Session One:

Pump Characteristics and ISO Efficiency Curves: Impact On; Efficient Design; Efficient Operation and Improvement in Reliability and Maintenance

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Summary

- Pumps account for some 20% of energy used by the industry.(1)
- Fossil fuel-generated energy is synonymous with greenhouse gas emissions, which in turn contribute to the climate change phenomenon.
- The strategic importance for reduction in energy use, and its impact on the carbon footprint of any industry has been recognized by progressive organizations worldwide.
- Pumps and pumping systems offer some of the largest potential, and opportunities, for organizations, to reduce the use of energy and its associated impact on the environment. These reductions in energy also result in cost savings, a “win/win” situation for the industry.
- Pumps can be categorized as being one of the most simple, and [in most instances], robust rotating equipment in the industry.
- Every pump is designed and built to perform at its optimum efficiency for a particular duty (i.e. specific volume of liquid discharged in a specific period of time at a specific head or pressure).
- Pumps also have the capability to operate and discharge, other volumes of liquid at other heads and pressures, at less than the optimum efficiency.
- Pump manufacturers generate discharge versus head curves for each pump along with similar curves for discharge versus power and discharge versus efficiency. These curves are generated in test facilities to various national and international standards and are termed as “Pump Characteristic Curves.”
- The single most energy efficient discharge versus head point on the pump curve is termed as the Best Efficiency Point (BEP). Lower efficiency curves at other discharges and head, at the same speed and the same size impeller, when plotted, generate concentric elliptical curves, around the BEP. These curves of equal efficiency are termed as “ISO Efficiency Curves.”
- Pump Characteristic Curves provide an important tool for design engineers, operators and maintenance personnel to arrive at an optimum energy design solution, or, to establish opportunities to curtail energy outgoings, as part of the operation of the pumping system.

- The curves also assist in evaluating the performance of the operating pump, and the need for undertaking pump refurbishment. New curves plotted after the pump is refurbished provides a status and effectiveness of refurbishment..
- Pump curves and their application provide the first opportunity to optimize energy outgoings in pumping systems.
- Pumps operate as a single piece of equipment, or in conjunction with other pumps, in a circuit.
- Pipe sizing, equipment in the pumping circuit, type of liquid handled; generate resistance to the liquid flow, which the pump has to overcome. The impact of these resistances governs the extent of liquid that the pump will be able to discharge. This point on the pump curve “discharge versus head” is termed at the “duty point.”
- It is imperative that pump system designers, operators and maintenance personnel strive to optimize energy outgoings by operating the pump/pumps at or close to the BEP.
- The impact of the duty point moving away from the BEP can have significant implication on the energy outgoings and life of the pump, by way of premature pump component failure as a result of, increased axial and radial loads , liquid recirculation within the pump, and cavitation.
- Ascertaining the anticipated pump performance over its entire range of operation is important at the design stage; monitoring the performance of the pump, again over its entire operating range, once the pumps are commissioned, is even more critical, to arrive at an energy efficient outcome. This monitoring can be undertaken by, measuring liquid flows, head pressures against which the pump has to operate, and plotting these parameters on the pump performance and characteristic curves.
- Pump characteristic curves also offer the opportunity to establish the optimum solution to operate the pump/pumps at or closest to the BEP as well as ascertain the implication of operating away from the BEP.
- Pump curves are a diagnostic tool, for establishing pump performance in an operating system. The curves are used to review the extent of deterioration in pump performance as a result of normal wear. More importantly, the pump performance, after the pump has been refurbished, can be compared with its performance before it was reconditioned using these curves.
- Pump curves interposed over system curves provide a basis for detailed review of the opportunities available to optimize energy, reduce maintenance and extend pump life by adopting one or more of the following:
    - Variable speed drives
    - Utilizing smaller pumps,
    - Rescheduling the sequencing and controls of pumps’ operation;
    - Changing the pumps’ impellers,
    - Throttling the pump discharge

Introduction

Pumps and pumping systems are one of the largest consumers of energy; accounting for over twenty per cent of power used in the industry.(1)

The need to efficiently manage energy outgoings is of particular significance, at this point in time for the global industry as it embarks on a low carbon economy.

Pumps, as large energy users, contribute towards the generation on green house gases. Even a relatively small percentage of energy saved, by pumping systems, as part of fine tuning of current operations can have a significant impact on green house gas emissions, energy costs, and the organizations' bottom line profits.

Every pump is designed and manufactured to operate most efficiently at a specific "duty point." The duty point is a correlation between the pump's output, as related to "discharge" (liquid flow/capacity) against a "head" (pressure), which it has to overcome.

Pump performance is subject to fixed and transient head/pressures that the pump encounters in the pumping circuit it operates, during its life cycle.

The impact of all these fixed and transient head/pressures, present a complex and challenging case for designers, of pumping systems, to arrive at an optimal and energy efficient outcome, over the entire range of pump/pumps operation.

The analysis of pump performance and operational outcomes are undertaken by utilizing pump characteristic curves. These curves are generated by pump manufacturers for each specific pump type. These curves are also utilized as starting blocks for the design and selection of pumps to arrive at an efficient outcome.

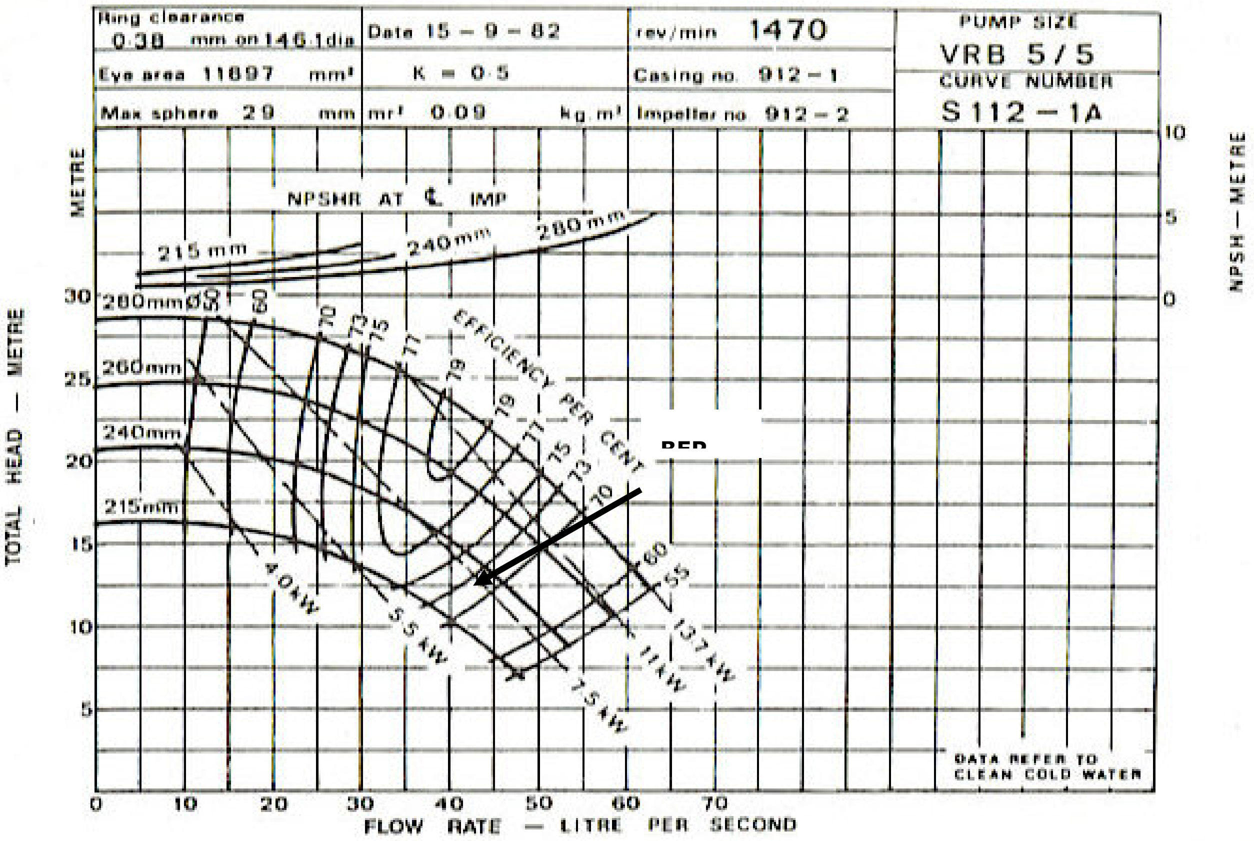
Pump ISO Efficiency and Other Curves

Every pump manufacturer generates pump curves for every type of pump to define:

- The liquid flow/discharge of the pump at various heads/pressure
- The power absorbed by the pump, at various heads/pressure and flow/discharge, for a particular size of pump with a maximum size impeller.
- The efficiency of the pump an various discharge/flow levels

The pump casing geometry (based on centrifugal pumps) generally allows for three to four different sized impellers to be installed in a specific pump casing.

