Work on Preparatory studies for implementing measures of the Ecodesign Directive2009/125/EC

ENER Lot 29 – Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under ENER Lot 11) – Task 1: Definition

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Table of Contents

List of Tables

List of Figures

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Task 1: Definition

The scope of the study includes pumps for private and public swimming pools, ponds, fountains and aquariums, as well as clean water pumps larger than those regulated under TREN Lot 11[1].

Note that pumps for private and public wastewater are covered by ENER Lot 28 (see: http://www.ecopumps.eu/).

The main objective of this working document is to set a solid foundation for the ENER Lot 29 preparatory study by defining the product scope for pumps for public and private swimming pools, ponds, fountains and aquariums, and to understand these products from a functional and technical point of view. It also structures appropriate pump categories while providing a first screening on the basis of their sales volumes and improvement potential.

- Section 1.1 provides a technical introduction to pumping, and some basic concepts.
- Section 1.2 sets out primary and secondary functional parameters and existing product categorisations.
- Section 1.3 defines the scope of pumps to be considered for analysis and includes a screening exercise. Brief product introductions are also provided.
- Section 1.4 lists existing test standards at the EU, Member State and third country levels.
- Section 1.5 lists existing legislation at the EU and third country levels.
- Section 1.6 discusses system boundaries of the 'playing field' for ecodesign. This is important for a realistic definition of design options and improvement potential and it is also relevant in the context of technically defending any implementing legislation or voluntary measures that may arise following the study. It then goes to discuss a proposed methodology for the analysis of water pumps.
- Section 1.7 lists the main conclusions of Task 1.

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[1] ENER Lot 11 preparatory study on ecodesign of motors

1.1 Technical introduction

1.1.1 How Pumps Work

Figure 1-1 shows the basic differences between a Rotodynamic and a Positive Displacement pump. A Positive Displacement pump in its simplest (and oldest) form is typified by a bucket lifting water from a well or river. It shows the principle of all pumps of this type; enclosed volumes of liquid are collected at the pump inlet and discharged at the outlet at increased head. The basic principle of a Rotodynamic pump is illustrated by the stirring of a cup of tea to the point where the rotating liquid is given sufficient energy to spill into a (rather deep) saucer, where the level (head) is higher than the mean level in the cup. In a Rotodynamic pump, a continuous flow of liquid passes through a rotating impeller, which imparts energy, is collected (usually by a volute or guide vanes) and discharged against an increased head.

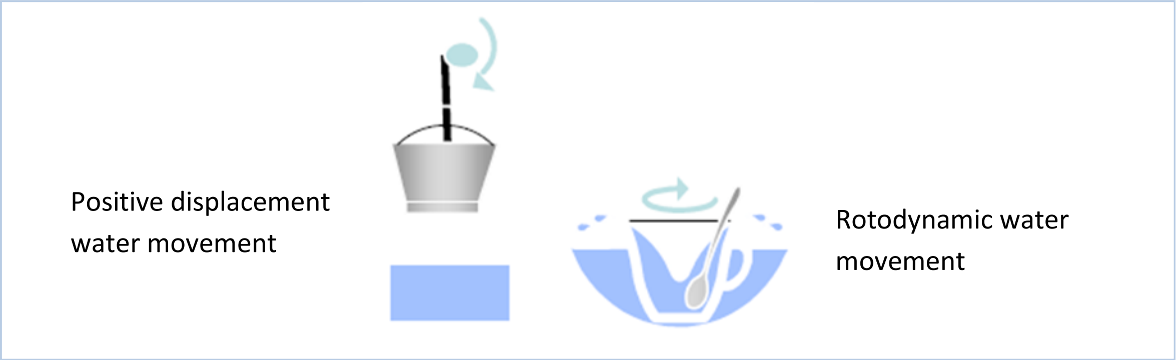


Figure 1-1: Operating principles of positive displacement and rotodynamic water pumps

Water is pushed into the pump inlet branch by the pressure acting on the water surface (usually atmospheric pressure) and, where applicable, the height of the water level above the pump. The water flow then passes from the inlet branch of the pump to the inlet of the impeller. It then has to change direction from axial to (near) radial as it enters the passage between the impeller vanes. In a well-designed impeller, at best efficiency flow the water will pass smoothly over the vane inlets with little disturbance. The vanes will then start to work on the water as it flows through the impeller, creating an increase in pressure and velocity. At best efficiency flow, the water will spiral out of the impeller in a free vortex of constant angle to the tangential direction. As the diameter of the volute increases, the flow velocity reduces and pressure is recovered. The volute cutwater angle should be a close match to the spiral angle and will peel off the water to guide it to the outlet branch. The water then leaves the pump with a much increased pressure and usually with a small increase in velocity.

In vertical multistage and submersible multistage well pumps, the volute function is carried out by several vanes which guide the water from the discharge of one impeller to the inlet of the next. Ideally these will be designed for minimum loss but, in small submersible pumps, getting the maximum flow from a fixed borehole diameter may force a reduction in the diameter of the guide vanes or alter their geometry so as to cause a small loss in pump efficiency. Figure 1-2 illustrates the flow paths of the rotodynamic pumps and shows the cutaway of motor coupled pumps.

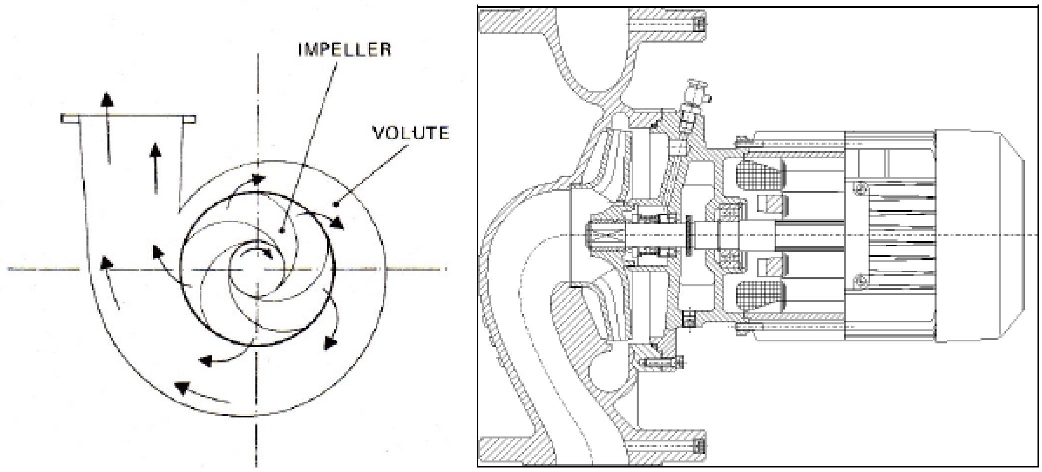


Figure 1-2: How rotodynamic pumps work: flow paths (left) and cutaway of motor coupled pump (right) (Source ENER Lot 11 preparatory study on ecodesign of motors)

Rotodynamic types are generally cheaper and more robust, and so account for the bulk (>90%) of sales. Positive Displacement types are more sophisticated and highly engineered, and despite their usually better efficiency, are just not currently cost effective for the different types of water applications considered in this study.

The pumps in this study are all centrifugal types, and there are various ways that these could be put into different categories. If product categories are too broad, then they do not mean much to the user, and any suggested design options would be likely to miss design / application subtleties in the secondary functional parameters and so be flawed.

The argument is always based firstly on the primary functional parameters, which are the flow and head. In these simple terms, within the centrifugal category, different styles are better suited for different head:flow duties. The style alters in a general way with reference to specific speed. While there will always be overlaps between different styles and their suggested range of application, the pragmatic way forward is to use the basic classification shown in the table to split the continuum of styles into manageable groups. Without this, it would be impossible to have a single implementing measure that could sensibly apply to all types.

1.1.2 The pump system

A pump will be described in a catalogue in terms of head, flow and, usually, power. In order to include a power curve, a specific gravity of unity is used (i.e. a density of 1000 kg/m^3), in other words the catalogue shows the power absorbed when pumping clean cold water. The actual mechanical power consumption is calculated as:

$$P_{mech} = Q \times H \times \text{density} \times g / \text{pump efficiency}.$$

Where,

Q = flow

H = head

g = gravitational constant

This means that it is not possible to give standard curves of power consumption against duty for all liquids, as generally the power consumption varies with fluid properties – although for this study because the project team are only considering clean water this is not a problem. In addition, the same pump can be used with different motor speeds and impeller sizes, which adds additional variation.

Because a pump will on average spend most of its life operating below its Best Efficiency Flow, part flow operation is also of interest. Furthermore, pumps can be designed to have different trade-offs between full and part flow efficiency. It is therefore important that performance at part flow is taken account of in the analysis.

There is no 'standard' flow distribution pattern for the types of pumps that are being considered in this study, and so an assumed pattern has been used in the analysis of energy consumption.

The concept of head is very useful and fairly easy to understand in a system such as that shown in Figure 1-3 below. The pump has to produce a head to overcome the static difference in water levels plus the equivalent head of the friction losses in the pipework. The advantage of using head is that the pump will deliver the same flow in the system shown no matter what liquid is being pumped (assuming its viscosity is low, clearly a centrifugal pump would not generate much head if trying to pump treacle). Confusion arises when the significance of head is not understood. Put simply, head is the effective work done on, or energy received by, the liquid per unit of mass, divided by g (the gravitational constant). This can be shown dimensionally:

A column of liquid of height (or head) H exerts a force F on its base of area A equal to its weight, i.e.

$$F = mass \times g = H \times A \times density \ \times g$$

Thus,

$$H = \frac{F}{A \ \times density \ \times g} = N \,/ \frac{m^2 \times kg}{m^3 \times g} = Nm/(kg \times ms^{-2})$$

Irrespective of the liquid pumped, a given pump at a given flow and speed does the same amount of effective work on each unit mass of liquid (and therefore generates the same head). This assumes that viscosity is low and that g varies very little on earth. (In space, a pump will generate an infinite head.) Pressure and power will vary with liquid density.

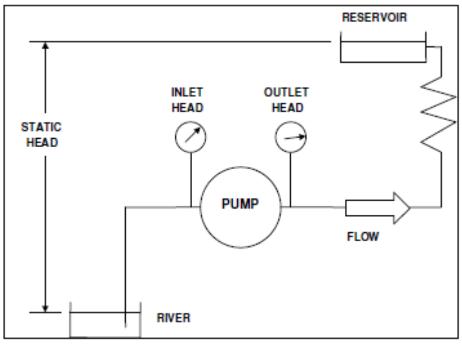


Figure 1-3: Illustration of an open pumping system

In this figure, Pump head = (outlet head – inlet head) = (static head + friction head)

1.1.3 Basic pump laws

The fundamental similarity (scaling) laws applying to rotodynamic pumps are:

$$\frac{Y_{P2}}{Y_{P1}} = \frac{H_{P2}}{H_{P1}} = \left(\frac{n_{P2}}{n_{P1}}\right)^2 \cdot \left(\frac{D_{P2}}{D_{P1}}\right)^2 \qquad \text{(Equation 1)}$$

where: Y= Specific hydraulic work (i.e. work done per unit of mass), D= Impeller diameter, n =Pump speed and H= Head

$$\frac{Q_{P2}}{Q_{P1}} = \frac{n_{P2}}{n_{P1}} \cdot \left(\frac{D_{P2}}{D_{P1}}\right)^3 \qquad \text{(Equation 2)}$$

where Q = flow

This shows, for example, that for two pumps which are exact scaled models, the power consumption (proportional to Q x H) is proportional to the impeller diameter to the fifth power at constant speed, or to speed cubed at constant diameter .

Resolving equation 1 and 2 results in

$$n_{P1} = n_{P2} \cdot \frac{(Q_{P2}/Q_{P1})^{1/2}}{(H_{P2}/H_{P1})^{3/4}} \qquad \text{(Equation 3)}$$

With a Q_{P1} = 1m³/s, H_{P1} = 1m and Pump 2 at best efficiency point equation 3 leads to the specific speed n_s (usually used in literature for n_{P1})

$$\text{Specific speed} \qquad n_s = n \cdot \frac{(Q_{opt})^{1/2}}{(H_{opt})^{3/4}} \qquad \text{(Equation 4)}$$

where n is speed in rotations per minute (rpm), Q_{opt} is flowrate in m³/s, and H_{opt} is total head across pump in m, all at best efficiency point. It is conventional to refer to n_s in units of rpm, although this is not strictly correct.

The specific speed is the most important similarity parameter in hydrodynamic pump technology. It has central focus throughout pump literature. It characterises the impeller shape, is suited to compare different impeller types and consequently pump types on a common basis.

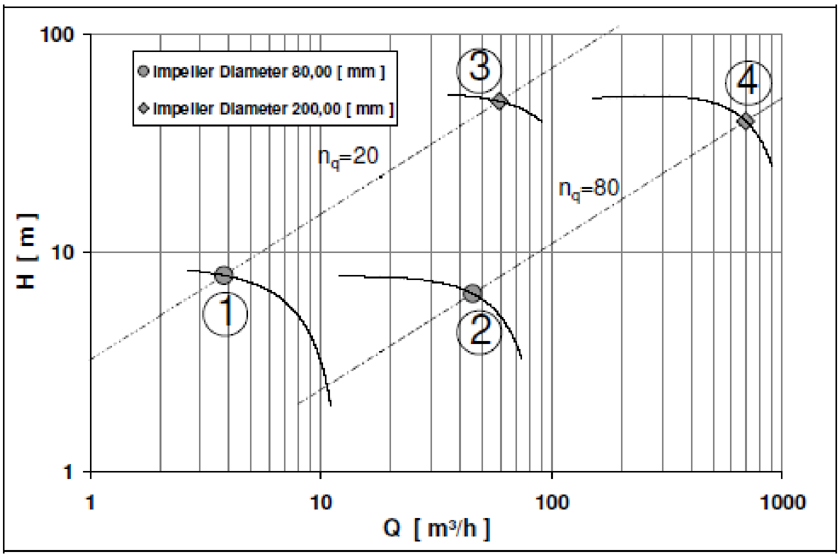


Figure 1-4: Duty points of pumps of different sizes but same specific speed

Figure 1-4 illustrates four different pump cases of two different pump types in a H-Q-Diagram. The two pump types are characterised by the specific speed. Though the pump sizes of for example No.1 and No.3 are completely different (more than a magnitude difference in flow) their geometrical ratio is similar and therefore they have also the same specific speed.

