Analytical Study of Performance of a Centrifugal Pump for Different Operating Conditions

Dadapeer D[1], Veeresh G Gunjalli[2]

Assistant Professor, Mechanical Engineering Department, A.G.M.R College of Engineering and Technology, Varur, Karnataka India[1],

Assistant Professor, Mechanical Engineering Department, K.L.E.I.T, Hubli, Karnataka, India[2],

***Abstract*: - *Centrifugal pumps are used extensively for hydraulic transportation of liquids over short to medium distance through pipelines where the requirements of head and discharge are moderate. From such literature, it was found that most previous research, especially research based on analytical and numerical approaches had focused on the design or near-design state of pumps. Few efforts were made to study the off-design performance of pumps. Therefore, Performance evaluation of turbo machine is essential in order to determine the safe operating zone.*

***Keywords*: - *hydraulic transportation, pipelines.*

I. ***Introduction*: -** The centrifugal pump is the most used pump type in the world. The principle is simple, well-described and thoroughly tested, and the pump is robust, effective and relatively inexpensive to produce. There is a wide range of variations based on the principle of the centrifugal pump and consisting of the same basic hydraulic parts. Principle of the centrifugal pump an increase in the fluid pressure from the pump inlet to its outlet is created when the pump is in operation. This pressure difference drives the fluid through the system or plant. It does so by converting energy of a prime mover (an electric motor or turbine) first into velocity or kinetic energy, and then into pressure energy of a liquid that is being pumped.

II. ***Description of the problem*: -** This work is to evaluate the head flow characteristics of a centrifugal pump. Further the performance of the pump at different rotating speed (design and off design speed) and different mass flow rate i.e. 130 kg/s to 220 kg/s is studied through characteristics curves. The analytical study gives the clear information about stalling of the pump and performance of the pump at different conditions.

III. Specifications of the Designed Pump

Outlet diameter of impeller = D_2 = 50 cm = 0.5 m
Width of the impeller = B_2 = 5 cm = 0.05 m
Outlet blade angle = β_2 = 30°
Total pressure of 101325 Pascal's
Design Mass flow rate: 155 Kg/s
Design Blade rotating speed: 1500 rpm (Anticlockwise direction)
Working fluid = Water at STP condition
Number of blades = 5
Design Delivery head = 130 m

IV. Ideal Velocity Triangles of a Centrifugal Pump

V. For the designed centrifugal pump analytical calculations were done by considering the ideal velocity triangle of centrifugal pump. Fig.1.1 shows the velocity triangles at the inlet and outlet tips of a vane fixed to the impeller. The inlet fluid velocity and inlet blade angle were drawn with respect to the impeller and along with this outlet fluid velocity and outlet blade angle also drawn. With these velocity triangles one can able to predict the performance characteristics of centrifugal pump.

VI. Assumptions

- Radial and tangential direction.
- The impeller passages are completely filled with the flowing fluid at all time (no void spaces)
- The streamlines have a shape similar to the blade's shape
- Incompressible, inviscid, and single phase fluid
- The velocity profile is symmetric

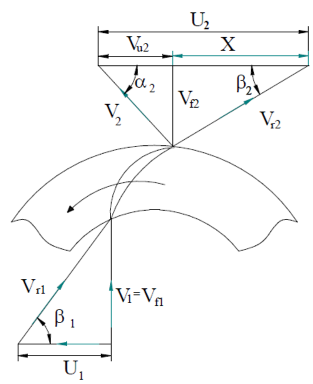


Fig.1.1 Velocity triangles at Inlet and outlet of a centrifugal pump

impeller
D_1 & D_2=Diameter of the impeller at inlet & outlet (m)
N = Speed (rpm)
$U_1 = \pi D_1 N/60$, Tangential velocity of the impeller at inlet (m/s)
$U_2 = \pi D_2 N/60$, Tangential velocity of the impeller at outlet (m/s)
V_1=absolute velocity of the liquid at inlet (m/s)
V_2= absolute velocity of the liquid at outlet (m/s)
V_{f1} & V_{f2} are the velocities of flow at inlet and outlet (m/s) V_{r1} & V_{r2} Relative velocities at inlet and outlet (m/s)
V_{u2} whirl velocity at outlet (m/s)
β_1 = blade angle at inlet
β_2 = blade angle at outlet
H = Head (m)

