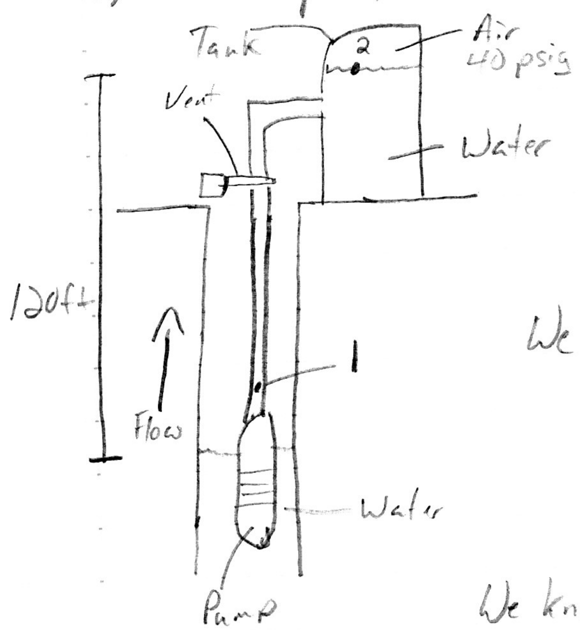
Giant Falcon

Homework 1.4 Chapter 7

7.11 A submersible deep-well pump delivers 745 gal/h of water through a 1-in Schedule 40 pipe when operating in the system below. An energy loss of 10.5 lb·ft/lb occurs in the piping system.
a) Calculate the power delivered by the pump to the water.
b) If the pump draws 1hp, calculate its efficiency.



$Q = 745\,gal/h$ $\quad z_2 - z_1 = 120\,ft$

$h_L = 10.5\,lb\cdot ft/lb$

$P_I = 1\,hp$ $\quad P_2 = 40\,psig = 5760\,lb/ft^2$

We know $\cancel{\frac{P_1}{\gamma}}^0 + z_1 + \cancel{\frac{v_1^2}{2g}}^0 + h_A + \cancel{h_R}^0 - h_L = \frac{P_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$

$\rightarrow z_1 + h_A - h_L = \frac{P_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$

$\rightarrow h_A = (z_2 - z_1) + h_L + \frac{P_2}{\gamma} + \frac{v_2^2}{2g}$

We know $v = \frac{Q}{A} = \frac{(745\,gal/h)\left(\frac{0.1337\,ft^3}{1\,gal}\right)\left(\frac{1h}{3600s}\right)}{0.00600\,ft^2} = 4.61\,ft/s$

Table

Then $h_A = (120\,ft) + (10.5\,\frac{lb\cdot ft}{lb}) + \frac{5760\,lb/ft^2}{62.4\,lb/ft^3} + \frac{(4.61\,ft/s)^2}{2(32.2\,ft/s^2)}$

$\rightarrow h_A = 223.14\,ft$

So $P_A = h_A \cdot \gamma \cdot Q = (223.14\,ft)(62.4\,lb/ft^3)\left[(745\,gal/h)\left(\frac{0.1337\,ft^3}{1\,gal}\right)\left(\frac{1h}{3600s}\right)\right]$

$\rightarrow P_A = 385.25\,lb\cdot ft/s \left(\frac{1\,hp}{550\,lb\cdot ft/s}\right) = \boxed{0.7005\,hp}$

We know $e_M = \frac{P_A}{P_I} = \frac{0.7005\,hp}{1\,hp} = 0.7005 = \boxed{70\%}$