The same four cases are shown in Figure 1-5 in more detail. The impeller diameter of pumps with the same specific speed is different and hence their flow rate at best efficiency point. The pump is designed for a system in which it has to be implemented (heating / cooling systems, open pump systems etc.). All these different systems mean different requirements to the pump itself and subsequently the hydraulic design. Hence, there is a requirement within industry for a large variety of pump sizes to service the European market. This allows pump manufacturers to optimize pump efficiency for each design. For example, usually a bigger sized impeller with the same specific speed has a better efficiency than the geometrically similar smaller version. To say 'the bigger the better' is however not necessarily correct because of the large amount of energy dissipated by operating points which may not match to the system. The choice of a pump for a specific application is also dependent on the NPSH-figure, noise, dirt etc.

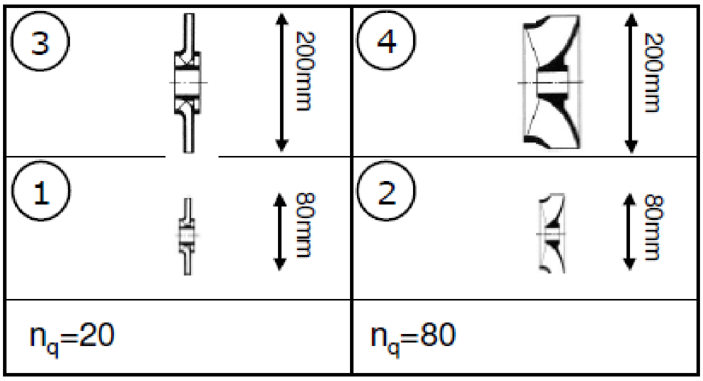


Figure 1-5: Principle impeller designs for typical pump sizes and specific speed

As induction motors are only available in fixed speeds, trimming the impeller is a common way to adjust the output of a pump to suit a particular application. The User therefore has an almost infinite range of pump options, which makes analysis difficult. But because the pump will be designed for best efficiency at full impeller, it is most appropriate to only consider performance at full impeller, as this is indicative of performance at all impeller diameters. As the Ecodesign Directive is aimed at improving pump design, this was seen as being the most appropriate impeller diameter to consider.

1.2 Product categorisation and performance assessment

1.2.1 Definition of Primary Functional Parameters

The primary functional parameters (i.e. 'what it does') are:

- Rated flow (Q, m^3/hour)
- Head (H, m)
- The fluid properties

Efficiency is not a primary functional parameter, on the basis that it relates to how a product does something, not what it does. 'Fluid properties' are included to make clear that the nature of fluids has a major impact on the selection of product.

The functional unit is the reference value for any pump considered, and is independent of type. It also helps to set the boundaries for comparison of different products. For the pumps in this study, this may be assessed by considering 'the quantity of water pumped at the specified head, (m^3/h, m)'.

1.2.2 Secondary Functional Parameters

The importance of secondary performance parameters is that they are often instrumental in guiding the specification of a pump, and so these must be considered when considering possible policy options. These include:

- **Pump speed.** The rotational speed of the shaft is the most important pump-operating variable. Pumps tend to be purchased to operate at the highest speed that the suction conditions (NPSH, net positive section head) will allow, since this usually results in the lowest first cost. (Since most pumps are driven by fixed speed induction motors, the speed options tend to be limited.) This can be false economy for many reasons, e.g. a two pole motor (2900rpm) can be cheaper than a four pole motor (1450rpm); more maintenance will be required since the life of wearing parts (such as impeller/casing wear rings, seals, bearings, couplings) will be reduced. Of the highest importance is the fact that the fastest pump may not be the most efficient option for the same duty point (Q/H), so that the initial price advantage can be lost in a short time by increased energy costs.

- **Bearing arrangements.** Pump impellers must be positively located both radially and axially. The radial bearings must resist radial thrusts and enable the impellers to maintain fine radial running clearances to minimise leakage between the impeller and casing. The axial bearings must resist axial thrusts, maintain the relative positions of the impeller and casing and ensure accurate location of axial seals. End Suction Own Bearings pumps use two anti-friction bearings, usually grease lubricated. Vertical Multistage pumps use the motor bearings for axial location; radial location being provided partly by the motor and partly by water lubricated plain bearings in the pump. Submersible Multistage Well pumps use the motor thrust bearing to accommodate the hydraulic downthrust and the weight of the pump rotating element, with a small thrust ring in the top of the pump to resist upthrust when starting; radial location is provided by water lubricated plain bearings. Aquarium pumps, pond pumps and fountain pump that use the technology of integrated motor with wet rotor normally do not require shaft bearings because, through a system of internal recirculation, the rotor shaft is constantly lubricated and cooled by the same pumped water.'
- **Net Positive Suction Head (NPSH).** This is the total head at the pump inlet above vapour pressure (corrected to the level of the first stage impeller inlet, if different). Two important values of NPSH are the NPSH required by the pump (NPSHR) and the NPSH available to the pump (NPSHA). The NPSHR is usually that at which the pump (or the first stage impeller if a multistage pump) loses 3% of its generated head due to cavitation. The NPSHA must exceed the NPSHR by a safety margin. The NPSHR reduces between pump best efficiency flow (BEQ) and about half flow, but increases rapidly above BEQ.
- **Shaft power or mechanical power**: power transmitted to a pump by the shaft. It is the product of speed and torque.

$$SP = \omega \times T$$

where,

ω is the angular speed of the shaft.

T is the torque transmitted.

- **Hydraulic power**: energy per second carried in a fluid, such as water or oil, in the form of pressure and quantity.

$$HP = Q \times \Delta p$$

where,

Q is the flow rate.

Δp is the change in pressure of the fluid over the pump.

- **Electrical power**: power input (in kW) of the pump.
- **Electricity and primary energy**: energy consumed by the pump. The primary energy includes the losses due to generation and transport of electricity.
- **Efficiency at operating/duty point.** This is a major determinant in lifetime operating costs. It is therefore important that a pump should be chosen which has a high efficiency, and that its best efficiency point (BEP) is as close as possible to the principal duty on site. The efficiency of a pump depends on its basic geometry, fine running clearances and a good surface finish.
- **Part load behaviour.** Throttled down to around half flow, a fixed speed pump can become noisy (see 'Noise' below) due to recirculation of the flow in the impeller and volute. At lower flows this could reduce bearing and seal life. At very low flows a pump can overheat. However, low flows should be avoided as far as possible because of loss of efficiency. It is therefore very important to avoid adding unnecessary margins to the required head and flow, which cause the pump to operate at reduced flow under actual site conditions.

1.2.3 Other relevant parameters

There are several other parameters considered to be relevant, namely noise, expected lifetime of the pump, and general construction.

- **Noise.** A pump of the types covered in this report operating under optimum conditions should be less noisy than its motor. If such a pump is noisy, then it is a fault condition. It could be a mechanical fault, such as failed bearings. However, it is more likely to be an operational fault. It could be running at too low a flow, which causes noisy cavitation in a volute and sometimes in an impeller, or it could be suffering from inadequate NPSHA, which causes noisy cavitation in an impeller.
- **Expected lifetime of the pump.** The lifetime of a water pump will rarely be dictated by obsolescence. The pump will usually be replaced when it fails, due to a broken component or an unacceptable drop in output. A large water pump operating under ideal conditions should work for 20 years with minimum

maintenance. The variations in the other pumps considered in this study are too large to specify a single expected lifetime. (Lifetimes of various types of pumps in the scope of the ENER Lot 29 study will be discussed in more details in Task 3).Unfortunately, most pumps lose efficiency due to wear in their wear rings, due to operation at part flow, and/or roughening of their cast iron volutes by corrosion products. It is not unusual to lose 10% of the new efficiency in ten years.

- **General construction.** Ease of maintenance varies with pump type. With End Suction Own Bearings pumps, the coupling spacer is removed and the pump rotating element can then be withdrawn without disturbing the motor or the pipework.

1.2.4 Importance of inlet pressure

Unlike a fan, a pump requires a minimum pressure at its inlet branch if it is to produce any flow at all. This is because at low pressures the water vaporises at the impeller inlet and the impeller is then unable to produce the pressure rise necessary to overcome the system resistance it is intended to work against.

The net positive suction head required by the pump (NPSHR) is defined above. To operate normally the pump will usually be arranged in the system such that the NPSH available at the pump inlet (NPSHA) is greater than the NPSHR throughout the intended flow range.

If the NPSHA is close to or less than the NPSHR, the head produced by the pump and the pump efficiency will both fall. It is therefore essential to provide adequate suction pressure to the pump if its optimum performance is to be achieved.

If the pressure at the pump suction is below atmospheric pressure, the pump performance can also deteriorate if air leaks into the pipework or through the pump seal. Even a very small leakage of air can reduce the pump head and efficiency significantly, so close attention to sealing is essential. In the case of Submersible pumps, if the water level in the well is too low air can be drawn into the pump through a vortex and again the performance will be adversely affected.

1.2.5 Improving Efficiency of Pumps

An extract from the 'SAVE Study on Improving the Efficiency of Pumps' is provided in Annex 1. It contains detailed information on the key factors in but design that affects the overall operating efficiency.

In addition to this, a description of the 'House of Efficiency Scheme' used in the ENER Lot 11 preparatory study is provided in Annex 2.

1.2.6 PRODCOM categories

PRODCOM is the official source of EU statistics on EU industrial production, and so is the primary reference used for classification of pumps. PRODCOM lists many subcategories considered suitable for ENER Lot 29 pumps. They are presented in Table 1-1.

Table 1-1: PRODCOM categories

PRODCOM code	Prodcom category
28.13	**Manufacture of other pumps and compressors**
28.13.14	***Other centrifugal pumps for liquids; other pumps***
28.13.14.13	Submersible motor, single-stage rotodynamic drainage and sewage pumps
28.13.14.15	Submersible motor, multi-stage rotodynamic pumps
28.13.14.30	Centrifugal pumps with a discharge outlet diameter > 15 mm, channel impeller pumps, side channel pumps, peripheral pumps and regenerative pumps
28.13.14.51	Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with a single entry impeller, close coupled
28.13.14.53	Centrifugal pumps with a discharge outlet diameter > 15 mm, single stage with a single entry impeller, long coupled
28.13.14.55	Centrifugal pumps with a discharge outlet diameter > 15 mm, single-stage with double entry impeller
28.13.14.60	Centrifugal pumps with a discharge outlet diameter > 15 mm, multi-stage (including self-priming)
28.13.14.71	Rotodynamic single-stage mixed flow or axial pumps
28.13.14.75	Rotodynamic multi-stage mixed flow or axial pumps
29.29	**Manufacture of other general-purpose machinery n.e.c.**
28.29.12	***Filtering or purifying machinery and apparatus, for liquid***
28.29.12.30	Machinery and apparatus for filtering or purifying water

1.2.7 EN-, ISO- and other classifications used by standardisation bodies

The only pertinent technical standard is the dimensional classification of pumps EN 733:1995 '*End-suction centrifugal pumps, rating with 10 bar with bearing bracket. Nominal duty point, main* *dimensions, designation system*'. Whilst the standard is well accepted within the industry, it is limited in scope to this style of pump only.

IEC standard 60335-2-41 '*Household and similar electrical appliances – Particular requirements for pumps*' and IEC 60335-2-55 '*Household and similar electrical appliances – Particular requirements for electrical appliances for use with aquariums and garden ponds*' are both pertinent to aquariums and garden pumps.

1.2.8 Labelling categories (EU Energy Label or Eco-Label)

There are currently no ecolabels at EU or Member State levels that can be used as a basis for pump categorisation. The voluntary circulator scheme (EC) No 641/2009 is a useful reference, in particular in the way that it takes account of operation at reduced flow. However, the flow-weighting scheme on which it is based is only feasible because the flow distribution is similar in most systems. This is not the case with many pumps considered in this study because they are used for a very wide range of duties. However, there are certain situations where this 'extended product approach' may be appropriate. A technical note on the extended product approach is located on the ENER Lot 29 website: http://lot29.ecopumps.eu/documents.

1.2.9 Proposed classification scheme for pumps

Given the lack of an existing classification scheme adequate for the study purposes, the following categorisation method is adopted. There are other categorising schemes available from other sources, but none of them has obvious merits over any others.

This section will provide some preliminary definitions of some of the products that could be included within the scope of the ENER Lot 29 study.

For each type of pump, the power ranges are agreed with stakeholders. Pumps may also have additional features from being customised for either mass market (small pumps) or designed for individual applications (large pumps).

Pumps come in a variety of generic types as shown see Figure 1-6.

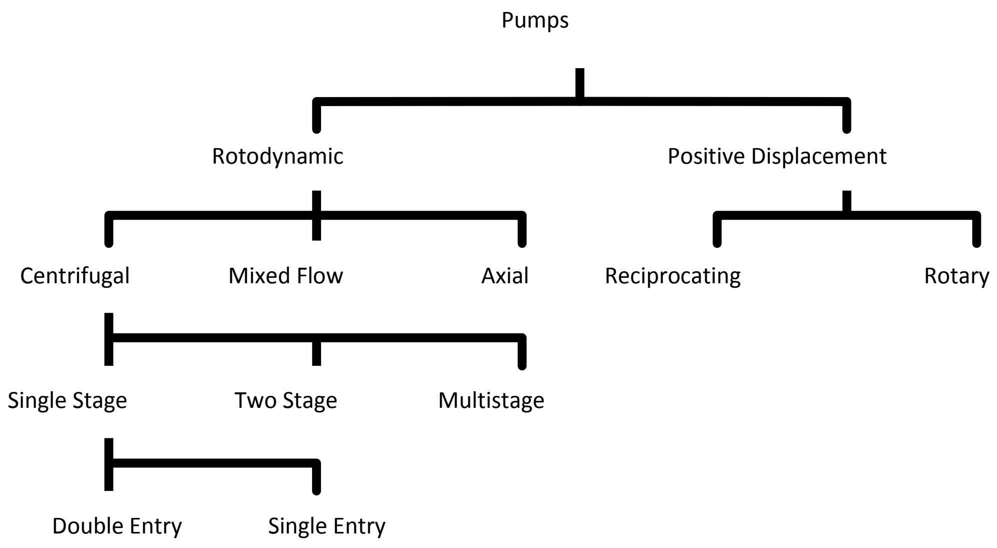


Figure 1-6: Preliminary classification for pumps

1.3 Product screening

This section discusses how the pump categories to be studied are derived from the above classification and presents the rationale for the screening of pump categories. This step is taken due to the large and inhomogeneous product groups. The approach taken is to assume that all pumps are included, unless there are sound reasons why they should be excluded. Care has been taken to try to ensure that no pumps are excluded due to the type of technology rather than the duty/service/function.

The key criteria the project team considers in the screening analysis include:

- Estimated total energy consumption and energy saving potential – this is largely a pragmatic consideration, as it will be better to focus on developing a robust case for the big energy saving targets than to attempt to regulate everything conceivably in scope.
- Other environmental aspects – where energy consumption is not a key environmental aspect, other aspects such as material consumption might be of importance and should be taken into account to avoid loopholes.
- Different products available to fulfil the application duty – i.e. could regulations be technology neutral? Regulations under the Ecodesign Directive can only be based on products available on the market; they cannot take account of the application in which they are used. Hence, where more than one product type is available to satisfy an application, great care must be taken to ensure a level playing field between different competing technology options.
- Size of custom / specials market – the existence of alternative products that do not fit definitions can easily lead to loopholes.

