26. Pumping Efficiencies and Costs

26.1 Important conversions and formulas

Total dynamic head = Friction head + Static head

$$1Hp = 0.746kW$$

$$1Hp = \frac{33,000\ \ ft - lb}{min}$$

$$1Hp = 3,960\ \ GPM - ft$$

$$1psi = 2.31ft$$

$$Water\ \ Hp\ \ =\ \ Flow\ \ *\ \ Head$$

$$Brake\ \ Hp\ \ =\ \ Input\ \ Hp * Motor\ \ efficiency$$

$$Water\ \ Hp\ \ =\ \ Brake\ \ Hp\ \ *\ \ Pump\ \ efficiency,\ \ and$$

$$\Longrightarrow Water\ \ Hp\ \ =\ \ Input\ \ Hp\ \ *\ \ Motor\ \ efficiency\ \ *\ \ Pump\ \ efficiency$$

PUMPS & PUMPING

1

Pump is a device for raising or moving water or any other fluid.

2

To move water, need to overcome resistance due its density, gravitational force & friction.

3

This resistance is dependent on:

- Height the water needs to be raised
- Quantity of water involved

4

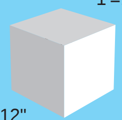
Force needs to be exerted by the pump to overcome the resistance

Force is the head which is measured in terms of the height of water - inches or feet

Force = Mass x Acceleration
(lb_f)   (lb_m)

$lb_f = lb_m$
(per definition)

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$



$$\text{Pressure exerted by a 1ft column of water} = \frac{62.4\ \text{lb}}{12\ \text{in} \times 12\ \text{in}} = 0.43\ \text{psi}$$

so 0.43 psi = 1ft (water column)
or 1 psi = 2.3ft

5

Pump will need to provided energy to raise the water

Energy = resistance force

Energy = Force x Distance

Energy units
ft-lb
KWh
Calories
Hp-h

6

Power needs to be delivered to the pump so it can provide energy. Power = Energy per time

Power Units
$\frac{\textbf{ft-lb}}{\textbf{min}}$
KW
Hp

1Hp = 0.746 kW

Watt determined that one horse on an average could lift 330lbs 100ft in one minute

$$1\text{Hp} = \frac{33{,}000\ \text{ft-lb}}{\text{min}}$$

$$\text{As 1 GPM (Water)} = \frac{8.34\text{lb}}{\text{min}}$$

$$\frac{\text{lb}}{\text{min}} = \frac{\text{GPM}}{8.34}$$

$$1\text{Hp} = \frac{33000\ \text{ft-lb}}{\text{min}} = \frac{33000\ \text{ft} \times \text{GPM}}{8.34\ \text{min}}$$

1Hp = 3,960 GPM-ft

1Hp is needed to raise one gallon of water 3,960 ft in one minute

Understanding the concept of power:

A 150lb person climbing 50ft will expend <u>7500 ft-lb of work (energy)</u>

1) Power requirement for climbing this in 5 minutes

$$\frac{7500}{5}\ \frac{\text{ft-lb}}{\text{min}} = 1500\ \frac{\text{ft-lb}}{\text{min}}$$

$$= 0.045\ \text{Hp}$$

2) Power requirement for climbing this in 1 minute

$$\frac{7500}{}\ \frac{\text{ft-lb}}{\text{min}} = 0.23\ \text{Hp}$$

Head

Total Dynamic Head

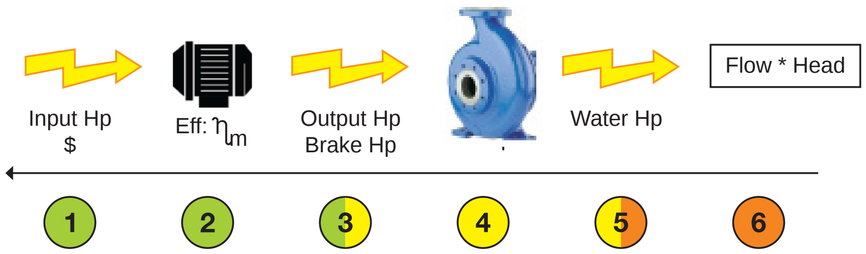
Total equivalent height of water column needed to pump

