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Thermodynamic pump performance monitoring in power stations

Presented at the IMechE seminar "Fluid Machinery in the Power Industry", Bristol, UK, 10 June 2015

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Synopsis

The thermodynamic method has been used to measure the performance of pumps in coal, gas, combined cycle and nuclear power plants in several countries. Applications include:

- Boiler feed pumps, with motors in the power range 1 to 8 MW
- Condensate extraction pumps
- Cooling water pumps
- Fire pumps

The method is described, and case studies are presented

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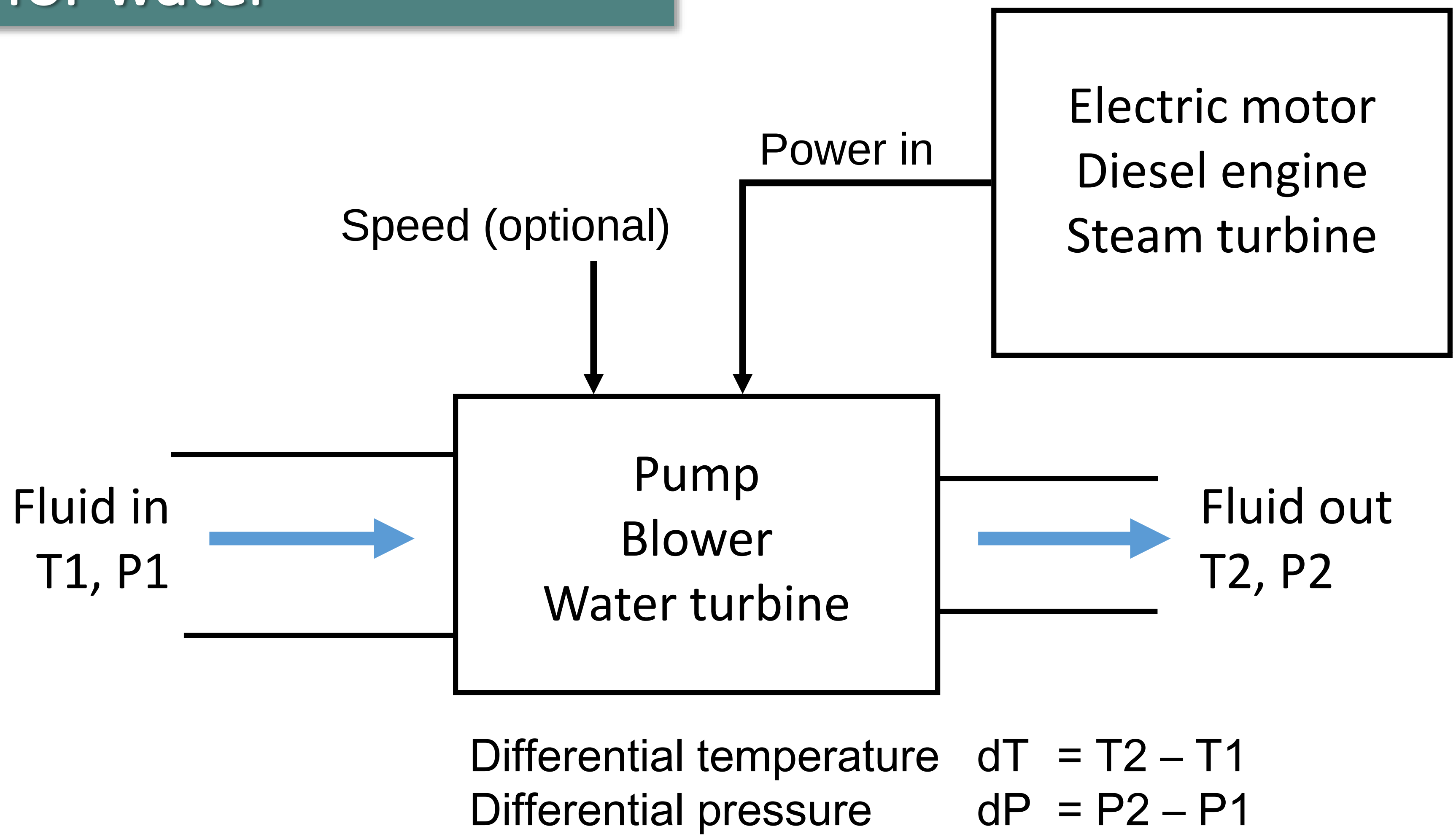
Measured parameters for water



Water is compressed in the pump and has a higher internal energy per unit mass at discharge (T2 > T1 ; P2 > P1)

Measurement of important pump parameters

- **Pump Efficiency:** $\eta = f\,(dT, dP)$

  Uncertainty generally < 1%

- **Flow Rate:** $q = f$ (dT, dP, and pump input power)

  Uncertainty generally < 2%

- **Other parameters:** Suction head, discharge head, total head, electrical power, speed

- ***Low Uncertainty:*** Calibration can be checked on-site

The pump equation

$$\color{blue}{P} \cdot \color{blue}{\eta} = \color{blue}{q} \cdot \rho \cdot g \cdot \color{blue}{H}$$

P = pump input power **η = pump efficiency**

q = flow rate **ρ = density** **g = gravitational constant** **H = total head**

4 unknowns (in blue) – if we measure any 3, we can derive the 4th

Usually: measure η, H, P and derive q

For steam turbines / diesel motors, measure η, H, and q and derive P

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Portable or continuous

- **Portable equipment**

- used for Power Station applications to date monitoring periods up to 24 hours

- **Continuous monitoring**

- already used in Water Industry
- available for Power Station applications

- **Technology**

- can be applied to both pumps and blowers, and to measure the power output of steam turbines

Probes for different applications

Cooling water, condensate extraction, river pumps

Temperature probes 0 – 60 ºC (sometimes using thermowells)

Pressure probes -1 to 35 bar g

Boiler feed and booster pumps

High temperature probes 0 - 230 ºC (always via thermowells)

