INSTITUTE FOR GRADU
IN PURE AND APPLIE

CENTRIFUGAL PUMP DESIGN AND PERFORMANCE OPTIMIZATION USING LOSS CORRELATIONS

OĞUZCAN MERCAN

SUPERVISORS: ASSOC. PROF. DR. EMRE ALPMAN

PROF. DR. ERKAN AYDER

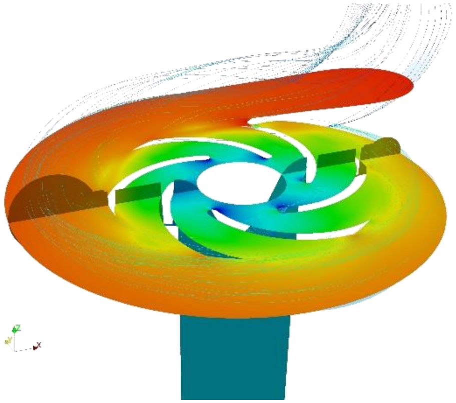
4 DECEMBER 2018

Outline

- Introduction
- Pump Theory
  - Design of impeller and volute
  - Loss models
  - Code implementation and CFD analysis
- Results & Discussion
  - Prediction results
  - CFD Results
  - Comparison
- Future Work

Introduction

- Flow inside the pump
  - Highly complicated
  - Can be successfully simulated using CFD
- Predicting the pump performance characteristics without
  - performing the time consuming and challenging CFD calculations



- The aim of this thesis
  - To develop a pump performance prediction code using theoretical and empirical energy loss equations from the literature

Introduction

Literature

- There are well known books on pump design topic by Pfleiderer, Gülich and Tuzson
- Loss correlations of Hamkins and Dick are performed for the prediction off-design conditions
- Wiesner developed a formula for the prediction of slip factors
- Blade loading losses are calculated via Pearsall's formula adapted to centrifugal pumps by Myles
- Various CFD simulation models of centrifugal pumps have been presented in literature

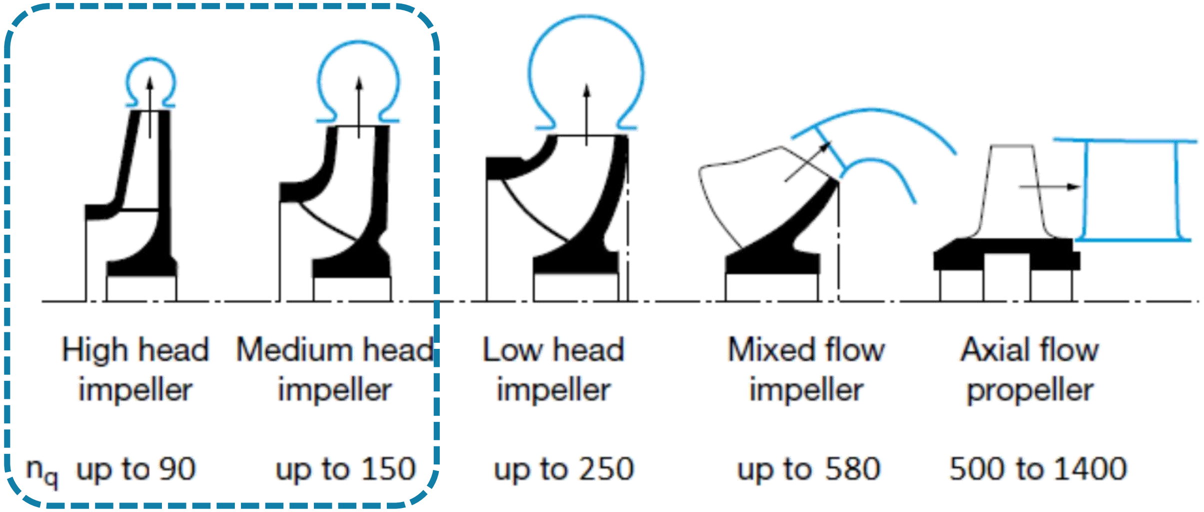
Outline

- Introduction
- Pump Theory
  - Design of impeller and volute
  - Loss models
  - Code implementation and CFD analysis
- Results & Discussion
  - Prediction results
  - CFD Results
  - Comparison
- Future Work

Pump Theory

Three characteristic dimensions should be known in the design calculation of a centrifugal pump

- H_m: Delivery head (m)
- Q: Flow rate (m^3/s)
- n: Rotational speed (rpm)



Pump Theory
Design of impeller

Main dimensions of impeller

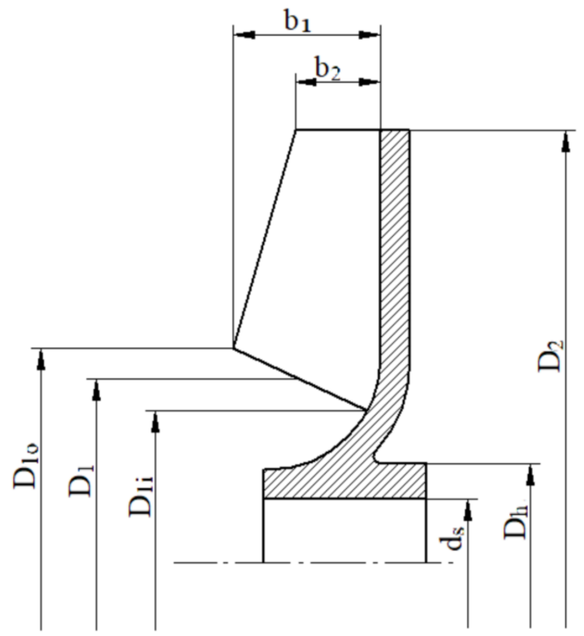
D_1 = Inlet diameter

b_1 = Inlet blade width

b_2 = Outlet blade width

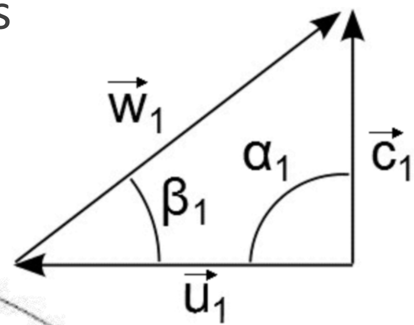
D_s = Pump shaft diameter

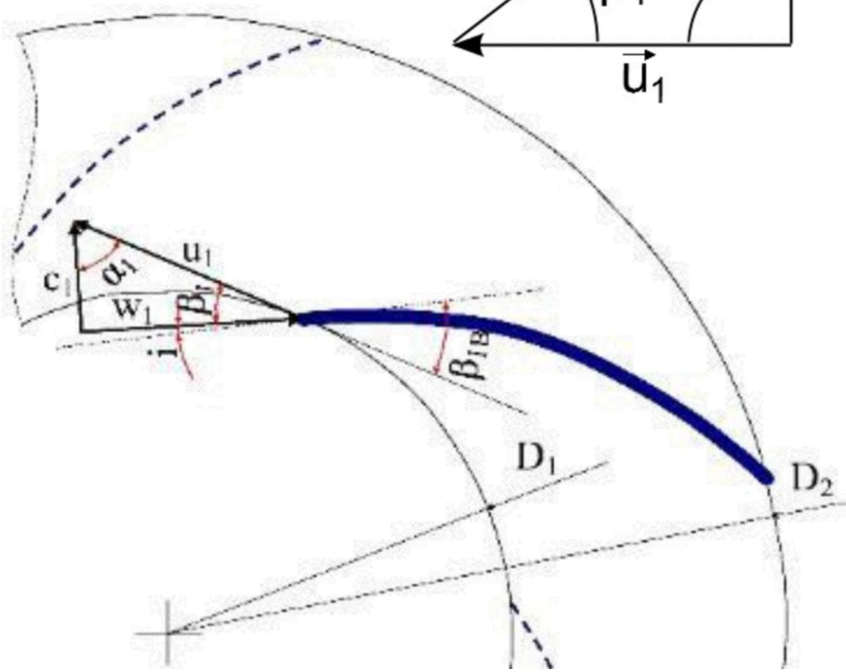
D_h = Impeller hub diameter



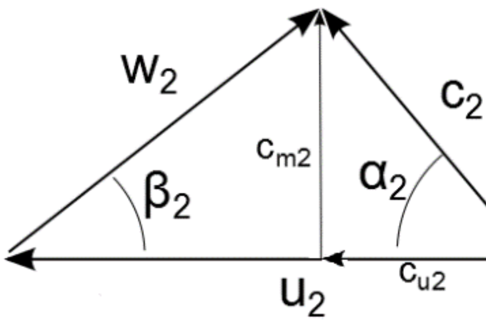
Pump Theory
Design of impeller

Inlet conditions





Outlet conditions



The velocity triangle is described by three vectors:

