PUMP CENTRE CONFERENCE 2014

The role of real time pump performance measurement in the realisation of '*fit for purpose pumping*'

Date: **27th March 2014**

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1 Synopsis

Pump performance monitoring can be used in conjunction with a decision support system to provide real time instructions guiding operators to the minimum possible operational cost for a pumping system - much like a SAT NAV system does for car drivers. Three case studies have been presented demonstrating savings between £326k and £1.17M from pump scheduling alone – with the data generated also being used to plan upgrade work with total potential savings of 46%.

2 Introduction

Historically the cost of energy has been subsidised by the environment and as the effect of this has been progressively realised then there has been a disproportionately large increase in the consumer cost of energy. Using the water industry as an archetype the average UK household rise in water charge has increased by 64%[1] over the last 10 years as opposed to an increase of 91% for domestic electrical energy[2]. Furthermore the industrial rate for electrical energy has risen by some 200%.

Figure 1: Electrical energy and water price indices

[1]http://www.bbc.co.uk/programmes/b006mg74/features/uk-water-bills-price-increase
[2] https://www.castlecover.co.uk/historic-home-utility-prices/

Considering '*all other things being equal*' then the only way for a water company to maintain profit is to reduce the unit cost of delivery, i.e. increase efficiency.

Improvements in technology have the potential to greatly assist with this mandate but suitable selection and deployment can often only be achieved through measurement leading to informed decision making; borrowing the adage;

…if you can't measure it – you can't improve it
Lord Kelvin 1880

By far pumping consumes the greatest quantity of electrical energy in water company operations and, indeed, often forms some 20% of process operations making the knowledge of pump performance a key metric in many industrial process.

The 'fingerprint' of a pumps performance is essentially the suite of graphs it was delivered with…

- Total Differential Head,
- Electrical [or Mechanical] Power,
- Hydraulic Efficiency and
- Volumetric Flow Rate

…only, and most importantly, updated for the current performance and not when new. Therefore step one of pump monitoring is to be able to effect measurement of these key parameters.

Therefore the challenge is to reduce the pump operating cost to a minimum and this can be achieved through pump performance monitoring and an associated decision support systems to provide instructions based on the results.

3 Methods of pump performance measurement

Numerous methods and types of equipment exist to measure pump performance under different circumstances; however these can be broadly grouped into two categories;

Conventional (pressure – volume) method	BS EN ISO 9906:2012 IEC 60041 ISO 5199
Thermodynamic (enthalpy – entropy) method	BS EN ISO 9906:2012 IEC 60041 ISO 5198/9 Pump Centre 69527

Table 1: Standards for pump performance measurement

A brief description is supplied whereby each method relies on the premise the efficiency is defined as the ratio of power OUT from the pump, divided by power IN

3.1 Conventional method

The conventional method computes the output power of the pump through measurements of differential pressure across, and volumetric flow rate through, the pump. The input power to the pump is usually obtained by measurement of gross electrical power and an assumption of motor efficiency – a typical layout is present in Figure 2.

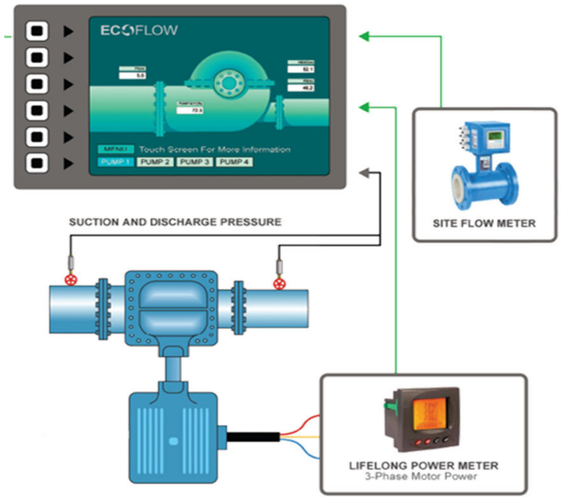


Figure 2: Conventional test method schematic

Therefore the hydraulic efficiency (η_H) would be evaluated by the following expression;

$$\eta_H = \frac{OUT}{IN} = \frac{Water\ Power}{Shaft\ Power} = \frac{\rho\ g\ H\ Q}{P_e\ \eta_m}$$

Equation 1

Where;

H = Total differential Head (m) – essentially Bernoulli's equation outlined in ISO5199 from measurements P_s and P_d
Q = Volumetric Flow Rate (m^3/s) – measured by electromagnetic, ultrasonic and other flow meters
P_e = Active Electrical Power (kW) – measured by a 3ϕ power meter
η_m = Motor Efficiency (%) – an informed assumption or OEM supplied characteristic
ρ = Fluid Density – from BS accepted definitions (have to measure fluid temperature to fully comply)
g = Acceleration due to Gravity (m/s^2)

