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Fluid flow analysis of hydroelectric centrifugal turbines with a circular and square profile for treated water

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ABSTRACT

In this paper we have discussed the practicality and feasibility of implementing hydroelectric centrifugal turbine systems with different entry profiles. This paper discusses the technical and economic feasibility of the two profiles of the hydroelectric turbine system. The paper analyses the velocity at input and output openings, pressure exerted by the fluid on the turbine surface and the temperature of the surface of circular and square profile respectively. The results will be further explained. Hydroelectric turbine systems can be used to meet the high demands of electricity; thus, such analysis is mandatory to attain maximum efficiency. This research paper highlights some of the advantages and disadvantages of a circular and a square profile for electricity generation. The research paper exhibits a Computational fluid Dynamics (CFD) of a fluid flow through a hydro turbine using flow simulations for the two profiles for a given flow rates. CFD is an important tool to determine such conditions using numerical analysis and data structures for fluid flow. An extensive study is conducted as well as the numerical studies on a spiral case Francis turbine with a circular and square profile are conducted successfully. The prototype models were prepared on Solid works 2019. We have undertaken three-dimensional steady simulation using "flow simulation" feature of Solid works 2019 in order to compute the average flow features as well as inspect the all-round turbine performance.

Keywords: *Hydroelectric Centrifugal Turbine, CFD, Solid works, Flow simulation*

1. INTRODUCTION

The importance of water throughout history, not solely as a supply of life however additionally as associate degree energy supply, has been a seamless since the beginning of civilizations. Additionally, the thought of the water as a basic resource associated with energy could also be a matter of explicit importance in recent years. Such a lot thus as that the "International Water Summit", presents as its saying "No energy, no water. No water, no energy", are the 2 sides of water-energy relationship. The Iberian Peninsula has not been bent this reality and, because of its scarce water resources, particularly among the south; it's traditionally developed a sturdy water policy. From the Romans with their giant infrastructure to the current "Agua" set up, through the large development of ditches and irrigated areas among the Muslim era, the multiple watercourse basins utilization throughout the middle Age, the massive development of marshes and large pumping systems created on the twentieth century, are oblivious to the need for water use. Therefore, despite not having nice rivers among the region, one will notice some attention-grabbing facilities such as: the recent water mills of Ares del Maestre or completely different water reservoirs with a combined storage capability of 185 hm3. During this context, the importance of associate degree optimized treatment of sewer water from each energetic and public health standpoint is crucial. This task is clearly internalized altogether initial world countries. Note that the amount of energy used as an example in Espana to treat the 3 ,000 hm3/year of urban sewer water represents the 1 percent of the country's total energy consumption. There are vast differences in their conception between little and large size sewer water Treatment Plants (WTP). whereas little and medium-sized WTP typically lack of aeration controls and their style is based on the mechanical strength and liability (which implies higher unit prices and consumption), in giant WTP, the look is optimized to realize energy consumptions well adjusted.

In this sense, whereas some giant WTP are presently operational with consumptions rounding to 20-30 kWh/hm3 throughout the year, the quality consumption for the sewer water purification park in Espana is around fifty kWh.

Computational fluid dynamic (CFD) techniques are accustomed study the flow conditions within hydraulic turbines over the past 3 decades. The numerical modelling of hydraulic turbines could also be a difficult task as a result of a specific modelling approach applied to analysis a selected operational condition does not essentially work for a further operational condition. Little changes in discharges and/or head considerably have an effect on the flow conditions within the rotary engine. There are many challenges for hydraulic rotary engine modelling in terms of getting helpful results. Associate degree open test suit permitting Researchers to move to modify such queries is, thus, necessary to develop the numerical capability for the study of hydraulic turbines. the most objective of the Francis test suit is to supply associate degree open platform to industrial and educational analyzers to explore and develop the capabilities of CFD techniques among the sector of hydropower research. The Centrifugal test suit consists of a high -head Centrifugal turbine model, whose pure mathematics, in conjunction with meshing and measuring (pressure, temperature and velocity) information are offered for tutorial analysis purpose.

Today, hydropower is that the foremost very important renewable energy supply among other sources for Turkey and each other countries around the world. Hydraulic turbines are used for hydropower generation. Hydraulic turbines turn out or so one-fifth of the full electricity among the world (World Energy Council, 2006). Their efficiencies will arise to ninety five percent and hydraulic turbines generate electricity with a minimum quantity of pollution. Additionally, they have a superb energy storing capability and are able to meet the daily dynamic electricity demand. Hydraulic turbines are essentially classified in 2 groups; impulse and reaction turbines. Impulse turbines work supported the momentum principle. Water hits the runner blades among the kind of a water jet and this impact causes a force on the runner, that causes the runner turn. Pelton rotary engine is associate degree example of impulse turbines. In reaction turbines, the flow is absolutely controlled through the rotary turbine. The P.E. of water is reborn to K.E. by a speed rise. It uses the action-reaction principle. Samples of reaction turbines are Francis and Kaplan sort turbines.

The aim of this thesis is to develop the way to modify the acknowledged method of a CFD simulation and study the flow of a generic fluid radial rotary engine style. The tactic can even be used as an abstract style tool for radial turbines and supports most fluids deigned. To point out the potential of the maneuver developed, while not going into full analysis with mesh dependent study and as high-quality mesh as doable, a comparison is made between the performance of 2 completely different pure 3D CFD simulations.