Friction Head

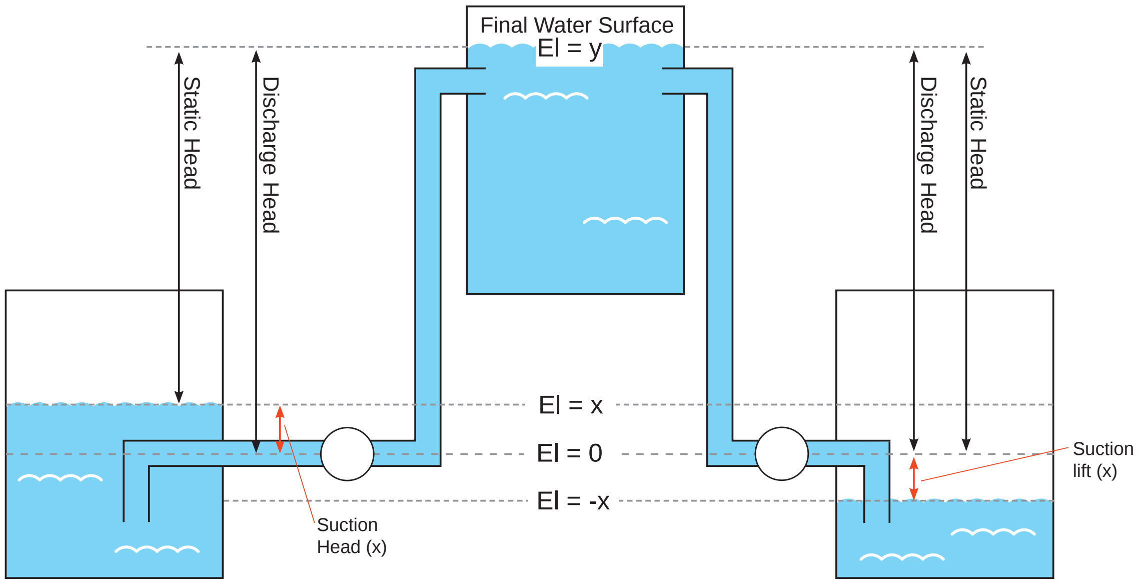
Head associated with energy losses due energy losses due to friction

Static Head

Head associated with the height the water has to be raised



Calculating Static Head



Case A:
Initial water level above pump

Static Head = y-x

Case B:
Initial water level below pump

Static Head = y-(-x)
= y+x

Given 6 **Calculate** 5

What is the required water horsepower to pump 300 GPM if the suction head and discharge heads are constant at 20 ft and 120 ft respectively and the system head losses are 5 ft.

Solution:

$$\frac{300\text{ GPM x }(120\text{-}20\text{+}5\text{ ft})}{3960\left(\frac{\text{GPM-ft}}{\text{Hp}}\right)} = \boxed{7.95\text{Hp}}$$

Given 2 4 5 **Calculate** 1

Find the input Hp Given the water Hp equals 8Hp and the pump and motor efficiencies are 80% and 50% respectively.

Solution:

Step 1: Find 3 knowing 4 & 5

$$0.5 = \frac{8\text{Hp}}{\text{Brake Hp}} = \text{Brake Hp} = 16\text{Hp}$$

Step 2: Find 1 knowing 2 & 3

$$0.8 = \frac{\text{Brake Hp}}{\text{Input Hp}} = \frac{16}{\text{Input Hp}}$$

$$\text{Input Hp} = \frac{16}{0.8} = \boxed{20\text{Hp}}$$

Given 3 **and existing** 2 **& replacement** 2 **Calculate** 1 **savings**

An older motor which is 82% efficient is to be replaced by a new, 94% efficient motor. Calculate the annual savings for the new motor given the output horsepower from both motors is 180Hp and the electricity cost is $0.075/kWh & the motor operates 24 hours per day throughout the year.

$$\text{Hp input to } \textit{new} \text{ motor} = \frac{180}{0.94} = 191.5\text{Hp}$$

$$\text{Hp input to } \textit{old} \text{ motor} = \frac{180}{0.82} = 218.5\text{Hp}$$

Annual Savings ❯ $(218.5\text{-}191.5)\text{Hp} \times \frac{0.746\text{ Kw}}{\text{Hp}} \times \frac{365 \times 24\text{ hrs}}{\text{Year}} \times \frac{\$0.075}{\text{Kwh}} = \boxed{\frac{\$23{,}779}{\text{Year}}}$

"Demand Charge" ($/kw) is imposed on consumer by the utility company to compensate it for the design & upkeep of equipment to meet the peak power draw by the consumer. The demand charge is in addition to the regular energy consumption charge ($/kw). The demand charge is based upon highest power consumption over any 15 minute period during the billing cycle. Oversized and inefficient equipment (motors & pumps) would mean higher demand charges.