- Circumferential velocity, **u**

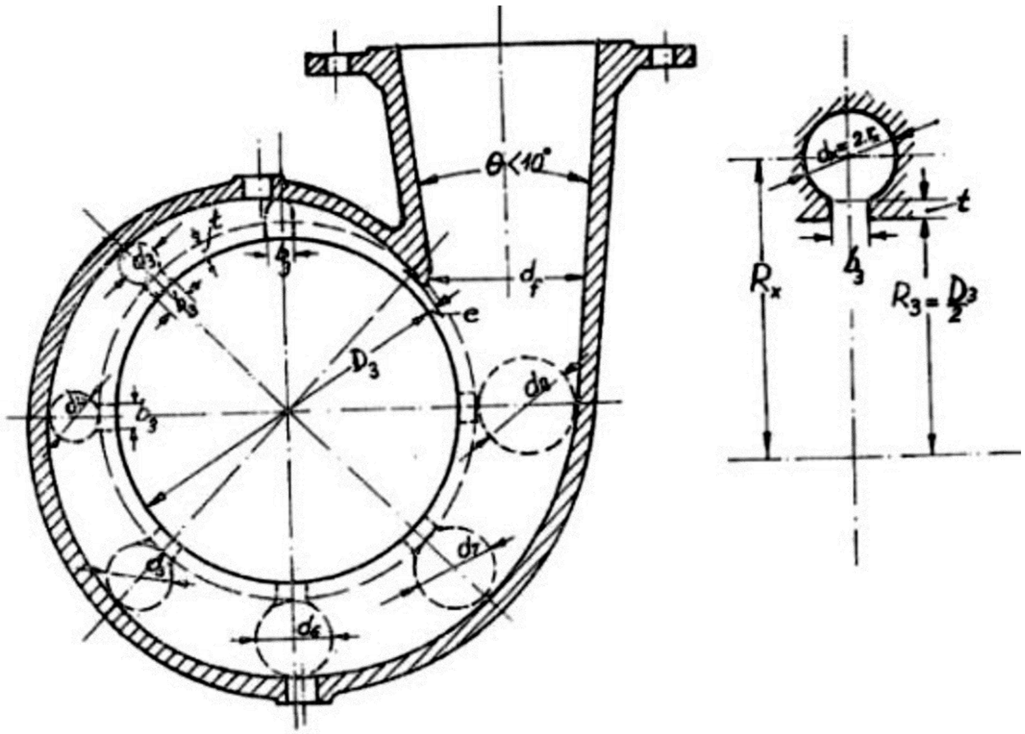
  multiplication of angular velocity ω, and impeller radius r

- Relative velocity, **w**
- Absolute velocity, **c**

  which is obtained through the vectorial addition of u and w

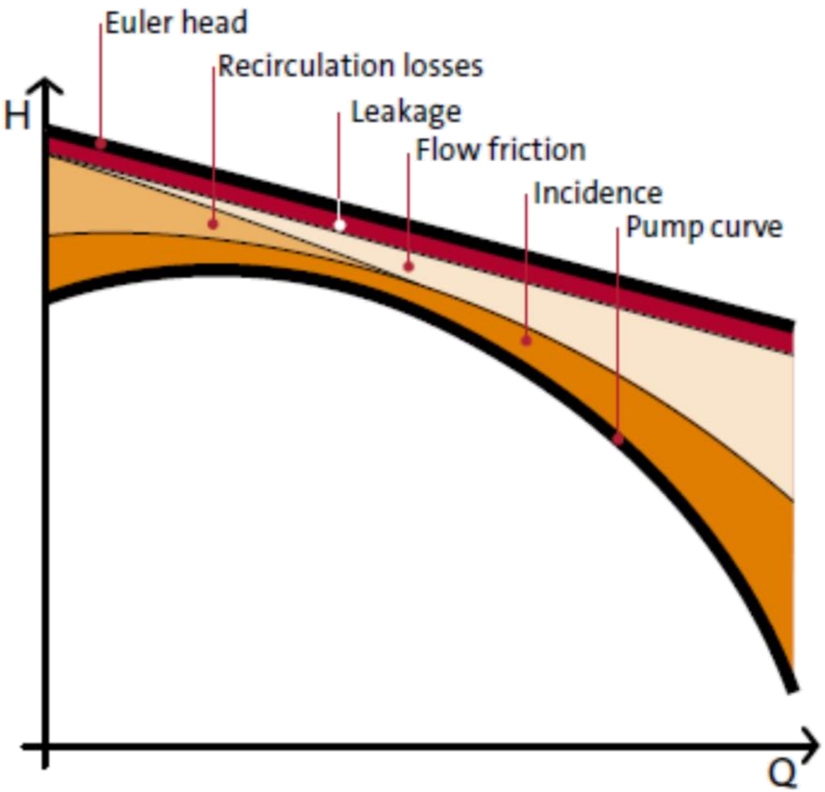
Pump Theory
Design of volute

- The gradually increasing volute flow cross sections are calculated from the flow rate and from an average velocity at the volute cross section center.
- The usual flow model assumes that the impeller outlet tangential velocity decreases in proportion to the radius to maintain constant angular momentum.



Pump Theory
Loss models

- Theoretical head
- Slip factor
- Inlet loss
- Impeller losses
  - Mismatching loss
  - Friction loss
  - Blade loading loss
- Volute losses
  - Mismatching loss
  - Friction loss
  - Diffusor loss
- Disc friction loss

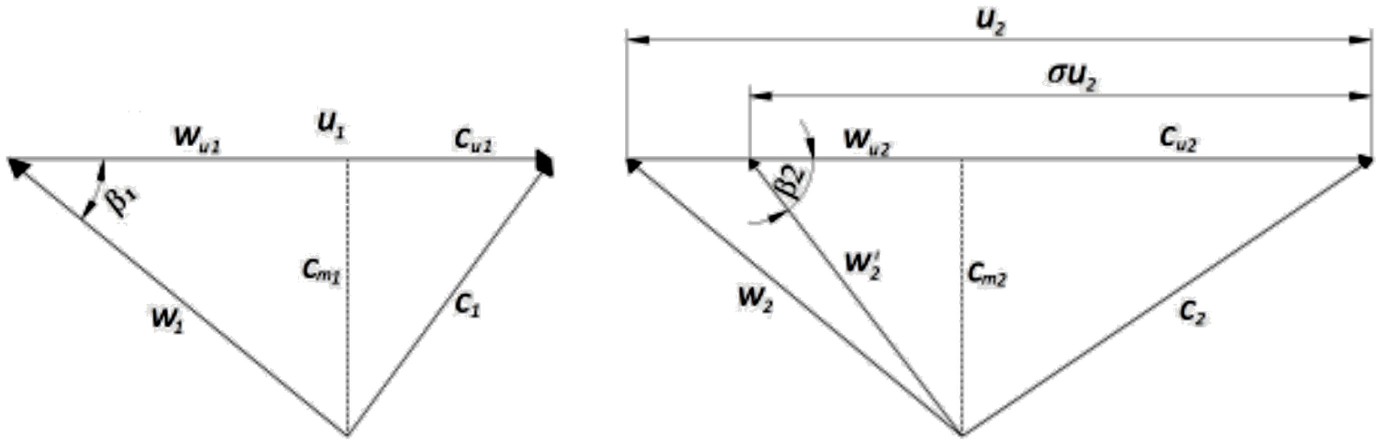


Pump Theory
Loss models

- Theoretical head (H_m) is calculated from Euler's pump equation, which gives the conservation of angular momentum across the impeller.
- The slip phenomenon has a strong influence on the working condition of centrifugal pumps. several methods have been proposed by a large number of authors, Stodola, Busemann, Stanitz, Wiesner, Backström etc.
- Wiesner obtained an empirical formula that predicts the slip factor, σ. The formula includes the relation of outlet blade angle β_2, and number of blades, *Z*.

Pump Theory
Loss models

- Tangential component of the absolute velocity cu_2 can be found by extracting tangential component of the relative velocity wu_2 from the peripheral velocity u_2, by taking into account of slip factor as σu_2



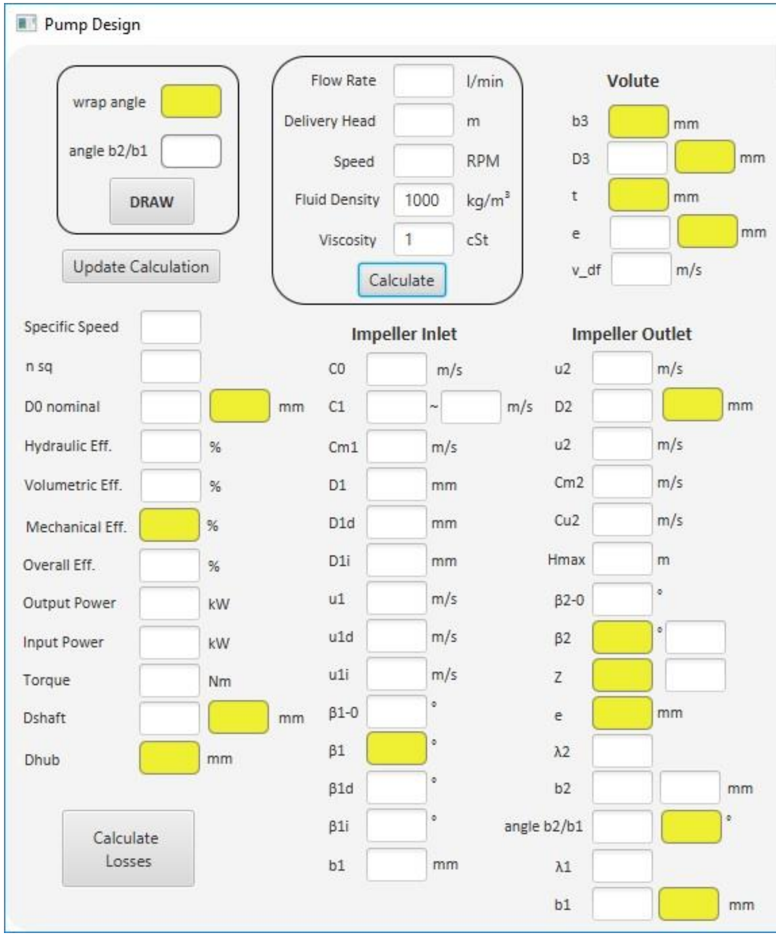
Pump Theory
Code implementation

- The pump design and performance optimization software has been implemented on Java 1.8 using Java FX.

- Eclipse which is an integrated development environment (IDE) is used in computer programming. The user interface has been created and edited using the Scene Builder software which is integrated with JavaFx.