2. MODEL PREPARATION

The figure enclosed represents the working and technicalities of the system. In this model the velocities, pressure exerted by the fluid on the surfaces and temperature of the fluid at inlet and outlet are considered as the outcome result. The guide vanes are provided to generate the flow pattern so as to generate the maximum velocity at the outlet.

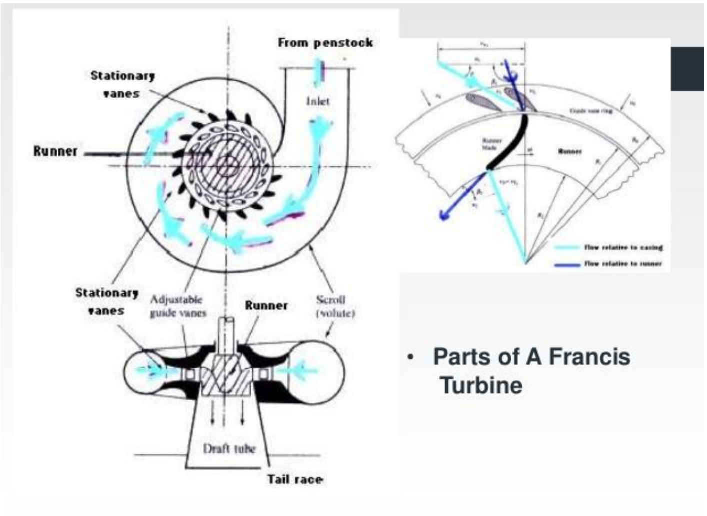


Fig. 1: Model Terminologies.

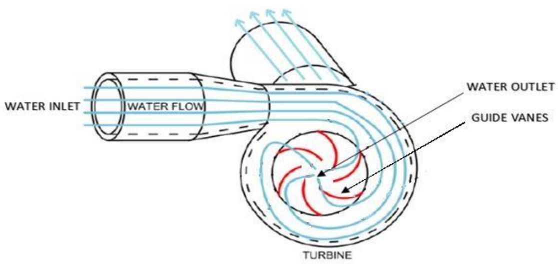


Fig. 2: Sketch Of Model

2.1 Prototype creation

The 3d prototype model was built on solid works. The step-by-step process is enlisted below.

- A circular profile and a square profile were sketched
- A reference line drawn
- The profile was revolved using Revolve feature of solid works.
- The inlet duct was sketched and extruded from the revolved body
- Shell command was used to make the body hollow, such that it can assemble the centrifuge.
- The centrifuge was mated using concentric mate.

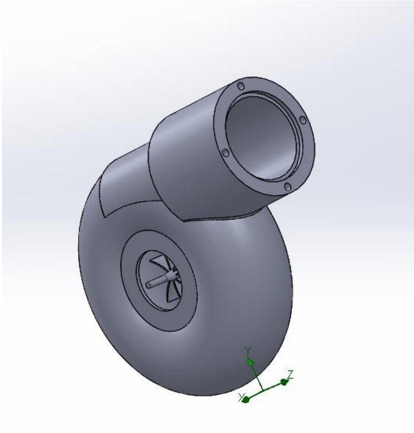


Fig. 3: Geometry of circular model

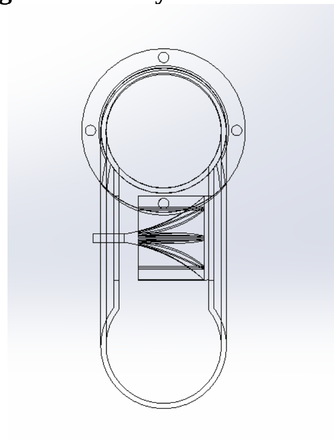


Fig. 4: Circular Model

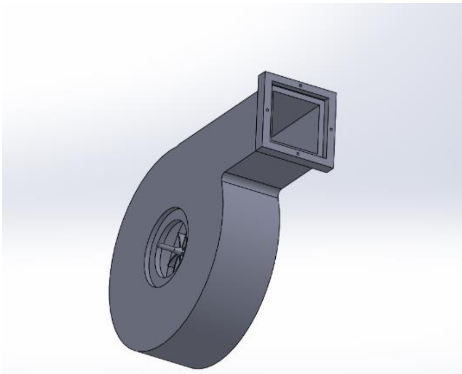


Fig. 5: Geometry of Square Profile

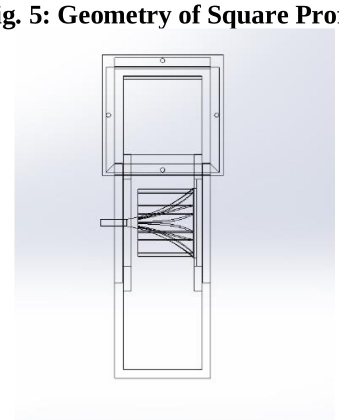


Fig. 6: Square Model

2.2 Mesh Creation

The turbine has been meshed and segmented into fluid and solid domains. The guide wanes are of solid domain and the volute is of fluid domain. The mesh was created independently for the two domains.

2.3 Flow Simulation Analysis

The flow simulation was conducted with the flow simulation feature of solid works. The process has been discussed below.

- With the add in drop list we must add the flow simulation feature, having the model inbuilt.