1.3.1 Description of pump categories considered

Many of the pumps in this study fall into the category of 'rotodynamic,'. Based on the specification of work, the following types of pump have been considered for inclusion:

- Swimming pool pumps
- Fountain pumps
- Pond pumps
- Aquarium pumps
- Aquarium blowers
- Spa pumps for domestic & commercial spa's
- Counter-Current Pumps
- Large clean water end suction pumps
- Large clean water vertical multistage pumps
- Large clean water submersible multistage pumps

Aquarium blowers are air pumps. Some of them fall into the category of centrifugal pumps, but many aquarium blowers work on a principle similar to a diaphragm pumps. Other than the submersible and vertical multistage pumps, all the other pumps are single stage and single entry pumps. An important point is that some types of pumps could theoretically be used in many different application categories, but this rarely happens in practice for reasons of cost or detailed design features. Pumps that are originally designed for use with liquids other than water are not within the scope of this study.

The following factors are to be considered in defining the exact specifications of pumps within each category:

1. Standard types. The Directive is aimed at commodity types of products, not those designed especially for specialist or niche applications where there are only very low sales or where custom / semi-custom designs are the norm.
2. When collecting data, manufacturers should not offer their 'nearest equivalent' type of pump from a different family that satisfies the required duty, as this would lead to distortions in the results.
3. As pumps are characterised by hydraulic values rather than power (kW) ratings, it is not possible to directly link them to the ranges in the motor study. However, indicatively it is unlikely that any pumps within the scope of the study will require an electrical motor in excess of 1 MW to drive them. However, it should be noted that most pumps beyond 160kW are non-standard engineered items, which are not considered suitable for setting ecodesign requirements.
4. As with many products, sales of those at the extreme of sizes will be very low compared to those in the 'centre ground', and in many cases can be considered to be low volume products that are engineered rather than series produced commodity types. Firm data is

not available on the proportion of the market that is excluded from the study in this way, and it will vary with the different pumps considered, but our best estimate is that it is less than 5% of the total sales of each style, which types are low volume and often for 'specialist' applications.

In each case, care must be taken to check that these considerations will not inadvertently allow excluded products from benefiting by being excluded from any policy options.

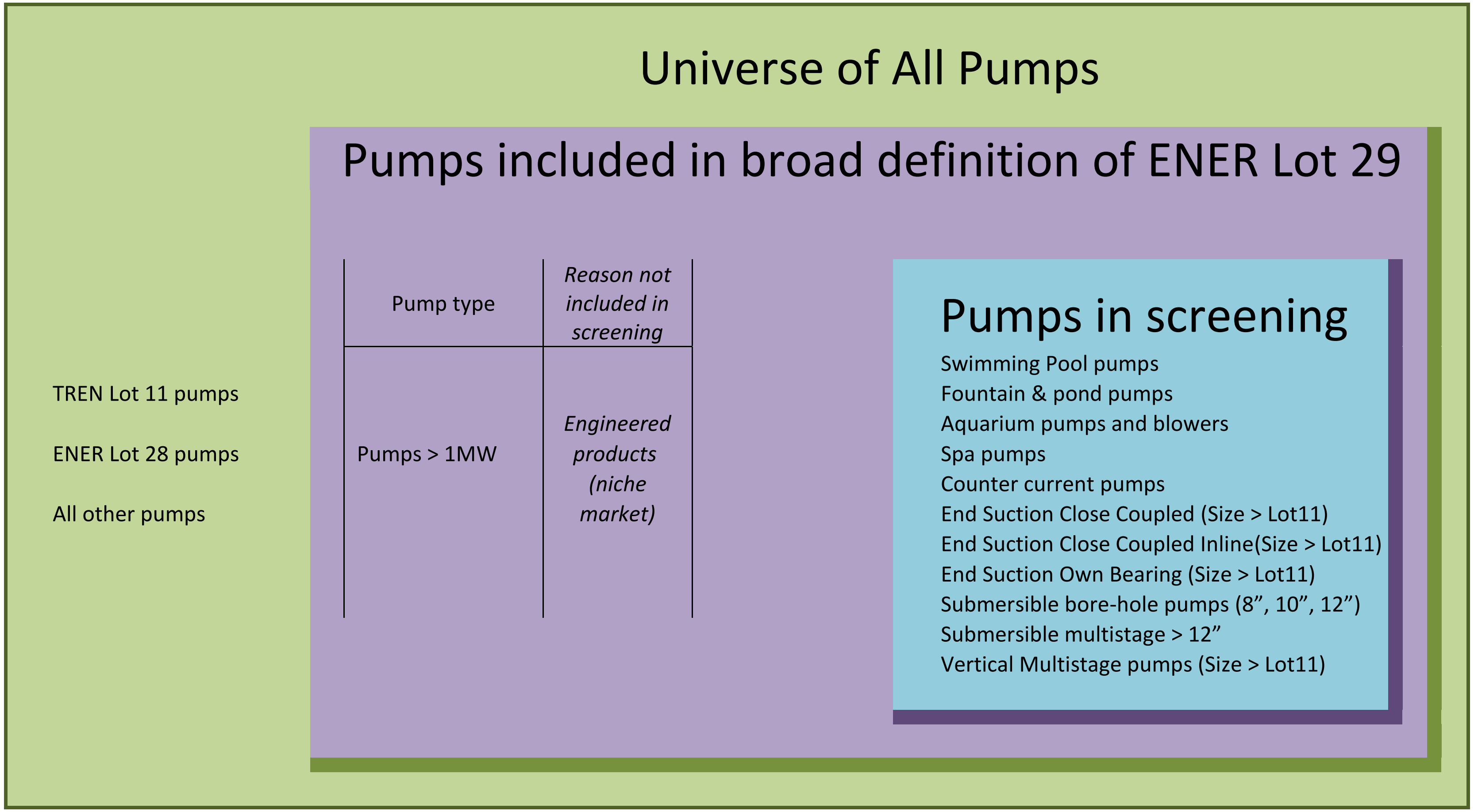
Table 1-2 shows the selected pump categories/sizes that are to be considered to develop the screening analysis. These were carefully selected to represent the manufacturing features that apply to all pumps within each of the categories. To do this adequately, it was found necessary to select a range of sizes for certain types of model.

Table 1-2: Pump categories and associated duties

Categories	Selected Duties (Q,H,speed)
Swimming Pool pumps (Domestic with built in strainer up to 2.2kW)	Q 5 – 20 m³/h H 8 – 11 m Speed 2,900 rpm
Swimming Pool pumps (Domestic/commercial with built in strainer over 2.2kW)	200 m³/h H 12 – 16 m 2900 – 1450 rpm
Fountain & pond pumps	Q 100 – 15,000 l/h H 0 – 8 m Speed 3,000 rpm
Aquarium pumps	Q 100 – 5,000 l/h H 0 – 4 m Speed 3,000 rpm
Spa pumps	P 0.75-3kW Speed 1,450 and 2,900rpm
Counter current pumps	Q 30,000 - 60,000 l/h H 10-14m Speed 2,900rpm
End Suction pumps (Size > ENER Lot11)	Q 200 - 2,000 m3/h H 10-90m Speed 1,450rpm
Submersible bore-hole pumps (8”, 10”, 12”)	Q 15 - 500 m3/h H 30-500m Speed 2,900rpm
Submersible bore-hole pumps > 12”	Q 300 - 2,500 m3/h H 25-200m Speed 1,450rpm
Vertical Multistage pumps (Size > ENER Lot11)	Q 100 - 700 m3/h H 20-400m Speed 1,450rpm and 2900rpm

Figure 1-7 shows which pump categories, out of the universe of all pumps, have been selected for screening. These pumps for screening are then analysed further in section 1.3.3.

It should be noted that pumps above 1MW are non-standard, engineered products, which are not considered possible to analyse further, therefore the upper limit for pumps in scope for this lot is 1 MW. However, consideration will be given to potential measures for these pumps in Task 8.



Pump type	*Reason not included in screening*
Pumps > 1MW	*Engineered products (niche market)*

Figure 1-7: Process to define pumps for screening

1.3.2 Details of the key types of pumps considered in this study

A. LARGE WATER PUMPS

For consistency, the same product classification and analysis as in the TREN Lot 11 study that covers pumps up to 150kW (4-pole) is used for these pumps:

- '*End suction water pump*' means a glanded single stage end suction rotodynamic water pump
  - '*End suction own bearing water pump*' (ESOB) is an end suction water pump with own bearings and the suction side in axial and the water pressure outlet in radial direction (Figure 1-9);
  - '*End suction close coupled water pump*' (ESCC) is an end suction water pump of which the motor shaft is extended to become also the pump shaft with the suction side in axial and the water pressure outlet in radial direction;
  - '*End suction close coupled inline water pump*' (ESCCi) means a water pump of which the suction side of the pump is in one line with the water pressure outlet of the pump;
- '*Vertical multistage water pump*' (MS-V) means a glanded multi stage (i > 1) rotodynamic water pump in which the impellers are assembled on a vertically rotating shaft;
- '*Submersible multistage water pump*' (MSS) means a multi stage (i > 1) rotodynamic water pump.

Such pumps have many uses, such as water supply or industrial cooling systems. The analysis will start at the upper size boundary of the proposed regulations, i.e. 1 MW for water pumps, which varies with both the type of pump and the actual duty (see Figure 1-8).

The TREN Lot 11 study upper boundaries were calculated on the basis that these were the approximate limits of the mass produced pumps. Above these sizes, and for the ranges which this new study covers, pumps are so large that they are increasingly tailored or 'engineered' for each application. The efficiencies in these large sizes can already be high, and so there may be little potential for increasing the efficiency. However, given the large annual energy consumption, even a small saving can have a large impact, and so is of particular interest to operators.

For submersible multistage pumps, the minimum power in the ENER Lot 29 study is considerably less than 150kW, due to TREN Lot 11 Pumps being limited to 6" diameter. The upper size considered for the ENER Lot 29 study is 12" diameter. The pumps beyond this size are engineered items, unsuitable for regulation.

End suction close coupled pumps are available in the power range considered in the ENER Lot 29 study, but they are relatively rare.

The upper motor size limits for the vertical multistage pumps, end suction own bear pumps and submersible multistage pumps is 1 MW as this fits with the ENER Lot 30 Motor study size range.

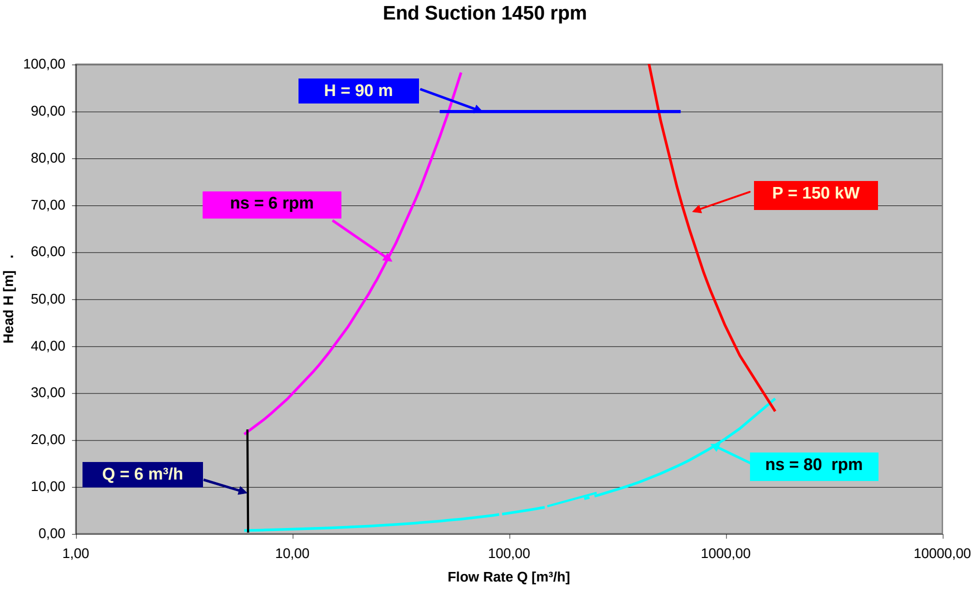


Figure 1-8: Boundaries of TREN Lot 11 preparatory study pumps (4 pole). The ENER Lot 29 study would include pumps to the right of the red maximum power line.

Large clean water pump manufacturers will typically sell pumps with a variety of pump ranges of different sizes in order to attempt to meet the various head and flow requirements of their clients' applications. For each pump range, further variation is possible by impeller trimming, which is important to maintain best efficiency at duties below the optimum.

For each pump, it will have its best efficiency at the top middle of the range. The best achievable efficiency will depend on size and specific speed. Specific speed underpins studies of pump efficiency, and it depends on shaft speed, number of stages, head and flow.

Figure 1-9: Example of an end suction own bearing pump

The other styles are physically similar, with the exception of the Multistage submersible that is designed for operation down deep boreholes (see Figure 1-10).

Figure 1-10: Multistage submersible pump (courtesy of KSB)

For these styles of pumps, the motor is specified separately from the pump, and so the pump will be analysed without the motor.

▶ B. SWIMMING POOL PUMPS

The swimming pool pumps referred to in this Lot are regarded as being the smaller packaged type sold for residential use (see Figure 1-11), with commercial premises using standard water pumps. Older style pumpsets comprising separate motor and pumps now comprise probably <1% of stock, and so can be considered obsolete technology. These domestic swimming pool pumps can also be used for Jacuzzis.

Conterflow pumps, which are used to provide an injection of high pressure flow from outlets on the side of a pool, have too low an energy consumption to be considered in this study (see Figure 1-12). SPA pumps for domestic & commercial spa's where the water is retained and filtered/treated (not those installed into domestic baths which are emptied each time after use) are also considered to have too low an annual energy consumption to be considered for this study.

Public swimming pools may have larger pumps that are driven by a separate motor. Our initial investigations show that these are effectively clean water pumps of the type already analysed within TREN Lot 11.

Domestic swimming pool pumps are typically made from plastic for reasons of efficiency, and of steel in commercial pool pumps for wear resistance and longevity. They are typically rated at around 1kW, and come as packaged units that comprise an integrated motor + pump + controls. They are limited to about 3kW, corresponding to the maximum power that can be drawn from a domestic mains outlet. The ENER Lot 29 study will also include domestic swimming pool pumps with built in strainer up to 3kW and large domestic /commercial swimming pool pumps with built in strainer over 3 kW. Given that pool pumps are a packaged product, and that it should be possible to define typical flow-time profiles, the extended product approach will be readily applicable. There is also much best practice information published on the efficient use of pool pumps, such as that published by swimming pool trade bodies and manufactures, would be a good source of information to be included on or with pumps.