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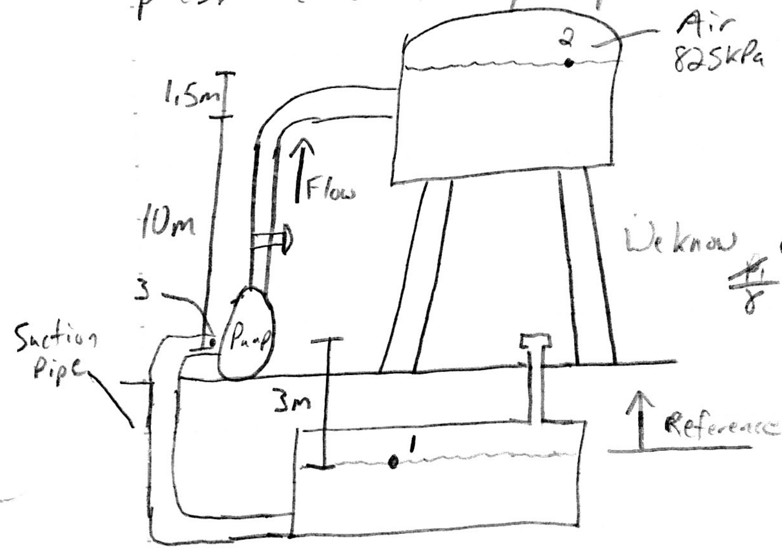
7.16 The figure shows a pump delivering 840 L/min of crude oil (sg = 0.85) from an underground storage drum to the first stage of a processing system. a) If the total energy loss in the system is 4.2 N·m/N of oil flowing, calculate the power delivered by the pump. b) If the energy loss in the suction pipe is 1.4 N·m/N of oil flowing, calculate the pressure at the pump inlet.



$sg = \frac{\gamma_{oil}}{\gamma_{H_2O}} \rightarrow \gamma_{oil} = (0.85)(9810\ N/m^3)$

$\gamma_{oil} = 8338.5\ N/m^3$

We know $\cancel{\frac{P_1}{\gamma}}^0 + \cancel{\frac{V_1^2}{2g}}^0 + \cancel{z_1}^0 + h_A = \frac{P_2}{\gamma} + \cancel{\frac{V_2^2}{2g}}^0 + z_2 + h_{L\,1,2}$

$\rightarrow h_A = \frac{P_2}{\gamma} + z_2 + h_{L\,1,2}$

$\rightarrow h_A = \frac{825\,kPa}{8338.5\,N/m^3} + 14.5m + 4.2\,N\cdot m/N$

$h_A = 98.94m + 14.5m + 4.2m$

$h_A = 117.64m$

Then $P = \gamma Q h_A = (8338.5\,N/m^3)(840\,L/min)\left(\frac{1\,m^3}{1000\,L}\right)\left(\frac{1\,min}{60\,s}\right)(117.64m)$

$\rightarrow P = 13733\ N\cdot m = 13733\,W = \boxed{13.733\,kW}$

We know $\cancel{\frac{P_1}{\gamma}}^0 + \cancel{\frac{V_1^2}{2g}}^0 + \cancel{z_1}^0 = \frac{P_3}{\gamma} + \frac{V_3^2}{2g} + z_3 + h_{L\,1,3}$

$\rightarrow \frac{P_3}{\gamma} = -\frac{V_3^2}{2g} - z_3 - h_{L\,1,3}$

$V_3 = \frac{Q}{A_3} = \frac{(840\,L/min)\left(\frac{1\,m^3}{1000\,L}\right)\left(\frac{1\,min}{60\,s}\right)}{3.090\times10^{-3}\,m^2} = 4.531\,m/s$

Then $P_3 = (8338.5\,N/m^3)\left(-\frac{(4.531\,m/s)^2}{2(9.81\,m/s^2)} - 3m - 1.4m\right)$

$\rightarrow P_3 = -45414.6\,N/m^2 = -45414.6\,Pa = \boxed{-45.41\,kPa}$

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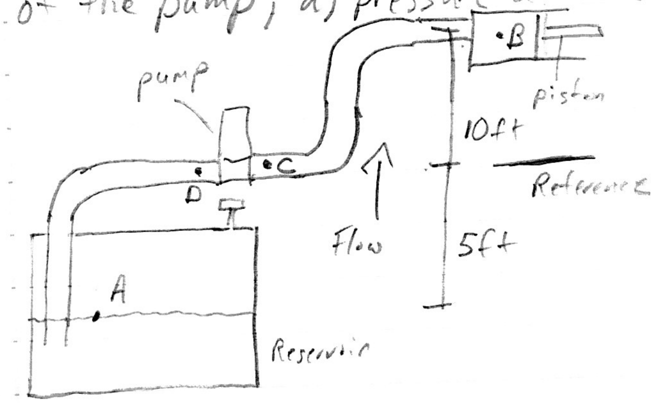
7.22 The figure shows the arrangement of a circuit for a hydraulic system. The pump draws oil with a specific gravity of 0.90 from a reservoir and delivers it to the hydraulic cylinder. The cylinder has an inside diameter of 5.0in, and in 15s the piston must travel 20in while exerting a force of 11000 lb. It is estimated that there are energy losses of 11.5 lb·ft/lb in the suction pipe and 35.0 lb·ft/lb in the discharge pipe (3/8 in Schedule 80). Calculate a) volume flow rate through the pump, b) pressure at the cylinder, c) pressure at the outlet of the pump, d) pressure at the inlet, and e) power delivered by pump.