- We must select Wizard feature.
- We must give the project name.
- We must set SI units
- We must conduct External analysis, and give the gravitational and rotational components.
- The default fluid inputs that we have considered is that of water.
- We must give the input velocity of the fluid to be 100m/s.
- Editing computational domain is necessary to get precise results.
- The centrifuge has been given a velocity of 300m/s.
- We set the Global goals next.
- The work is simulated and flow trajectories are achieved.
- We get the velocity, pressure of surface and temperature as our outputs.

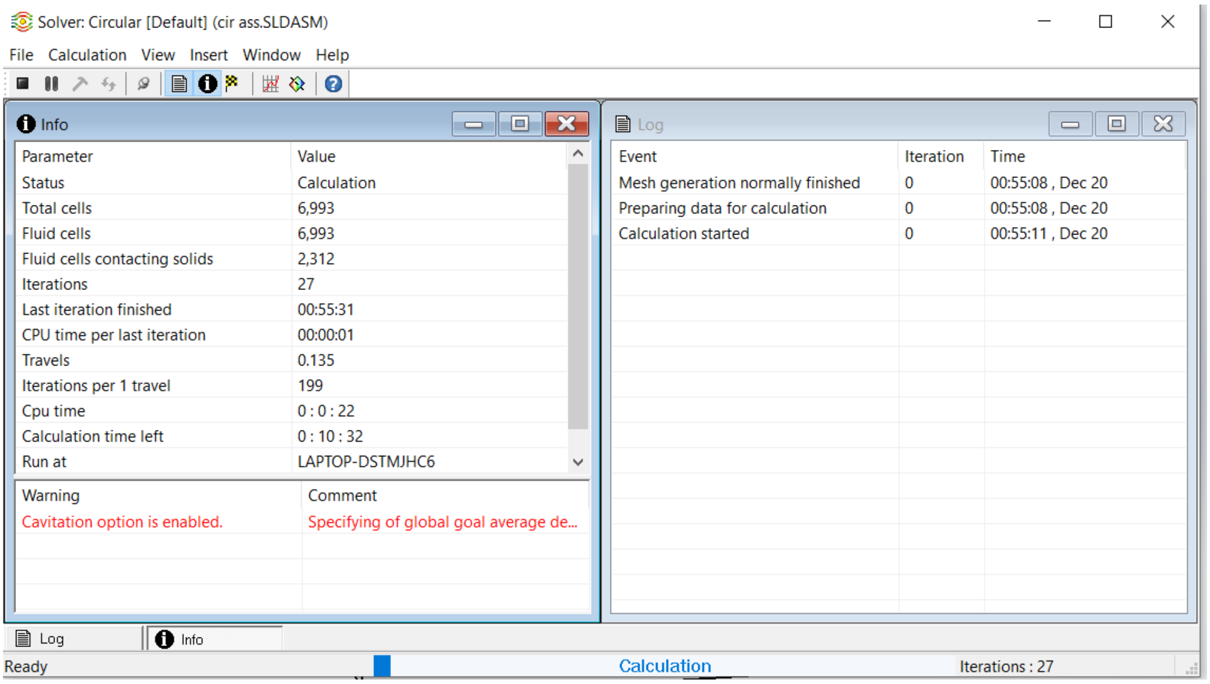


Fig. 7: Circular Profile Flow Analysis

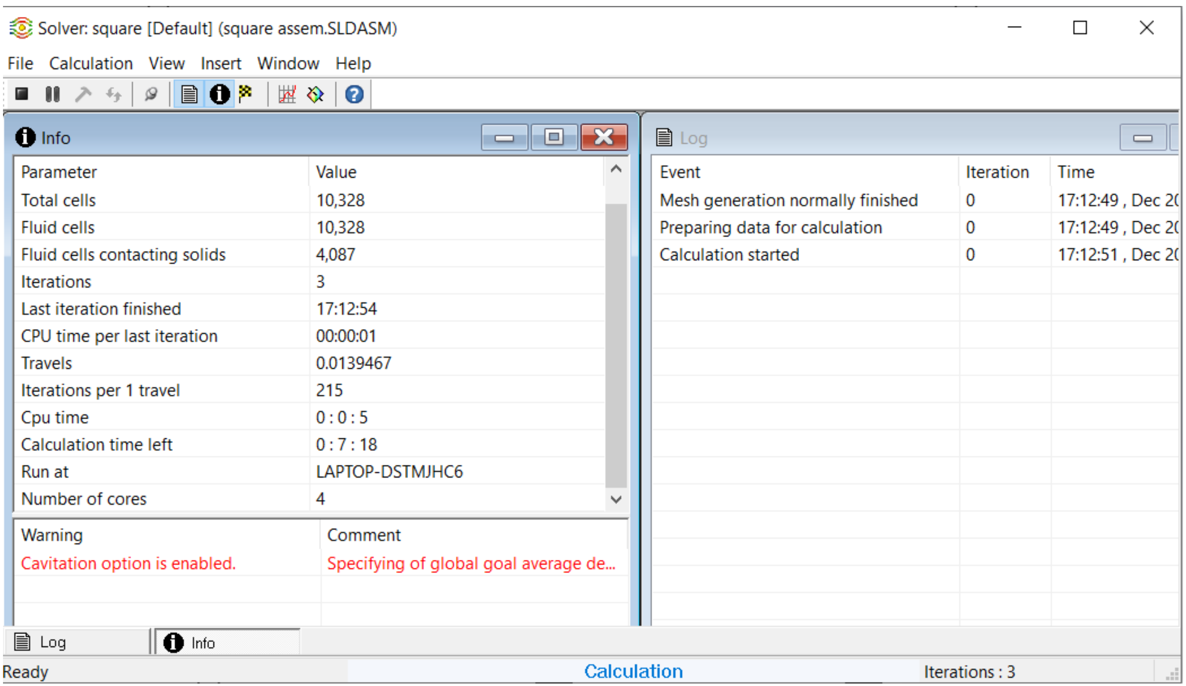


Fig. 8: Square Profile Flow Analysis

3. GOVERNING EQUATIONS

Governing equations those are used to solve the computational domains are as follows-

Navier stokes equation-(considering it in a encapsulated scenario)

$$_{\varrho}\partial u/\partial t(\text{velocityflow})+_{\varrho}u.\nabla u(\text{flux})=-\nabla_{\varrho}(\text{pressure})+\mu\nabla^{2}u(\text{viscosity})+f(\text{bodyforce})$$

where

ϱ= density
∂u= velocity field
f= ϱg (density x gravity)

Rate of change of momentum = forces acting on fluid particle

Continuity Equation

$$\partial \varrho / \partial t + \nabla (\varrho u) = 0$$

For a simplified understanding we consider continuity equation in the following manner,
An orifice with two different areas for inlet and outlet, thus forcing two different velocities at the 2 ends.
