Pumping Energy Efficiency - more than just testing pumps

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Abstract:

Testing pumps to determine pumping energy efficiency results in only part of the pumping energy efficiency answer.

This paper explores the "unseen and often unrecognised" areas of pumping energy efficiency, namely those associated with the hydraulic efficiency of the pipeline delivery system.

Traditional energy efficiency audits have concentrated on testing the pump's absolute efficiency as well as identifying any OFF-BEP (Best Efficiency Point) operation.

This approach ignores the "elephant in the room", the hydraulic efficiency, which in turn is solely a function of pumped head.

Examining hydraulic efficiency includes any items which will result in a reduction of friction head, such as pipeline optimisation, predictable pipeline performance deterioration, filter configuration, excess residual head and others.

Pumping system energy efficiency incorporating hydraulic efficiency can be optimised either in the design stage, which results in a "fit for purpose" pumping system or resulting from an audit of an aged pumping system, in which case some capital expenditure may be required to optimise pump performance, paid for with pumping electricity savings.

The author has extensive experience in this field, having identified over $600,000 worth of achievable annual pumping electricity costs over the last 6 years on 13 irrigation systems in Australia, with an average return on investment (ROI) of 2.0.

The presentation will show case some of the findings of these audits.

Pumping Energy Efficiency - more than just testing pumps

Introduction

Testing irrigation pumps is the time-honoured method of establishing the pumping energy efficiency.

This involves measuring the flow rate, pump head and input energy, usually electrical kW, to establish a pump hydraulic efficiency.

There are two parameters that are sought in a pump test:

1) The absolute pump efficiency, a measure of the mechanical condition of the pump. With the efflux of time, pumps wear and become less efficient, therefore require periodic testing.
2) The point at which the pump is working relative to its Best Efficiency Point (BEP). Pumps operating at a duty too far left or right of BEP will be less efficient, even though the pump is in top condition.

There is a third crucial parameter which is not regarded as part of pumping energy efficiency, and yet it has a profound influence on pumping costs.

That is pipeline hydraulic efficiency (and associated equipment). Items such as pipeline friction, pipeline ageing, filters, hydraulic valves, emitters and residual head, in fact any component which results in a friction head component.

And it doesn't stop there. If an irrigation system is deficient in residual head, low emitter CU's and DU's will prevail, meaning that the irrigation scheduling co-efficient will be raised to compensate, resulting in up to 20% more water pumped. That's 20% more pumping energy used!

It is the authors experience, after 50 years in pumping and hydraulics, having conducted over 1300 pump tests and dozens of pipeline friction tests, that there is as much pipeline hydraulics energy efficiency losses existing in irrigation systems as there is pumping hydraulics losses.

This presentation highlights some of the authors findings.

Theory

The formula[1,2] for calculating the annual cost of electrical energy for irrigation pumping is:

$$\$/yr = \frac{2.73 \times (\textbf{pumped head in metres}) \times (\$/kWh) \times (ML/yr)}{(\textbf{Pump } \eta) \times (\textbf{motor } \eta)}$$

This can also be expressed as:

$$\$/yr = \frac{3.15 \times (\textbf{pumped head in feet}) \times (\$/kWh) \times (MgUS/yr)}{(\textbf{Pump } \eta) \times (\textbf{motor } \eta)}$$

Accordingly, the principle variable parameters for pumping energy efficiency are:

- Pumped head
- Volume pumped
- Pump efficiency
- Motor efficiency

} covered in testing pumps

Pumped head is one of the principle parameters for measuring pumping energy efficiency

However, pumped head is **the** principle parameter for measuring pipeline hydraulic efficiency.

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Pump hydraulic efficiency

Pump efficiency is defined by three essential components[1]:

- Pumped head (metres/feet)
- Pumped flow rate (litres per second/gpm)
- Electrical energy input (Electrical kilo Watts [EkW])

Since the concept and practice of pump testing irrigation pumps is universally accepted and well understood, and because of time limitations of this presentation, only assessing pipeline hydraulic efficiency will be discussed.