High pressure probes to 300 bar

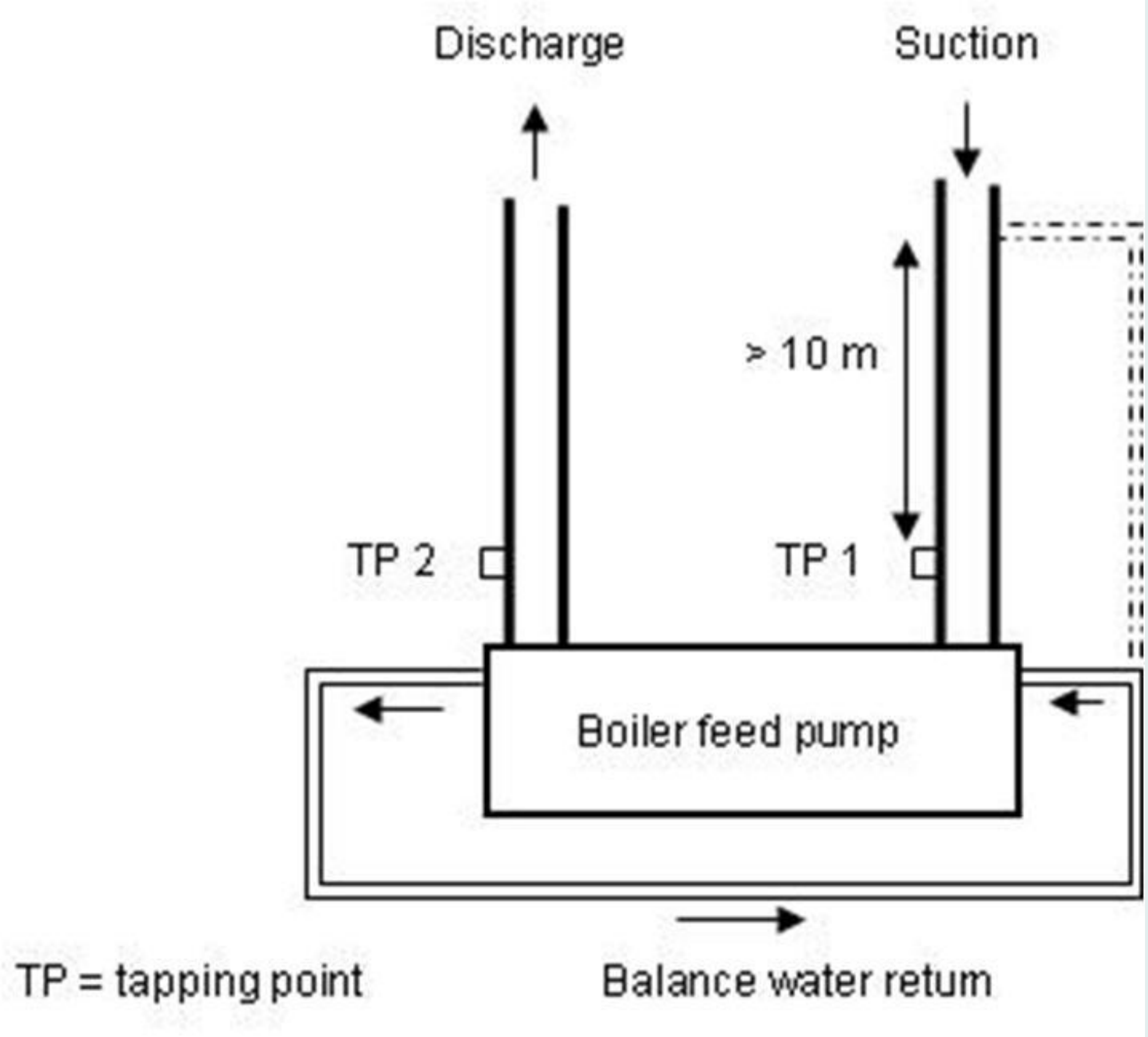
Benefits

- Accurate pump performance measurements
- Lower energy costs
- Lower maintenance costs

Case study: 1 MW feed water pumps

- Pumps had excessive vibration and suffered from first stage cavitation
- First stage re-designed
- Pumps tested before and after the re-design

Schematic showing temperature and pressure test points



