's side and bottom walls are designated as slip boundaries. Symmetry is givento the channel's top. Free surface effects aren't taken into account in this analysis because the turbine is thought to run at a depththat minimises the surface impact. The Savonius turbine, which is located inside the rotating zone, has a rotating wall condition(no-slip wall). The angular velocity of rotation zone is taken depending on tip speed ratio. As a result, several simulations areperformedwithdifferentTSRsandfreeflowvelocity.

Table1: BoundaryconditionsforNumericalAnalysis

Name	**Boundarytype**	**Boundarycondition**
Inlet	VelocityInlet	0.5m/s, uniformflow
Outlet	Outflow	Outflow
Channelside,bottom,andtopwall	Freeslipwall	Stationary
Turbine	Noslip wall	Accordingto TSR

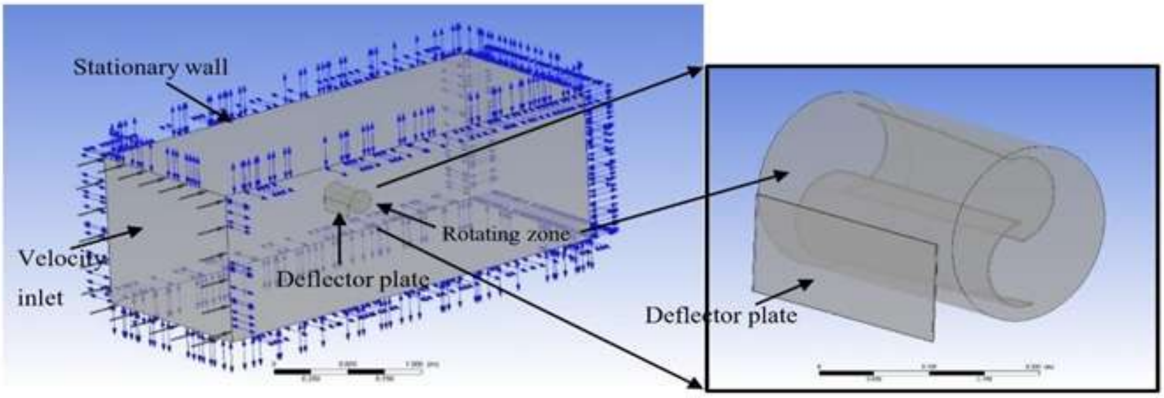


Fig4: BoundaryconditionsforCFDanalysis

Meshing

Meshing has been done in Ansys Mesh System. For CFD investigations, a large flow domain is desired, but it must be constrainedaccording to the computational load and the type of the flow issue being handled [29]. Computational subdomain was meshedusing non-conformal unstructured lattice with tetrahedral elements. Because the mesh quality has a significant impact on theaccuracy of CFD outcomes, an unstructured grid allows greater flexibility for automatic mesh generation in complex geometries.Fig. 5 shows the meshed model for rotor and stator zone of 0° blade twist. Number of elements for rotor zone is 4,62,451 andmaximumskewnessis0.79637. Number ofelementsfor rotorzoneis4,64,189and maximum skewnessis0.79985.

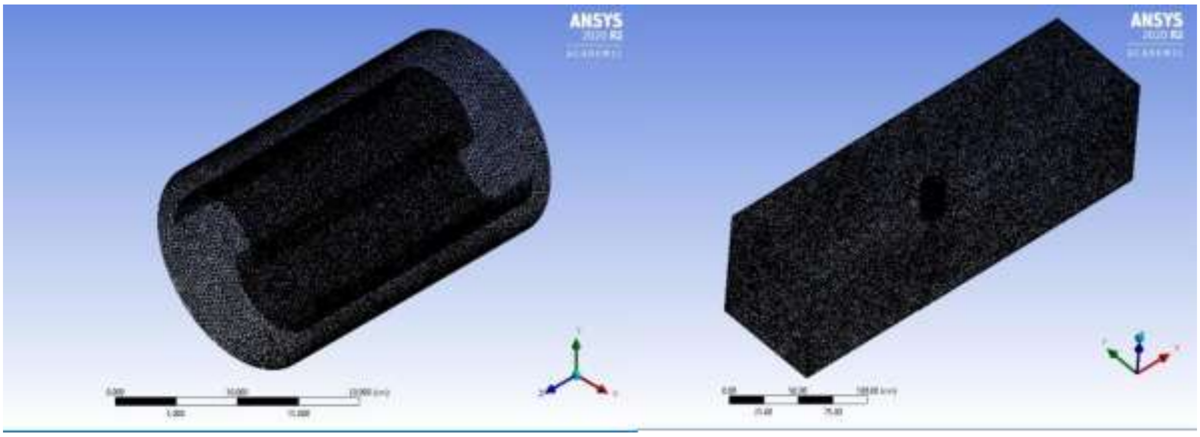


Fig5: (a)MeshforRotorZoneof0°bladetwist(b)Mesh forStatorZoneof0°bladetwist

3. SimulationProcedure

Flow solver used in present study is ANSYS FLUENT, which was utilised to resolve unsteady incompressible Navier-Stokesequations. The Reynolds averaged Navier- Stokes equations are solved using the finite volume approach to representthe flowfield.Thecasewiththerelevantboundaryconditionsisspecifiedand solved inorder to achieveanumericalsolution.