A summary of the features of this method are;

- Resilient for all head ranges from zero upwards
- Requires the measurement of flow rate, therefore;

- Suitable and accurate for a test loop
  - Mostly unsuitable for site use due to absence of straight pipe in the individual pump main
- Any errors in flow rate measurement are propagated directly to an error in pump efficiency computation
- Simple mathematics for beginners

3.2 Thermodynamic method

First documented by a French scientist in 1912 the then named Thermometric technique used an enthalpy – entropy mapping method to determine pump efficiency without the need for flow rate measurement.

The premise is rooted in fundamental thermodynamics in that if you measure any two thermodynamic state variable's (TSV) (which include temperature and pressure) then you can calculate any other TSV (which include enthalpy and entropy).

Expanding upon Equation 1,

$$\eta_H = \frac{OUT}{IN} = \frac{OUT}{OUT + LOSSES} = \frac{1}{1 + \frac{LOSS}{OUT}}$$

Equation 2

Where;

$$LOSSES = \rho\, C_P\, \Delta T\, Q$$

and

$$OUT = \rho\, g\, H\, Q$$

Expanding Equation 2 reveals;

$$\eta_H = \frac{1}{1 + \frac{\rho\, C_P\, \Delta T\, Q}{\rho\, g\, H\, Q}} = \frac{1}{1 + \frac{C_P\, \Delta T}{g\, H}}$$

Equation 3

Where;

C_P = Specific Heat Capacity of the fluid – from BS accepted definitions (have to measure fluid temperature to fully comply)
ΔT = Temperature differential across the pump (m°K)

Therefore Equation 3 demonstrates that the efficiency of a pump can be calculated by measurements of pressure and temperature only without the need for flow rate measurement.

Thus so far the 'fingerprint' of the pump has been established except flow rate, which can now be calculated by the rearrangement of Equation 1;

$$Q = \frac{P_e\, \eta_m\, \eta_H}{\rho\, g\, H}$$

Therefore completing the measurement procedure for the pumps' performance by the Thermodynamic method. A typical layout is presented in Figure 3 below.

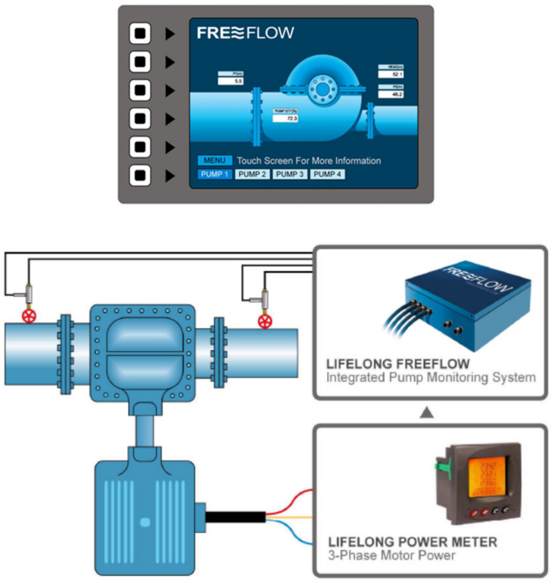


Figure 3: Thermodynamic test method schematic

A summary of the features of this method are;

- Pump efficiency can be measured through a ½" BSP tapping on each side of the pump – see Figure 4

- Doesn’t require the straight lengths of the pipe as with the conventional method
- Excellent for in-situ, on-site pump performance monitoring
- Superior accuracy at higher heads
- Purchase cost is lower and irrespective of pump size
- Installation cost is low
- Accuracy at low heads <10m is poor
- Requires very accurate difference thermometer sets 0.001°C

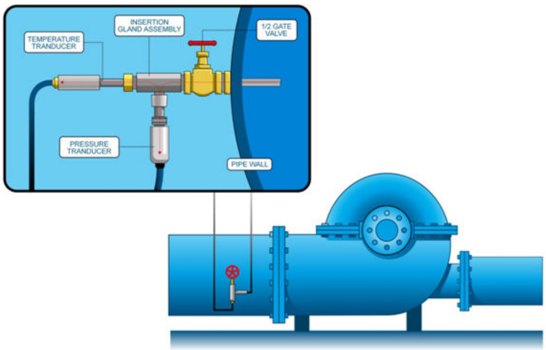


Figure 4: Transducers tapping point

3.3 Comparison of the two methods

A brief comparison has been annotated to describe the applications best suited to each method;

The Conventional method…

- is costly to implement, on site, requiring a flow meter on every pump
- it is usually not possible to install a flow meter in each pump due to physical space constraints which also limit the accuracy of application
- is well suited to test loops but not for site use
- has no upper or lower head limitations

The Thermodynamic method….

