Design and CFD Analysis of Bifurcation of Pelton Turbine Hydraulic Losses and Provoke Velocity for the Nozzle

Sase Negash We/Gebriale#

 # Lecture, Department of Mechanical Engineering, Debre Berhan Univeristy. P.O.Box. 445, Ethiopia.

Abstract - *Pelton turbines are a type of hydraulic turbine in which energy carried by water are converted into kinetic energy through nozzles at the end of the distributer. The performance of this turbine depends on many factors, about which distributer plays a major components on its performance. Hence, this paper attempts to study the effect of different parameters of the distributer such as the bending radius, split angle, the length and diameter of the distributer and the joint of the distributer on the performance characteristics of the Pelton turbine.*

The design of the distributer has been ascertain with the flow rate of 0.07 m^3/s, with the total head of 50 m and 138-170 mm as diameter. The detail numerical analysis has been determined and real time simulations of the design has been performed by CATIA V5 and Ansys Fluent. The results obtained from the numerical simulation with respect to static pressure, velocity magnitude, and velocity vectors were plotted for all models. The comparison analysis made on the models were based on the colour magnitude on the legend bar of velocity and pressure. From the simulation it has been concluded that, when the diameter of the distributer increase results showed reduction of head losses. However, increasing the diameter of the distributer increase the cost of the pipe and decreases the hydraulic energy inside the nozzle, which affects the flow performance of the turbine, hence an optimal diameter of 142 mm has been ascertain with the above design specifications. Further the optimum split angle and the length of the distributer were analysed and discussed.

Keywords: *Micro-hydro Pelton turbine, Distributer, Bifurcation, Bending radius, Split angle, Joint of distributer, CATIA, Ansys Fluent.*

I. INTRODUCTION

Human beings have used the power of flowing water for thousands of years. The ancient Greece used this hydropower to grind corn and wheat to flour [1]. Hydropower traditionally represents the energy generated by damming a river and using turbine systems to generate electrical power. Water wheels were used extensively in the ancient times, but it was only at the beginning of the 19th Century that the invention of the hydro turbines got popularized.

Pelton turbines are impulse turbines used for high head and low flow hydro applications. Performance and reliability related components of a Pelton turbine consist of a distributor/ manifold, housing, needle valve, nozzle, impulse runner and discharge chamber [2].

The function of the distributor (manifold) is to provoke an acceleration of the water flow toward each of the main injector's nozzle. The advantage of this design is to keep a uniform velocity profile of the flow. Depending on the age of the turbine unit and original hydraulic design, the distributor size may contribute to losses and turbulence [3]

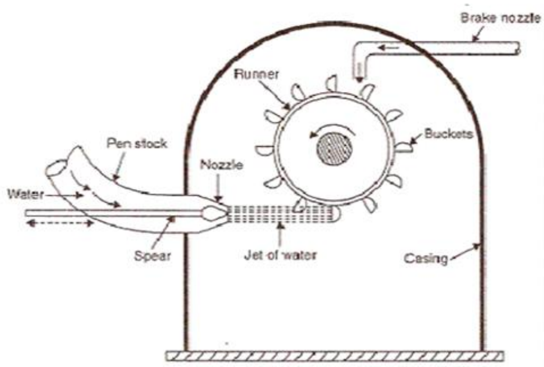

Fig. 1. Components of Pelton Turbine [4]

Energy losses occur in valves and fittings. Various types of fittings, such as bends, couplings, tees, elbows, filters, strainers, etc., are used in hydraulic systems. The nature of path through the valves and fittings determines the amount of energy losses [5]. The more the bending radius and the split angle which approaches 900 in the path, the greater are the losses. This research were aimed at in designing and simulating the distributer of micro hydro Pelton turbine in order to achieve minimum losses with an optimum design of bending radius and splitting angle.

In many fluid power applications, energy losses due to flow in bends and splitting angle exceed those due to flow in the whole pipes [6]. Therefore most of the time fluid flow may get chocked and create back flows, if the bending is sudden or if the split angle approaches 900. In general, the higher of the pipe bend and the split angle, the greater the losses, which were the main concept used to optimize the distributer with minimum losses by considering these aspect in the design.