Pump Theory

Code implementation

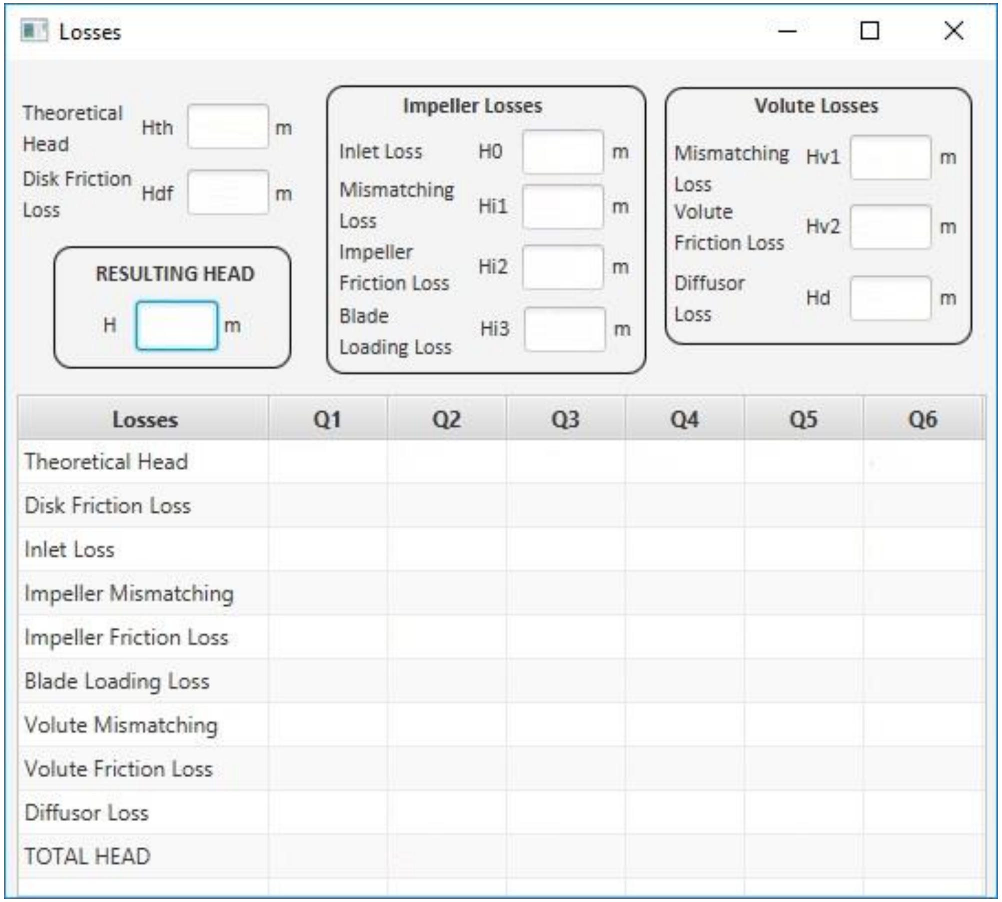


- ❑ Performing initial calculations
  - Flow rate (Q)
  - Delivery head (H)
  - Pump speed (n) are entered
- ❑ Calculations can be modified by pressing ‘Update Calculation’
- ❑ ‘Calculate Losses’ button executes the loss calculation and opens a new pop-up window that shows the losses

Pump Theory

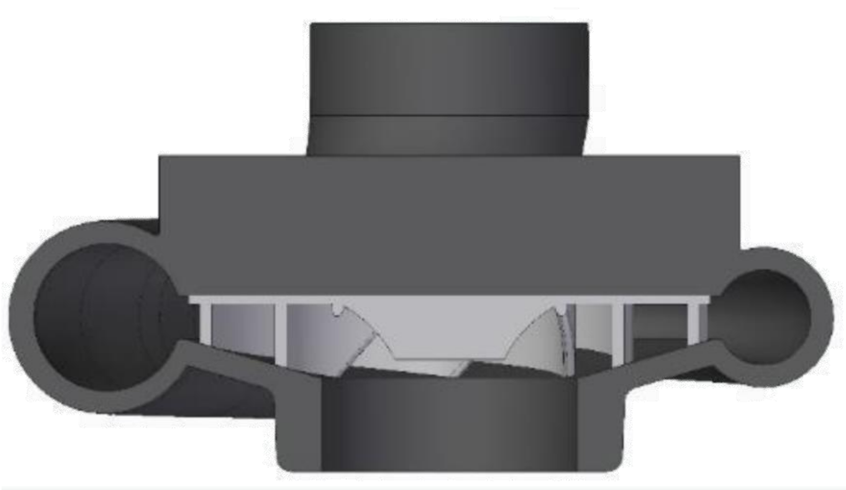
Code implementation

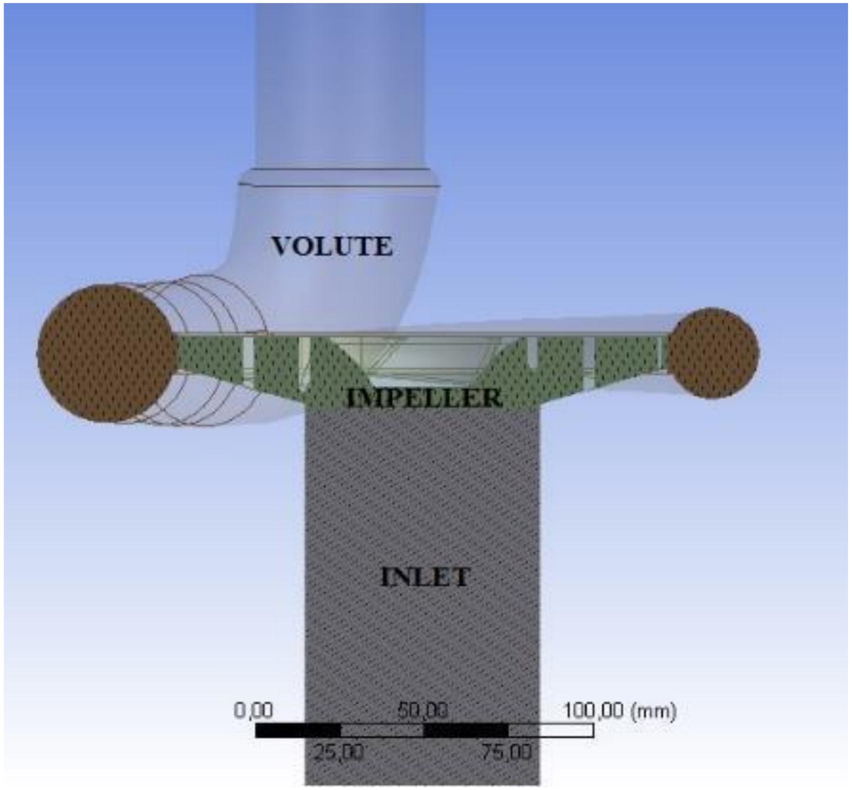
- Delivery head at design point and off-design conditions are obtained.
- The design can be modified if the final results are below the desired values by returning to the previous window.
- Iterations end by obtaining the performance curve



Pump Theory
CFD Analysis - Pre-processing

- Solid modeling
- Creating domains

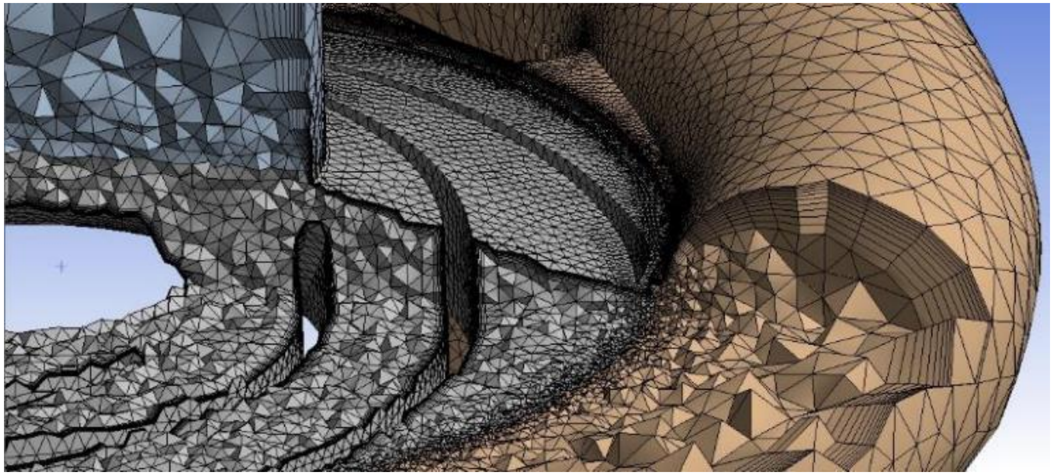




Pump Theory
CFD Analysis - Pre-processing

- Meshing

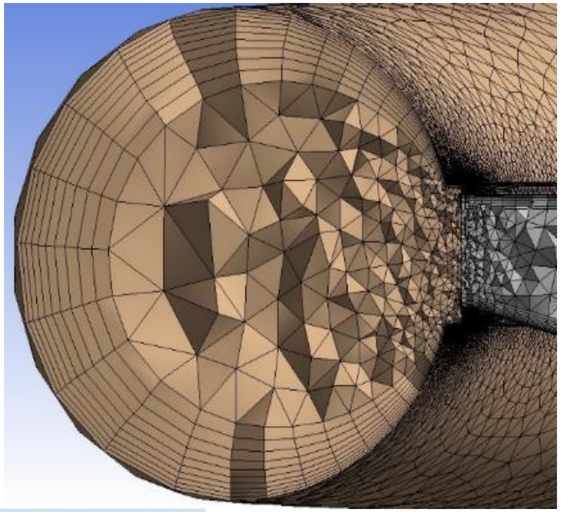
- Impeller domain have a critical role for calculations. Therefore impeller has more elements compare to inlet and outlet.
- Interiors between impeller - inlet domain and impeller-outlet domain have smaller mesh size due to higher accuracy of analysis.