Sample trial calculation for a design condition at constant speed N = 1500 rpm, mass flow rate m = 155 kg/s (Ref. table 1.2)

Manometric efficiency is assumed based on the mass flow rate, Assuming the manometric efficiency = 95%

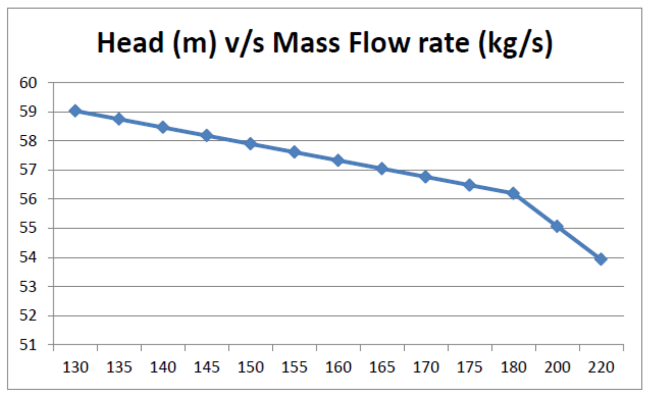
- Discharge, (m^3/s)
  $Q = m/\rho = 155 / 1000 = 0.155\ m^3/s$
- Tangential velocity of the impeller at outlet (m/s)
  $U2 = \pi D_2 N/60 = \pi*0.5*1500/60$
  $= 39.275$ m/s
- Flow velocity at outlet (m/s)
  $Q = 0.155 = \pi * D_2*B_2*V_{f2}$
  $V_{f2} = Q/ \pi * D_2*B_2$
  $= 0.155/ \pi * 0.5*0.05$
  $= 1.973265$ m/s
- $\tan \beta_2 = \tan 30 = 0.57$
  $X = V_{f2}/ \tan \beta_2 = 1.973265 / 0.57 = 3.461869$ m/s
- Whirl velocity at outlet (m/s)
  $V_{u2} = U_2 - X = 39.275 - 3.461869 = 35.81313$ m/s
- Head (m)
  $V_{u2} * U_2 / g = 35.81313*39.275/9.81 = 136.2113$ m

The above calculations were done for design conditions i.e for mass flow rate of 155 kg/s and speed of 1500 rpm from which the theoretical head is getting as 136.2113 m.

Similar calculations were done for different discharges (130 kg/s to 200 kg/s), different speeds (1000 rpm to 2000 rpm) and the results are tabulated as shown in the table 1.1 to table 1.7.

Table 1.1 performance parameters for varying mass flow rates (130 to 200 kg/s) at constant speed 1000 rpm

m kg/s	Q m^3/s	N rpm	U_2 m/s	V_{f2} m/s	tan β_2	X m/s	V_{u2} m/s	H m
130	0.13	1000	26.18333	1.654997	0.57	2.903503	23.27983	59.02817
135	0.135	1000	26.18333	1.718651	0.57	3.015176	23.16816	58.74502
140	0.14	1000	26.18333	1.782304	0.57	3.12685	23.05648	58.46186
145	0.145	1000	26.18333	1.845958	0.57	3.238523	22.94481	58.1787
150	0.15	1000	26.18333	1.909612	0.57	3.350196	22.83314	57.89554
155	0.155	1000	26.18333	1.973265	0.57	3.461869	22.72146	57.61238
160	0.16	1000	26.18333	2.036919	0.57	3.573542	22.60979	57.32923
165	0.165	1000	26.18333	2.100573	0.57	3.685216	22.49812	57.04607
170	0.17	1000	26.18333	2.164227	0.57	3.796889	22.38644	56.76291
175	0.175	1000	26.18333	2.22788	0.57	3.908562	22.27477	56.47975
180	0.18	1000	26.18333	2.291534	0.57	4.020235	22.1631	56.1966
200	0.2	1000	26.18333	2.546149	0.57	4.466928	21.71641	55.06396
220	0.22	1000	26.18333	2.800764	0.57	4.913621	21.26971	53.93133