Muh. Anis Mustaghfirin et al [7] on their paper analyzed the distributer design and geometry analysis with uniformity of two-phase flow distribution in curved round distributor, in which it emphasis the major role played by the distributor on the fluid flow distribution through multiple channels, particularly in two phase flow.

II. METHOD AND DESIGN OF THE TURBINE DISTRIBUTER

Head and flow rate are the two most important things in a hydraulic turbine [7]. Head is a water pressure which is created by the difference in elevation between the water intake and the turbine flow is the water quantity which is expressed as volume per second or minute

Net head is the gross head minus the head losses that occur when water flows from the intake to the turbines through canals and distributer [8]. Water loses energy (head loss) as it flows through a pipe, fundamentally due to the friction against the pipe wall depends on the wall material roughness, bends, sudden contractions and the velocity head.

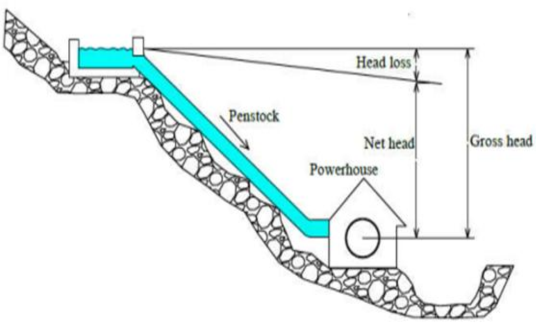

Fig. 2. Layout of Impulse Turbine [9]

Note that the potential head can be obtained using Bernoulli's equation to analyze the fluid flow as depicted in the above Fig. 2

Head Loss in Distributer

The key question in analyzing different type of manifolds/ distributer is the uniformity of the flow distribution and the pressure drop. The uniformity of the flow is disturbed due to the split angle of the bifurcation and the bending [10]. It is possible to reduce the disturbance due to bending by increasing the radius and also as the split angle gets low the non-uniformity of the flow decreases [11]. Incorporating head losses in the distributer and neglecting the elevation difference, the Bernoulli equation will be:

$$\frac{P_{in}}{\rho g}+\frac{1}{2g}{V_{in}}^2=\frac{P_{exit}}{\rho g}+\frac{1}{2g}{V_{exit}}^2+H_d \qquad \textit{Rearranging for } H_d \text{ Gives}$$

$$H_d=\frac{(P_{in}-P_{exit})}{\rho g}+\frac{1}{2g}\left({V_{in}}^2-{V_{exit}}^2\right) \qquad \text{Where } H_d - \textit{head loss in the distributer} \ldots [1]$$

TABLE 1: Clarification of Each Distributer.

BC*	Parts of BUC**	Split angle (Degree)	Bending radius (mm)	Length, (m)
1	Inlet	Reference frame		
	Outlet lower	0	300	3.3
	Outlet upper	30	300	3.3
2	Inlet	Reference Frame		
	Outlet lower	-20	300	1.3
	Outlet upper	30	300	1.5
3	Inlet	Reference Frame		
	Outlet lower	-30	200	0.9
	Outlet upper	40	200	1.0
4	Inlet	Reference Frame		
	Outlet lower	-30	300	1.0
	Outlet upper	40	300	1.2
5	Inlet	Reference Frame		
	Outlet lower	-30	300	2.0
	Outlet upper	40	300	1.7

*BC=Bifurcation Consideration
**BUC= Bifurcation under Consideration

Distributer Design

Distributer and other complex pipe junctions frequently forms an integral part of a hydro scheme [12]. Distributers are pipes which parts the flow in to the nozzles.