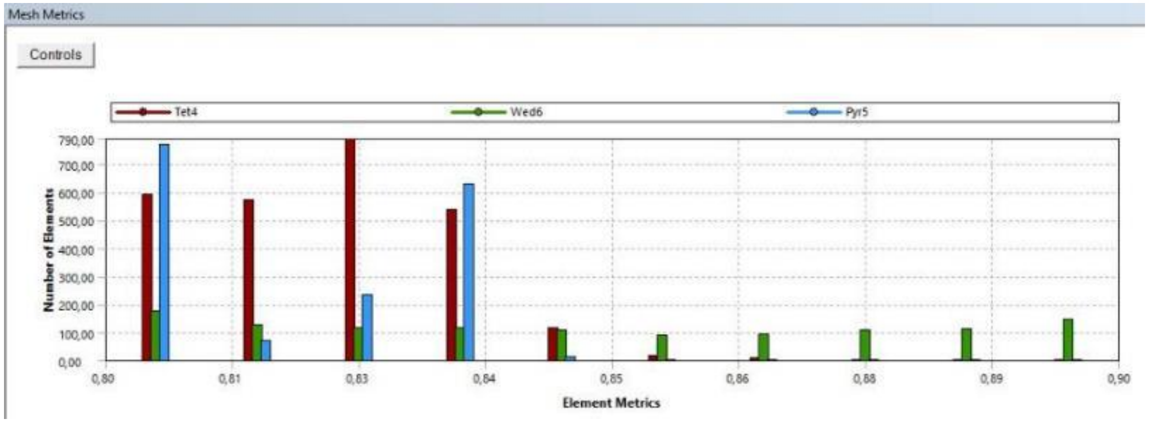


Pump Theory
CFD Analysis - Pre-processing

❑ Meshing

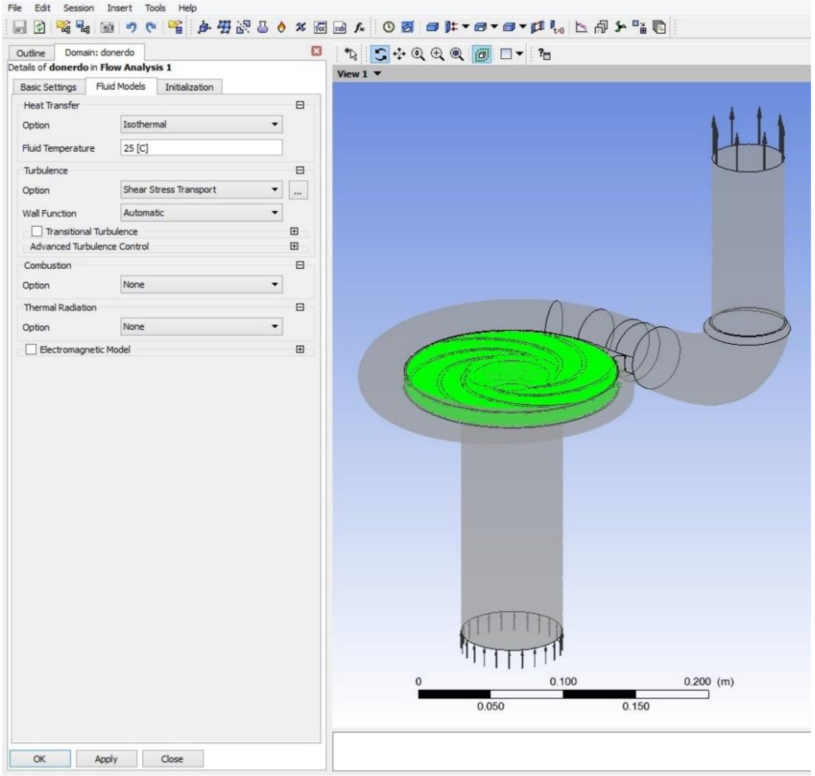
- Boundary layer mesh (inflation) was applied and layer compression method is selected to preserve the number of layers
- The quality of the resulting grid was checked with the skewness parameter





Pump Theory
CFD Analysis - Pre-processing

- Solver settings
- ✓ The fluid is incompressible and the rotation of the impeller was performed with MRF (Multiple Reference Frame)
- ✓ Steady state analysis were performed.
- ✓ k-ω based Shear Stress Transport model was used as the turbulence model
- ✓ Static meshing is applied for all domains



Pump Theory
CFD Analysis - Pre-processing

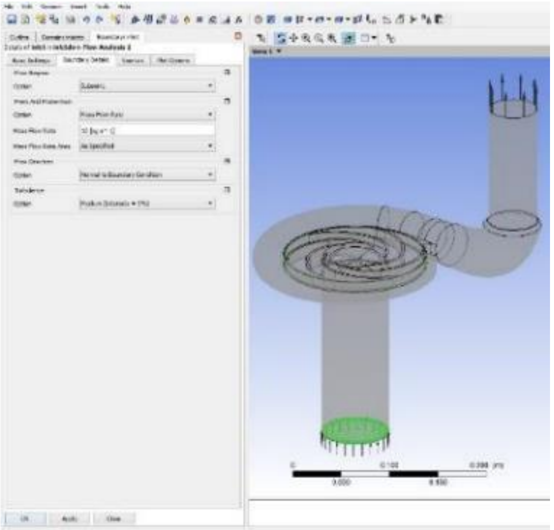
Boundary Conditions

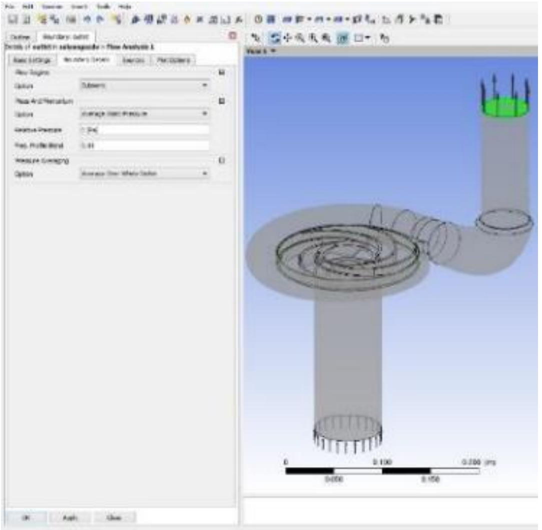
Inlet

- The mass flow rate (kg/s) is defined normal to the flow direction of the inlet boundary

Outlet

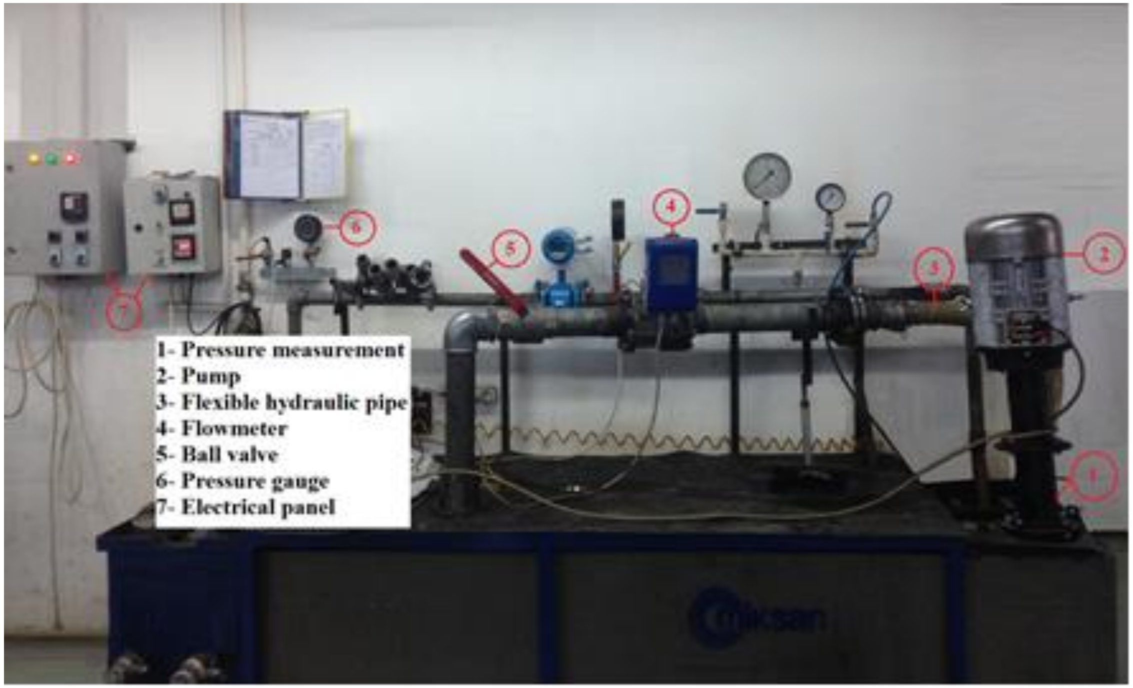
- Static pressure of 0 Pa (atmospheric pressure) was defined at the pump outlet





Pump Theory
Experimental Setup

- Pump-1 outlet is connected to G2 T-pipe,
- Pump-2 is connected to G1½ T-pipe,
- Pump-3 is connected to G1¼ T-pipe.



