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Characteristics of Series and Parallel Centrifugal Pumps

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Abstract: A pump is a device used to lift fluids from a lower surface to a higher surface and to move fluids from low pressure to higher pressure. One such device is a centrifugal pump, a dynamic pressure pump widely used to move fluids with high head. The fluids that can be moved are incompressible fluids. In specific applications, pumps can be used to move substances like this centrifugal pump, this is done so that we can use the tool.

Keyword: Centrifugal Pumps, Pump Performance Testing, Laboratory Test Equipment, Fluid Mechanics, Pump Efficiency.

INTRODUCTION

Centrifugal pumps are one of the most widely used pump types in various industrial sectors, such as water treatment, power generation, refrigeration systems, and chemical processing. These pumps operate by relying on the centrifugal force generated by the impeller to move fluid through pipes.(Oyewola et al., 2021)Centrifugal pump performance is greatly influenced by several factors, such as impeller design, rotational speed, pressure, and power consumption. Therefore, to ensure the pump is operating optimally and according to specifications, accurate performance testing is required.(Gevorkov & Dominguez-García, 2023).

On an industrial scale, centrifugal pump testing is performed using sophisticated equipment and facilities. However, for educational, research, and development purposes, simpler and more affordable test equipment that can be applied in the laboratory is required.(Semenzin et al., 2020)Laboratory-scale centrifugal pump test equipment is essential for assessing pump performance by measuring technical parameters such as flow, pressure, head, and efficiency, under more controlled operational conditions and can be tailored to the testing needs.(Mousmoulis et al., 2017).

The creation of this laboratory-scale centrifugal pump tester aims to provide solutions for education and research in the field of mechanical engineering, especially in understanding the basic principles of fluid mechanics and pump performance testing.(Jia et al., 2022).

Figure 1. Centrifugal Pump

This test equipment allows students and researchers to conduct hands-on experiments to analyze the relationships between technical variables and evaluate pump efficiency and reliability under various operating conditions. It can also be used to test new pump designs on a smaller scale before industrial implementation.

A centrifugal pump is a non-positive displacement pump that operates on the principle of centrifugal force. Fluid enters through the suction nozzle and enters the impeller at an initial pressure close to atmospheric pressure. The rotation of the impeller generates centrifugal force, accelerating the fluid and directing it along the impeller blades toward the outside. The fluid then enters the volute, where its velocity is reduced and converted into pressure energy. This process causes the fluid pressure to increase before finally exiting through the discharge nozzle into the piping system. This mechanism enables centrifugal pumps to continuously flow fluid.(Repsa & Kronbergs, 2021).

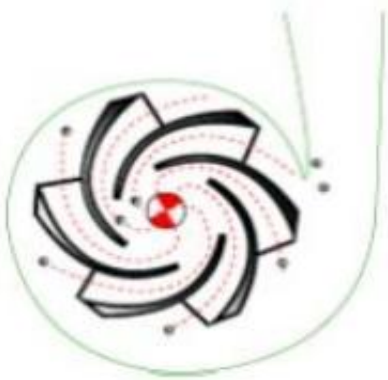

Figure 2. Working Principle of Centrifugal Pump

Centrifugal Pump Components

In general, the main parts of a centrifugal pump are divided into several parts as follows:

Moving components

Shaft

This component functions to transmit the rotating moment from the drive while the pump is operating, this component can also act as a mount for the impeller and other moving parts.

Impeller

This component functions to convert mechanical energy from the pump into velocity energy in fluids that are pumped continuously (continuously). This process will result in the suction channel working effectively. maximum and continuous so that there is no fluid vacuum in the house pump.

Shaft Sleeve

This component functions to protect the shaft from erosion, corrosion and wear.stuffing box. This component can be used as an internal bearing,leakage jointAnddistance sleever.

Wearing Ring

This component is installed on the casing (wearing ring casing) and impeller (wearing ring impeller). The main function of this component is to minimize leaks due to gaps between the casing and impeller.casingwith impeller.