1MW feed water pump – temperature probe in thermowell

1 MW feed water pump – pressure probes attached near existing analogue meters

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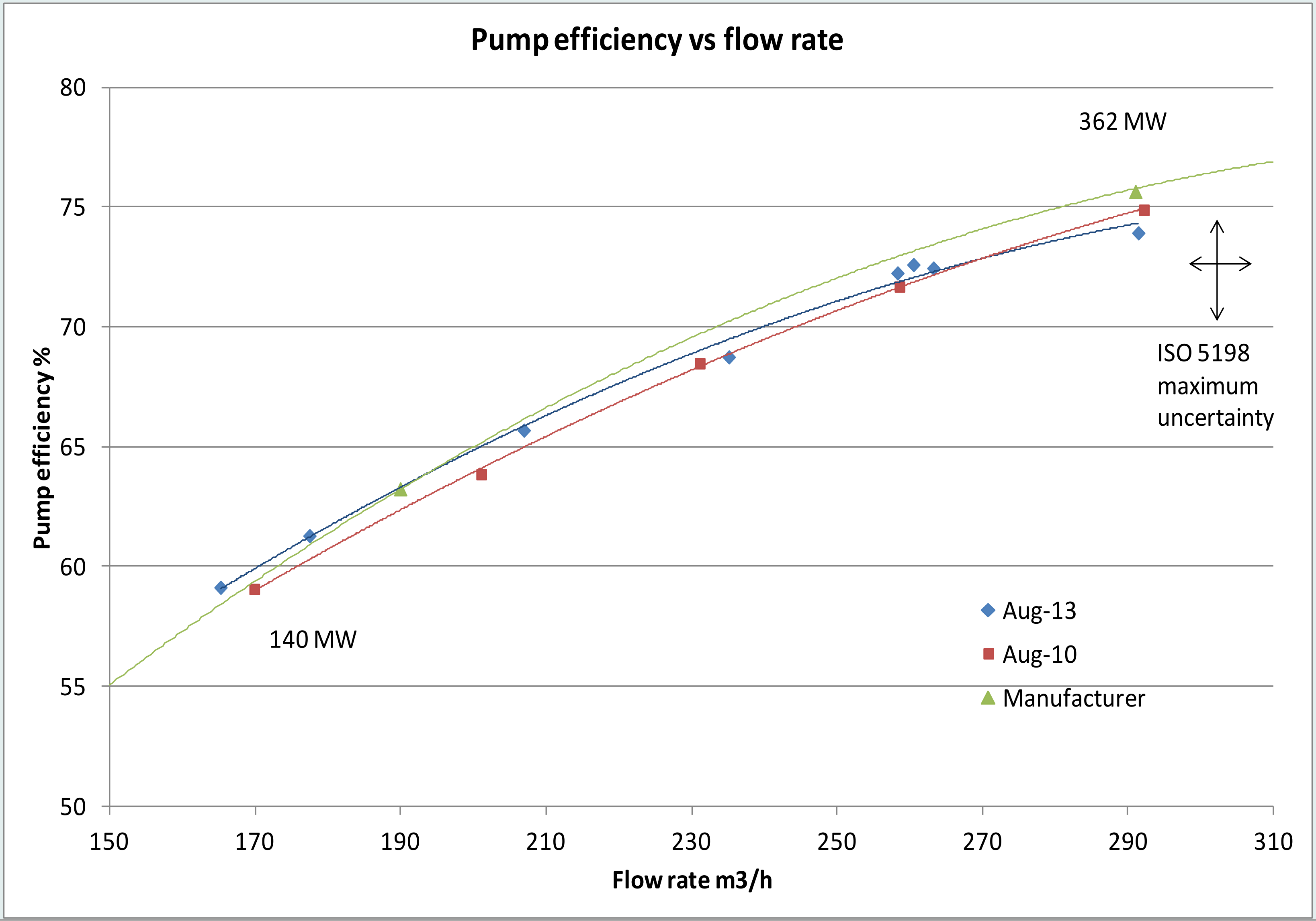
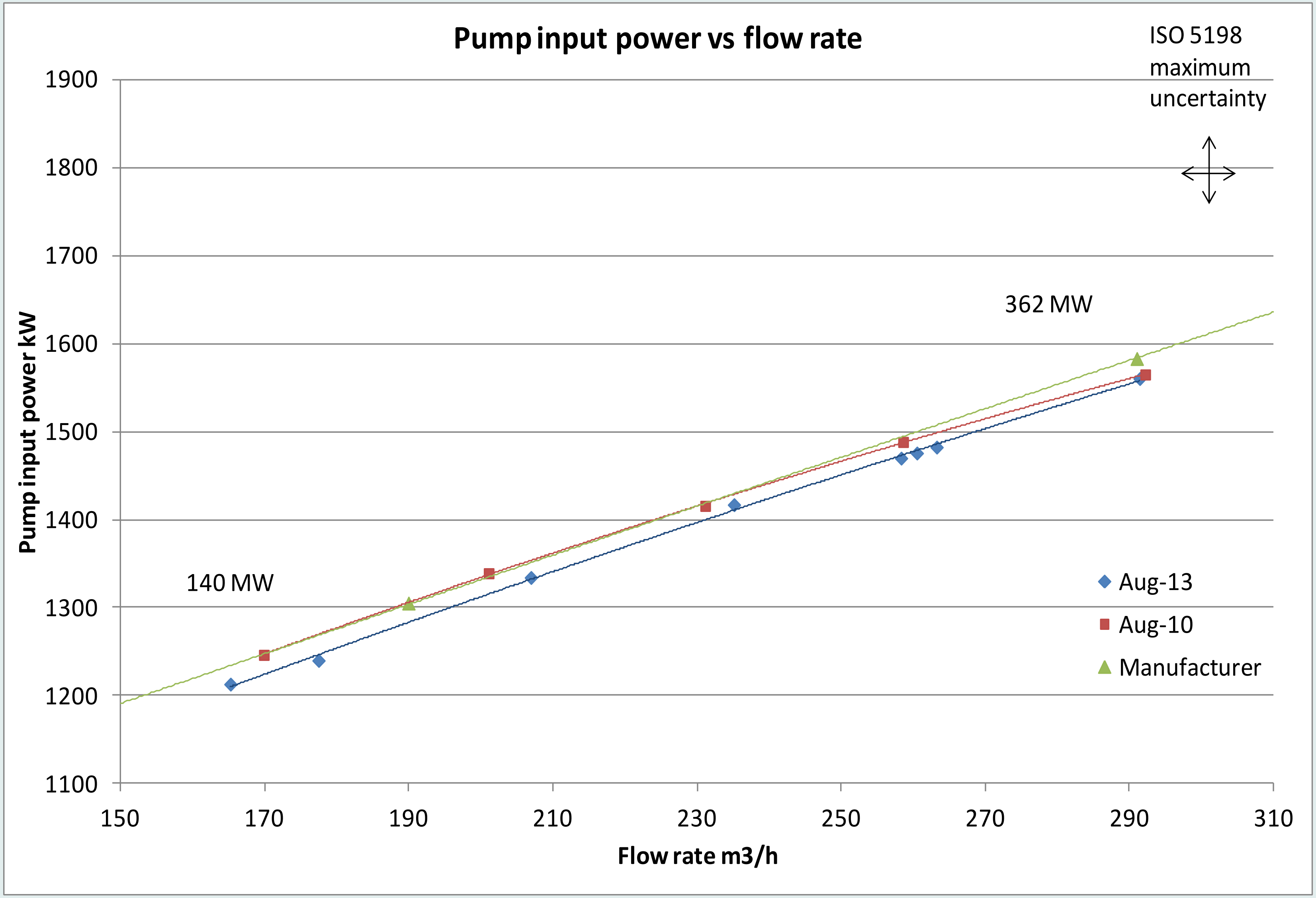
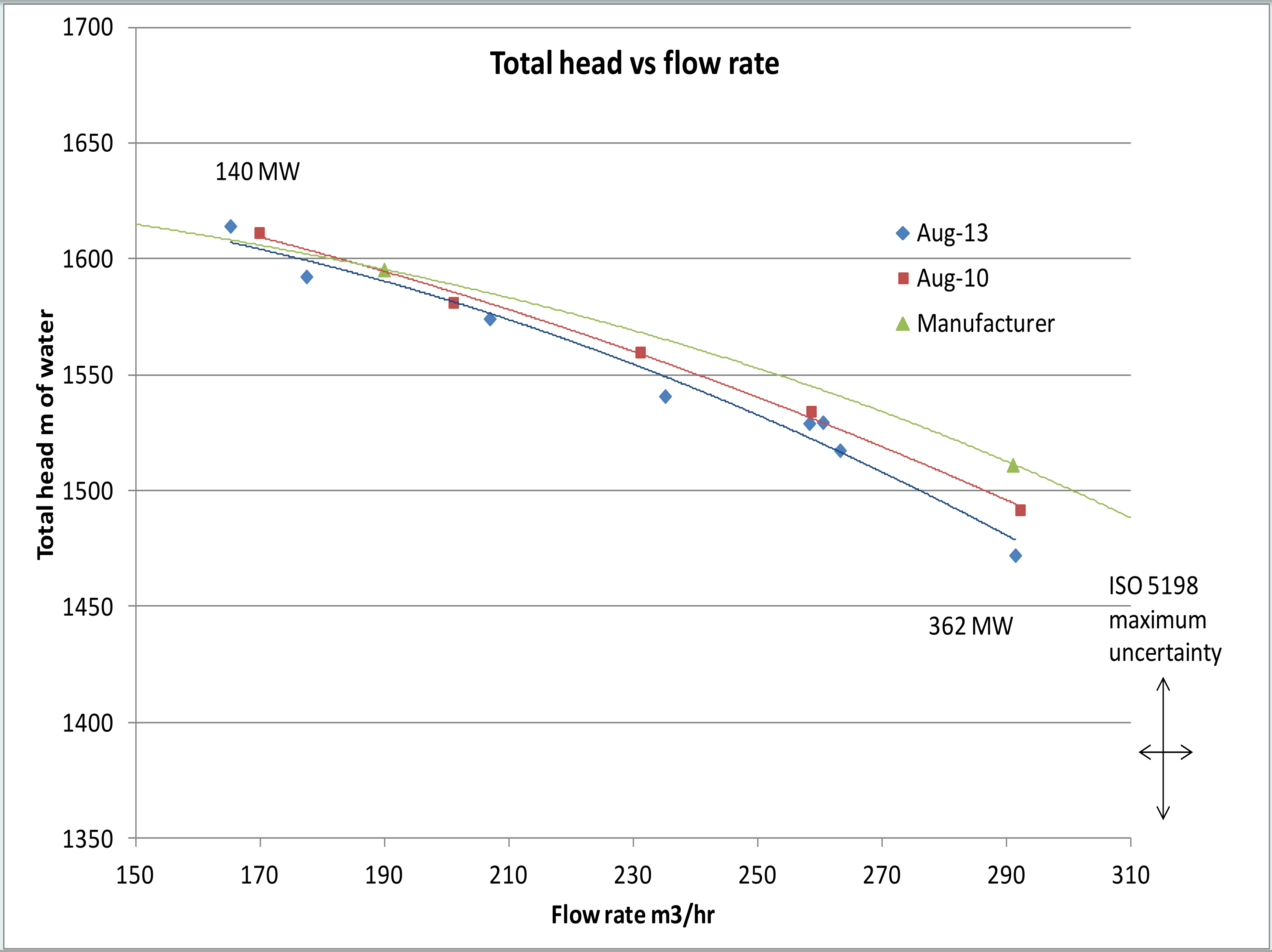
Efficiency vs flow rate for feed water pump