The flow/discharge versus head/pressure curve for each of the impellers along with the corresponding power absorbed is generally plotted on a single pump data sheet. All points of equal efficiency using the largest impeller are connected to produce concentrically elliptical curves which are termed as ISO Efficiency Curves [Figure 1].



TYPICAL PERFORMANCE CURVES OF A CENTRIFUGAL PUMP AT 1470r.p.m

Figure 1

A single point on the particular curve which corresponds to the highest efficiency is termed as the Best Efficiency Point (BEP). [Figure 1]

Pump system designers, operators and maintenance personnel use the pump curves to optimize the pump performance in the pumping circuit.

The importance of operating the pumps at the BEP, apart from optimizing energy outgoings, also reduces the wear and premature failure of seals, bearings, and shafts and associated maintenance costs. Impact of operating a pump away from the BEP are shown in Figure 5.

This is predominantly as a result of the radial loads/thrust on the pump shafts being zero at the BEP. (In practice, however, some minor radial loads can be expected). [Figure 2]

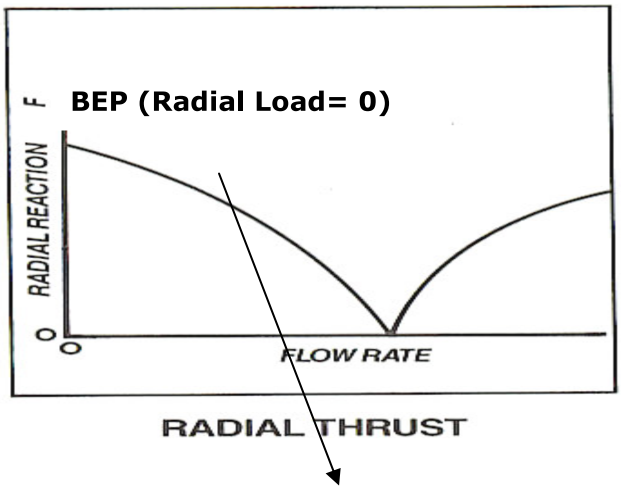


Figure 2

Two distinct types of curves are used by manufacturers to portray the discharge versus head; discharge versus power absorbed by pumps and discharge versus efficiency. These are as follows:

I. Dedicated curves [Figure 3]:

- Dedicated discharge/flow versus head/pressure curve for each pump impeller;
- Dedicated discharge/flow versus power absorbed curve for each pump impeller
- Dedicated discharge/flow versus efficiency curve for each pump impeller

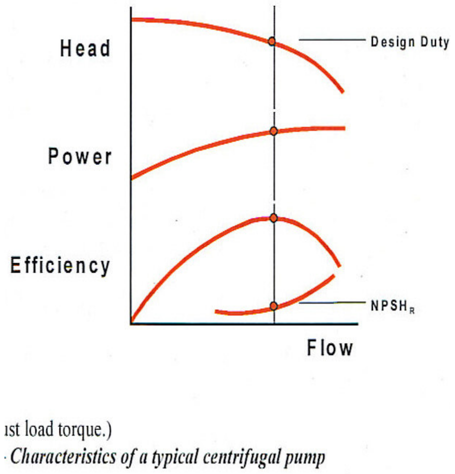
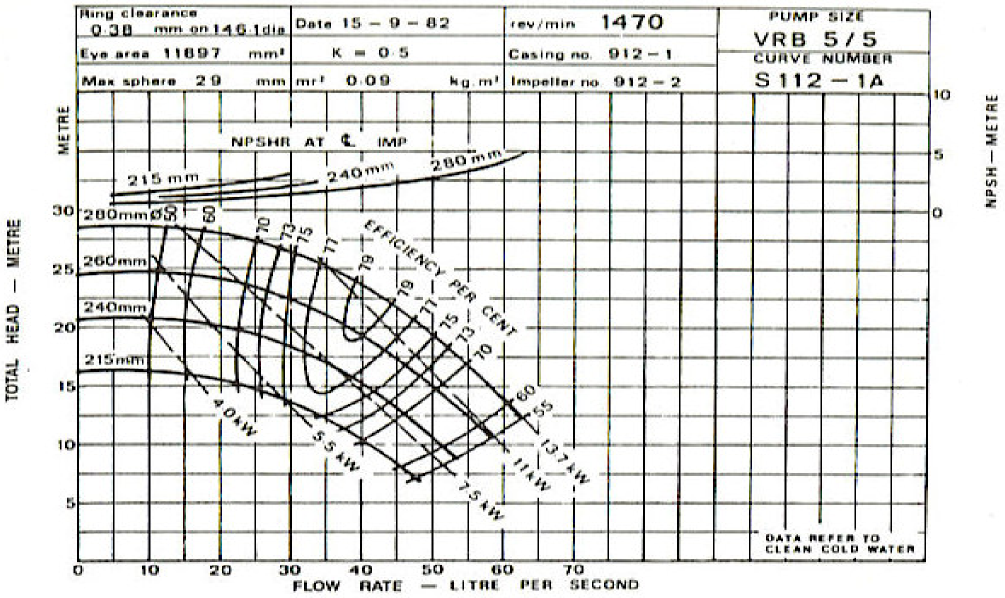


Figure 3

II. Combined curves [Figure 4]:

- All curves associated with discharge/flow, head/pressure and power absorbed are interposed and represented on a single data sheet.



TYPICAL PERFORMANCE CURVES OF A CENTRIFUGAL PUMP AT 1470r.p.m

Figure 4

Cavitation

Cavitation is a phenomenon, whereby some of the liquid being pumped vaporizes and forms into bubbles on the low pressure (predominantly suction) side of the impeller, as a result of the pressure being reduced to less than the vapour pressure of the liquid. The bubbles, implode back into a liquid, as a result of, sudden change to high pressure; towards the [predominantly] discharge end of the impeller. The resultant impact of the implosion of the bubbles is termed as cavitation, which in its disastrous state, can be quite intimidating, with violent pump vibrations and ultimate failure.

In more common applications, cavitation in pumps can occur without any appreciable noise or wear being evident.

The effects of cavitations are manifested by pitting and corrosion like effects on pump casing and impellers. More importantly, however, is the fact that cavitation contributes to significant damage to seal, bearing and pump shafts, consequently resulting in premature component failure and associated maintenance costs.

To avoid cavitation, it is imperative that the Nett Positive Suction Head Available (NPSHA) [which is calculated as part of the pumping system design is always greater than Nett Positive Suction Head Required (NPSHR)]. The NPSHR is unique for each pump and is represented in the pump data sheets as a NPSHR curve.

The NPSHR curve is used by designers and operators, to avoid pumps being configured, to operate at a duty point where cavitation could occur [Figure 4].

