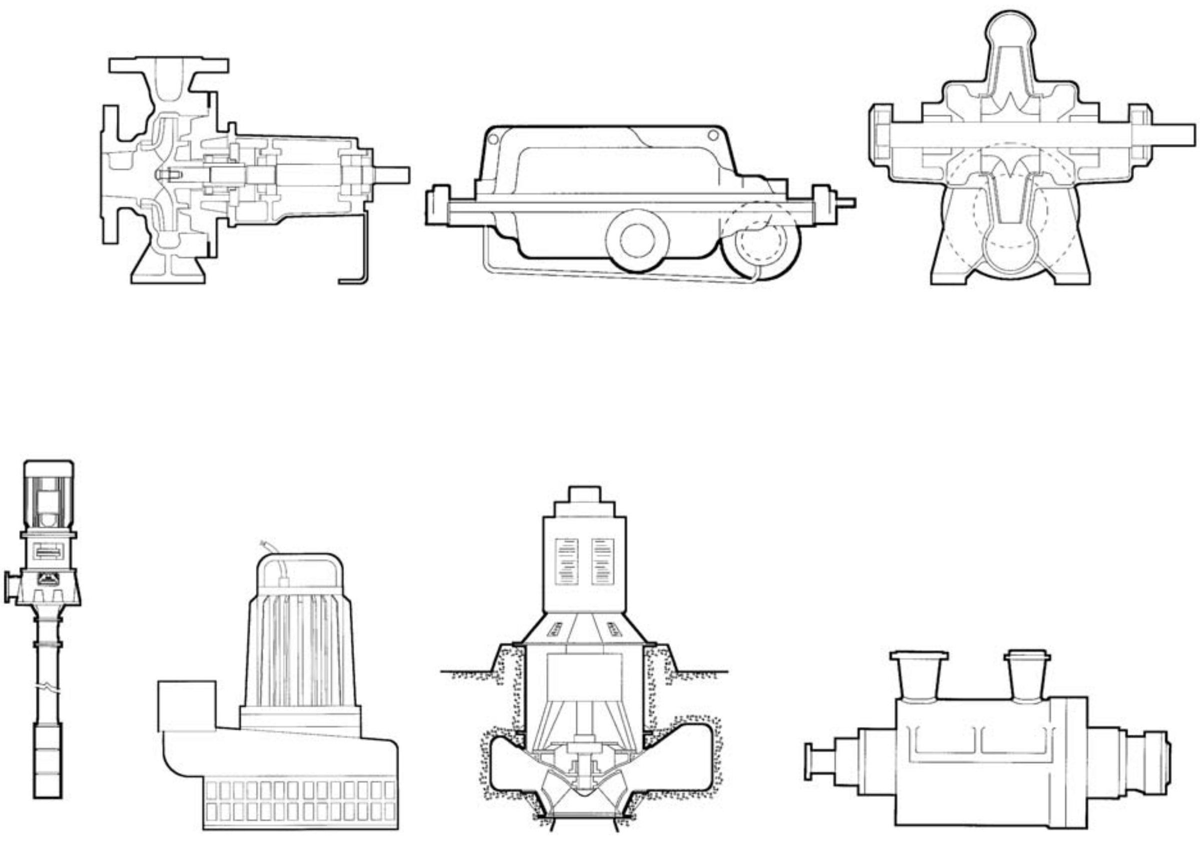
EUROPEAN ASSOCIATION OF PUMP MANUFACTURERS
ASSOCIATION EUROPEENNE DES CONSTRUCTEURS DE POMPES
EUROPAISCHE VEREINIGUNG DER PUMPENHERSTELLER
ASSOCIAZIONE EUROPEA DEI PRODUTTORI DI POMPE

Europump

GUIDE TO THE SELECTION OF ROTODYNAMIC PUMPS



Contents

Tables

Figures

1. Purpose of this Guide to pump procurement

This Guide provides an introduction to the very complex subject of the selection of pumps. It is aimed at anyone who wishes to purchase or select a pump and, at the same time, wishes to save money on their energy bill. Almost invariably, this saving will be far more than the first cost of the pump. The reader may be the end user, a contractor or a consultant. This Guide provides the reader with the basic principles of pump procurement, giving pointers to the pump type and performance they should consider. Pumps are divided into their main types, then their basic construction and performance are considered, their principal applications are described, the basic principles of pump selection are explained and, last but not least, target efficiencies are set to help minimise energy usage. The hope is that both pump users and the environment will benefit.

2. Method of classifying pumps

Table 1 shows pump types listed under two main categories, Rotodynamic and Positive Displacement, each of which has three sub-categories. It excludes many types of specialist pumps (e.g. Jet, Liquid Ring, Regenerative), but these only account for a relatively small amount of absorbed energy. Since around 90% of pumping energy in the UK is absorbed by rotodynamic pumps, this Guide concentrates only on this category.

		Pump Type	Table
ROTODYNAMIC	Centrifugal	Single Entry Volute - Conventional	3
		Single Entry Volute – Solids Handling	4
		Single Entry Volute – Non-Clogging	5
		Single Entry Volute – In-Line	6
		Double Entry Volute	7
		Two Stage Volute	8
		Multistage Radial Split	9
		Multistage Axial Split	10
		Multistage Barrel Casing	11
		Single Stage Well	12
		Multistage Well	13
	Mixed Flow	Volute	14
		Bowl	15
	Axial Flow	Well	16

POSITIVE DISPLACEMENT	Rotary	Progressing Cavity
		Sliding Vane
		Peristaltic
		Screw
		Lobe
		Gear
	Reciprocating	Diaphragm
		Plunger
		Piston
	Open	Archimedean Screw

Table 1.
Categorisation of pump types

3. Industries and applications

Table 2 shows the major industries which use rotodynamic pumps, together with the main applications on which the pumps are used. It also guides you to the exact table numbers, within section 5, where further descriptions of the pump types that can be used for each of the applications can be found.

Principal Industries	Typical Applications (+ Table nos. detailing pump types used)
General Services	Cooling water(3)(7), Service water(3), Fire-fighting (3)(7)(8)(12)(13), Drainage (16)
Agriculture	Irrigation (3)(7)(9)(15)(16), Borehole (3)(13), Land drainage (15)(16)
Chemical / Petrochemical	Transfer (3)
Construction / Building Services	Pressure boosting (3)(8), Drainage (4), Hot water circulation (6), Air conditioning (6), Boiler feed (9)
Dairy / Brewery	Transfer (3), 'Wort' (4), 'Wash' to fermentation (7)
Domestic	Hot water (6)
Metal Manufacture	Mill scale (4), Furnace gas scrubbing (7)(12)(13), Descaling (9)
Mining / Quarrying	Coal washery (4), Ore washing (4), Solids transport (4), Dewatering (4)(9)(10)(13), Water jetting (8)
Oil / Gas Production	Main oil line (7)(10)(11), Tanker loading (7), Water injection (10)(11), Seawater lift (13)
Oil / Gas Refining	Hydrocarbon transfer (3)(6)(7)(9)(10), Crude oil supply (7), Tanker loading (7), Product pipeline (9)(10), Reactor charge (11)(13)
Paper / Pulp	Medium / low consistency stock (3), Wood chips (4), Liquors / Condensate (4), Stock to head box (7)
Power Generation	Large cooling water (3)(7)(14), Ash handling (4), Flue gas desulphurisation process (4), Condensate extraction (7)(8)(13), Boiler feed (9)(10)(11)
Sugar Manufacture	Milk of lime / syrup (3), Beet tailings (4), Juices (4), Whole beets (5)
Wastewater	Raw and settled sewage (5), Grit-laden flows (5), Stormwater (5)(15)(16)
Water Supply	Raw water extraction (7)(12)(13)(14)(15), Supply distribution (7)(8)(9), Boosting (7)(8)

Table 2.
Principal industries and their applications

4. Rotodynamic Pump characteristic curves

Pumps are always defined by the basic pump characteristic curves (Fig 1). These show the relationship between head, power and efficiency against flow. It is important to note just how 'peaky' the efficiency curve is, showing that running at a flow above or below Best Efficiency Point (BEP) is likely to lead to a significant reduction in pump efficiency.

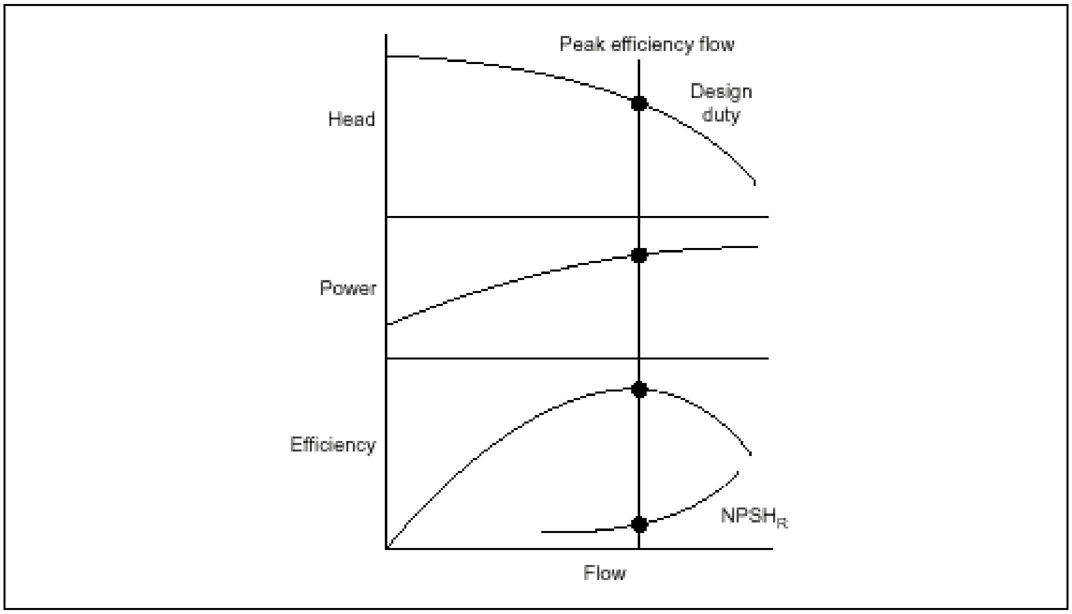


Fig 1.
Pump characteristics

The curves shown in Fig 1 are fairly typical of a Centrifugal pump. A Mixed Flow pump would have a much steeper head curve, a power curve which would probably fall continuously from zero to maximum flow, and an efficiency curve which would be more 'peaky'. An Axial Flow pump would have even steeper head and power curves than a Mixed Flow pump, and an efficiency curve which would be even more 'peaky'. These variations are important in that they affect maximum pipe pressures, motor sizes and off-peak operating efficiencies. (The definitions of Mixed and Axial Flow types are covered in section 7.)

Also shown on Fig 1 is the Net Positive Suction Head required by the pump ($NPSH_R$). The NPSH is defined as the total head at the pump inlet above vapour pressure (corrected to the level of the first stage impeller inlet, if different). The $NPSH_R$ is usually (but not always) the NPSH at which the pump (or the first stage impeller if a multistage pump) loses 3% head due to cavitation. The Net Positive Suction Head available to the pump on site ($NPSH_A$) must exceed the $NPSH_R$ by a safety margin. This would rarely be less than 0.5m but will usually be greater because of many factors, including pump speed, size, liquid pumped and operating range. More information on this safety margin is given in Ref 1, which provides a useful coverage of the subject of NPSH.

The importance of selecting a pump to operate as closely as possible to its BEP cannot be over-emphasised. Not only should this save on energy costs, it will have several other benefits. The pump should run smoothly with minimum internal disturbing forces, thereby saving on maintenance costs due to premature failure of components such as bearings, wear rings, bushes, couplings and seals. The risk of damage to pump components due to cavitation should be reduced. Vibration should be minimised, benefiting other equipment. Noise should be minimised, improving the environment. Pressure pulsations should also be minimised, reducing the risk of problems in the pumping system as a whole. Fig 2 indicates some of the problems which can result from operating away from BEP. Some of these problems may not be serious in small pumps, but they increase in severity as pump power increases, and should therefore be discussed with the pump supplier.