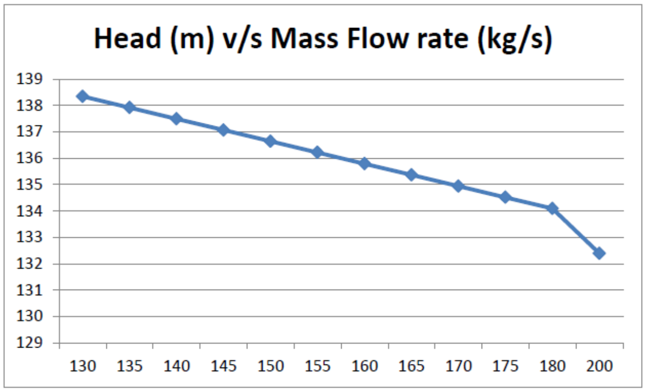
Graph 1.1 Head (m) V/S Mass flow rate (kg/s) at constant speed 1000 rpm

Graph 1.1 shows that as mass flow rate increases for a fixed speed i.e 1000 rpm, head is going to decrease and at some point there is sudden drop in the head i.e at 200 kg/s

Table 1.2 performance parameters for varying mass flow rates (130 to 200 kg/s) at constant speed 1500 rpm

m kg/s	Q m^3/s	N rpm	U_2 m/s	V_{f2} m/s	tan β_2	X m/s	V_{u2} m/s	H m
130	0.13	1500	39.275	1.654997	0.57	2.903503	36.3715	138.335
135	0.135	1500	39.275	1.718651	0.57	3.015176	36.25982	137.9102
140	0.14	1500	39.275	1.782304	0.57	3.12685	36.14815	137.4855
145	0.145	1500	39.275	1.845958	0.57	3.238523	36.03648	137.0608
150	0.15	1500	39.275	1.909612	0.57	3.350196	35.9248	136.636
155	**0.155**	**1500**	**39.275**	**1.973265**	**0.57**	**3.461869**	**35.81313**	**136.2113**
160	0.16	1500	39.275	2.036919	0.57	3.573542	35.70146	135.7865
165	0.165	1500	39.275	2.100573	0.57	3.685216	35.58978	135.3618
170	0.17	1500	39.275	2.164227	0.57	3.796889	35.47811	134.9371
175	0.175	1500	39.275	2.22788	0.57	3.908562	35.36644	134.5123

180	0.18	1500	39.275	2.291534	0.57	4.020235	35.25476	134.0876
200	0.2	1500	39.275	2.546149	0.57	4.466928	34.80807	132.3887

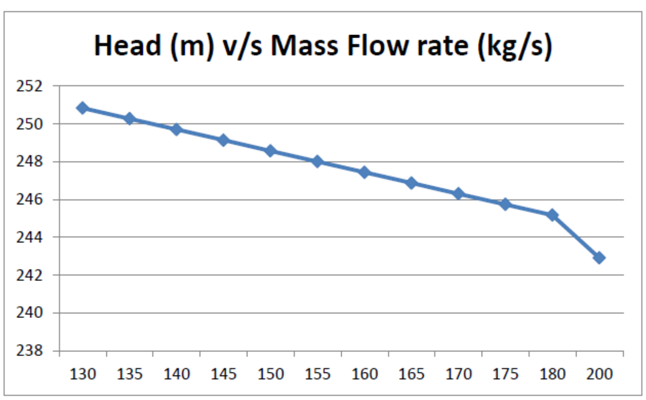


Graph 1.2 Head (m) V/S Mass flow rate (kg/s) at constant speed 1500 rpm

Graph 1.2 shows that as mass flow rate increases for a fixed speed i.e 1500 rpm, head is going to decrease and at some point there is sudden drop in the head i.e at 200 kg/s, this indicates the separation of flow from the impeller blade.

Table 1.3 performance parameters for varying mass flow rates (130 to 200 kg/s) at constant speed 2000 rpm