Figure 1-11: Packaged swimming pool pump unit, showing (left to right) prefilter, pump and motor

Figure 1-12: Example of a counter-flow domestic swimming pool pump

▶ C. AQUARIUM PUMPS

An aquarium is a 'living environment' whose health depends on many elements; water parameters involved are numerous (e.g. pH, content of Nitrite, of Nitrate, of Phosphate, temperature, etc.) and they are interrelated and influenced by other factors such as species of living organisms hosted (e.g. fish, shellfish, invertebrates), ratio biomass/water volume, presence of plants, etc..

The pump/filter plays a vital role in the aquarium ecosystem and must operate continuously 24/24. Any control of the rotation speed of the pump, from a ON/OFF option up to a variable speed drive (VSD), can be harmful for the livestock because:

The water flow thru the biological filter needs to be continuous, to guarantee the perfect functioning of the device (risk of inactivation of the filter) and to exclude the risk of Ammonia (NH_3/NH_4^+) and Nitrite (NO_2^-) accumulation. Nitrite ion is the most dangerous for the stock and can cause its death.

The water turnover could be neap and not able to assure the catabolites disposal. The catabolites are the result of protein metabolism of fish.

Fish excrete a lot of waste, mainly ammonia (NH3/NH4+), a toxic compound. Ammonia rapidly accumulates, until enough colonies of bacteria are established in the filter. These bacteria convert ammonia into nitrite (NO2-), that is even more toxic than ammonia. Nitrite too accumulates in water until it is converted by another type of bacteria, into nitrate, a low toxic compound. This end state, with enough bacteria to convert ammonia and nitrite into nitrate, allows the filter to maintain fish safe. If water flow through the filter is stopped, water cannot be depurated and ammonia and nitrite start to accumulate again.

Ammonia and Nitrite concentration above 0,5 mg/L should be considered highly toxic to aquatic fauna.

Most aquarium pumps are circulating pumps connected to a device that works as a filter. Inside the filter water is forced to flow through different types of filtering materials, in such a way that water is cleared from dirt and detoxified from fish waste. Most Aquarium pumps use the technology of integrated motor with wet rotor. Since the 80's, the aquarium industry has seen a progressive technological shift with the replacement of traditional asynchronous motors with permanent magnet synchronous motors characterized, as known in the literature, by a much higher yield together with lower power consumption than asynchronous motors. Today, aquarium pumps exclusively employ high efficiency permanent magnet motors.

In addition, over the last decade, the industry has made great efforts to optimise the hydraulic design with a view to improving the performance and get further reduction of energy consumption. Today are widely available on the market hydraulic solutions characterized by an high yield such as oriented blades impellers, flexible blades impellers, closed impellers; thanks to the very low hydraulic power the above mentioned design solutions are able to guarantee the correct direction of rotation without using electronics that controls the start-up phase of the pump. On models with higher performance, although they represent a niche market (salt water aquariums), they are also used with electronic controls that ensure the correct direction of rotation of the impeller.

The market is further complicated by some pumps that are connected to additional devices, for example, a heating element, a UV-C lamp or a particular filtering unit. At this stage, it is suggested that any MEPS that might be defined are based on the pump alone, but the test standard will need to take account of the need to remove these other elements (when not necessary to the functionality of the pump itself, for example some aquarium filters as shown in Figure 1-13). While this is a shift from the pure 'extended product approach' that aims to consider as much of the system as possible, it is likely that trying to define 'standard' to fit within regulations would be difficult and give little real benefit.

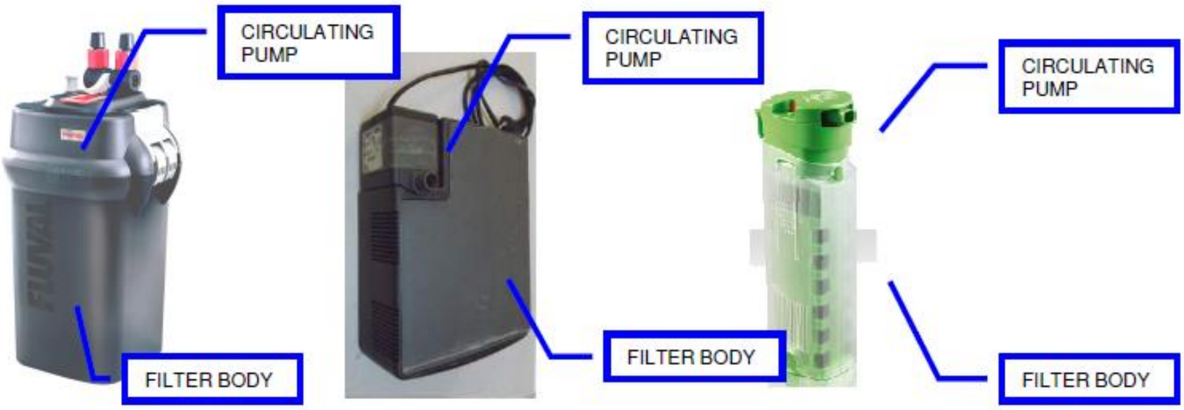


Figure 1-13: Aquarium filters - As described above the circulating pump forces the water through the filter body

Most Aquarium pumps use the technology of integrated motor with wet rotor: the older style pumpset comprising separate motor and pumps can be considered obsolete. Mainly for aquaria applications that need supplementary circulating current, a further circulating pump is also needed Figure 1-14. These are low power units typically <120W although larger pumps are available. The inefficiencies in these pumps cause heating of the water that in some cases may be unwanted.

Figure 1-14: Circulating pumps

D. FOUNTAIN & POND PUMPS

A pond is a living ecosystem and pump intended for the filtration has a vital role must operate continuously throughout the period of use. Also fountains pumps usually play a "filtration role" inside the pond; moreover they guarantee oxygenation of water avoiding the risk of ipoxia in the pond. Pond pumps and fountain pumps are basically built in the same way and differ only for the point of work on the flow/head characteristic curve. Fountain pumps need to work at high head and low flow, while pond pumps need to work at low head and high flow.

Pond pumps drive water through a filter whereas fountain pumps are designed for higher heads for decorative features such as fountains or waterfalls (see Figure 1-15). Fountain pumps will have an internal and possibly satellite inlet filter for protecting the pump.

In pond pumps dirty water will be sourced from a ground filtration unit and often also from a protein skimmer that removes residue from the surface (see Figure 1-16). Most of these types of pump use the technology of integrated motor with wet rotor: the older style pumpset comprising separate motor and pumps can be considered obsolete.

Power ratings vary enormously from <5W to >1kW, with an average power around 40 W. They typically filter up to 25 m³ per hour. They are usually manufactured with a permanent magnet motor.

The upper boundary will need debate in order to ensure no conflict with standalone motors and pumps considered in TREN Lot 11.

Figure 1-15: Typical fountain pump with satellite inlet filter and with internal inlet filter

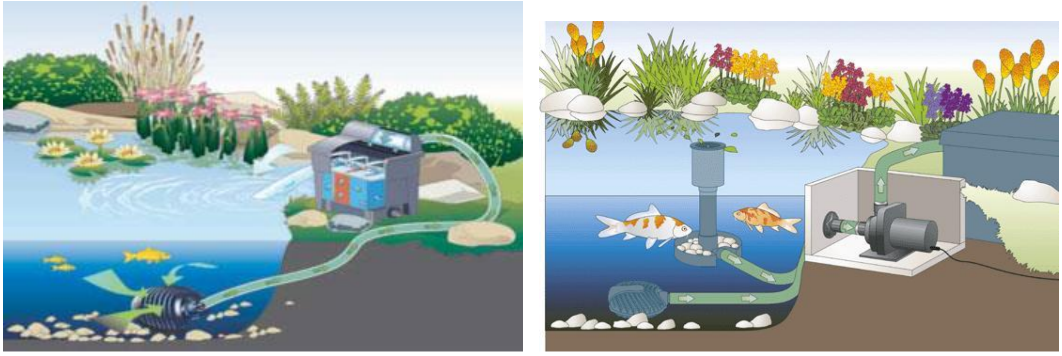


Figure 1-16: Typical pond pump and external filtration unit (left) and Surface – protein – skimmer and dry pond pump (right) from Oase

1.3.3 Evaluation of importance of pump types

Table 1-3 shows an estimation of the annual energy consumption and energy savings potential for the EU stock in 2011 of the pumps considered for the screening analysis. To calculate the annual energy consumption of the pumps, the average hydraulic power is multiplied by the annual operating hours and then added the power absorbed by the motor (assumed as 20%).

Any pump type with significant environmental impact and improvement potential should be kept within the scope. With that reason, the share of total environmental impacts (of the EU stock of pumps considered in the study), per pump type, have been estimated by means of a simplified Life Cycle Assessment (using the EcoReport tool) that includes a simplified bill of materials, the energy consumption, the product life span and the market data. The aim of this exercise is to do a first analysis of the environmental impacts and improvement potential of pumps covered by the definition of the ENER Lot 29 preparatory study. The results are presented in Table 1-4.

Table 1-3: Energy consumption and energy savings potential for the EU stock of pumps considered for the screening analysis (Source: Europump)

	Pump type (and sub-categories)	EU Installed stock 2011	EU Annual sales	Hydraulic pump power	Annual operating hours	Annual energy consumption at EU level* 2011	Improvement potential	Potential savings at EU level 2011	Share of energy consumption	Product level energy savings from EPA	Existing market penetration of EPA	Potential energy savings to overall market from EPA Regulation	Actual savings Potential from EPA Regulation
		Units	Units	kW	Hours	GWh	%	GWh	%	%	%	%	GWh
Swimming Pool pumps (integrated motor+pump)	Domestic with built in strainer up to 2.2 kW	4,800,000	480,000	0.8	1,500	6,912	2.0%	138.2	14.7%	10.0%	0.0%	10.0%	691.20
	Domestic/commercial with built in strainer over 2.2 kW	115,000	11,500	5	3,375	2,329	2.0%	46.6	5.0%	10.0%	0.0%	10.0%	232.88
Fountain, pond, aquarium, spa and counter-current pumps	Fountain and pond pumps to 1 kW	1,845,000	205,000	0.02	6,000	266	2.0%	13.3	1.4%	0.0%	0.0%	0.0%	0.00
	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W	8,050,000	1,150,000	0.005	8,720	421	2.0%	21.1	2.2%	0.0%	0.0%	0.0%	0.00
	Aquarium power head to 120W	350,000	50,000	0.005	8,720	18	2.0%	0.9	0.1%	0.0%	0.0%	0.0%	0.00
	Spa pumps for domestic & commercial spa's	42,000	4,200	1.1	350	19	2.0%	0.6	0.1%	0.0%	100.0%	0.0%	0.00
	Counter-Current Pumps	1,000,000	100,000	3	20	72	2.0%	1.4	0.2%	0.0%	0.0%	0.0%	0.00
End suction (ES) water pumps (over 150kW-P2)	ES CloseCoupled from 150 kW to 1 MW	1,000	100	150	3,600	648	1.0%	6.5	0.7%	25.0%	50.0%	12.5%	81.00
	ES CloseCoupled Inline from 150 kW to 1 MW	1,000	100	150	3,600	648	1.0%	6.5	0.7%	25.0%	50.0%	12.5%	81.00
	ES Own Bearing from 150 kW to 1 MW	5,500	550	325	3,000	6,435	1.0%	64.4	6.9%	25.0%	50.0%	12.5%	804.38
Submersible bore-hole pumps	8" Submersible bore-hole pumps	73,000	7,300	33	2,565	7,415	2.0%	148.3	15.8%	15.0%	15.0%	12.8%	945.40
	10" Submersible bore-hole pumps	31,670	3,167	65	2,725	6,731	2.0%	134.6	14.3%	15.0%	15.0%	12.8%	858.26
	12" Submersible bore-hole pumps	15,160	1,516	121	3,114	6,855	2.0%	137.1	14.6%	15.0%	15.0%	12.8%	873.97
	Submersible bore-hole pumps larger than 12"	4,500	450	288	3,352	5,213	1.3%	69.3	7.4%	15.0%	15.0%	12.8%	664.66
Vertical multi-stage pumps	Vertical multi-stage pump (25 to 40 bar	29,000	2,900	68	2,700	6,389	2.0%	127.8	13.6%	25.0%	50.0%	12.5%	798.66

	Pump type (and sub-categories)	EU Installed stock 2011	EU Annual sales	Hydraulic pump power	Annual operating hours	Annual energy consumption at EU level* 2011	Improvement potential	Potential savings at EU level 2011	Share of energy consumption	Product level energy savings from EPA	Existing market penetration of EPA	Potential energy savings to overall market from EPA Regulation	Actual savings Potential from EPA Regulation
		Units	Units	kW	Hours	GWh	%	GWh	%	%	%	%	GWh
	and/or 100 to 180 m3/hr)												
	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)	2,875	275	125	3,450	1,488	1.5%	22.3	2.4%	25.0%	50.0%	12.5%	185.98
Totals		16,365,705	2,017,058			51,859		939					6,217

* Calculated as: ((Hydraulic pump power * Annual operating hours) +20%) * EU Installed stock

Table 1-4: Contribution (in %) of each of the pumps covered in the screening analysis to the overall environmental impacts at EU level

	SPPS	SPPL	FPP	AP	APH	SPA	CCP	ESCC	ESCCI	ESOB	SBHP08	SBHP10	SBHP12	SBHP12+	VMSPS	VMSPL	Total
Total Energy (GER)	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
of which, electricity (in primary PJ)	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Water (process)	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Water (cooling)	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Waste, non-haz./ landfill	22,6%	3,8%	0,4%	0,6%	0,0%	0,0%	0,4%	1,3%	1,3%	13,1%	11,3%	10,4%	10,5%	8,0%	13,1%	3,0%	100%
Waste, hazardous/ incinerated	22,7%	3,8%	0,4%	0,8%	0,0%	0,0%	0,3%	1,3%	1,3%	13,1%	11,3%	10,3%	10,5%	8,0%	13,0%	3,0%	100%
Greenhouse Gases in GWP100	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Acidification, emissions	22,2%	3,9%	0,3%	0,5%	0,0%	0,0%	0,1%	1,3%	1,3%	13,3%	11,5%	10,4%	10,6%	8,1%	13,2%	3,1%	100%
Volatile Organic Compounds (VOC)	22,4%	3,8%	0,4%	0,6%	0,0%	0,0%	0,3%	1,3%	1,3%	13,2%	11,4%	10,4%	10,6%	8,0%	13,1%	3,1%	100%
Persistent Organic Pollutants (POP)	23,6%	3,8%	0,5%	0,7%	0,0%	0,1%	1,1%	1,3%	1,3%	12,7%	10,9%	10,3%	10,3%	7,7%	12,7%	3,0%	100%
Heavy Metals	22,4%	3,8%	0,4%	0,6%	0,0%	0,0%	0,3%	1,3%	1,3%	13,2%	11,4%	10,4%	10,6%	8,0%	13,1%	3,1%	100%
PAHs	23,3%	3,8%	0,5%	0,7%	0,0%	0,1%	0,6%	1,3%	1,3%	12,9%	11,2%	10,2%	10,4%	7,9%	12,9%	3,0%	100%
Particulate Matter (PM, dust)	23,8%	3,6%	0,8%	1,4%	0,0%	0,1%	1,3%	1,3%	1,3%	12,3%	10,5%	10,6%	10,2%	7,5%	12,4%	3,0%	100%
Heavy Metals	22,5%	3,8%	0,4%	0,6%	0,0%	0,0%	0,3%	1,3%	1,3%	13,2%	11,4%	10,4%	10,6%	8,0%	13,1%	3,1%	100%
Eutrophication	23,1%	3,8%	0,5%	0,8%	0,0%	0,1%	1,0%	1,3%	1,3%	12,8%	10,9%	10,5%	10,4%	7,8%	12,8%	3,0%	100%

