# EXPERIMENTAL STUDY ON PERFORMANCE OF CENTRIFUGAL PUMP

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A centrifugal pump is designed to enhance the fluid pressure head through energy transfer. Fluid enters the impeller axially, which increases the fluid velocity and pressure by converting mechanical energy. The present work aims to conduct an experimental performance analysis of a centrifugal pump. The experimental test setup as per ISO 9906 (grade 1) is developed for better accuracy and minimum uncertainty. The experimental analysis is carried out, for the 7.5 hp end suction pump, at various speeds and valve opening positions. After conducting a repeatability test, the performance curves are obtained at various operating conditions. The performance curves identified the best efficiency region by varying valve positions in the interval of 1% in the optimum region. At BEP, the head coefficient ranges from 0.90 to 0.82, the flow coefficient from 0.16 to 0.13, and the pump efficiency from 66 % to 63 %, depending on the pump speed.

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## 1 Introduction

A centrifugal pump is a device that transfers fluids (liquids or gases), or slurries, by dynamic action. There is a conversion of electrical and mechanical energy into fluid energy. The amount of electrical energy used by the pumps in an average industrial facility will vary by plant type. A typical pulp and paper mill will use 30 % of their energy usage to drive pumps. A chemical plant may use 27 % and a petroleum refinery may use 60 %. Over a short time, the cost of the energy to drive the pump will exceed the initial purchasing and installation costs. The reduction in energy consumption and efficiency ($\eta$) enhancement can be achieved by proper design, assembly with auxiliary parts, and regular services of centrifugal pumps. The actual performance of a centrifugal pump can be judge by experimental readings. The precise and accurate readings should build the confidence to accept reading among researchers, manufacturers, and consumers. Also, the precision class (grade 1 category) experiment setup of the centrifugal pump gives better repeatability and the ability to address minor variations in the pump efficiency due to design changes.

The Indian standards, IS 13538 [1], and the international standards, ISO 9906 [2], are described with the precision class of centrifugal pump hydraulic performance acceptance test and followed globally. Also, the American National Standard Institute/Hydraulic Institute (ANSI/HI) 1.6 [3] standards for centrifugal pump test detailed procedures on the setup and conduct of hydrostatic and performance tests are globally accepted by industries. D. F. de Souza et al. [4] discussed guidelines for an energy assessment of water pumping systems in multifamily buildings. The pump with an efficiency of 40% was rated as very low-VL for all motor efficiency classes (IE1 to IE5). Whereas the pump with 60 % efficiency was rated as average and gradually increased to very high-VH as the energy consumption in the pumps decreased and the motors' energy efficiency classes increased. The impeller draws and throws a large scale of fluid during its rotation, and that results in the generation of axial and radial force in the impeller. These may result in imbalance, noise creation, and reduce the life of the centrifugal pump. V. Godbole et al. [5] concluded that the axial thrust reduces the pump efficiency by 3.5 %. The fluid dynamic excitation at the impeller blade passing frequency mainly depends on the radial cavity space between the impeller and the volute tongue [6]. R. Barrio et al. [7] studied fluid-dynamic load induced in a centrifugal pump with a specific volute with four different impellers outer diameter (OD) by progressive trimming of preliminary geometry of impeller. The researcher suggested 5 % to 10 % of the radial gap with respect to the impeller radius for a volute pump. G. Wegener et al. [8] suggested that the effects of hysteresis, reproducibility, surrounding environment properties, etc., should be considered while calculating the uncertainty. Using more accurate instruments, frequently calibrating them, improving the physical conditions for experiments, and enhancing the metrological process are a few recommendations for reducing these effects. S. Lorefice et al. [9] have described the traceability of calibration and uncertainty analysis for volume measurement instruments. D. W. Braudaway et al. [10] claimed that the data acquisition system had an uncertainty associated with it. The reasons for these uncertainties could be the internal resistance of the system, electrical or magnetic interferences, improper calibration, system environment, etc. Hence, a simple method to account for these uncertainties was described by the authors [10].

The objective of the present work is to carry out experiments on a centrifugal pump with ISO 9906 (grade 1) standard setup and analyze the obtained performance curves based on experimental readings. The developed test setup is used for measuring the flow rate (Q), net head (H), torque (T), speed (N), and net positive suction head (NPSHr) of the centrifugal pump. The outline of this paper is as follows. At first, the experimental set-up and instrumentation are described, followed by results and discussion based on the obtained performance curves of the selected centrifugal pump.

