Exercise 9

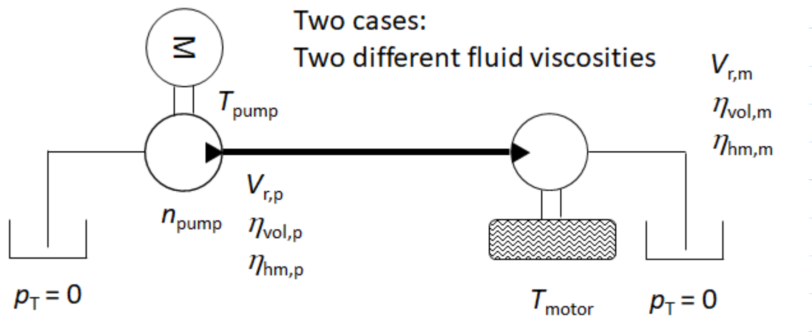
$T_{motor} := 100 \cdot N \cdot m$

$n_{motor} := 20 \cdot \frac{1}{s}$

$V_{r.m} := 48.6 \cdot 10^{-6} \cdot m^3$

$\eta_{v.m} := 0.95$

$\eta_{hm.m} := 0.9$



$V_{r.p} := 26 \cdot 10^{-6} \cdot m^3$

$\eta_{v.p} := 0.95$

$\eta_{hm.p} := 0.9$

$D_{pipe} := 21 \cdot 10^{-3} \cdot m$

$\nu_1 := 48 \cdot 10^{-6} \cdot \frac{m^2}{s}$

$\nu_2 := 12 \cdot 10^{-6} \cdot \frac{m^2}{s}$

$\rho := 870 \cdot \frac{kg}{m^3}$

$R_z := 40 \cdot 10^{-6} \cdot m$

$\varepsilon := \frac{R_z}{D_{pipe}}$

$L_{pipe} := 20 \cdot m$

Inputs

rotational speed of motor [r/s]

motor’s swept volume [m3/r]

volumetric efficiency of motor [-]

hydromechanical efficiency of motor [-]

volumetric efficiency of pump [-]

hydromechanical efficiency of pump [-]

pump’s swept volume [m^3/r]

motor's torque [Nm]

pipe length [m]

pipe's internal diameter [m]

kinematic viscosity of hydralic fluid, case 1 [cSt]

kinematic viscosity of hydralic fluid, case 2 [cSt]

density of hydraulic fluid [kg/m^3]

pipe's internal surface roughness [m]

Outputs

- Motor pressure and flow rate
- Pipe flow (laminar or turbulent) Case 1 and Case 2
- Pipe pressure losses, Case 1 and Case 2
- Pump pressure and torque
- Motor (OUTPUT) power
- Pump (INPUT) power

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Solution

Motor's torque and rotational speed are known.
Motor's output power can be calculated.
Motor's efficiencies (cokumetric and hydromechanical) are known, thus motor's hydraulic input power can be calculated (pressure and flow rate).
Pump's output pressure is motor pressure plus pressure loss in pipe.
Flow in pipe can be either laminar or turbulent (calculate Reynolds number).
Pump's hydraulic output power can be calculated.
Pump's efficiencies are known, so also mechanical input power can be calculated.

Motor

$$p_{motor} := \frac{T_{motor} \cdot 2 \cdot \pi}{V_{r.m} \cdot \eta_{hm.m}}$$

$$p_{motor} = 143.648 \text{ bar}$$

$$q_{v.motor} := \frac{n_{motor} \cdot V_{r.m}}{\eta_{v.m}}$$

$$P_{motor} := T_{motor} \cdot 2 \cdot \pi \cdot n_{motor}$$ mechanical output power

$$q_{v.motor} = 0.00102 \ \frac{m^3}{s}$$

$$P_{motor} = 12.566 \text{ kW}$$

$$q_{v.motor} = 61.389 \ \frac{l}{min}$$

Pipe

$$A_{pipe} := \frac{\pi}{4} \cdot D_{pipe}^{2}$$

$$A_{pipe} = \left(3.464 \cdot 10^{-4}\right) \ m^2$$

$$v_{pipe} := \frac{q_{v.motor}}{A_{pipe}}$$

$$\varepsilon = 0.0019$$

$$v_{pipe} = 2.954 \ \frac{m}{s}$$

$$Re_{pipe.1} := \frac{D_{pipe} \cdot v_{pipe}}{\nu_1}$$

$$Re_{pipe.2} := \frac{D_{pipe} \cdot v_{pipe}}{\nu_2}$$

$$Re_{pipe.1} = 1.292 \cdot 10^{3}$$ laminar

$$Re_{pipe.2} = 5.17 \cdot 10^{3}$$ turbulent

$$\lambda_{laminar} := \frac{64}{Re_{pipe.1}}$$

$$\lambda_{laminar} = 0.04952$$

$$\lambda_{turb} := \frac{6.4}{\left(\ln\left(Re_{pipe.2}\right) - \ln\left(1 + 0.01 \cdot Re_{pipe.2} \cdot \varepsilon \cdot \left(1 + 10 \cdot \sqrt[2]{\varepsilon}\right)\right)\right)^{2.4}}$$