Pipeline hydraulic efficiency

Since pipeline hydraulic efficiency is essentially the friction of the pipeline delivery system, hydraulic efficiency includes, but not limited to:

1) Pipe friction optimisation
2) Pipe performance deterioration
3) Filter losses
4) Excess Residual head

We are going to examine these applications of hydraulic efficiency and quantify the contribution that they make to pumping energy efficiency.

1) Pipeline friction optimisation

All pipes have friction losses, which equate to energy costs in pumping. Keeping these costs to a minimum but at the same time minimising pipe costs is a process called optimisation.

Therefore, assessing a pipe’s friction losses is critical to determining if the correct size pipe has been used, and assessing if it is economical to duplicate or replace a pipe to reduce pumping costs.

This process is ideally made in the initial design process, where the higher capital costs of a larger pipe selection will be more than be offset with lower pumping energy costs.

The process can also be made as a result of a field audit, however, the economics are less attractive since the cost of the optimised pipe solution is actually added to the original pipe cost.

Both processes involve using software which can calculate Nett Present Value (or amortised costs) for the electricity costs of a pipeline given a range of operating parameters.

Example

Compare the following two pumping systems: (NOTE: numbers rounded/estimated)

Both systems: 1 km (0.6 mile) pipe, pumped flow rate 50 l/s (792 USgpm) and 200ML (53 MgUS)/yr

	System 1	System 2
Pipe size	150NB (6”)	200NB (8”)
Pipe cost (est)	$42,000	$55,000
Friction loss	45m (148 feet)	11m (36 feet)
Pump cost (est)	$25,000	$15,000

Electricity cost/yr	$8,800	$2,200
Electricity cost/15 yrs	$163,000	$40,000
Total LLC pipe+pump+15yr/elect	$230,000	$110,000

The larger pipe/smaller pump combination saves $120,000 over 15 years.

This is an example of pipeline optimisation. Ideally, more calculations should be carried out with other pipe diameters, to achieve the lowest Life Cycle Costing (LCC) for the pipe+pump+15yr/electricity cost.

2) Pipe performance deterioration

The day after an irrigation pipe is placed into service, its performance has already commenced to deteriorate. Pipes which pump raw river, dam water or recycled water are particularly prone to a steady drop in performance due to biofilm build-up, especially in warm weather.

New PVC and Poly pipes above 6" (150NB) have a Hazen & Williams (H&W) C value (friction factor) of around 155. It's a reasonable chance that within a year, the pipes' C value may be down to 140 (10% drop) and continue downwards thereafter. The hotter the climate, the worse the effect, as biofilm thrives with warmth.

Glacial melts are not immune to this. In New Zealand South Island (lat 45 deg), glacial flour is a common component of glacial river water and is known to significantly deteriorate pipe performance over time(3).

What that means is that over time, there's higher friction than originally designed for these pipes.

So, either there will be a deficit in operating pressure (lower irrigation efficiency) or if the pumping system has a VFD and surplus HQ capacity (unlikely), higher operating costs as the pump is ramped up to overcome additional pipe friction.

Water Authorities in Australia, such as Goulbourn-Murray Water recommends derating PVC and Poly pipe performance 10% at design stage to allow for pipe performance deterioration.

South Australia's SA Water has traditionally designed pipeline systems off the River Murray with low range C Values as low as 110(4).

The author's experience would indicate that a 20% derating after 10 years is reasonable when using unchlorinated river or dam water, or recycled water.

A 20% reduction in H&W C Value means that for the same head loss, 20% less flow can be pumped, or for the same flow to be maintained, approx. 40% additional friction losses will occur.

Cases of up to 60% pipeline performance reduction over 10 years have been found due to iron hydroxide or contamination from river borne Bryozoa, aquatic invertebrate animals, typically about 0.5 millimetres (0.020 in) long (5), both of which attach to the inside pipe wall.