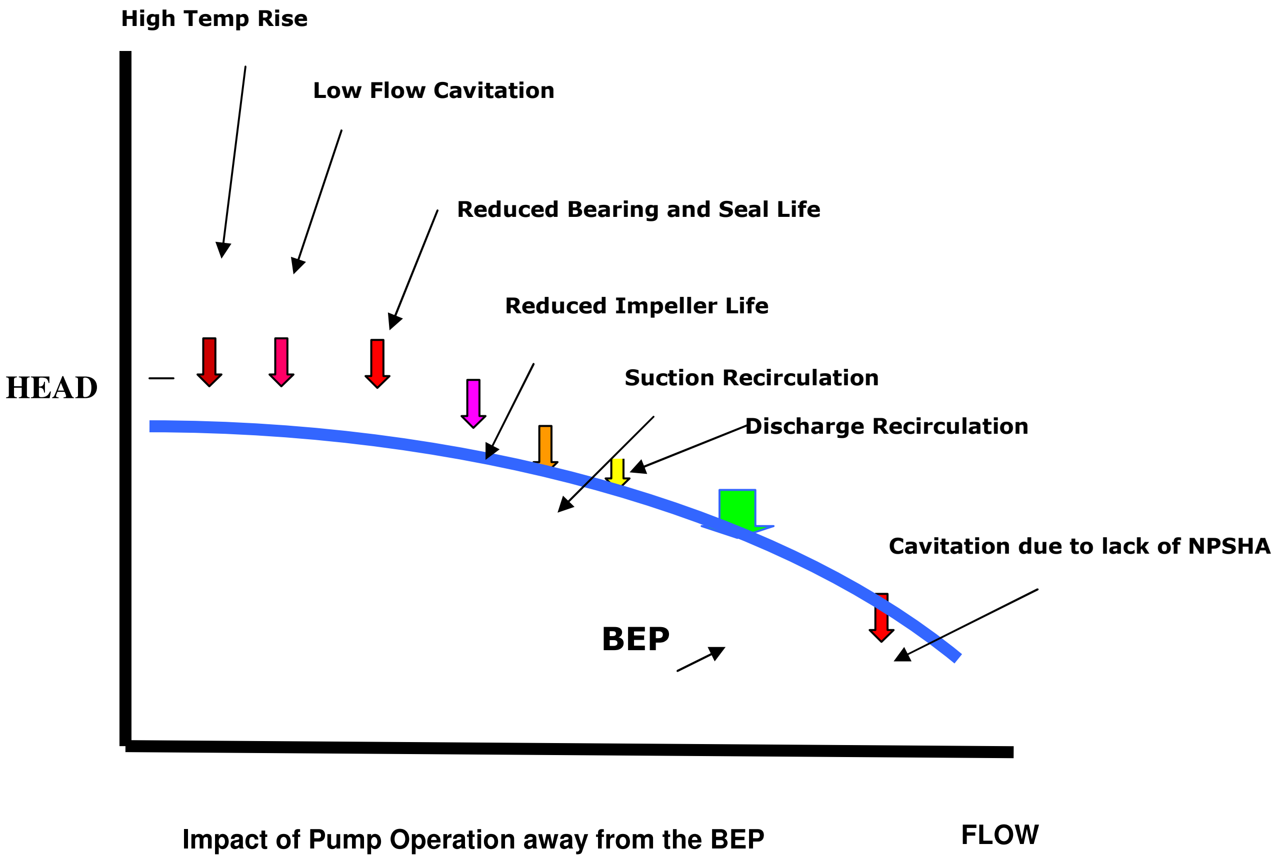


Figure 5

Analysis of Pump Curves

A basic analysis of pump curves indicates the following [Ref Fig 4]:

- Pump discharge/flow decreases as pump head increases
- Pump power increases with an increase of pump discharge/flow
- Pump efficiency decreases on either side of the BEP on the Pump Curve
- NPSHR of the pump increases as we move away from the BEP and is more predominant to the right hand side of the BEP on the curve (i.e. as the discharge/flow increases and head/pressure decreases the NPSHR increases. The increase in NPSHR is a somber reminder that to avoid cavitation the NPSHA should be greater than NPSHR, and that this margin is being reduced.

It is therefore important, that pump design and operation, wherein, the pump flow/discharge and head/pressure are subject to variation, as part of the system requirement, a detailed assessment is undertaken, to avoid specific operating instances, where a pump could cavitate.

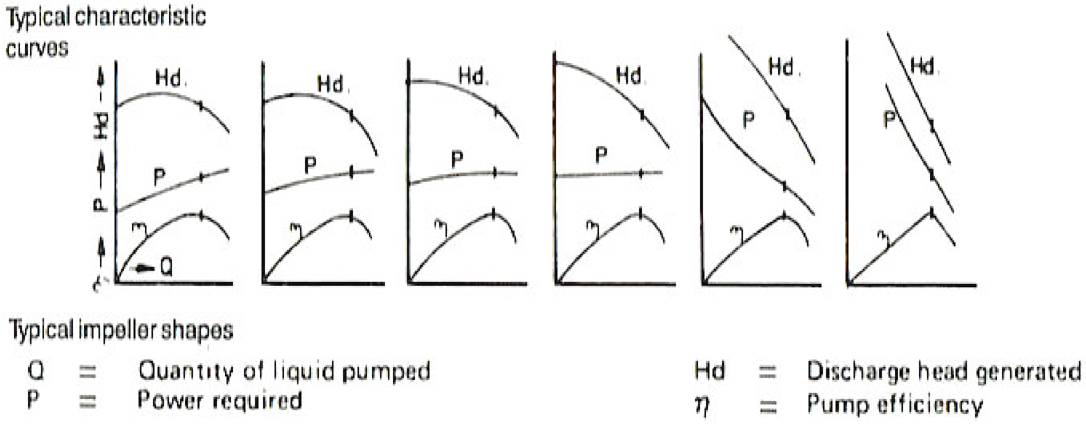
The following factors which have a bearing on pump efficiency and maintenance also need to be considered in the design process:

- Re-circulation in pumps as a result of high heads, which increases wear and imposes significant axial and radial loads on the pump shafts.
- Pump and prime mover set up to offer least transmission losses.
- Piping [sizing and type] and valve configuration to offer least system resistance.

A very basic rule in pump design and particularly in operations is that "if a pump is designed or was used to pump a specific volume of liquid at a specific head, the same pump may not successfully pump larger volumes of the liquid at a lower head without premature damage to pump and pump components".

Pump curves are generated, by varying the head/pressures, on pumps, and measuring the corresponding discharge/flow, in a laboratory type set up. Elaborate measuring equipment to monitor discharge/flow, head/pressure and power is used.

Different types of pumps have different characteristic curves as denoted in the following [Figure 6]:



Radial flow **Mixed flow** **Axial Flow**

Figure 6

The discharge/flow versus the head/pressure curve originates where the pump discharge/flow is shut off, and ends where the pump discharge/flow is at its maximum, and where the head/pressure is at its minimum.

A typical pump is generally connected by suction and discharge piping which transfers the liquid from one location to another. A difference in liquid levels, between the system where the pump acquires the liquid to be pumped, and the level of the reservoir where it is finally delivered is evident in most cases.

The difference in these two levels is known as the static head; represented by H in [Figure 7]. Additionally, the pump has to overcome resistance through the piping, valves and other appliances in the circuit. This resistance is termed as friction head represented by Hf [Figure 7].