- is comparatively low cost for site use purchase
- has simple installation requirements and as such is low cost to install
- is not dependent on straight lengths of pipe to effect an accurate measurement
- is well suited to on site application, generally for heads >15m
- has head limitations to obtain the best accuracy

The outcomes are the same for each method, measurement of head, power, efficiency and flow rate but each method is suited to different applications.

Therefore; *for +100 year old technology why isn’t the Thermodynamic method more widely deployed in the pumping industry?*

The principle reason has been the requirement to measure very small temperature differentials which has been much improved of late with the advent of the semiconductor industry.

A further reason is not related to the measurement technology but to the downstream information system which produces an outcome from the measurement, i.e. the software decision support system. Great strides have been made in hydraulic analysis methods and most importantly how pumping station operatives interact with such a system to overcome the cultural barrier to adoption.

4 What does modern day system look like

Data Acquisition Unit (External)

Data Acquisition Unit (Internal)

Transducers

5 How can this data be used to achieve 'Fit for Purpose Pumping'?

When measured, in real time, and stored in an historian the data will provide quantified information on;

- Pump curves
- System curve(s)
- Demand profile (load characteristics)

With this information it is possible to create an expert system / decision support system (DSS) to compute the most efficient combination of pumps, and speeds, to meet the current operation duty – or any other specified duty.

With dynamic systems like distribution zones or tank level changes, where the system curve is not constant, the head and consequently pump efficiency will constantly change – and so a real time pump scheduling system is required.

Such a set-up is akin to a Satellite Navigation system for the operative of a vehicle; providing real time instructions which update as the circumstances change; like traffic congestion or road closures.

The DSS is not guaranteed to save energy, as with some magic additive you put in your fuel tank, it will only ensure that the station is running at its lowest possible operating cost for the available plant. However it is unlikely that the station will currently be operated at its lowest cost by virtue of the mass of potential pump combinations; for example a station with 10 fixed speed pumps will have 1023 possible combinations to choose from and if they are variable speed pumps the combinations are infinite!

Therefore a structured and automated method is required to compute the efficiency (or specific power) of all possible combinations under all possible circumstances.

The DSS will effectively ensure that where ever the pumping station is required to operate, it will be operate at the lowest attainable operating cost.

6 Case study #1: UK water company, large high lift station

An international organisation operating a water company in the UK contracted DERITEND and RIVENTA to install a real time thermodynamic pump efficiency monitoring system with a decision support system which integrated via MODBUS to the corporate SCADA system.

There are 11 pumps, 2 of which are not used, ranging in motor rated power between 750kW and 1600kW; with 7 units driven by dated variable speed drives.

The head ranges between 80 and 95m and normal flow rates are between 150 and 300 MLD.

The key facts are presented next, annualised;

- Energy used **39 GWh**
- Energy cost **£3.7 M**

A month long pump monitoring assessment period, to understand the current operating regime, showed that there were large variations hydraulic and financial operating behaviour. The variation in pump efficiency of a group of pumps is displayed below.