The alternative to allowing for pipeline performance degradation is to design pigging entry and exits infrastructure into pipeline systems, predicted to suffer from performance degradation. This is now becoming a more common practice in Australia with those designers "in the know".

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Case Study 1

"There's a wheel barrow in my pipeline"[(6)]. This is a colloquialism meaning there's an unexplained head loss in my pipeline. An associate approached the author in 2000 saying there was a wheel barrow in his pipeline and asked the author to find it!

His pumping system delivering recycled water through a 450NB PVC (18") pipe 10km (6 mile) long to a storage dam had sustained a 10% increase in pumped head and 15% increased energy cost over 18 months.

A detailed pipeline friction audit conducted by the author determined that the loss in pumping energy efficiency was only attributed to the increase in friction in the pipeline, caused by a build-up of biofilm.

The pipeline was pigged, which then restored the pumping energy efficiency to like new.

This experience led to a permanent pigging entry point being installed at the pumping station.

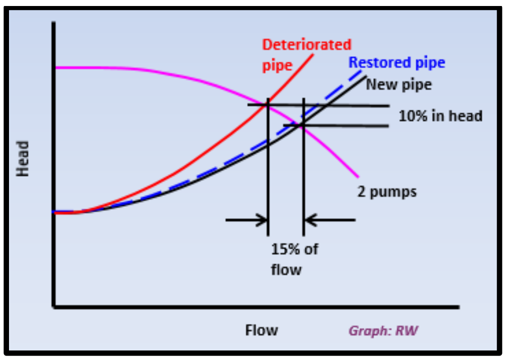

Figure 1: A new recycled water irrigation pumping system at Christies Beach, SA, in 1999 suffered a 15% electricity cost increase ($2,500) over 18 months. The cause was found to be biofilm build-up in the pipeline. Pigging the pipe restored its performance. This chart shows the performance reduction in terms of the increase in system curve steepness, resulting in a reduction of pump output.

Case Study 2

The author conducted a detailed pressure and flow audit on a turf farm[(7)] pumping and pipeline delivery system, feeding river water at 28 l/s to a 200m (660 feet) long lateral move.

The pump was costing about $12,500 /yr in electricity.

The pumping system had been twice audited over the last 5 years by a "qualified" irrigation auditor and given a clean bill of health.

The results from the authors audit was that the pump, despite being 30 years old, was well maintained and was 65% efficient, down from 75% but due entirely from operating too far left of BEP.

The pipeline returned a friction value of H&W C Value = 80, down from new pipe approx 155. Pigging the pipe revealed that it was severely affected with iron hydroxide.

Despite iron hydroxide water usually having a tell-tale brown water stain, the water was absolutely clear with no staining apparent.

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Over its 15 years of service, it appeared that, as the pipeline deteriorated in performance, the pump was progressively speeded up by changing the belt drive ratio, there being plenty of power available and the flows were reduced by variously configuring the type of irrigation with reducing flow rates. However, no one identified the deteriorating pipe performance as the problem.

The additional pumping electricity costs due to the increased pipe friction loss was $5,200/yr, or 43%. Amortised at 3.5% with an electricity price index of 7%pa, that's equal to $58,000 over 15 yrs. That was the same as the cost of replacing the pipeline and fitting a VFD to the pump!