Pump input power vs flow rate for feed water pump



Head vs flow rate for feed water pump



Case study: Concentrate extraction pumps

Concentrate extraction pumps

- supplying the feed water pumps in the previous case study
- tested at the same time as the feed water pumps
- compared with manufacturer's data

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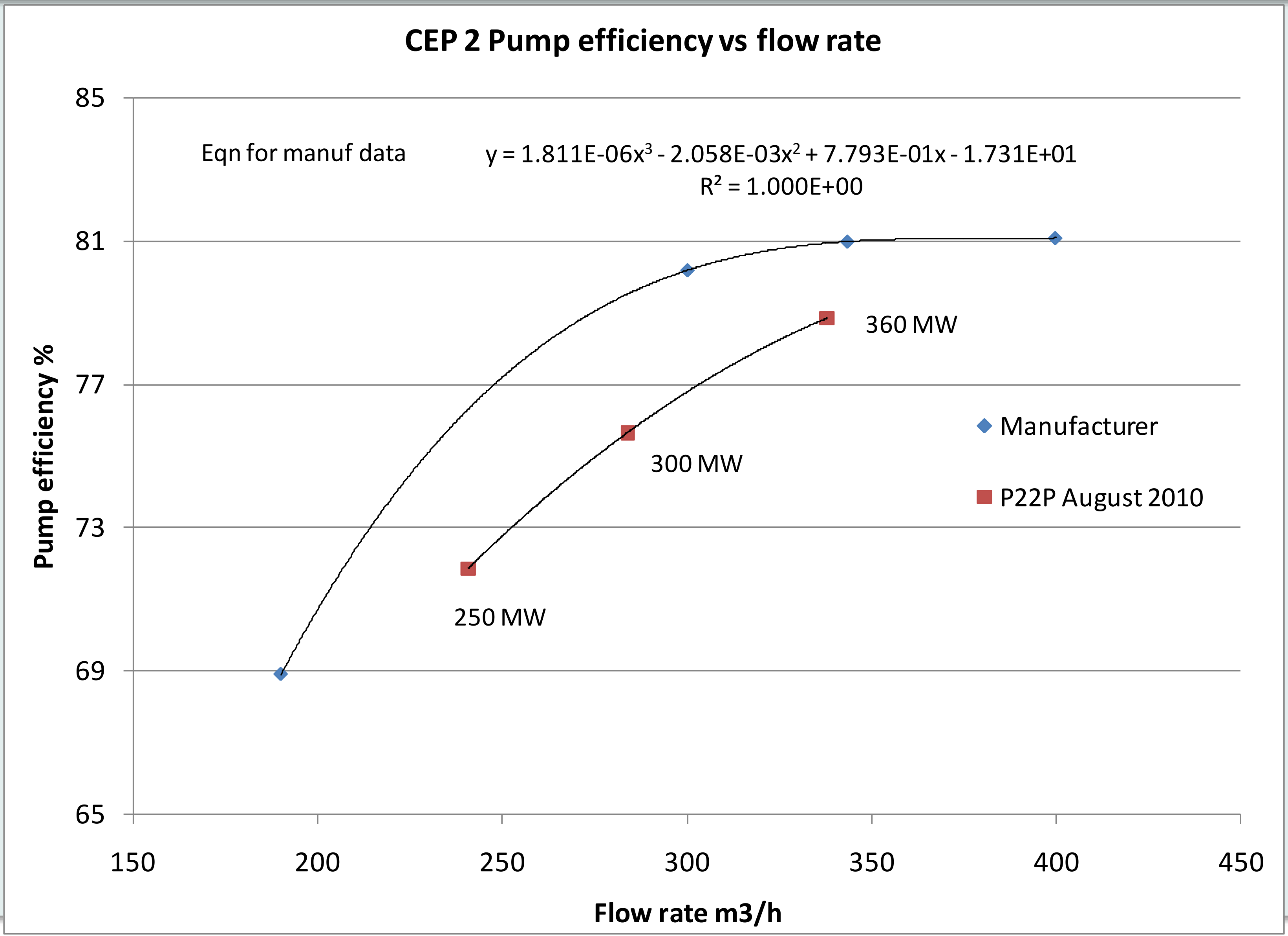
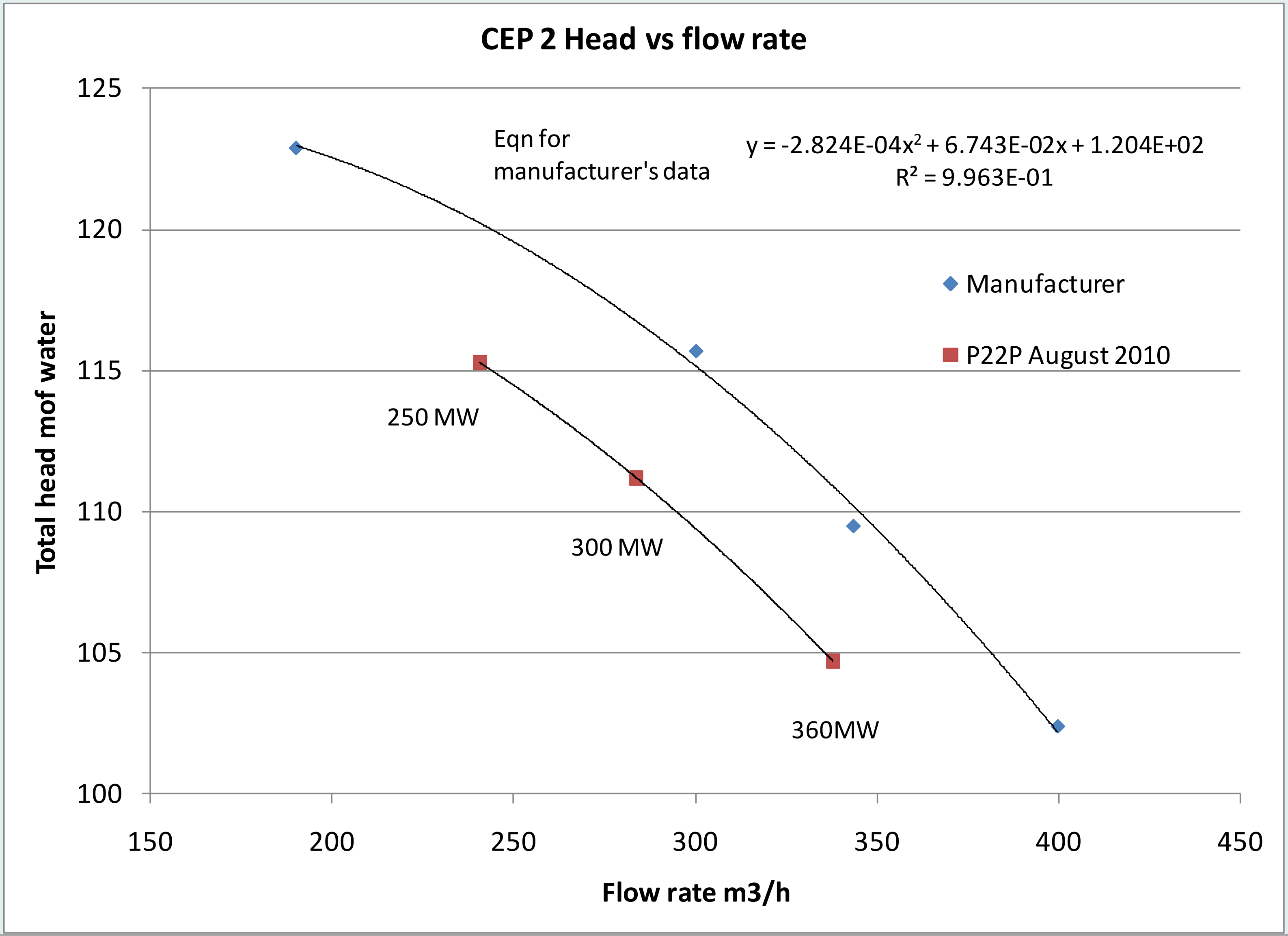
Loss in efficiency of condensate extraction pump



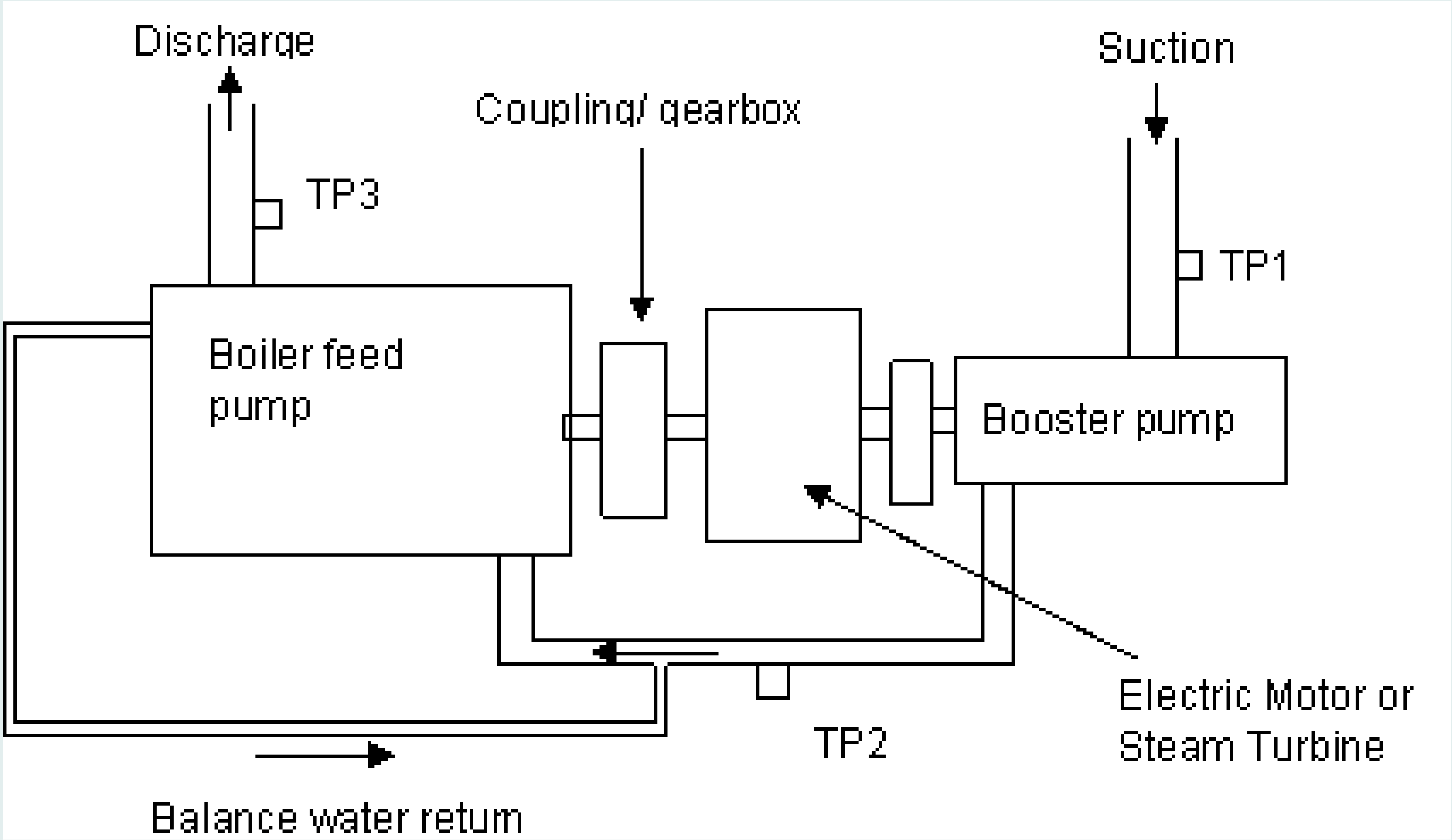
Head and flow rate for condensate extraction pump