m kg/s	Q m^3/s	N rpm	U_2 m/s	V_{f2} m/s	tan β_2	X m/s	V_{u2} m/s	H m
130	0.13	2000	52.36667	1.654997	0.57	2.903503	49.46316	250.8369
135	0.135	2000	52.36667	1.718651	0.57	3.015176	49.35149	250.2706
140	0.14	2000	52.36667	1.782304	0.57	3.12685	49.23982	249.7043
145	0.145	2000	52.36667	1.845958	0.57	3.238523	49.12814	249.1379
150	0.15	2000	52.36667	1.909612	0.57	3.350196	49.01647	248.5716
155	0.155	2000	52.36667	1.973265	0.57	3.461869	48.9048	248.0053
160	0.16	2000	52.36667	2.036919	0.57	3.573542	48.79312	247.439
165	0.165	2000	52.36667	2.100573	0.57	3.685216	48.68145	246.8727
170	0.17	2000	52.36667	2.164227	0.57	3.796889	48.56978	246.3064
175	0.175	2000	52.36667	2.22788	0.57	3.908562	48.4581	245.7401
180	0.18	2000	52.36667	2.291534	0.57	4.020235	48.34643	245.1737
200	0.2	2000	52.36667	2.546149	0.57	4.466928	47.89974	242.9085

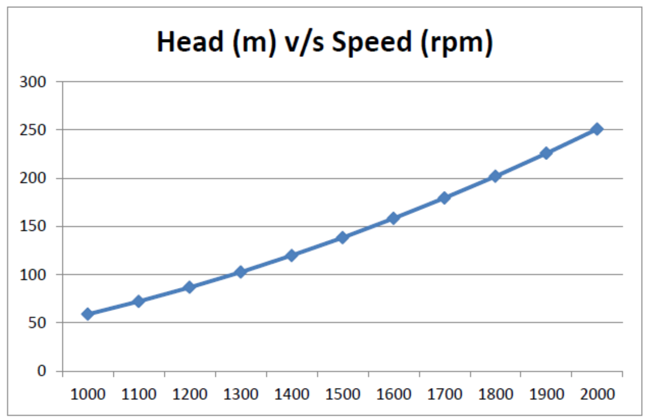


Graph 1.3 Head (m) V/S Mass flow rate (kg/s) at constant speed 2000 rpm

Graph 1.3 shows that as mass flow rate increases for a fixed speed i.e 2000 rpm, head is going to decrease and at some point there is sudden drop in the head i.e at 200 kg/s, this indicates the separation of flow from the impeller blade.

Table 1.4 performance parameters for varying speed (1000 to 2000 rpm) at constant mass flow rate 130 kg/s

N rpm	m kg/s	Q m^3/s	U_2 m/s	V_{f2} m/s	tan β_2	X m/s	V_{u2} m/s	H m
1000	130	0.13	26.18333	1.654997	0.57	2.903503	23.27983	59.02817
1100	130	0.13	28.80167	1.654997	0.57	2.903503	25.89816	72.23392
1200	130	0.13	31.42	1.654997	0.57	2.903503	28.5165	86.76747
1300	130	0.13	34.03833	1.654997	0.57	2.903503	31.13483	102.6288
1400	130	0.13	36.65667	1.654997	0.57	2.903503	33.75316	119.818
1500	130	0.13	39.275	1.654997	0.57	2.903503	36.3715	138.335
1600	130	0.13	41.89333	1.654997	0.57	2.903503	38.98983	158.1797
1700	130	0.13	44.51167	1.654997	0.57	2.903503	41.60816	179.3523
1800	130	0.13	47.13	1.654997	0.57	2.903503	44.2265	201.8527
1900	130	0.13	49.74833	1.654997	0.57	2.903503	46.84483	225.6809
2000	130	0.13	52.36667	1.654997	0.57	2.903503	49.46316	250.8369

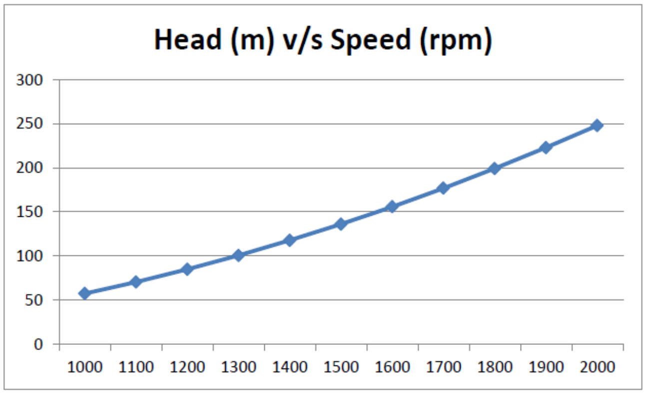


Graph 1.4 Head (m) V/S Speed (rpm) at constant mass flow rate 130 kg/s

Graph 1.4 shows that as speed increases for a fixed mass flow rate, head is going to increase.