## 2 Experimental setup and instrumentation

The grade one accuracy experimental test setup of measuring capacity up to 15hp power input, 100 $m^3/hr$ of flow, and 50 meters of the head with net positive suction head measurement is developed at the institute laboratory as shown in Figure 1. The selection of instruments, preparation of layout, and structure are as per standard [2].

The selection of design inputs of centrifugal pump data is decided based on a survey of the most widely used pumps for different applications. As a result, the 38-meter head, 50 $m^3/hr$ flow rate, and 2980 rpm speed pump design data (7.5 hp) are chosen.


**Figure 1: Centrifugal pump test setup.**
Source: own, RGD lab, Department of Mechanical Engineering, S.V.N.I.T.- Surat.

**Table 1: Design parameters of centrifugal pump**

| Parameter | Value |
|---|---|
| Impeller suction eye diameter, $D_1$ (mm) | 80 |
| Impeller outlet diameter, $D_2$ (mm) | 172 |
| Impeller outlet width, $b_2$ (mm) | 19 |
| Impeller blade inlet angle, $\beta_1$ (°) | 24 |
| Impeller blade outlet angle, $\beta_2$ (°) | 36 |
| Impeller blade wrap angle, $\varphi$ (°) | 127 |
| Impeller blade number, Z (nos.) | 6 |
| Impeller blade thickness, $\delta$ (mm) | 4 |
| Volute base diameter, $D_3$ (mm) | 189 |
| Volute inlet width, $b_3$ (mm) | 24 |
| Volute tongue angle, $\varphi_o$ (°) | 24 |
| Volute outlet diameter, $D_d$ (mm) | 65 |

Source: own

A radial flow single-stage impeller pump is the best suited for this range. One-dimensional design methodology is used for the initial selection of design data. The impeller and volute of the centrifugal pump are designed based on meridional plane velocity and constant velocity methods, respectively. The main geometric parameters of the impeller and volute are shown in Table 1. The geometrical model of the single-stage radial flow centrifugal pump follows ISO 2858:1975 [11].

The developed test setup is used for measuring the flow rate, net head, torque, speed, and NPSHr of the centrifugal pump. As per the literature, a centrifugal pump test setup having instruments of a high degree of accuracy with a control and data acquisition system would lead to minimum uncertainty in the results. The test setup is equipped with a variable frequency drive (VFD), Programmable Logic Controller (PLC) supported by SCADA software for automatic control, and a Data Acquisition system (DAQ) with RS 485 interface for data logging. A computer system will be connected for data storage and result plot of centrifugal pump performance. ABB makes an induction electric motor of 22 kW of capacity with 2900 rpm which is used for pump shaft prime mover. FUJI makes 30 hp capacity of variable frequency drive (VFD), which is used for maintaining constant speed or centrifugal pump. The speed of the test pump can be varied using PLC, which takes corrective action through proportional-integral (PI) control and generates a proportional 4-20 mA current signal as command output. Onyx makes metal bellow coupling which is used to transmit torque from drive end to driven end. The bellow coupling with zero-backlash and tight design tolerance allows transmitting torque with zero slip. The coupling can allow radial, axial, and angular misalignments up to 200 microns, 500 microns, and 1.5 degree, respectively. Test bed frame is made from c section channel and fitted on a concrete structure with the help of a U-shaped foundation bolt. Accurate taping hole is provided on the test frame for inline assembly of the pump, torque transducer, and electric motor. Honeywell VBA type flanged mounted tow-way ball valves are used for modulating control of flowing fluid in suction and discharge pipelines. They are regulated by 0-10 mV analog signals through a programmable logic controller (PLC). The modulating control is used for the percentage-wise opening and closing of the valve. The frictional loss of a flowing fluid is proportional to the flow area. As a result, one commercial size larger is chosen for suction and discharge lines, i.e., 6-inch and 4-inch, resulting in lower frictional losses. The effective lengths of the suction and discharge pipes are 12 and 18 meters, respectively. A Hollow mesh structure type pipe is used for the discharge flow line in the sump, affecting in reducing the swirl effect of water flow and minimizing water recirculation in the sump. The pumping fluid is contained in RCC made sump size of 8×4×3 cube meter and separated by a thin separation wall for suction and discharge fluid. The distance between the suction pipe and the discharge pipe submerged in two tanks is 5 meters to minimize fluid flow disturbances passing from the discharge to the suction tank. PLC will centrally control the centrifugal pump testing. User interference for the operation and control of the pump test is provided by SCADA software installed on a computer.