* NOTE: Acronyms are presented on the next page

List of acronyms:

SPPS	Domestic with built in strainer up to 2.2 kW
SPPL	Domestic/commercial with built in strainer over 2.2 kW
FPP	Fountain and pond pumps to 1 kW
AP	Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W
APH	Aquarium power head to 120W
SPA	Spa pumps for domestic & commercial spa's
CCP	Counter-Current Pumps
ESCC	End Suction Close Coupled from 150 kW to 1 MW
ESCCI	End Suction Close Coupled Inline from 150 kW to 1 MW
ESOB	End Suction Own Bearing from 150 kW to 1 MW
SBHP08	8" Submersible bore-hole pumps
SBHP10	10" Submersible bore-hole pumps
SBHP12	12" Submersible bore-hole pumps
SBHP12+	Submersible bore-hole pumps larger than 12"
VMSPS	Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)
VMSPL	Vertical multi-stage pump (>40 bar and/or >180 m3/hr)

As seen in Table 1-3 and Table 1-4, there are big differences in energy consumption and environmental impacts of the pumps in the scope. However, the definition of the product groups to be included in the preparatory study is clear and includes all these types of pumps. Therefore, all pump types in the definition of the preparatory study will be considered for analysis in the following Tasks:

- Swimming Pool pumps (integrated motor+pump)
  - Domestic with built in strainer up to 2.2 kW
  - Domestic/commercial with built in strainer over 2.2 kW
- Fountain and pond pumps to 1 kW
- Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W[2]
- Aquarium power head to 120W
- Spa pumps for domestic & commercial spa's
- Counter-Current Pumps
- End Suction Close Coupled from 150 kW to 1 MW
- End Suction Close Coupled Inline from 150 kW to 1 MW

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[2] The upper limit of 120W was chosen as the vast majority of aquarium pumps are below this figure and the motors are not covered by other regulations

- End Suction Own Bearing from 150 kW to 1 MW
- 8” Submersible bore-hole pumps
- 10” Submersible bore-hole pumps
- 12” Submersible bore-hole pumps
- Submersible bore-hole pumps larger than 12”
- Vertical multi-stage pump (> 40 bar and > 180 m3/hr)
- Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)

1.4 Test Standards

This section presents the relevant test standards and procedures identified to date.

In technical use, a standard is a concrete example of an item or a specification against which all others may be measured or tested.

The focus is on the environmental performance and related technical aspects, e.g. energy consumption in relation to functional performance of the product. The issue of particular interest is standardisation methodology and related parameters, e.g. allocation of environmental loads to different life cycle stages, usage scenarios, and data requirements.

The definition of product performance is restrictive in that it would not permit changes in physical design of the product, which is in contravention of Article 15 5(e) of the Ecodesign Directive: '*in principle, the setting of an ecodesign requirement shall not have the consequence of imposing proprietary technology on manufacturers.'* Given the large number of pump types in existence, this single standard (which corresponds to some of the ‘Centrifugal – Single entry volute conventional’ pumps in Figure 1-6), is inadequate as a means of classifying pump types, and it would certainly be inappropriate to use EN 733:1995 as the basis for any efficiency standards.

1.4.1 Clean water classification

Clean water is defined in Regulation 547/2012. Some EU Directives, such as the Abstraction of Surface Water for Drinking water (74/440/EC) clearly elaborate water quality standards while others like the Nitrate Directive (91/676/EEC) do not. Standards exist for drinking water quality, bathing waters excluding swimming pools and spas, and fishery waters but do not exist for groundwater and clean water in the scope study. There are different levels of pool water quality (pH, Cl content, etc) in different Member States in the EU. There is some standardisation work ongoing on the homogenisation of swimming pool definitions, sizes, pumps, etc, However, this work is not available at the time of writing.

1.4.2 Verification of efficiency values

It is important that the actual efficiencies of products placed on the market comply with any claimed energy performance class. Manufacturers currently use a statistical approach such that all of their pumps (except for a small statistical proportion) will exceed the declared efficiency value after allowing for the permitted test tolerance. They will test typically to ISO 9906:1999 Grade 2, which allows for a - 5% tolerance on quoted efficiency. (Acceptance) testing is generally done at the manufacturer's own test facility, and may be witnessed by a representative of the purchaser. For larger pumps, a user may request a test of the actual pump to Grade 1, but this costs additional money, and so will not be done unless specifically requested. Verification of efficiency levels are clearly defined in Commission communication (2012/C 402/07) ECO design requirements for water pumps.

Although ISO 9906 does also publish the measurement uncertainties for different measurement techniques, manufacturers will not normally make any specific allowance during acceptance testing for the uncertainties inherent in their test methods, since these uncertainties will usually be less than the permitted tolerance.

Manufacturers will take a statistical risk in how they position the declared and mean production values of efficiency. Those who control production to give a tighter spread may choose either to produce pumps with a lower mean efficiency and reap any cost savings, or quote a higher efficiency.

It is often the case that the manufacturer will only test a small percentage of each pump size included in this report, either for customers or for quality control purposes.

If an independent testing body is asked to measure the performance of a pump, it is in their interests to use a test method with a small uncertainty. This will not only give a more accurate indication of the true efficiency, but will also minimise the efficiency 'allowance' to take account of measurement uncertainties that needs to be given to the pump being tested (see Figure 1-17). Nonetheless, too much allowance given by independent testing body can lead to false efficacy claims, which could be used as loopholes by manufacturers.

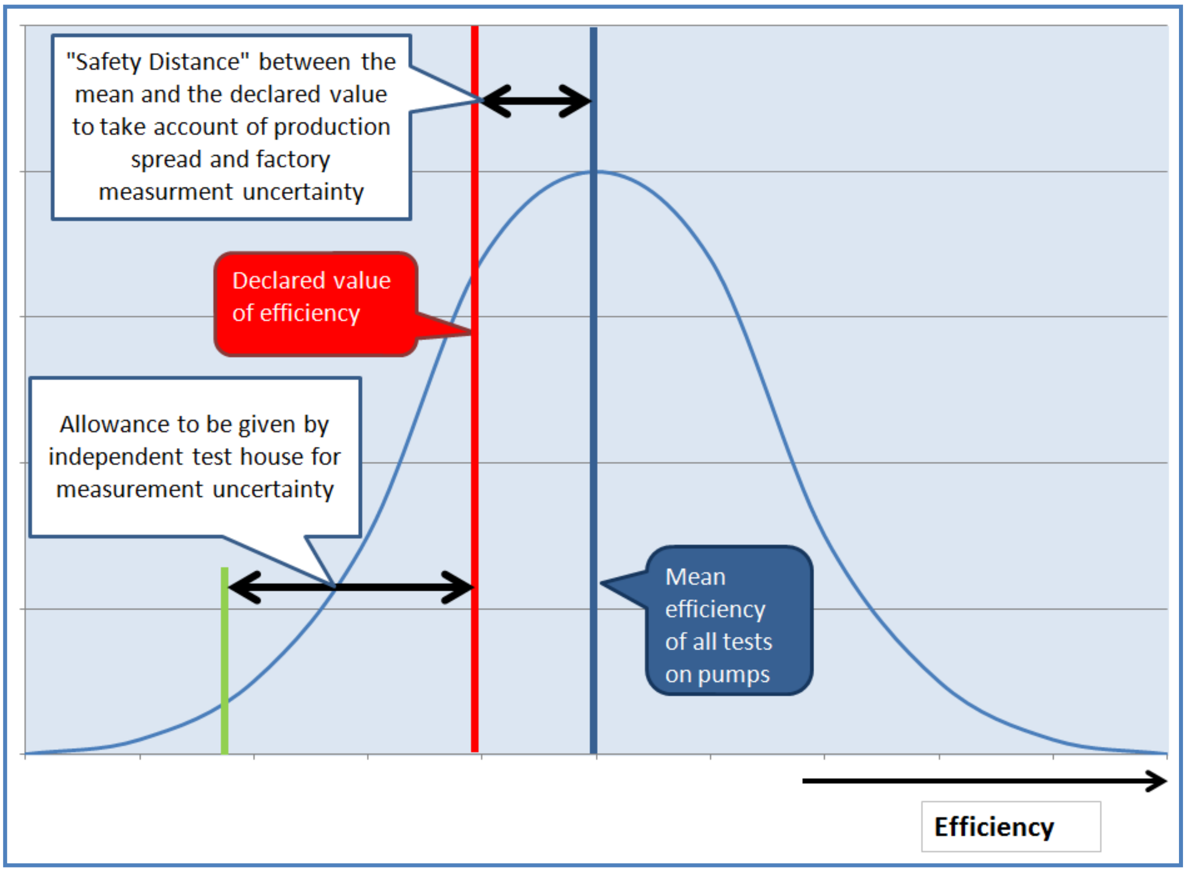

Figure 1-17: Testing and verification of pumps (only relevant to testing of products by an external test house)

1.4.3 Standards at European Union level

There are no energy related standards, which the consortium is aware of for any of the pump categories within ENER Lot 29. However, there are many technical standards governing the construction and design of these pumps, as presented in Table 1-5.

The CEN TC197 'Pumps' technical committee has been created in 1990 to prepare and publish European standards, establishing the technical safety requirements for liquid pumps and pump units, in conformity with the Machinery Directive 89/392/CE.

Table 1-5: Non-energy related EU standards relevant for pumps within study scope

Reference	Title
EN 733:1995	End-suction centrifugal pumps, rating with 10 bar with bearing bracket. Nominal duty point, main dimensions, designation system
EN 1092-2	Flanges and their joints. Circular flanges for pipes, valves, fittings and accessories, PN designated. Cast iron flanges
EN 12483	Liquid pumps. Pump units with frequency inverters. Guarantee and compatibility tests.
EN 12723	Liquid pumps. General terms for pumps and installations. Definitions, quantities, letter symbols and units.

Reference	Title
EN 13463-1	Non-electrical equipment for potentially explosive atmospheres. Basic method and requirements.
EN 60034	Rotating electrical machines
EN 60335-2-41	Household and similar electrical appliances – Safety – Part 2-41: Particular requirements for pumps
EN 60335-2-55	Household and similar electrical appliances - Safety - Part 2-55: Particular requirements for electrical appliances for use with aquariums and garden ponds

1.4.4 Standards at Member State level

Water quality standards and filtration practices change from Member State to Member State. This seriously affects the functionality of the pump. There are very different levels of pool water quality (pH, Cl content, etc) in different Member States, and standardisation work is currently being done in that sense. Some aspects of the whole pool water treatment (water quality, installation, equipment) will affect the choice of the pump size. Hence, regulating energy efficiency in swimming pool pumps without considering this issue could have negative effects on pool water quality.

In the UK there is the Publically Available Standard (PAS) 39 '*Management of public swimming pools. Water treatment systems, water treatment plant and heating and ventilation systems. Code of practice*'

In France there is Circulaire DGS/EA4 2008-65 '*La Direction Générale de la Santé à publié en février une circulaire relative aux dispositions réglementaires applicables aux piscines ouvertes au public, à l'utilisation des produits et procédés de traitement de l'eau (PHMB) et notamment à ceux mettant en oeuvre des lampes à rayonnement ultraviolet (UV) pour la déchloramination des eaux.*'

In Germany there is the DIN 19.643—'*treatment and disinfection of swimming pool and bathing tub water*' standard.

1.4.5 International Standards

Table 1-6 presents the international standards relevant for ENER Lot 29 pumps.

Table 1-6: International standards relevant for pumps within study scope

Reference	Title
ISO 1940-1	Mechanical vibration. Balance quality requirements for rotors in a constant (rigid) state. Specification and verification of balance tolerances
EN ISO 9906	Rotodynamic pumps. Hydraulic performance acceptance tests. Grades 1 and 2.

Clean water pumps test typically to ISO 9906:1999 Grade 2, which allows for a - 5% tolerance on quoted efficiency. This is also the standard used for testing WWT pumps, although it is obviously not an appropriate indicator of how a pump will wear when subject to real life operating conditions.

Voluntary standards do exist for swimming pools in the US. For instance, the ANSI/APSP-11 2009, which is an standard for water quality in public pools and spas that was adopted in 2009 by the American National Standards Institute (ANSI).

1.4.6 Conclusions on test standards

▶ A. LARGE WATER PUMPS

For large water pumps, the project team will adopt the same ISO 9906 test standard as used in the TREN Lot 11 study. This defines how pump performance and hence efficiency is measured. In addition, the project team will use the MEPS calculation methodology as described in the TREN ENER Lot 11 Regulation (currently at working draft stage). However, it should be noted that these TREN Lot11 Ecodesign Regulations are based on full diameter impellers, and will not directly influence the optimum selection of impeller diameter.

▶ B. SWIMMING POOL PUMPS

From initial investigation, it appears that there is insufficient consistency in test standards vary between EU Member States, which is a major problem that needs to be resolved. There are no performance tests standards that apply specifically to swimming pool pumps, and so the project team suggests the use of ISO 9906. The energy performance methodology for End Suction Close Coupled pumps in the draft Ecodesign Pump Regulation could be applied, although the actual MEPS (Minimum Energy Performance Standard) levels will obviously be different because the TREN Lot 11 pumps do not include the motor or filter.

Some pumpsets use an alternative motor, such as one fed by an inverter, but the project team will look to the ENER Lot 30 study for performance data on these products.

Further, pool pump safety is a critical issue, and so there are many relevant standards, especially relating to the design of the suction inlet.

