Department of Primary Industries

primefact

Electric Irrigation Pumps - Performance and Efficiency

January 2015 Primefact 1410
DPI Agriculture Water Unit

Tests of irrigation pumps across New South Wales have found that many were not performing efficiently, either because the wrong pump had been chosen for the job, or because the pump was worn.

If the pump is not doing its job, this can increase pumping costs and reduce productivity. To contain costs, you need to monitor your energy usage regularly and repair and maintain the pump to operate efficiently.

This Primefact describes a simple way to work out the pumping costs and the energy efficiency of your electric pump.

When you have determined the operating cost you can perform quick checks to detect any change, and when you have determined the pump efficiency, you can compare it to the manufacturer's figures to decide when repair or replacement is cost-effective.

Measuring operating costs

One way of tracking pumping costs is to work out how much it costs to pump a megalitre of water. To do this, you need to measure:

1. the power consumption rate in kilowatts (kW)

2. the flow rate in litres per second (L/s).

Combining these measures with the cost of electricity gives the pumping cost.

(Worksheets with the following steps are provided at the end of this Primefact for your use.)

Step 1: Measure the power used

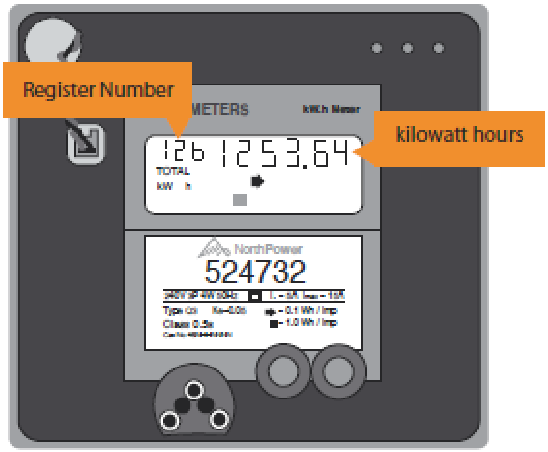
You can measure the power used by reading your electricity meter. Electronic meters are most commonly used but single and multiple meters continue to be used on many farms.

Electronic meters

Electronic meters usually measure and record the electricity used for the main rate, shoulder rate and the off-peak rate in separate registers. The various rates are switched 'on' and 'off' by the internal clock at the appropriate times.

Electronic meters record your electricity consumption in a time-of-use format. They may also have registers for the date, the time and for testing the display.

Electronic Power Meter



Each register has a 3-figure identification number. For example, the current off-peak kilowatts may be given register number '126'. You should check with your local energy authority what the display register numbers are for each of your rates.

The meter scrolls through each register at 4–6 second intervals.

- The register number appears, often in smaller numbers, on the LCD screen (in the diagram, in the top left-hand corner) and may have a short description underneath (for example: 126 — off-peak).

- The usage in kilowatt-hours appears in the larger main display. It is usually a 6-figure number (for example: 1253.64).

When the time rate that is currently being measured is reached, the number may flash. Record this number. If none of the displays flash, record the readings from all the displays.

Let the pump run for at least 15 minutes before taking the next reading.

In systems that consume large amounts of electricity, there may be a multiplier programmed into the electronics. If so, it will be noted on the electricity supplier's bill for this meter as 'Mult' or 'M' and the display may read to a couple of decimal places. If there is a multiplier, run the pump for at least 30 minutes before taking the second register reading.

If the second reading has not changed, you are reading the wrong register.

Reading an electronic meter

1st reading (register 126) = 1253.64 kWh

2nd reading (register 126) = 1254.16 kWh

Multiplier stated on power bill = 40

Power usage

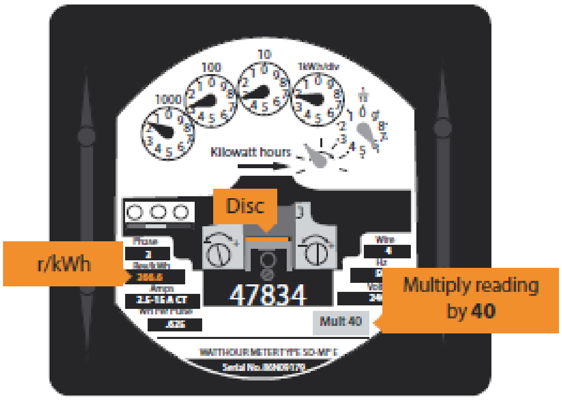
$$= \frac{(1254.16 - 1253.64) \times 40 \times 3600}{1800 \text{ (no. secs in 30 mins)}}$$

$$= \frac{0.52 \times 40 \times 3600}{1800}$$

$$= 41.6 \text{ kW}$$

Disc meters

Disc Power Meter



Reading a disc meter

Note the rating figure, the revolutions per kilowatt hour (r/kWh), marked on the electricity meter.