Table 1.5 performance parameters for varying speed (1000 to 2000 rpm) at constant mass flow rate 155 kg/s

N rpm	m kg/s	Q m^3/s	U_2 m/s	V_{f2} m/s	tan β_2	X m/s	V_{u2} m/s	H m
1000	155	0.155	26.18333	1.973265	0.57	3.461869	22.72146	57.61238
1100	155	0.155	28.80167	1.973265	0.57	3.461869	25.3398	70.67655
1200	155	0.155	31.42	1.973265	0.57	3.461869	27.95813	85.06853
1300	155	0.155	34.03833	1.973265	0.57	3.461869	30.57646	100.7883
1400	155	0.155	36.65667	1.973265	0.57	3.461869	33.1948	117.8359
1500	155	0.155	39.275	1.973265	0.57	3.461869	35.81313	136.2113
1600	155	0.155	41.89333	1.973265	0.57	3.461869	38.43146	155.9145
1700	155	0.155	44.51167	1.973265	0.57	3.461869	41.0498	176.9455
1800	155	0.155	47.13	1.973265	0.57	3.461869	43.66813	199.3043
1900	155	0.155	49.74833	1.973265	0.57	3.461869	46.28646	222.9909
2000	155	0.155	52.36667	1.973265	0.57	3.461869	48.9048	248.0053

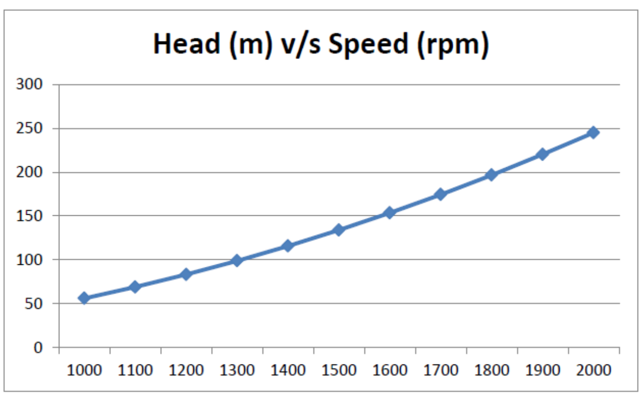


Graph 1.5 Head (m) V/S Speed (rpm) at constant mass flow rate 155 kg/s

Graph 1.4 shows that as speed increases for a fixed mass flow rate, head is going to increase.

Table 1.6 performance parameters for varying speed (1000 to 2000 rpm) at constant mass flow rate 180 kg/s

N rpm	m kg/s	Q m^3/s	U_2 m/s	V_{f2} m/s	tan β_2	X m/s	V_{u2} m/s	H m
1000	180	0.18	26.18333	2.291534	0.57	4.020235	22.1631	56.1966
1100	180	0.18	28.80167	2.291534	0.57	4.020235	24.78143	69.11918
1200	180	0.18	31.42	2.291534	0.57	4.020235	27.39976	83.36958
1300	180	0.18	34.03833	2.291534	0.57	4.020235	30.0181	98.94778
1400	180	0.18	36.65667	2.291534	0.57	4.020235	32.63643	115.8538
1500	180	0.18	39.275	2.291534	0.57	4.020235	35.25476	134.0876
1600	180	0.18	41.89333	2.291534	0.57	4.020235	37.8731	153.6492
1700	180	0.18	44.51167	2.291534	0.57	4.020235	40.49143	174.5386
1800	180	0.18	47.13	2.291534	0.57	4.020235	43.10976	196.7559
1900	180	0.18	49.74833	2.291534	0.57	4.020235	45.7281	220.3009
2000	180	0.18	52.36667	2.291534	0.57	4.020235	48.34643	245.1737

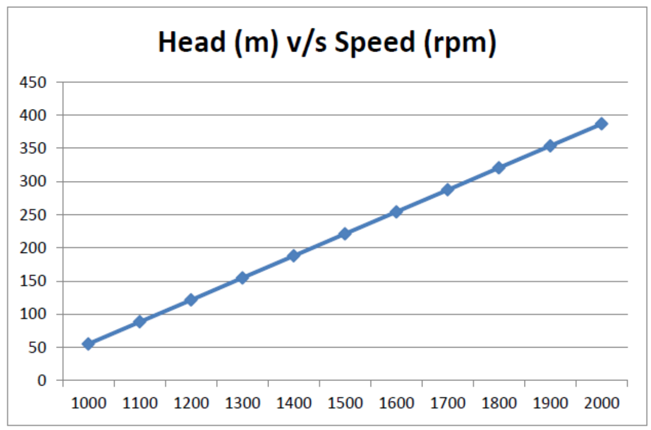


Graph 1.6 Head (m) V/S Speed (rpm) at constant mass flow rate 180 kg/s

Graph 1.6 shows that as speed increases for a fixed mass flow rate, head is going to increase.