a) We know $Q = \frac{A \cdot \Delta L}{\Delta t}$

$\rightarrow Q = \frac{((\pi \cdot 5in^2)/4) \cdot 20in}{15s}$

$\rightarrow Q = (26.18 \ in^3/s)\left(\frac{(1ft)^3}{(12in)^3}\right)$

$\rightarrow \boxed{Q = 0.01515 \ ft^3/s}$

b) We know $P_B = \frac{F}{A} = \frac{11000 \ lb}{((\pi \cdot 5in^2)/4)} = 560.23 \ lb/in^2 \left(\frac{(12in)^2}{(1ft)^2}\right) = 80672 \ lb/ft^2$

c) We know $\frac{P_C}{\gamma} + \frac{V_C^2}{2g} + \cancel{Z_C}^{\,0} - h_{LD} = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + Z_B$

$\rightarrow P_C = P_B + \gamma\left(\frac{V_B^2}{2g} + Z_B - \frac{V_C^2}{2g} + h_{LD}\right)$

$V_C = \frac{Q}{A_C} = \frac{0.01515 \ ft^3/s}{0.000976 \ ft^2} = 15.52 \ ft/s$

$V_B = \frac{L}{t} = \frac{20in}{15s} = 1.333 \ in/s \left(\frac{1ft}{12in}\right) = 0.1111 \ ft/s$

$\gamma_{oil} = sg(\gamma_{H_2O}) = (0.90)(62.4 \ lb/ft^3) = 56.16 \ lb/ft^3$

Then $P_C = 80672 \ lb/ft^2 + (56.16 \ lb/ft^3)\left[\frac{(0.1111 \ ft/s)^2}{2(32.2 \ ft/s^2)} + 10ft - \frac{(15.52 \ ft/s)^2}{2(32.2 \ ft/s^2)} + 35.0ft\right]$

$\boxed{P_C = 82989 \ lb/ft^2}$

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7.22 continued

d) We know $\cancel{\frac{P_A}{\gamma}}^{0} + \cancel{\frac{V_A^2}{2g}}^{0} + Z_A - h_{LS} = \frac{P_D}{\gamma} + \overbrace{\frac{V_D^2}{2g}}^{=V_C^2} + \cancel{Z_D}^{0}$

$$\rightarrow P_D = \gamma\left(Z_A - h_{LS} - \frac{V_D^2}{2g}\right)$$

$$\rightarrow P_D = (56.16\ \mathrm{lb/ft^3})\left(-5\,ft - 11.5\,ft - \frac{(15.52\ \mathrm{ft/s})^2}{2(32.2\ \mathrm{ft/s^2})}\right)$$

$$\rightarrow \boxed{P_D = -1136.7\ \mathrm{lb/ft^2}}$$

e) We know $\cancel{\frac{P_A}{\gamma}}^{0} + \cancel{\frac{V_A^2}{2g}}^{0} + Z_A + h_A - h_{LS} - h_{LD} = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + Z_B$

$$\rightarrow h_A = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + Z_B - Z_A + h_{LS} + h_{LD}$$

$$\rightarrow h_A = \frac{80672\ \mathrm{lb/ft^2}}{56.16\ \mathrm{lb/ft^3}} + \frac{(10.1111\ \mathrm{ft/s})^2}{2(32.2\ \mathrm{ft/s^2})} - 10\,ft + 5\,ft + 11.5\,ft + 35.0\,ft$$

$$\rightarrow h_A = 1497.97\ ft$$

Then $P = \gamma h_A Q = (56.16\ \mathrm{lb/ft^3})(1497.97\ ft)(0.01515\ \mathrm{ft^3/s})$

$$\rightarrow P = 1274.5\ \cancel{\mathrm{lb \cdot ft/s}}\left(\frac{1\ hp}{550\ \cancel{\mathrm{lb \cdot ft/s}}}\right) = \boxed{2.317\ hp}$$