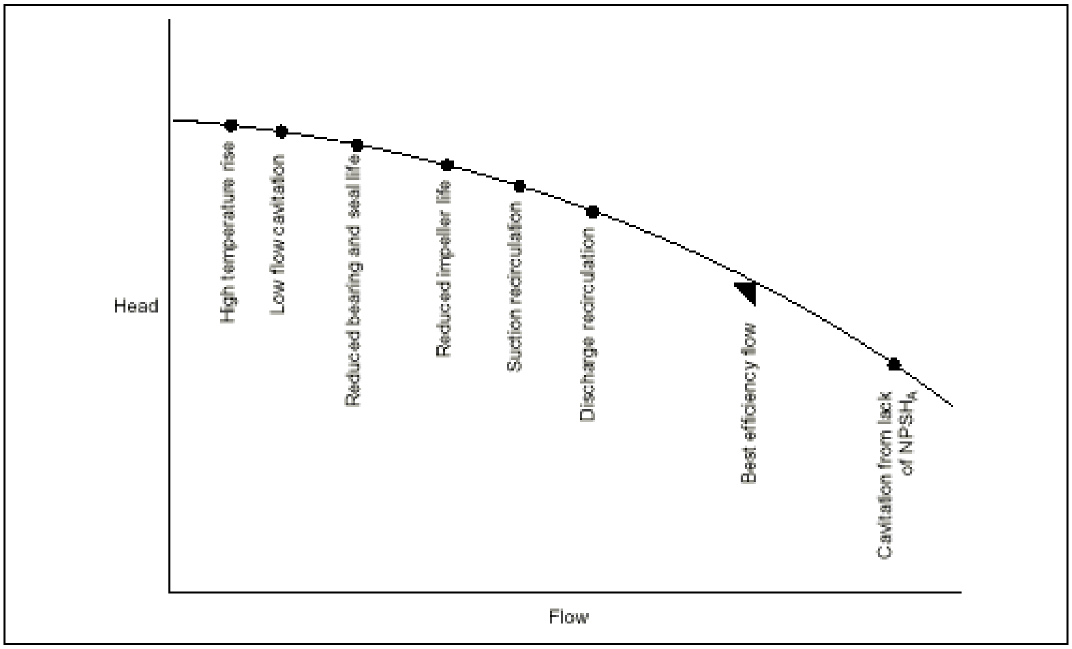


Fig 2.
Onset of possible adverse effects when operating away from BEP

5. Details of pump types

The following Tables 3 to 16 give details of the rotodynamic pump types listed in Table 1.

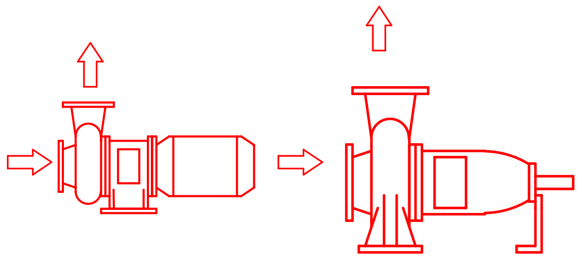
In practice there are dozens of variations on the basic pump themes, each one taking on the attributes dictated by its particular market. Branch positions can change, the shaft can be horizontal or vertical or even inclined, there are many options in shaft sealing, the drive may be by fixed or variable speed motor or diesel engine or belt, etc., etc..

The tables show drawings of the most common arrangements of each of the 14 types, together with brief descriptions. They also show typical characteristic curves. However, the actual curve shapes can vary considerably, so the curves produced by the maker of a pump being considered must be checked to make sure they suit the application. Comments on performance are made on the sheets which should help in this respect.

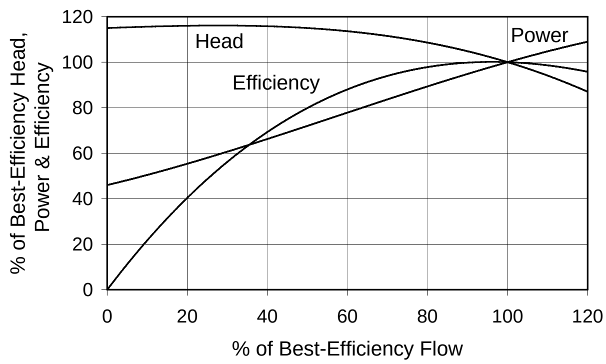
Finally, the main applications of each pump type are listed to help with the choice of pump. Obviously, this can only be a general guide, the suitability of each selection for an application must be judged on its merits.

Pump Type / Performance	Description / Applications

Single Entry Volute - Conventional



Typical Performance



Smaller pumps tend to be relatively low cost with efficiency on the low side. Back wear rings with impeller balance holes (to reduce thrust and gland pressure) cause some efficiency loss. Efficiency falls relatively slowly as flow moves away from best-efficiency.
On some pumps of this type , head may fall with reducing flow (as shown). If so, at reduced flow surging may occur and pumps will not run in parallel at low flows.

Power may increase considerably beyond best-efficiency flow. To cover this, larger motors may be needed.

Some small pumps are fitted with integral speed controllers which can be used for energy saving.

Description

Impeller may be mounted on motor shaft, or pump may have its own shaft and bearings with pump driven via a coupling. Standard pumps to ISO 2858 (EN 22858, ex Din 24256) and EN 733, ex DIN 24255, enable back pull-out of rotating element without disturbing pipework, if using spacer coupling, without disturbing motor. Some pumps have special inlet casings for self-priming.

Shaft is sometimes vertical with pump suspended in a sump by a column pipe, with no pump gland, and discharging to surface through a separate pipe between casing discharge flange and column/motor support/mounting plate.

Applications

General: Cooling water, Service water, Fire-fighting (special characteristics required).
Agriculture: Irrigation (usually with priming device), Borehole (small flows and depths using ejector in borehole).
Chemical/Petrochemical: Transfer (superior construction and special materials, often glandless using magnetic drive or canned motor, sometimes vertical sump type).
Building Services: Pressure boosting in tall buildings.
Dairy/Brewery: Transfer (special stainless steel fabricated construction with crevices avoided to permit ‘Clean in place’).
Oil/Gas Refining: Fuel oil, Gas oil, Lubricating oil, Kerosene, Petrol (‘Process’ type, centre-line supported, special shaft seals, complying with API 610)
Paper/Pulp: Medium/low consistency stock (special designs with single shrouded impellers, often stainless steel).
Power Generation: Large cooling water, (vertical shaft, largest have concrete volutes).
Sugar: Milk of lime and syrup.

Table 3.
Details of Single Entry Volute – Conventional Pumps

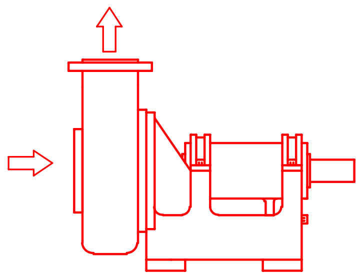
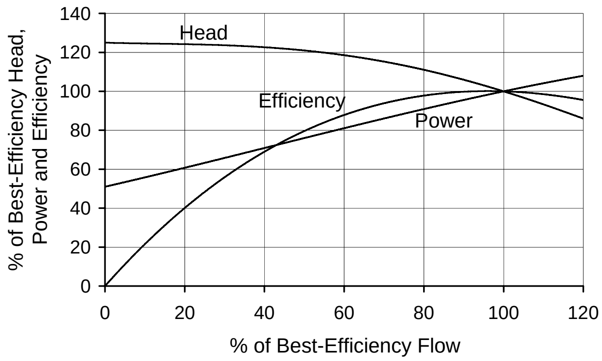
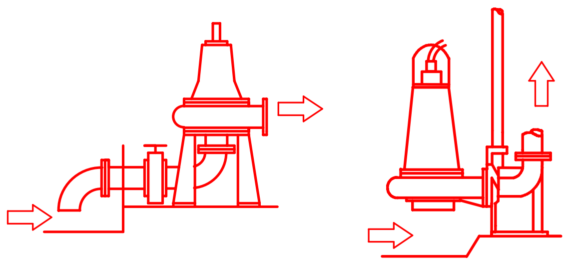
Pump Type / Performance	Description / Applications
<u>Single Entry Volute – Solids Handling</u>  **Typical Performance**  Efficiency generally low, because of low number of thick impeller vanes, 'pump-out' vanes on impeller shrouds and concentric casings. Head usually rises to zero flow. Power usually rises beyond best-efficiency flow, although pumps do not normally operate here. Head/flow/power adjusted by speed (belt drive or variable speed motor) since impellers cannot be cut.	**Description** Very robust construction. Usually horizontal shaft but some pumps have vertical shaft, using either cantilevered shaft suspended in sump with no gland, or driven by submersible motors. Impellers and casings usually in hard nickel or chrome iron for larger solids, and rubber or polyurethane lined for small solids. Impeller usually screwed on to shaft to protect it. Gland packing flushed with clean water or expeller used to keep gland dry while running. Bearings and front cover axially adjustable to take up wear on radial wear faces. Speed and head are limited to minimise wear. Higher heads achieved by running pumps in series. **Applications** <u>Brewery</u>: Brewed barley mash ('wort'). <u>Construction</u>: Drainage (diesel engine driven and self priming by vacuum pump, or vertical submersible motor driven). <u>Metal Manufacture</u>: Mill scale. <u>Mining/Quarrying</u>: Coal washery, Ore washing, Solids transport, Dewatering open cast mines (cantilevered shaft). <u>Paper/Pulp</u>: Wood chips, Liquors, Condensate. <u>Power Generation</u>: Ash handling, Flue gas desulphurisation process. <u>Sugar</u>: Beet tailings, Sugar juices.

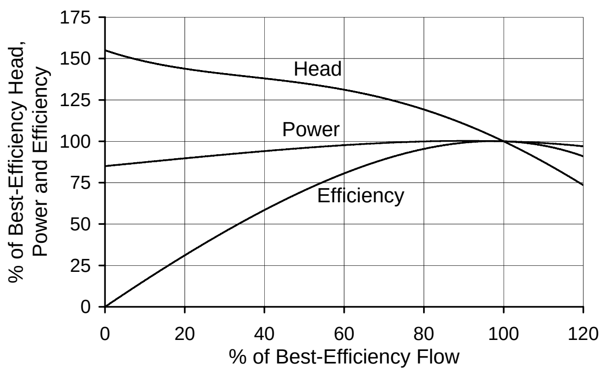
Table 4.
Details of Single Entry Volute – Solids Handling Pumps

Pump Type / Performance	Description / Applications

Single Entry Volute – Non-Clogging



Typical Performance



Efficiency can be on the low side, particularly for small pumps. Requirement for ‘non-clogging’ or ‘unchokability’ necessitates use of one or two vane impellers (except in large sizes). Back vanes on impellers to reduce axial thrust and protect seal also absorb power and reduce efficiency. Pumps handling material heavy in grit use multi-vane ‘vortex’ impellers, set back from main flow and having low efficiency.

Head will usually rise continuously to zero flow, allowing parallel operation.

Power will usually peak reasonably close to best-efficiency flow.

Pump is usually required to pass a sphere of between 75 and 150mm diameter. However, ‘sphere size’ is only a crude guide to solids handling performance.

Description

Usually vertical pump shaft.

Normally, pump will be in wet well using integral submersible internally dry motor, with oil reservoir with two seals between pump and motor to avoid contamination from pumped fluid. Units are usually mounted on rails to guide them down into well, making a self-sealing joint at discharge pipe and allowing simple installation and removal.

Submersible motors may require cooling, depending on size of unit and whether they need to operate un-submerged. Cooling may be by enclosed circuit using oil or glycol , or by jacket using pumped liquid where suitable. These units are also used in dry wells, inherently protected against flooding.

Sometimes, pumps in dry wells are driven through intermediate shafting by conventional motor on higher floor to avoid flooding.

Applications

Sugar: Whole beets (horizontal shaft).
Wastewater: Raw sewage, Grit-laden flows (‘vortex’ impeller), Settled sewage, Stormwater.

