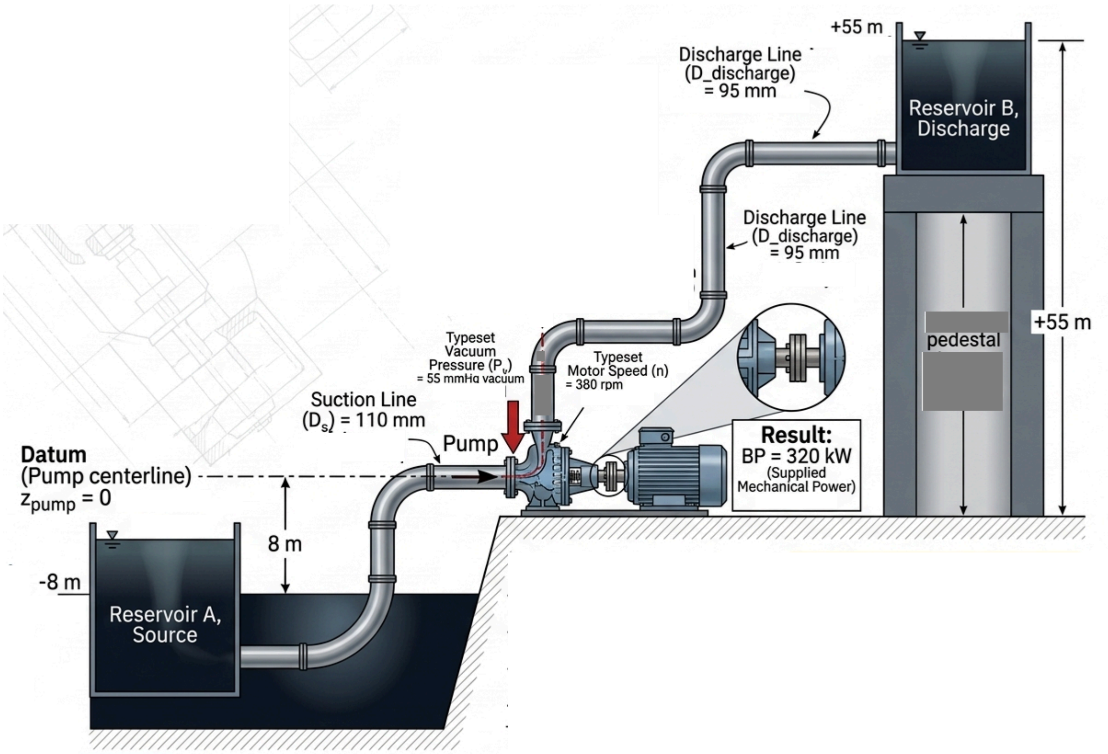
To determine the hydraulic operating efficiency of a fluid system with distinct gauge pressure measurements, we must perform an energy balance across the pump's physical boundaries. Unlike idealized systems that measure from open reservoir surface to reservoir surface, this problem provides explicit pressure conditions at measured locations along the suction and discharge pipes.



Let us categorize the given values from the problem statement and the reference documentation:

- **Volumetric Flow Rate (Q):** 0.25 m^3/s
- **Brake Power (BP):** 320 kW
- **Suction Side (State 1):** Diameter (D_1) = 110 mm (0.110 m); Pressure (P_1) = 55 mmHgvacuum; Position (z_1) = -8 m (below pump centerline)
- **Discharge Side (State 2):** Diameter (D_2) = 95 mm (0.095 m); Pressure (P_2) = 260 kPa; Position (z_2) = +55 m (above pump centerline)

The total dynamic head (TDH) is the total energy per unit weight that the pump adds to the fluid. By applying the steady-flow energy equation between the suction measurement node (1) and discharge measurement node (2), we track changes in elevation head, kinetic velocity head, and static pressure head:

$$TDH = \left(z_2 - z_1\right) + \frac{v_2^{\ 2} - v_1^{\ 2}}{2g_o} + \frac{P_2 - P_1}{\gamma_w} + h_L$$

As noted in the reference solution, line friction losses between these specific physical tracking points are assumed to be negligible ($h_L = 0$).