$$\lambda_{turb} = 0.03852$$

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$$\Delta p_{pipe.1} := \lambda_{laminar} \cdot \frac{L_{pipe}}{D_{pipe}} \cdot \frac{1}{2} \rho \cdot v_{pipe}^{2}$$

Pressure losses in pipe

Laminar

$\Delta p_{pipe.1} = 1.79\ bar$

$$\Delta p_{pipe.2} := \lambda_{turb} \cdot \frac{L_{pipe}}{D_{pipe}} \cdot \frac{1}{2} \rho \cdot v_{pipe}^{2}$$

Turbulent

$\Delta p_{pipe.2} = 1.392\ bar$

Because of lower viscosity the pressure loss in turbulent case is smaller (the flow velocity and density are the same).

Pump

$$n_p := \frac{q_{v.motor}}{V_{r.p} \cdot \eta_{v.p}}$$

$$n_p = 41.423\ \frac{1}{s}$$

$$n_p = \left(2.485 \cdot 10^{3}\right)\ \frac{1}{min}$$

$$p_{p.lam} := p_{motor} + \Delta p_{pipe.1}$$

$$p_{p.lam} = 145.439\ bar$$

$$p_{p.turb} := p_{motor} + \Delta p_{pipe.2}$$

$$p_{p.turb} = 145.041\ bar$$

$$T_{p.lam} := \frac{p_{p.lam} \cdot V_{r.p}}{2 \cdot \pi \cdot \eta_{hm.p}}$$

$$T_{p.lam} = 66.87\ N \cdot m$$

$$T_{p.turb} := \frac{p_{p.turb} \cdot V_{r.p}}{2 \cdot \pi \cdot \eta_{hm.p}}$$

$$V_{r.p} = 26\ mL$$

$$T_{p.turb} = 66.687\ N \cdot m$$

$$P_{out} := T_{motor} \cdot 2 \cdot \pi \cdot n_{motor}$$

$P_{out} = 12.566\ kW$ motor's output power, both laminar and turbulent

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$P_{in.lam} := T_{p.lam} \cdot 2 \cdot \pi \cdot n_p$

$P_{in.lam} = 17.404\ kW$ pump's input power, laminar

$P_{in.turb} := T_{p.turb} \cdot 2 \cdot \pi \cdot n_p$

$P_{in.turb} = 17.357\ kW$ pump's output power, turbulent

$P_{pipe.lam} := q_{v.motor} \cdot \Delta p_{pipe.1}$ power loss in pipe, laminar

$P_{pipe.lam} = 183.172\ W$

$P_{pipe.turb} := q_{v.motor} \cdot \Delta p_{pipe.2}$ power loss in pipe, turbulent

$P_{pipe.turb} = 142.469\ W$

$P_{p.loss.lam} := P_{in.lam} \cdot \left(1 - \eta_{v.p} \cdot \eta_{hm.p}\right)$ power into pump - power out= power loss in pump, laminar

$P_{p.loss.lam} = 2.524\ kW$

$P_{p.loss.turb} := P_{in.turb} \cdot \left(1 - \eta_{v.p} \cdot \eta_{hm.p}\right)$ power into pump - power out= power loss in pump, turbulent

$P_{p.loss.turb} = 2.517\ kW$

$P_{m.loss} := p_{motor} \cdot q_{v.motor} \cdot \left(1 - \eta_{v.m} \cdot \eta_{hm.m}\right)$ power into motor- power out= power loss in motor, both laminar and turbulent

$P_{m.loss} = 2.131\ kW$

$P_{in.lam} - P_{p.loss.lam} - P_{pipe.lam} - P_{m.loss} = 12.566\ kW$

$P_{out} = 12.56637\ kW$

power into pump - power loss in pump - power loss in pipe - power loss in motor = motor's mechanical power (out), laminar case

$P_{in.turb} - P_{p.loss.turb} - P_{pipe.turb} - P_{m.loss} = 12.566\ kW$

$P_{out} = 12.56637\ kW$

power into pump - power loss in pump - power loss in pipe - power loss in motor = motor's mechanical power (out), laminar case

$P_{motor} = 12.566\ kW$

motor's mechanical power, calculated with torque and rotational speed

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