Pushing a fluid for a time dt,
Volume lost on one side = Volume gained on the other side

Area = A1/A2

Velocity = v1/v2

Volume lost (A1 X v1 X dt) = Volume gained (A2 X v2 x dt)

Momentum Equation

F= m x a

m x dv/dt

d(mxv)/dt = rate of change of momentum

Energy in flowing fluid

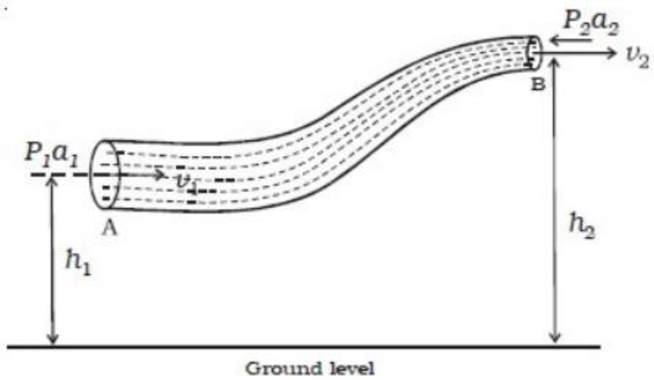


Fig. 9:

Energy due to pressure= F x d = ϱ x A x v

Turbine Power
The power available from water can be calculated as follows-
Pa = γ.Q.H/75
Pa= pressure available
Γ= specific weight in kg/m^3
Q= rate of flow in m^3/sec
H = head in m

Manning's Formula-
$V = 1/n\ R^{2/3}\ s^{1/2}$
Q= AX V

Q= discharge
S= slope of gradient
D= INTERNAL DIAMETER OF PIPE
R = HYDRAULIC RADIUS IN m
V= VELOCITY IN m/s
n=Manning roughness coeff

assumptions for circular profile prototype-
Radius= 50units

Area= 7850 units^2
Diameter= 100units
n= 0.018
v=1/0.018 x $50^{2/3}$ x $s^{1/2}$

4. RESULTS AND DISCUSSIONS

In this paper the main results will be presented. The flow of the turbine with the effect of fluid on it was studied on the commercially available software of Solid works using flow simulation. The difference of the two profiles of circular and square profile is examined, the two models are studied under velocity, pressure and temperature domains.

The study is conducted under fully loaded conditions.

There are 3 domains stated above under which the study is conducted, the data , pictorial representation and graph is listed.