Outline

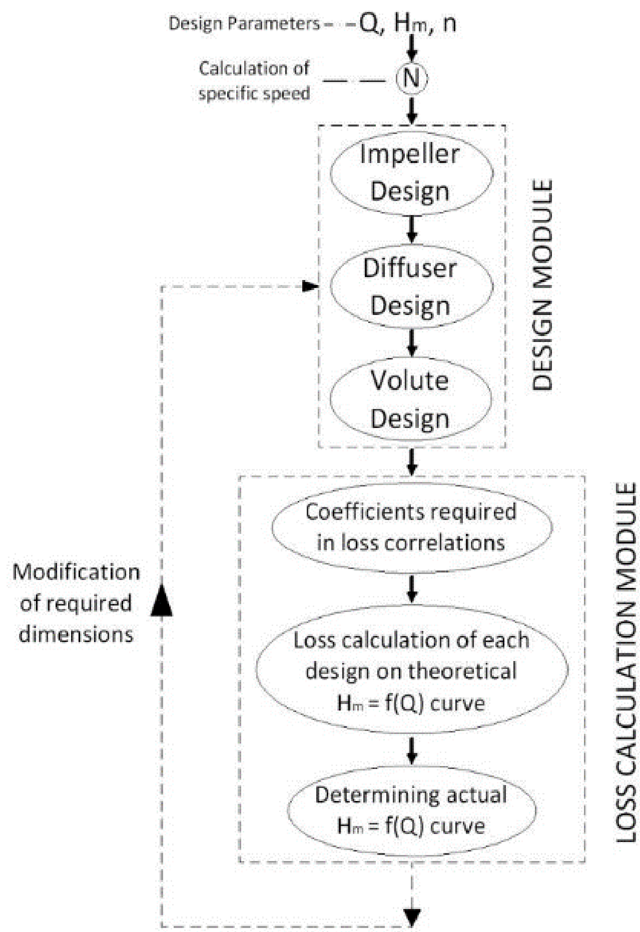
- Introduction
- Pump Theory
  - Design of impeller and volute
  - Loss models
  - Code implementation and CFD analysis
- Results & Discussion
  - Prediction results
  - CFD Results
  - Comparison
- Future Work

Results and Discussion
Loss correlation predictions

The main design parameters

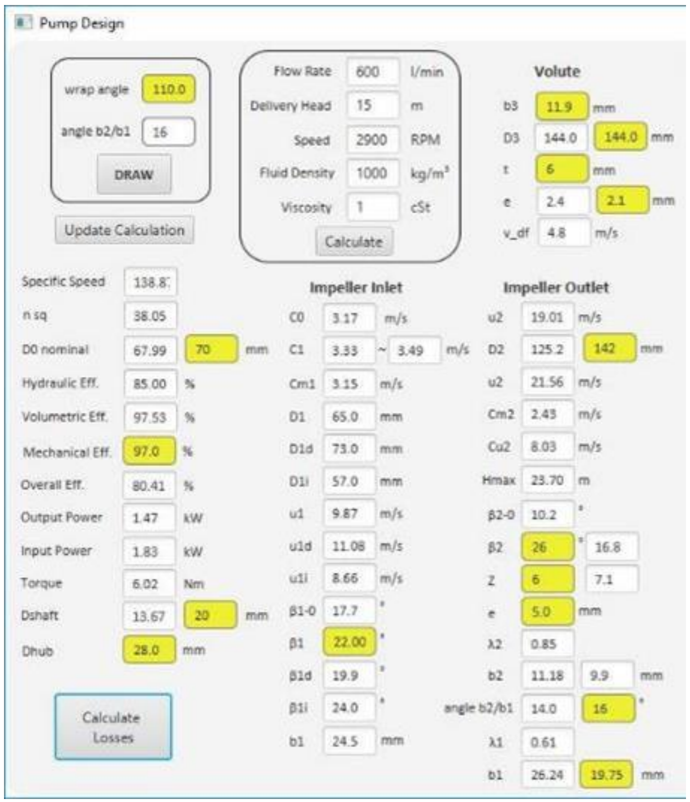
- Flow rate, Q
- Delivery head, H_m
- Rotational speed, n

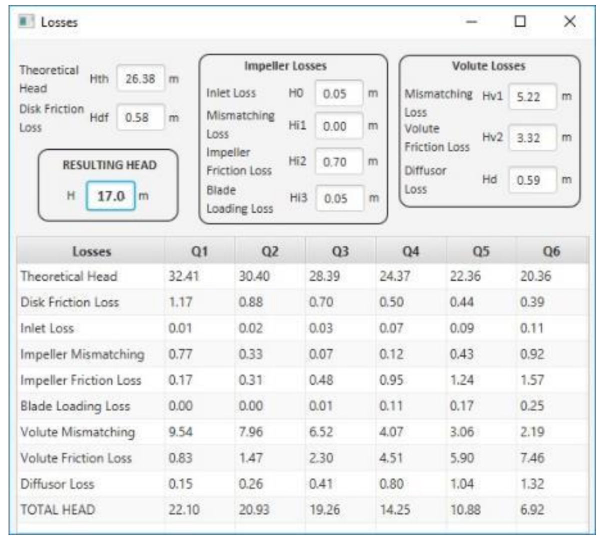
The calculations can be repeated for each design until the desired pump performance is achieved



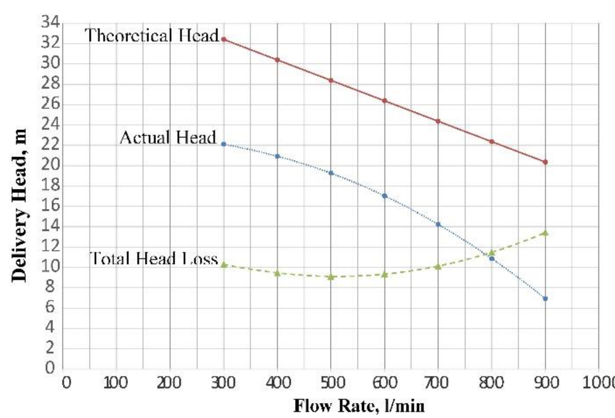
Results and Discussion

Loss correlation predictions – Pump-1





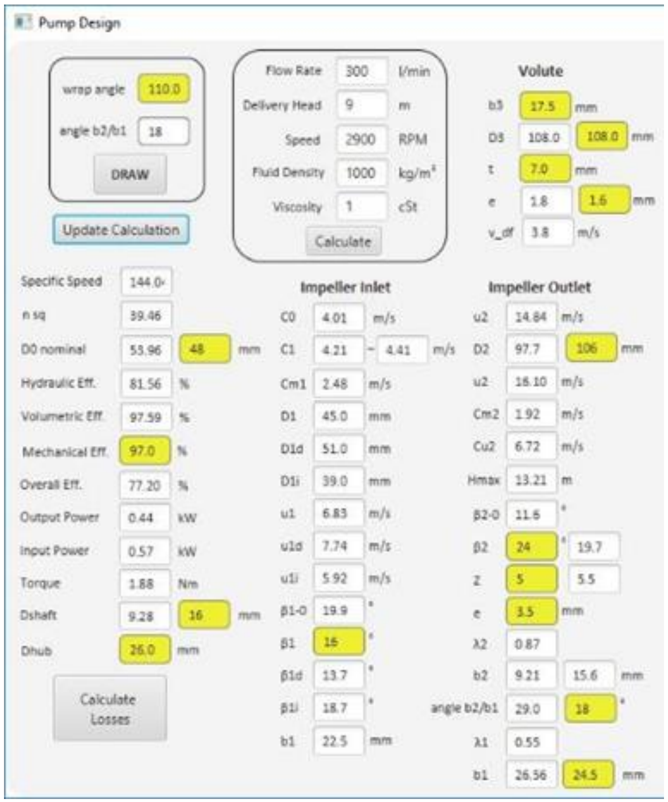
Losses	Q1	Q2	Q3	Q4	Q5	Q6
Theoretical Head	32.41	30.40	28.39	24.37	22.36	20.36
Disk Friction Loss	1.17	0.88	0.70	0.50	0.44	0.39
Inlet Loss	0.01	0.02	0.03	0.07	0.09	0.11
Impeller Mismatching	0.77	0.33	0.07	0.12	0.43	0.92
Impeller Friction Loss	0.17	0.31	0.48	0.95	1.24	1.57
Blade Loading Loss	0.00	0.00	0.01	0.11	0.17	0.25
Volute Mismatching	9.54	7.96	6.52	4.07	3.06	2.19
Volute Friction Loss	0.83	1.47	2.30	4.51	5.90	7.46
Diffusor Loss	0.15	0.26	0.41	0.80	1.04	1.32
TOTAL HEAD	22.10	20.93	19.26	14.25	10.88	6.92



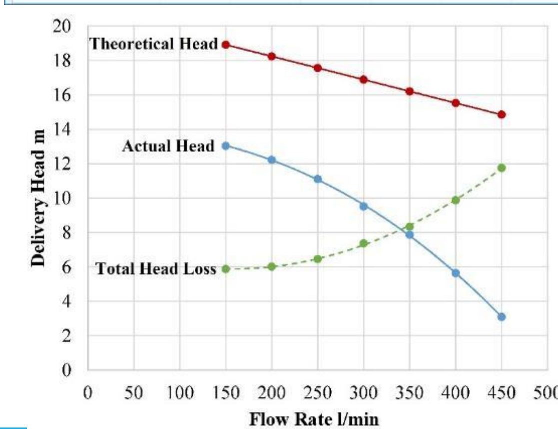
Symbol	Value	Unit
D_1	65	mm
D_2	142	mm
b_1	19.75	mm
b_2	9.9	mm
β_1	22	°
β_2	26	°
z	6	-
e	5	mm
n	2900	rpm
Q	600	l/min