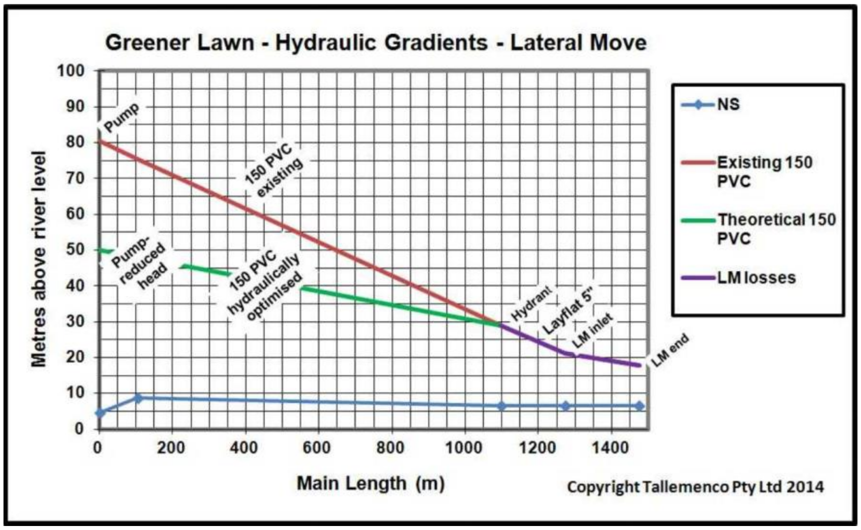

Figure 2: Hydraulic grade lines shows both the new pipe performance (in green) and existing performance measured on site (in red) of the 1km (0.6mile) of 150NB (6") PVC pipeline on a turf farm the author audited in NSW in 2014. The additional electrical energy due to the clogged pipe, amortised over 15 years, was equivalent to replacing the pipe and fitting a VFD.

3) Filter losses

The selection of a filter that's too small for the job (lower capital cost) will result in a higher head loss and therefore a higher energy cost. In addition, the filter will backflush more frequently, resulting in a shorter life. The ultimate cost will likely be many times the initial cost saving.

A filter that is too large or unsuitable for the job will result in significantly higher backflush flow rates, which can damage pumping equipment and result in low irrigation efficiency, hence higher pumping costs.

<u>Cast Study 3:</u>

A recycled water irrigation pumping system designed and commissioned by the author (as an employee of Hydrotech Aust) was installed in an irrigation system at Sanctuary Cove, Gold Coast, QLD, in 1997.

It was designed to operate ultimately with 2 pumps and two filters but was installed in Stage 1 with only one pump and one filter. The client later added a second pump, but did not add the second filter, to save costs.

The author, in the capacity of an independent consultant, was called to site about 10 years later, to discover that the single filter had a history of wear and malfunction. The addition of the second filter would have averted this situation.

Figure 3: A recycled water irrigation pump station was installed initially with one filter, one pump. Later, the second pump was added, but not the second filter. This resulted in significant maintenance and early failure of the single filter. In addition, when the second pump was installed, the clean water head loss across the filter increased from 1m (3') to 4m (13'), a 3 metre (10 feet) head loss increase, costing approx $5,000 over 15 yrs in pumping electricity costs.

Case Study 4

A three pump recycled water pumping station was designed and assembled by the author in 1999 (whilst an employee of Hydrotech Aust Pty Ltd), to specifications for a contractor acting on behalf of a golf course in central NSW. The pumping system was installed by the contractor, but no commissioning was requested.

The author, out of personal interest and passing by the golf course 11 years later, called in to see how the unit was performing.

The Superintendent, eager to vent his frustration, explained that the pumps and VFD's had suffered significant failure over the 11 years.

A brief visual audit (free of charge) established that (unbeknown to the author at the time the pump system was supplied) four x 48" media filters were deployed after the pumps. The filter backflush flow rate added 50% addition flow rate over and above the pumps' maximum output. As no pressure sustaining valve was ever installed, the pumps spent much of their life running off the end of their curve and cavitating.

This is a case of simply the wrong filter selection, and no local knowledge to recognise the problem that it produced.

The energy efficiency cost of this disaster can only be imagined. It could be measured in terms of pump down time labour, pump and VFD repairs, plus a significant amount of additional pumping to overcome the extremely poor CU's and DU's which would have resulted from irrigating with virtually no field pressure for the duration of 4 x 48" media filters backflush, probably 40 minutes each backflush cycle.

The water source was a recycled pond adjacent to the pumping station and was overloaded with algae, meaning that the filter likely backflushed frequently.

