Compression of Pump Characteristics

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★ Objectives:

Investigate the performance of two pump types under various operating conditions:

- Positive displacement reciprocating pump (single-cylinder, double-acting): We'll analyze this pump's characteristics at both constant and variable speeds.
- Centrifugal pump (horizontal): We'll also examine this pump's behavior at constant and variable speeds.

The goal: Compare the performance of these two pumps under identical speed conditions. This will help us understand which pump is better suited for specific applications depending on factors like flow rate, pressure, and desired control.

★ Introduction & Theory

"*Pumps The Heart of Fluid Flow*"

Pumps are the workhorses of fluid systems, adding energy to keep liquids and gases flowing. From the familiar piston pump in car engines to the extraordinary centrifugal pumps in municipal water supplies, they come in various designs to suit different needs.

- **Positive Displacement Pumps:** These pumps, like the piston pump, trap a specific volume of fluid and force it out with each cycle. This precise control makes them ideal for high-pressure applications like hydraulic systems.
- **Centrifugal Pumps:** These rely on rotating impellers to convert kinetic energy from a motor or engine into the fluid's flow. Their efficient design makes them popular choices for

moving large volumes of liquids in buildings, water treatment facilities, and irrigation systems.

- **Diaphragm Pumps:** Utilizing a flexible diaphragm, these pumps offer good control and are suitable for handling slurries, viscous fluids, and delicate tasks like chemical dosing.
- **Gear Pumps:** These pumps use interlocking gears to create fixed chambers that move fluid. Their simple design makes them reliable for lubrication systems, fuel delivery, and other applications requiring a steady flow.

By understanding these different pump types, we can select the most appropriate one for each application.

Pump Performance Testing and Characteristic Parameters:

This experiment investigates pump performance by running them at constant speed and varying flow rates. The resulting data is used to plot pump performance curves.

Characteristic Parameters:

a) **Water Power (Pump Power):** Represents the rate of energy transferred by the pump to the fluid. Calculated using:

Water power (kW) = ($\rho * g * \dot{Q} * hp$) x 10^{-3}

where:

- ρ (rho) = Density of water (1000 kg/m³)
- g = Acceleration due to gravity (9.81 m/s²)
- $\dot{Q}$ = Volumetric flow rate (m³/s)
- hp (hp) = Head gain in meters of water (pump head)

b) **Brake Power:** Represents the power provided by the motor to drive the pump. Calculated using:

Brake power (kW) = $\omega m * \tau = 2\pi\omega m * F * R$ x 10^{-3}

where:

- ωm (omega_m) = Motor speed (rev/s)
- F (F) = Brake load (N) = spring load (kg) x 9.81
- R (R) = Torque arm radius (m) (assumed 0.15 m)

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c) **Overall Efficiency:** Ratio of output power to input power.

- Overall efficiency = $\frac{Water\ power}{Brake\ power}$

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d) **Volumetric Efficiency (ηv):** Ratio of measured flow rate to the theoretical flow rate for positive displacement pumps.

Volumetric efficiency (ηv) = $\frac{Q^{\cdot}}{Q^{\cdot}c}$

where:

- $\dot{Q}c$ (Qc) = Calculated volumetric flow rate (m^3/s)

Calculated Volumetric Flow Rate ($\dot{Q}_c$):

- **Positive Displacement Reciprocating Pump:**
  - Single acting: $\dot{Q}c = A_p * L * \omega_p$ (m^3/s)
  - Double acting: $\dot{Q}c = 2 * A_p * L * \omega_p$ (m^3/s)

where:

- A_p = Total cross-sectional area of cylinder (assumed 15.55 x 10^{-4} m^2)
- L = Stroke of piston (assumed 0.0413 m)
- ω_p (omega_p) = Pump speed (rev/s) (related to motor speed based on gear ratio $\omega_p = \frac{\omega m}{5}$)

- **Centrifugal Pump:**

$$Qc = \frac{0.75}{12.5} \text{x } 10^{-3} * \omega_p \text{ (m}^3\text{/s)} \longrightarrow (\omega_p = 2\omega_m)$$

Note: The calculated volumetric flow rate ($\dot{Q}c$) for positive displacement pumps is a theoretical value based on pump geometry and speed.