The Adept MagFlow 6410 type electromagnetic flowmeter with a measuring range of 0.2 m/s to 12 m/s is installed through a flanged end connection joint in the discharge line. It has an output signal of 4 mA to 20 mA with a response time of less than 100 mSec, and accuracy is ± 0.3 % of the measuring value. The upstream and downstream distance from the flowmeter is kept at ten times and fifteen times of internal pipe diameter for the stability of fluid flow in the horizontally mounted piping system. The FKP and FKH type vacuum and pressure transducers, manufactured by Fuji, are installed at the suction and discharge flow lines, respectively, and have a span range of -1 bar to 1.3 bar and 0.3125 bar to 5 bar. The transducers have low response time, high accuracy ±0.1 % for FKP, and ±0.2 % for FKH for all calibrated span, stability, and performance over the operating range of pressure and temperature. The span is adjusted with calibration of the output signal in 4-20 mA. the Magtrol makes TMB 310; an inline torque transducer worked on the strain gauge principle is used. It measured the torque by non-contact differential transformer torque measuring technology. It has an accuracy of < ±0.1 % and less response time. This instrument has (0 to 50 N. m) measuring span for torque, and rpm is up to 4000. The integrated electronic circuit, supplied by a single DC voltage (VDC), provides torque and speed signals without any additional amplifier. The conditioning electronic circuit incorporated in the transducer converts the voltage to a nominal torque signal of 0 to ± 5 VDC and sends it to PLC as an analogue input signal. The level transmitter and RTD are mounted on the sump. The contact type capacitance level transmitter is used for sump water height level measurement during the testing of the pump. It has an accuracy of ± 0.5 % of full scale with 5 mm of resolution.

A single stage 7.5 hp centrifugal pump is designed, developed, and tested with an experiment test rig. The methodology to carry out performance test of centrifugal pump is represented by flow chart as shown in Figure 2. By throttling the discharge valve of the pump discharge line, the volumetric flow rate can be controlled. A fully open valve has maximum flow, whereas a reduction in flow is achieved with a partially closed valve. Whereas speed variation is done with VFD.

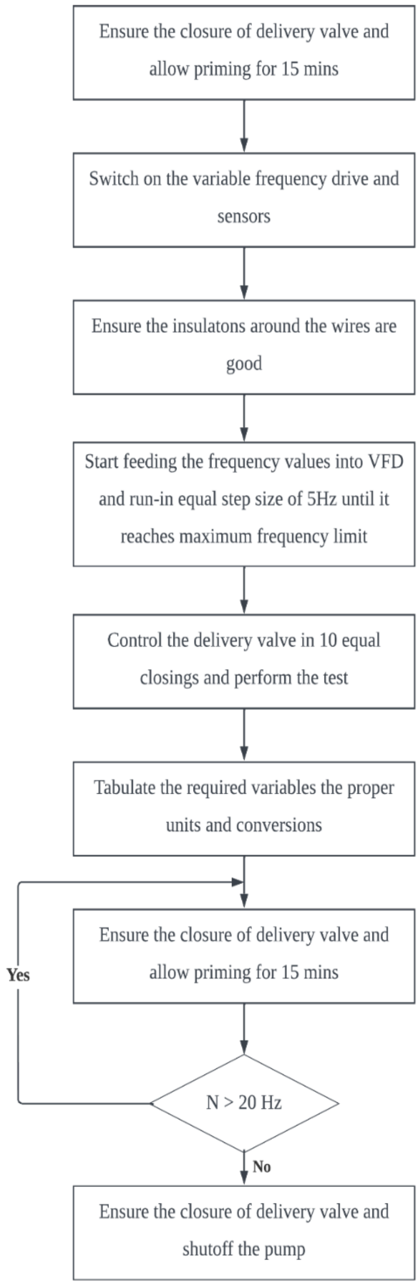


**Figure 2: Testing methodology for experimental analysis of centrifugal pump.**
Source: own

## 3 Results and discussion

For experiment analysis developed grade 1 pump setup is used. Initially, the experiment is carried out at a rated speed of the pump for a minimum to maximum mass flow rate conditions, i.e., shutoff to full open condition of discharge valve. After satisfactory results and analysis, the same procedure is applied for the other speed range, i.e., from 45 Hz to 25 Hz in the interval of 5 Hz. The repeatability of the experimental setup is also checked. The non-dimensional performance curves are plotted based on obtained readings at different speed for different mass flowrate.