The following table shows the tabulation of the five types of bifurcation

Hydro-Works uses the modern method of internal reinforcing where it is appropriate, and computational fluid dynamic (CFD) analysis were used to ensure weather the flow is stable flow and low head losses [13]. So the design and analysis of the distributer is carried out by globally accepted software called Ansys. There are many types of consideration to be considered while designing the distributer bifurcation, such as splitting angle, bending radius, distributer diameter, etc., hence for the present design five different types of bifurcation consideration were used as depicted in the table. 1. Internal flows in the distributor were simulated using Finite Volume (FV) methods [14]

A simple layout of the distributer splitting angle, bending radius and other consideration of the distributer parameter with its nozzle set aligned with 400 mm pitch diameter of runner with the geometrical constraints at split angle of 700 (the sum of the lower and upper splitting angle) is shown in Fig. 3. The exteded length (stator guide), the nozzle length and the clearance between nozzle exits and bucket taking into account the minimum clearance between the nozzle and buckets were given as 250 mm [15]. Hence from the above Fig. 3 the total length taken by considering the clearance between nozzle exit and bucket, nozzle length and stator guide is 457 mm.

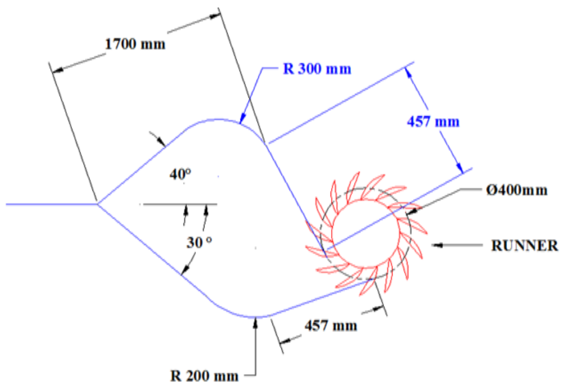

Fig. 3. Distributer Geometry with the Runner Diameter.

III. RESULTS AND DISCUSSIONS

In the present study, the distributer were analyzed by using CATIA V5 and tabulated in terms of split angle, bending radius, diameter and length and the geometry analysis were calculated depending on the runner pitch diameter.

The distributer optimization were analyzed using ANSYS Fluent and the best optimized design has been taken as the final design and the results were presented. The results presented mainly focus on the distributer decissive terms such as the pressure drop, out let velocity, efficiency and discharge. These terms were measured by observing the output figure of the legend bar of the distributer. The legend bar included in the analysis were pressure contour, velocity contour, the stream line and the vorticity contour of the flow.

Simulation Results of Distributer.

The analysis of the flow simulation of the distributer were carried out to obtain the minimum head loss and keeping in view the consideration of manufacturability. The simulation results have been tabulated in Tables. 2-6 for each of the five Distributer bifurcation.

From the above tables, the selection has been made based on values of head losses and the outlet velocity and the total head loss were calculated and summarized as followed by using equation [1]. The total loss for the single distributer have been calculated by taking into account both the upper and lower bifurcation.

It has been observed from table 7 that as the length of the pipe increases the loss also increase which has been clearly depicted in bifurcation 1 and 5. Due to considerably high head losses as indicated in bifurcation 1 and 5 these two type of bifurcation were rejected. Furthermore, the bifurcation type 2, 3 and 4 have almost equal hydraulic loss but varies in the length and radius, hence for the best distribution selection amongst bifurcation type 2, 3 and 4, the pressure and velocity contour were further analyzed.

Pressure and Velocity Contour

The pressure and velocity contour distribution for the bifurcation type 2, 3 and 4 has been portrayed in Figs. 4—13. As observed in Figs. 4-8 of the pressure contour, the low pressure at the bending radius of the distributer has irregular flow pattern and observed a sudden change in pressure, especially in bifurcation 2 and 3 as compared to bifurcation consideration 4 which has a smooth transition of pressure as well as less head loss. Hence bifurcation consideration 4 suited the best as per the considerations set for the design.