R (r/kWh as marked on meter) = 266.6

Next, with the irrigation system set up in an average position and running, time the spinning horizontal disc on the power meter for at least 10% of R. (In this example, R is 266.6, so 10% is about 30 revs.)

N (number of disc revolutions) = 30

T (time of test) = 386 seconds

In systems that consume large amounts of electricity, the disc may be geared down so it doesn't run too fast. If so, you will notice a multiplier 'M' is marked on the meter.

M (multiplier as marked on meter) = 40

From this data you can calculate the power usage in kilowatts.

Power usage

$$= \frac{N \times 3600 \times M}{R \times T}$$

$$= \frac{30 \times 3600 \times 40}{266.6 \times 386}$$

$$= 42 \text{ kW}$$

In this example, the pump uses 42 kW.

Perform this test regularly, over a season or between seasons, to check the pump's power consumption. If you find that it takes less time for the same number of disc revolutions than when you first tested the pump, the power use is higher, and you will need to find out why.

This comparison is only possible when the irrigation is set up in the same position as the initial test, with the same number of sprinklers, and with the pumping water level roughly the same.

Multiple disc meters

If there are three meters, for example, one for each phase of a 3-phase power supply, measure the three meters individually and add the kW figures together.

Note: Measuring each meter separately gives an accurate answer. Rarely are three meters exactly the same.

If a very accurate result is needed, you need to monitor the system over all the irrigation positions for one complete cycle. In this case you need to record the total electricity used, the total hours of use and the total amount pumped over the period.

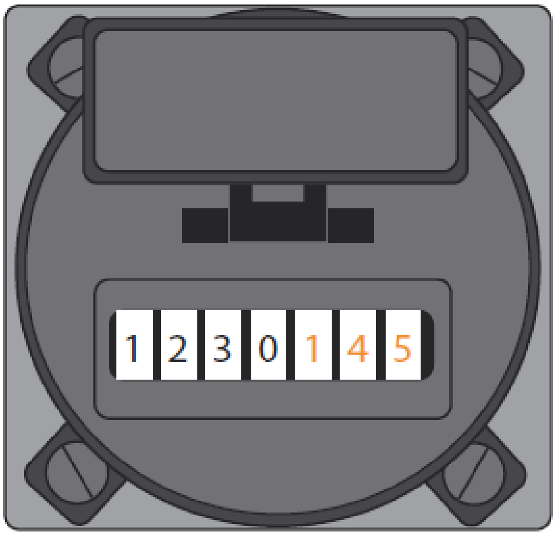
Step 2: Measure the flow rate (Q)

The second measure needed to calculate pumping cost per megalitre is the flow rate of the system (Q).

The flow rate is the amount (or quantity) of water pumped in a certain amount of time, usually given in litres per second (L/s). It should be measured after the system has had sufficient time from start-up to be running normally.

Measure the flow rate by reading your water meter at the pump for preferably the whole irrigation cycle or at least half an hour and dividing the litres pumped by the time in seconds.

Water Meter



Water meter reading at start: 1108.345 kL

Water meter reading after 35 minutes: 1230.145 kL

$$Q = \frac{(1230.145 - 1108.345) \times 1000}{35 \times 60}$$

$$= \frac{121\,800}{210}$$

$$= 58 \text{ L/s}$$

Estimating flow rate by discharge

If no water meter is fitted or it is losing accuracy, the flow rate of a spray irrigation system where all the sprinklers are the same model and size can be estimated by measuring the sprinkler discharge.

Use several sprinklers: at least one at the start of the line, one in the middle and one at the end. Record how long each sprinkler takes to fill a container (for example, a 10-litre bucket or a 20-litre drum).

To find the flow rate of each sprinkler in L/s, divide the container volume (in litres) by the time required to fill it (in seconds). You can then find the average for the sprinklers you measured.