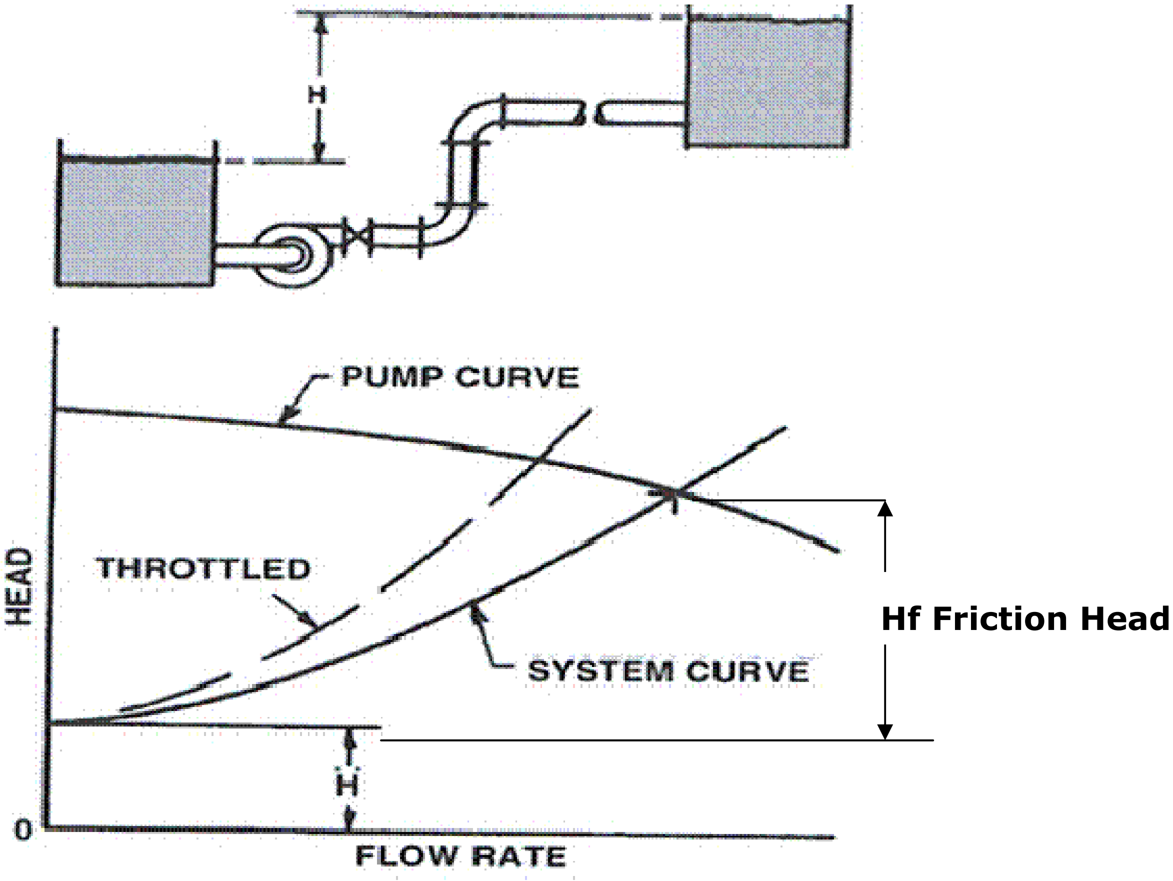


Fig. 2 Positive Suction Head

Figure 7

On the other hand, a pump or a set of pumps could be used to circulate a liquid in a closed circuit comprising of equipment like heat exchangers, boilers, etc. In this instance, the pump does not have a static head but all the head/pressure it has to overcome is solely related to frictional resistances through the piping and equipment, commonly termed as friction head. [Figure 7]

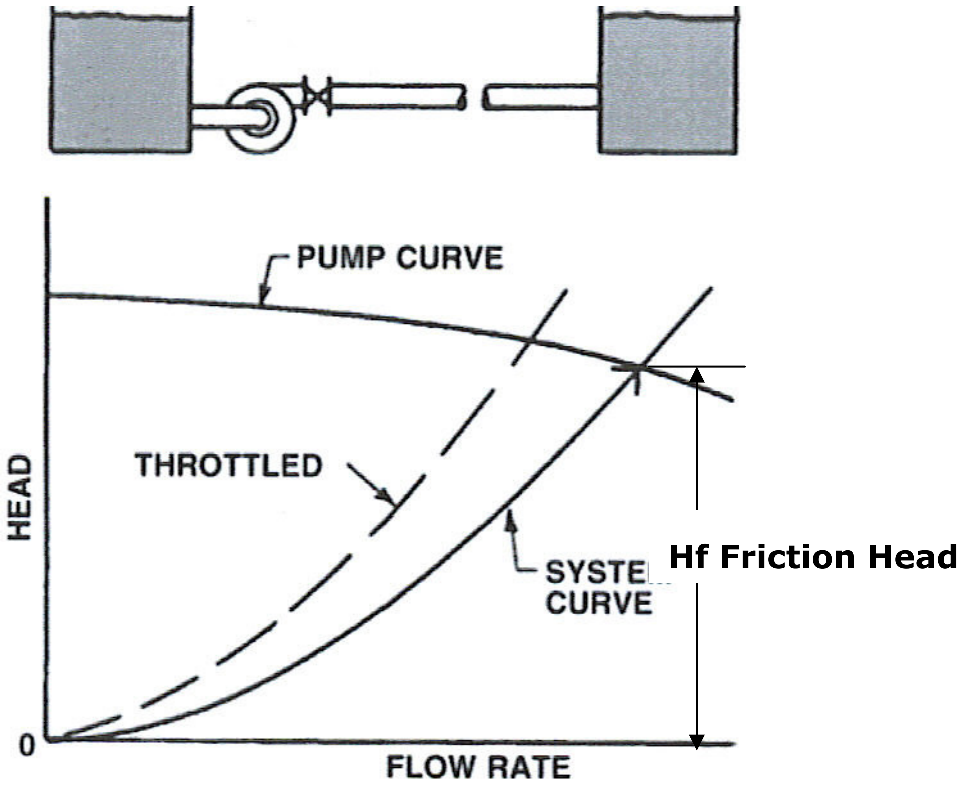
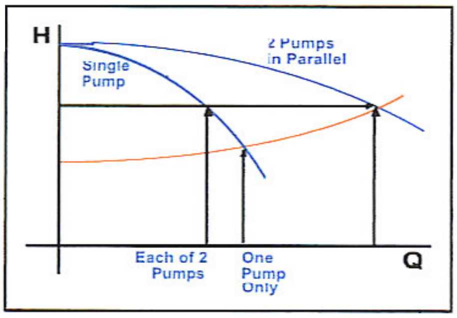


Fig.1 No Static Head All Friction

Figure 8

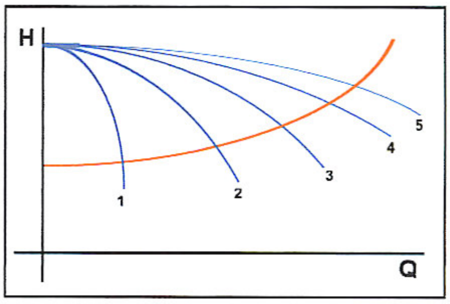
The volume of discharge/flow through a closed circuit is totally related to the friction losses/ head. As the discharge/flow gets reduced, the friction losses/head also gets reduced. A relationship where the liquid discharge/flow through a piping system at a specific head pressure intersects the pump curve is known as the duty point. The curve which gets generated from minimum discharge/flow through the pumping circuit to the maximum discharge/flow (duty point) is known as the system curve [Figures 7 and 8].

System curves are used by designers and pump operators to review pump performance when pumps operate as a single unit, and particularly when operating in parallel, with other pumps, taking into consideration, transient static and friction heads/pressures, which, have an impact on the overall pump operation [Figures 10 & 11].