Table 5.
Details of Single Entry Volute – Non-Clogging Pumps

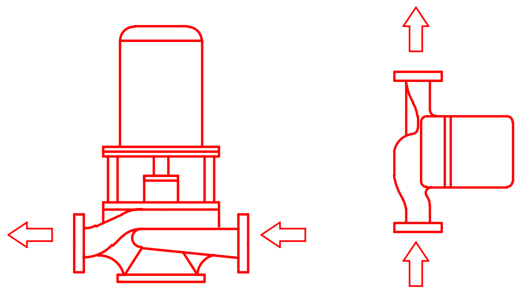
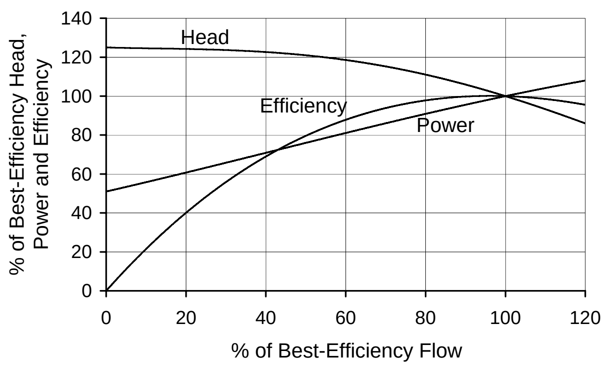
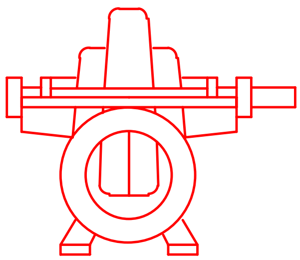
Pump Type / Performance	Description / Applications
<u>Single Entry Volute – In-Line</u>  **Typical Performance**  Efficiency is reduced a little by cramped arrangement of suction and discharge passages. Back wear rings with impeller balance holes (to reduce thrust and gland pressure) cause some efficiency loss. Head usually rises continuously with reducing flow, except on some of the smaller pumps. Power will sometimes rise at higher flows, may require larger motors to cover this. Smaller pumps will often have integral speed control, enabling automatic head control to suit demand.	**Description** Larger pumps have vertical shafts and are usually located (and often supported) by pipework. Motor is fitted above pump, so that forces on pump flanges do not affect pump/motor alignment. Motor and impeller can be removed without disturbing pipework. Smaller pumps have horizontal shafts and are usually supported by pipework. Canned rotors are used to avoid shaft seals, and bearings are lubricated by pumped liquid. Smaller pumps (up to about 200 mm branches) are often built with two pumps combined, sometimes known as 'twinpumps' or 'twinsets'. These can be used as duty/standby and sometimes in parallel. **Applications** <u>Building Services</u>: Hot water circulation, Air conditioning. <u>Domestic</u>: Hot water circulation. <u>Oil/Gas Refining</u>: Fuel oil, Gas oil, Kerosene, Petrol.

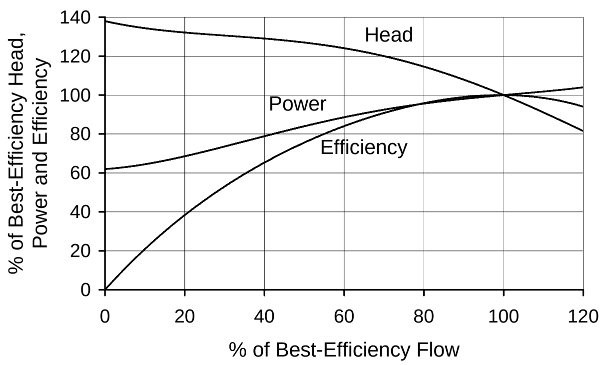
Table 6.
Details of Single Entry Volute – In-Line Pumps

<table>
<tr><th>Pump Type / Performance</th><th>Description / Applications</th></tr>
<tr><td>

<u>Double Entry Volute</u>



Typical Performance



Efficiency good and usually falls away fairly slowly as flow moves away from best-efficiency.

Head usually rises continuously with reducing flow, allowing parallel operation.

Power often rises at higher flows, so motor powers may need to be increased to suit.

Suction performance benefits from two impeller inlets.

</td><td>

Description

Usually horizontal shaft, axially split. Lifting cover gains access to rotating element without disturbing pipework or motor. Shaft may be vertical if space is limited or flooding is possible (in which case motor will be on higher floor). Axial hydraulic balance minimises axial thrust. Larger high head pumps have double volutes to reduce radial thrust. In-line branches simplify pipework.

Applications

<u>General</u>: Cooling water, Fire-fighting (special characteristics required).
<u>Agriculture</u>: Irrigation (usually with priming device).
<u>Brewery</u>: ‘Wash’ to fermentation tanks.
<u>Metal Manufacture</u>: Furnace gas scrubbing.
<u>Oil/Gas Production</u>: Main oil line (radially-split for higher heads), Tanker loading.
<u>Oil/Gas Refining</u>: Crude oil supply (radially-split for higher heads, API 610), Fuel oil, Gas oil, Kerosene, Petrol (‘Process’ type, centre-line supported, special shaft seals, API 610), Tanker loading.
<u>Paper/Pulp</u>: Low consistency stock to head box (impeller vanes offset to minimise pulsations).
<u>Power Generation</u>: Condensate extraction (vented back to condenser), Large cooling water.
<u>Water Supply</u>: River and reservoir extraction, Supply distribution, Boosting.

</td></tr>
</table>

Table 7.
Details of Double Entry Volute Pumps

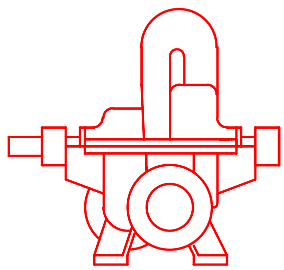
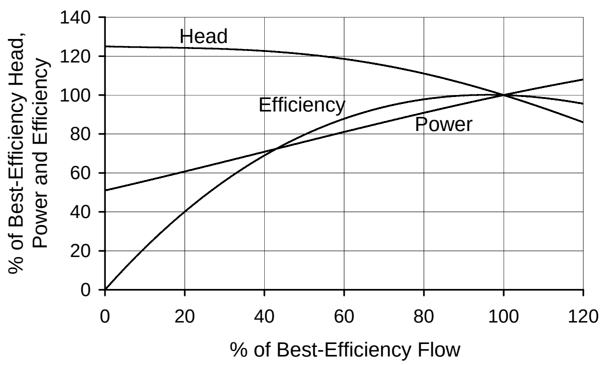
Pump Type / Performance	Description / Applications
<u>Two Stage Volute</u>  **Typical Performance**  Efficiency reduced a little by losses in crossover passage and inter-stage bush. However, probably more efficient than equivalent single-stage Double Entry Volute pump for same duty. Head usually rises continuously with reducing flow, allowing parallel operation. Two impellers in series produce relatively high head (without expense of using two pumps). Power likely to increase at higher flows, so motor powers may need to be increased to suit.	**Description** Two impellers are usually mounted back-to-back on shaft with pressure breakdown bush in between. Integral cross-over passage from outlet of first stage impeller to inlet of second stage impeller. Second stage gland under first stage discharge pressure, so sealing must suit. Inherent axial balance, so low axial thrust. **Applications** <u>General</u>: Fire-fighting (special characteristics required). <u>Building Services</u>: Pressure boosting in tall buildings. <u>Mining/Quarrying</u>: Jetting water monitors. <u>Power Generation</u>: Condensate extraction (vented back to condenser). <u>Water Supply</u>: Supply distribution, Boosting.

Table 8.
Two Stage Volute Pumps

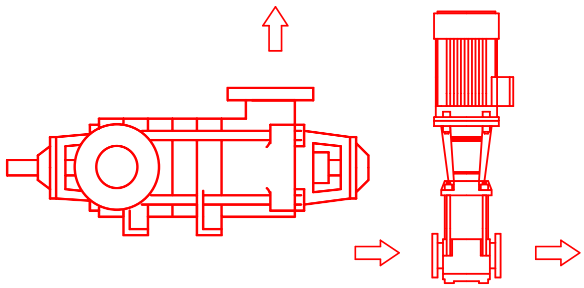
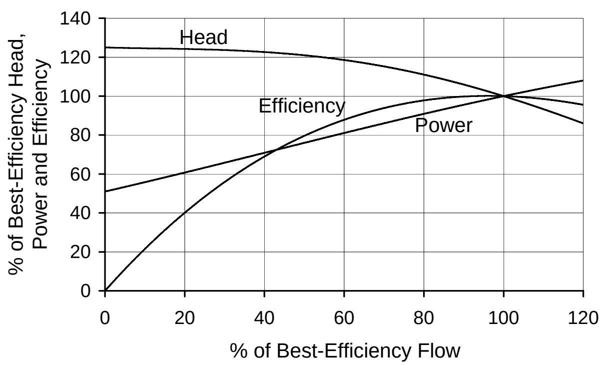
Pump Type / Performance	Description / Applications
Multistage Radial Split  **Typical Performance**  Used for relatively high head duties where single or two stage pumps are unsuitable. Efficiency suffers somewhat from tight hydraulic passages and relatively large shaft diameter at impellers. Also from larger wear ring clearances on hot pumps. Efficiencies of smaller pumps can benefit from use of thin sheet metal hydraulic components. Efficiency will be better than 1 or 2 stage pumps for high head applications. Head usually rises continuously with reducing flow, allowing parallel operation, but rise to zero flow is minimised to limit maximum pressure on pipework. Power increases at higher flows, so motor powers may need to be increased to suit.	**Description** Usually three or more stages. Each impeller discharges into a multi-vaned diffuser leading to return guide vanes which feed flow to inlet of next impeller. Stages are held together by long through-bolts. Larger pumps have horizontal shafts and may be driven through step-up gearboxes to increase speed and pressure. All impellers face same direction and rarely have back wear rings, so a balance disc or drum is usually fitted at discharge end with leakage returned to suction. On abrasive duties, a heavy thrust bearing may also be required. On hot duties, may be centre-line supported and use balance drum and thrust bearing. Smaller pumps usually have vertical shafts with motor mounted on top. Hydraulic components may be sheet metal or plastic composite. **Applications** Agriculture: Small scale irrigation. Building Services: Boiler feed (fabricated stainless steel components in smaller pumps). Metal Manufacture: Descaling (with external thrust bearing). Mining: Dewatering. Oil/Gas Refining: Fuel oil, Gas oil, Kerosene, Petrol ('Process' type, Centre-line supported, special shaft seals, complying with API 610), Product pipeline. Power Generation: Boiler feed. Water Supply: Supply distribution (high pressure).

Table 9.
Details of Multistage Radial Split Pumps

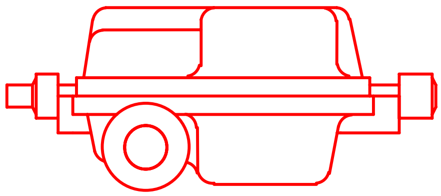
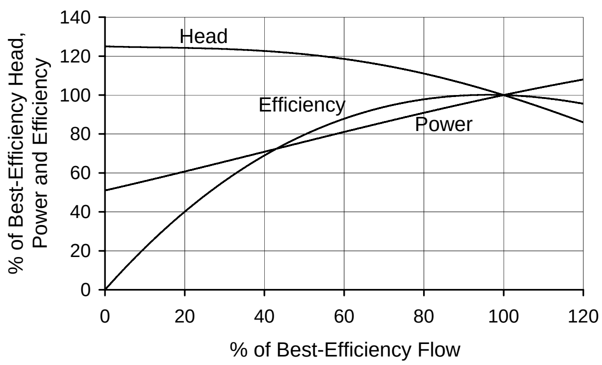
Pump Type / Performance	Description / Applications
<u>Multistage Axial Split</u>  **Typical Performance**  Used for relatively high head duties where single or two stage pumps are unsuitable. Efficiency suffers somewhat from tight hydraulic passages and relatively large shaft diameter at impellers. Also from larger wear ring clearances on hot pumps. Head usually rises continuously with reducing flow, allowing parallel operation, but rise to zero flow is minimised to limit maximum pressure on pipework. Power increases at higher flows, so motor powers may need to be increased to suit.	**Description** Each impeller discharges into a double volute which feeds flow back to next impeller. Impellers are split into two sets, mounted back-to-back. First set fed by suction at one end of pump and discharges into crossover passage from middle of pump to other end, where it feeds second set of impellers which discharge at centre of pump. A pressure breakdown bush is fitted between last impeller of first set and final impeller. Another breakdown bush is necessary before first impeller of second set, with leakage returned to suction. Axial thrust is basically balanced, so a large thrust bearing is not needed. Axial split of casing involves difficult sealing to atmosphere and between stages. Hot pumps are centre-line supported. **Applications** <u>Mining</u>: Dewatering. <u>Oil/Gas Production</u>: Water injection, Main oil line. <u>Oil/Gas Refining</u>: Fuel oil, Gas oil, Kerosene, Petrol ('Process' type, centre-line supported, special shaft seals, complying with API 610), Product pipeline. <u>Power Generation</u>: Boiler feed.