TurbulenceModel

Turbulence must be taken into account while modelling water flow. For modelling turbulence, a variety of models are available,and themodelused is determined by theflow shape and Reynoldsnumber. In the research by Mohamed et al. [30] it wassuggested that Realizable k-ε turbulence model is better to simulate the rotating behaviour of blades or air foil, flow through thechannel,aboundarylayerorseparatedflows.Asaresult,theRealizablek-εmodelwasusedtorepresenttherotationalmotionof turbine blades in present study. This model includes a novel turbulent viscosity formulation and a new dissipation rate transportequation derived from an exact solution for the transport of mean-square vorticity fluctuations. Furthermore, it does not take intoaccountthe anticipated linkbetweentheReynoldsstresstensor andthestrainrate tensor. ThetransportequationsforRealizablekεmodelaregivenas[31]:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (4)$$

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_j}(\rho \varepsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+\rho C_1 S\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{\nu\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \quad (5)$$

where, k =turbulent kinetic energy; ε = dissipation rate of the turbulent kinetic energy; ρ = density of fluid; u_j= velocitycomponents; x_j = Cartesian coordinate, t = time; μ = viscosity μ_t = turbulent viscosity; σ_k = constant of k-ε turbulence model; G_k =generation of turbulence kinetic energy due to the mean velocity gradients; G_b= generation of turbulence kinetic energy due tobuoyancy;Y_M= effectofthechangingdilatationincompressible turbulencetotheoveralldissipationrate.

II. RESULTS AND DISCUSSIONS

A total of 99 simulations were performed in this study for different tip speed ratio (TSR) values varying from 0.5 to 1.5 and forblade twist ranging for 0˚, 12.5˚ and 25˚ for 3 different deflector plate configurations. Simulation results were achieved for all oftheparametervaluesinvestigated.

VelocityContours

At the blade's tip, a high speed zone has beenobserved., as shown in Fig 6. Low speed zone(wakezone)isnoticedbehindrotorbladesdue to turbine rotation as shown in Fig 6. Theflow velocity in the wake zone is substantiallyreduced.Theflowvelocityisperiodically raisedatthehigherandlowerendsofthewake zone, resulting in a "periodic high speedzone."

Figure 7-9 illustrates, velocity contour plotswhich depicts the changes in velocity acrossdifferent places around the SHT having bladetwistangle0°,12.5°and25°respectivelyat

TSR of 0.7andalso with 3configurations ofdeflectorplate.

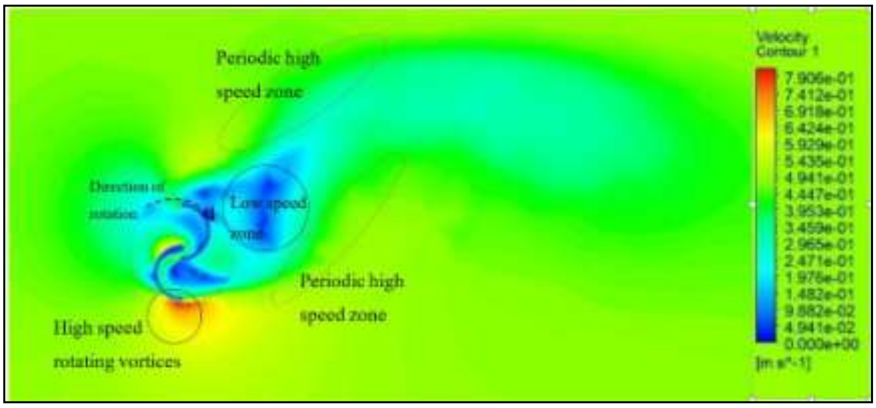
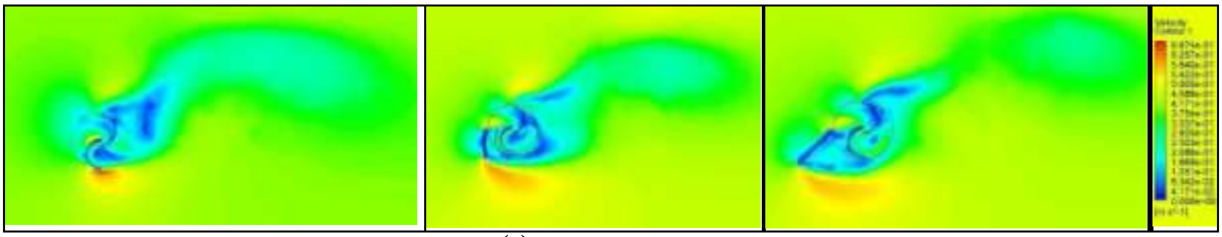
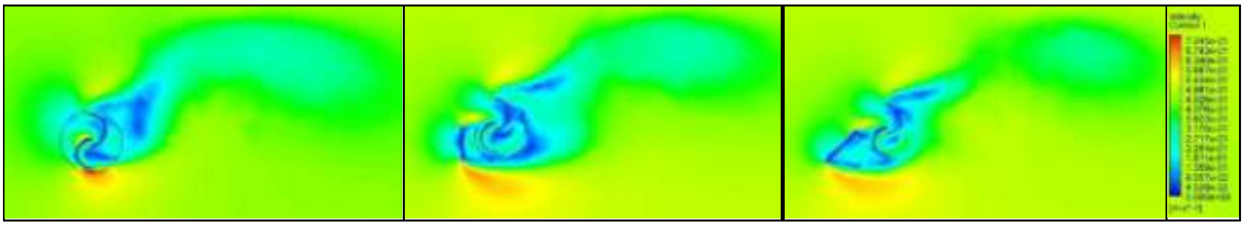


