Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 28 – Pumps for Private and Public Wastewater and for Fluids with High Solids Content – Task 4: Technical analysis - Working Document

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Task 4: Technical Analysis

This chapter presents the technical analysis of pumps covered in the scope of the ENER Lot 28 study. The technical analysis of product categories described in this chapter uses the product definitions presented earlier in the Task 1 report of this study as its basis. Analysis of the environmental impacts of a product requires the examination of its complete life cycle, starting with the amount of raw materials used during the manufacturing phase and ending with the disposal efforts required at its end-of-life stage. The aim of this task is to examine the technical characteristics of the different product categories covered in this study, which is necessary to form a basis for identifying and defining the base cases that will be further developed in Task 5 of this study.

The first subtask of this report provides insights into the technical basis for the fluid flow and common pump technologies. This is followed by four subtasks concerning the different life-cycle stages of the pumps for private and public wastewater and for fluids with high solids content:

- production phase;
- distribution phase;
- use phase of the product;
- end-of-life phase

The next subtask concerns recommendations for possible mandates to be issued by the European Commission and standardisation organisations for ENER Lot 28 products followed by a final subtask summarising the main conclusions of this task.

4.1 Technical basics

Pumps are available in a wide variety of designs and configurations, which can be split into two distinct categories, positive displacement pumps and rotodynamic pumps. As per the definition stated in Task 1, 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. 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.

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. If the pump is a mixed flow or centrifugal type, the water then has to change direction from axial to (near) radial as it enters the passage between the impeller vanes. In axial flow pumps there is no change in direction of the water flow. 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. In mixed flow and centrifugal type pumps, at best efficiency flow, the water will spiral out of the impeller in a free vortex of constant angle to the tangential direction. In axial flow pumps the water is pushed in the pump without any change in the radial location of the fluid particles. 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 an increased pressure.

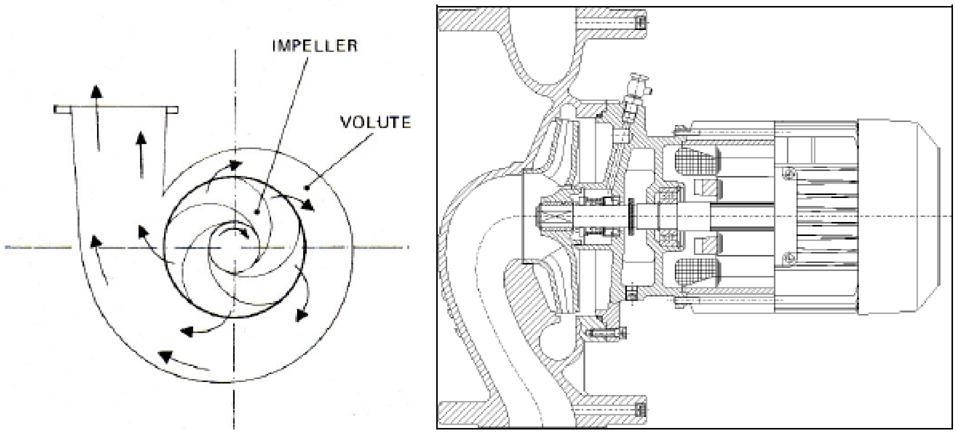

Figure 1 – How rotodynamic pumps work: flow paths (left) and cutaway of motor coupled pump (right) (Source EUP Lot 11 Pumps)

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. They are generally suited to higher pressure pumping applications than are used for rotodynamic pumping applications and for very viscous liquids.

Task 1 Sections 1.0.2 to 1.0.3 contains further details on pump systems and the basic pump laws.

4.1.1 Fluid flow concepts

The flow rate of fluid into a pump is always the same as the flow of fluid out of a pump when measured in terms of mass or weight. The volume of the flow is also the same as long as there are no changes in density. Pressure, velocity and height are the three main forms of energy found within a pump system. The energy in the pump system can change from one form to another.

As liquid flows through a pipe it gives rise to friction. This in turn is a source of energy loss in the liquid as the pump overcomes the friction in the form of pressure losses. The amount of pressure loss depends on the following factors:

- Flow rate
- Pipe length
- Pipe diameter
- Pipe surface roughness
- Piping design
- Viscosity of liquid
- Density of liquid

The flow within a pipe can be either turbulent or laminar depending on the viscosity of the liquid and the design velocity used for the system. The losses associated with laminar flow are dramatically different to those associated with turbulent flow. In laminar flow the layers of liquid slide smoothly over the each other as it travels down the pipe. Laminar flows tend to occur in liquids with a high viscosity when pumped at a low velocity. In turbulent flows the individual particles in the liquid take erratic flow patterns along the pipe, with eddies and local vortices. Most of the flow from rotodynamic pumps is turbulent. The flow within a wastewater pump is predominantly turbulent.

Pump pipework systems are made up of components such as valves, tees, bends and filters in addition to the simple pipes. These components all contribute to the friction in the system and therefore the losses. Wastewater pumping systems do not have filters.

4.1.2 Common products and technologies

The products involved in this study are described in detail in Task 1, section 1.1.7.

There are number of factors that contribute to the overall efficiency of a pump. A detailed discussion of these factors is provided in the 'SAVE Study on Improving the Efficiency of Pumps' was for the European Commission and issued in February 2001. Chapter 5 of this study is provided in its entirety in Annex of this document. It is important to note that the SAVE study was undertaken with clean water pumps and therefore considerable care should be taken when applying its findings to wastewater pumps. The study was produced by Darmstadt University, who emphasise that the main intention of this work was to identify, respectively quantify the various design factors affecting the efficiency of centrifugal pumps in a fundamental and exemplary manner. The focus of the evaluation was on single stage standard industrial pumps of an overall size, which is typical for this type of pumps.