Step 1: Convert Boundary Pressures to a Consistent Unit System

To compute the net static pressure head, both pressure parameters must be converted into standard absolute or gauge values in kilopascals (kPa or kN/m^2):

- **Discharge Pressure (P_2):** Given directly as a positive gauge reading: P_2 = 260 kPa
- **Suspension Pressure (P_1):** Given as a vacuum pressure (55 mmHg vacuum). A vacuum represents a pressure *below* atmospheric pressure, meaning its gauge value is negative. Using the standard atmospheric baseline (760 mmHg = 101.325 kPa):

$$P_1 = (-\ 55\ mmHg)\left(\frac{101.325\ kPa}{760\ mmHg}\right) = -\ 7.3327\ kPa$$

Step 2: Compute Fluid Stream Velocities via Continuity

Using the volumetric flow rate (Q = 0.25 m^3), calculate the velocities inside the suction and discharge pipes:

- **Suction Pipe Velocity (v_1):**

$$Q = \frac{\pi}{4}{D_1}^2 v_1$$

$$0.25\frac{m^3}{s} = \frac{\pi}{4}(0.110m)^2 v_1$$

$$v_1 = 26.3066\ \frac{m}{s}$$

- **Discharge Pipe Velocity (v_2):**

$$Q = \frac{\pi}{4}{D_2}^2 v_2$$

$$0.25\frac{m^3}{s} = \frac{\pi}{4}(0.095m)^2 v_2$$

$$v_2 = 35.2698\ \frac{m}{s}$$

Step 3: Evaluate Individual Head Components

Now evaluate each energy head component using standard water specific weight $\left(\gamma_W = 9.81\ \frac{kN}{m^3}\right)$ and gravity $\left(g_o = 9.81\ \frac{m}{s^2}\right)$:

- **Static Elevation Head Differential:**
  Since the suction line sits *below* the centerline (z_1 = -8 m) and discharge sits *above* (z_2 = 55 m), the total height difference is:

  $$\Delta z = z_2 - z_1 = 55m - (-8m) = 63\ m$$

- **Kinetic Velocity Head Component:**

  $$h_v = \frac{v_2^2 - v_1^2}{2g_o} = \frac{(35.2698\ m/s)^2 - (26.3066\ m/s)^2}{2(9.81\ m/s^2)} = 28.1306\ m$$

- **Static Pressure Head Component:**

  $$h_p = \frac{P_2 - P_1}{\gamma_w} = \frac{260kPa - (-7.3327\ kPa)}{9.81\ kN/m^3} = 227.2510\ m$$

  TDH = 63m + 28.1306m + 27.2510m = 118.3816m

<u>Step 4:</u> Compute Water Power (WP) and Pump Efficiency (η_P)

Calculate the net fluid power (WP) transferred into the stream:

$$WP = Q\gamma_W TDH = \left(0.25\frac{m^3}{s}\right)\left(9.81\ kN/m^3\right)(118.3816\ m)$$

Finally, divide the fluid power by the mechanical brake power (BP = 320 kW) to determine the hydraulic pump efficiency:

$$\eta_P = \frac{WP}{BP} * 100\% = \frac{290.3309\ kW}{230\ kW} * 100\% = 90.728\%$$

This problem provides a valuable lesson in pump system health. The suction vacuum pressure is measured at -7.33 kPa_{gauge}. Assuming standard atmospheric pressure (101.325 kPa), the absolute suction pressure is:

$$P_1 = 101.325\ kPa - 7.333\ kPa = 93.992\ kPa_{abs}$$

For ambient water, this pressure is high enough to keep the liquid safely above its vapor pressure (3.17 kPa at 25°C), meaning the pump will operate smoothly without cavitating. However, if the suction vacuum drops much lower (closer to a full vacuum), the water will instantly flash into vapor bubbles. These bubbles will then violently collapse against the impeller blades, causing severe cavitation damage and rapid mechanical failure. Monitoring the suction vacuum is a primary way plant engineers track and prevent cavitation in the field.