The velocity contours (Figs. 9-13) shows how the velocity is distributed or the flow pattern of each bifurcation consideration. It has been observed that there is a huge difference between distributer 2, 3, and 4. In distributer 2 and 3 the velocity contour were uneven at the curved (bending radius) of the distributer which depicts a very high velocity as seen in fig. 10 and 11, however the distributer 4 has the smooth curve and transition which best suited the design. Therefore distributer type 4 is consider the best optimized design in terms of split angle, bending radius and length

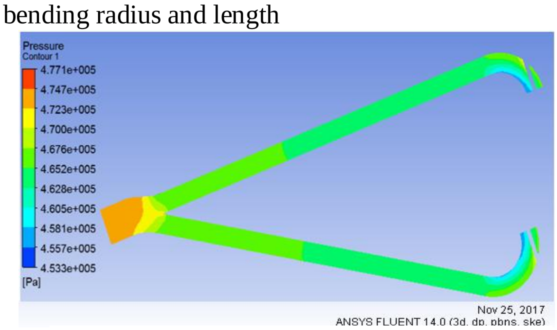

Fig. 4: Pressure Distribution for Bifurcation Consideration 1

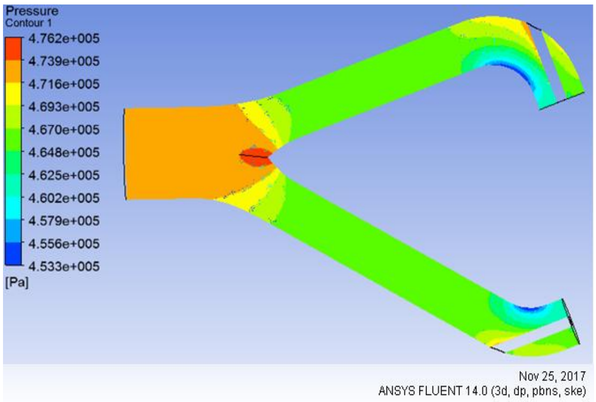

Fig. 5: Pressure Distribution for Bifurcation Consideration 2

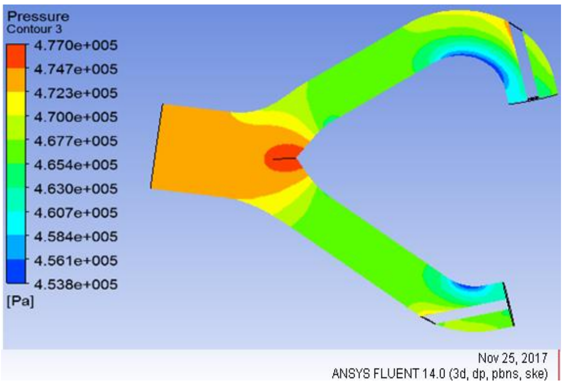

Fig. 6: Pressure Distribution for Bifurcation Consideration 3

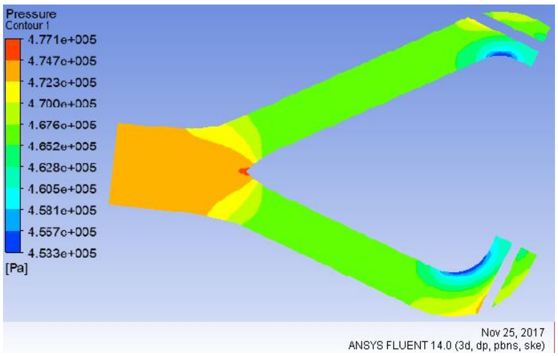

Fig. 7: Pressure Distribution for Bifurcation Consideration 4

Fig. 8: Pressure Distribution for Bifurcation Consideration 5

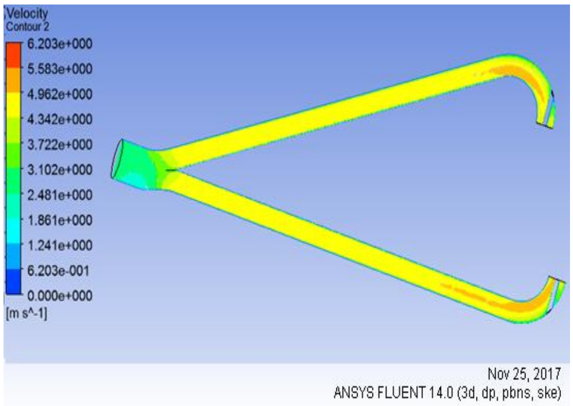

Fig. 9: Velocity Distribution for Bifurcation Consideration 1

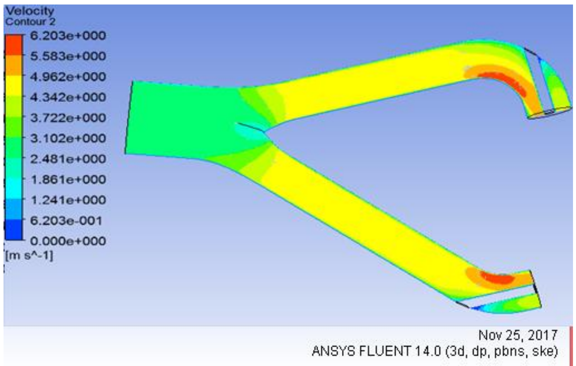

Fig. 10: Velocity Distribution for Bifurcation Consideration 2