Table 10.
Details of Multistage Axial Split Pumps

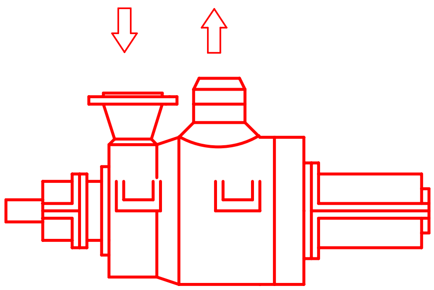
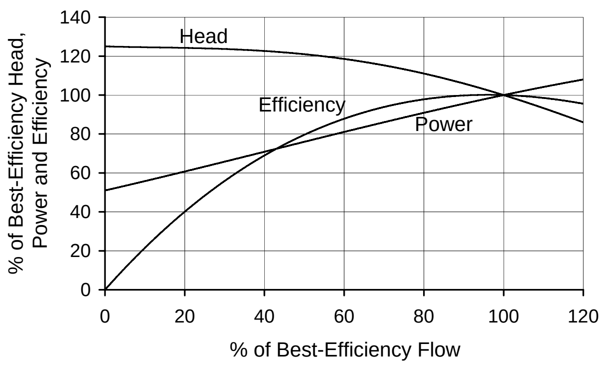
Pump Type / Performance	Description / Applications
Multistage Barrel Casing  **Typical Performance**  Used for relatively high head duties where single or two stage pumps are unsuitable. Efficiency suffers somewhat from tight hydraulic passages and a large shaft diameter at impellers. Also from larger wear ring clearances on hot pumps. Head rises continuously with reducing flow, allowing parallel operation, but rise to zero flow is minimised to limit maximum pressure on pipework. Power increases at higher flows, but pumps rarely run beyond best-efficiency flow.	**Description** Stages are built up much as for Multistage Radial Split pump, then inserted into a forged steel barrel casing which provides full pressure containment, which is then closed by a heavy cover. Suction end of barrel is only subjected to suction pressure. Axial thrust is usually accommodated by a balance drum with a thrust bearing to take residual thrust. Hot pumps are centre-line supported. **Applications** Oil/Gas Production: Water injection, Main oil line. Oil/Gas Refining: Reactor charge (anti-corrosive materials and allowance for high differential expansion). Power Generation: Boiler feed.

Table 11.
Details of Multistage Barrel Casing Pumps

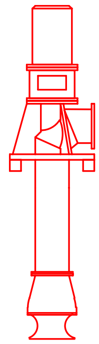
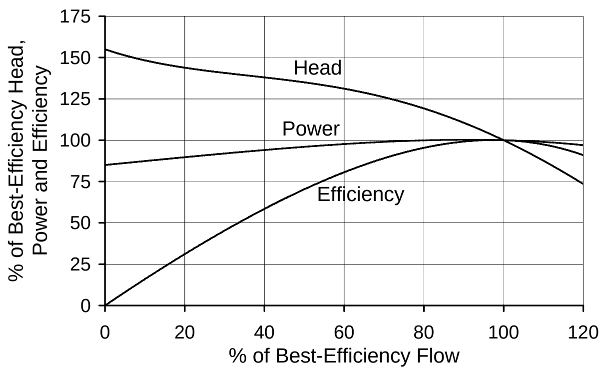
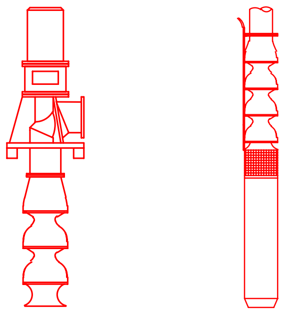
Pump Type / Performance	Description / Applications
Single Stage Well  **Typical Performance**  Pump efficiency is reasonably good if losses in column pipe, discharge bend and thrust bearing are deducted from motor output. Head is suitable for parallel operation. Power usually peaks at or near best-efficiency flow.	**Description** Pump is suspended from floor level. Flow enters through a bellmouth to give well distributed flow to impeller (provided intake arrangement feeding pump has been well designed). Impeller discharges to a multi-vane axial/inward diffuser and thence to column pipe and discharge bend. Discharge flange can be above or below floor. Axial thrust is taken by a thrust bearing below motor, or the motor bearings . The pump can also be driven by a submersible motor. **Applications** General: Fire-fighting (special characteristics required). Metal Manufacture: Scrubber circulation. Water Supply: River and reservoir extraction.

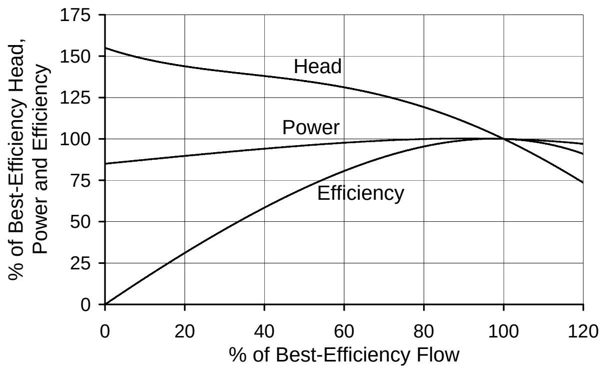
Table 12.
Details of Single Stage Well Pumps

<table>
<tr><th>Pump Type / Performance</th><th>Description / Applications</th></tr>
<tr><td>

<u>**Multistage Well**</u>



Typical Performance



Pump efficiency reasonably good but submersible motor less efficient than conventional motor. Column pipe losses may be significant in deep well.

Head is suitable for parallel operation.

Power usually peaks at or near best-efficiency flow.

</td><td>

Description

Above-ground motor version is basically similar to Single Stage Well pump, except that several impeller/diffuser stages are connected in series. For high heads or small diameters, radial impellers and diffusers are used (similar to Multistage Radial Split pump arrangement).

Shaft drive may be used in wells up to 30m deep, although use in deeper wells may still be economical.

Submersible motor version is used in deep wells, with motor mounted below pump to aid cooling. Motor usually water-filled with integral thrust bearing.

Applications

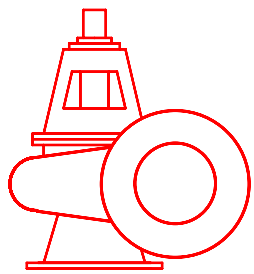
<u>General</u>: Fire-fighting (special characteristics required).
<u>Agriculture</u>: Borehole (driven by shafting or submersible motor).
<u>Metal Manufacture</u>: Scrubber circulation.
<u>Mining</u>: Dewatering underground mines with submersible motor drive.
<u>Oil/Gas Production</u>: Seawater lift.
<u>Oil/Gas Refining</u>: Reactor charge (suspended in canister).
<u>Power Generation</u>: Condensate extraction (special first stage impellers, suspended in canister).
<u>Water Supply</u>: Borehole extraction (driven by submersible motor or shafting in shallow wells).

</td></tr>
</table>

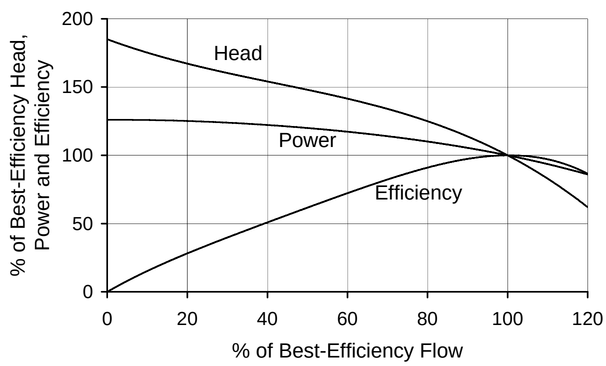
Table 13.
Details of Multistage Well Pumps

<table>
<tr><th>Pump Type / Performance</th><th>Description / Applications</th></tr>
<tr><td>

<u>**Mixed Flow Volute**</u>



Typical Performance



Efficiency reasonably good but falls fairly quickly above and below best-efficiency flow.

Head rises fairly steeply with reducing flow. Best-efficiency head is relatively low. Instability is possible at around 60% flow.

Power rises with reducing flow, so a larger motor may be required to cover this.

</td><td>

Description

Generally used for higher flows and lower heads. Usually vertical shaft with bottom entry. Rotating element can be removed without disturbing pipework. Impeller sensitive to inlet conditions so inlet pipe (usually a bend) needs careful design. Motor may be supported from ground level or on a higher floor.

Applications

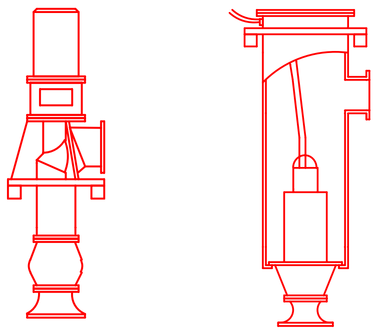
<u>Power Generation</u>: Condensate cooling water (largest flows have concrete volutes).
<u>Water Supply</u>: Reservoir extraction (very large flows only).

</td></tr>
</table>

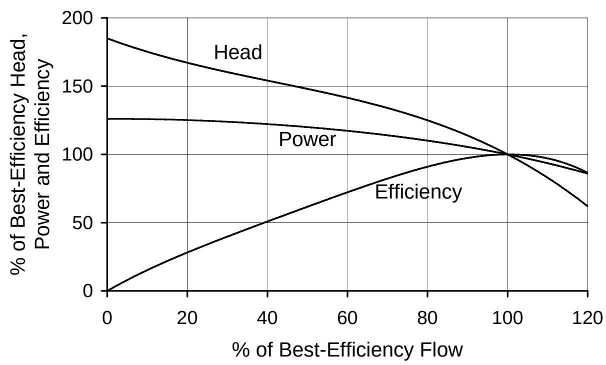
Table 14.
Details of Mixed Flow Volute Pumps

Pump Type / Performance	Description / Applications

Mixed Flow Bowl



Typical Performance



Efficiency falls fairly quickly above and below best-efficiency flow. Efficiency of conventional version is reasonably good if losses in column pipe, discharge bend and thrust bearing are deducted from motor output. Submersible motor version loses some efficiency due to losses in canister.

Head rises fairly steeply with reducing flow. Best-efficiency head is relatively low. Instability is possible at around 60% flow, limiting the operating range.

Power rises with reducing flow, so a larger motor may be required to cover this.

Description

Conventional pump is suspended from floor level. Flow enters through a bellmouth to give well distributed flow to impeller (provided intake arrangement feeding pump has been well designed). Impeller discharges to a multi-vane axial/inward diffuser and thence to column pipe and discharge bend. Discharge flange can be above or below floor. Axial thrust is taken by a thrust bearing either below the motor or by the motor bearings.

Submersible motor version is usually lowered into a canister below floor. Motors are dry internally, having oil reservoir with two seals between pump and motor to avoid contamination from pumped fluid.

Applications

Agriculture: Irrigation (often with submersible motor), Land drainage (usually with submersible motor).
Wastewater: Stormwater (surface water only).
Water Supply: River and reservoir extraction.

Table 15.
Details of Mixed Flow Bowl Pumps

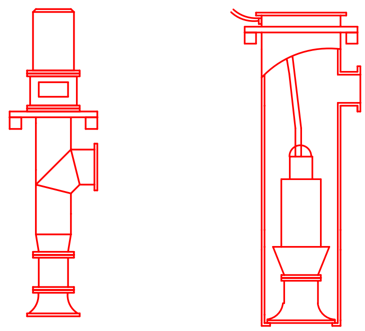
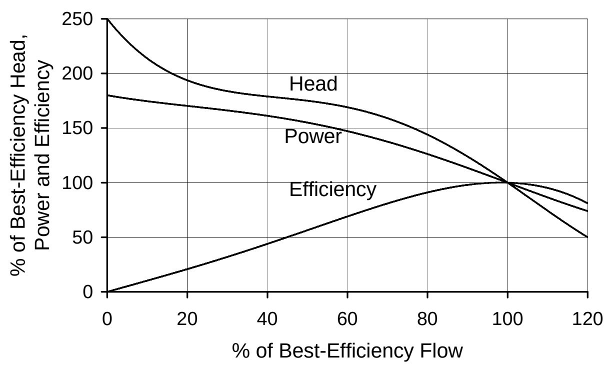
Pump Type / Performance	Description / Applications
Axial Flow Well  **Typical Performance**  Efficiency falls quickly above and below best-efficiency flow. Efficiency of conventional version is on the low side, even after losses in column pipe, discharge bend and thrust bearing are deducted from motor output. Submersible motor version loses some efficiency due to losses in canister. Head rises rapidly with reducing flow. Instability is very likely around 60% flow limiting the operating range. Best-efficiency head is low. Power rises rapidly with reducing flow. It is unlikely that motor will be sized to cover power at low flow. Performance is very dependent upon providing good inlet flow to bellmouth. Intake model tests are advisable.	**Description** Conventional pump is suspended from floor level. Flow enters through a bellmouth to give well distributed flow to impeller (provided intake arrangement feeding pump has been well designed, very important for this pump type). Impeller discharges to a multi-vane axial diffuser and thence to column pipe and discharge bend. Discharge flange can be above or below floor. Axial thrust is taken either by a thrust bearing below motor or by the motor bearings. Submersible motor version is usually lowered into a canister below floor. Motors are dry internally, having oil reservoir with two seals between pump and motor to avoid contamination from pumped fluid. **Applications** General: Drainage. Agriculture: Irrigation (often with submersible motor), Land drainage (usually with submersible motor). Wastewater: Stormwater (surface water only).