26.2 Practice Problems

1. 1 MGD is pumped against a 14' head. What is the water Hp? The pump mechanical efficiency is 85%. What is the brake horsepower?

   water Hp = flow * head

   $$\frac{1,000,000\ gal}{day} * \frac{day}{1440\ min} * 14\ ft * \frac{Hp}{3,960\ GPM - ft} = \boxed{Water\ Hp = 2.46\ Hp}$$

   pump Hp = brake Hp * pump efficiency

   $$Brake\ Hp = \frac{2.46}{0.85} = \boxed{Brake\ Hp = 2.89Hp}$$

2. A 8 ft diameter cylindrical wetwell receives an average incoming flow if 135 gpm and is pumped down with a pump that delivers 450 gpm again a total dynamic head of 120 ft. The pump is controlled using two floats; a stop float located at 2.5 ft and a start float located at 16 ft. If the pump motor is rated at 88% and the pump at 77%, what is the monthly (30 days/month) for running this pump if power costs are $0.11/Kwh?

   When the pump is on, the volume of wetwell that will be pumped down with the 450 gpm pump and a 135 gpm flow to the wetwell:

   $$\frac{450\ gal}{min} - \frac{135\ gal}{min} = \frac{315\ gal}{min}$$

   Minutes required to pump down the wetwell :

   $$0.785 * 8^2 * (16 - 2.5) ft^3 * \frac{7.48\ gal}{ft^3} * \frac{min}{315\ gal} = 16.1\ min$$

   Time to fill wetwell with pump off @135gal/min influent flow:

   $$[0.785 * 8^2 * (16 - 2.5)] ft^3 * \frac{7.48\ gal}{ft^3} * \frac{min}{135\ gal} = 37.6 min$$

   # of cycles per day:

   $$\frac{cycle}{(16.1 + 37.6)\ min} * \frac{1440\ min}{day} = \frac{26.8\ cycles}{day}$$

   # of hrs pump operational:

   $$\frac{16.1\ min}{cycle} * \frac{26.8\ cycles}{day} * \frac{hrs}{60\ min} = \frac{7.19\ hours}{day}$$

   Monthly electrical cost:

   $$\frac{450\ gpm * 120\ ft}{0.88 * 0.77} * \frac{Hp}{3,960\ gpm - ft} * \frac{0.746\ kW}{Hp} * \frac{7.19 hrs}{day} * \frac{30\ days}{month} * \frac{\$0.11}{kWh} = \boxed{\frac{\$356}{month}}$$

3. A 6-year old pump motor is to be replaced at a net cost of $15,800. The new motor, just like the old one, would run 65% of the time. Both existing and replacement motors would operate at 125 output Hp. The existing motor efficiency is 86% while the replacement motor would be guaranteed at 94% efficiency. Electricity currently averages $0.088 per kWh.

   (a) Calculate the energy cost savings per year (to the nearest dollar) if the existing motor is replaced with the new motor (neglect any consideration of impact upon demand charges or interest on capital).

(b) What is payback period to the nearest tenth of a year.

Solution:

Calculate energy cost savings per year:

Input Hp for old motor: $\frac{125}{0.86} = 145.35Hp$

Input Hp for old motor: $\frac{125}{0.94} = 132.98Hp$

Energy cost savings:

$$(145.35 - 132.98)Hp * \frac{0.746 \ \ kW}{Hp} * \frac{(365 * 24 * 0.65)hrs}{yr} * \frac{\$0.088}{kWh} = \boxed{\frac{\$4,624}{yr}}$$

Calculate payback:

$$\$15,800 * \frac{yr}{\$4,623.94} = \boxed{3.4yr}$$