fact sheet

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Fundamentals of energy use in water pumping

Lifting and moving water around farms with pumping systems for irrigation consumes plenty of energy as water is a heavy liquid. Every litre of water has a mass of one kilogram. A cubic metre of water has a mass of 1000 kg, or a tonne, and a volume of 1000 litres. A Megalitre (ML) has a mass of one million kilograms or one thousand tonnes.

First facts first:

Fact 1. Earth's gravity, g = 9.81 metres per second per second (m/s2)
Fact 2. 1 Litre (L) of water = 1 kilogram (kg)
Fact 3. 1 MegaLitre of water (ML) = 1 million kilograms or 1 thousand tonnes

When we lift water we use energy to work against Earth's gravity. Energy is measured in Joules (J), or kiloJoules (kJ), or MegaJoules (MJ). Diesel or electrical energy are most commonly used through pumping systems to lift water for irrigation on Australian farms.

Energy facts:

Fact 4. 1 kiloJoule (kJ) = 1000 Joules (J)
Fact 5. 1 MegaJoule (MJ) = 1000 kiloJoules (kJ)
Fact 6. 1 Litre of Diesel contains 38.4 MegaJoules (MJ) of energy (Energy density)

Pump located at St George grower Ian Brimblecombe's property. Photo courtesy: Seedbed Media.

Fact 7. 1 kiloWatt-hour (kWh) of electricity contains 3.6 MegaJoules (MJ) of energy

In a perfect world with no energy losses in pumps and motors, and no other energy losses due to friction, pipe bends, valves, and fittings, you would use 9.81 Joules of energy to lift one litre of water up a height of one metre. In other words, you would use 9.81 MegaJoules of energy to lift one MegaLitre of water up one metre of height with a make-believe pumping system that has no energy losses. That is, in an ideal world:

Fact 8. 1 ML lifted 1 metre of height uses 9.81 MJ of energy

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Best Practice

If we use diesel energy in this perfect pumping system with no energy losses, using Fact 6 and calculating 9.81 MJ ÷ 38.4 MJ per Litre of diesel, we obtain:

Fact 9. 1 ML lifted 1 metre of height uses 0.255 Litres of diesel

If we use electricity in this perfect pumping system with no energy losses, using Fact 7 and calculating 9.81 MJ ÷ 3.6 MJ per kWh of electricity, we obtain:

Fact 10. 1 ML lifted 1 metre of height uses 2.725 kiloWatt-hours (kWh) of electricity

Unfortunately, in the real world, large proportions of the energy we put into pumps and motors is always lost, and we will always use much more than 0.255 L diesel or 2.725 kWh to lift a Megalitre (ML) of water up one metre of height. However, this analysis does provide us with the absolute minimum amount of energy used in the task of pumping one MegaLitre (ML) of water up one metre of height with diesel and electrical energy.

In the real world, as pumps and motors always work with far less than 100 percent efficiency, energy consumption to lift 1 ML up one metre will always be much larger than the values given above. Based on real world values, if the average pump efficiency was taken as 70 percent, the average drive train efficiency was taken as 95 percent, the average large diesel motor efficiency was 35 percent and the average electrical motor efficiency was taken as 90 percent, we can calculate results for the diesel driven pumping system of:

- 1 ML lifted 1 metre of height using diesel would use 1.10 Litres of diesel.

We calculated these results for the diesel pump system by taking our perfect pumping system consumption of 0.255 Litre of diesel ÷ (0.7 × 0.95 × 0.35) = 1.10 L diesel, with our realistic pump, drive train and diesel motor efficiencies respectively given in the brackets. For the electrical pumping system, we can calculate a result of:

- 1 ML lifted 1 metre of height would use 4.55 kiloWatt-hours (kWh) of electricity.

We calculated these results for the electrical pump system by taking our perfect pumping system consumption of 2.725 kWh of electricity ÷ (0.7 × 0.95 × 0.9) = 4.55 kWh, with our realistic pump, drive train and electrical motor efficiencies respectively given in the bracketed term.
With this real world pumping system, if diesel cost $1 per Litre and electrical energy cost $0.25 per kWh, as an example, we could obtain realistic pumping costs where:

- 1 ML lifted 1 metre of height using diesel would cost you $1.10, and
- 1 ML lifted 1 metre of height using electricity would cost you $1.14.

This comparison of two identical pumps, with the same type of drive train, where the only difference consists of the electrical or diesel motor efficiency highlights cost differences. The difference in your running costs to pump 1 ML of water lifting 1 metre can be calculated by substituting values for motor efficiencies and electricity and diesel costs on farm into the calculations above.

Now the height that we have used in the discussion above is representative of what we call the “Total Dynamic Head” of the pump. The Total Dynamic Head that a pump must work against consists of the following three components added together: the vertical height difference between the water supply and the water storage, the friction, and minor headloss in pipes valves, bends, and fittings in pipes.

These three components make up the Total Dynamic

Head (TDH) that the pump must work against, and is actually the height component that we have been discussing in the sections above. So re-writing Facts 9 and 10 to be theoretically sound and correct for real pumps including efficiency (Eff.) values, we obtain:

Fact 11. Diesel (L) to pump 1 ML = (0.255 × TDH) ÷ ($Eff_{.Pump}$ × $Eff_{.Drive}$ × $Eff_{.Motor}$)

and

Fact 12. Electricity(kWh) to pump 1 ML =(2.725 × TDH) ÷ ($Eff_{.Pump}$ × $Eff_{.Drive}$ × $Eff_{.Motor}$)

where the efficiency (Eff.) of the pump, drive train (belt or gearbox), and diesel or electric motor should be written using decimals (for example 0.7 for 70 percent, 0.95 for 95 percent etc). Eff. for pumps would be in the range of 0.5 to 0.9. Efficiency (Eff.) of drives = 1.0 for direct coupled or in the range from 0.9 to 0.97, depending on belt slip, or 0.95 for gearbox drives.

Large diesel motor efficiency (Eff.) would range from 0.25 (old/worn) to 0.4 (modern).

Multiply results from Facts 11 and 12 by unit energy price to provide pump operating cost.

For more information:

Visit www.cottoninfo.com.au/energy-use-efficiency

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