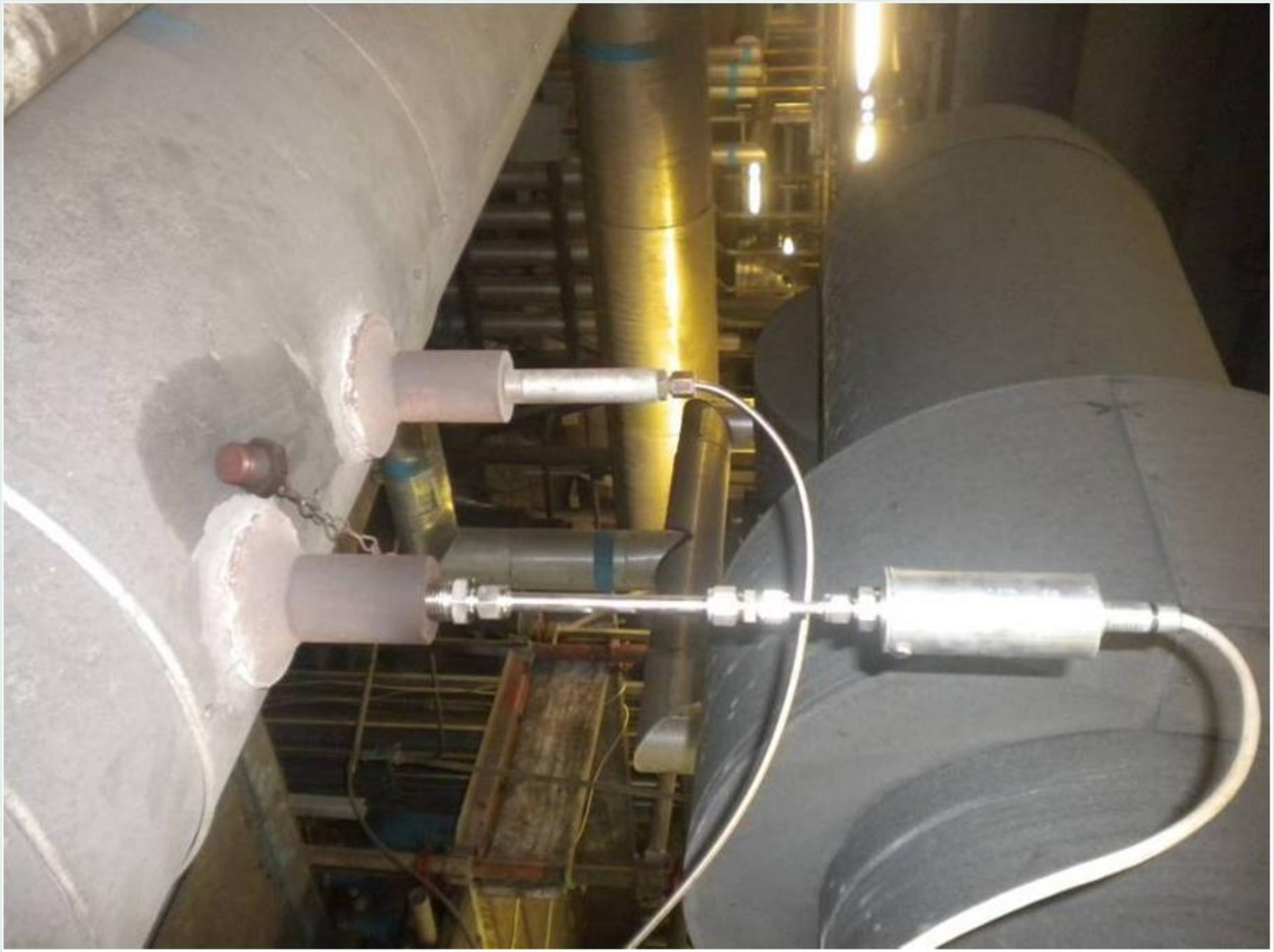
Case study: 8MW boiler feed pump with fluid drive and booster pump

8 MW boiler feed pump, with fluid drive, and booster pump running off same motor

Test points for boiler feed and booster pump combination



Temperature probe (foreground) fitted into existing thermowell (suitable for 175° C and 220 bar pressure)



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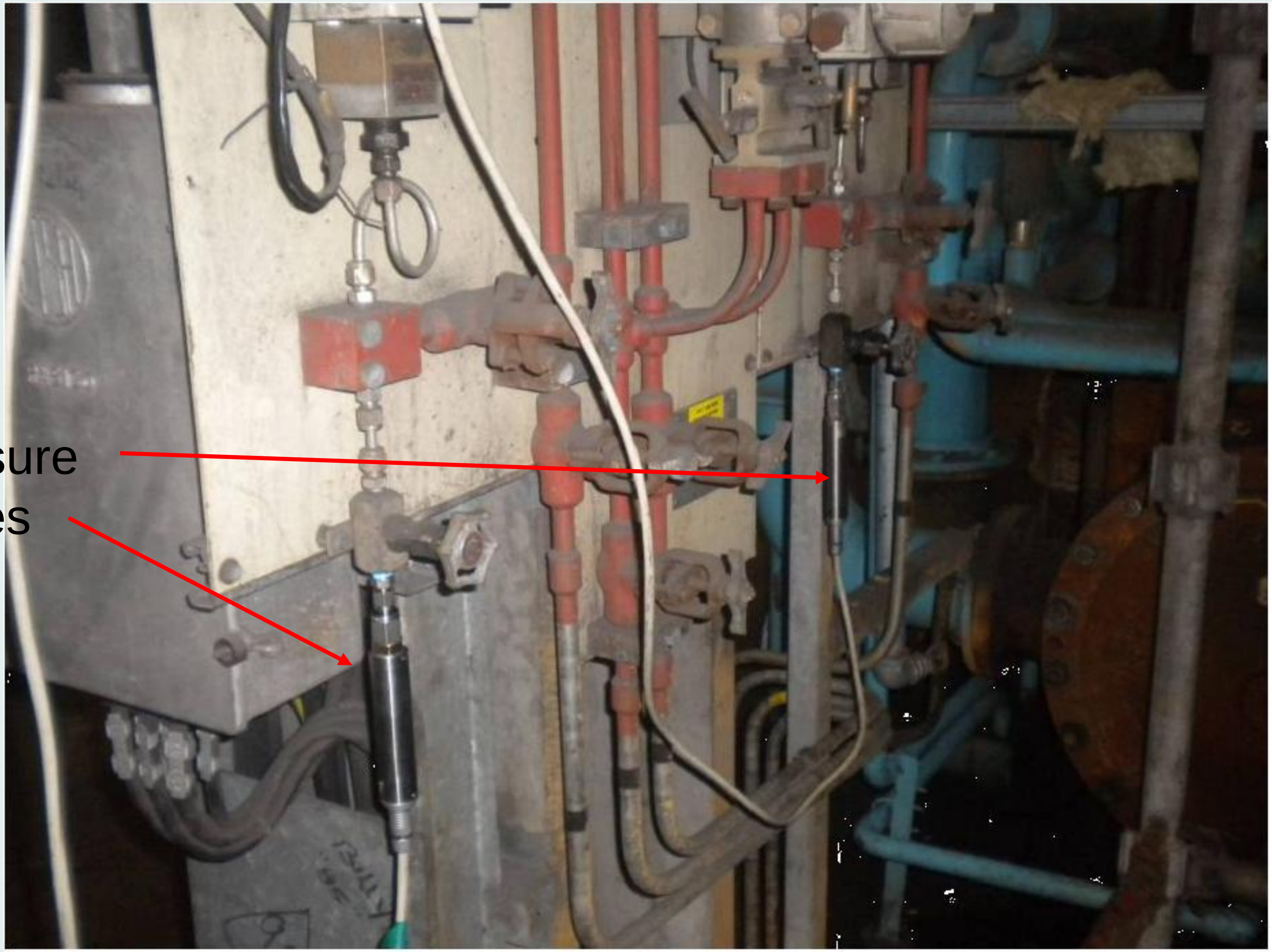
High pressure probes (application is 220 bar)