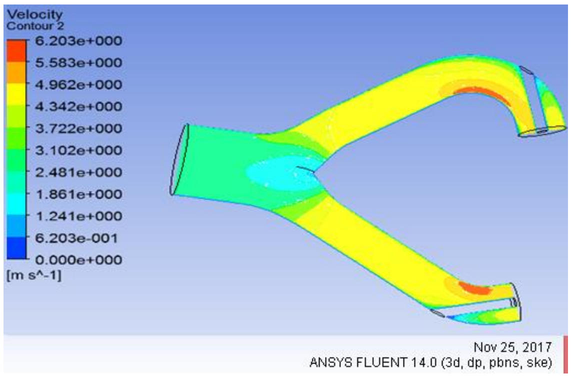

Fig. 11: Velocity Distribution for Bifurcation Consideration 3

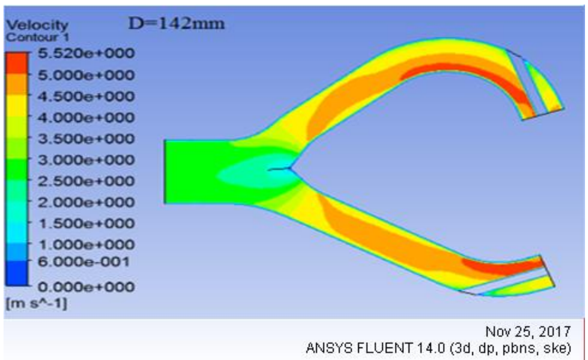

Fig. 12: Velocity Distribution for Bifurcation Consideration 4

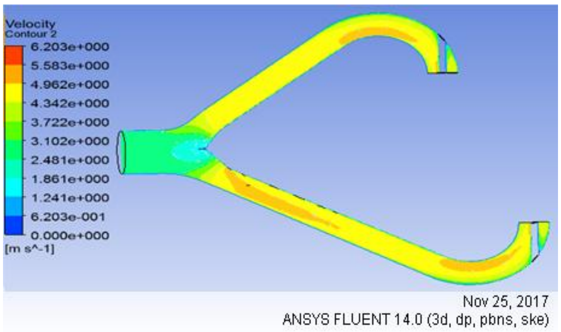

Fig. 13: Velocity Distribution for Bifurcation Consideration 5

Head Loss Calculation Based on Different Diameter

The selected optimized distributer bifurcation type 4 is further optimization based on the diameter variations. From appendix A; for 150 mm diameter, the bifurcation has high loss and hence it is rejected and for diameter 160 mm and 170 mm the head loss is observed to be minimum however they have the outlet velocity, which is the inlet for the nozzle comparatively small. A distributer having a diameter of 150 mm and 142 mm has the highest outlet velocity which enhances the nozzle to produce a high jet power i.e. directly convert into kinetic energy. It is a fact that while choosing the distributer diameter, the efficiency of the nozzle has to be observed at different nozzle diameter since there will be a high head loss when the efficiency drops by a fraction, and therefore depending on the above fact, the distributer having a diameter of 142 mm is selected. The following table summarizes for different distributer diameter