★ Apparatus&Equipment

Experimental Setup (Figure 1):

The experiment utilizes a closed-loop water circuit. Water from a reservoir is pumped through the system and returns. Here's a breakdown of the key components:

- **Pump:** The pump under test is installed within the circuit.
- **Graduated Tank:** This tank collects water after it exits the pump, allowing measurement of the volumetric flow rate. The tank has markings to indicate the volume of collected water.
- **Release Valve:** Attached to the graduated tank, this valve allows collected water to be discharged for repeated measurements.
- **Motor and Dynamometer:** A DC motor drives the pump. A spring dynamometer is connected between the motor shaft and the pump shaft to measure the torque applied.
- **Speed Control:** The motor speed is controlled by a knob on a control panel.
- **Pressure Gauges:** Two pressure gauges are installed. One measures the suction pressure at the pump inlet, and the other measures the delivery pressure at the pump outlet.

Figure1. Pump testing setup

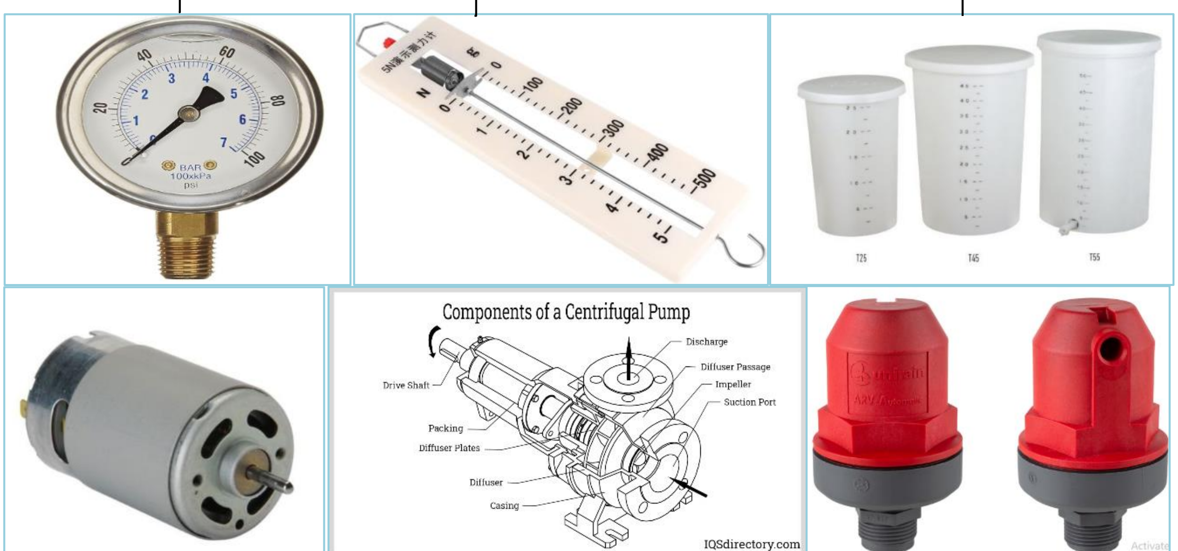

Figure 2. breakdown of testing setup (components)

★ Procedure

Starting the Experiment

1. Isolate the Pump: Ensure only the pump under test is operational. Close the valves of any other pumps in the system. Double-check that both the suction and delivery valves of the test pump are fully open.
2. Open Pressure Gauges: Open the valves on the pressure gauges connected to the test pump (one for suction pressure and one for delivery pressure).
3. Set Motor Speed to Zero: Locate the motor's variable speed control on the control panel and turn it fully counter-clockwise to ensure zero voltage output.
4. Power On: Turn on the power supply to the entire unit following proper safety protocols (may involve checking emergency stops and ensuring a clear workspace).
5. Zero Dynamometer: While the motor shaft is horizontal (not spinning), adjust the spring dynamometer to achieve a zero reading on its scale. This ensures an accurate baseline measurement for torque.