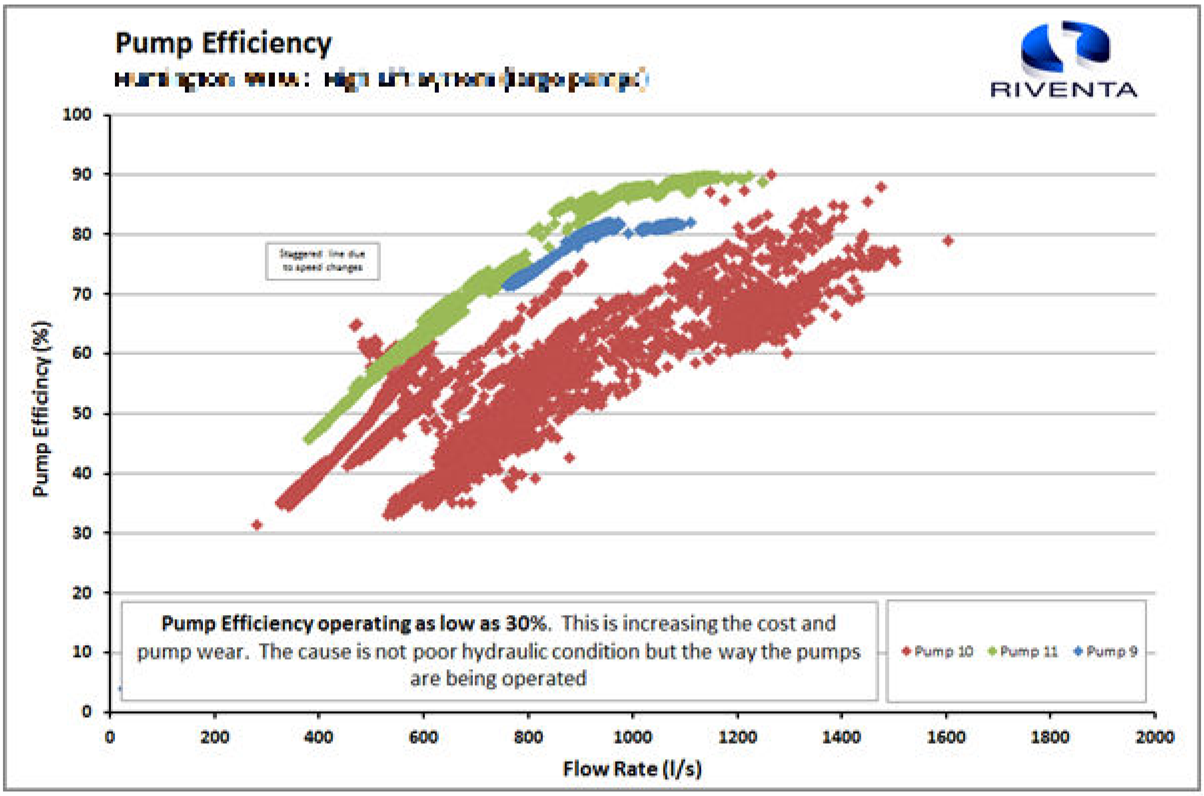


Figure 5: Pump Efficiency

Summary of the large pumps

- A **244%** variation was observed in the operating cost to deliver 1 million litres for the large **pumps 9, 10 and 11**
- The cost of delivering water, with pumps 9-11, varied from **£20/Ml** to **£69/Ml** according to how they were operated
- The pump efficiency of the large pumps varied from **32%** to **89%** due to the current operating regime

Summary of the small pumps

- A **16%** variation has been observed in the operating cost to deliver 1 million litres for the small **pumps 3, 6 and 7**
- The cost of delivering water, with pumps 3, 6 and 7, varied from **£27/Ml** to **£31/Ml** according to how they were operated
- The pump efficiency of the small pumps varied from **80%** to **85**%.

The financial implications of these hydraulic variations can be seen in the variation of specific power overleaf