4.1 Circular Profile Data

X [m]	Y [m]	Z [m]	Volume [m^3]	Surface [m^2]	Pressure [Pa]	Temperature [K]	Velocity [m/s]
0.0573936668	-0.0454089029	0.135866557	3.2054142e-05	186715.566	293.199739	99.9843965	
0.0882087323	-0.0454089029	0.135866557	3.20440719e-05	189627.786	293.201229	99.9956957	
0.0573936668	-0.0123171624	0.135866557	3.0374701e-05	278585.99	293.200861	99.9497386	
0.0882087323	-0.0123171624	0.135866557	3.03651585e-05	287761.622	293.201785	99.9600976	
0.0573936668	-0.0454089029	0.163947266	2.67648873e-05	230278.514	293.200232	99.9777634	
0.0882087323	-0.0454089029	0.163947266	2.67564789e-05	234253.8	293.201752	100.003705	
0.0573936668	-0.0123171624	0.163947266	2.53625709e-05	370613.337	293.201272	99.9140557	
0.0882087323	-0.0123171624	0.163947266	2.5354603e-05	385694.577	293.199926	99.9134418	
0.119018958	-0.0454089029	0.135866557	3.20440751e-05	189753.595	293.199381	100.026541	
0.280270401	0.280107752	0.183128199	2.69970584e-06	30030478.6	293.261042	124.422877	
0.265203408	0.266048218	0.195892604	2.70587182e-06	29650986.2	293.33684	127.22214	
0.280280261	0.266048218	0.195892604	2.70587182e-06	27902465.8	293.289709	141.844261	
0.265203408	0.280093198	0.195892604	2.70587182e-06	30689806.3	293.157338	123.710038	
0.280280261	0.280093198	0.195892604	2.70587182e-06	29913276.5	292.983625	130.469754	
0.234557311	0.237958258	0.208670972	2.76478537e-06	32071783.4	293.562938	112.434929	
0.249962425	0.237958258	0.208670972	2.76478537e-06	28724914.8	293.124977	144.605966	
0.234557311	0.252003238	0.208670972	2.76478537e-06	32678157.4	293.637798	98.2882664	
0.249962425	0.252003238	0.208670972	2.76478537e-06	30731364.3	293.490691	120.644299	
0.234557311	0.237958258	0.22144934	2.76478537e-06	32209372	293.583992	110.669432	
0.249962425	0.237958258	0.22144934	2.76478537e-06	29037037.4	293.123171	142.358329	
0.234557311	0.252003238	0.22144934	2.76478537e-06	32680811.3	293.610452	99.7327498	
0.249962425	0.252003238	0.22144934	2.76478537e-06	30975805.3	293.462883	119.579915	
0.265203408	0.237958258	0.208670972	2.7058718e-06	23662845	292.820656	167.87367	
0.280280261	0.237958258	0.208670972	2.7058718e-06	19018687.8	293.93583	171.895358	
0.265203408	0.252003238	0.208670972	2.7058718e-06	27879277.3	293.106323	148.133205	
0.280280261	0.252003238	0.208670972	2.7058718e-06	24921375.7	293.243559	166.522207	
0.265203408	0.237958258	0.22144934	2.7058718e-06	24284749.3	293.040882	161.515428	
0.280280261	0.237958258	0.22144934	2.7058718e-06	20180470.9	294.220968	159.684493	

Fig. 10:

4.2 Square Profile Data

X [m]	Y [m]	Z [m]	Volume [m^3]	Surface [m^2]	Pressure [Pa]	Temperature [K]	Velocity [m/s]
-0.11866937	0.0094604035	0.310003731	5.35806637e-06	103658.436	293.200105	99.9967709	
-0.0979068018	0.0094604035	0.310003731	5.35638308e-06	104664.203	293.202718	99.9914899	
-0.11866937	0.0280257303	0.310003731	5.1567339e-06	105617.259	293.200348	99.9937071	
-0.0979068018	0.0280257303	0.310003731	5.15511386e-06	107596.136	293.204688	99.9833229	
-0.11866937	0.0094604035	0.32363917	5.35683263e-06	105156.804	293.200287	99.994644	
-0.0979068018	0.0094604035	0.32363917	5.35514973e-06	106818.944	293.203487	99.9861006	
-0.11866937	0.0280257303	0.32363917	5.15554651e-06	108437.278	293.200128	99.9897907	
-0.0979068018	0.0280257303	0.32363917	5.15392685e-06	111694.719	293.207052	99.9729676	
-0.0771474941	0.0094604035	0.310003731	5.35638361e-06	106170.038	293.206213	99.9761415	
-0.0563881853	0.0094604035	0.310003731	5.35638361e-06	108852.013	293.21189	99.9496254	
-0.0771474941	0.0280257303	0.310003731	5.15511437e-06	110620.148	293.211322	99.952891	
-0.0563881853	0.0280257303	0.310003731	5.15511437e-06	116104.13	293.223131	99.8992248	
-0.0771474941	0.0094604035	0.32363917	5.35515026e-06	109265.734	293.20959	99.9614675	
-0.0563881853	0.0094604035	0.32363917	5.35515026e-06	113611.322	293.218693	99.9188555	
0.0266490497	0.490695534	0.310003731	6.24542891e-06	44778.6398	293.027624	106.049936	
0.00588974091	0.490695534	0.32363917	6.24399085e-06	75956.619	293.101754	108.157266	
0.0266490497	0.490695534	0.32363917	6.24399085e-06	27892.3337	293.270678	108.860618	
-0.0356288766	0.490695534	0.33727304	6.24399118e-06	211945.561	293.184171	105.899779	
-0.0148695678	0.490695534	0.33727304	6.24399118e-06	172365.471	293.215354	108.109871	
-0.0356288766	0.490695534	0.35090691	6.24399118e-06	236558.671	293.218092	107.569544	
-0.0148695678	0.490695534	0.35090691	6.24399118e-06	160318.8	293.225355	109.842201	
0.00588974091	0.490695534	0.33727304	6.24399118e-06	57915.045	293.11206	109.900454	
0.0266490497	0.490695534	0.33727304	6.24399118e-06	10840.2894	291.766962	110.667216	
0.00588974091	0.490695534	0.35090691	6.24399118e-06	56153.839	293.126902	111.241799	
0.0266490497	0.490695534	0.35090691	6.24399118e-06	10219.0811	290.031753	111.694859	
-0.11866937	0.490695534	0.364540779	6.24595279e-06	455451.457	293.189763	100.676966	
-0.0979068018	0.490695534	0.364540779	6.24399056e-06	377879.174	293.221372	100.762617	

Fig. 11:

4.3 Simulation outcomes for circular profiles

Velocity Outputs

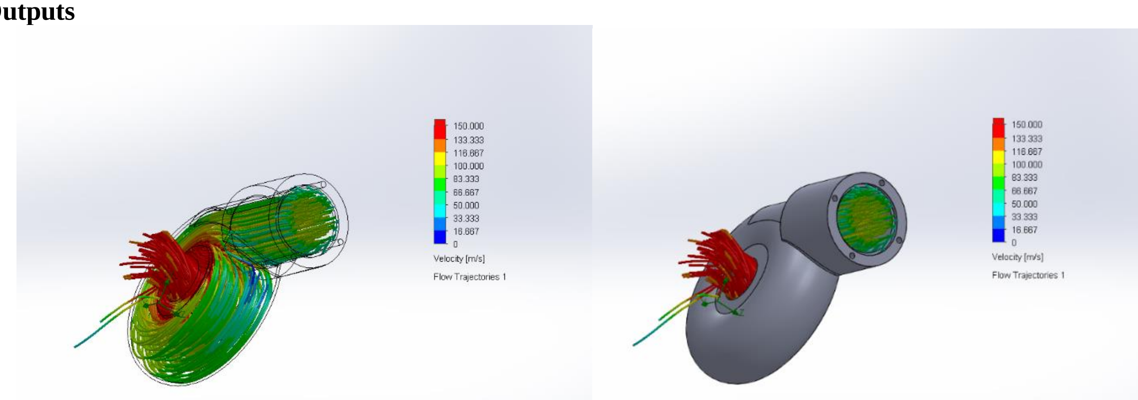


Fig. 12: Velocity Contours

Pressure exerted on circular surface outputs

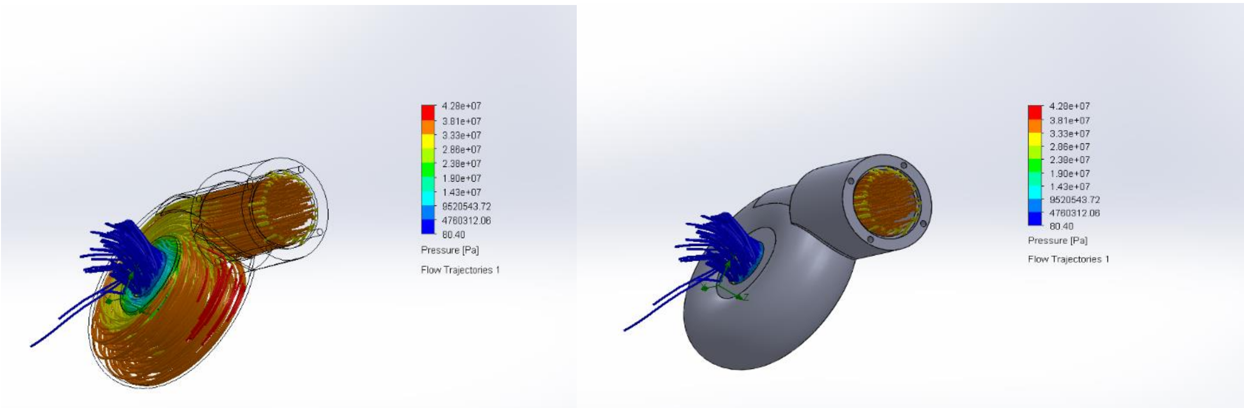


Fig. 13: Pressure Contours

Surface Temperature outputs

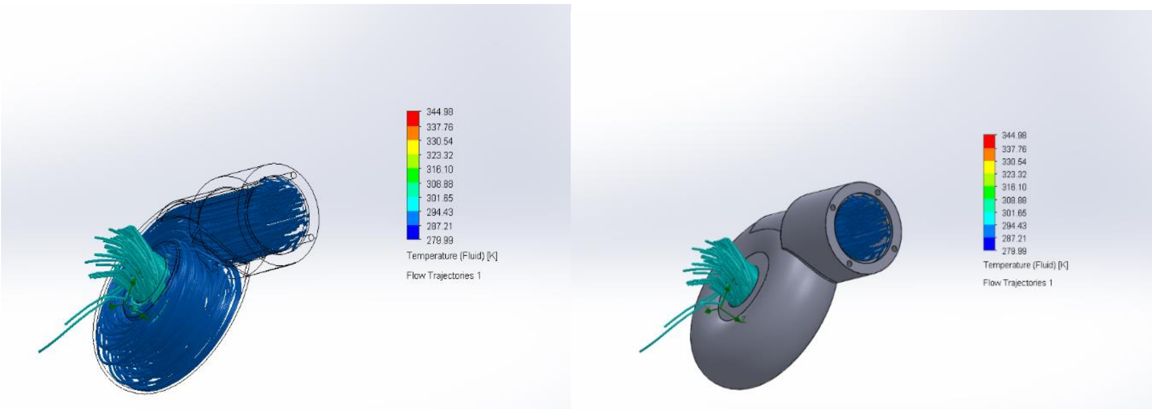


Fig. 14: Temperature Contours

4.4 Simulation Outcomes For Square Profiles