Table 16.
Details of Axial Flow Well Pumps

6. Selecting a pump

This section gives a quick overview of the fundamentals of choosing and using a pump for best efficiency. This is **not** an exhaustive guide, but is designed to be just sufficient for non-technical personnel to get a better understanding of the technical background to this work. The following applies to most types of rotodynamic pumps.

6.1 Choosing the pump duty point

The first step in pump selection is to determine the principal duty point, i.e. the required flow and head. The cheapest pump for the duty will probably be that which runs at the highest available speed, whilst still being able to cope with the suction conditions on site over its full operating range. However, it should be remembered that just one additional point of efficiency may be sufficient to pay for the pump over its lifetime, through savings in energy costs. Thus, a lower speed pump, if it is more efficient, may prove to be more economical in the long term. Another option which should be considered is to split the flow, i.e. to have two or more pumps running in parallel (or even, very occasionally, in series). This can also give flexibility if covering wide flow ranges. For more detail of the efficiency implications of this, see section 7.1 below.

The chosen duty of the pump should not be over-estimated. This frequently happens when allowance is made for a possible future increase in demand, and/or the system designer has been prudent and over-sized the system, and/or the purchaser has added his own 'safety' margin. Certainly the problem can be overcome by throttling the flow with a valve. However, deliberately restricting the system flow is far inferior to better matching of the pump to the actual system requirements in the first place. All throttling results in an unnecessary increase in energy costs, and can lead to other operational problems as explained earlier in section 4 and Fig 2.

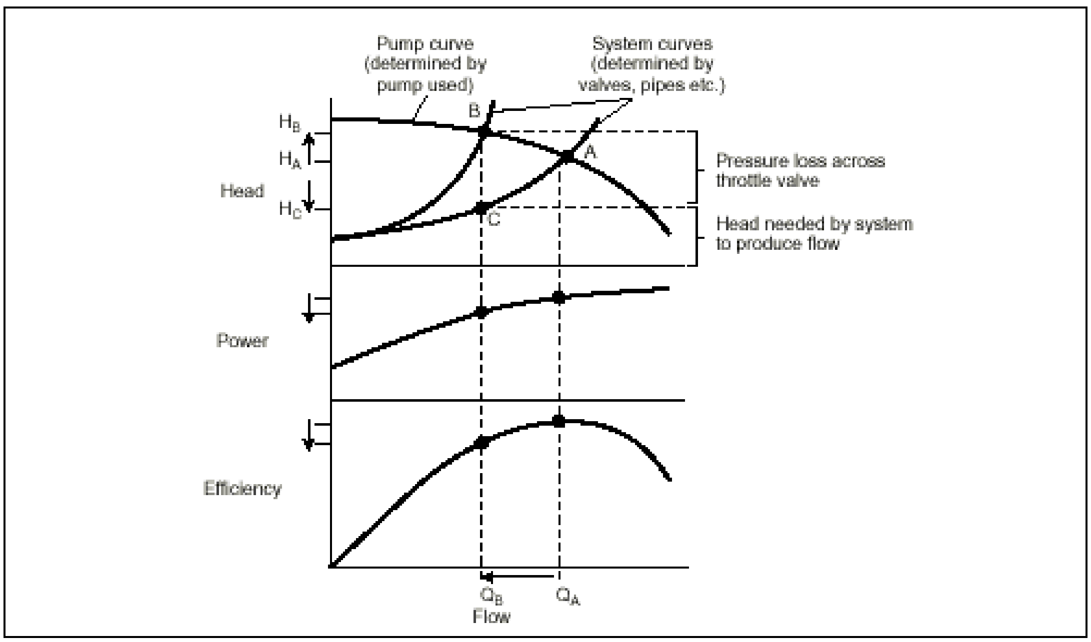


Fig 3.
Illustration of the effect of throttling a pump

Fig 3 shows what happens if a pump is over-sized. Q_B represents the flow required at the chosen duty. The curve passing through points A and C is the normal system curve, i.e. the variation of head across the pump if flow increases from zero to Q_B, Q_A and beyond. The pump head/flow curve (passing through A and B) meets the normal system curve at point A, so that the pump operates at head H_A delivering flow Q_A. Since Q_A is greater than the flow required (Q_B), the pump is over-sized.
In order to reduce the flow from Q_A to Q_B, the discharge valve must be partially closed to throttle the flow. This produces a new system curve passing through point B, so that the pump now produces the required flow Q_B, but is working at the higher head H_B. If the pump had not been over-sized, flow Q_B would have been obtained by a pump head/flow curve passing through point C, so that the pump would only be working at head H_C. Thus, the difference between H_C and H_B is purely head lost in the throttle valve, and therefore wasted energy. (For this illustration, the small variations shown in power and efficiency should be ignored.)

6.2 Impeller modifications to match the duty
The need for throttling can be avoided by reducing the diameter of the impeller and thereby eliminating this unnecessary energy loss. Just looking at best-efficiency points (black dots), Fig 4 shows that the power absorbed by a reduced diameter impeller D2 is considerably less than that absorbed by a maximum diameter impeller D1, whilst that absorbed by the minimum diameter D3 is less again. Usually manufacturers offer the same pump casing with a range of impeller diameters because of this. Manufacturers may also offer different designs of impellers for one casing, to cope with higher or lower flows at better efficiencies than are given by the 'standard' impeller.

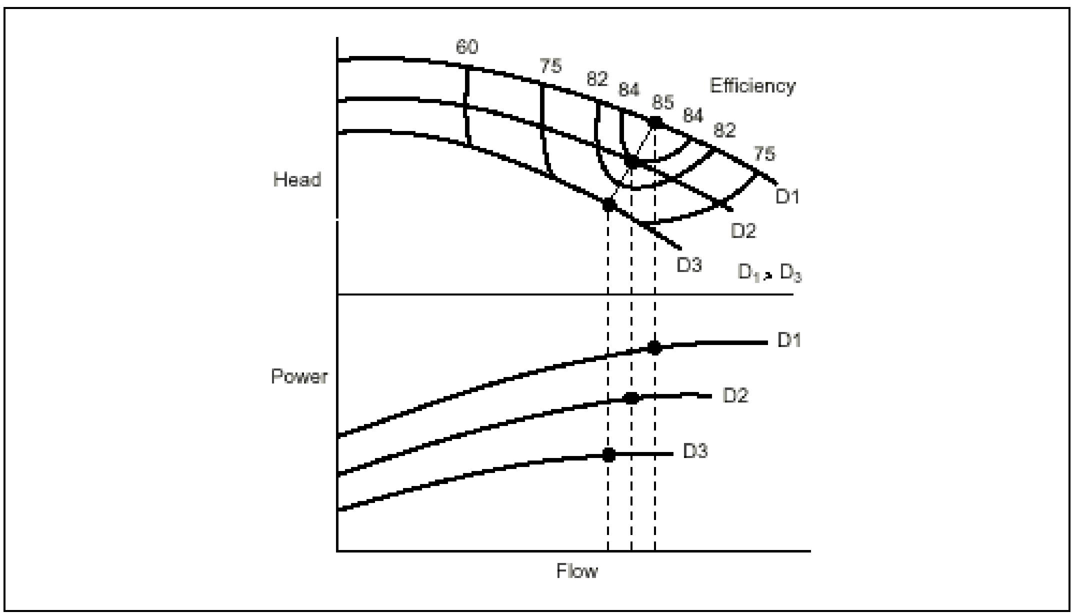


Fig 4.
Pump characteristics showing various impeller diameters

In the case of axial flow pumps, reducing the impeller diameter is not practical. In this case the pump performance can be changed by altering the angle setting of the blades. This is usually a permanent alteration but some pumps do have blades which can be reset after manufacture or even during operation.

Pumps are not usually made to standard duties. This makes comparing efficiencies less simple than with products that are made to standard duties (such as motors).

6.3 The selection process

Fig 5 gives a very rough indication of the head/flow coverage of basic pump types when running at speeds of up to 3000 rev/min. (Some pump types will always run slower than this.) This plot will help when deciding which pump type is most likely to suit the chosen duty. Pumps can be provided to work beyond these ranges but will mostly be special designs.

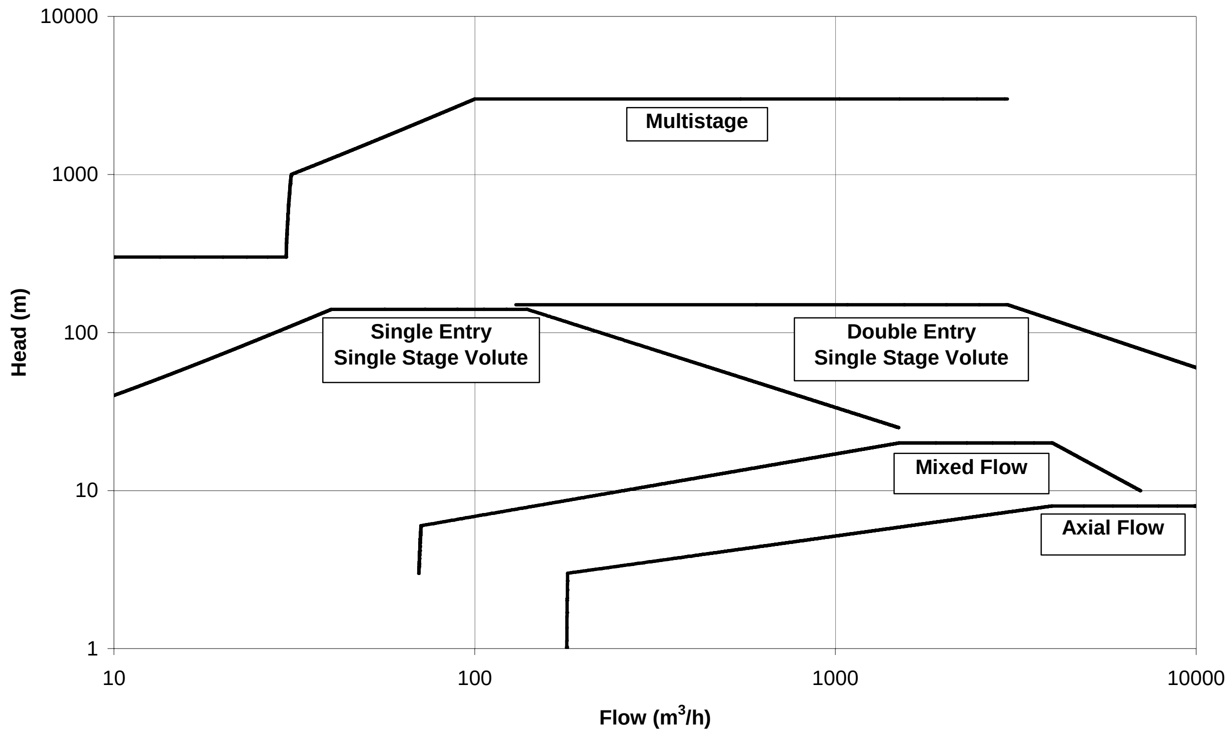


Fig 5.
Indication of head and flow coverage of basic pump types

When selecting a pump from an existing range, a manufacturer will use "tombstone" curves, which show their ranges of pumps to cover a range of duties (Fig 6). The ideal duty will be towards the right of the top of a tombstone, at the point which corresponds to the BEP of the selected pump. (Each tombstone is built up from the individual pump curves such as that shown in Fig 4). However, for economic reasons manufacturers have to restrict the number of pumps that they offer. This means that even a manufacturer of particularly efficient pumps may lose out when quoting an efficiency in competition with a less efficient pump, whose BEP just happens to be nearer the requested performance. The worked example in section 6.4 below makes this clearer.