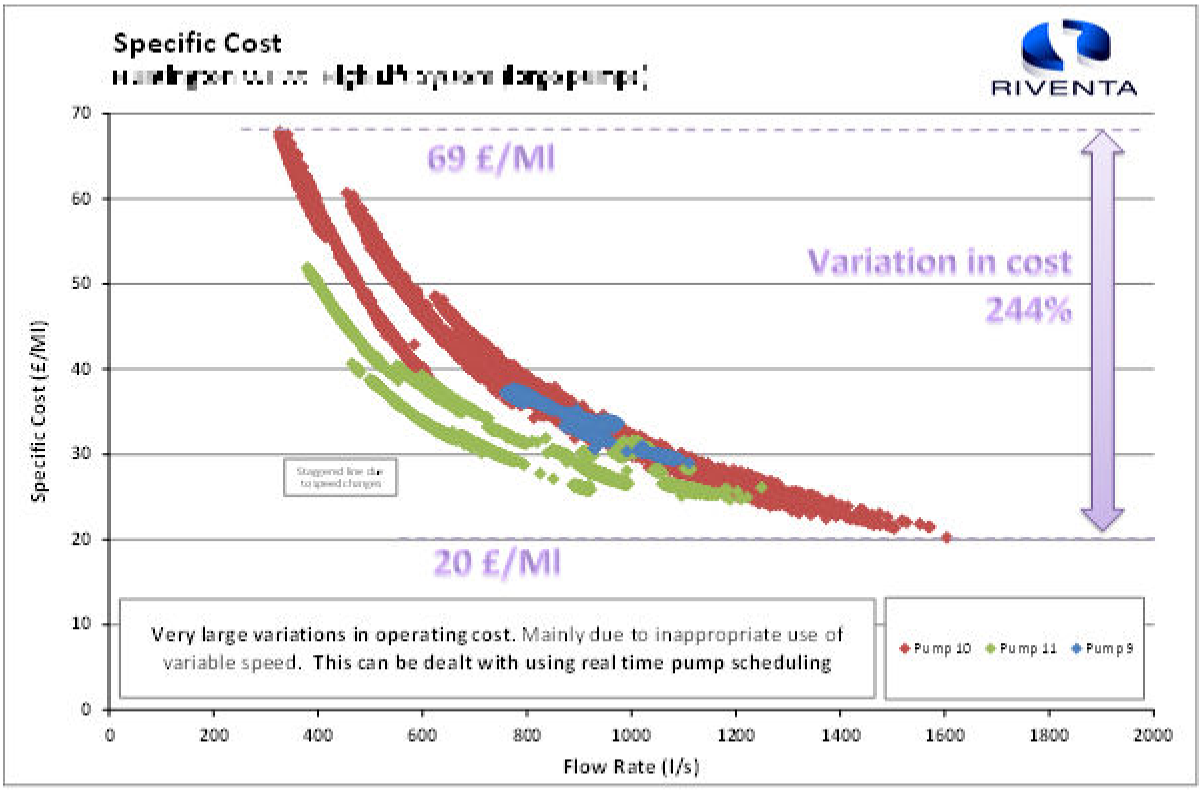
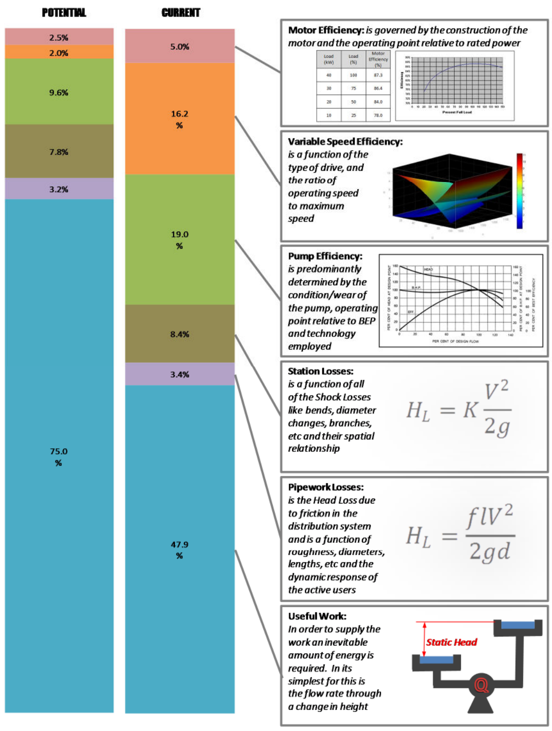


Figure 6: Specific Power



Summary of the station

- An **83%** variation has been observed in the operating cost to deliver 1 million litres for the **complete High Lift station**
- The cost of delivering water, through the entire station, varied from **£27/Ml** to **£49/Ml** according to how the system was operated
- The pump efficiency of the combined system varied from **64%** to **85%** according to how the system was operated
- It is possible to use the existing pump assets with real time pump scheduling and maintain operation **above 80%** pump efficiency **(from 64%)** and not exceed **£39/Ml (from £49/Ml)**
- The current annual energy bill, before implementation is estimated to be approximately **£3,687,334** (39,226,959 kWh @ 9.4p/kWh)
- Therefore the saving through real time pump scheduling is **13.7%** or **£505,607** per annum

A Green Pump IndeX (GPX) assessment, above, demonstrated that currently for every £1 that is spent as electrical energy only 48p is used to successfully deliver water to customers' homes – the rest is losses. With suitable investment in correctly specified best practice technology it has been calculated that the annual energy cost could be reduced by up to 46%, or £1.7M through deployment of best practice pump, motor, drive and decision support technology.

In summary; pump monitoring was deployed with great success to understand the pump station and compute a more efficient way of operating, to meet the same demand, with annual savings of £505k. By virtue of the data obtained it has been possible to identify a work scope that that could realise a total of £1.7M of annualised electrical energy savings in this single system.

7 Case study #2: Korean water company, large distribution station

A large distribution station with 11 fixed speed pumps (2047 combinations), varying between 750kW and 1500kW, was installed with a real time pump monitoring and DSS system.