Velocity outputs

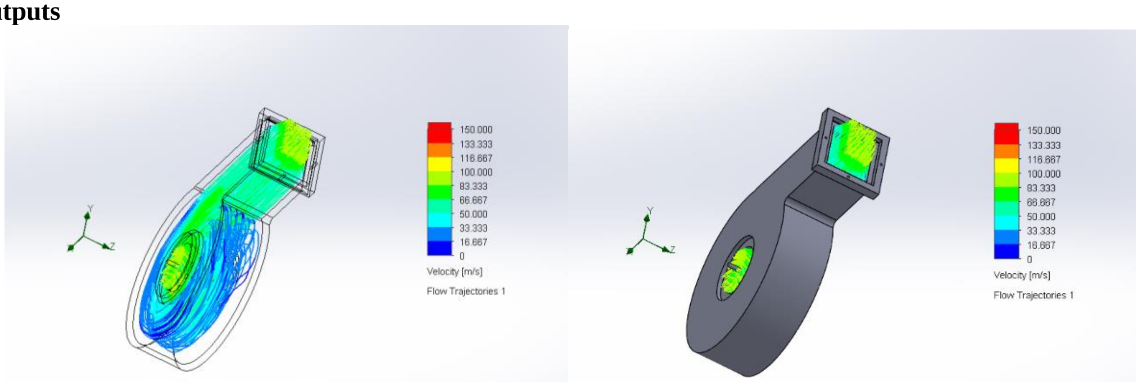


Fig. 15: Velocity Contours

Pressure exerted on Square surface outputs

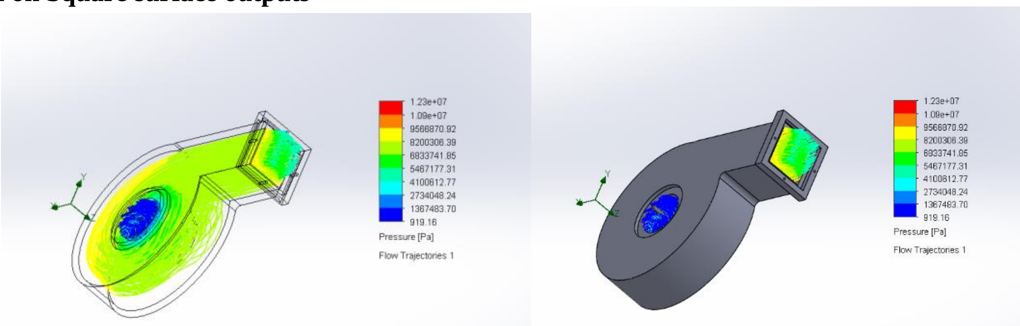


Fig. 16: Pressure Contours

Surface Temperature outputs

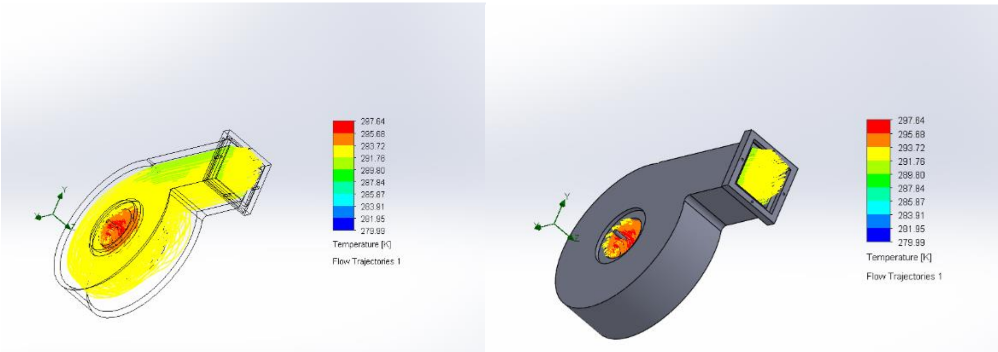
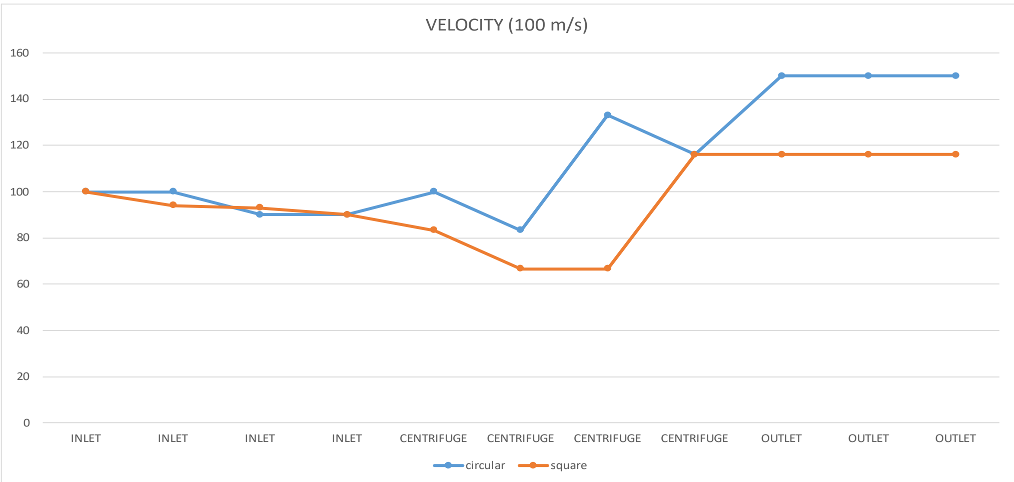
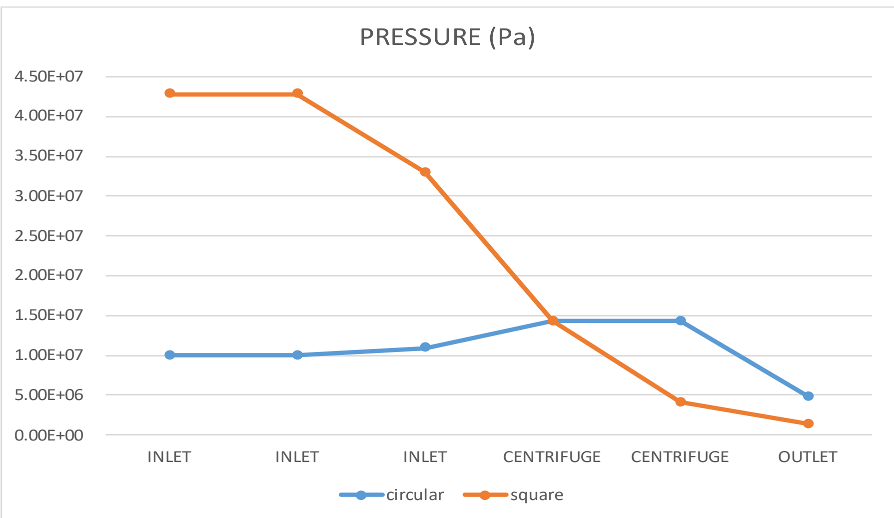