Results and Discussion

Loss correlation predictions – Pump-2



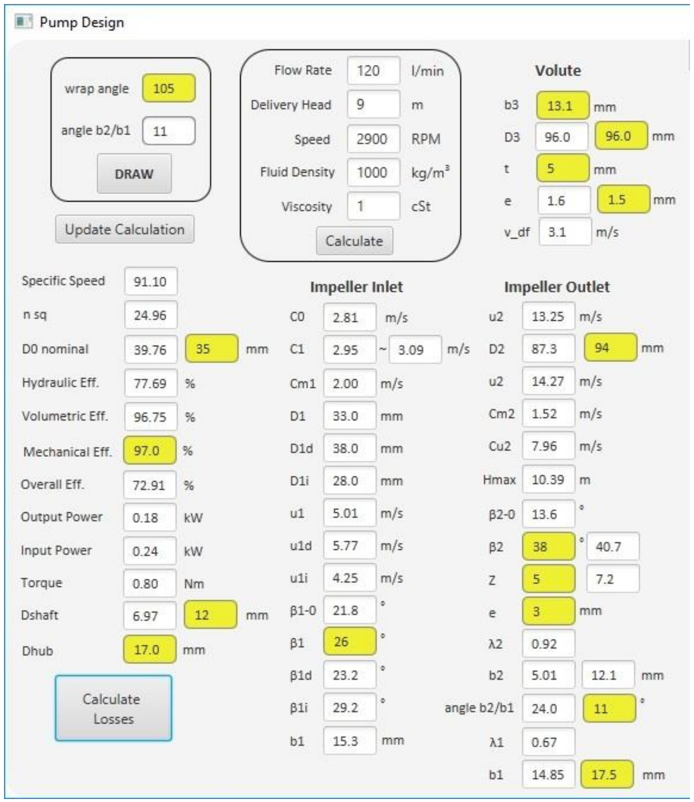
Losses	Q1	Q2	Q3	Q4	Q5	Q6
Theoretical Head	18.92	18.24	17.57	16.21	15.53	14.85
Disk Friction Loss	0.91	0.69	0.55	0.39	0.34	0.30
Inlet Loss	0.02	0.03	0.05	0.11	0.14	0.18
Impeller Mismatching	0.17	0.02	0.02	0.49	0.95	1.57
Impeller Friction Loss	0.12	0.21	0.33	0.65	0.85	1.07
Blade Loading Loss	0.08	0.18	0.28	0.50	0.62	0.75
Volute Mismatching	5.72	5.04	4.41	3.27	2.76	2.30
Volute Friction Loss	0.60	1.06	1.66	3.25	4.24	5.37
Diffusor Loss	0.09	0.17	0.26	0.51	0.66	0.84
TOTAL HEAD	13.04	12.22	11.11	7.84	5.65	3.09

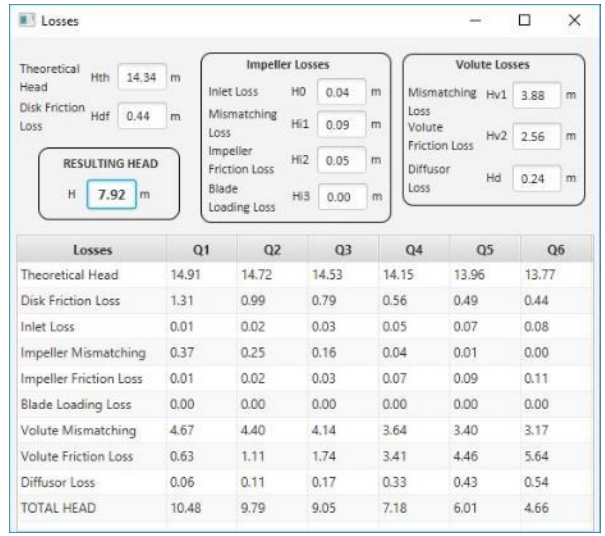


Symbol	Value	Unit
D_1	48	mm
D_2	106	mm
b_1	24.5	mm
b_2	15.6	mm
β_1	16	°
β_2	24	°
z	5	-
e	3.5	mm
n	2900	rpm
Q	300	l/min

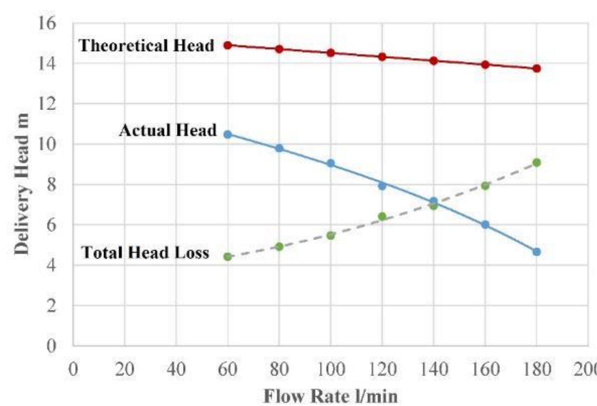
Results and Discussion

Loss correlation predictions – Pump-3





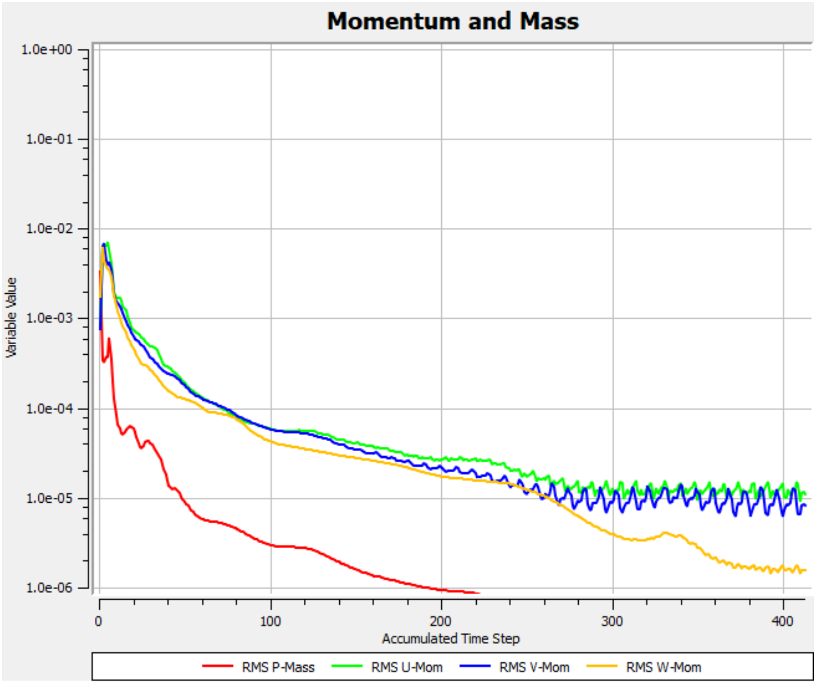
Losses	Q1	Q2	Q3	Q4	Q5	Q6
Theoretical Head	14.91	14.72	14.53	14.15	13.96	13.77
Disk Friction Loss	1.31	0.99	0.79	0.56	0.49	0.44
Inlet Loss	0.01	0.02	0.03	0.05	0.07	0.08
Impeller Mismatching	0.37	0.25	0.16	0.04	0.01	0.00
Impeller Friction Loss	0.01	0.02	0.03	0.07	0.09	0.11
Blade Loading Loss	0.00	0.00	0.00	0.00	0.00	0.00
Volute Mismatching	4.67	4.40	4.14	3.64	3.40	3.17
Volute Friction Loss	0.63	1.11	1.74	3.41	4.46	5.64
Diffusor Loss	0.06	0.11	0.17	0.33	0.43	0.54
TOTAL HEAD	10.48	9.79	9.05	7.18	6.01	4.66

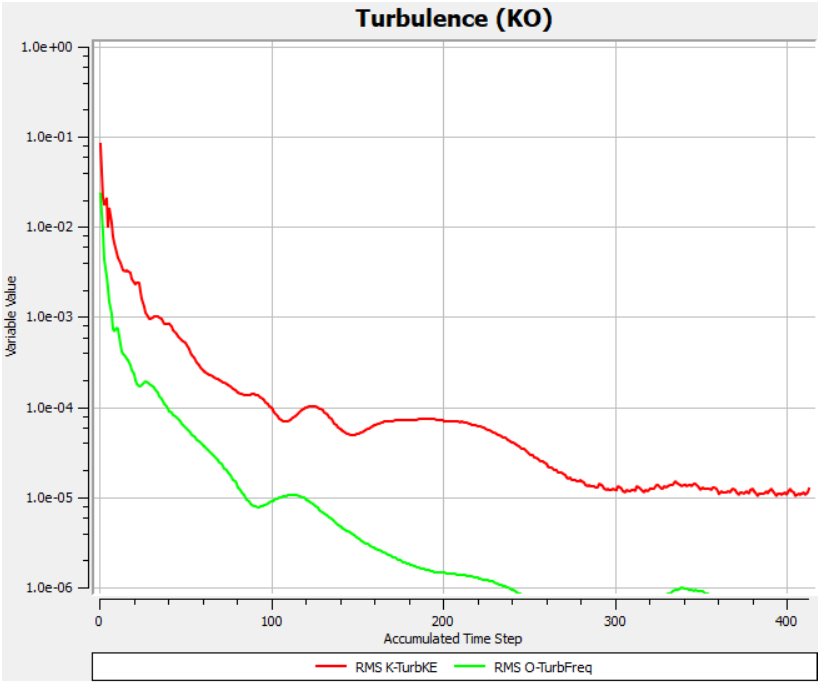


Symbol	Value	Unit
D_1	35	mm
D_2	94	mm
b_1	17. 5	mm
b_2	12.1	mm
β_1	26	°
β_2	38	°
z	5	-
e	3	mm
n	2900	rpm
Q	120	l/min