Suction Entrapment poses severe risks from:

- Hair entrapment if the flow rating of the cover is too small for the pump or pumps.
- Limb entrapment where a limb is sucked into an opening, for instance if the cover flow rating is insufficient for the pump, or the drain cover missing or broken.
- Body entrapment where the body is sucked against the drain cover.
- Disembowelment where a person sits on or against the suction. This may occur when a drain cover is missing, loose, cracked, or not properly secured.

- Mechanical entrapment when a finger, toe or item of jewellery is caught in the suction. This hazard is present when the drain cover is missing, broken, loose, cracked, or not properly serviced.

EN 13451-3: '*Swimming pool equipment — Part 3: Additional specific safety requirements and test methods for inlets and outlets and water/air based water leisure features*', provides guidance on these measures.

The US Virginia Graeme Baker pool and Spa Safety Act imposes specific requirements on owners and operators of swimming pools[3].

ASME/ANSI A112.19.17 describes safety equipment that might include Safety vacuum Release, suction limiting, automatic shut-off Systems for use on residential and commercial swimming pools, Spas, Hot Tubs and Paddling pools.

ANSI/ASME A112.19.8 specifies anti-entrapment covers. Pools and spas should have a minimum of two drains to reduce maximum suction. ANSI/IAF-7 gives detailed information on suction design.

The pool installations shall comply the applicable existing standard HD 60 364-7-702.

Table 1-7 presents some relevant standards on performance and safety for swimming pools and their components.

Table 1-7: Preliminary list of available standards applying to swimming pool pumps

Standard	Scope
A112.19.8-2007	Suction Fittings for use in Swimming Pools, Wading Pools, Spas, Hot Tubs, and Whirlpool Bathtub Appliances
ASTM F1346	Standard Performance Specification for Safety Covers and Labelling Requirements for All Covers for Swimming Pools, Spas and Hot Tubs
AS5102 – 2009	Performance of Household Electrical Appliance – Swimming Pool Pumps-Units. Part1: Energy consumption and performance Part2: Energy Labelling and minimum energy performance standard requirements
CSA C222 No 68-92	Motor-Operated Appliances (Household and Commercial)
CSA C222 No 108-01	Liquid Pumps
NSF/ANSI 50	Circulation System Components and Related Materials for Swimming Pools, Spas/Hot Tubs
UL 778	Motor-Operated Water Pumps
UL 1081	Swimming Pool Pumps, Filters, and Chlorinators
UL 1241	Junction Boxes for Swimming Pool Luminaires
UL Subject 379	Outline of Investigation for Transformers for Fountain, Swimming Pool, and Spa Luminaires

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[3] www.cpsc.gov

Standard	Scope
UL Subject 676A	Outline of Investigation for Potting Compounds for Swimming Pool, Fountain, and Spa Equipment
UL 2452	Outline of Investigation for Electric Swimming Pool and Spa Cover Operators
EN 13451-1 part 1:	Pool with public use / swimming pool equipment: general safety requirements and test methods
EN 13451-3 part 3:	Pool with public use / additional specific safety requirements and test methods for pool fittings for water treatment purposes
HD 60 364-7-702	Low-voltage electrical installations - Requirements for special installations or locations –Swimming pools and fountains

C. AQUARIUM PUMPS

For aquarium pumps, there is no specific standard. To this pump type, the following standards will also apply:

- EN 60335-2-41: Household and similar electrical appliances – Safety – Part 2-41: Particular requirements for pumps
- EN 60335-2-55: Household and similar electrical appliances - Safety - Part 2-55: Particular requirements for electrical appliances for use with aquariums and garden ponds
- UL 1018: Standard for Safety for Electric Aquarium Equipment.

D. FOUNTAIN & POND PUMPS

For the fountain pumps, there is no specific standard. To this pump type, the following standards will also apply:

- EN 60335-2-41: Household and similar electrical appliances – Safety – Part 2-41: Particular requirements for pumps
- EN 60335-2-55: Household and similar electrical appliances - Safety - Part 2-55: Particular requirements for electrical appliances for use with aquariums and garden ponds
- UL 788:Motor operated Water Pumps
- CSA C22.2 No. 108-1 Liquid Pumps Fountain pumps will have integral filters to protect the hydraulics, and so a protocol on how or if these are included in the test methodology will need to be established.

1.5 Existing Legislation

1.5.1 Legislation and Agreements at European Union Level

1.5.1.1 *Health and Safety*

ISO EN 809:1998: 'Pumps and pump units for liquids. Common safety requirements' establishes safety requirements for the construction, assembly, erection, operation and servicing of:

- Rotodynamic pumps
- Rotary positive displacement pumps
- Reciprocating displacement pumps
- Pump units

The Pressure Equipment Directive (PED) 1997/23/EC applies to the design, manufacture and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure PS greater than 0.5 bars. The pumps in the scope of this study are exempt from the PED as they are covered under the machinery directive (EN809).

1.5.1.2 *Overview of the WEEE (Waste Electrical and Electronic Equipment) Directive 2012/19/EU*

The WEEE Directive implements the principle of 'extended producer responsibility': Producers are expected to take responsibility for the environmental impact of their products, especially when they become waste. The WEEE Directive applies this in relation to electrical and electronic equipment (EEE).

The broad aims of the WEEE Directive are to address the environmental impacts of electrical and electronic equipment and to encourage its separate collection, and subsequent treatment, reuse, recovery, recycling and environmentally sound disposal.

The WEEE Directive seeks to improve the environmental performance of all operators involved in the lifecycle of EEE, especially those dealing with waste of EEE. Accordingly, it sets certain requirements relating to the separate collection of waste of EEE, standards for its treatment at permitted facilities, and requires its recycling and recovery to target levels. It makes producers responsible for financing the majority of these activities. Distributors have responsibilities in terms of the provision of facilities to enable the free take-back of waste of EEE by consumers and also the provision of certain information to consumers of EEE.

The product must meet the following three criteria to be affected by the WEEE Directive:

- Main power source is electricity (including batteries)
- Less than 1,000v AC or 1,500v DC
- Electricity is needed for primary function

It must be one of the categories of EEE / WEEE specified in Annex A1 of the WEEE Directive[4].

Even if a pump is sold without a motor, it will usually be powered by an electric motor. The power range of the pumps considered in this study is very broad, from small aquarium pumps to large water pumps. Aquarium and pond pumps are household appliances that meet the three criteria for WEEE directive, although they are not explicitly mentioned in the regulation. It is recommended that future revisions of the WEEE Directive Annex A1 include aquarium and pond pumps.

Swimming pool pumps, counter-current pumps and spa pumps could be considered household appliances, if they are meant to be used in domestic installations. However, these products usually require installation and therefore are not likely to be part of the Municipal Solid Waste (MSW) stream, but recovered and disposed by professional installers. However, there is a growing market for smaller domestic above ground pools, and these pumps for these installations will most likely be handled by householders. Therefore it is recommended that these are also included in future revisions of the WEEE Directive Annex A1.

The rest of larger pumps (borehole, vertical submersible and end suction pumps) are not household appliances and therefore it is clear that the WEEE Directive does not affect them.

1.5.1.1 *RoHS 2 (Restriction of Hazardous Substance Directive) Directive 2011/65/EU*

The RoHS Directive was firstly implement in 2006, restricting the use of certain Hazardous Substances in electrical and electronic equipment. It bans the putting on the EU market of new Electrical and Electronic Equipment (EEE) containing more than the permitted levels of certain materials[5].

The RoHS Directive covers the same products as the WEEE Directive. The control-systems and printed circuit-boards of aquarium and pond pumps covered by this Directive need to be accounted for in the ENER Lot 29 preparatory study. Other pumps tend to be controlled and driven by external units, which are considered under separate lots.

1.5.2 Third Country Legislation

There is no legislation that the consortium is aware of, that imposes significant additional technical constraints on the design or construction of pumps in ENER Lot 29 beyond the factors already mentioned.

The American Petroleum Institute (API) imposes standards for pumps used in the oil industry. These are driven by safety requirements, which often result in reduced efficiency through

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[4] 1.Large household appliances; 2.Small household appliances; 3.IT & telecommunications equipment; 4.Consumer equipment; 5.Lighting equipment; 6.Electrical and electronic tools; 7.Toys leisure and sports equipment; 8.Medical devices; 9.Monitoring and control instruments; 10.Automatic dispensers.

[5] Lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) or polybrominated diphenyl ethers (PBDEs).

demanding for instance larger clearances. It is understood that these standards do not impact on the design of water pumps for the European market.

1.6 Product performance assessment

1.6.1 Boundaries of the system

The boundaries for each pump category are decided on a product-by-product basis. A fundamental consideration is whether the product includes or excludes the motor.

To be consistent with the Ecodesign Directive (2009/125/EC), the approach adopted is as follows:

- Where the motor can be removed and tested separately, the motor and pump shall be considered as separate products.
- Where the motor cannot be easily removed from the assembly, it shall be considered as an integral product, and the combined pump+motor combination shall be regulated as a product.
- Exceptions may be made for products that have a motor that can be separated, but where the motor is not subject to existing regulations (ref 2009/125/EC) or possible future regulations as part of Ecodesign ENER Lot 30.

Pump performance data and subsequent analysis considers the pump shaft power only, (known sometimes as P2). It is only converted into electrical power (P1) in order to estimate the environmental impact of the pumps. This is done by assuming that the motor is on the IE3 efficiency class border, where $P1 = P2 / \eta_{mot}$, where η_{mot} is the assumed motor efficiency (at full load).

However, some pumps considered in this study, namely the aquarium, pond and swimming pool pumps, have integrated motors. Therefore, it may be more appropriate to regulate these pumps with the pump, motor and controls together. This approach has been successfully implemented in the past with heating system circulator pumps which resulted in the voluntary circulator scheme (EC) No 641/2009.

1.6.2 The Extended Product Approach

Definition of the Extended Product Approach

It is important to distinguish between the Extended Product Approach (EPA) and the Extended Product (EP).

Extended Product Approach (EPA): is a methodology to calculate the energy efficiency Index (EEI) of an Extended Product (EP), which incorporates load profiles and control method. The Energy Efficiency Index (EEI) is a dimensionless figure used to define the energy efficient performance of pumps. Unlike the Minimum Efficiency Index (MEI)[6] it also takes into consideration efficiency related factors from load profiles and control methods.

Extended Products (EP): consists of physical components

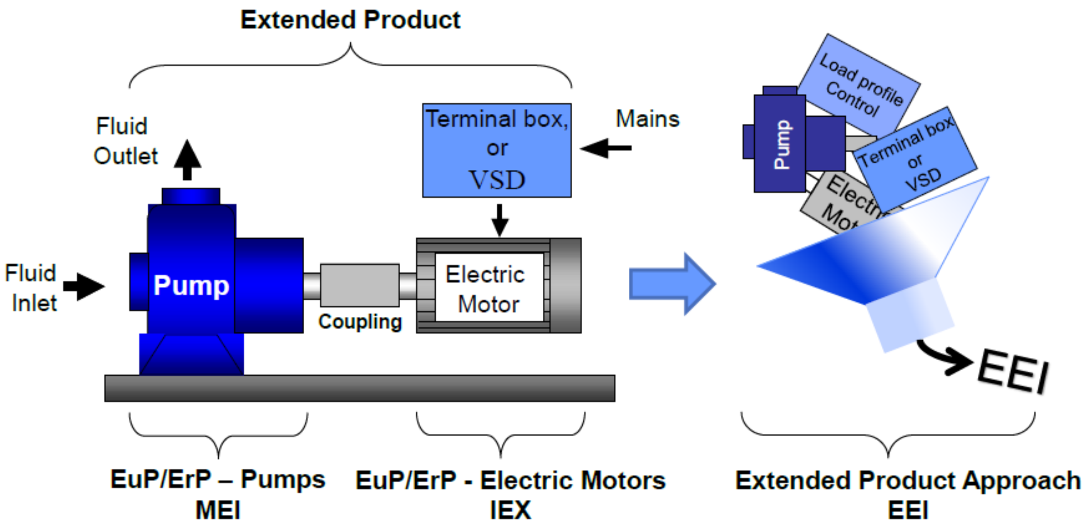

Figure 1-18 Definition of Extended Product Approach – (Source Europump)

The EPA thus extends the boundary of the product to include not just the pump itself, but also the motor and any controls within the defined system. By doing this, the much larger energy savings that are possible from the optimum selection and control of components under real life operating conditions can be achieved.

While the focus of the EPA is on the system, actually, it will only regulate the pump, motor, and controls– it will not consider any pipework (hydraulic) or indeed cabling (electrical) losses that are within the system. This approach is in line with that used in the ENER Lot 11 Circulator regulation[7].

Extended Product Approach System Types

The EPA can be used with both closed loop systems, such as swimming pool pump systems, and open loop systems, such as many clean water transfer systems. It can also be used in for constant flow systems and variable flow system. The result of this is that the EPA can be applied to all the pump types considered in this study.

In order to apply the EPA to a particular pump application a load profile first needs to be derived. A load profile describes the proportion of time a pump typically spends pumping a particular flow rate. In variable flow systems this change in flow rate can achieve through the use of variable speed drives, or through throttling valves in the system. An example of a load profile in variable flow systems is shown in the figure below.

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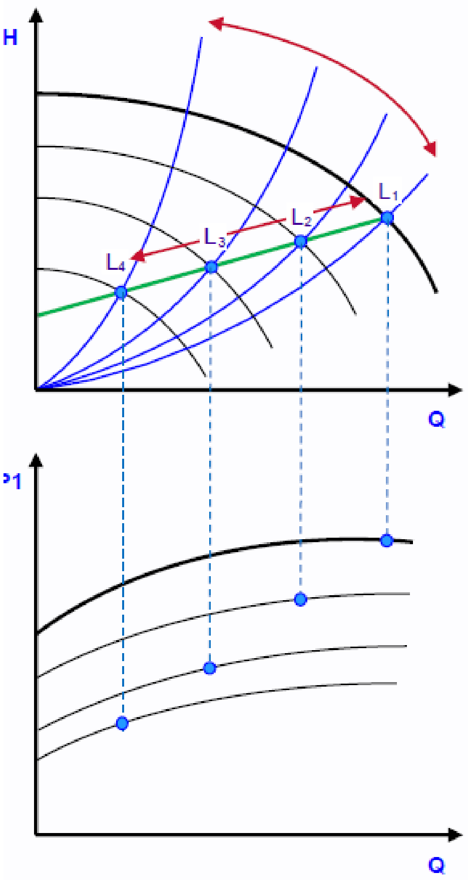
[6] The Minimum Efficiency Index (MEI) is a dimensionless figure that is derived from a complex calculation based on a pump's efficiencies at the best efficiency point (BEP), 75% BEP and 110% BEP and the specific speed. The range is used so that manufacturers do not take an easy option of providing good efficiency at one point.