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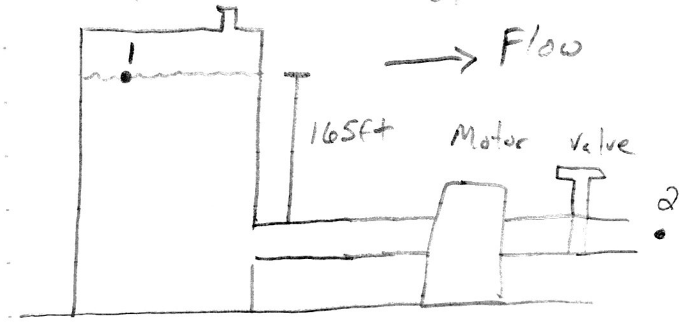
7.30 Water at 60°F flows from a large reservoir through a fluid motor at the rate of 1000 gal/min in the system in the figure. If the motor removes 37 hp from the fluid, calculate the energy losses in the system.



$1000 \ \text{gal/min} = 2.228 \ \text{ft}^3/\text{s}$

We know $\cancel{\frac{p_1}{\gamma}}^{0} + \cancel{\frac{v_1^2}{2g}}^{0} + z_1 - h_L + \cancel{h_A}^{0} - h_R = \cancel{\frac{p_2}{\gamma}}^{0} + \frac{v_2^2}{2g} + z_2$

$\rightarrow h_L = z_1 - h_R - \frac{v_2^2}{2g} - z_2$

We know $P_R = h_R \gamma Q \rightarrow h_R = \frac{P_R}{\gamma Q} = \frac{(37 \ \text{hp})(550 \ \text{lb ft/s})}{(62.4 \ \text{lb/ft}^3)(2.228 \ \text{ft}^3/\text{s})}$

$\rightarrow h_R = 146.37 \ \text{ft}$

$v_2 = \frac{Q}{A} = \frac{2.228 \ \text{ft}^3/\text{s}}{0.3472 \ \text{ft}^2} = 6.417 \ \text{ft/s}$

Then $h_L = 165 \ \text{ft} - 146.37 \ \text{ft} - \frac{(6.417 \ \text{ft/s})^2}{2(32.2 \ \text{ft/s}^2)} - 0 \ \text{ft}$

$\rightarrow \boxed{h_L = 17.99 \ \text{ft}}$

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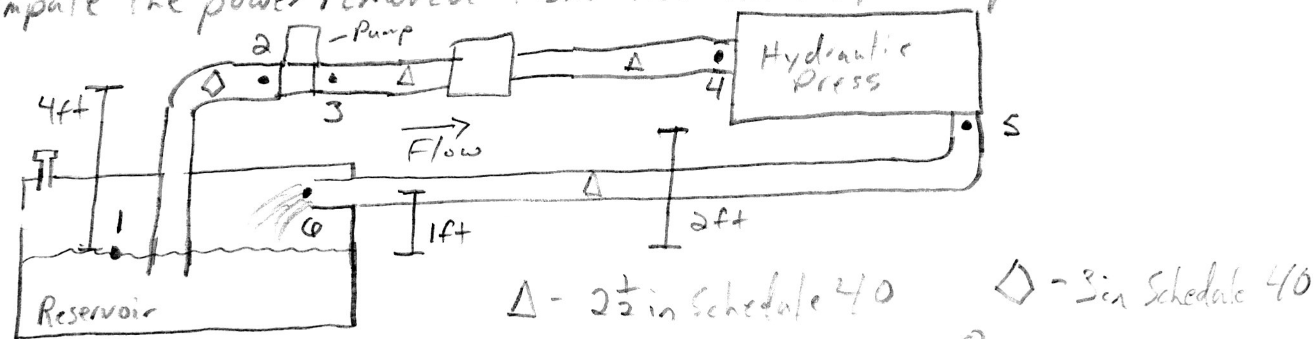
7.35 The figure shows a diagram of a fluid power system for a hydraulic press used to extrude rubber parts. The following data are known:
Fluid is oil with $sg = 0.90$ $\quad Q = 175\ gal/min$ $\quad P_I = 28.4\ hp$
$e_M = 80\%$ $\quad h_{L1,2} = 2.80\ lb\cdot ft/lb$ $\quad h_{L3,4} = 28.50\ lb\cdot ft/lb$ $\quad h_{L5,6} = 3.50\ lb\cdot ft/lb$
Compute the power removed from the fluid by the press.