Two identical Pumps in Parallel

Figure 10



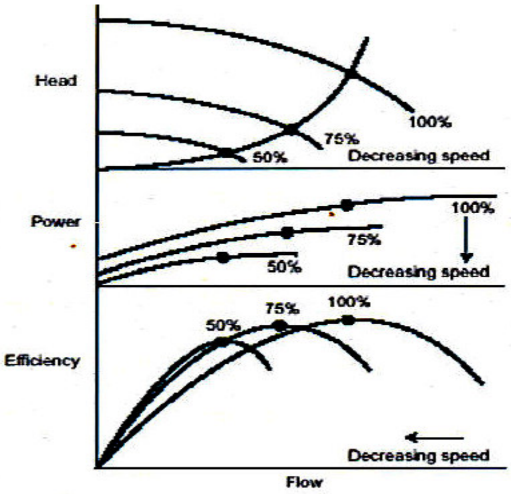
Five identical Pumps in Parallel

Figure 11

Variable Speed Drives (VSD)

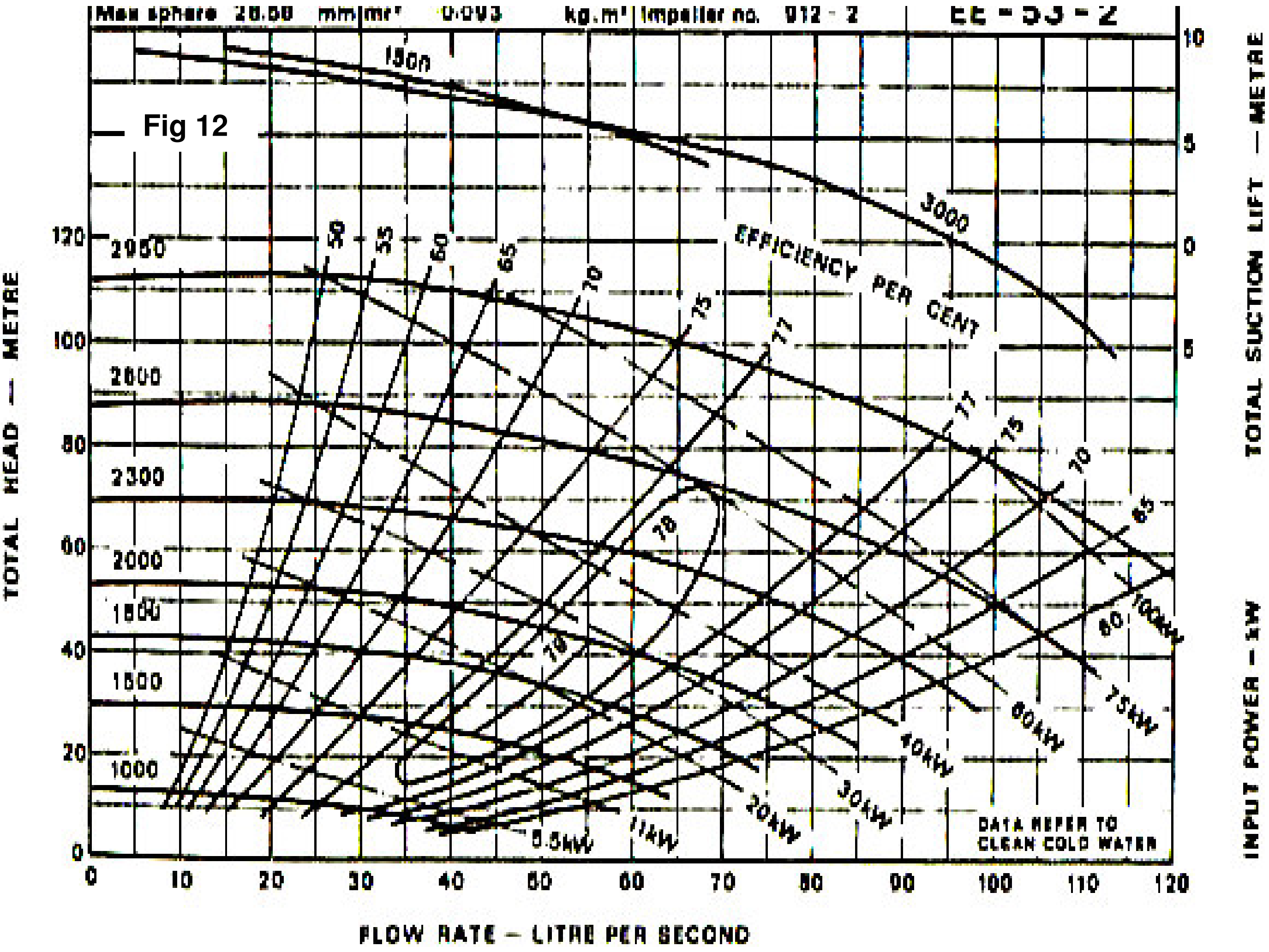
Pump operation using variable speed drives (VSD) results in specific curves being generated for discharge/flow v/s head/pressure and discharge/flow v/s power absorbed for each pump speed [Figures 12 & 13]. These curves are used to ascertain:

- Implications of utilizing VSDs (in most cases, savings in energy and outgoings over constant speed pumps) in variable flow operations.
- Requirements to maintain a constant head/pressure in the system with variable discharge/flow
- Requirements to maintain a constant discharge/flow with variable head/pressure.
- The net effect of using VSD on pumps in preference to a number of different sized pumps to sequentially operate at constant speed.



Effect of speed reduction on pump characteristics

Figure 12



TYPICAL PERFORMANCE CURVES OF A CENTRIFUGAL PUMP AT VARYING SPEEDS.

Figure 13

Pump Operation and Maintenance

Pumps are designed to operate in diverse configurations and for varied applications.

The following represents a few pump configurations.

- A single pump transferring constant discharge/flow of liquid at a constant head/pressure
- A single pump required to transfer liquid at various discharge/flow but at a constant static head/pressure
- A single pump required to circulate at a constant discharge/flow and near constant head (friction head only) in a closed circuit.
- A single pump required to circulate liquid at varied discharge/flow and varied head/pressure (friction head only) in a closed circuit.

The above four types of pump set ups can also be applicable, to more than one pump operating in parallel [Figures 10 & 11].

Multiple pumps operating in parallel, at varying discharge/flow or varying head/pressure present significant challenges to the design engineer as well as operating personnel. This is a result of the duty point on the system curve varying following a change in head/pressure or discharge/flow.

To arrive at an energy efficient outcome, as well as to avoid undue stress on pump components, during certain stages of the pumping cycle (which could impact on the life cycle cost of the pumps) a detailed overview of the entire plant operation, taking all operating parameters into consideration, is undertaken.

A pump operating in a multiple [parallel] pump circuit, with varying discharge/flow requires a detailed assessment of the various resistances and the associated discharge/flow generated by a single pump when operating alone and as each of the other pumps [operating in parallel] are sequentially energized.

The piping and equipment in the circuit, in most instances, is constant. However, the discharge/flow requirement through the system could vary from, just one pump, to all pumps operating at full designed capacity.

In the design, and, operation of multiple parallel pumps systems, one must be aware that when only one pump operates the pump discharge/flow/output would be the largest, as the head/pressure is minimum. If the calculated head/pressure is higher than that actually evidenced on site, (commonly, as a result of safety factors and design contingencies) there is every possibility that the pump could be operating away from the BEP, even in a cavitating mode.

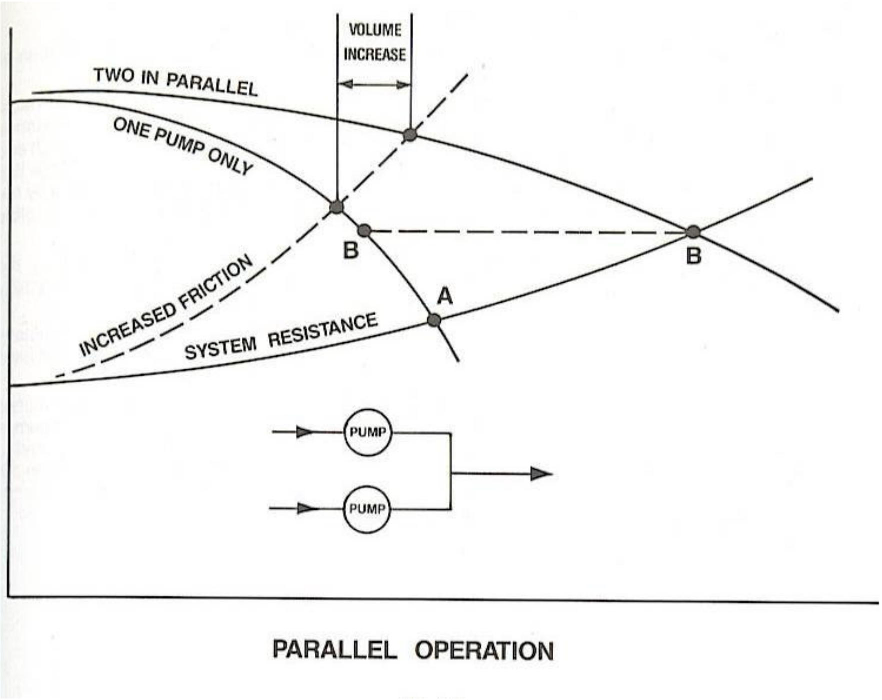


Figure 14

On the other end of the spectrum, the designer and operator has to be aware that the pump sizing has to be such that when more than one pump is in operation, the head/pressure developed does not increase to a level where recirculation or low flow cavitation can occur [Figure 5]. In the extreme situation, the pump may even be operating as if its discharge/flow is fully closed whereby the liquid in the pump could heat up and ultimately vaporize resulting in catastrophic pump failure.