Fig6: Velocitycontoursfor0°twistangleatTSR=0.7 and0.5m/s



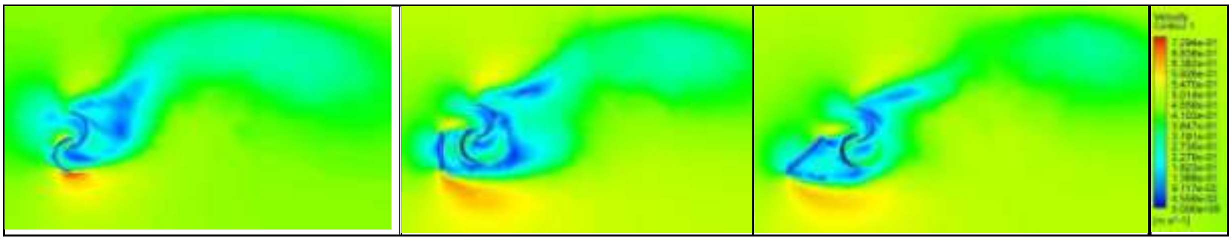
(a) (b) (c)

Fig7: Velocitycontoursfor0°bladetwistangleatTSR=0.7(a) withoutdeflectorplate(b)Withdeflectorplate at 90˚(c)Withdeflectorplate at 45˚



(a) (b) (c)

Fig8: Velocitycontoursfor12.5°bladetwistangleatTSR =0.7 (a)withoutdeflectorplate(b)With deflectorplateat90˚(c) Withdeflectorplate at45˚



(a) (b) (c)

Fig9: Velocitycontoursfor25°bladetwistangleatTSR=0.7 (a)withoutdeflectorplate(b)Withdeflectorplateat 90˚(c)Withdeflectorplate at 45˚

PressureContours

Pressurecontourplotsareusedtoanticipatepressuredifferences in various places close to turbine blades in flowdomain.Blueandredcoloursshowtheminimumandmaximum pressure values in pressure contours, respectively.Fig10showsthathighpressurezoneiscreatedneartheadvancing blade whereas low pressure zone is created nearreturning blade.Thus,thesetwopressurezonesproduceapressure drop across the rotor and causes the blades to rotatewhich in turn produces power by energy extraction by theSavoniushydrokineticturbinefromtheflowing water.

Fig 11-13 depicts pressure contour of rotor for 0°,12.5°,25°twist angle respectively at TSR of 0.9 for 3 different deflectorplate configuration andfree stream velocity of 0.5m/s.Wecan observe that pressure decreases on rotor from upstream todownstream.