To calculate the total flow rate of the system, multiply the average by the number of sprinklers operating.

First sprinkler takes 9 seconds to fill a 10-litre bucket = 10 ÷ 9 = 1.11 L/s

Middle sprinkler takes 8 seconds to fill a 10-litre bucket = 10 ÷ 8 = 1.25 L/s

End sprinkler takes 7 seconds to fill a 10-litre bucket = 10 ÷ 7 = 1.43 L/s

Average flow = (1.11 + 1.25 + 1.43) ÷ 3

= 1.26 L/s

There are 46 sprinklers operating, so the total flow rate is = 1.26 x 46 = 58 L/s

Step 3: Calculate the power per megalitre pumped

From the power usage and the flow rate, the kilowatt-hours per megalitre (kWh/ML) for your pump can be calculated.

This is called the ‘calibration’ value (the value used where no water meter is installed and electricity meter readings are read to infer the amount of water used).

Pump calibration (kWh/ML)

= kW ÷ (Q x 0.0036)

= 42 ÷ (58 x 0.0036)

= 201.1 kWh/ML

(Note: 0.0036 converts kilowatt-seconds per litre to kilowatt-hours per megalitre.)

Step 4: Calculate the pumping cost

Having calculated the power used to pump a megalitre, if you know the cost per kWh, you can calculate the cost of pumping.

Note: The charges per kWh may be difficult to work out exactly if your supplier has different rates for day or night, weekends, and so on. Contact your supplier for help to work this out.

Pumping costs

If supply costs 25 cents per kWh:

Pumping cost = 201 kWh/ML x $0.25

= $50.25 per ML

Some typical pumping costs for a range of irrigation systems are shown in Appendix 1.

Measuring pump efficiency

Irrigation pump efficiency is a measure of how well the pump converts electrical energy into useful work to move water. The aim of careful pump selection and regular pump maintenance is to have the pump performing as efficiently as possible (ie moving the most water for the least energy required). Efficient pump operation minimises running costs per megalitre pumped.

Pump efficiency of 70% to 85% should be achievable in most circumstances. An acceptable minimum for a centrifugal irrigation pump is 65%, and 75% for a turbine pump. An efficiency figure below these means either the wrong pump was chosen for the job, the pump is worn and needs repair or maintenance is needed.

The key to containing your pumping costs is to regularly monitor your energy usage and check on any significant change that suggests attention is needed.

To calculate pump efficiency, you need to know the flow rate (Q) and the pump pressure, or total head (H or TH) of the system. The pressure and flow that a pump is working at is called the **duty** or **duty point**. Pump efficiency varies over the range of possible duties for any specific pump.

When you have calculated the pump duty, you can compare it to the manufacturer's specifications shown in the pump's performance curves. The two efficiency figures can then be compared to see if there is room for improvement and therefore possibly a reduction in costs.

Step 5: Determine Total Head

Total Head (TH or H) or Total Dynamic Head (TDH) is the Discharge Head plus the Suction Head.

(For surface irrigation systems, skip Step 5. An adequate estimate of total dynamic head for surface systems is the vertical height in metres from source water level to the end of the discharge pipe, or, if the discharge is submerged, to the height of the water above the discharge, that is, water level to water level, plus the losses due to friction in the suction pipe.)

a. Measure the Discharge (or Delivery) Head

This is the pressure read from the gauge fitted at the pump when the system is at full operating pressure. This reading needs to be converted to equivalent metres of head. (This is sometimes called Pressure Head.)

TIP: New pumps usually have a pressure gauge installed but they often suffer physical damage quickly. A better method is to fit an access point on the delivery side of the pump where you can temporarily install a pressure gauge whenever you want to take a reading. The gauge can be easily detached when not needed.

A change in the pump operating pressure through the season or across seasons, when irrigating the same block or shift, immediately tells you something has changed. A sudden reduction usually indicates a new leak or a blockage on the suction side; a gradual reduction usually indicates wear of the impeller or sprinkler nozzles; and an increase usually suggests a blockage somewhere in the system downstream of the pressure gauge.

Pressure can be thought of as equivalent to a pipe of water of a certain height in metres. This is referred to as 'head' (H). At sea level, the pressure at the bottom of a pipe of water 10 metres high is about 100 kilopascals (kPa).