The pump curves offer a tool to review the pump's performance over the entire operating range, thereby highlighting any cause for potential inefficiencies and undue stress on pump components while in operation.

The curves are used to ascertain the pumps operating performance by plotting operating pump data on the curves. As far as possible, pump operating points should be designed to be within ten per cent of the best efficiency points. It is important that with parallel pumping or where a pump is subjected to varied discharge/flow a detailed analysis is undertaken to ascertain the maximum hours the pump will have to operate for a specific duty. This duty should form the basis for an optimized energy outcome .One would expect the pump to operate at or near the BEP at this duty with other duty points operating preferably within a range of ten percent of the BEP.

- **Pump Operating Configurations**

Two distinct pumping requirements; commonly encountered by the industry are:

- Pumps in Parallel required to maintain a constant head/pressure at all times, with varying flow/discharge [Figure 15]

This set up is commonly encountered in closed circuits where field demand requires that a minimum head or pressure is maintained in the circuit, so that all field equipment requiring the desired flow is satisfied.

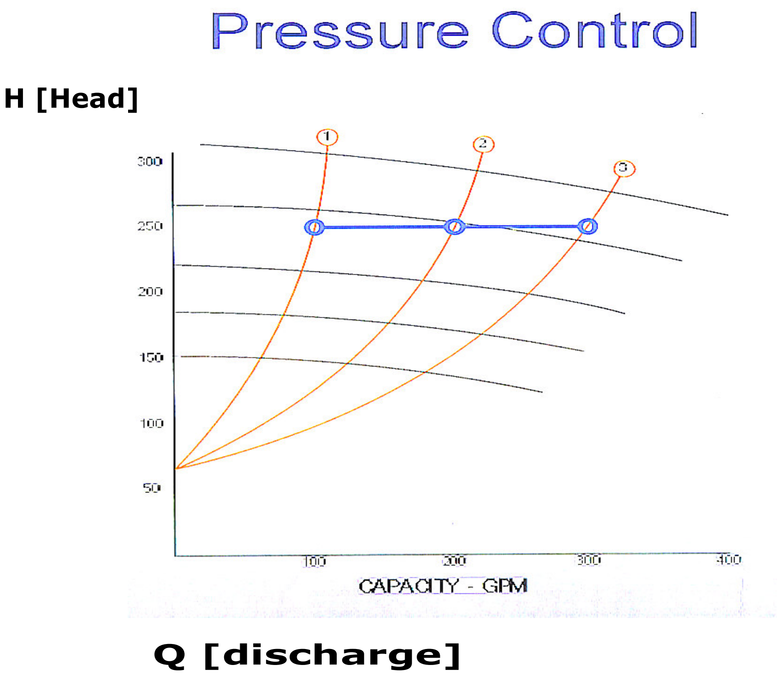


Figure 15

The change in system curves as a result of flow variation is denoted in Figure 15.

Constant head/pressure in constant speed pumps is maintained by cycling the pumps in and out of the pumping circuit, in combination with throttling and by pass valves. In most instances this is an inefficient mode of control. Pumps with “flat” rather than “steep” Flow v/s head curves are used for this application.

The use of VSD’s offers a more energy efficient outcome. This alternative also offers, the added benefit, for future enhancement of pumping requirements, with minimal, if any additional cost outlays. However, it is important to note, that with VSD operation, speed reduction over the lower discharge ranges may not be possible, as minimum flows through the pumps, could result in pump operating close to its shut off head, resulting in recirculation, low flow cavitation, etc. In such instances by pass arrangements after the pump speed is reduced to a specific level is to be incorporated.

The pumps’ performances at various stages of operation are analyzed after the system is commissioned. The control strategies and sequencing of pumps may need attention to optimize energy out goings and life cycle costs.

- Pumps in Parallel required to maintain a constant flow/discharge at all times with varying head/pressure

The change in system curves as a result of variation in flows is denoted in Figure 16.

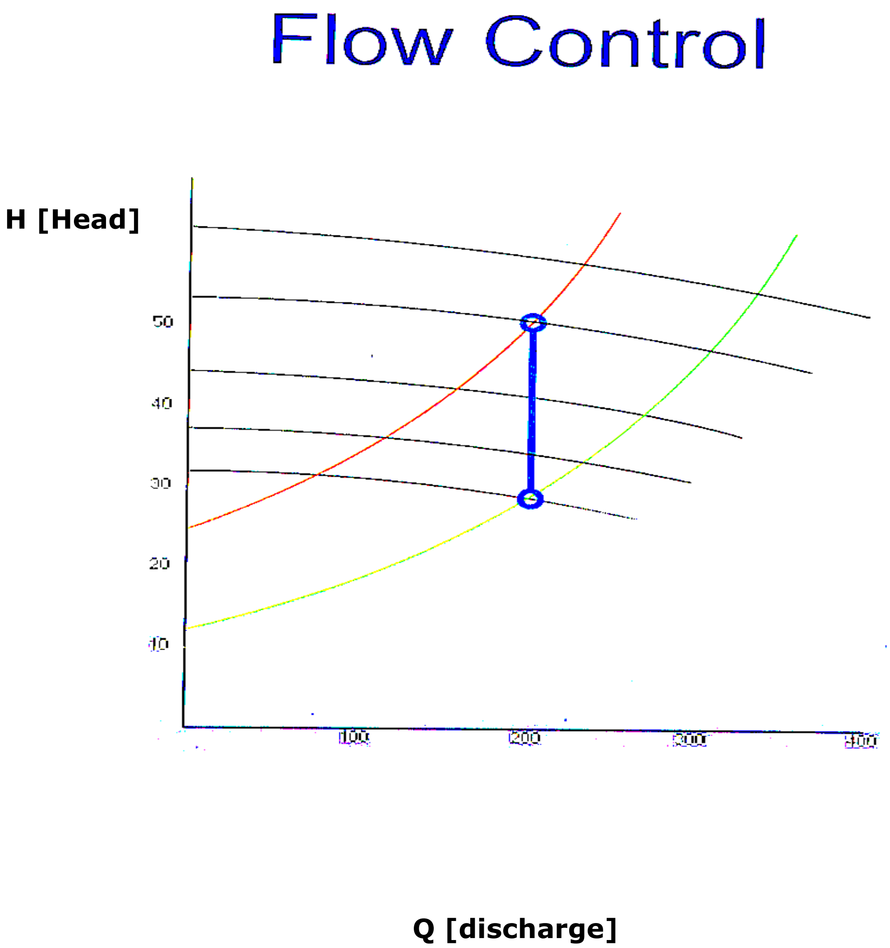


Figure 16

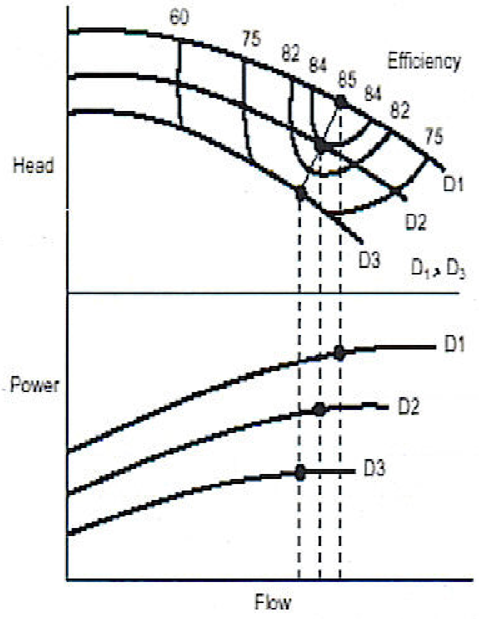
Constant flow/discharge in constant speed pumps is maintained by cycling the pumps in and out of the pumping circuit with either bypassing the liquid back into the pump suction [very energy inefficient method] or by throttling of the motorized discharge valves on the pumps [again not the most efficient system but an improvement over by pass control].