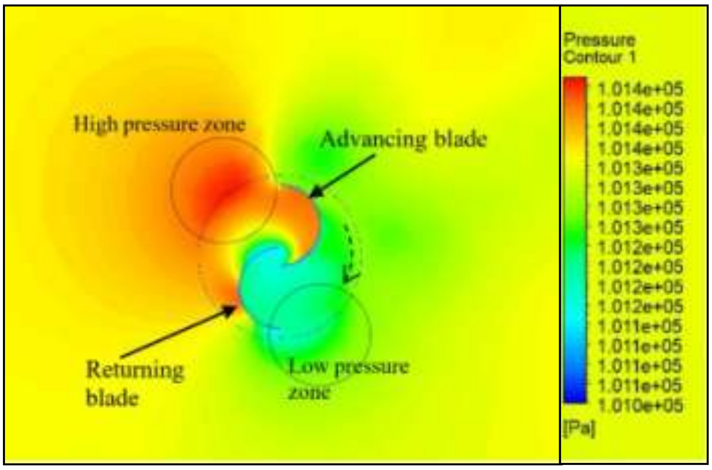
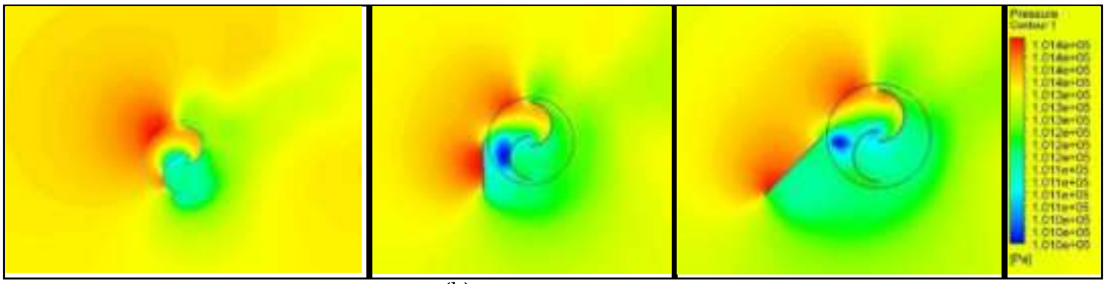
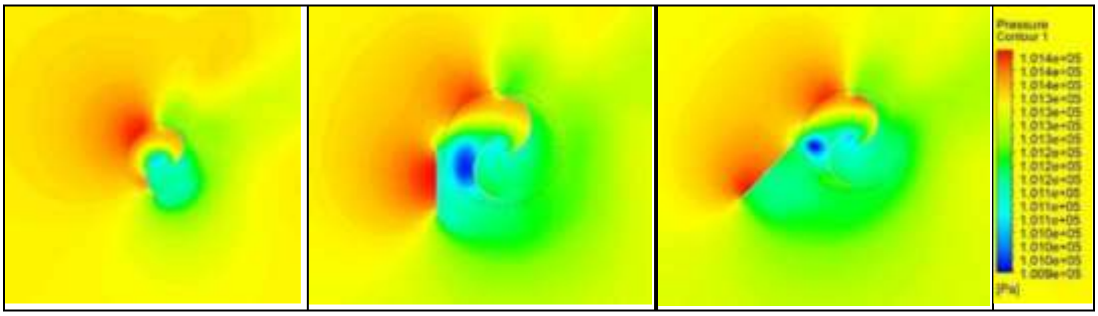


Fig 10: Pressure contours for 0° twist angle at TSR = 0.7 andflowvelocityof0.5m/s



(b) (b) (c)

Fig11: Pressurecontoursfor**0°bladetwistangle** at**TSR=0.9(a)** withoutdeflectorplate **(b)**with deflectorplateat90˚ **(c)**with deflectorplateat45˚



(a) (b) (c)

Fig 12: Pressure contours for **12.5°blade** twist angle at **TSR = 0.9(a)** without deflector plate **(b)** withdeflectorplate at 90˚**(c)** withdeflector plate at45˚

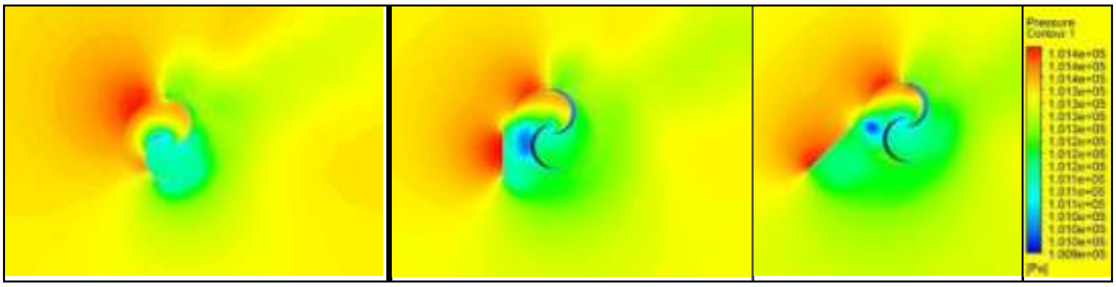
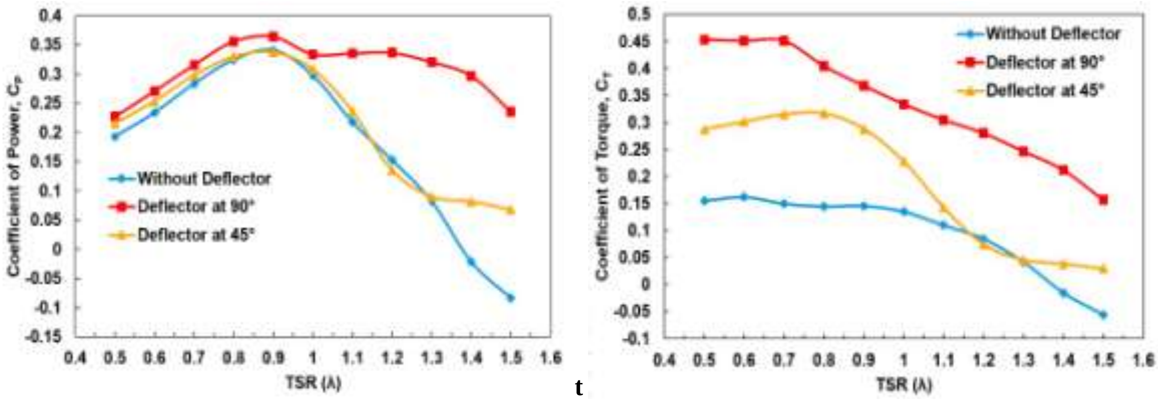