Stopping the Experiment

1. **Reduce Motor Speed:** Gradually return the motor's variable speed control knob to the zero position (fully counter-clockwise) to slow down the pump.

2. **Close the pump inlet valve (s)**. When using the centrifugal pump first close the discharge valve before the inlet valve if the pump is to remain primed.

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Constant Speed Test (15 rev/s):

1-**Set Motor Speed**: Gradually rotate the motor speed control knob clockwise until the pump reaches a constant speed of 15 revolutions per second (rev/s). Monitor the speed using the provided tachometer or speed indicator.

2-**Adjust Delivery Pressure**: While maintaining the constant speed, adjust the opening of the delivery valve until the delivery pressure reaches the desired value listed in the data table.

Record Data:

Note the spring load reading on the dynamometer.

3-**Record the time required to collect exactly 5 kg of water in the graduated tank**. This will be used to calculate the mass flow rate.

Variable Speed Test (Delivery Pressure = 0.4 bar):

1-**Set Delivery Pressure**: Adjust the delivery valve to achieve a constant delivery pressure of 0.4 bar.

2-**Vary Motor Speed**: Gradually increase the motor speed using the control knob. Refer to the data table for specific speed values required for each test run.

3-**Record Data for Each Speed**:

- Note the spring load reading on the dynamometer.
- Record the time required to collect exactly 5 kg of water in the graduated tank. This will be used to calculate the mass flow rate.

★Data collection

Table 1 Data for the centrifugal pump

w=15 rev/sec *current=1.6 A*

P_s (bar)	P_d (bar)	Spring load (kg)	Mass (kg)	Time (sec)
0	0.4	1.45	5	17.4
0	0.5	1.41	5	18.73
0	0.6	1.41	5	19.96
0	0.7	1.41	5	20.32
0	0.8	1.41	5	22.1

For constant P_d = 0.4 bar

P_s (bar)	w (rev/s)	Spring load (kg)	Mass of water (kg)	Time (sec)
0	10	1.95	5	32.69
0	12	1.21	5	24.79
0	15	1.4	5	17.85
0	17	1.6	5	15.55
0	20	1.8	5	12.06

Table 1 Data for the reciprocating pump

Data for the reciprocating pump for constant ωm = 15 rev/s

P_s (bar)	P_d (bar)	Spring load (kg)	Mass (kg)	Time (sec)
0	0.5	0.7	5	13.1
0	1.0	0.9	5	13.0
0	2.0	1.0	5	12.8
0	3.0	1.4	5	12.9
0	4.0	1.7	5	13.5

Data for the reciprocating pump for constant Pd = 1.5 bar

Ps (bar)	w (rev/s)	Spring load (kg)	Mass of water (kg)	Time (sec)
0	10	0.8	5	20.3
0	12	0.81	5	18.6
0	14	0.85	5	15
0	16	0.9	5	13
0	18	0.95	5	11.4
0	20	1	5	10.5

★Results

○ Centrifugal pump

Table 3. Results for the centrifugal pump for constant ω_m = 15 rev/s

P_d (bar)	$\dot{Q}$ (m^3/s)	Brake load F (N)	Water power (KW)	Brake power (KW)	Overall efficiency	Pump head hp (m)	Volumetric efficiency
0.4	0.000287	14.2245	0.01149425	0.20117507	0.057135572	4.07747197	0.159642401
0.5	0.000267	13.8321	0.01334757	0.19562541	0.068230249	5.09683996	0.148306342
0.6	0.000251	13.8321	0.01503006	0.19562541	0.076830816	6.11620795	0.139167223
0.7	0.000246	13.8321	0.01722441	0.19562541	0.088047913	7.13557594	0.136701662
0.8	0.000226	13.8321	0.01809955	0.19562541	0.092521453	8.15494393	0.125691302