Head	Pressure
5 m	50 kPa
10 m	100 kPa
15 m	150 kPa
20 m	200 kPa
25 m	250 kPa
30 m	300 kPa

If your pressure gauge reads only in psi, convert to kPa by multiplying by 6.9.

Example:
40 psi = 40 × 6.9 = 276k Pa = 27.6 m head

b. Determine the Suction Head

Suction head is the distance between the centre line of the pump and the source water level, plus losses in the suction pipe if the pump is positioned above the water level. Typical suction head figures for centrifugal pumps are 3 to 5 metres.

Most problems with pumps positioned above the water level occur in the suction line, so ensure everything is right here. Common problems include blocked inlet or foot-valve or strainer, pipe diameter too small, pipe damaged or crushed, suction height too great, or air trapped at the connection to the pump.

Turbine and axial flow pumps must be submerged to operate, so they usually do not have any suction head.

Example: Pressure Head = 27.6 m
Suction head = 4.0 m
Total Head = 31.6 m

Another useful figure that can now be calculated is the pumping cost per ML per metre of head. This allows a meaningful comparison between different pump stations.

Pumping cost per ML per metre head:

= cost ($/ML) ÷ TH (m)

= $50.25/ML ÷ 31.6m

= $1.59 / ML / m head

Step 6: Determine motor efficiency (Me)

Electric motors have an efficiency value. That is, they lose some of the energy going into them as heat.

This energy loss changes with the size of the motor. The table below is a guideline for motors operating at full load.

Power rating	Approximate motor efficiency
Below 5 kW	82% (0.82)
5 to 15 kW	85% (0.85)
15 to 50 kW	88% (0.88)
50 to 100 kW	90% (0.90)
>100 kW	95% (0.95)

Submersible motors lose about 4% more than air-cooled electric motors (for example, where Me is 88% for an air-cooled motor it would be 84% for a submersible).

Voltage losses through long electrical cables may also be significant. This should be checked with an electrical engineer.

Step 7: Determine transmission losses (Df)

If the engine is not directly coupled to the pump, there is a loss of energy through the transmission.

This loss is taken into account by what is termed the **drive factor** (Df).

Transmission type	Energy transmitted	Df
V-belt drives	90%	0.9
Gear drives	95%	0.95
Direct drive	100%	1.0

Step 8: Calculate pump efficiency (Pe)

Pe = (Q × H) ÷ (power consumed × Me × Df)

This example includes the data from the previous steps we have discussed. The drive from the motor to the pump is a V-belt in this case.

Pe (%) = (Q × H) ÷ (power × Me × Df)

= (58 × 31.6) ÷ (42 × 0.9 × 0.9)

= 1832.8 ÷ 34.02

= 53.9%

Step 9: Calculating potential $ saving

Most centrifugal pumps are designed to operate with at least 75% efficiency, and most turbine pumps are designed to operate with at least 85% efficiency.

The pump in our example is only about 54% efficient. How much would be saved by improving the efficiency from 54% to 75%?

Our pumping cost is $50.25 per ML. The improvement is calculated as follows:

Cost saving per ML:

= $50.25 – (50.25 x (54 ÷ 75))

= $50.25 – (50.25 x 0.72)

= $50.25 – 36.18

= $14.07

If 900 ML are pumped during a season, the total cost saving is $14.07 × 900 = $12,663.

If impeller wear is the problem and the cost of replacement is $10,000, it would be paid for in less than one season. After that, the savings are all increased profit.

Notice that a reduction in the pump efficiency figure of 21% (75% to 54%) causes an increase in pumping cost of 39% ($36.18/ML to $50.25/ML).

Other factors that affect cost and pump efficiency

Two other variables affect cost and pump efficiency: pump speed and impeller size.

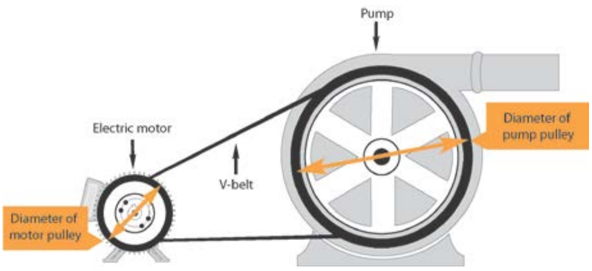
Pump speed

You must know the pump speed in order to read the pump curves. The curves are usually prepared for specific pump speeds and impeller sizes.