The system was installed in December 2011 and a period of data collection, calculation and training ensued. The water company then conducted their own independent review using their instrumentation reporting the following results;

Month	2011			2012		
	Energy used (kWh)	Volume pumped (m^3)	Specific Power (kWh/Ml)	Energy used (kWh)	Volume pumped (m^3)	Specific Power (kWh/Ml)
March	2,688,000	10,037,860	267.8	2,708,832	10,730,510	252.4
April	2,975,840	9,825,150	302.9	2,925,216	11,017,260	265.5
May	2,955,680	10,266,020	287.9	2,909,280	11,637,000	250.0
June	2,789,080	10,163,340	274.4	3,107,232	11,537,780	269.3
July	2,992,920	11,243,850	266.2	3,082,560	12,175,510	253.2
TOTAL	**14,401,520**	**51,536,220**	**279.4**	**14,733,120**	**57,098,060**	**258.0**
Specific Power reduction from 2011 to 2012						**21.4**
Energy saving from 2011 to 2012						**7.7%**

Table 2: Specific power reduction

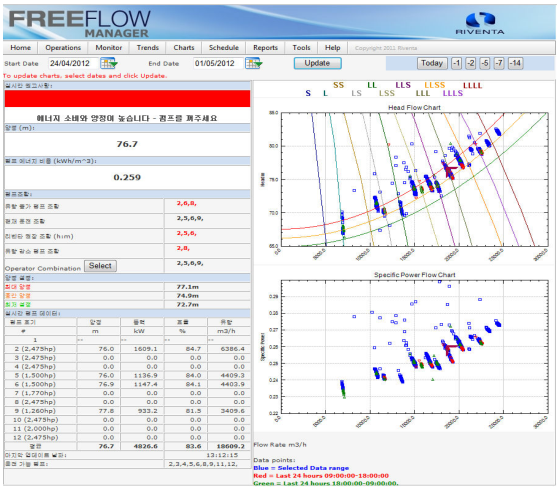
The specific power for the station dropped from **279.4 kWh/Ml** to **258.0 kWh/Ml** – which is a decrease of **21.4 kWh/Ml** or **7.7%**. [Specific Power is a true measure of Station cost performance, because it takes account of Water Volume Output compared with Energy Input for the station]

The Real-time Operator Instructions [which are recommendations that match pump operation to system changes] that have been followed by the operators has enabled a reduction in the energy used per million litres of water delivered – which is a significant saving in real terms.

With an annual energy use of **35 GWh** and a resulting energy bill of **£3.0M**, this represents a saving **£230k** per annum through real time pump scheduling.

Since the original appraisal the water company have gradually improved year on year on the saving and their latest release is a **10.9%** annual saving or **£326k**.

An example of the dashboard of the Decision Support Software can be seen next.



Individual pump performance is measured in real-time. This information has enabled the water company to identify that Pump No. 7 should be refurbished, which will improve station performance and future reliability. This information can also be used by the company to identify the next pump that should be refurbished and enable the budget allocation to be planned in advance.

Figure 7 shows that the proportion of electrical energy actually utilised to deliver water to customers' houses varied at the site from 63 to 73%.

RIVENTA have since been contracted in a consulting capacity to ensure that capital funds are deployed with the greatest tangible reward to the business.

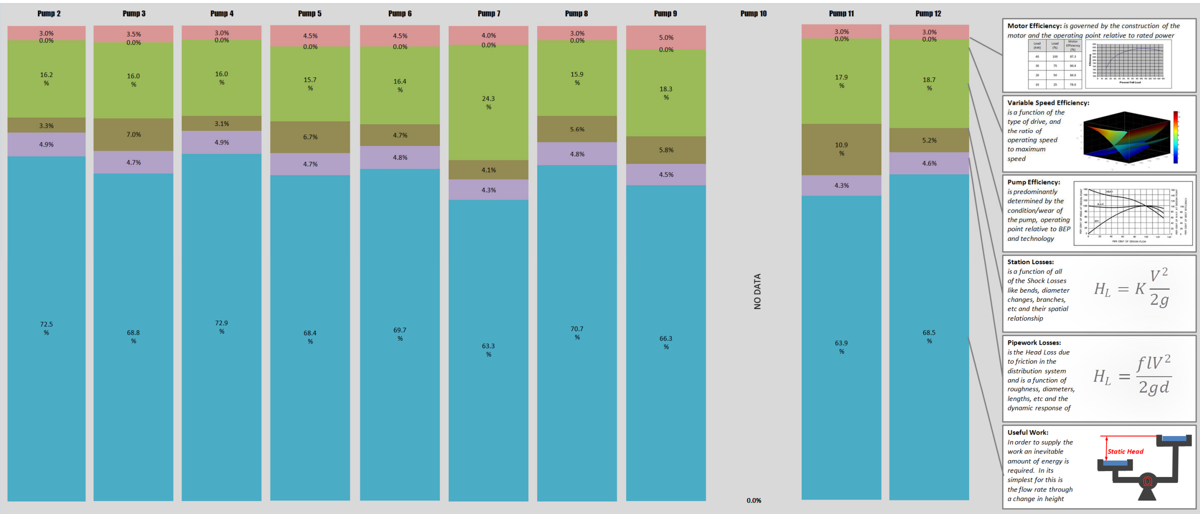


Figure 7: GPX analysis

8 Case study #3: Sub network optimisation

A sub network consisting of 31 pumps across 4 sites, was installed with a real time pump monitoring and decision support system, supplying bulk transfer of raw water to the Seoul Metropolitan area.