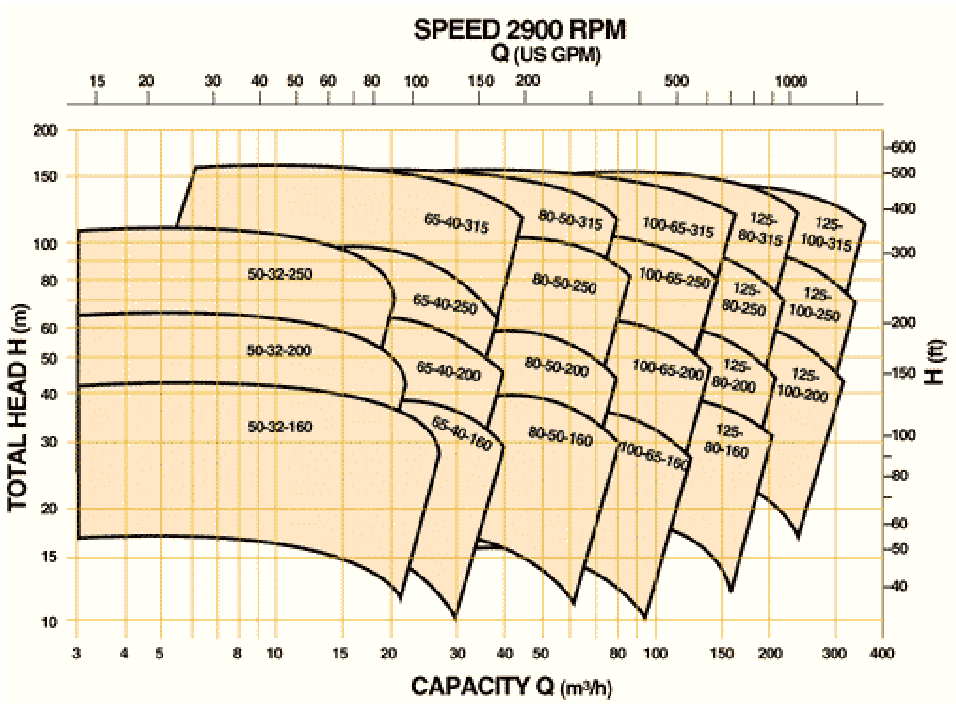
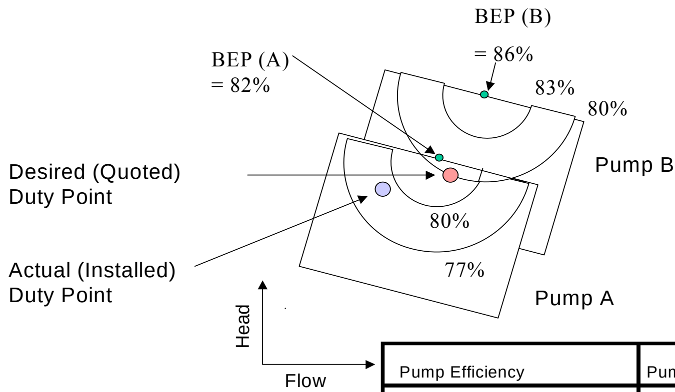


Fig 6.
'Tombstone' curves for the selection of pumps by duty

6.4 Worked example



Pump Efficiency	Pump A	Pump B
Peak (BEP)	82%	86%
At desired (quoted) duty point	81.5%	80%
At actual (installed) duty point	79%	<77%

A user requests quotes for a pump at a particular desired duty. Manufacturers A and B offer the pumps shown, which are the best that they can offer from the ranges that they have. (These two pumps are excerpts from two manufacturers' ranges of the type shown in Fig 6).

There are two important points to note:

While pump B has a higher BEP, pump A actually has a higher efficiency than pump B at the desired duty.

Over-specifying the duty means that at the actual installed duty, the efficiency of the pump will be considerably less than quoted. (In this particular case it would be better to reduce the diameter of the impeller further, to suit the installed duty without throttling, or perhaps to use a quite different pump to either of those quoted for.)

6.5 Importance of pump operating speed

Often a manufacturer will offer the same pump at different motor speeds to allow the one pump to be used over a much wider range of duties. For instance, changing from the most common 4-pole motor to a faster 2-pole motor will enable the same pump to deliver twice as much peak flow at 4 times the head. Of course, using a relatively high speed pump will not be possible if suction conditions are not adequate. (The effect of running a pump with 4 and 2 pole motors is the same as what happens when running at 50% and 100% speeds as shown in Fig 7 below).

Variable Speed Drives allow a pump to operate efficiently over a wide range of speeds and hence duties, and so are very good for saving energy (Fig 7). They are particularly useful in systems where there is a wide variation in demanded flow.

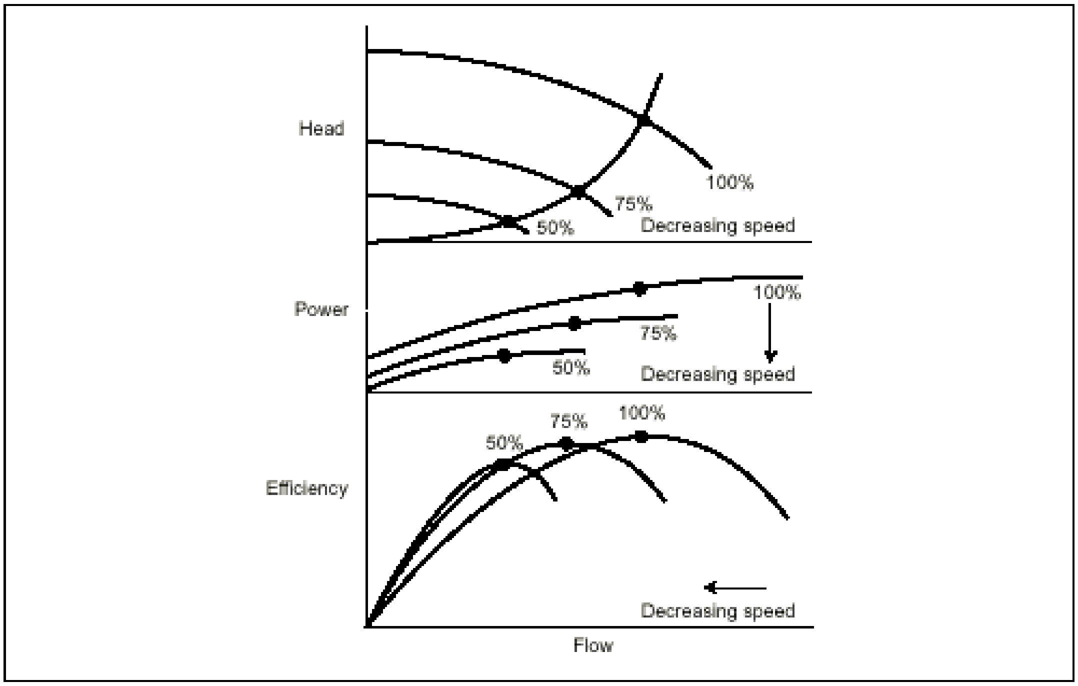


Fig 7.
Effect of speed reduction on pump characteristics

What this all means is that the same basic pump can serve different duties depending on both the diameter and design of impeller fitted and the speed of the motor chosen. The power consumption will vary with these parameters and with other factors such as liquid specific gravity and viscosity. The size of motor required therefore needs to be determined for each application.

7. Optimising the pump efficiency

It is not possible to decide whether the efficiency of a pump being quoted is high or low without some sort of benchmark. This section is intended to provide some assistance in this respect.

7.1 Allowing for the effect of Specific Speed

The Specific Speed (Ns) of a pump is a number which tends to define its shape and performance. It may be given in any units of speed, flow and head. The most common units for these variables in the UK are speed in revolutions per minute (rev/min), flow in cubic metres per hour (m^3/h) and head in metres (m).

To determine the Specific Speed (Ns) of a pump, enter Fig 8 at the best-efficiency head and flow and read off 'K'.

Then:

$$Ns = K \times \frac{(rev/min)}{1000} \qquad \ldots\ldots\ldots\ldots (1)$$

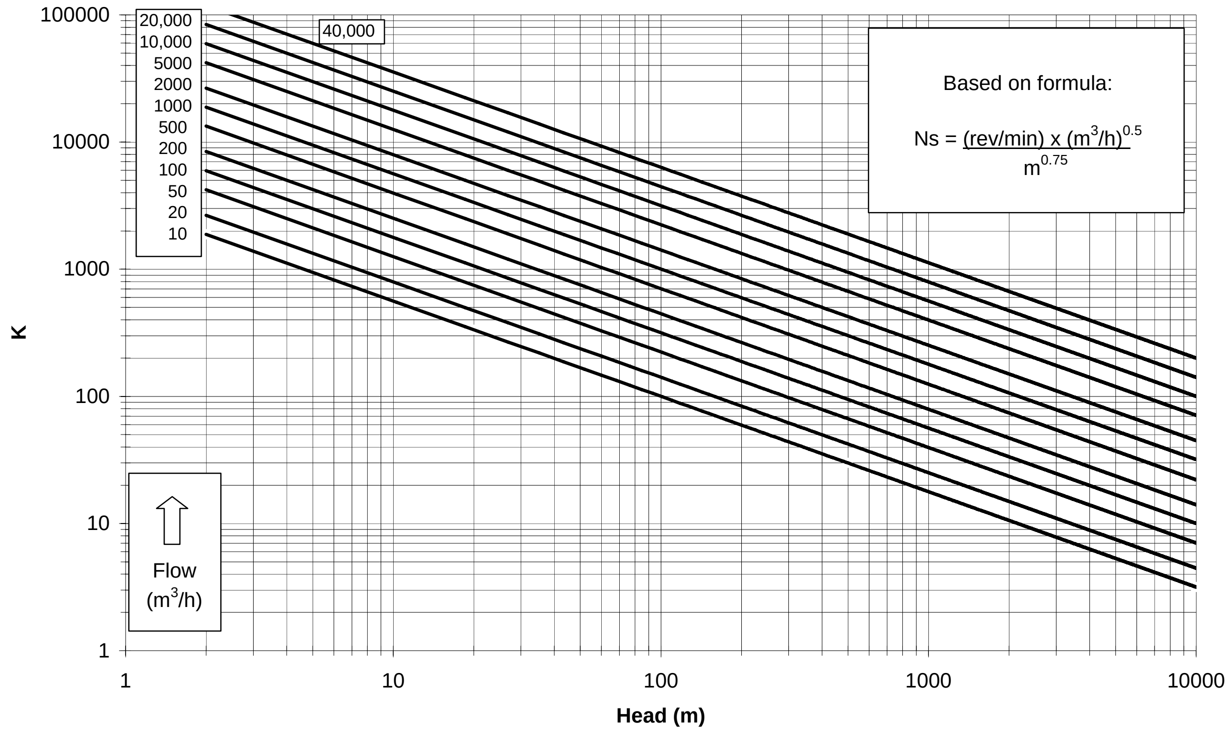
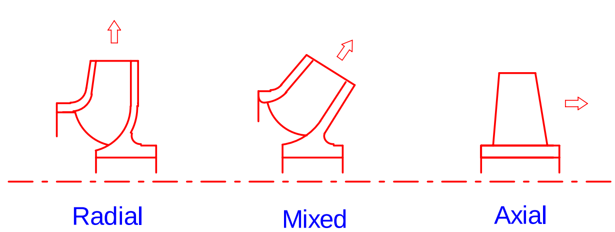


Fig 8.
Plot to determine value of K

Roughly speaking, at Specific Speeds below about 3500 the impeller can be considered to be of the 'Radial Flow' type. Above about 11000 Specific Speed, the impeller can be considered to be of the 'Axial Flow' type. Between these approximate values, the impeller can generally be considered to be of the 'Mixed Flow' type. (Note that there is no universal standard for deriving Specific Speed. Speed, flow and head may be used in a wide variety of units, so great care must be taken to ascertain which units are being used when a Specific Speed is quoted.)

These designations are reflected in the shapes of the impellers, as shown below:



Optimum Specific Speed occurs at about 2650. At Specific Speeds higher and lower than this, for a given family of pumps of similar size (basically the same flow and speed), efficiency falls away at an ever increasing rate. As mentioned in section 6.1 above, the pump speed can be selected to improve efficiency by moving the pump Specific Speed closer to optimum. Also, the required duty flow can be split by using two or more pumps running in parallel, again moving the Specific Speed of the individual pumps closer to optimum and thus improving pump efficiency.

A guide to the number of points of efficiency (C) to be added to a quoted efficiency figure in order to bring it to around the value of a pump of the same flow but of Optimum Specific Speed is provided by Fig 9. (Note that ‘one point of efficiency’ is defined as the difference between, say, 66% and 67%.)

Thus: ‘Equivalent efficiency’ at Optimum Specific Speed = Quoted efficiency + C …….. (2)

This ‘Equivalent efficiency’ at Optimum Specific Speed can then be compared with other pumps using plots such as Figs 10 and 11 below.