Fig13: Pressurecontoursfor**25°blade**twistangleat**TSR=0.9(a)**withoutdeflectorplate **(b)**with
(a)
deflectorplateat90˚**(c)**withdeflectorplateat45˚
(b)
(c)

VariationofPowerCoeff.(Cp)&TorqueCoefficient(Ct)w.r.t.TSR

Figure14-15representsthevariationofpowercoefficient(Cp)andtorquecoefficient(Ct)withrespecttoTSRfordifferentvaluesofblade twistangle viz.12.5˚,25˚ alongwith3configurationofdeflectorplate.



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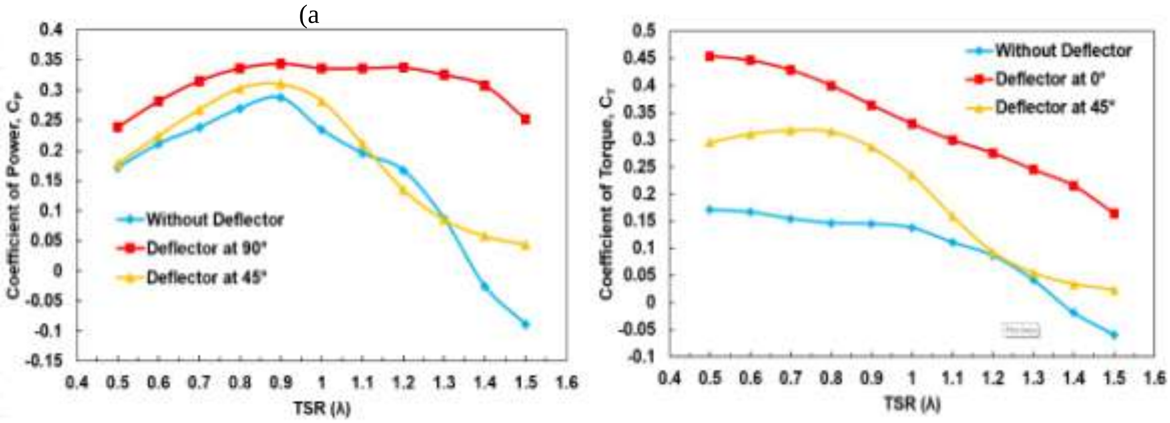
(a



(c) (b)

Fig15: Variationof**(a)Cp**and **(b)Ct**w.r.t.TSRfor**25°**twistangleofblade

Table2providesthemaximumpowercoefficient(Cp),andthetipspeedratiothatcorrespondsfordifferentbladetwistangles along withdeflector configuration.

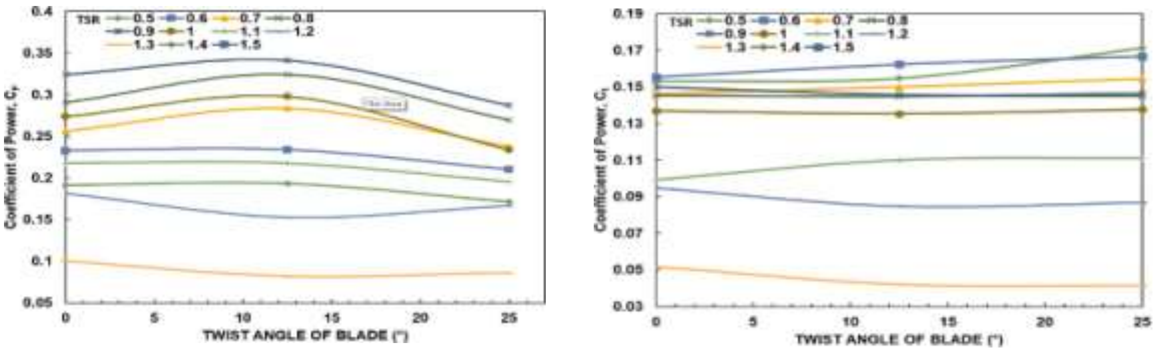
BladeTwistAngle(°)	**Deflector plateconfiguration**	**Maximum Coefficient of Power(Cp max)**	**TipSpeed Ratio**
0	w/odeflectorplate	0.312	0.9

	deflectorplate at 90°	0.351	0.9
	deflectorplate at 45°	0.340	0.9
12.5	w/odeflectorplate	0.341	0.9
	deflectorplate at 90°	0.364	0.9
	deflectorplate at 45°	0.337	0.9
25	w/odeflectorplate	0.287	0.9
	deflectorplate at 90°	0.344	0.9
	deflectorplate at 45°	0.309	0.9