The customer conducted their own extensive trials before and after installation publishing an aggregated saving of 5.5%, or £1.17M across the 4 sites – see an excerpt below.

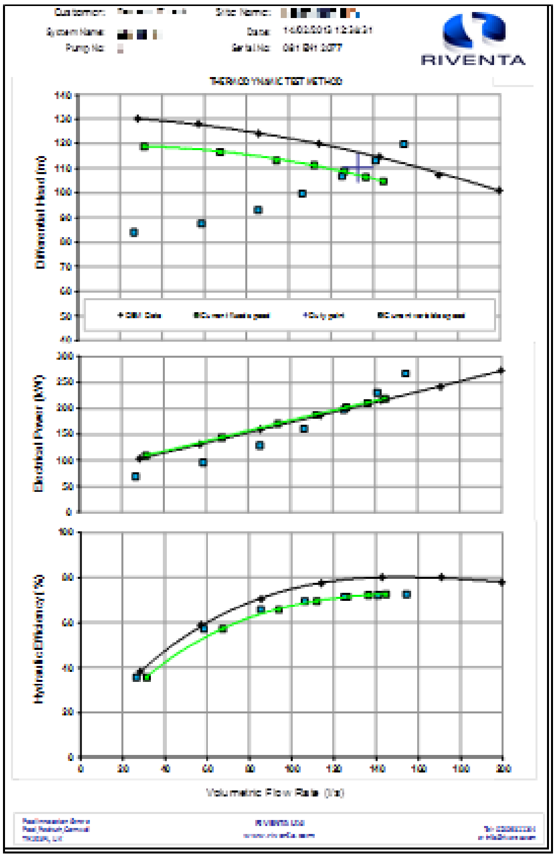
Site	Flow rate (MLD)	Energy (GWh)	Cost (£M)
#1	1,104	87	6.96
#2	336	31	2.48
#3	408	29	2.32
#4	1,392	119	9.52
Total	3,240	266	21.28
Saving		**5.5%**	**£1.17M**

The results were audited by the Korean government and formally accepted by the United Nations as a CDM scheme – allowing the customer to trade the Carbon Credits. This generated a further revenue in addition to the electrical energy saving.

9 Other uses of the data

9.1 Pump refurbishment

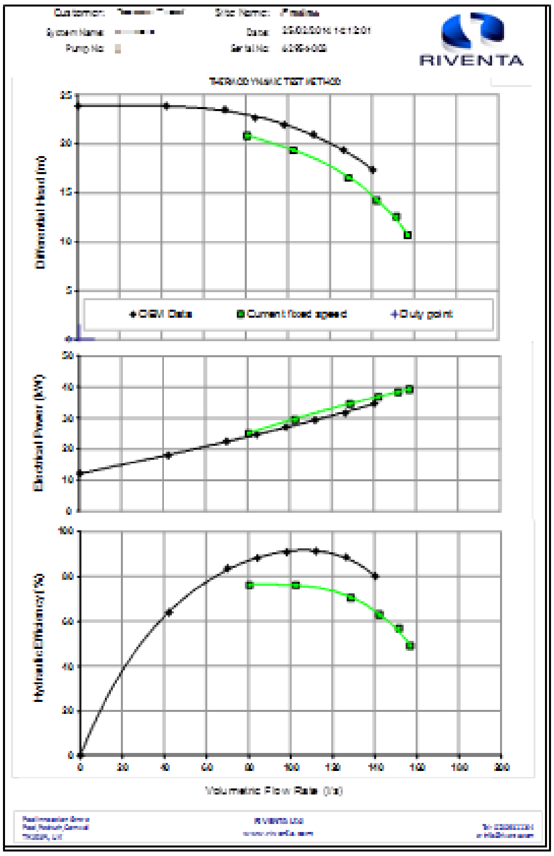
The need for pump refurbishment is marked by a reduction in the head and efficiency verses flow rate graphs. The example below shows a well sized pump but showing signs of increased internal clearances and surface roughness.



The power of this data is realised through achieving the greatest reduction in OPEX for a given CAPEX budget through targeted refurbishment.