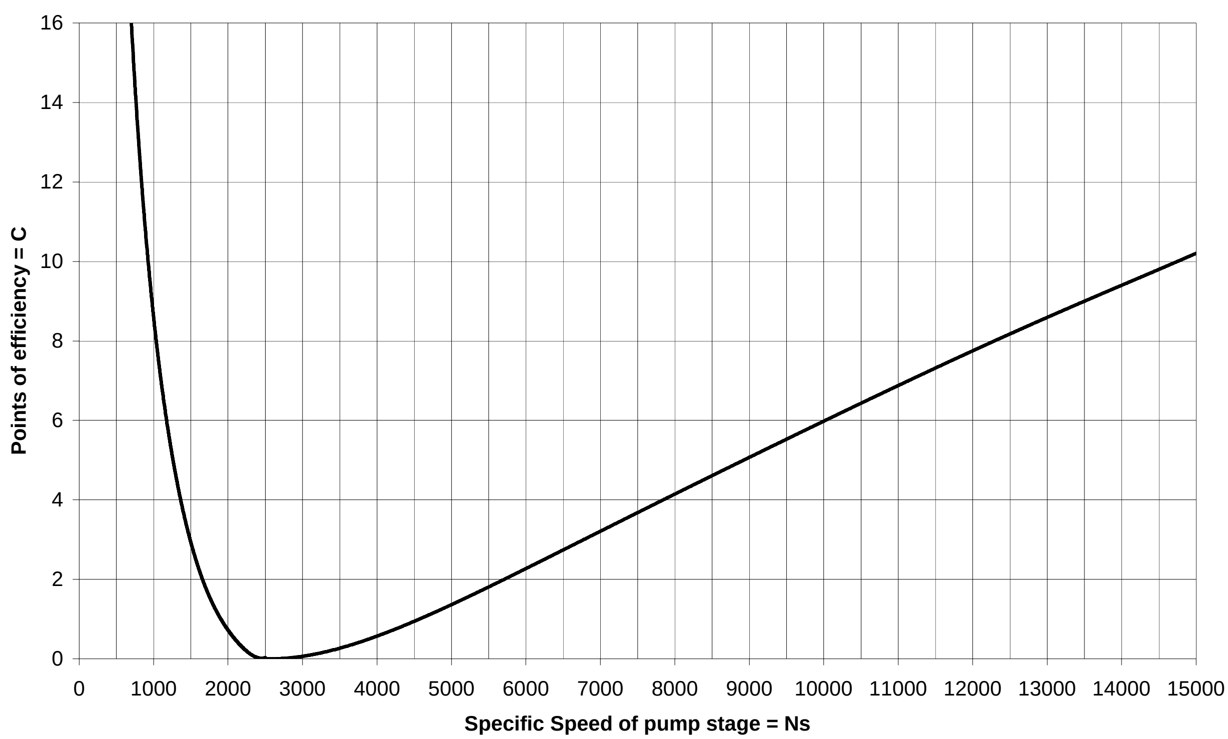


Fig 9.
Plot to determine value of C

7.2 Attainable efficiency levels

The plots on Figs 10 and 11 below give a rough guide to the mean Best Efficiency levels of rotodynamic pumps at Optimum Specific Speed. These should not be taken too literally, since they are based on fairly small samples and efficiency variation can be very wide for some pump types (e.g. in the case of Single Entry Volute - Solids Handling pumps, the pump geometry (and therefore efficiency) depends on the solids size, shape, concentration and hardness, on the pump material chosen, on the impeller design and on the method of shaft sealing).

To use the plots, the Specific Speed (Ns) at a pump’s chosen duty should first be calculated using formula (1) in section 7.1 above. Then its quoted efficiency should be converted to Optimum Specific Speed, using formula (2) in section 7.1, before comparing with Figs 10 and 11. In most cases this derived efficiency at Optimum Specific Speed is unlikely to come very close to the plotted efficiencies, since the pump’s chosen flow will probably lie above or below Best Efficiency flow and/or the impeller diameter may be reduced. However, the curves do provide a rough benchmark, by indicating the sort of efficiency that can be obtained if it is possible to find a pump which is close to Best Efficiency at the chosen duty. For illustration of the procedure, see the worked example below (section 7.3).

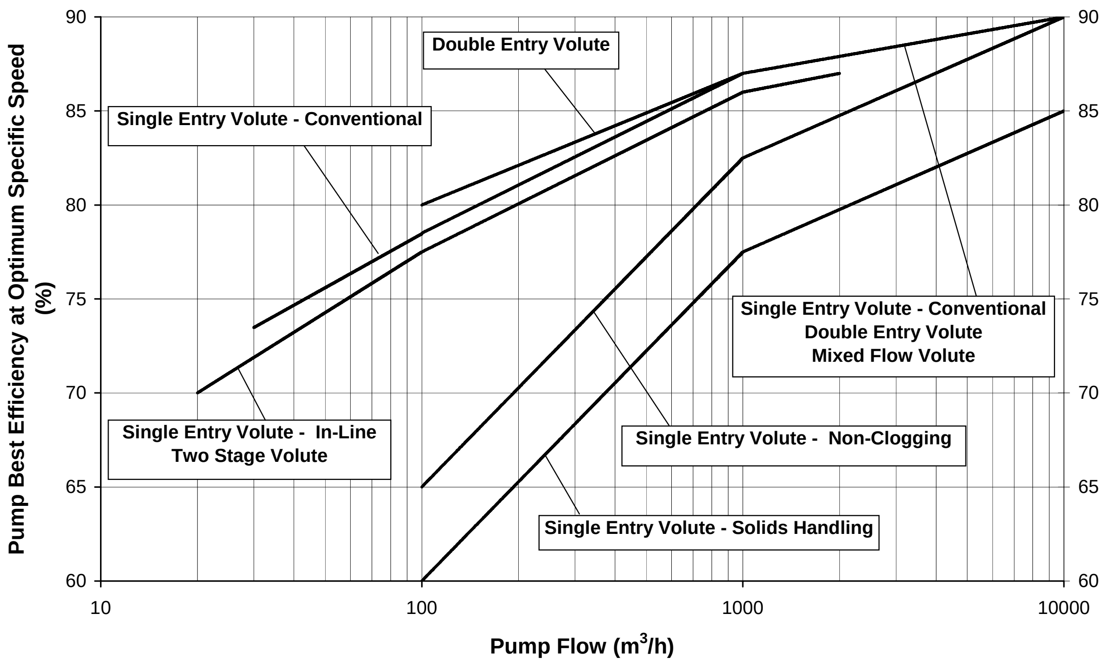


Fig 10.
Mean Best Efficiencies of Volute pumps

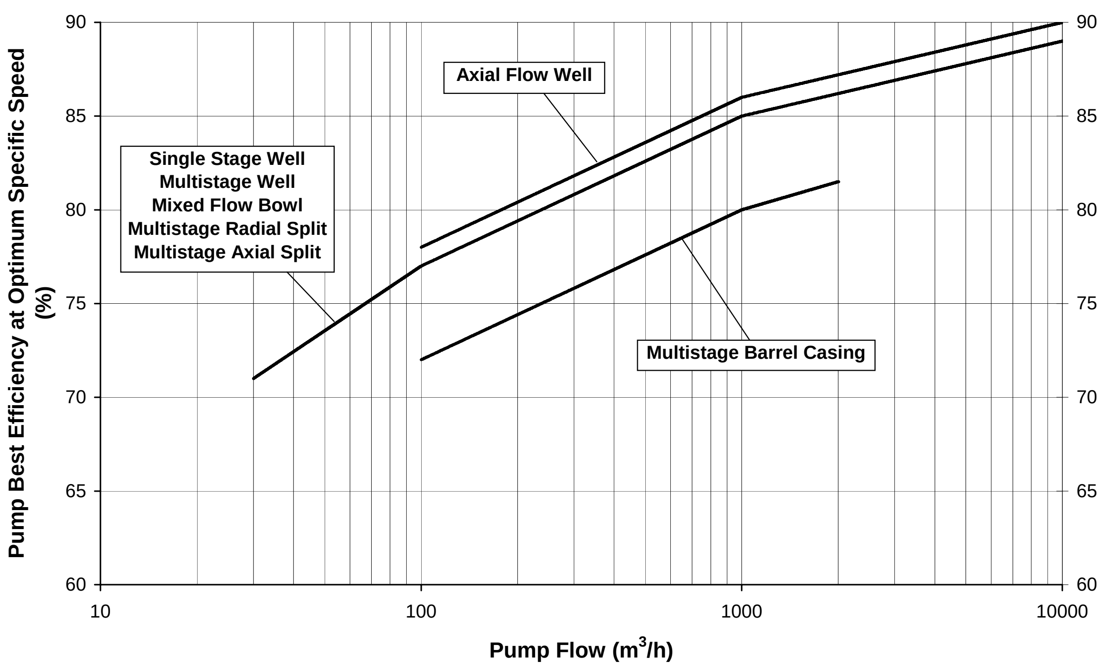


Fig 11.
Mean Best Efficiencies of Multistage and Well pumps

7.3 Worked example

Chosen duty:	1000 m^3/h at 120m.
Chosen pump type (Fig 5):	Double Entry Volute.
Quoted pump performance:	78% efficiency at 1460 rev/min.
Value of K from Fig 8:	870.
Ns from section 7.1, formula (1):	$870 \times \frac{1460}{1000} = 1270.$
Value of C from Fig 9:	5.
'Equivalent efficiency' from section 7.1, formula (2):	78 + 5 = 83%.
Mean Best Efficiency from Fig 10:	87%.
Action:	Seek further quotes.

In this example, if the quoted pump performance had been at 2900 rev/min, K would be the same but Ns would nearly double to 2520. Since this is practically Optimum Specific Speed, the quoted efficiency would probably have been several points better. It is therefore assumed that in this case the Net Positive Suction Head available to the pump was too low to permit the higher running speed.

8. Useful Pump information

8.1 Total Head "H"

In the pumping technique there are more alternatives of mutual positions of a pump and a tank when pumping through a simple piping system. This arrangement is described in detail on Figures 8.1 and 8.2).

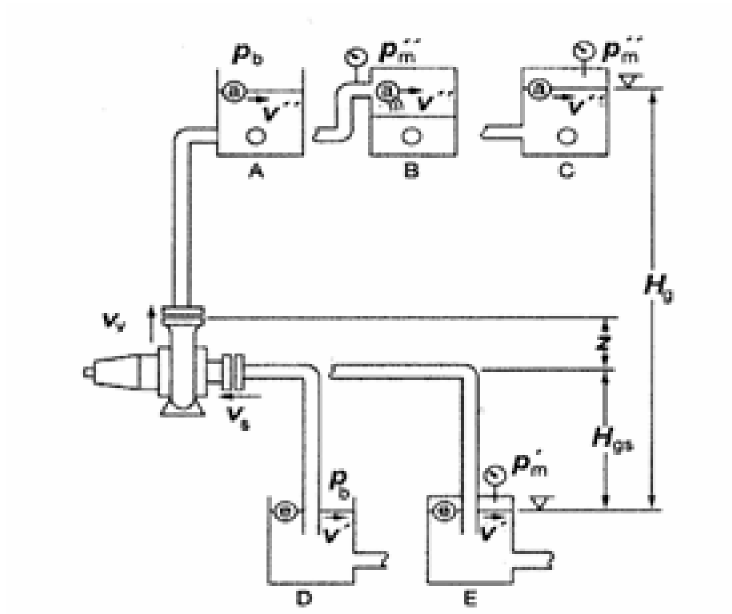


Figure 8.1
Pumping system with various arrangement in <u>negative NPSH</u> operation

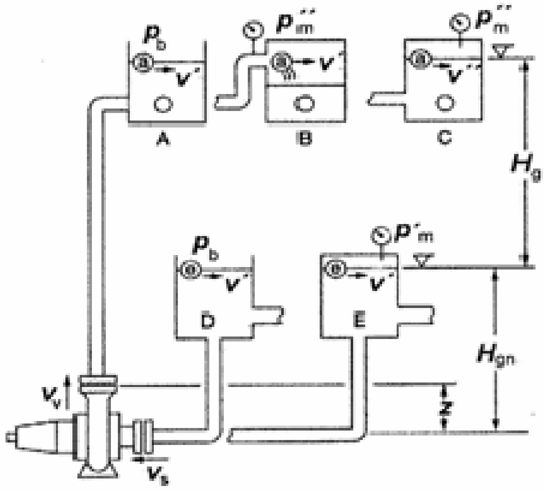


Figure 8.2
Pumping system with various arrangement in positive NPSH operation

A open discharge tank with piping mouthing under free water surface
B closed discharge tank with free outlet from pipeline
C closed discharge tank with mouthing of piping under level
D open tank in negative/positive NPSH arrangement
E closed tank in negative/positive NPSH arrangement
H_{gs} geodetic NPSH (difference of levels with discharge branch centre line for the case of the pump situated above suction tank)
H_{gn} geodetic positive NPSH (difference of levels with discharge branch centre line for the case of the pump situated below suction tank)
z difference in elevation of discharge branch above suction branch
p'_m atmospheric pressure in suction tank with negative/positive NPSH
p''_m atmospheric pressure in discharge tank
p_b barometric pressure (in open tank)
p_s pressure in pump suction nozzle
p_v Pressure in pump discharge nozzle
v_s liquid velocity in pump suction nozzle
v_v liquid velocity in pump discharge nozzle

$$H = H_g + (p'' - p')\ /\rho.g\ +\ (v''^2 - v'^2)\ /\ 2.g\ + \Sigma H_z \qquad [m]$$

1 2 3 4
static part dynamic part

The value *H* is called *total head.* The total head (relation 1.2) has its static share expressed by terms 1 and 2 and the dynamic part (depending on v^2 by terms 3 and 4) on the right hand side of the equation.