Pumps with “steep” rather than “flat” Flow versus Head curves are used for this application.

The use of VSD’s generally offers the most energy efficient outcome and in many instances offers the added benefit of future enhancement of pumping requirements with minimal if ant additional cost outlays.

The pumps’ performances at various stages of operation are analyzed after the system is commissioned. The control strategies and sequencing of pumps may need attention to optimize energy out goings and life cycle costs.

Another factor that comes into play in many systems after they are commissioned and put into service is that the pumps are oversized for the application. Throttling of the pump discharge valve is a relatively common and at times non energy efficient method adopted by the industry handling relative clean fluids. A more realistic and energy efficient method would be to reduce the size of the impeller [Figure 17] or even consider using VSD’s on the pumps.

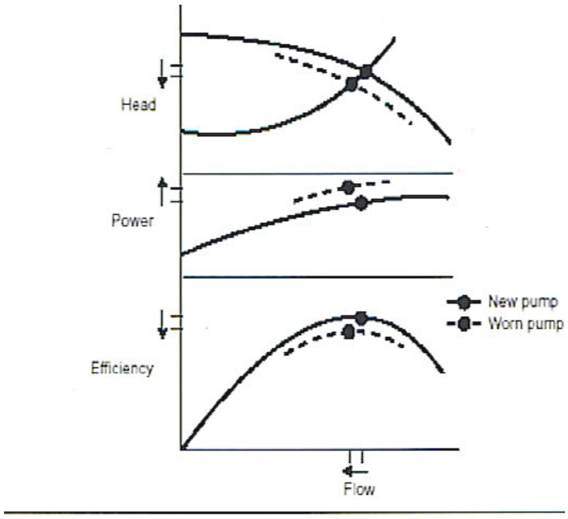


Pump characteristics showing various impeller diameters

Figure 17

- **2. Pump Wear and Maintenance**

Pump curves offer the opportunity for maintenance personnel to confirm that newly commissioned pumps, achieve the designed and ordered performance outputs.



- Effect of wear on pump characteristics

Figure 18

Pump curves also offer a basis for monitoring the performance of the pumps and the need for overall and refurbishment, i.e. the performance is monitored against the commissioned data using the pump curves as a guide in evaluating expected wear and the associated implications on the pumps' performance [Figure 18].

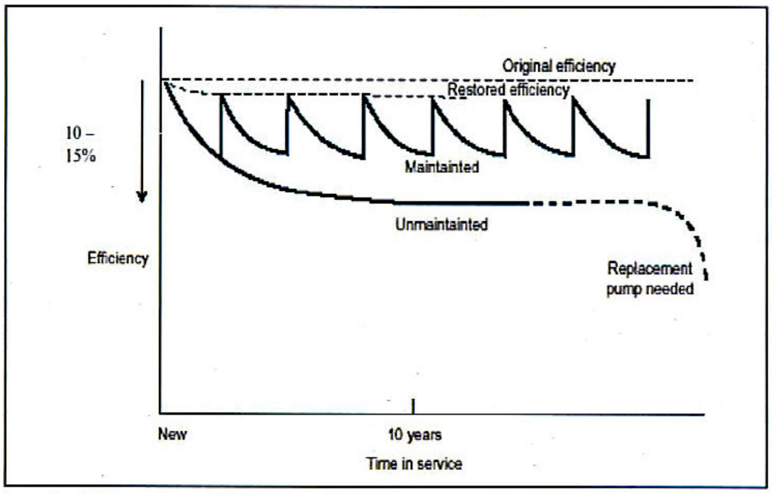


Figure 6.2 The effect of maintenance on pump efficiency and lifetime

Figure 19

Pump curves generated after the pump is refurbished and put back into service provide a feedback on the extent of wear, the success or otherwise of the refurbishment, including an indication of the life expectance of the pumps [Figures 18 &19].

References

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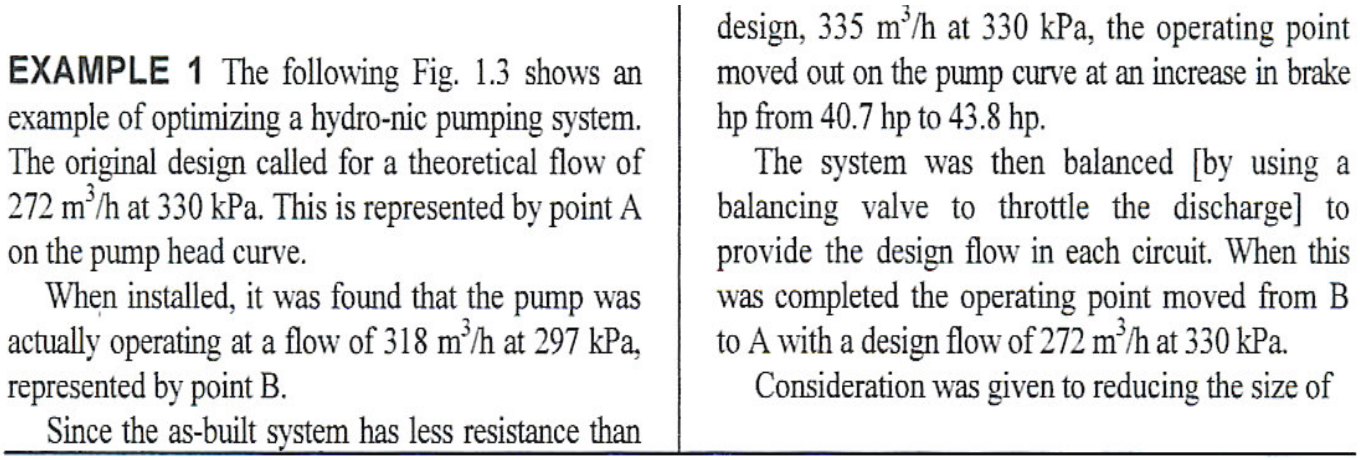
Appendices $^{(5)}$



EXAMPLE 1 The following Fig. 1.3 shows an example of optimizing a hydro-nic pumping system. The original design called for a theoretical flow of 272 m^3/h at 330 kPa. This is represented by point A on the pump head curve.

When installed, it was found that the pump was actually operating at a flow of 318 m^3/h at 297 kPa, represented by point B.

Since the as-built system has less resistance than design, 335 m^3/h at 330 kPa, the operating point moved out on the pump curve at an increase in brake hp from 40.7 hp to 43.8 hp.

The system was then balanced [by using a balancing valve to throttle the discharge] to provide the design flow in each circuit. When this was completed the operating point moved from B to A with a design flow of 272 m^3/h at 330 kPa.