It has been established through observation that even if the pressure distribution of a distributer having a diameter of 170 mm is smooth compared to the rest of the distributor diameters, noting the fact that as the diameter increase the velocity will decrease as the flow rate remains constant. One of the main purpose of the distributer is to direct the flow to the nozzles, in addition the distributer has the role in converging pipe in transition to kinetic energy (convert potential energy to kinetic) and the flow has to be undisturbed to increase the performance of the nozzle. Depending on this fact a distributer having an outlet diameter of 142 mm is best suited among the rest since it has a high velocity change at the exit of the distributer as compared to the others. This distribution is clearly seen from the dark red and yellow colors contour, as they are denoted for higher velocity in velocity legend bar. Also by observing the velocity distribution of a distributer having diameter 170 mm (Appendix C), it has a smooth velocity distribution, but as the function of a distributer this is not an advantage. Therefore in comparison, distributer having a diameter of 142 mm with a medium head loss and rough pressure distribution has been best optimized design for our configuration. This has been further compensated through the velocity distribution and the higher nozzle efficiency demand.

IV. CONCLUSION AND RECOMMENDATION

The objective of the study is to reduce hydraulic loses and optimize efficiency of distributer by varying their corresponding parameters. The split angle, bending radius, length of the distributer and their diameters were essential parameters for minimum head loss and maximum efficiency. The study has been conducted by varying the bending radius from 200 mm to 300 mm, the diameter from 138 mm to 170 mm and the splitting angle from 0 degree to 70 degree, in conjunction to the turbine blade configuration which has a 400 mm pitch circle diameter of the runner. When the length of the distributer increase the head loss also increase and hence the effect of length has been considered vital and hence further analyzed in minimizing the head losses.

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Table 2. Pressure and velocity distribution for bifurcation type 1

P108 - V_lower	P143 - Q	P104 - static pressure outlet lower	P105 - static pressure outlet upper	P106 - dynamic pressure outlet upper	P107 - dynamic pressure outlet lower	P109 - V_upper	P142 - V_in	P144 - Q_lower	P145 - Q_upper	P146 - static pressure in
m s^-1	m^3 s^-1	Pa	Pa	Pa	Pa	m s^-1	m s^-1	m^3 s^-1	m^3 s^-1	Pa
4.7671	0.14	4.6121E+05	4.6109E+05	11235	11326	4.7062	2.549	-0.07	-0.07	4.7368E+05

Table 3. Pressure and velocity distribution for bifurcation type 2

P169 - dynamic pressure lower	P170 - dynamic pressure upper	P171 - dynamic pressure in	P167 - static pressure lower	P166 - static pressure in	P165 - Q	P164 - V_upper	P163 - V_lower	P162 - V_in	P168 - static pressure upper
Pa	Pa	Pa	Pa	Pa	m^3 s^-1	m s^-1	m s^-1	m s^-1	Pa
11197	11217	3186.8	4.6351E+05	4.7373E+05	0.14	4.7408	4.7238	2.5236	4.6314E+05

Table 4. Pressure and velocity distribution for bifurcation type 3

P138 - static pressure outlet	P97 - outlet dynamic pressure lower	P96 - inlet dynamic pressure	P95 - inlet total pressure	P94 - inlet static pressure	P141 - V_upper	P139 - V_in	P140 - V_lower	P98 - outlet dynamic pressure upper	P134 - Q	P135 - Q_lower	P136 - Q_upper
Pa	Pa	Pa	Pa	Pa	m s^-1	m s^-1	m s^-1	Pa	m^3 s^-1	m^3 s^-1	m^3 s^-1
4.6382E+05	11157	3187.3	4.7692E+05	4.7373E+05	4.7315	2.5248	4.715	11153	0.14	-0.07	-0.07

Table 5. Pressure and velocity distribution for bifurcation type 4

P154 - Q	P132 - dynamic pressure lower	P131 - dynamic pressure upper	P125 - V_in	P126 - V_lower	P127 - V_upper	P128 - static pressure in	P129 - static pressure lower	P130 - static pressure upper	P155 - Q_lower	P156 - Q_upper
m^3 s^-1	Pa	Pa	m s^-1	m s^-1	m s^-1	Pa	Pa	Pa	m^3 s^-1	m^3 s^-1
0.14	11128	11114	2.5241	4.706	4.7192	4.7373E+05	4.6375E+05	4.6303E+05	-0.07	-0.07