Fig. 23: Temperature Contours

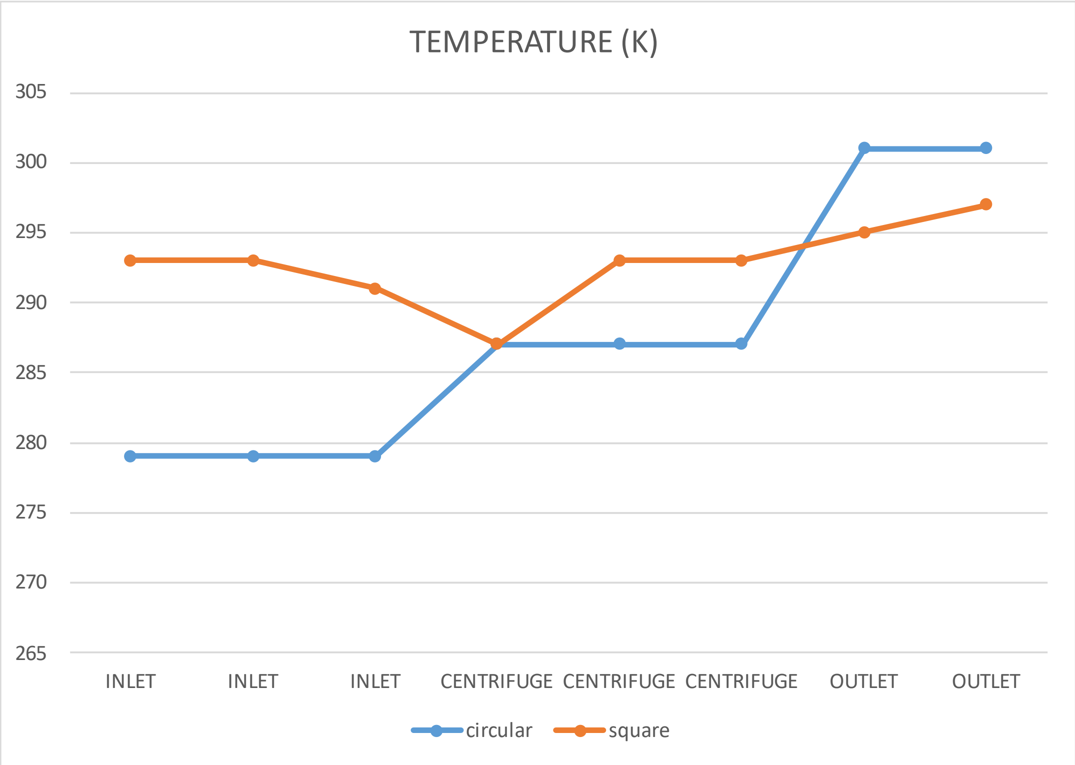
4.5 Graphical Interpretetion
Velocity comparison



Pressure exerted on surface comparison



Temperature on surface comparison



5. CONCLUSION

The objective of this thesis was CFD simulation of various profile. It can be concluded that simulation was successful. The simulation reduces the amount of time needed for setup geometry and meshes for further inspection (for both rectangular and circular profiles). The method involved in the thesis showed good results for most of the geometries. The process can be further worked upon with more experience and knowledge in CFD. When both the profiles that is circular and rectangular were compared; Circular profile gave better results in terms of efficiency and velocity output. As compared to square profile pressure exerted on the walls of circular profile was less. Even the Temperature and velocity outputs of circular profile were encouraging. Temperature was less and velocity was more in circular profile than square profile. Finally we concluded that CFD was a better and promising tool. But has further scope of improvements to give more precise results. From CFD we can finaly conclude that it helps us by giving estimates of the outputs which can help us in developmental stages.

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