We know $\frac{p_4}{\gamma} + \cancel{\frac{v_4^2}{2g}} + z_4 + \cancel{h_A} - h_R - \cancel{h_L} = \frac{p_5}{\gamma} + \cancel{\frac{v_5^2}{2g}} + z_5$

$\rightarrow h_R = \frac{p_4}{\gamma} + z_4 - \frac{p_5}{\gamma} - z_5$

We know $\cancel{\frac{p_1}{\gamma}} + \cancel{\frac{v_1^2}{2g}} + z_1 - \cancel{h_A} - \cancel{h_R} - h_L = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2$

$\rightarrow p_2 = \gamma\left[z_1 - h_L - \frac{v_2^2}{2g} - z_2\right]$

So $\gamma_{oil} = sg\,\gamma_{H_2O} = (0.90)(62.4\ lb/ft^3) = 56.16\ lb/ft^3$

$v_2 = \frac{Q}{A} = \frac{(175\ gal/min)(0.1337\ ft^3/1\ gal)(1\ min/60\ s)}{0.05132\ ft^2} = 7.60\ ft/s$

Then $p_2 = (56.16\ lb/ft^3)\left(0\ ft - 2.8\ ft - \frac{(7.60\ ft/s)^2}{2(32.2\ ft/s^2)} - 4\ ft\right)$

$p_2 = -432.26\ lb/ft^2$

We know $\frac{p_2}{\gamma} + \frac{v_2^2}{2g} + \underbrace{z_2}_{=z_3} + h_A - \cancel{h_R} - \cancel{h_L} = \frac{p_3}{\gamma} + \frac{v_3^2}{2g} + \underbrace{\cancel{z_3}}_{=z_2}$

$\rightarrow p_3 = \gamma\left[\frac{p_2}{\gamma} + \frac{v_2^2}{2g} + h_A - \frac{v_3^2}{2g}\right]$

So $P_A = e_M \cdot P_I = 0.80(28.4\ hp) = 22.72\ hp\left(\frac{550\ lb\cdot ft/s}{1\ hp}\right) = 12496\ \frac{lb\cdot ft}{s}$

Then $P_A = h_A \cdot \gamma \cdot Q \rightarrow h_A = \frac{P_A}{\gamma Q} = \frac{12496\ lb\cdot ft/s}{(56.16\ lb/ft^3)(175\ gal/min)(0.1337\ ft^3/1\ gal)(1\ min/60\ s)}$

$\rightarrow h_A = 570.59\ ft$

then $v_3 = \frac{Q}{A} = \frac{0.38996\ ft^3/s}{0.03326\ ft^2} = 11.72\ ft/s$

So $p_3 = (56.16\ lb/ft^3)\left(\frac{-432.26\ lb/ft^2}{56.16\ lb/ft^3} + \frac{(7.60\ ft/s)^2}{2(32.2\ ft/s^2)} + 570.59\ ft - \frac{(11.72\ ft/s)^2}{2(32.2\ ft/s^2)}\right)$

$\rightarrow p_3 = 31543\ lb/ft^2$

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7.35. continued

We know $\frac{p_3}{\gamma} + \cancel{\frac{v_3^2}{2g}}^{0} + \cancel{z_3}^{0} + \cancel{h_A}^{0} - h_L - \cancel{h_R}^{0} = \frac{p_4}{\gamma} + \cancel{\frac{v_4^2}{2g}}^{0} + \cancel{z_4}$

$$\rightarrow p_4 = \gamma\left(\frac{p_3}{\gamma} - h_L\right)$$
$$\rightarrow p_4 = 56.16\ \text{lb/ft}^3 \left(\frac{31543\ \text{lb/ft}^2}{56.16\ \text{lb/ft}^3} - 28.50\ \text{ft}\right)$$
$$\rightarrow p_4 = 29942\ \text{lb/ft}^2$$