Table 6. Pressure and velocity distribution for bifurcation type 5

P147 - Q	P113 - static pressure lower	P116 - V_lower	P114 - static pressure upper	P117 - V_in	P118 - dynamic pressure lower	P115 - V_upper	P119 - dynamic pressure upper	P148 - Q_lower	P149 - Q_upper	P150 - static pressure in
m^3 s^-1	Pa	m s^-1	Pa	m s^-1	Pa	m s^-1	Pa	m^3 s^-1	m^3 s^-1	Pa
0.14	4.6193E+05	4.7028	4.624E+05	2.555	11108	4.6905	11041	-0.07	-0.07	4.7363E+05

Table 7. Head Loss and Pressure Drop Calculated Values for Different Bifurcation

Bifurcation Consideration	Parts of bifurcation Under consideration	Split angle	Bending radius, (mm)	Length, (m)	Velocity, (m/s)	Head loss, (m)
1	Inlet	Reference frame			2.55	
	Outlet lower	0	300	3.3	4.77	0.448
	Outlet upper	30	300	3.3	4.7	0.49
	Total head loss					0.94
2	Inlet	Reference frame			2.55	
	Outlet lower	-20	300	1.3	4.72	0.23
	Outlet upper	30	300	1.5	4.74	0.30
	Total head loss					0.53
3	Inlet	Reference frame			2.55	
	Outlet lower	-30	200	0.9	4.71	0.21
	Outlet upper	40	200	1.0	4.73	0.32
	Total head loss					0.53
4	Inlet	Reference frame			2.55	
	Outlet lower	-30	300	1.0	4.69	0.17
	Outlet upper	40	300	1.2	4.71	0.22
	Total head loss					0.4

5	Inlet	Reference frame			2.55	
	Outlet lower	-30	300	2.0	4.7	0.33
	Outlet upper	40	300	1.7	4.69	0.63
	Total head loss					0.96

Table 8. The head loss calculation for the 4 different diameters

Bifurcation Option	Parts of Bifurcation Under consideration	D (mm)	Split angle	Bending radius (mm)	Length (m)	Outlet Velocity (m/s)	Head loss (m)
4	Inlet	266	Reference Frame			2.52	
	Outlet lower	142	-30	300	1.0	4.697	0.172
	Outlet upper	142	40	300	1.2	4.710	0.226
	Total Head loss						0.4
	Inlet	266	Reference Frame			2.52	
	Outlet lower	150	-30	300	1.0	4.12	0.23
	Outlet upper	150	40	300	1.2	4.15	0.23
	Total Head loss						0.46
	Inlet	266	Reference Frame			2.52	
	Outlet lower	160	-30	300	1.0	3.62	0.13
	Outlet upper	160	40	300	1.2	3.64	0.17
	Total Head loss						0.30
	Inlet	266	Reference Frame			2.52	
	Outlet lower	170	-30	300	1.0	3.25	0.11
	Outlet upper	170	40	300	1.2	3.25	0.13
	Total Head loss						0.24

APPENDIX A- ANSYS Simulation Result Table for Bifurcation Type 4 at Different Diameter

At D=142 mm

P224 - mass flow out	P223 - total pressure in	P154 - Q	P132 - dynamic pressure lower	P131 - dynamic pressure upper	P125 - V_in	P126 - V_lower	P127 - V_upper	P128 - static pressure in	P129 - static pressure lower	P130 - static pressure upper	P155 - Q_lower	P156 - Q_upper
kg s^-1	Pa	m^3 s^-1	Pa	Pa	m s^-1	m s^-1	m s^-1	Pa	Pa	Pa	m^3 s^-1	m^3 s^-1
69.874	4.7692E+05	0.14	10952	10957	2.5193	4.6973	4.7104	4.7375E+05	4.6423E+05	4.6363E+05	-0.07	-0.07