Table 1.7 performance parameters for varying speed (1000 to 2000 rpm) at constant mass flow rate 200 kg/s

N rpm	m kg/s	Q m^3/s	U_2 m/s	V_{f2} m/s	tan β_2	X m/s	V_{u2} m/s	H m
1000	200	0.2	26.18333	2.546149	0.57	4.466928	21.71641	55.06396
1100	200	0.2	26.18333	2.546149	0.57	4.466928	34.80807	88.2591
1200	200	0.2	26.18333	2.546149	0.57	4.466928	47.89974	121.4542
1300	200	0.2	26.18333	2.546149	0.57	4.466928	60.99141	154.6494
1400	200	0.2	26.18333	2.546149	0.57	4.466928	74.08307	187.8445
1500	200	0.2	26.18333	2.546149	0.57	4.466928	87.17474	221.0397
1600	200	0.2	26.18333	2.546149	0.57	4.466928	100.2664	254.2348
1700	200	0.2	26.18333	2.546149	0.57	4.466928	113.3581	287.4299
1800	200	0.2	26.18333	2.546149	0.57	4.466928	126.4497	320.6251
1900	200	0.2	26.18333	2.546149	0.57	4.466928	139.5414	353.8202
2000	200	0.2	26.18333	2.546149	0.57	4.466928	152.6331	387.0153



Graph 1.7 Head (m) V/S Speed (rpm) at constant mass flow rate 200 kg/s

Graph 1.7 shows that as speed increases for a fixed mass flow rate, head is going to increase.

Conclusion

Table 1.1 to 1.3 shows the results of centrifugal pump carried by analytical method and it can be observed that as the mass flow rate increases for fixed speed, head also increases.

Form graph 1.1 to 1.3 it can be observed that as mass flow rate increases the head also increases, but at some point there is sudden drop in the head that indicates, there is a flow separation takes place i.e at 200 kg/s so the stalling effect is going to occur at this point.

Table 1.4 to 1.7 shows the results of centrifugal pump at constant mass flow rate and the speed will be varied, from the graph 1.4 to 1.7 it can be observed that as the speed increases blade torque also increases therefore the input power required to run the pump also increases.

Reference

[1] Abdulkadir Aman, Sileshi Kore and Edessa Dribssa* flow simulation and performance prediction of centrifugal pumps using cfd-tool
[2] K M Guleren and A Pinarbasi* Numerical simulation of the stalled flow within a vaned centrifugal pump
[3] R.RAGOTH SINGH1,2 & M.NATARAJ3 parametric study and optimization of centrifugal pump impeller by varying the design parameter using computational fluid dynamics: part i
[4] E.C. Bacharoudis*,1, A.E. Filios2, M.D. Mentzos1 and D.P. Margaris1 Parametric Study of a Centrifugal Pump Impeller by Varying the Outlet Blade Angle
[5] LIU Houlin*, WANG Yong, YUAN Shouqi, TAN Minggao, and WANG Kai Effects of Blade Number on Characteristics of Centrifugal Pumps
[6] SHI Weidong, ZHOU Ling*, LU Weigang, PEI Bing, andLA NG Tao Numerical Predictionand Performance Experiment i n a Deep-well Centrifual Pump with Different ImpelOutlet W idth
[7] K.M. Pandey*, A.P. Singh1 and Sujoy Chakraborty2 Numerical studies on effects of blade number variations on performance of centrifugal pumps at 2500 rpm.
[8] Thord Wennberg1, Anders Sellgren2, Lee Whitlock3 Predicting the performance of centrifugal pumps when handling complex slurries
[9] Khin Cho Thin, Mya Mya Khaing, and Khin Maung Aye Design and Performance Analysis of Centrifugal Pump