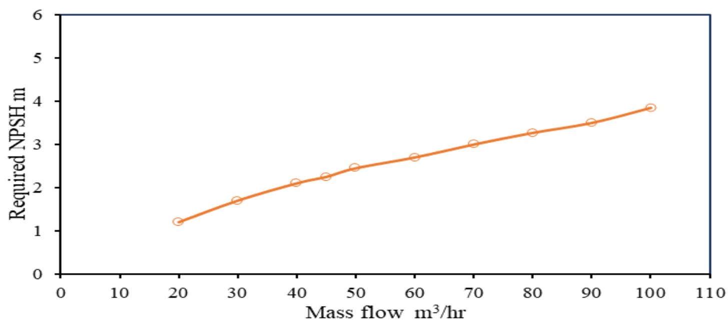


**Figure 3: NPSH curve for 50 HZ speed.**
Source: own

First, the NPSHr test is performed to determine whether cavitation is possible. The testing method of the 3 % drop in the head is followed to measure the NPSH-R for the tested centrifugal pump. Figure 3 depicts the NPSHr test results for 50 Hz speed. NPSHr tests have been performed for the flow of 20 $m^3$/hr to 100 $m^3$/hr. By maintaining these flow rates at a constant level, the suction valve is throttled till there is a pressure head drop of 3 %. The NPSHr is recorded as 2.25 m, 2.70 m, and 3.50 m for the flow rate of 45 $m^3$/hr, 59 $m^3$/hr, and 92 $m^3$/hr, respectively. Comparatively, both the values are below the NPSH available, and this pump is less prone to cavitation. Friction loss calculation suggests the effective total head loss at maximum flow, duty point flow, and lowest possible flow are 2.80 m, 1.11 m, and 0.16 m, respectively for the present test setup. The overall uncertainty in measured pump efficiency is ± 0.63 %, ±0.72 %, and ±1.54% for duty flow, highest flow, and lowest flow measuring data, respectively. Whereas; relative uncertainty in efficiency is in the range of ±0.010 % (Duty point), which is quite lower. The lower value of absolute and relative uncertainties in the measurement of efficiency, torque, flow, and total head parameters will satisfy the requirements of the grade 1 setup as per standards.

The performance characteristics curves are plotted in a non-dimensional form as shown in Figure 4 and Figure 5. The variations of head coefficient (ψ) for different speeds ranging from 50 Hz to 25 Hz are plotted for different flow coefficients (ϕ) as shown in Figure 4. The obtained nature of ψ – ϕ curves agreed well with the theoretical performance curve. One can observe the maximum head coefficient at (discharge valve) shut-off conditions, which decreases with the opening of a discharge valve, i.e., an increase in flow coefficient. Figure 4 also reveals that for a constant value of flow coefficient, the head coefficient increases as we increase the speed of the pump by varying frequency from 25 Hz to 50 Hz up to the 0.225 flow coefficient. For flow coefficient values greater than 0.225, head coefficients are high at the low speed of the pump. This is due to the significant fluid frictional losses within the pump at high speed and higher mass flow rate due to unaccounted secondary eddies and turbulence. The operational range of the current pump is anticipated up to the flow coefficient value of 0.225.