Non-moving components

Casing (pump housing)

This component is the outermost part of the pump which functions as protective elements inside, diffuser housing, inlet nozzle, outletnozzleand as a flow director from the impeller convert velocity energy into pressure energy.

Base Plate

This component functions as a place to seat all pump components.

Diffuser

This component is attached to the pipe using bolts. This component serves to direct the flow to the next stage and change kinetic energy in the fluid becomes pressure energy.

Wearing Ring Casing

This component is attached to the casing to prevent leaks from occurring. due to a gap incasingAndimpeller.

Stuffing Box

This component functions for several positionsmechanical packingthat surroundsshaft sleeveThis component can also prevent leakage occurs in the area where the pump penetratescasing, like air that can enter the pump and liquid that comes out of the pump.

Discharge Nozzle

This component functions as a place for pressurized fluid to exit from in the pump.

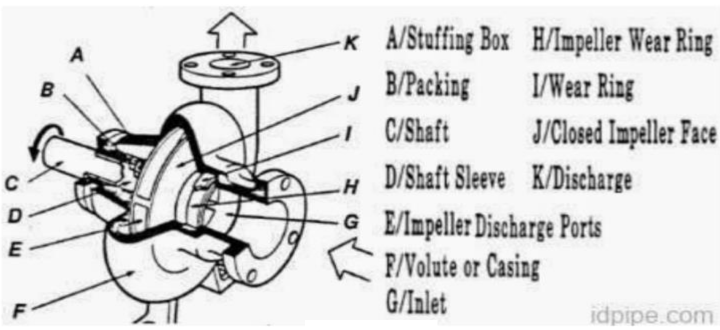

Figure 3. Centrifugal Pump Components

METHOD

This research uses a design and development approach to design, build, and test a laboratory-scale centrifugal pump tester. This approach was taken to ensure that the developed tool meets standards for providing students with an understanding of the characteristics and performance of centrifugal pumps.

The initial stage of the research involved identifying problems in centrifugal pump testing and determining the need for test equipment capable of accurately measuring performance parameters such as flow rate, pressure, and efficiency. Next, a literature review was conducted on centrifugal pump operating principles and the development of existing test equipment to identify deficiencies and opportunities for development.

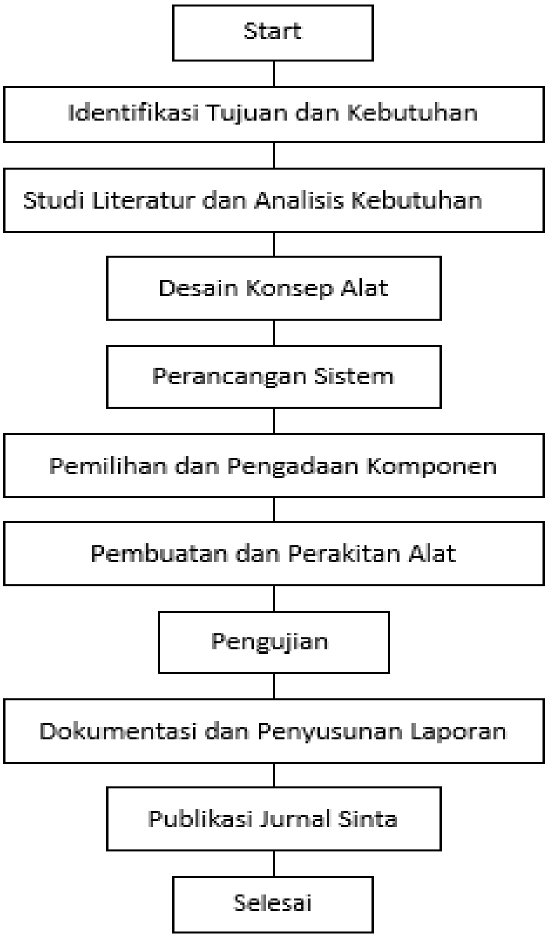

Figure 4. Research Flow Chart

The next stage is the test equipment design process, which involves determining technical specifications, selecting materials, and creating a three-dimensional model using CAD software. This is followed by manufacturing planning, which includes component procurement and assembly of measurement systems, such as flow meters and pressure gauges. The process continues with fabrication and assembly of the test equipment according to the planned design.