The author's offer to the Local Council (who administered the golf course) to rectify the design was rejected.

Figure 4: This collage of photos shows a three pump system teamed up with a massive 4 x 48" media filtration system, requiring a flow output 50% in additional to the pump system capacity during backflush, but which was not allowed for. With no pressure sustaining valve, the result was that the pumps and VFD's suffered periodic failure, not to mention the significant field pressure loss during backflush and hence low CU's and DU's to the golf course it served.

4) Excess residual head

All emitters require a nominal head pressure to correctly operate. This value is always defined by the emitter manufacturer. To ensure this head is always available, a margin is usually built in to the pumped head in the design stage, usually up to 5 metres head (16 feet), to ensure that there is always sufficient operating head at the emitter.

However, some irrigation systems operate with excessive residual heads, resulting in excess energy consumption.

(Probably many more operate with less head than required, but that's a story for another presentation!)

Case Study 5

The author was commissioned by a Victorian Govt Dept to undertake audits[8] on a sample of vegetable farms in the Gippsland, VIC.

A pump supplying water from a river system delivered water to a 200m (660 feet) long Lateral Move (LM). The audit revealed that the surplus head at the end of the lateral move was 11m (36 feet). This is 6m (20 feet) more than is required.

Considering the total pumped head required for this LM was only 38m (125 feet), the excess represents a 16% energy efficiency impost. This amounted to $680/yr electricity costs, or $12,900 over 15 yrs.

A simple impeller trim would have optimised this LM's pumping energy efficiency, costing about $1,000, with a ROI of 1.5.

A VFD fitted to this pump would have optimised its energy efficiency, with a cost of $5,000, or a ROI of 7.3 years.

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Additional excess head losses (7m or 23 feet) were also identified in the layflat hose supplying the LM, contributing even more energy efficiency losses, at 18%.

The pump itself was measured at 68% efficient, deemed not worth any attention.

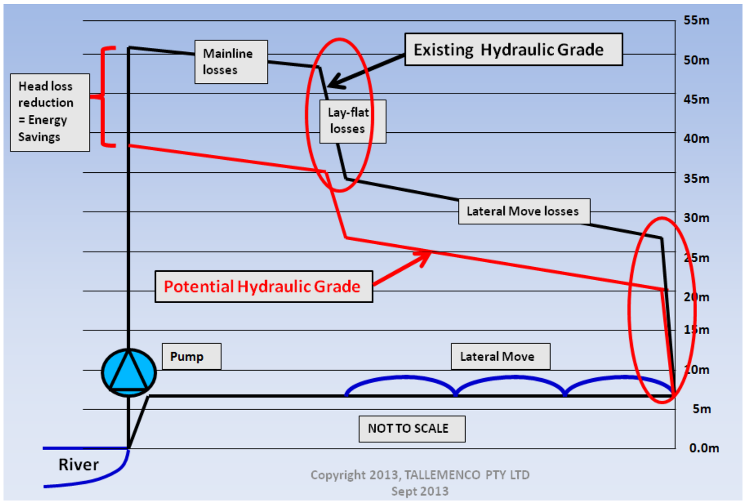

Figure 5: Hydraulic Gradients (HG) above indicates just where the head losses were occurring on this lateral move irrigation system. The black HG line indicates the existing system, the red HG line indicates an energy optimised system. Energy savings of $680/yr (or 16%) were achievable by reducing the LM's excess residual head simply by trimming the pump impeller.

Conclusion

Testing pumps to determine pumping energy efficiency is important, but only represents part of the pumping energy efficiency story in an irrigation system.

Pipeline energy efficiency is the "elephant in the room" representing a major component of pumping energy efficiency.

Components such as pipes being too small, pipe performance being degraded over time with silt and biofilm, and poorly sized irrigation system components such as filters, hydraulic valves and emitters all contribute to significant pumping energy in-efficiencies.

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