At D=150 mm

P247 - mass outflow	P246 - total pres... in	P248 - d_hyd	P249 - static pressure in	P250 - static pressure lower	P251 - static pressure upper	P253 - total pressure upper	P252 - total pressure lower	P254 - V_in	P255 - V_lower	P256 - V_upper
kg s^-1	Pa	m	Pa	Pa	Pa	Pa	Pa	m s^-1	m s^-1	m s^-1
69.874	4.7692E+05	0.118	4.7375E+05	4.6663E+05	4.6607E+05	4.7484E+05	4.7542E+05	2.5206	4.1246	4.1539

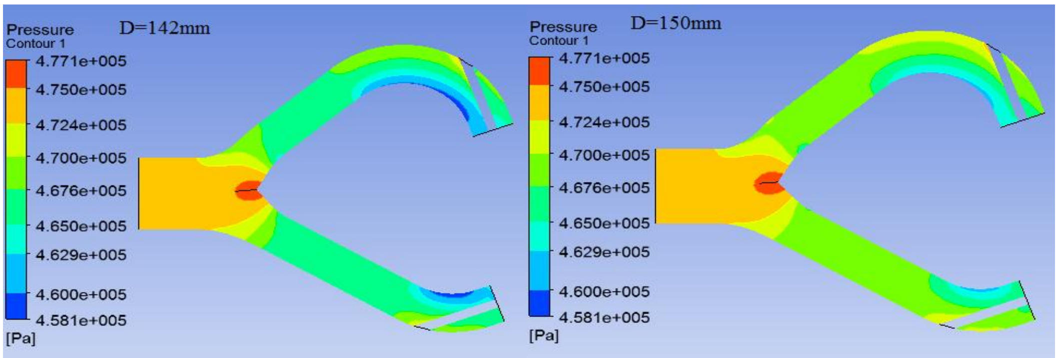
At D=160 mm

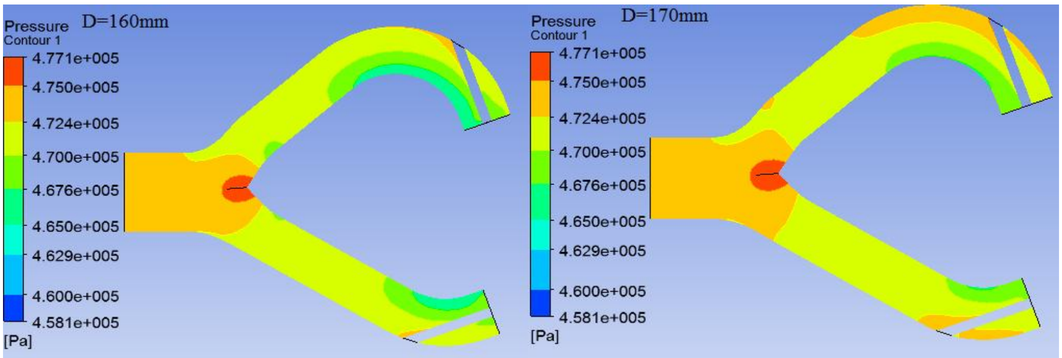
P232 - outflow mass	P231 - total pressure in	P235 - static pressure lower	P234 - static pressure in	P236 - static pressure upper	P239 - V upper	P238 - V lower	P237 - V in	P242 - dynamic pressure in	P241 - dynamic pressure lower	P240 - dynamic pressure upper
kg s^-1	Pa	Pa	Pa	Pa	m s^-1	m s^-1	m s^-1	Pa	Pa	Pa
69.874	4.7692E+05	4.6904E+05	4.7374E+05	4.6859E+05	3.6422	3.6276	2.5209	3178	6734.3	6713.1

At D=170 mm

P293 - total pressure in	P294 - mass outflow	P295 - d_hyd	P296 - static pressure in	P297 - static pressure lower	P298 - static pressure upper	P299 - V_upper	P300 - V_lower	P301 - V_in
Pa	kg s^-1	m	Pa	Pa	Pa	m s^-1	m s^-1	m s^-1
4.7692E+05	69.874	0.138	4.7374E+05	4.7074E+05	4.7034E+05	3.2485	3.2489	2.524

APPEMDIX B- Pressure Contour of the Distributer for Different Diameter





APPENDIX C-Velocity Contour of Distributer for Different Diameter.