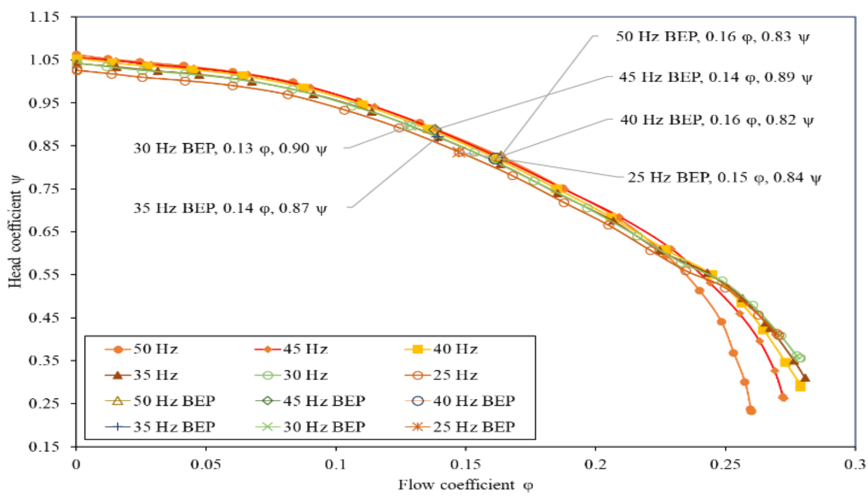


**Figure 4: Variations in head coefficient for different flow coefficient.**

Source: own

Figure 5 represents the graph of pump efficiency (η) vs. flow coefficient (ϕ) for the full range of experiments. It also reveals good agreement with the available theory of the centrifugal pump performance curve. The best efficiency points (BEP) are identified at various speeds of the pump based on the highest efficiency of a curve, and the value of the flow coefficient as well as the head coefficient is calculated at this point. Table 2 reveals the details of ψ, ϕ, and η at BEP for different speeds of the centrifugal pump. The head coefficient at BEP varies from 0.90 to 0.82, and the flow coefficient from 0.13 to 0.16. The greatest efficiency is obtained at 50 Hz and declines progressively with decreasing speed. Pump efficiency at the BEP ranges from roughly 66 % to 63 %, depending on pump operating speed.

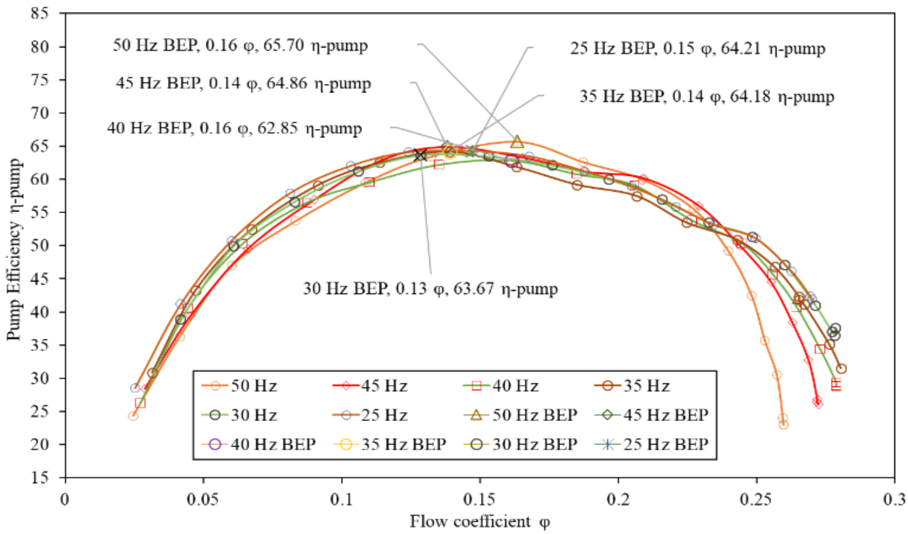


**Figure 5: Variations in efficiency for different flow coefficient**

Source: own

**Table 2: Experimental head coefficient, flow coefficient, and pump efficiency at BEP**

| Speed, Hz | Head coefficient, ψ | Flow coefficient, ϕ | Pump efficiency, % |
|---|---|---|---|
| 50 | 0.83 | 0.16 | 65.70 |
| 45 | 0.89 | 0.14 | 64.86 |
| 40 | 0.82 | 0.16 | 62.85 |
| 35 | 0.87 | 0.14 | 64.18 |
| 30 | 0.90 | 0.13 | 63.67 |
| 25 | 0.84 | 0.15 | 64.21 |

Source: own

## 4 Conclusions

In this work, the experimental analysis of a single-stage centrifugal pump with a power input capacity of 7.5 horsepower, a head of 38 meters, a flow rate of 50 cubic meters per hour, and a speed of 2980 rpm is carried out. The following conclusions are derived from the results.

1. The ISO 9906 grade 1 established centrifugal pump test configuration yields uncertainty observed values within allowable limits of ± 2.9%.
2. For the chosen centrifugal pump, the experimental BEP head coefficient, flow coefficient, and efficiency range from 0.82 to 0.90, 0.13 to 0.16, and 66% to 63%, respectively.

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