- If the pump is directly coupled to the electric motor, the speed is fixed by the speed of the motor: 2-pole motors run at 2900 rev/min and 4-pole motors run at 1440 rev/min.

Note: Because the speed of electric motors varies a little, it would be good to check your motor speed with a rev counter.

- If the motor is not directly coupled to the pump, the speed is altered by the gearing ratio of the transmission. Gear drives normally have the ratio stamped on the identification plate.
- The ratio for a V-belt and pulley drive can be calculated from the diameter of the pulleys on the motor and the pump (see the diagram below – ensure the pump is stopped before measuring the pulleys).



rpm of pump = rpm of motor × diameter of motor pulley ÷ diameter of pump pulley

A complication for working out the cost and efficiency is Variable Speed Drives (VSD), also known as Variable Frequency Drives (VFD). They are becoming increasingly popular as their price reduces and for the benefits they offer. These units are added to electric motors and allow the speed to be altered by changing the frequency of the alternating current. They allow electrically driven pumps to have their speed set at exactly what is required for the pump duty and they eliminate the need for throttling the irrigation system using valves.

Savings of one quarter of the usual power consumption are often reported by irrigators, and may be as much as half depending on the situation.

For determining the cost and efficiency of a pump, the measurements outlined in this Primefact should be made several times with the pump set at different typical speeds.

Impeller size

Impeller wear has the same effect as a reduction in impeller size.

You need to know the size of impeller fitted to your pump to work out which performance curve applies to your pump. Sometimes the impeller size is stamped on the pump's ID plate. If not, you need to find out the size by dismantling the pump and measuring it, or asking the person who made the change.

Sometimes an impeller is deliberately reduced in diameter to adjust the pump's performance and obtain a specific duty.

To give a range of duties, manufacturers may offer impellers of different diameters for the same pump casing.

Available impeller sizes are shown on the pump curves.

Power factor

Power factor may substantially affect your running costs and perhaps the operation of your pump as well. This is not an intrinsic factor of the pump itself, but information is provided in Appendix 2.

In conclusion

Keeping track of your pump's performance and costs is not difficult. It may save you a lot of money and keep your irrigation system performing properly

Worksheets are included with this Primefact to help you measure your pump performance and efficiency. If you identify your pump is operating below the acceptable minimum level, check the internal condition for wear or maintenance and the suitability of the pump for its current duty, or take steps to improve the drive or replace it with a VSD.

More information

Primefact 1411 Selecting an irrigation pump

Origin Energy
http://www.originenergy.com.au/files/EnergyFactSheet-PowerFactorCorrection2008.pdf

Acknowledgements

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Agfact E5.10, first edition, January 2003, Peter Smith and Alan Richards Irrigation Officers, Tamworth and Paterson

Agfact E5.11, first edition November 2003, Alan Richards, Irrigation Officer Maitland, and Peter Smith, Irrigation Officer Tamworth

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Appendix 1: Typical costs

Typical Electric Pumping Costs for Different Irrigation Systems ($/ML)					
Irrigation System	Total Head (m)	Electricity Cost per kWh			
		$0.25	$0.30	$0.35	$0.40
Flood Furrow	**10**	11.31	13.57	15.83	18.10
Lateral Move	**30**	33.93	40.72	47.50	54.29
Centre Pivot	**60**	67.86	81.43	95.00	108.58
Drip	**50**	56.55	67.86	79.17	90.48
Spray line	**55**	62.21	74.65	87.09	99.53
Traveller - Medium Pressure	**70**	79.17	95.00	110.84	126.67
Traveller - High Pressure	**100**	113.10	135.72	158.34	180.96

Appendix 2: Power factor

With alternating current (AC) electrical power, both the voltage and the current (amps) alternate polarity between positive and negative. At the power generator, both the volts and the amps are alternating at the same time. However, during each alternating cycle, depending on the type of load, some energy is temporarily stored in electric or magnetic fields and returned to the power grid a fraction of a second later. Appliances with resistive electrical loads (such as heaters, stoves, etc.) have no effect on the timing of the amps and voltage in each cycle. This means the power generated is the same as the power used by the appliance, and the power factor is 1.0. But appliances with inductive loads (such as transformers, motors, etc. – anything with a type of wound coil) cause the amps to lag the voltage. When this occurs, some of the power generated is not available for the appliance to use, so the power factor is less than 1.0.