Table 4. Results for the centrifugal pump for constant Pd = 0.4 bar

w (rev/sec)	$\dot{Q}$ (m^3/s)	Brake load F (N)	Water power (KW)	Brake power (KW)	Overall efficiency	Pump head hp (m)	Volumetric efficiency
10	0.000153	19.1295	0.00611808	0.27054579	0.022613839	4.07747197	0.084973318
12	0.000202	11.8701	0.00806777	0.16787713	0.048057584	4.07747197	0.112052351
15	0.00028	13.734	0.01120448	0.194238	0.057684293	4.07747197	0.155617803
17	0.000322	15.696	0.01286174	0.22198629	0.057939329	4.07747197	0.178635227
20	0.000415	17.658	0.01658375	0.24973457	0.066405495	4.07747197	0.230329832

- ## Reciprocating pump

Table 5. Results for the reciprocating pump for constant ωm = 15 rev/s

P_d (bar)	$\dot{Q}$ (m^3/s)	Brake load F (N)	Water power (KW)	Brake power (KW)	Overall efficiency	Pump head hp (m)	Volumetric efficiency
0.5	0.000382	6.867	0.01908397	0.097119	0.196500885	5.09683996	0.212044105
1	0.000385	8.829	0.03846154	0.12486729	0.308019336	10.1936799	0.213675214
2	0.000391	9.81	0.078125	0.13874143	0.563097849	20.3873598	0.217013889
3	0.000388	13.734	0.11627907	0.194238	0.598642232	30.5810398	0.215331611
4	0.00037	16.677	0.14814815	0.23586043	0.628117862	40.7747197	0.205761317

Table 6. Results for the centrifugal pump for constant Pd = 1.5 bar

w (rev/sec)	$\dot{Q}$ (m_3/s)	Brake load F (N)	Water power (KW)	Brake power (KW)	Overall efficiency	Pump head hp (m)	Volumetric efficiency
10	0.000246	7.848	0.03694581	0.11099314	0.332865724	15.2905199	0.136836344
12	0.000269	7.9461	0.04032258	0.11238056	0.358803886	15.2905199	0.149342891
14	0.000333	8.3385	0.05	0.11793021	0.423979557	15.2905199	0.185185185
16	0.000385	8.829	0.05769231	0.12486729	0.462029004	15.2905199	0.213675214
18	0.000439	9.3195	0.06578947	0.13180436	0.499144908	15.2905199	0.243664717
20	0.000476	9.81	0.07142857	0.13874143	0.514832319	15.2905199	0.264550265

★Sample of calculations

Given the following inputs:-

$w = 15$ rev/s $P_d = 0.8$ $P_s = 0$ Spring Load = 1.41 kg Mass = 5

Time = 22.1 s

1) Water Power $= \rho * g * \dot{Q} * hp * 10^{-3}$

- Volumetric flow rate $(\dot{Q}) = \dfrac{m}{\rho * \Delta t} = \dfrac{5}{1000 * 22.1} = 2.26 * 10^{-4}$

- Pump Head $(h_p) = \dfrac{\Delta P}{\rho g * 10^{-5}} = \dfrac{0.8 - 0}{1000 * 9.81 * 10^{-5}} = 8.155$ m

∴ Water power $= 1000 * 9.81 * 2.26 * 10^{-4} * 8.155 * 10^{-3} = 0.0181$

2) Brake Power $= 2\pi * w * FR * 10^{-3} = 2 * \pi * 15 * 0.15 * \cancel{14.2245}\ 13.8321 * 10^{-3} = 0.1955$

- Brake Load (F) = Spring load * 9.81 = 13.8321

3) Overall efficiency $\eta = \dfrac{\text{Water power}}{\text{Brake power}} = \dfrac{0.981}{0.1955} = 0.0926$