Table2:
Maximumpowercoefficient(C_p)correspondingtobladetwistangle,deflectorplateconfiguration,andtipspeedratio

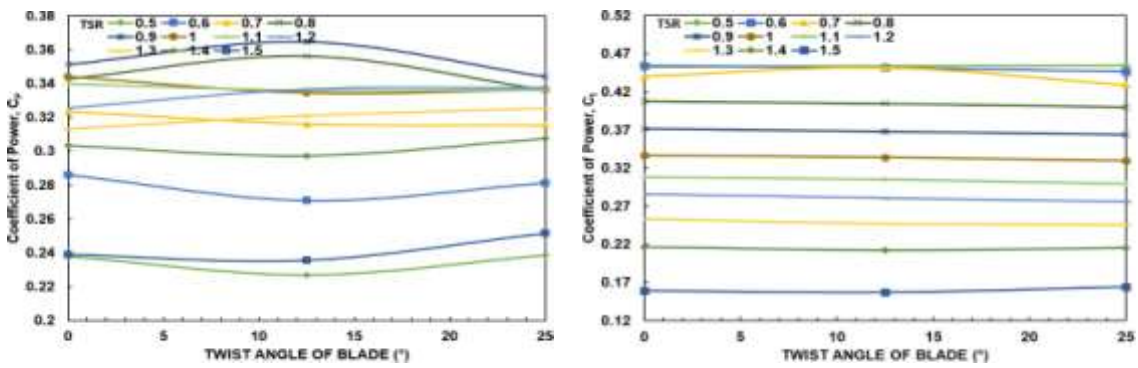
EffectoftwistangleofbladesontheperformanceofSHKTurbine

Figure16-18illustratesvariationofcoefficientofpower(Cp)andcoefficientoftorque(Ct)withrespecttotwistangleofbladescorrespondingtodifferentTSRalong withdifferentconfigurationofdeflectorplate.



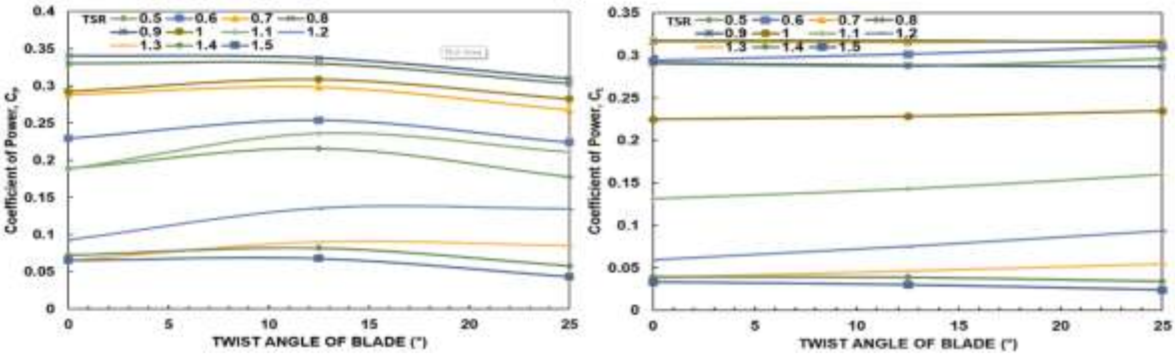
(d) (b)

Fig16: Variationof**(a)Cp**and**(b)Ct**w.r.t.Twistangleofbladescorrespondingto different TSRforturbinewithoutdeflectorplate



(a) (b)

Fig 17: Variation of **(a) Cp**and **(b) Ct**w.r.t. twist angle of blades corresponding to differentTSRfor turbinewith**deflector plateat 90**°



(a) (b)

4. Validation

The results for SHK Turbine having twist angle of 0°, 6.25°, 25° with no deflector plate have been validated from Kumar et al.[18].Tip speedratio (TSR)considered is0.9withfreestreamvelocityof0.5m/s.Thesummarized tableisshown below:

Twist Angle(°)	**Tip SpeedRatio**	**V1 (m/s)**	**PresentStudy -Coefficient of Power(CP)**	**Kumaret CoefficientofPower(CP)**	**al.-Error%**
0	0.9	0.5	0.312	0.31	0.64
12.5	0.9	0.5	0.341	0.34	0.29
25	0.9	0.5	0.282	0.28	0.71