The completed instrument was then tested using a centrifugal pump to ensure its performance met the expected specifications. Furthermore, the instrument was calibrated to obtain accurate measurements. The final stage of the research was the analysis of the test results to evaluate the instrument's performance. Based on this evaluation, improvements or modifications were made to enhance the instrument's accuracy and functionality.

RESULT AND DISCUSSION

Based on the centrifugal pump characteristics practicum that has been conducted, data was obtained in the form of water volume, flow time, inlet pressure (Hs), and outlet pressure (Hd) at various valve opening variations. This data is used to calculate the flow rate (Q), total head (H), and other performance parameters such as water power (WHP), pump power (SHP), and pump efficiency.(P, Djoko Yudisworo W, Prihastuty E. 2022).

Figure 5. Centrifugal Pump Series Based on Characteristics

The calculation results show that in a single pump, the relationship between flow rate (Q) and head (H) is inversely proportional, where increasing flow rate causes a decrease in head. This is in accordance with the basic characteristics of centrifugal pumps, which show that the pump's ability to generate pressure will decrease as the fluid flow rate increases.

Characteristics Based on Centrifugal Pump Series.

Series Pumps

Pumps installed in series aim to increase pressure in a pipe network. For a series pump configuration, the datum head correction will be based on the distance between the pump outlet and the datum.

Figure 6. Series Circuit

A series pump configuration results in a significant increase in total head compared to a single pump, while the flow rate remains relatively unchanged. This occurs because the pressure from each pump is added together, resulting in a higher head. Therefore, a series configuration is more suitable for systems requiring high pressure.

Parallel Pump

A pump installed in parallel aims to increase the capacity/water discharge and to save electricity by regulating the pump on/off according to the required water discharge.(Rahman et al., 2023). For parallel pump configurations, the datum head correction will be seen from the distance of the outlet on the manifold and the pump inlet to the datum.

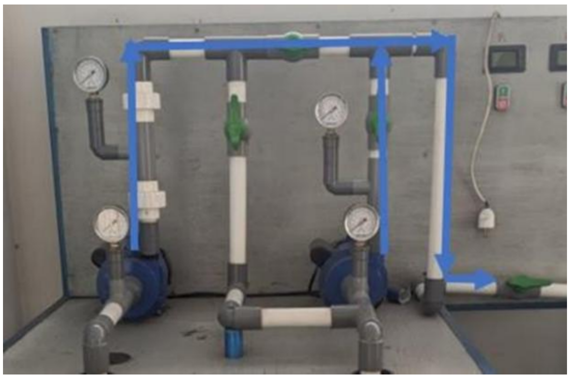

Figure 7. Parallel Circuit

In contrast, in a parallel pump configuration, the flow rate increases significantly, while the resulting head is relatively the same as a single pump. This is because the fluid flow is divided among the individual pumps and then recombined, thereby increasing the flow capacity.(Septiani et al., 2023)This configuration is more effective when used in systems that require large discharges.

Performance Characteristics of the Pump

The performance of a pump is usually a reflection of: Head, efficiency and Bare Horse Power (BHP) as a function of capacity.(Ansori & Widodo, 2018) And this description will be in the form of a table or graph. The actual characteristics of a pump installation cannot be obtained from theory but from direct observation and measurement of the pump.

Cavitation

Cavitation is the phenomenon of evaporation or the formation of bubbles in a flowing liquid due to a pressure difference that reduces it to below its saturated vapor pressure. If the pressure is low enough, the liquid will form bubbles even at room temperature. Cavitation typically occurs on the suction side; if cavitation occurs, the pump's suction power will be reduced.(Wahyudi, 2019)If this is allowed to continue, it will cause whispering noise and vibrations that can damage the pump housing and pipes (water hammer).