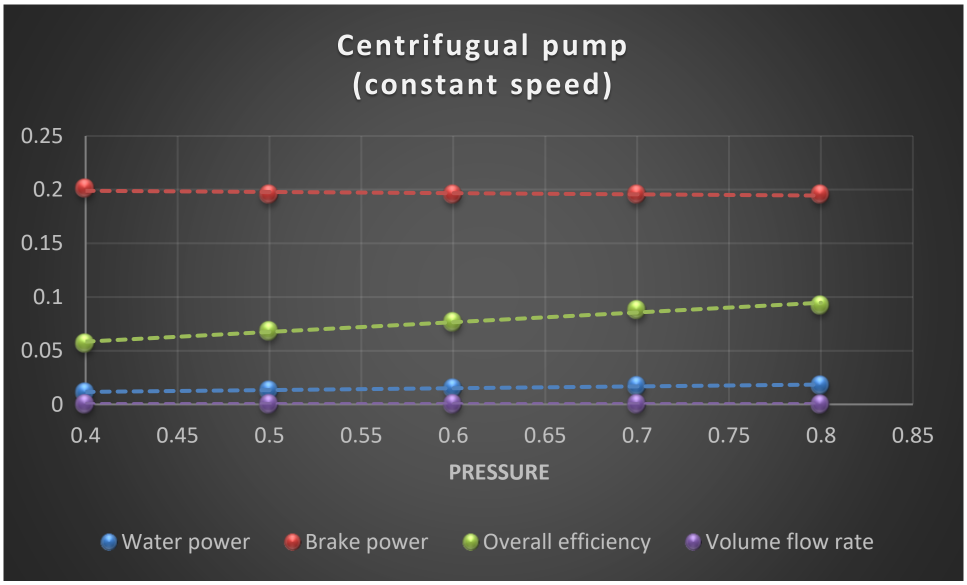
4) Volumetric efficiency $= \dfrac{\dot{Q}}{\dot{Q}_c} = \dfrac{2.26 * 10^{-4}}{1.8 * 10^{-3}} = 0.1255$

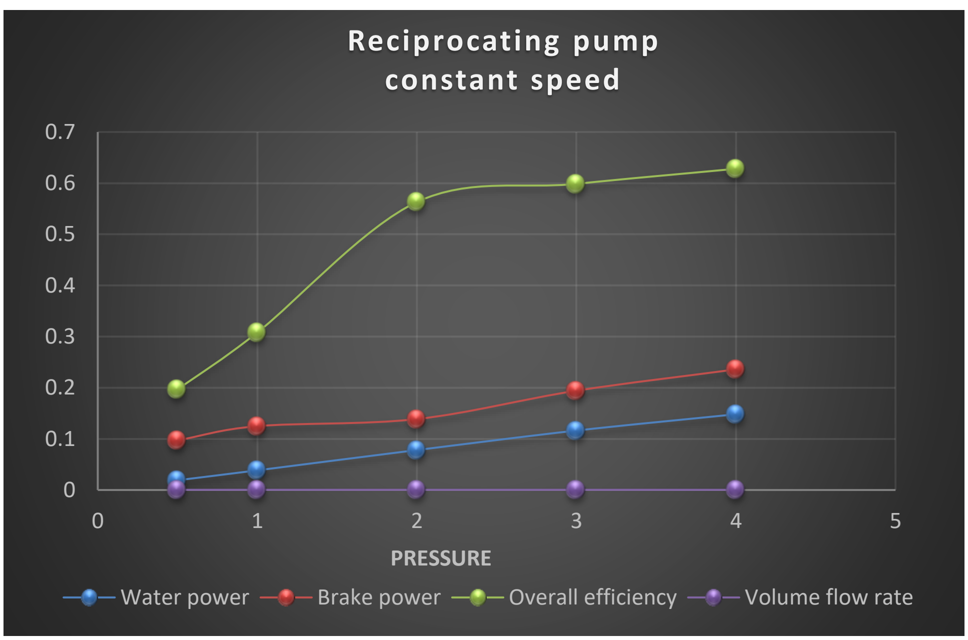
$\dot{Q}_c = \dfrac{0.75}{12.5} * 10^{-3} * 30 = 1.8 * 10^{-3}$