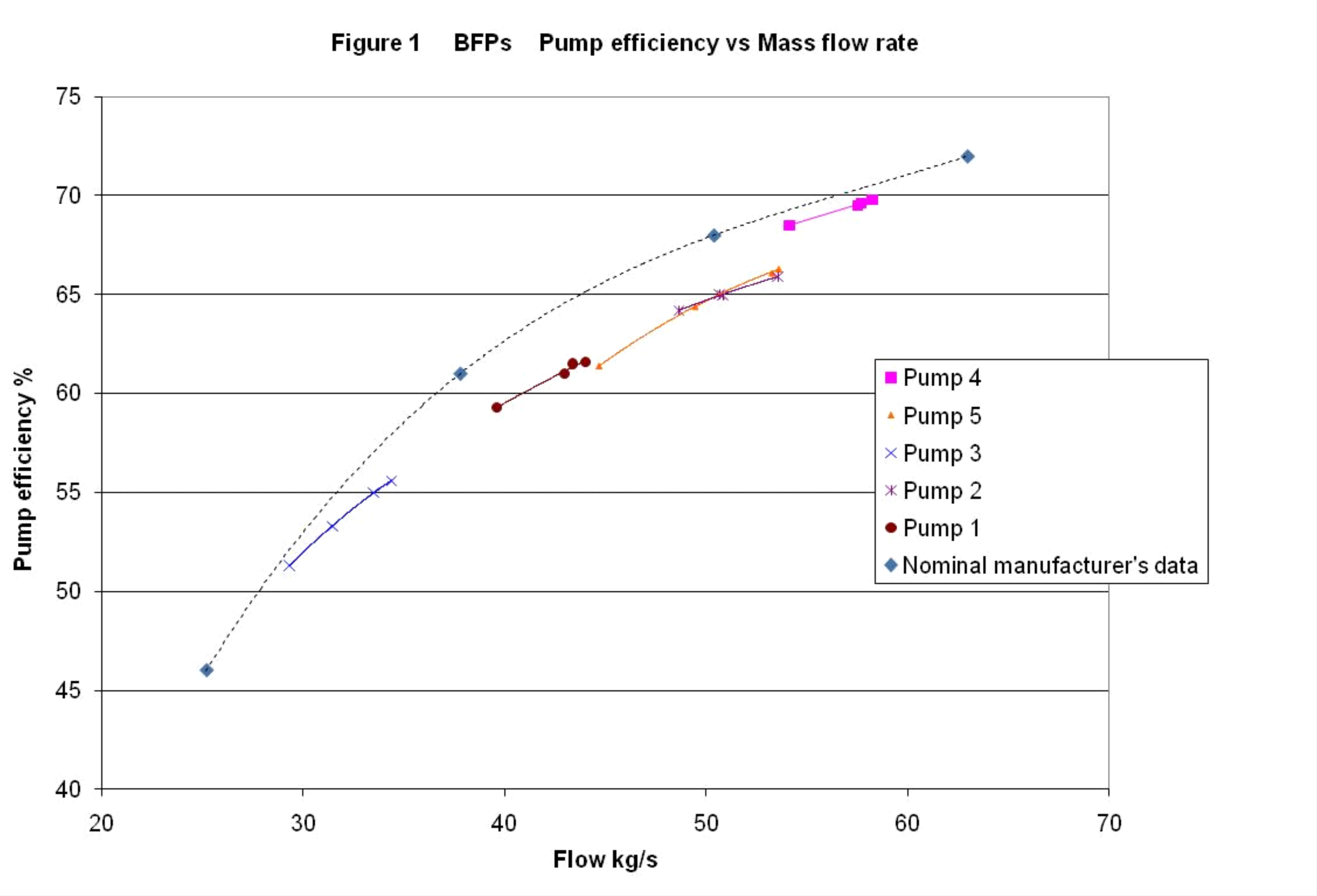
Pressure probes



Energy losses in BFP

Energy losses in boiler feed pump system	Coupling speed RPM	Generator MW	Motor input power kW	Total fluid drive power losses kW	Motor power losses kW	Pump input power kW	Pump power losses kW	Water power kW	Mass flow rate kg/s
Manufacturers data	5730	(Design duty point)	9090	882	273	7936	**1127**	6809	260
	5380	(Duty point)	8064	**1301**	242	6521	926	5595	237
P22P data	4960	267.6	6586	**1580**	198	4560	733	3827	197
	4827	237.8	6004	**1631**	180	3954	659	3296	177
	4694	214.8	5476	**1673**	164	3413	677	2736	152
	4563	185.0	5043	**1707**	151	2970	652	2318	132