Net Positive Suction Head (NPSH-Net Positive Suction Head)

If the static pressure of a liquid flow decreases to the saturated vapor pressure, cavitation will occur. To avoid this, care must be taken to ensure that the flow in the pump does not have a static pressure lower than the saturated vapor pressure, so it is given an NPSH.(Fajri Hidayat & Fajri, 2019).

Total Liquid Head

To find the total head, we must first know the condition of the water up to the surface, the friction loss in the outlet pipe, so the head is the difference in height between the water surface on the suction side and the pressure side.(Kusumaningsih et al., 2018).

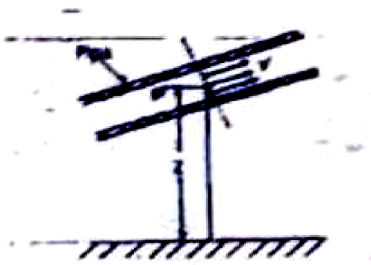

Figure 8. Flow Through Pipe

The figure shows the flow of a liquid (an incompressible fluid, such as water) through a channel cross-section. At this cross-section, the liquid has a static pressure p, with an average velocity v and a height Z measured from the reference plane. Therefore, the liquid at this cross-section is said to have a total head H, which is expressed by the following equation.

$$H = \frac{P}{\gamma} \pm \frac{V^2}{2g} \pm Z$$

Where :

H = Total head of liquid (m)
P = static pressure (kgf/m2)
Z = height (m)
V = flow velocity (m/s)
γ = specific gravity of the liquid (kgf/m3)

Based on the equation above, the three terms of the equation are $\frac{P}{\rho}$, $\frac{V^2}{2}$ andgz

ThirdHead is respectively referred to as pressure head, velocity head, and potential head. These three heads are nothing other than the mechanical energy contained in one unit weight (1 kgf) of fluid flowing in the relevant cross-section. The unit of energy per unit weight is equivalent to a unit of length (height). Therefore, the total head H, which is the sum of the pressure head, velocity head, and potential head, is the total mechanical energy per unit weight of fluid, and is expressed in units of the height of the fluid column in meters.(Putro & Widodo, 2020).

In SI units (Le Systeme International d'Unites), head H is often expressed as specific energy Y, which is the mechanical energy contained in the flow of a unit mass (1kh) of liquid. Based on this definition, the specific energy of pressure, velocity, and potential can be expressed respectively as P/p, $v^2/2$, and gZ. Then the total specific energy equation can be written as follows:

$$Y = g.H = \frac{P}{\rho} + \frac{V^2}{2} + g.Z$$

Where:

Y : Total specific energy (J/kg)
g : Acceleration due to gravity (m/s2)
ρ : Mass of liquid (kg/m3)

Total Pump Head

The total pump head that must be provided to flow the planned amount of water can be determined from the installation conditions that will be served by the pump.(Siregar & Damanik, 2020). In Figure 4, the total pump head can be written with the following equation:

$$H = ha + \Delta hp + hl + \frac{Vd^2}{2.g}$$

Where :
H : Total pump head (m)
Ha : Total static head (m)

This head is the difference in height between the water level on the outlet side and the suction side. The positive sign (+) is used if the water level on the outlet side is higher than the suction side.

Δhp : difference in pressure head acting on the two water surfaces (m)

$$\Delta hp = hp2 - hp1$$

h1 : various head losses in pipes, valves, bends, joints, etc. (m)

$$h1 = h_{1d} - h_{1s}$$

*V*d : velocity at exit head (m/s)

$\frac{Vd^2}{2.g}$: Exit velocity head (m)