We know $\frac{p_5}{\gamma} + \cancel{\frac{v_5^2}{2g}}^{0} + z_5 + \cancel{h_A}^{0} - h_L - \cancel{h_R}^{0} = \cancel{\frac{p_6}{\gamma}}^{0} + \cancel{\frac{v_6^2}{2g}}^{0} + z_6$

$$\rightarrow p_5 = \gamma(z_6 - z_5 + h_L)$$
$$\rightarrow p_5 = 56.16\ \text{lb/ft}^3(-1\ \text{ft} - 0\ \text{ft} + 3.50\ \text{ft})$$
$$\rightarrow p_5 = 140.4\ \text{lb/ft}^2$$

Then $h_R = \frac{p_4}{\gamma} + z_4 - \frac{p_5}{\gamma} - z_5$

$$\rightarrow h_R = \frac{29942\ \text{lb/ft}^2}{56.16\ \text{lb/ft}^3} + 2\ \text{ft} - \frac{140.4\ \text{lb/ft}^2}{56.16\ \text{lb/ft}^3} - 0\ \text{ft}$$
$$\rightarrow h_R = 532.66\ \text{ft}$$

Then $P_R = h_R \gamma Q = (532.66\ \text{ft})(56.16\ \text{lb/}\cancel{\text{ft}^3})(0.38996\ \cancel{\text{ft}^3}\text{/s})$

$$\rightarrow P_R = 11635\ \cancel{\text{lb}\cdot\text{ft/s}}\left(\frac{1\ \text{hp}}{550\ \cancel{\text{lb}\cdot\text{ft/s}}}\right) = \boxed{21.16\ \text{hp}}$$

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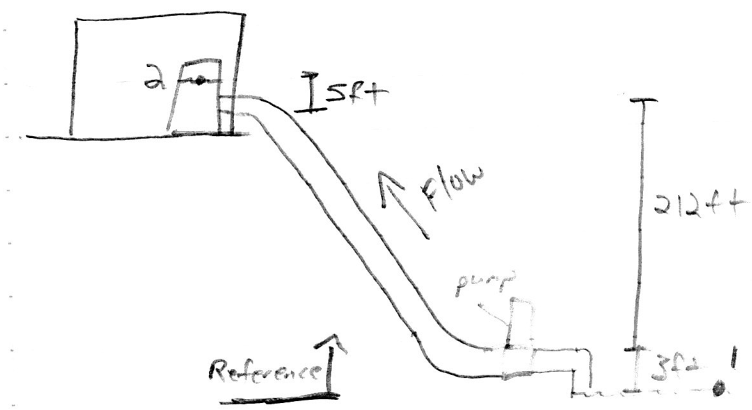
7.42. Professor Crocker is building a cabin on a hill side and has proposed the water system shown in the figure. The distribution tank in the cabin maintains a pressure of 30.0 psig above the water. There is an energy loss of 15.5 lb·ft/lb in the piping. When the pump is delivering 40 gal/min of water, compute the hp delivered by the pump to the water.



We know $\cancel{\frac{p_1}{\gamma}}^{0} + \cancel{\frac{v_1^2}{2g}}^{0} + \cancel{z_1}^{0} + h_A - h_L - \cancel{h_R}^{0} = \frac{p_2}{\gamma} + \cancel{\frac{v_2^2}{2g}}^{0} + z_2$

$\rightarrow h_A = \frac{p_2}{\gamma} + z_2 + h_L$

$\rightarrow h_A = \frac{(30\ lb/in^2)\left(\frac{12\ in}{1\ ft}\right)^2}{62.4\ lb/ft^3} + 220ft + 15.5ft$

$\rightarrow h_A = 304.7\ ft$

We know $P_A = h_A \cdot \gamma \cdot Q = (304.7\ ft)(62.4\ lb/ft^3)(40\ gal/min)\left(\frac{0.1337\ ft^3}{1\ gal}\right)\left(\frac{1\ min}{60\ s}\right)$

$\rightarrow P_A = 1694.7\ lb\cdot ft/s \left(\frac{1\ hp}{550\ lb\cdot ft/s}\right) = \boxed{3.08\ hp}$