Case study: Multiple boiler feed pumps operating in parallel



Case study: Circulation pumps

Nuclear power station, USA

3 MW water circulation pumps

High water velocity

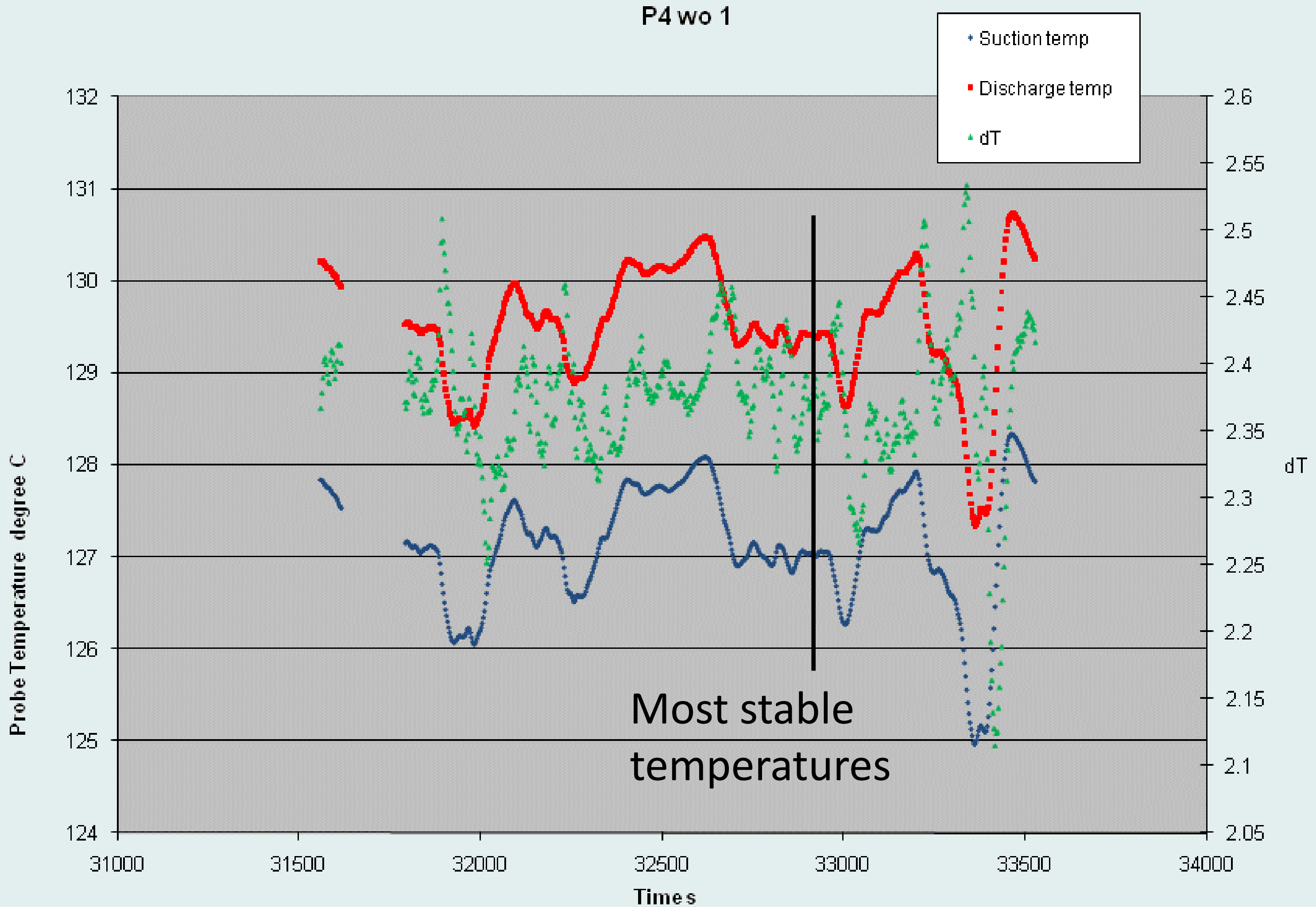
Water sampling technique

Suction tapping and sampling point

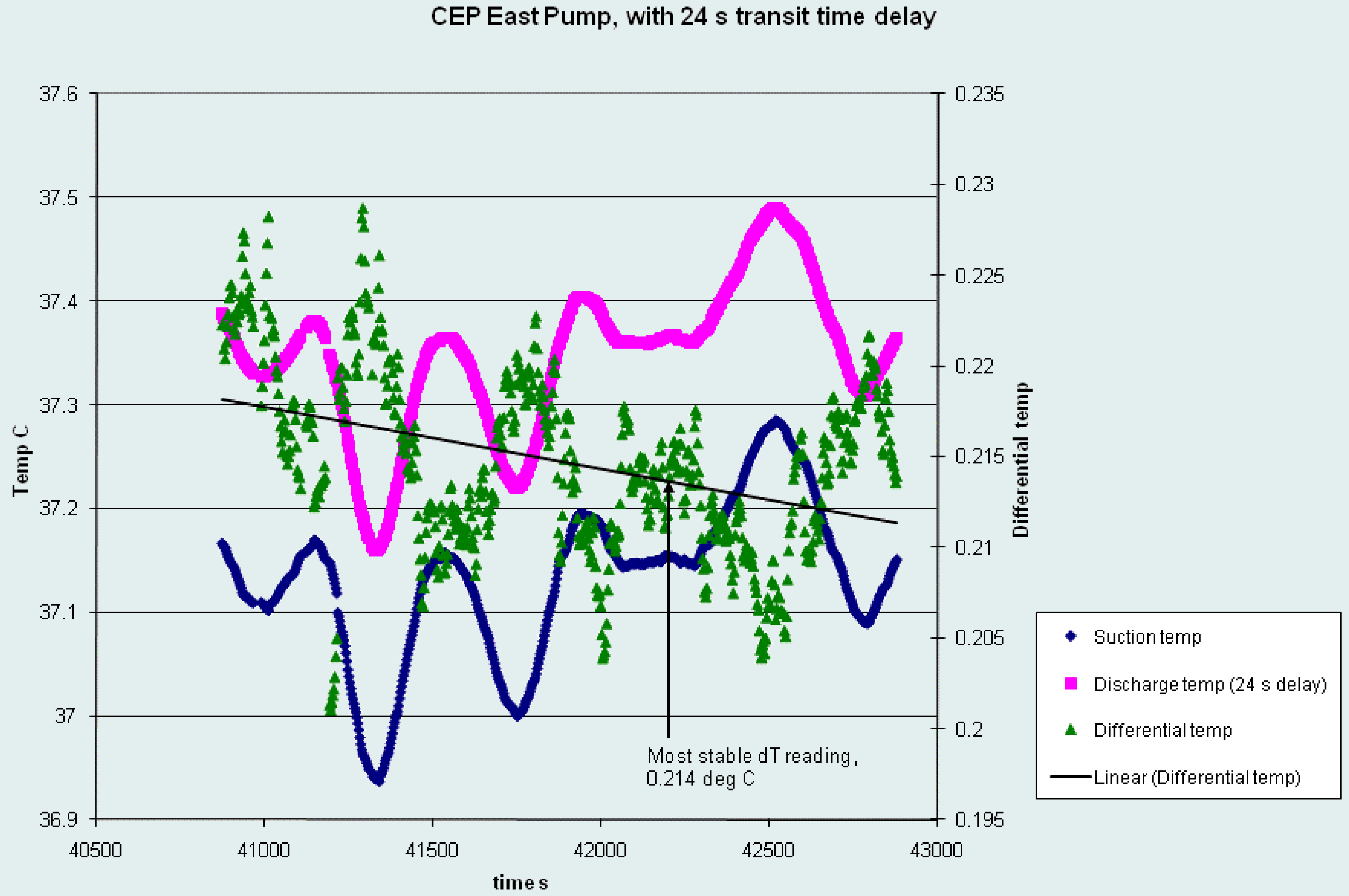
Some limitations of the method

- Difficult to get accurate results for boiler feed pumps with water injection seals. However, most have mechanical seals
- Two sources of suction water at different temperatures cause unstable suction temperatures (for example, from both a cooling tower and a river)
- Suction water may not be well mixed if there is a short pipe length from reservoir to suction flange

