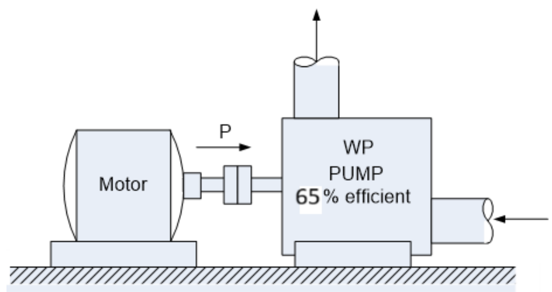
Given: Discharge (Q): 3700 L/min → 60 s3.7 m^3 ≈ 0.06167 m^3/s
Total Head (H): 7.50 m
Pump Efficiency (η): 65% (or 0.65)
Rotational Speed (N): 520 rpm
Shaft Diameter (d): 40 mm=0.04 m
Specific Weight of Water (γ): 9.81 kN/m^3



Find: Torsional Shear Stress (S_s): The internal stress in the shaft material.

The power required by the pump, WP

$$WP = Q \cdot \gamma \cdot H$$

$$WP = \left(3.7\frac{m^3}{min}\right)\left(\frac{1\,min}{60\,s}\right)\left(9.81\frac{kN}{m^3}\right)(7.5m) = 4.5371\,kW$$

Since the pump has an efficiency of **65%** , the power transmitted by the motor shaft is:

$$\eta_{eff} = \frac{WP}{P}$$

$$0.65 = \frac{4.5371\,kW}{P}$$

$$P = 6.9802\,kW$$

Power is related to torque by:

$$P = \frac{2\pi\,T\,N}{60}$$

$$6.9802\,kW = \frac{2\pi\,T\,(520\,rpm)}{60}$$

T = 0.1282 kN-m

Torsional shear stress in a solid shaft is given by:

$$S_s = \frac{16\,T}{\pi\,D_o^{\ 3}}$$

$$S_s = \frac{16\,(0.1282\ kN{-}m)}{\pi\,(0.04\ m)^3}$$

$$S_s = 10,200.5401\ kPa$$

$$S_s = 10.20\ MPa$$

Most common shaft materials (like AISI 1045 steel) have a shear yield strength of about 150–250 MPa. A stress of 10.20 MPa is very low, meaning the shaft is heavily over-designed for this specific head and flow. It is unlikely to break under these conditions.

NOTES for Shaft Material Selection (Shigley's Mechanical Engineering Design by Richard Budynas, Keith Nisbett Page 361**)**

Shaft materials are selected based on their ability to handle loading stresses while maintaining rigidity. Deflection in shafts is not influenced by strength but rather by stiffness, which is determined by the modulus of elasticity. Since the modulus of elasticity is nearly constant for all steels, controlling shaft deflection is primarily a geometric decision rather than a material choice. However, the necessary strength to resist loading stresses plays a crucial role in material selection. Many shafts are made from low-carbon steel, such as ANSI 1020-1050, in either cold-drawn or hot-rolled form. When higher strength is required, alloy steels like ANSI 1340-50, 3140-50, 4140, 4340, 5140, and 8650 are used. While heat treatment can improve strength, excessive hardening may negatively impact endurance limits and toughness, making it important to balance material properties.

Surface hardening is generally not necessary unless the shaft serves as a bearing surface. In such cases, carburizing grades like ANSI 1020, 4320, 4820, and 8620 are commonly used. Manufacturing considerations also influence material selection. Cold-drawn steel is typically preferred for shaft diameters under three inches, whereas hot-rolled steel requires full machining to remove surface imperfections. For large shafts, heat treatment may be needed to relieve residual stresses before final machining to prevent warping.

Production volume and cost efficiency further impact the selection process. In low-production scenarios, machining (turning) is commonly used, while high-production environments may benefit from casting, hot forming, or cold forming to minimize material waste. Cast iron shafts can be an economical choice when large quantities are needed, especially when integrating gears directly into the shaft. Additionally, the properties of the shaft are influenced by its manufacturing history, including cold work, rolling, and heat treatment. In environments where corrosion resistance is a priority, stainless steel may be a more appropriate material choice.

Consider the Factor of Safety (FS)

Consider a Factor of Safety = 3 based on reliability, operating conditions, and uncertainty in loads.

$$FS = \frac{S_{fail}}{S_{all}} = \frac{S_y}{S_{all}}$$

$$3 = \frac{S_y}{10.20\ MPa}$$

$$S_y = 30.6\ MPa$$

For standard applications → AISI 1020 (Mild Steel)
For higher loads or fluctuating stresses → AISI 1045 (Medium Carbon Steel)
For heavy-duty or high-torque applications → AISI 4140 (Alloy Steel)

Since AISI 1020 (Mild Steel) has a shear strength of 150 MPa, it is more than sufficient (since 150 MPa >> 30.6 MPa). However, if the shaft experiences high cyclic loads, shock loads, or operates in a harsh environment, a stronger material like AISI 1045 or AISI 4140 may be preferred.