Table3:Validationofresultsobtainedinthisresearch

III. CONCLUSIONS

Accordingtothesimulationfindings,theturbine'sperformanceintermsofcoefficientofpowerhasamaximumvalueofCpof0.364 at a TSR value of 0.9 at a blade twist angle of 12.5° with deflector plate at 90° and free stream velocity of 0.5 m/s. Thehighest value of coefficient of torque Ct for the turbine's performance is 0.454 at a TSR value of 0.5 at a blade twist angle of 25°with deflector plate at 90° and free stream velocity of 0.5 m/s. It is observed that as the TSR value increases, coefficient of power(Cp) first increases and afterwards decreases but there is decrease in coefficient of torque (Ct), so it is recommender to keep theTSRinthe range of0.7-0.9 for improvedperformance oftheturbine.
Considering varying Cp with respect to twist angle of blade then we can observe that Cp may increase or decrease based on TSRvalueanddeflectorangle(δ).Forexample,SHKTurbinewithdeflectorplateat90°showsthatforTSR=0.7theCpvaluekeepson decreasing as we increase the twist angle but for TSR=0.8 and TSR=0.9 the Cp value first increases till blade twist angle of12.5°andthereafterdecreases.ButforTSR=1theCpvaluefirstdecreasestillbladetwistangleof12.5°andthereafterincreasesas we increase the blade twist angle. It is also observed from the analysis that when TSR is increased above 1.4 then coefficient oftorque(Ct)becomesnegativewhichshowsinherentunsteadyaerodynamicbehaviour.SoitcanbeconcludedthatoperatingSHTatTSRofabove 1.4isunfavourable.

Thecurrentstudymightbevaluableforfutureresearchintotheperformanceof Savoniushydrokineticturbines withvarioussystem parameters such as blade shape factor, number of stages , blade arc angle and operating parameter such as blockage ratioand flow velocity and. The scope for further improvisation is still open to further study and development, and will undoubtedlyhelp usmeetrisingpowerdemandbyachievingrenewable energy

REFERENCES

[1] Loots, I., Van Dijk, M., Barta, B., Van Vuuren, S.J., Bhagwan, J.N. A review of low head hydropower technologies andapplicationsinaSouthAfricancontext.Ren

ewableandSustainableEnergyReviews,2015; 50:1254–68.https://doi.org/10.1016/j.rser.2015.05.064.

[2] WorldEnergyOutlook2019.OECD;2019.https://doi.org/10.1787/caf32f3b-en.

[3] InternationalEnergyAgency(IEA),CO2emissions Analysis-GlobalEnergyReview.Paris;2021.

[4] InternationalRenewableEnergyAgency(IRENA). RenewableCapacityStatistics.AbuDhabi;2022.

[5] Renewables,RenewableEnergyPolicyNetworkforthe21stcentury(2018)-GlobalStatus Report.Paris;2018.

[6] Tanbhir,T.,Nawshad,U.A.,Islam,N.,Sina,I.,Syfullah,K.,&Raiyan,R.(2011).Microhydropower:promisingsolutionforoff-gridrenewableenergysource. InternationalJournalofScientific andEngineeringResearch,2(12), 1–5.

[7] Khan,M.J., Iqbal,M.T.,&Quaicoe,J.E.(2008).River currentenergyconversionsystem:progress, prospectsandchallenges. RenewableandSustainableEnergyReviews,12,2177–2193.https://doi.org/10.1016/j.rser.2007.04.016.

[8] Vermaak,H.J.,Kusakana,K.,&Koko,S.P.(2014).Statusofmicro-hydrokineticrivertechnologyinruralapplications:Areviewofliterature.Renewable andSustainable Energy Reviews,29, 625–633.https://doi.org/10.1016/j.rser.2013.08.066.

[9] Balat,M.(2006).HydropowersystemsandhydropowerpotentialintheEuropeanUnioncountries.EnergySources,PartA:Recovery,UtilizationandEnvironmentalEffects,28(10):965-978.https://doi.org/10.1080/00908310600718833

[10] Kamoji,M.A.,Kedare,S.B.,&Prabhu,S.V.(2008).ExperimentalinvestigationontheeffectofoverlapratioandbladeedgeconditionsontheperformanceofconventionalSavoniusrotor.WindEngineering, 32(2),163–178.https://doi.org/10.1260/030952408784815826.

[11] SavoniusS.TheS-rotoranditsapplications.MechanicalEngineering 1931;53(5):333-8

[12] Akwa,J.V.,Vielmo,H.A.,&Petry,A.P.(2012). AreviewontheperformanceofSavoniuswindturbines.RenewableandSustainableEnergy Reviews, 16(5),3054–3064.https://doi.org/10.1016/j.rser.2012.02.056.