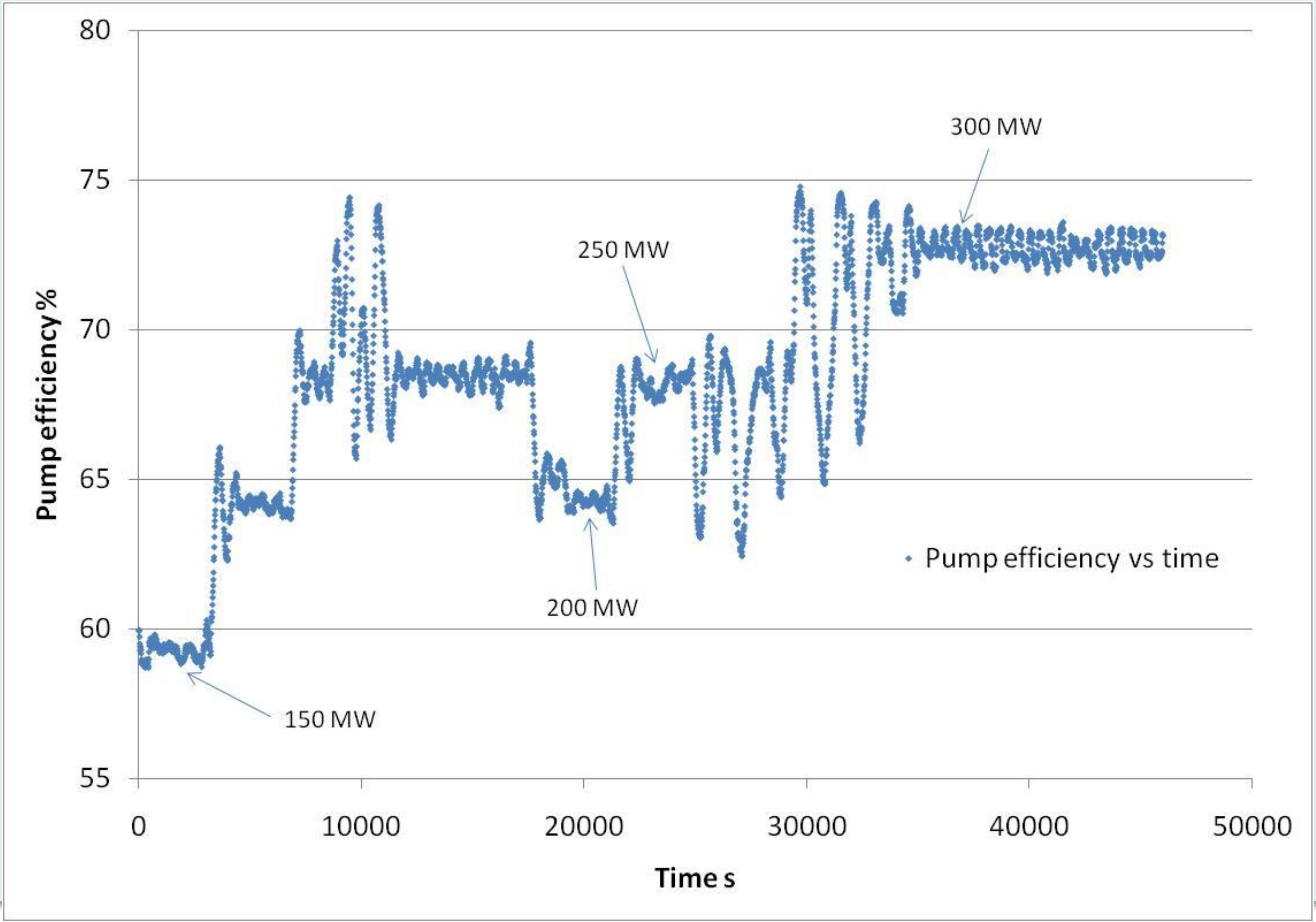
Time required to obtain data - boiler feed pump



Condensate extraction pump temperatures



Boiler feed pump efficiency overnight



Continuous monitoring

- Accurate measurements under all operational conditions
- Interfacing with PLC / SCADA for data presentation and recording, trending and alarms
- Rapid identification of pump and pump system problems

Tapping points for continuous monitoring

- T1 – suction temperature
- T2 – discharge temperature
- P1 – suction pressure
- P2 – discharge pressure
- dT = T2-T1
- dP = P2 –P1
- Electrical power to motor measured
- Speed measured for variable speed drives

Continuous monitoring equipment uses embedded web pages for set-up and access to live data

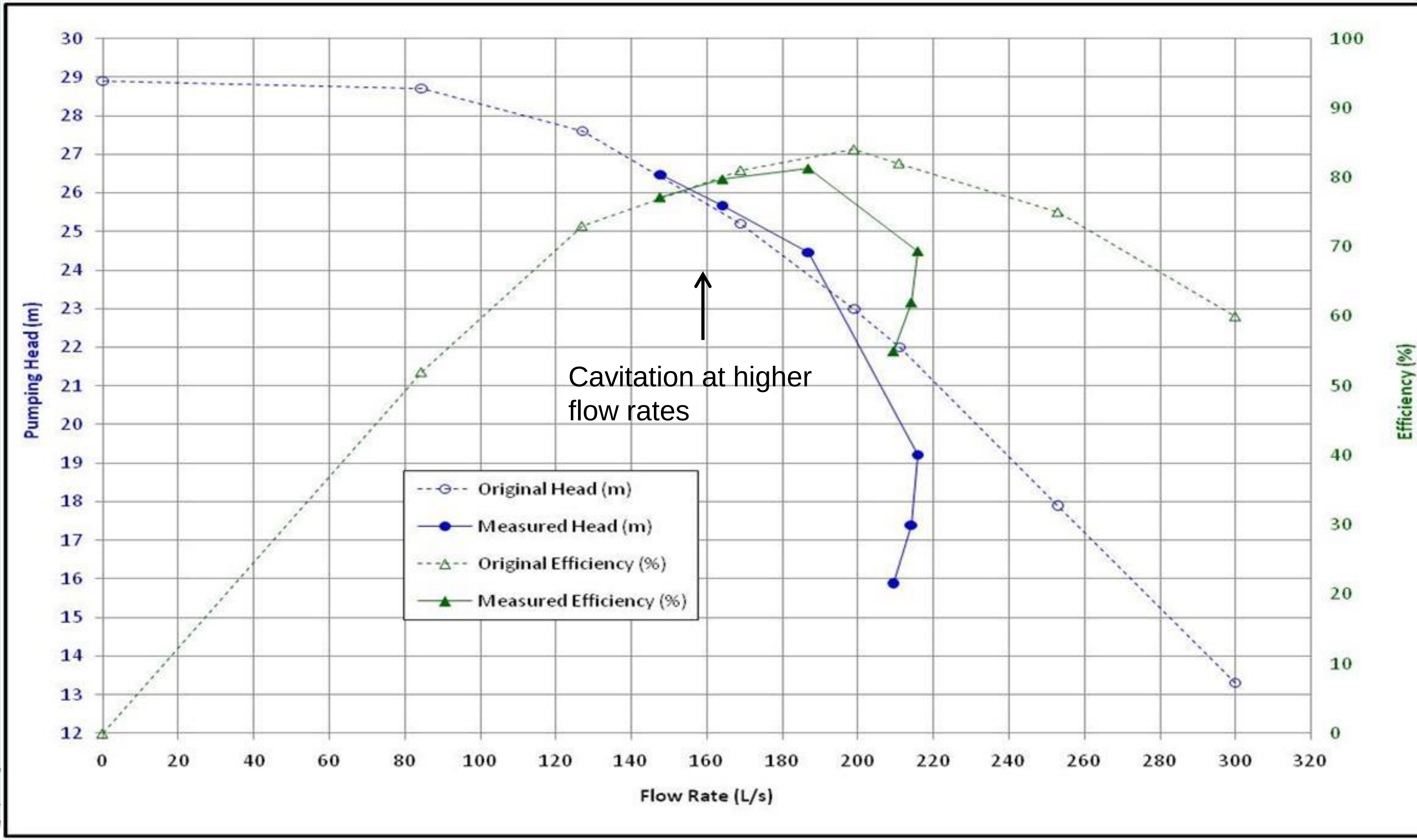
- **Home**
- **Status**
- **Data**
- **Instrument**
- **Calc Range**
- **Network**
- **Configuration**
- **Run/Stop**

uPM Data

Set date time 09/06/14 09:13:40

	average	stdev	units
T1:	79.8747	0.0008	F
T2:	79.9892	0.0008	F
dT:	0.1145	0.0005	F
P1:	11.297	0.279	PSI
P2:	166.967	0.303	PSI
dP:	155.670	0.392	PSI
Head:	363.76		ft
Suction Head:	26.55		ft
Eff:	85.92		%
Overall Eff:	82.66		%
Flow:	20208.89		Gpm
Power:	1671.70	2.61	kW
Speed:	890.0	0.0	RPM

Example of cavitation



Conclusions and recommendations

- The thermodynamic method has been successfully used to accurately measure pump performance for most types of pump in power plants
- To achieve this, temperature and pressure probes with the requisite dynamic range and long-term stability of calibration accuracy were constructed
- Appropriate data acquisition and filtering procedures have been developed
- The future continuous monitoring of power station pumps will provide rapid identification of incipient failures, and reduce energy and maintenance costs

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