Consideration was given to reducing the size of

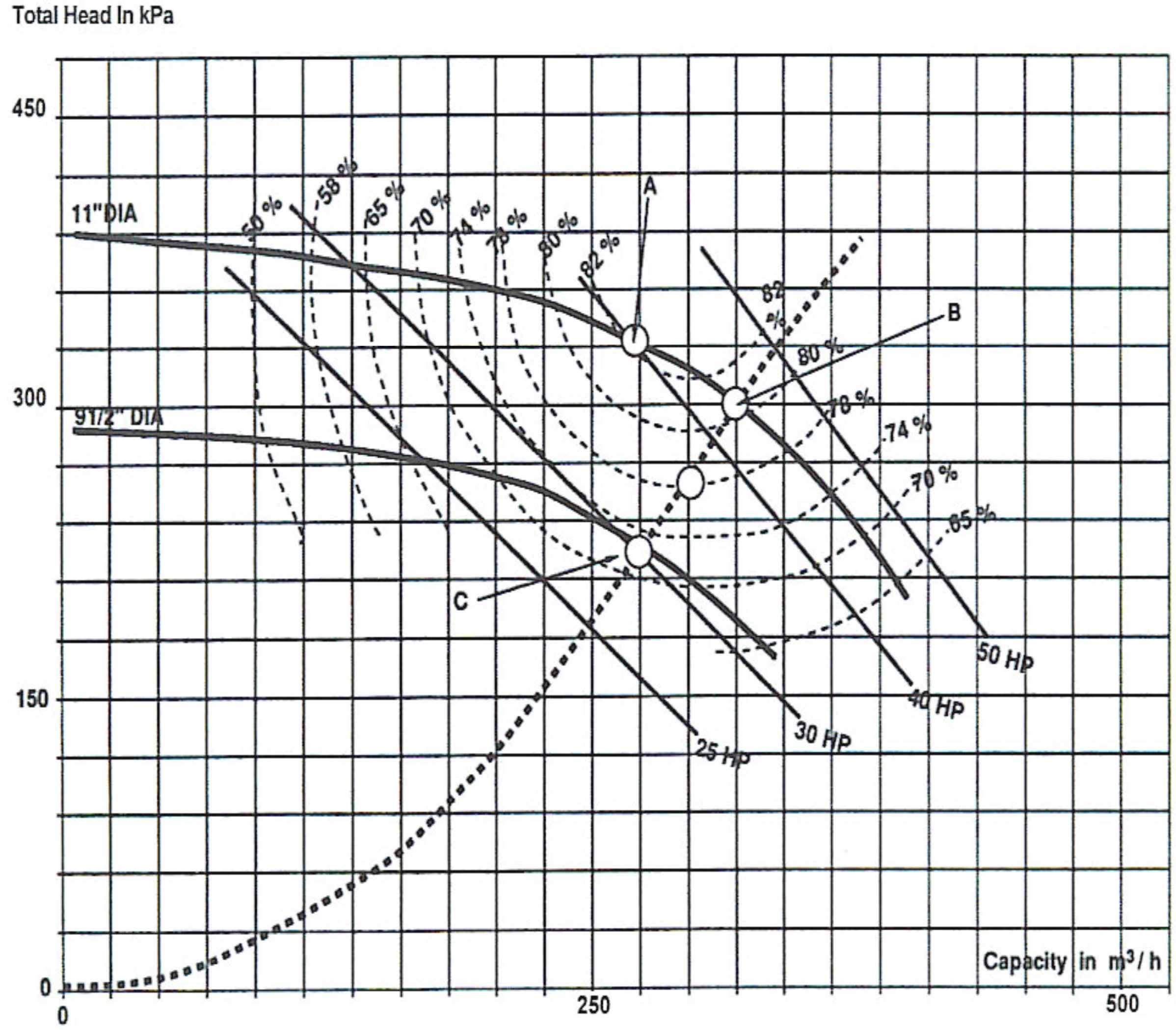
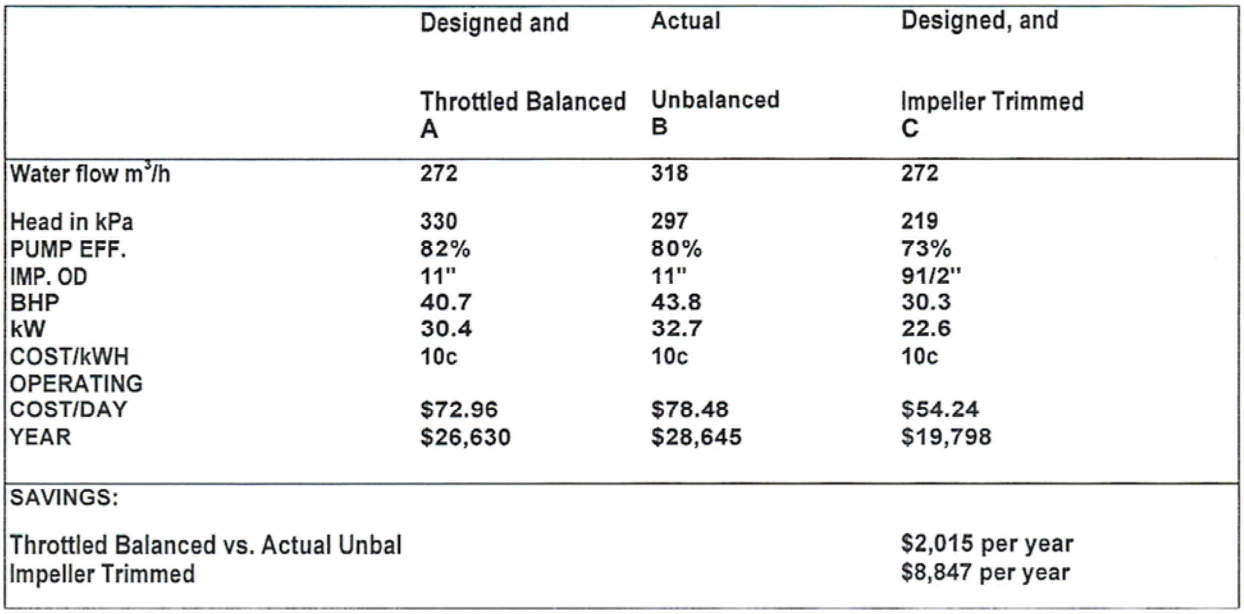


Fig1.3Pump head and system curve

The change in system curves as a result of flow variation is denoted in Fig 15



	Designed and	Actual	Designed, and
	Throttled Balanced A	Unbalanced B	Impeller Trimmed C
Water flow m³/h	272	318	272
Head in kPa	330	297	219
PUMP EFF.	82%	80%	73%
IMP. OD	11"	11"	91/2"
BHP	40.7	43.8	30.3
kW	30.4	32.7	22.6
COST/kWH	10c	10c	10c
OPERATING			
COST/DAY	$72.96	$78.48	$54.24
YEAR	$26,630	$28,645	$19,798
SAVINGS:			
Throttled Balanced vs. Actual Unbal			$2,015 per year
Impeller Trimmed			$8,847 per year

Fig 1.4

Optimized pump performance With Throttled balanced and impeller trimmed

the pump impeller since the pump could operate at a lower horsepower and still provide the design at a lower resulting head.

Point C is the point on the system curve with a reduction in head to 219 kPa and a reduction in brake horsepower to 30.3 hp. This point was found by first determining the actual flow through the main balancing valve in the supply at point B along with the pump head of 297 kPa and then calculating the new impeller size using the laws for pumps.

At constant speed:

$$\frac{\text{Diameter 1}}{\text{Diameter 2}} = \frac{q_1}{q_2} = \sqrt{\frac{\Delta H_1}{\Delta H_2}} = \sqrt[3]{\frac{P_1}{P_2}}$$

$$\text{And Diameter 2} = \text{Diameter 1} \cdot \frac{q_2}{q_1} =$$

$$= 280 \cdot \frac{272}{318} = 240 \text{ the new impeller diameter.}$$

The diameter is rounded off to 240 mm. As a result of balancing, we are at point A on the original impeller curve and a new system curve through this point. When the new impeller is installed and the main balancing valve STAD-M readjusted to a wide open position, the operating point A shifts to point C which is 272 m³/h at 219 kPa.

Fig. 1.4 shows the results of pump optimization. At $ 0.1 per kWH, balancing alone reduced the original design operating cost from $28,645 per year to $26,630, a reduction of $2,015 per year (7 percent). Trimming the pump impeller, reduced the original design operating cost from $28,645 per year to $19,798, a reduction of $8,847 per year (30.9 percent).

The balancing valve is not just a tool for accurately setting the flow to design conditions, but also for measuring flows accurately so that the pump size can be determined based on the actual installed running conditions.