★Result and discussion

<u>Constant speed test</u>

1-





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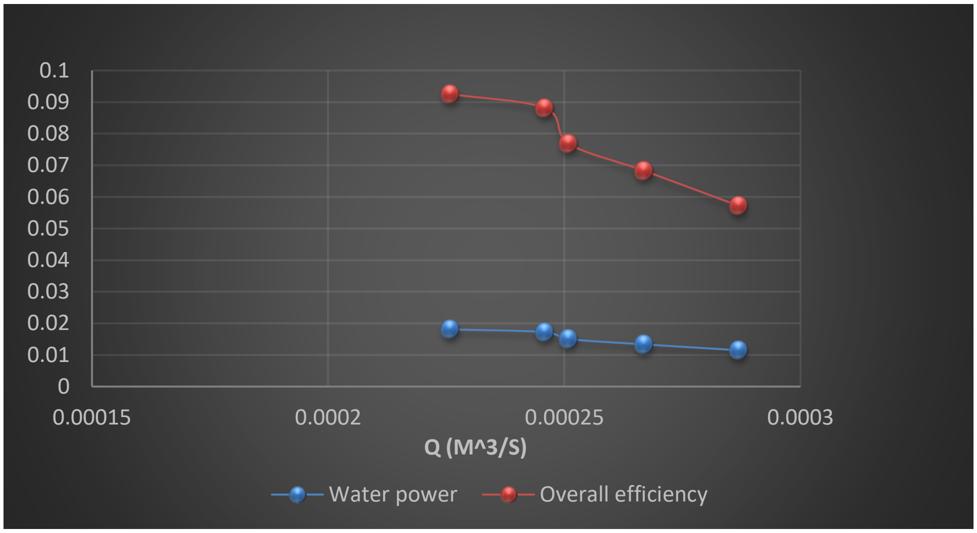

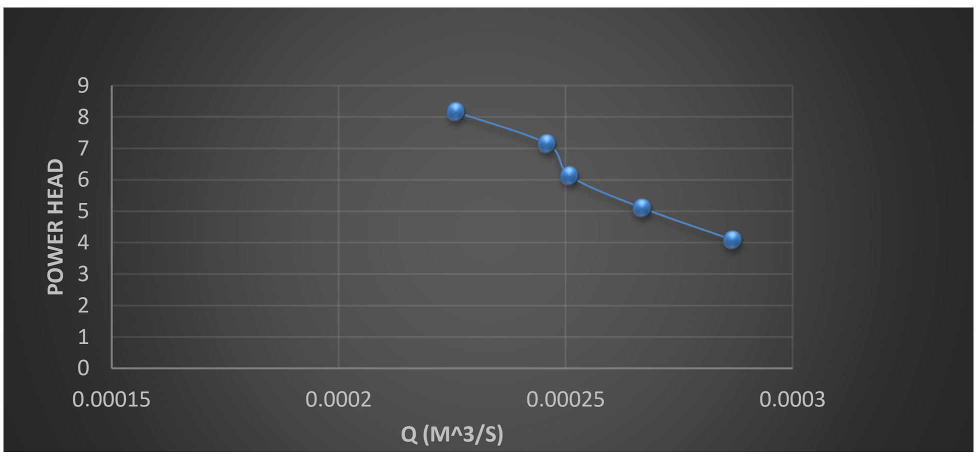

3-

Reciprocating Pump:

Ideal for: Precise delivery of small amounts of liquids at high pressures.

Applications:

- Hand pumps for inflating tires or bicycle wheels.
- Dosing pumps for injecting precise amounts of chemicals.
- Positive displacement pumps for transferring viscous liquids like grease or thick syrups (due to their self-priming **ability).**

Limitations:

- **Low flow rate: Not suitable for large volume transfers.**
- **Complexity: Moving parts can wear, requiring more maintenance.**
- **Viscosity limitations: May struggle with very thick liquids.**

Centrifugal Pump:

Ideal for: Continuous flow of large volumes of liquids at moderate pressures.

Applications:

- Supplying water in buildings and municipalities.
- Transferring fuels and chemicals in factories.
- Circulating coolants in industrial processes.

Limitations:

- **Pressure:** Generally not suited for extremely high-pressure applications.
- **Initial cost**: May have a higher upfront cost compared to some reciprocating pumps.
- **Priming:** Requires priming (filling the pump casing with liquid) before starting unless self-priming.

Constant speed test