[7] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0035:0041:EN:PDF

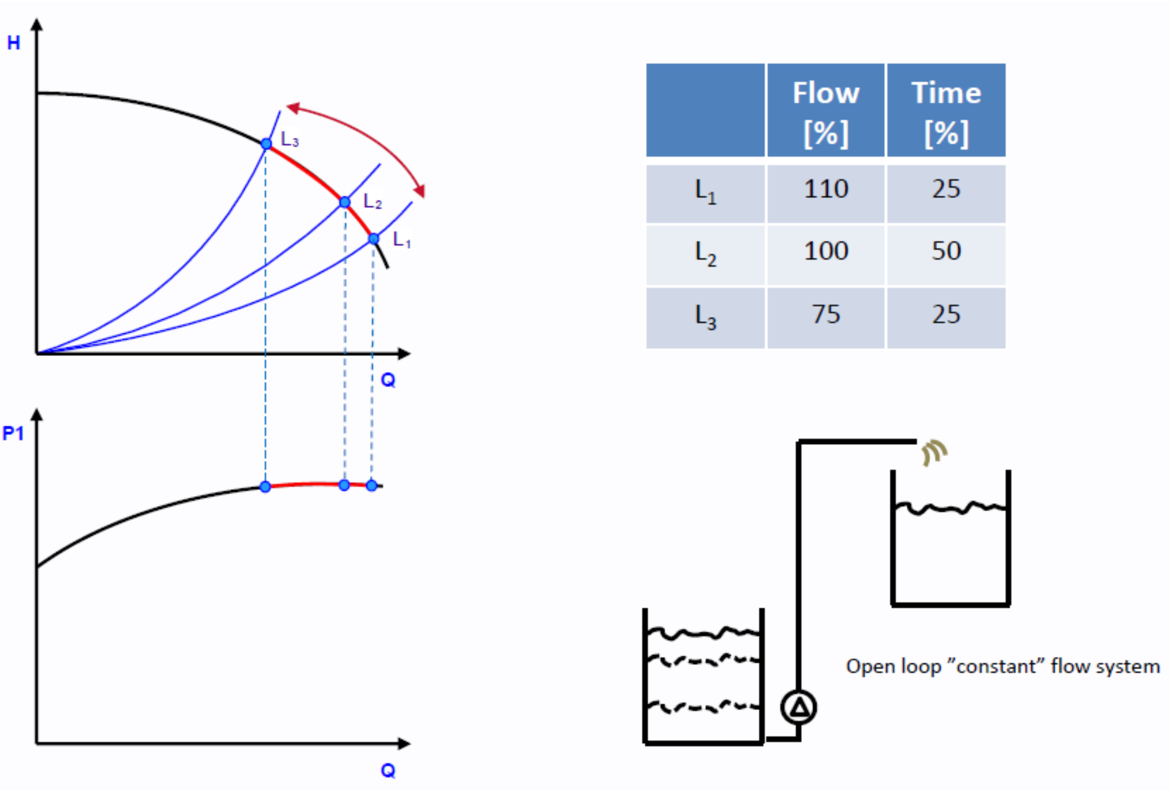


	Flow [%]	Time [%]
L_1	100	6
L_2	75	15
L_3	50	35
L_4	25	44

Figure 1-19 Load profile for a typical variable flow system such as found in HVAC systems (Source Europump)

Some of the larger clean water pumps could be used in a variable slow system. There are some domestic swimming pool pumps that are also used with variable flow systems but these are the exception rather than the norm.

In constant flow system the change of flow can be due to a change in the static head, such as occurs when filters become blocked. An example of load profile for a constant flow system is shown in Figure 1-20



	Flow [%]	Time [%]
L_1	110	25
L_2	100	50
L_3	75	25

Figure 1-20: Load profile for a typical constant flow system

Some of the pumps considered within the scope of this study, such as swimming pool pumps, aquarium and pond pumps, are typically used in constant flow applications. As such they potentially could have load profiles similar to that shown in Figure 1-20. Each individual pump type requires its own load profile.

1.7 Conclusions

Task 1 presents an overview of the pumps that are included within this study. These pumps vary in scale from very large clean water pumps to small pumps used in swimming pools and gardens. Although aquarium blowers may fit into the very broadest interpretation of the scope of this study, they were excluded after an initial screening process due to the fact that they pump air rather than water. The final list of pumps included in the study are:

- Domestic swimming pool pumps with built in strainer up to 2.2 kW
- Domestic/commercial swimming pool pumps with built in strainer over 2.2 kW
- Fountain and pond pumps to 1 kW
- Aquarium pumps (domestic/small aquarium - non-commercial) to 120 W
- Aquarium power head to 120W
- Spa pumps for domestic & commercial spa's

- Counter-Current Pumps
- ES Close Coupled from 150 kW to 1 MW
- ES Close Coupled Inline from 150 kW to 1 MW
- ES Own Bearing from 150 kW to 1 MW
- 8" Submersible bore-hole pumps
- 10" Submersible bore-hole pumps
- 12" Submersible bore-hole pumps
- Submersible bore-hole pumps larger than 12"
- Vertical multi-stage pump (25 to 40 bar and/or 100 to 180 m3/hr)
- Vertical multi-stage pump (>40 bar and/or >180 m3/hr)

The primary functional parameters of the pumps are defined as 'Rated flow', 'Head' and 'Fluid properties'. The fluid properties will be less relevant to the large clean water and swimming pool pumps, however further investigations are required as to what the appropriate fluid properties would be for fountain and pond pumps which are likely to involve an element of solids handling.

In common with other clean water pumps, it is recommended that the larger pumps are tested to ISO 9906:1999 Grade 2.

Although there are a currently a number of standards at EU level relating to the safety requirements of pumps, no energy related standards were found. Regarding legislation, only the electronic parts such as printed circuit boards are affected by the RoHS Directive, and small household pumps such as aquarium and pond pumps are affected by the WEEE Directive.

The boundaries of the systems are defined depending on how the pump and motor are manufactured. Where the motor can be removed and tested separately, the pump and motor are considered as separate products. Where they cannot be easily separated they shall be considered as an integral product and should be regulated as such. Exceptions may be made for products that have a motor that can be separated and where the motor is not subject to existing regulations.

There may be the opportunity to regulate all the pumps in the study using the extended product approach.

Annex 1: Extract from the chapter 5 of the 'SAVE Study on Improving the Efficiency of Pumps'

This section is included for reference, and is an extract from the Study on Improving the Energy Efficiency of Pumps[8]

▶ INTRODUCTION

Due to the fact that the majority of the pump manufacturers within the EU have reached a level of knowhow which enables them to carry out hydraulically correct designed centrifugal pumps, the value of the practically attainable overall pump efficiency η of these machines is mainly influenced by factors such as surface roughness of parts which are in contact with the flow as well as the internal leakage flows through the sealing gaps. Especially the surface roughness of hydraulic parts strongly depends on the manufacturing techniques used. Further on the surface quality is a property which can get worse during life time of a pump and thereby causes energy losses during pump operation.

To quantify the effects of these above mentioned factors the following investigations on single-stage centrifugal pumps were carried out at the chair for Turbomachinery and Fluid Power at Darmstadt University of Technology:

- The influence of different values of surface roughness
- The influence of smoothing several parts of pumps
- The influence of different gap clearances on the internal leakage flow rate

The specific speeds of the considered pumps covered the range from ns = 10 min-1 up to ns = 100 min-1 (corresponding to values from 520 min-1 up to 5200 min-1 in US-units) and represents the typical field of application of standard centrifugal pumps. By the aid of the similarity laws it is possible to transfer the results obtained for one pump size to another (respectively from one speed of rotation to another).

To carry out the investigations a special software tool was used, which was developed within the scope of a former research project named 'Attainable Efficiencies of Volute Casing Pumps' sponsored by the Research Fund of the German Pump Manufacturer Association.

The main capability of this program is to estimate the maximum theoretically attainable efficiency ηmax,th of volute casing pumps. We explicitly want to point out that this software tool is no CFD code. To determine the friction losses for the parts shown in Figure A1 respectively the leakage flow rates through the sealing gaps the program uses differential equations as well as simplified mathematically loss approaches. All calculations are carried out on the base of a

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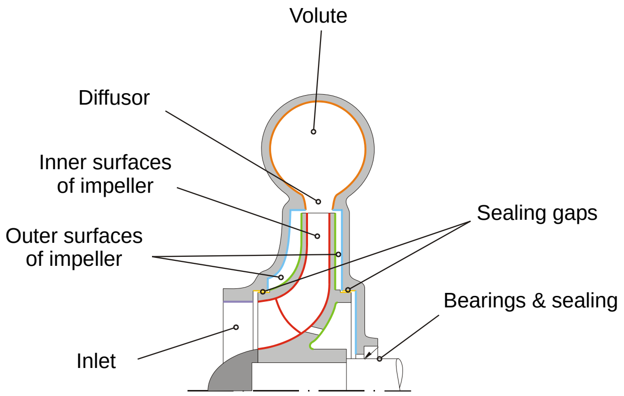
[8] ETSU, AEAT PLC (2001) Study on Improving the Energy Efficiency of Pumps. Prepared for the European Commission

hydraulic design process considering common industrial design standards in respect to the geometrical settings.



Considered Losses

- hydraulic losses:

friction losses
deceleration losses
wake losses
mixing losses (Volute)

- volumetric losses (gap flow)

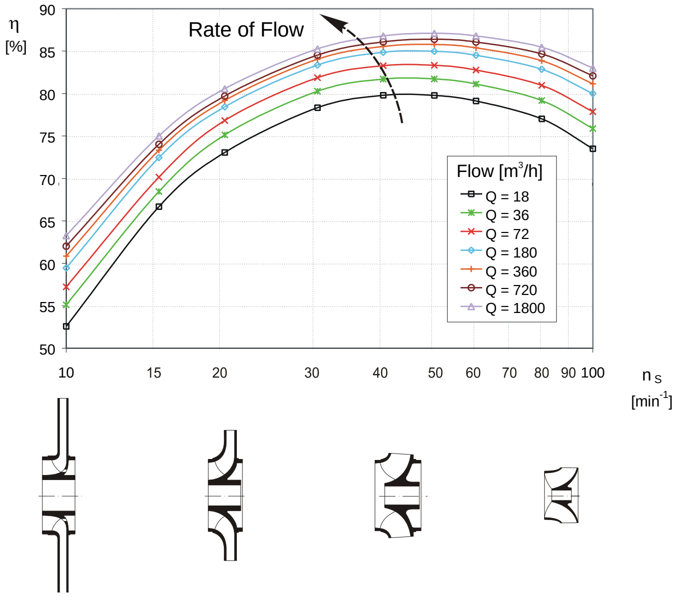
- mechanical losses

Figure 1-21: Loss-causing components of a centrifugal pump.

In order to evaluate the efficiency values estimated by the computer program additional experimental investigations were carried out at a centrifugal pump with a specific speed of ns = 12 min-1. This special test pump, designed according to usual industrial standards was equipped with very narrow sealing gaps (radial gap clearance equal to 0.1 mm) as well as hydraulic smooth surfaces. For this optimized pump the value of the inner efficiency ηi was measured at a special high precision test rig and compared to the theoretical value obtained by the computer program. The comparison of both values (for pump operation at the point of best efficiency) results in a very good agreement.

▶ RESULTS OF THE THEORETICAL INVESTIGATIONS

For the purpose within this SAVE study the above mentioned software tool was partly modified respectively extended in its capabilities. All the following figures which demonstrate the influence of the parameters surface roughness as well as gap clearance show efficiency values η respectively differences of efficiency values Δη in per cent points that were plotted versus the value of specific speed ns as defined in Figure 1-20 (where n is the speed of rotation, Q the rate of flow and H the pump head).



Specific speed:

$$n_s = n \cdot \frac{Q^{1/2}}{H^{3/4}}$$

$$n_s\,[\mathrm{min}^{-1}],\quad n\,[\mathrm{min}^{-1}],\quad Q\,[\frac{\mathrm{m}^3}{s}],\quad H\,[\mathrm{m}]$$

$$n_{s,US-units} = 51.64 \cdot n_s$$

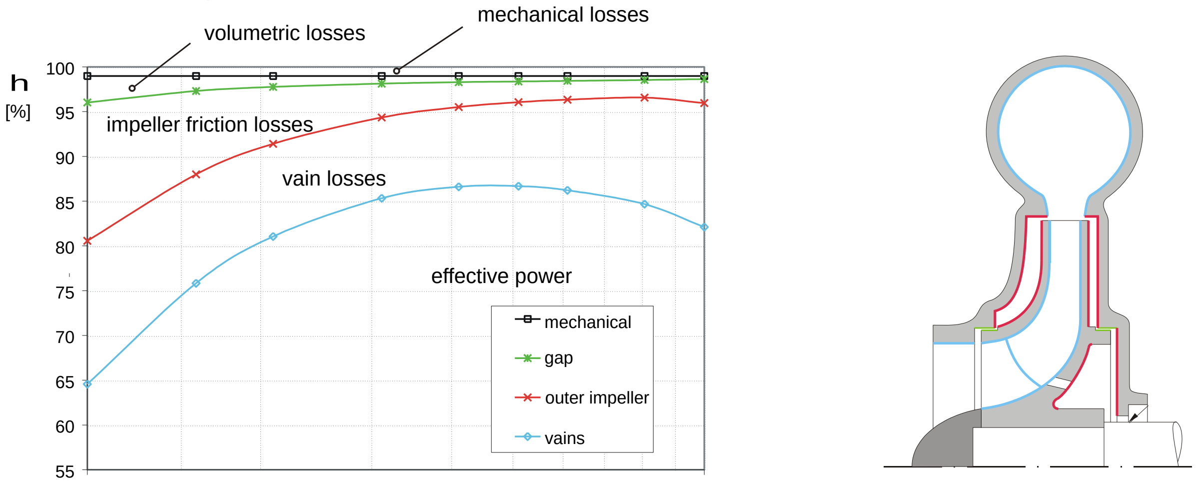
In the following:

$$n = 1450\,\mathrm{min}^{-1}$$
$$Q = 180\,m^3/h$$

Figure 1-22: The influence of rate of flow

As shown in Figure 1-20 every specific speed value corresponds to a typical impeller geometry, which means that low specific speeds characterize more radial extended impellers while higher specific speeds correspond to mixed flow respectively more axial types of impellers. Figure A2 exemplarily shows the dependence of the overall efficiency η on the rate of flow respectively pump size at constant speed of rotation (n = 1450 min-1). It can be stated that an increase of the rate of flow leads to higher values of the overall pump efficiency, which is the effect of an increasing Reynolds number Re. The above figure also shows that the efficiency values for very low specific speeds are definitely smaller than for higher ones, which is due to the geometric as well as hydraulic attributes of such types of pumps.