The appliance still requires its full power demand so the extra power has to be generated and transmitted down the system. The consequence is that the consumer is charged for this extra power. It also means that the transmission system must have enough capacity for the higher power ie. higher capacity cables and components. If the sustained power factor is low enough, the extra power required may overload the cables, connectors, etc. so power companies may refuse to supply electricity to consumers with poor power factor. If the available power becomes sufficiently low, voltage drops may be experienced. Excessive voltage drops can cause overheating and premature failure of motors and other inductive appliances.

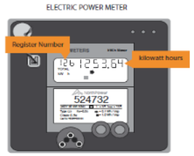
For electric induction motors specifically, low power factor results by running them lightly loaded. A motor must be operated near its rated load in order to realize the benefits of a high power factor design. Power factor is also improved by not operating equipment above its rated voltage, and by replacing standard motors with energy-efficient motors.

Until recently, determining the power factor required specialist measurements. Now, there are meters available that provide the power factor on the spot. Unfortunately, power factors measured in irrigation farms of 0.8 or less are common.

A power factor of anywhere between 0.9 and 1 means your business is using its energy effectively. However a power factor of below 0.9 may mean your business is using energy ineffectively, resulting in unnecessary electricity expenses. A figure of 0.95 is considered a practical maximum.

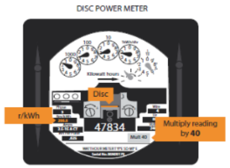
The good news is that poor power factor can be corrected. Where inductive loads cause the amps to lag the voltage, capacitance loads cause the amps to lead the voltage. Capacitors store and release energy in a directly opposite manner to an inductor. When the circuit is balanced, all the energy released by the inductor is absorbed by the capacitor. A capacitor provides the power that is needed to start up and magnetize the motor, thus eliminating the need to get it from the electric grid.

Power factor can be improved by installing Power Factor Correction equipment called Capacitor Banks. Capacitor Banks work to correct energy supply inefficiencies and reduce peak demand on the electricity network.



PUMPING COSTS WORKSHEET – ELECTRONIC METER

Electricity meter	Worked example	Your readings	Your readings
1. Register reading at start (R1)	1253.64		
2. Register reading at finish (R2)	1254.16		
3. Time between readings (T)	1800 seconds (30 min)		
4. Multiplier as stated on power bill (M)	40		
5. **kW per meter** $= \frac{(R2 - R1) \times 3600 \times M}{T}$	$= \frac{0.52 \times 3600 \times 40}{1800}$ = 42 kW		



PUMPING COSTS WORKSHEET – DISC METER

Electricity meter	Worked example	Your readings	Your readings
1. R/kWh as marked on meter (R)	266.60		
2. Multiplier as marked on meter (M)	40		
3. Number of disc revolutions (N)	30		
4. Time duration (T)	386 seconds		
5. **kW per meter** $= \frac{N \times 3600 \times M}{R \times T}$	$= \frac{30 \times 3600 \times 40}{266.6 \times 386}$ = 42kW		

PUMPING COSTS WORKSHEET – CONTINUED

	Worked example	**Your readings**	**Your readings**
6. Flow rate (Q)	58 Litres per second		
7.**Pump calibration** = $\frac{kW}{Q \times 0.0036}$	= $\frac{42\ kW}{58 \times 0.0036}$ = 201 kWh/ML		
8.**Pumping costs** (@ 25 cents/kWh)	= 201 × \$0.25 = \$50.25 per ML		

PUMP EFFICIENCY WORKSHEET

	Worked example	**Your readings**	**Your readings**
1. Power consumption (kW)	42 kW		
2. Flow rate (Q)	58 L/s		
3. Pressure gauge at pump	276 kPa x 0.1 = 27.6 m		
4. Suction lift	4 m		
5. Total head (H)	= 27.6 + 4.0 = 31.6 m		
6. Motor efficiency (Me)	70 kW motor = 0.9		
7. Transmission loss (Df)	V-belt = 0.9		
8. **Pump Efficiency** (Pe) Pe = $\frac{Q \times H}{kW \times Me \times Df}$	= $\frac{58 \times 31.6}{42 \times 0.9 \times 0.9}$ = 53.9%		