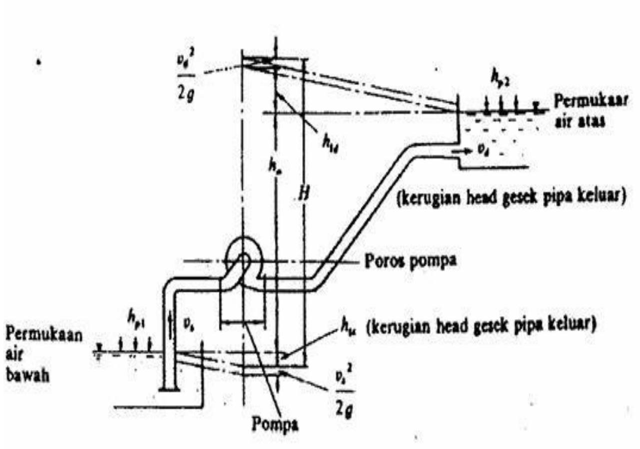

Figure 9. Flow Through Pipe

Head loss factor (h)

Loss head is the head to overcome losses in pipe flow, including friction losses in the pipe and losses due to bends, reducers & valves.(Homepage & Eka Prayoga, 2025). The following is the formulation of head loss in pipes, including :

Head loss in straight pipe

$$h_{l1} = \frac{10{,}666.Q^{1{,}85}}{C^{1{,}85}.D^{4{,}85}} \; x \; L$$

Where :
v : average velocity in the pipe (m/s)
v : 0.849 . C.R0.63S0.54
C : pipe coefficient based on Hazen-William (see the following table)

Table 1. Pipe Coefficients (Hazen-William)

Jenis Pipa	C
Pipa besi cor baru	130
Pipa besi cor tua	100
Pipa baja baru	120-130
Pipa baja tua	80-100
Pipa dengan lapisan semen	130-140
Pipa plastik (PVC)	80-100

D : Pipe inner diameter (m)
S : Gradient

$$S = \frac{h_{l1}}{L}$$

h_{l1} : head loss (m)
Q : Flow rate (m3/s)
L : Pipe length (m)

Head loss due to pipe bends

In pipe flow, losses occur when the pipe size, cross-sectional shape, or flow direction change. Head losses in this transition region can be generally expressed using the formula :

$$h_{12} = f\,(v^2/2g)$$

Where :
V : average velocity of fluid in the pipe (m / s)
f : Loss coefficient (bend or fracture)
g : acceleration due to gravity (9.81 m/s2)
h12 : head loss due to pipe bends (m)

Loss coefficient at pipe bends (f)

the coefficient at each 900 pipe bend is as follows :

$$f_l = \left[0{,}131 + 1{,}847.\left(\frac{D}{2R}\right)^{3{,}5}\right]\left(\frac{\theta}{90}\right)^{0{,}5}$$

Where :
D : Pipe inner diameter (m)

R : Radius of curvature of the axis of the bend (m)
Θ : Turning angle (0)
ft: Curved bend loss coefficient

Head loss on valves

$$h_v = f_v \frac{v^2}{2g}$$

Where :
hv : Valve head loss (m)
fv : Valve loss coefficient

The head loss coefficient values for various types of valves (h) can be seen in the table below.

Table 2. Head loss coefficient values for various types of valves (h)

Jenis katup \ Diameter(mm)	100	150	200	250	300	400	500
Katup sorong	0.14	0.12	0.10	0.09	0.07	0	0
Katup kupu-kupu	0.6 – 0.16						
Katup putar	0.09 – 0.026						
Katup cegah jenis ayun			1.2	1.15	1.1	1.0	0.98
Katup cegah tutup jenis takanan			1.2	1.15	1.1	0.9	0.8
Katup cegah jenis angkat bebas	1.44	1.39	1.34	1.3	1.2		
Katup cegah tutup cepat jenis pegas	7,3	6.6	5.9	5.3	4.6		
Katup isap dengan saringan	1.97	1.91	1.84	1.78	1.72		

Sumber: Ir. Sularso, 1983, hal 39

Water Power (Water Horse Power, WHP)

Water power is the energy effectively received by the pump per unit of time, which is expressed by the following equation:

$$WHP = y.\ Q.Hp = p.g.Q.\ Hp$$

Water power can also be expressed in

$$WHP = m_w \text{ x } HP$$

In the British Gravitational system of units, water power is expressed by the following equation:

$$WHP = \frac{m_w.\ HP}{33000} = \frac{144.P_t.Q_t}{33000}$$

Where :
WHP : Water power (kW)
Q:Water capacity (m^3/s)
HP : Headpump effective (m)
Y:Specific gravity of water (N/m3)
ρ : Masswater type (996.5 kg /m3) at 27°C
G: Acceleration due to gravity (m/(s2))
mw: Water produced by the pump (lb/min)
Qt: Water dischargein British units sh (ft3)/min)
P : Total pressure (Psi)