[13] Altan, B.D., Atilgan, M. (2008). An experimental and numerical study on the improvement of the performance of Savoniuswindrotor. EnergyConversion andManagement;49(12):3425-3432.https://doi.org/10.1016/j.enconman.2008.08.021

[14] Wahyudi, B., Soeparman, S., Wahyudi, S., and Denny, W. (2013). A simulation study of Flow and Pressure distributionpatterns in and around of Tandem Blade Rotor of Savonius (TBS) Hydrokinetic turbine model. Journal of Clean EnergyTechnologies;1:286-291.https://doi.org/10.7763/JOCET.2013.V1.65

[15] Saha, U.K., Rajkumar,M.J..(2006). On the performance analysis of Savonius rotor with twisted blades. Renewable Energy;31(11):1776–88.https://doi.org/10.1016/j.renene.2005.08.030

[16] Akwa JV, Vielmo HA, Petry AP. (2012). A review on the performance of Savonius wind turbines. Renew Sustain EnergyRev;16(5):3054–64.https://doi.org/10.1016/j.rser.2012.02.056

[17] SahaUK,ThotlaS,MaityD.(2008)OptimumdesignconfigurationofSavoniusrotorthroughwindtunnelexperiments.JournalofWindEngineeringandIndustrialAerodynamics;96(8–9):1359–75.https://doi.org/10.1016/j.jweia.2008.03.005

[18] KumarA.,SainiR.P.,(2017).PerformanceanalysisofaSavoniushydrokineticturbinehaving twistedblades.RenewableEnergy, 108, 502-522.https://doi.org/10.1016/j.renene.2017.03.006.

[19] PhamL.RiverineHydrokineticTechnology: AReview.OregonTech–REE516TermPaper;2014.

[20] SheldahlRE,FeltzLV,BlackwellBF.(1978).Windtunnelperformancedatafortwoandthree-bucketSavoniusrotors.AIAAJournalofEnergy;2(3):160–4.https://doi.org/10.2514/3.47966

[21] ZhaoZ,ZhengY,XuX,LiuW,HuG.(2009).ResearchontheImprovementofthePerformanceofSavoniusRotorBasedonNumericalStudy.In:Proceedingsofinternationalconferenceonsustainablepowergenerationandsupply(SUPERGEN);p.1–6.https://doi.org/10.1109/SUPERGEN.2009.5348197

[22] Kailash G, Eldho TI, Prabhu SV. (2012). Performance study of modified Savonius water turbine with two deflector

plates.InternationalJournalof RotatingMachinery,vol., ArticleID 679247,p.12.http://dx.doi.org/10.1155/2012/679247.

[23] KamojiMA,KedareSB,PrabhuSV.(2009).Experimentalinvestigationsonsinglestagemodified Savoniusrotor.AppliedEnergy;86(7–8):1064–73.

[24] Golecha K, Eldho TI, Prabhu SV. (2011). Influence of the deflector plate on the performance of modified Savonius waterturbine.AppliedEnergy;88:3207–17.https://doi.org/10.1016/j.apenergy.2011.03.025

[25] Golecha, K., Eldho, T.I., Prabhu,S.V..(2012). Performance study of modified savonius water turbine with two deflectorplates. InternationalJournalofRotating Machinery, ArticleID679247.https://doi.org/10.1155/2012/679247

[26] Kerikous, E., &Thevenin, D. (2019). Optimal shape of thick blades for a hydraulic Savonius turbine.Renewable Energy,134,629–638.https://doi.org/10.1016/j.renene.2018.11.037.

[27] Grönman, A., Tianinen, J., &Jaatinen-Värri, A. (2019). Experimental and analytical analysis of vanedSavonius turbineperformance under different operating conditions. AppliedEnergy, 250, 864–872.https://doi.org/10.1016/j.apenergy.2019.05.105.

[28] Iio, S., Katayama, Y., Uchiyama, F., Sato, E., & Ikeda,T. (2011). Influence of setting condition on characteristics ofSavonius hydraulic turbine with a shield plate. Journal of Thermal Science, 20(3), 224–228.https://doi.org/10.1007/s11630-011-0462-9

[29] Bhattacharjee, S., Arora, B. B., &Kashyap, V. (2019). Optimization of Race Car Front Splitter Placement Using CFD (No.2019-01-5097).SAE TechnicalPaper,2019-01-5097,https://doi.org/10.4271/2019-01-5097

[30] Mohamed, M.H., Janiga, G., Pap, E., Thévenin, D., (2010). Optimization of Savonius turbines using an obstacle shielding thereturningblade.Renewable Energy,35(11), 2618-2626.https://doi.org/10.1016/j.renene.2010.04.007

[31] Singh, H. &Arora, B. (2021). Performance characteristics of flow in annular diffuser using CFD. International Journal ofTurbo&Jet-Engines,2021-03,https://doi.org/10.1515/tjeng-2021-0003