9.2 Impeller diameter change

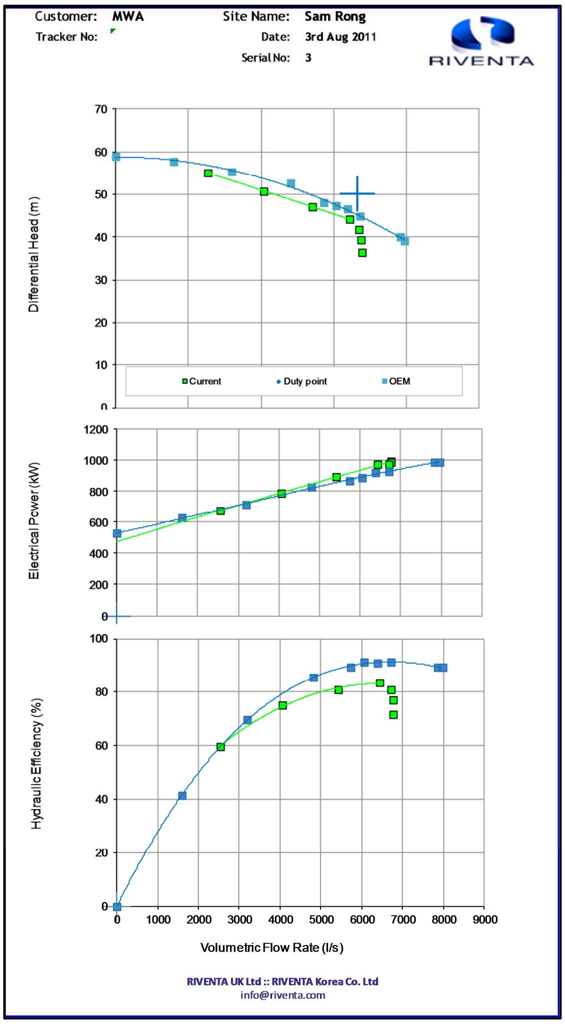
Often pumps are oversized due to caution at the design stage or changes to the network into which it pumps resulting in a different system curve and thus operating point. Tests like the example below demonstrate how the data can be used to detect and rectify oversized pumps through impeller diameter reductions.



Pumps are sometimes throttled to prevent cavitation due to oversizing; test results are essential here to evaluate the un-throttled system and compute the optimum diameter reduction.

9.3 NPSH problems: cavitation

Over-sized pumps or pumps with low Net Positive Suction Head available (NPSHa) often suffer from cavitation which will reduce the efficiency of the pump and dramatically shorten the serviceable life. The signs of cavitation show clearly in pump test data due to the discontinuity and sharp decline in efficiency.



Steps can be taken to investigate the suction line resistance, increase the NPSHa or modify the pump to improve the NPSHa-r relationship.

9.4 Other measures

Pump performance data can also be used to enumerate the impact of other best practice technologies like variable speed drives, low friction coatings, composite wear rings, etc.

10 Concluding remarks

- Pump performance data can be measured accurately on-site, for each pump individually, using the thermodynamic method first formulated over 100 years ago
- The method is widely deployed in the UK and in other parts of the World for spot pump performance testing
- Due to advances in semiconductor electronics, and hydraulic analysis methods, real time pump monitoring systems have been deployed, through integrated decision support software, to guide pump operatives to achieve the minimum possible operating cost
- The pump performance monitoring system essentially acts like a satellite navigation system in a vehicle – providing real time instructions to meet the minimum possible operating cost even when system factors are changing
- This has been demonstrated through local and international case studies with the following savings;
    - **14% (£505k)**
    - **11% (£326k)**
    - **5.5% (£1.17M)**

A system of performance measurements can not only be used to effect operational savings through pump scheduling, with sometimes spectacular results, but the resulting data can be used to guide CAPEX decision making to drive tangible bottom line change for pump owners.

Taking the old maxim.....

'Knowledge is power'

Sir Francis Bacon 1597

and applying it to pump owners.....

'Knowledge is power reduction!'

Pump Centre Exhibition 2014

11 About the authors

Steve Barrett has been the sales director of global operations in Riventa Ltd since 2001; managing distributors in Asia and Europe. As an electronics engineer by trade, and with a strong hydraulic analysis and software team at his disposal, Steve is well placed provide instrumentation and decision supports systems to effect real operational change for the pump ownership community.

Darren Harris is the Pump Services manager for the Deritend Group providing technical support for pump and system sizing, design and re-engineering.

With the wealth of data collected from pump monitoring, and over 30 years' experience, from Concentric pumps, Weirs and then Deritend, Darren is well equipped to ensure pump owners deploy finite capital funds to realise maximum operational benefit.