Pump Power (Shaft Horse Power, SHP)

Pump power is the power to drive the pump which is equal to the water power plus power losses in the pump.(Yani, 2022). The calculation of pump power is obtained using the following equation:

$$SHP = \frac{WHP}{\eta_P}$$

Where:
SHP : pump shaft horsepower (kW)
WHP : water horse power in (kW)
η_P : Pump efficiency (%)

$$\eta_P = \frac{WHP}{P_m} x100\%$$

Pm = Motor power (kW)→ see the data for the pump used
1HP = 0.736kW = 75kg m/s
1kgf = 9.81 N

Mechanical Efficiency (q)

Mechanical efficiency is a comparison of the mechanical performance of a pump which is shown by the following equation :

$$\eta_m = \frac{WHP}{SHP} \times 100\%$$

Flow Rate

Flow rate is a quantity that states the volume of fluid flowing through a cross-section in a certain time interval.(Yani A, Istiqomah N., 2022)Flow rate is used to determine the fluid flow capacity in a piping or pump system. Mathematically, flow rate can be expressed as the ratio of fluid volume to flow time, namely :

$$Q = \frac{V}{t} \quad (m^3/dtk)$$

Where :
Q: Debitflow (m3/sec)
V: VolumeFluid (m3)
t:time (sec)

In centrifugal pump practicums, flow rate calculations are used as the main parameter to analyze pump performance, especially in determining the relationship between flow rate, head, and pump efficiency.

Flow Rate

Mathematically, fluid velocity can be expressed as the ratio between the flow rate and the cross-sectional area of the flow, namely:

$$v = \frac{Q}{A} \quad (\mathbf{m^3/dtk})$$

Where :
V = fluid velocity (m/s)
Q = fluid flow (m3/sec)
A = cross-sectional area of the pipe (m2)

In centrifugal pump practicums, fluid velocity is used to analyze the kinetic energy of the flow and influences the calculation of velocity head and energy loss in the system.

I. Effective Head

In centrifugal pump practicums, effective head is used to evaluate the pump's performance in producing the pressure required to flow fluid in a piping system.

$$Hp = (Hd - Hs)$$

Where :
Hp : Effective Head (m)
Hd : Head Discharge (m)
Hs : Head Suction (m)

CONCLUSION

Based on the results of tests and analysis that have been carried out on the characteristics of centrifugal pumps, it can be concluded that pump performance is greatly influenced by the relationship between flow rate, head, and the system configuration used.In a single pump, it is found that an increase in flow rate tends to cause a decrease in the head value, which is in accordance with the basic characteristics of a centrifugal pump where fluid energy is divided between pressure energy and kinetic energy.

In a series pump configuration, test results show a significant increase in total head compared to a single pump, while the flow rate remains relatively unchanged. This is due to the accumulated pressure from each pump operating sequentially. Conversely, in a parallel configuration, the flow rate increases significantly, while the resulting head remains relatively constant. This occurs because the fluid flow is divided and then recombined, resulting in a greater flow capacity. Calculations of performance parameters such as flow rate, fluid velocity, effective head, and water power (WHP) show that higher flow rate and head values increase the pump's energy requirements. Furthermore, pump efficiency is not constant and is affected by operating conditions, with an optimum operating point that produces the most efficient performance. Overall, the results of this study indicate that the choice of pump configuration is highly dependent on system requirements, with series configurations being more suitable for applications requiring high pressure, while parallel configurations are more effective for applications requiring large flow rates. Therefore, the use of the centrifugal pump test equipment designed in this study can assist in understanding pump performance characteristics and support a more comprehensive learning process and analysis of piping systems.

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