In respect to a better comparability all results of the investigations shown in the following diagrams (Figure 1-20) were generated for operating conditions characterized by a flow rate of 180 m3/h and a speed of rotation n = 1450 min-1.



$$n = 1450\,\mathrm{min}^{-1}$$
$$Q = 180\,m^3/h$$

Figure 1-23: Partial losses within a centrifugal pump

Depending on the value of specific speed which directly corresponds to the shape of the impeller different influences on the losses caused by several pump components can be mentioned. For pumps with lower specific speeds volumetric losses as well as losses due to disk friction at the back and front shroud of the impeller are very significant. This also applies to the losses within in the volute casing. For higher specific speeds the influence of blade friction losses within the impeller dominates and mainly determines the level of the overall efficiency η. According to former investigations based on statistically evaluated data it is known, that the largest potential regarding an improvement of efficiency does exist at low specific speeds.

INFLUENCE OF DIFFERENT VALUES OF SURFACE ROUGHNESS

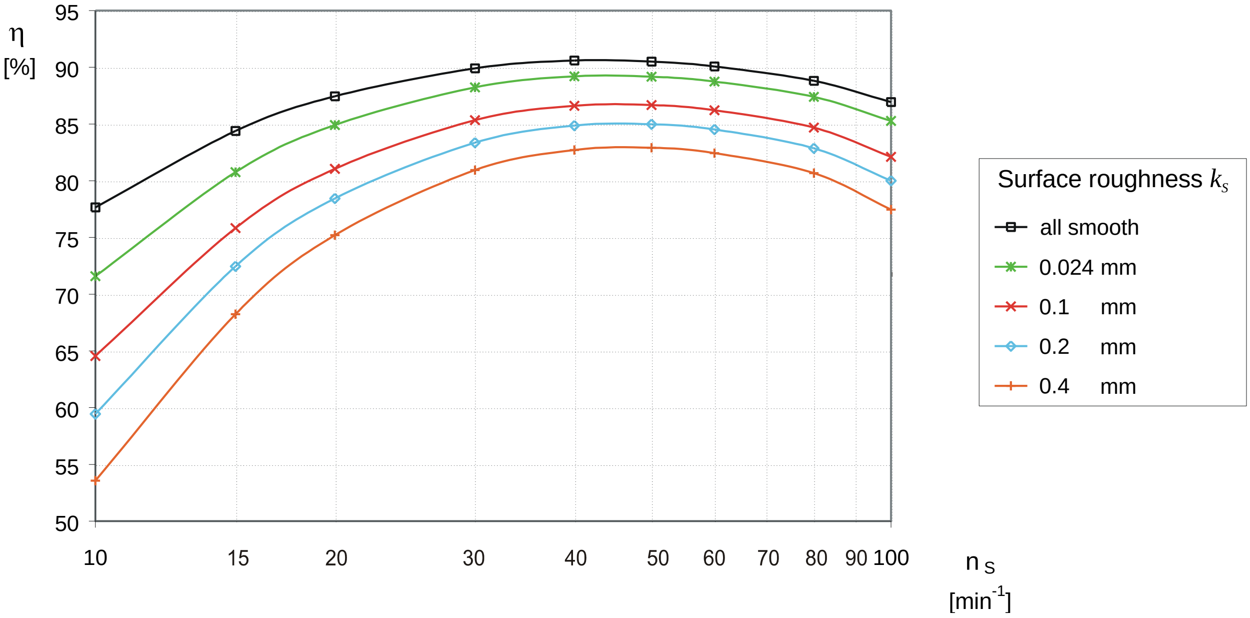


Figure 1-24: The influence of surface roughness

Figure 1-20 demonstrates the general influence of different values of surface roughness whereas all inner surfaces of the pump show identical conditions.

It is remarkable that the gain of efficiency due to smoothing the inner surfaces of a centrifugal pump is estimated more than 5 per cent points compared to pumps showing top quality sand-cast-rough surfaces (surface roughness ks ≈ 0.024 mm). Compared to pumps showing a very low surface quality (e.g. due to low quality of manufacturing, corrosion or incrustation which can result in a value for the surface roughness up to ks = 0.4 mm) a theoretical efficiency improvement of even more than 20 per cent points could be estimated for pumps of very low specific speed (ns = 10 min-1).

THE INFLUENCE OF SMOOTHING SEVERAL PARTS OF PUMPS

Since smoothing a whole pump is a very cost intensive manufacturing process (especially for small and medium sized pumps produced by a normal sand cast method) the influence of smoothing only several parts of the pump (i.e. volute, casing, outer surface of impeller, inner surface of impeller) was investigated theoretically by the aid of the described software.

The result of this parameter study shows, that also in case of partial smoothing the maximum efficiency improvement is to be expected for pumps with low specific speeds and can reach values of roughly 6.5 per cent points (e.g. in case of smoothing the outer surfaces of a radial impeller showing a origin surface roughness ks = 0.2 mm). With respect to an overall surface treatment of the impeller the investigations showed also, that a smoothing of the inner surfaces is primarily favourable for pumps with higher specific speeds (ns > 30 min-1), where the hydraulic losses were mainly quantified by the flow velocity within the impeller.

▶ The Influence of Only Partly Smoothing the Outer Surface of the Impeller

Due to the fact that especially for radial pump impellers (ns < 30 min-1) smoothing the outer surfaces of the impeller front and back shroud (by turning) is a very efficient and less costly procedure to reduce the losses, i.e. improvement of pump efficiency, the effect of smoothing the impeller front and back shroud only partly was also investigated by an appropriate theoretical parameter study.

As a result of this study it could be estimated, that smoothing only 40 % of the outer surface of the back and front shroud (starting the turning process at the impeller outlet diameter D2) an efficiency improvement of roughly 5.5 per cent points still can be estimated. This value decreases to 3.5 per cent points in the case of smoothing only 20 % of the outer surface of the back and front shroud. Du to this fact there is no need to smooth the impeller at smaller diameters where turning gets more difficult because of the more complicated impeller contour.

As a validation of the above mentioned effect for the test pump (ns = 12 min-1) available at the chair of Turbomachinery and Fluid Power at Darmstadt University of Technology an improvement of efficiency of about 2 per cent points could be measured by smoothing 50 per cent of the outer surface of the impeller back and front shroud (whereas the original surface roughness ks before smoothing showed a very low (good) value of roughly 0.03 mm).

Figure 1-20 summarises the theoretical estimation results obtained by the several parameter studies. The labelled efficiency values roughly quantify the maximum gain of efficiency (in per cent points) that can be expected by smoothing the wetted surfaces of a centrifugal pump showing a surfaces roughness equal to a ks value of 0.2 mm. Depending on the specific speed of a pump the efficiency values can be significantly less.

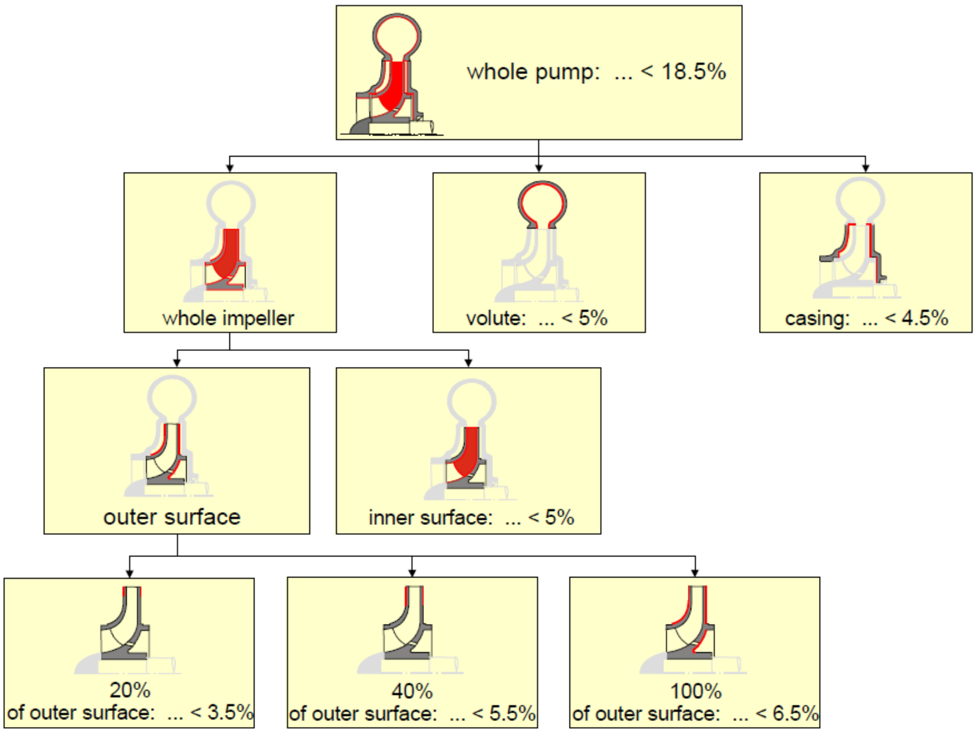


Figure 1-25: Maximum improvement of efficiency for several smoothing steps (estimated by theoretical calculations for medium size pump of 180 m3/h)

Annex 2: Extract from the ENER Lot 11 Preparatory study - The 'House of Efficiency' scheme

This section is included for reference, and is an extract from the ENER Lot11 Preparatory study report, section 8.1.12.3).

The decision scheme 'House of Efficiency' takes into account design and application purposes as well as the pump minimum efficiency dependence on flow. The minimum acceptable efficiency is therefore different for each pump type. The pass-or-fail scheme is based on two criteria A and B.

- Criterion A is the pass-or-fail minimum efficiency requirement at the best efficiency point (b.e.p.) of the pump:
- Criterion B is the pass-or-fail minimum efficiency requirement at part load (PL) and at overload (OL) of the pump:

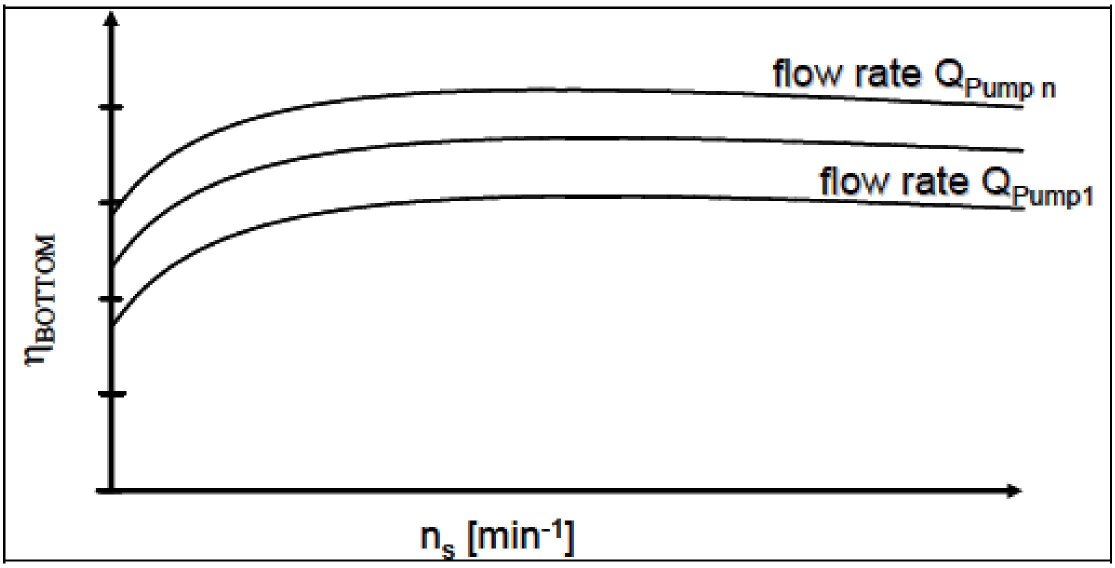


Figure 1-26: Bottom lines for different geometrical pump sizes (defined for nominal flow rate Qn > Q1) within one pump type

That leads to bottom lines specific to each pump type at a certain flow (see Figure 1-20) which have to be defined, based on statistical data.

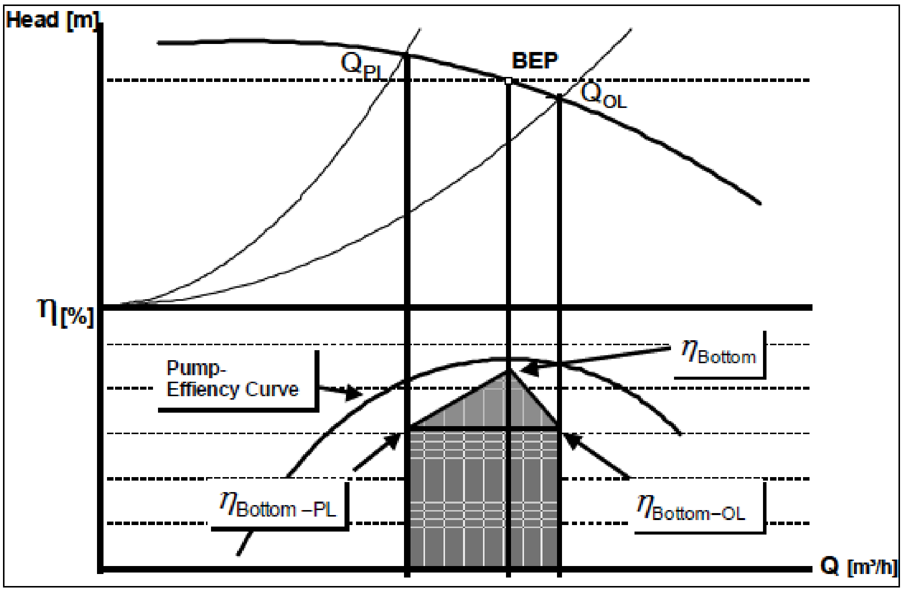


Figure 1-27: 'House of Efficiency' - explanatory representation of the scheme in a η (Q): flow-Plot

In Figure 1-20 the representation of the two criteria is shown in an η(Q):flow-plot. The pump efficiency curve with its maximum at the best efficiency point does not cross the 'roof of the efficiency house'. The part and over load minimum acceptable efficiencies at 0.75·QBEP and 1.10·QBEP build the roof-triangle with the minimum acceptable efficiency at best efficiency point. As a result, the pump efficiency curve has to be broad and high to fulfil the criteria. The shown example is for a pump passing the agreed efficiency criteria (not yet set) and would therefore pass the energy efficiency check. Subsequently it would be eligible for CE-marking in accordance with the applicable Directive. Pumps with robust trade-off criteria like NPSH, noise, application for dirty water or other aspects should separately be considered with their own minimum acceptable efficiency and specific factor 'x' to be defined.

The application of this scheme requires the definition of pump specific bottom lines for different flows as well as the factor 'x' for part load and overload based on the statistical data provided by the manufacturers.

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