H_g ***elevation head*** – difference of liquid level in suction and discharge tanks (if the discharge piping is mouthing above the liquid level in the discharge tank, see the alternative B in the figs. 1.7 and 1.8, the *elevation head Hg* refers to the centerline of the discharge cross section).

$(p'' - p')/\rho.g$ ***gauge head*** – pressure difference above levels in suction and discharge tanks.

(In case of two vented tanks with atmospheric pressure $p'' = p' = p_o$ the gauge head equals to 0).

$(v''^2 - v'^2) / 2.g$ ***velocity head*** – difference of velocity heads in the tanks

(Very often this term is negligible as velocities of level differences in the tanks are usually very small.)

ΣH_z ***friction head loss***. At flowing of some actual (viscous) liquid the equation hydraulic friction losses (local and longitudinal) ΣHz should be involved and added to the single enumerated heads as well as inlet and outlet head losses of the piping system.

All components of the head H are in [m]; pressure p [Pa], velocity v [m/s],density ρ [$m^3.kg^{-1}$], gravitational constant g in [$m.s^{-2}$].

Practically we can often neglect the term of velocity heads. In case the tanks B, C and E (figs. 1.7 and 1.8) are closed, the equation (1.2) is simplified to the formula:

$$H = H_g + (p'' - p') / \rho.g + \Sigma H_z \qquad [m]$$

For open tanks A as well as D other simplification occurs $(p'' = p' = p_b)$. The total head is then calculated as follows:

$$H = H_g + \Sigma H_z \qquad [m]$$

This simplified formula is very often used in practical applications.

8.2 Speed of Rotation

If the pump is driven by an electric motor (squirrel cage asynchronous motor), the following basic rates of speed are available that are calculated from mean values of pump asynchronous electric motors:

Pole number	2	4	6	8	10	12	14
50 Hz	2900	1450	960	725	580	480	415
60 Hz	3500	1750	1160	876	700	580	500

8.3 Pump power input calculation

Centrifugal pump power input is the mechanical power input consumed at the pump coupling or shaft from the drive and is calculated acc. the following formula:

$$P = \rho.g.Q.H / 1000.\eta \qquad [kW]$$

where density ρ is in kg/dm^3
gravity g is in m/sec^2
pump flow Q is in l/sec
pump head H is in m
pump efficiency η is in %/100

8.4 Motor power output

Drivers used for driving pumps must perform the required power output corresponding with requirements of any operation conditions (see power input in the whole working area on pump performance curve).

In practice there is used reserve for motor output acc. to figure 8.3 (from standard ISO 9908):

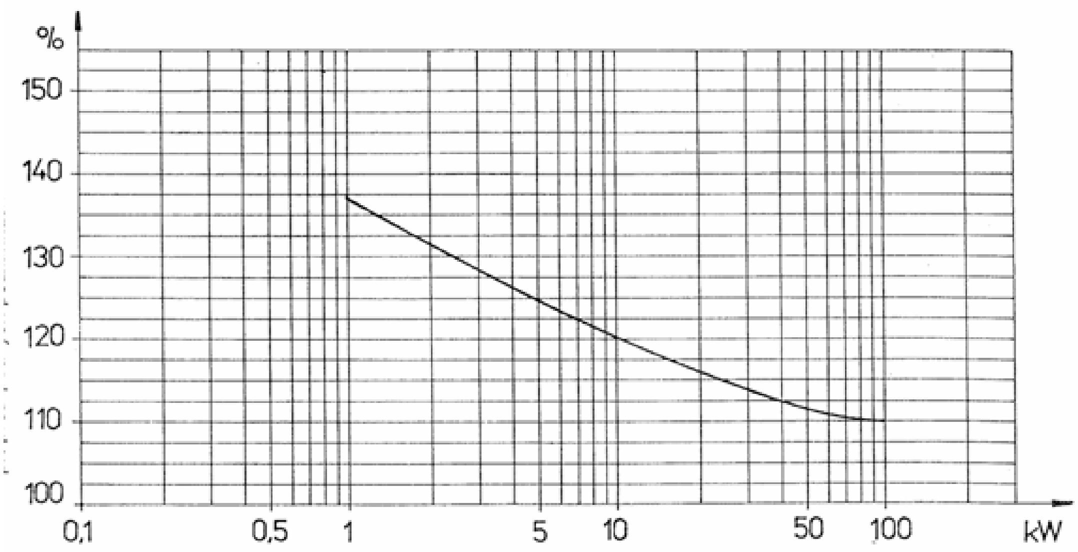


Figure 8.3
Required driver power output as percentage of pump power input for range of application from 1 to 100 kW

8.5 Net Positive Suction Head NPSH

NPSHR – “net positive suction head required” characterize suction ability of pump and is determined by pump supplier.

NPSHA – “net positive suction head available” is done by pumping system on suction side.

It is necessary for correct pumping: **NPSHA > NPSHR**

8.5.1 NPSHA calculations

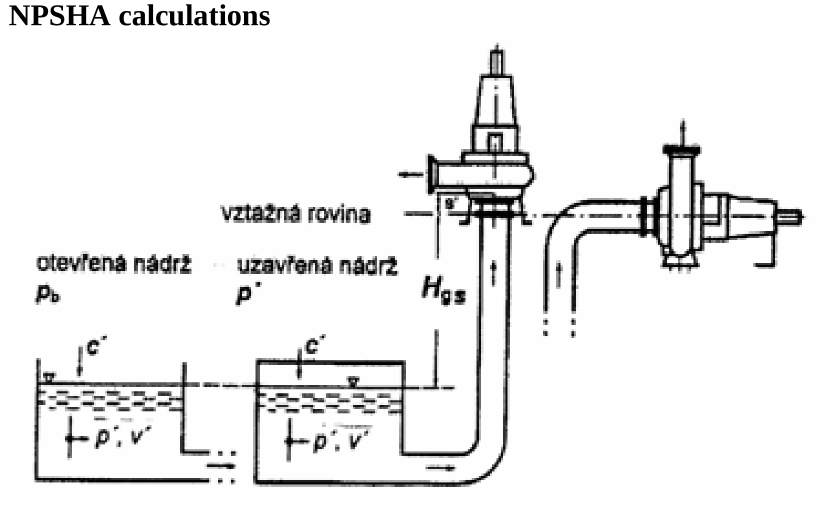


Figure 8.4
***NPSHA*_examination in suction mode for horizontally and vertically installed pump**

$NPSH_A$ is calculated in this case according to the following formula:

$$NPSHA = (p' - p_t) / \rho.g + c'^2 / 2.g - H_{zs} - H_{gs} \pm s' \qquad [m]$$

where c' – velocity of decrease of suction tank free surface
s' – vertical distance of suction nozzle to impeller inlet centerline
p_t - vapour presure

If pumping cold water from the open tank (fig. 1.15) at zero altitude the previous formula is simplified to the formula that is **sufficiently precise for practical application**:

$$NPSHA = 10 - H_{zs} - H_{gs} \pm s' \qquad [m]$$

8.5.2 NPSHA - at positive NPSH pumping mode (pump below inlet tank)

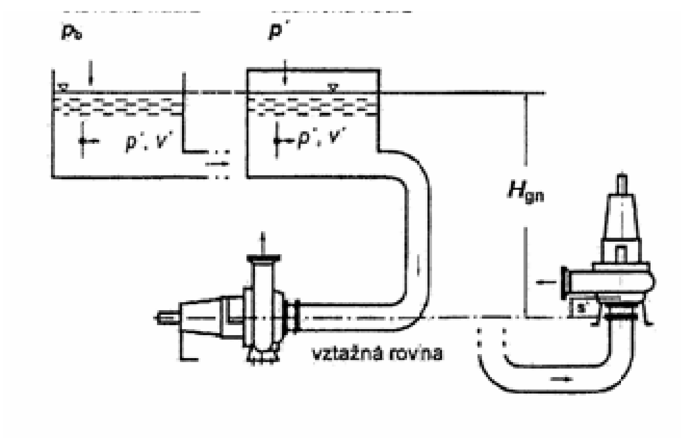


Figure 8.5
***NPSH$_A$* examination in positive *NPSHA* mode for horizontally and vertically installed pump**

At positive NPSHA operating mode (fig. 1.16) the pump is installed conversely below the inlet tank free liquid level. In the preceding formulas $-H_{gs}$ is changed to $+H_{gn}$:

$$NPSHA = (p' - p_t) / \rho.g + c'^2 / 2.g - H_{zs} + H_{gn} \pm s' \qquad [m]$$

If pumping cool water from the open tank (fig. 1.16 in the left) at zero altitude the preceding formula is simplified to the formula **sufficiently precise for practical application**:

$$NPSHA = 10 - H_{zs} + H_{gn} \pm s' \qquad [m]$$

9. Life Cycle Cost (LCC)

It is likely that the design of the pumping system and the way the pump is operated will have a greater impact on the energy consumption than the pump efficiency alone. An LCC analysis should always be carried out to compare different technical alternatives of designing, operating and maintaining a pumping system. The LCC represents the total expenses to purchase, install, operate, maintain and repair a pumping system during its projected life. Down-time and environmental costs are also considered.

A well-documented guide has been published by Hydraulic Institute and Europump (Ref 6). The guide explains how the operating costs of a pumping system are influenced by system design, and shows in detail how to use an LCC analysis to estimate these costs. Using the recommendations of that guide, not only the initial investment cost should be taken into account, but also all the others costs and expenses to operate the system during its projected life.

10. Useful References

- ‘NPSH for Rotodynamic Pumps’, Europump Guide No. 1, 1999.
- ‘Efficiency prediction method for centrifugal pumps’, Hydraulic Institute, 1994.
- ‘Centrifugal pumps and allied machinery’, Anderson, H.H., Elsevier Advanced Technology, 1994.
- ‘Theoretically attainable efficiency of centrifugal pumps’, Stoffel, B. and Lauer, J., Summary of the final report on the research project for VDMA, Technical University of Darmstadt, 1994.
- ‘Attainable efficiencies of volute casing pumps’, Europump Guide No. 2, 1999.
- ‘Pump life cycle costs: A guide to LCC analysis for pumping systems’, Europump and Hydraulic Institute, 2000. (ISBN 1-880952-58-0)
- ‘Study on improving the efficiency of pumps’, Report produced for the European Commission – SAVE, 2001.
- ‘European Guide to Pump Efficiency for Single Stage Centrifugal Pumps’, SAVE Project Team and EUROPUMP, 2003.
- Variable Speed Pumping : A Guide to Successful Applications’, Europump and Hydraulic Institute , 2004 .(ISBN 1-85617-449-2)
- System Efficiency : A Guide For Energy Efficient Rotodynamic Pumping Systems – Written and Published by Europump.

11. Acknowledgement

This Guide was originally written by David T Reeves, Pump Engineering Consultant.
Members of the Europump Technical Commission in particular;
John Bower – Flowserve
Jan Nevěřil –SIGMA Group a.s.
Aldo Janigro – Assopompe
Steve Schofield – BPMA
Have subsequently modified the guide to suit a European marketplace in doing so they wish to give reference and thanks for David’s original work.

12. Further information

For further information please contact :

Europump General Secretariat
Diamant Building, Blvd. A.
Reyers 80 B-1030 Brussels
Belgium
Tel: +32 2 706 82 30
Fax: +32 2 706 82 53
E-mail: secretariat@europump.org
Web: www.europump.org

.