Results and Discussion
CFD Results

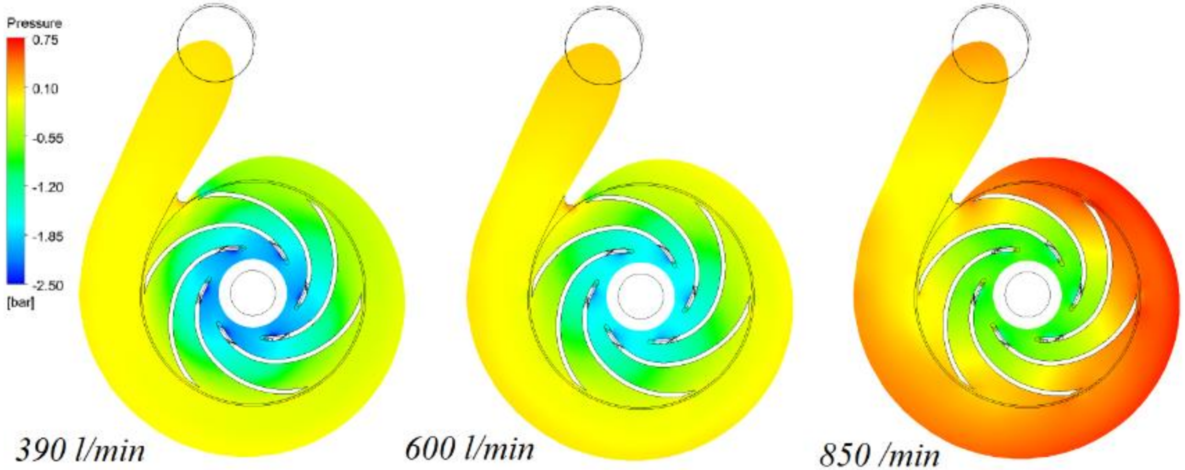
- Approximately 450 iterations were run to reach the convergence criteria of residuals.
- Residual type of RMS (root mean square) is selected.





Results and Discussion

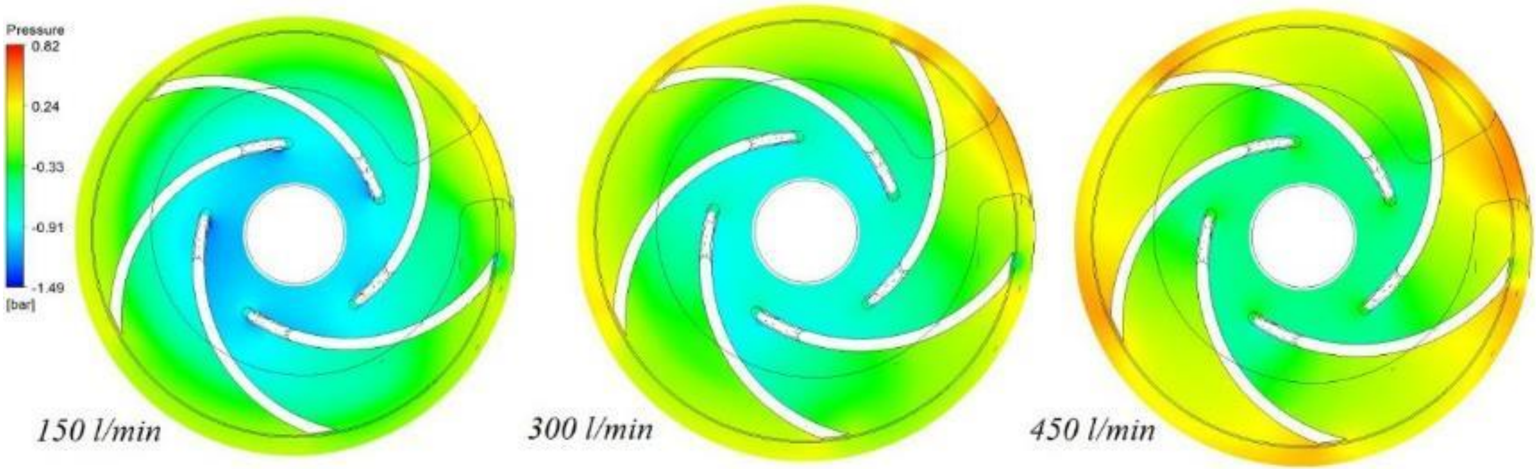
CFD Results – Pump-1



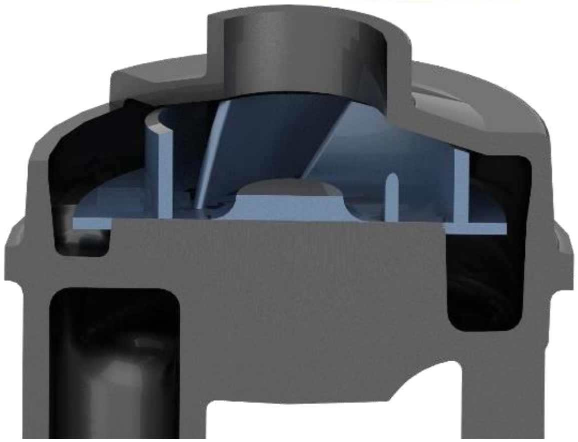
Flow rate (l/min)	ΔP (bar)	H (m)
390	2.03	20.71
600	1.82	18.56
850	1.1	11.22

Results and Discussion

CFD Results – Pump-2

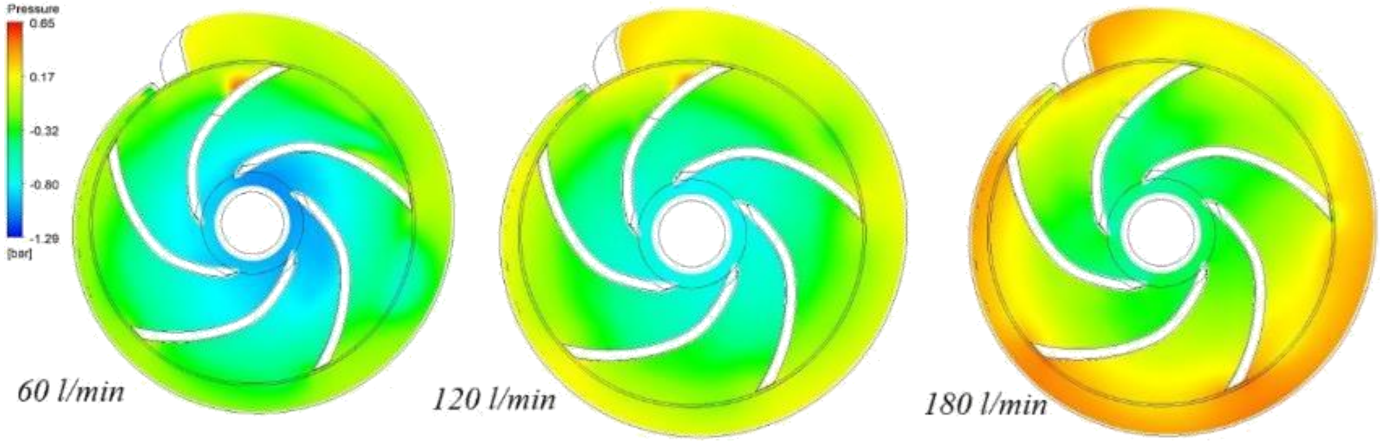


Flow rate (l/min)	ΔP (bar)	H (m)
150	1.03	10.51
300	0.86	8.77
450	0.64	6.53



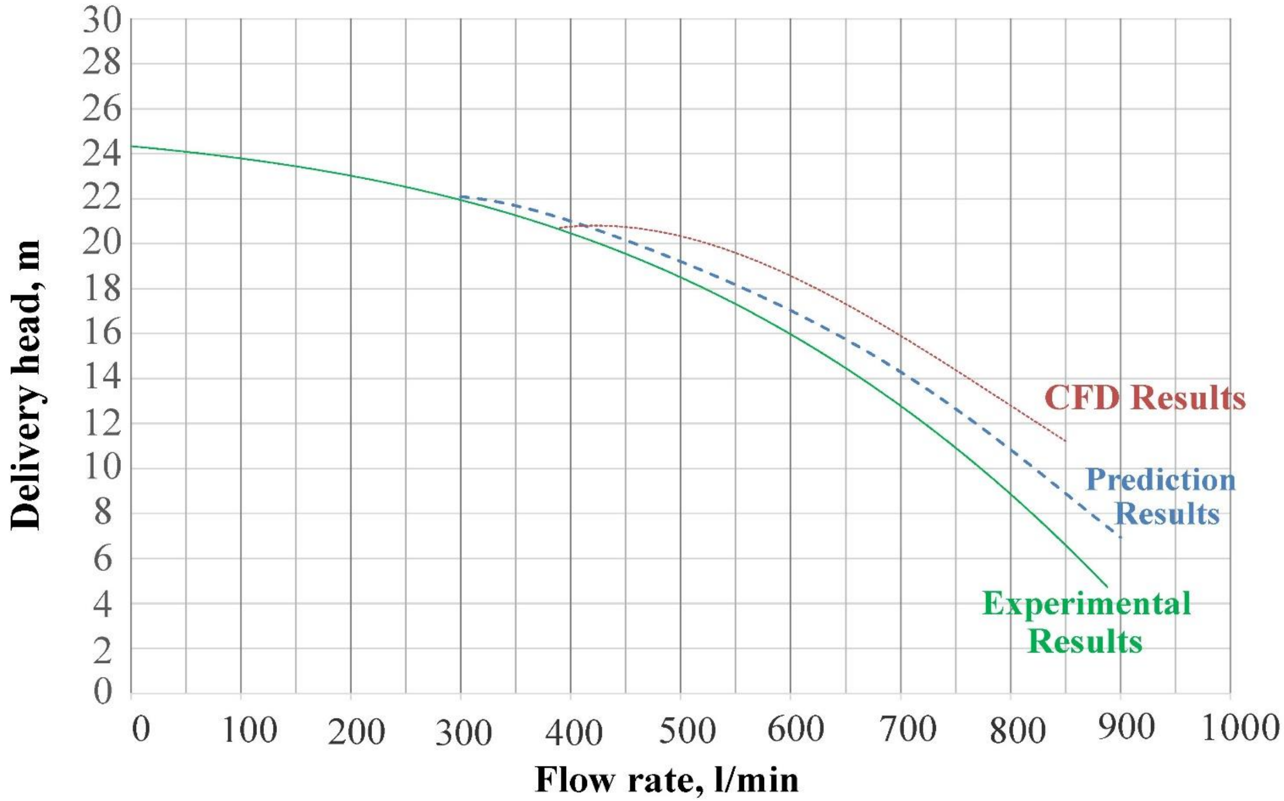
Results and Discussion

CFD Results – Pump-3

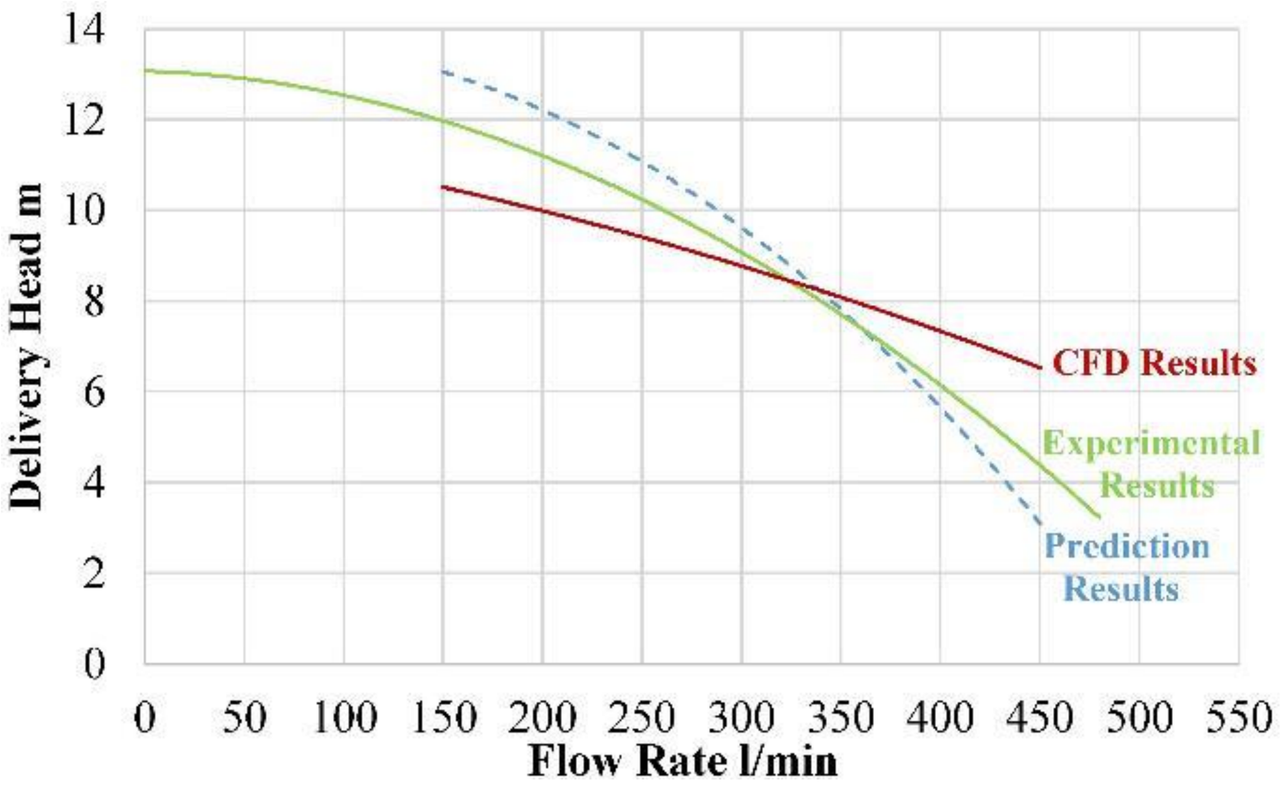


Flow rate (l/min)	ΔP (bar)	H (m)
60	0.96	9.79
120	0.73	7.46
180	0.43	4.39

Results and Discussion
Comparison of Results – Pump-1

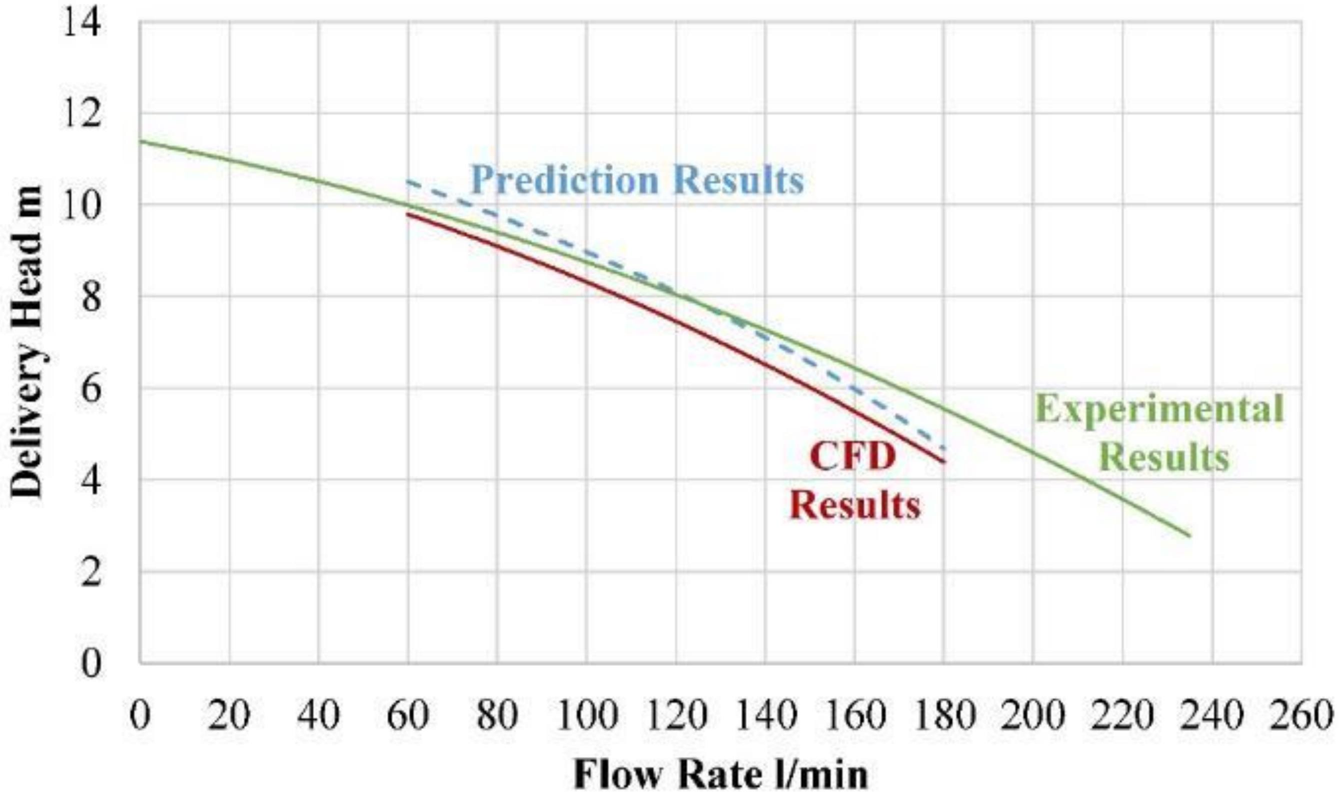


Results and Discussion
Comparison of Results – Pump-2



Results and Discussion

Comparison of Results – Pump-3



Results and Discussion

Comparison of Results

	Q (l/min)	Prediction (m)	Performance (m)	CFD (m)
Pump-1	**390**	21.05	20.9	20.71
	600	17.03	15.85	18.56
	850	8.90	6.51	11.22
Pump-2	**150**	13.04	11.53	10.51
	300	9.52	8.99	8.77
	450	3.09	4.07	6.53
Pump-3	**60**	10.48	9.78	9.79
	120	7.92	7.9	7.46
	180	4.66	5.46	4.39

Results and Discussion
Comparison of Results

- The performance predictions are compared with CFD calculations and experimental measurements of the same pump geometry.
- The performance tool has the advantage of less effort and time spent compare to CFD analysis.
- Predictions showed that the volute design has a significant effect on the pump performance.
- Characteristics of three different pumps using loss correlations are in good agreement with performance curves at BEP and off-design points of the pumps with specific speed range between 40 to 180. Therefore, the developed performance prediction code is highly reliable and consistent.

Results and Discussion
Future Work

There are certain options would be added to the prediction software such as

- ❑ Material Library
- ❑ Trapezoidal section for volute calculations
- ❑ Save project
- ❑ Export blade profile
- ❑ Printing H-Q curve

Thank You for Listening