Regarding an appreciable improvement of the efficiency of centrifugal pumps one has always to consider that the possible gain of efficiency, which can be achieved, e.g. by the reduction of the gap width or additional surface treatments, strongly depends on the initial state of these parts as well as the absolute size of the pump. Other aspects, which also limit the potential of a possible efficiency increase, are requirements arising from operating reliability.

Besides the issue of operating reliability there are many other technical requirements such as production, assembly or system aspects, which determine, respectively dominate the design process of centrifugal pumps. It is therefore not always reasonable or even possible to apply all the design features and recommendations discussed in the SAVE Study.

- **Impellers**

Impellers have a key role in contributing towards the efficiency and performance of waste water pumps. The impellers used in wastewater pumps are different than those used in clean water pumps as they have to allow the free passage of solids through them and also have to be resistant to becoming clogged. There are a number of impeller types available to pump purchasers when looking to pump wastewater.

There are a number of factors to consider when looking to specify an impeller for pumping wastewater. Firstly, the impeller must be suitable for the type of wastewater being pumped. For example, if the wastewater contains large solid particles then it is important to use an impeller that is either going to allow the solid to pass through the pump freely, or one that will cut the solid in smaller more pumpable pieces. A second consideration might be the resistance the impeller has to wearing, as this both decreases the efficiency of an impeller and increases the maintenance cost of the pump. Impellers that have high solids handling ability and an increased resistance to wearing, such as vortex impellers, are often less efficient than other types of impellers, but may have a significantly increased reliability and lifespan. This may result in lower whole life costs and reduced maintenance requirements.

The selection of lower efficient, higher reliability, vortex impellers, rather than higher efficiency single/multi vane impellers, will often be preferable in terms of whole life costs when pumping wastewater with high grit content. This is because grit is very abrasive on impellers and causes rapid wearing. Vortex impellers may also be specified when pumps are located in remote areas and a high level of reliability is required. This is because it can be very costly to repair or unclog pumps that are installed in remote locations.

The three main types of impellers found in wastewater pumps are described as follows:

- Channel impellers
- Vortex impellers
- Grinder impellers

These impeller types are described in further detail below.

  - **Channel impellers**

Channel impellers are available as single vane and multi-vane variants.

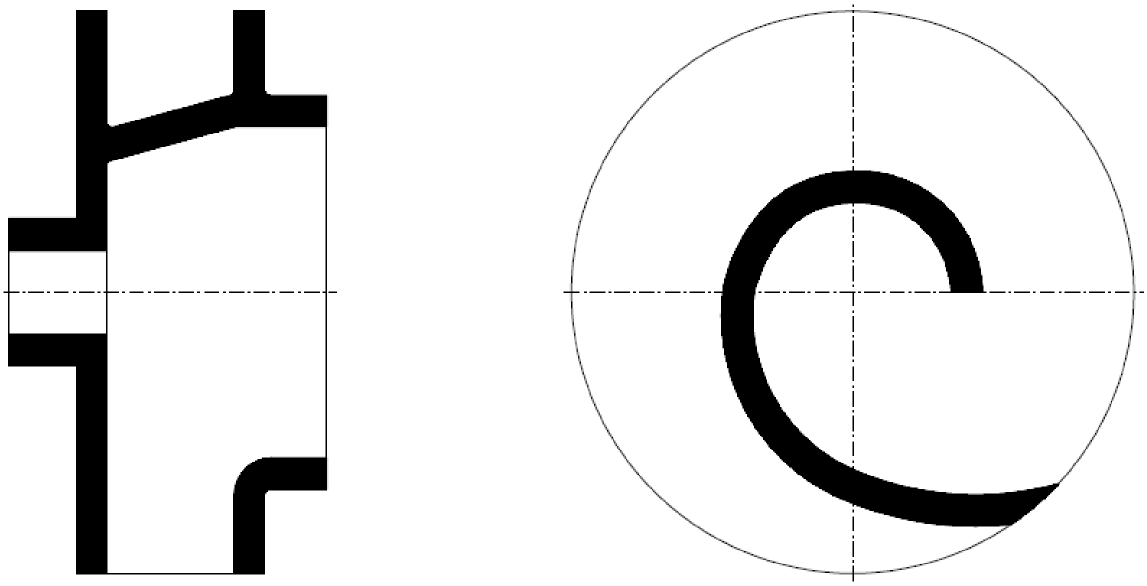

Figure 2: Example of the plan and section through a single-vane impeller – (source: Europump)

Single-vane impellers have a large free passage that allows solids to pass through them. They are less efficient than traditional multiple-vane impellers used in clean water pumping. Single vane pumps typically have an efficiency range between about 40 to 80%. As this efficiency is very much depending on the specific speed it is only possible, to speak roughly about 71% as average. It is important to note that not all hydraulics will reach this value (especially high head hydraulics).

The free passage through the impeller allows balls of solid materials to pass through easily, however there is the potential for longer, fibrous materials to become entangled around it. There is also the potential for solids to collect on the leading edge of the impeller.

Intermittently operated pumps have a natural self-cleaning facility when they stop and fluid is allowed to back flow through the pump, which in turn cleans debris from the leading edge of the impeller. There are also physical modifications, which can be made to the impeller and pump that can decrease the risk of clogging, such as backswept leading edges and adding relief grooves to the pump insert ring, which push solids out of the pump.

An issue with single-vane impellers is they are difficult to dynamically balance and therefore a prone to increased levels of vibration and bearing wear compared to conventional impellers.

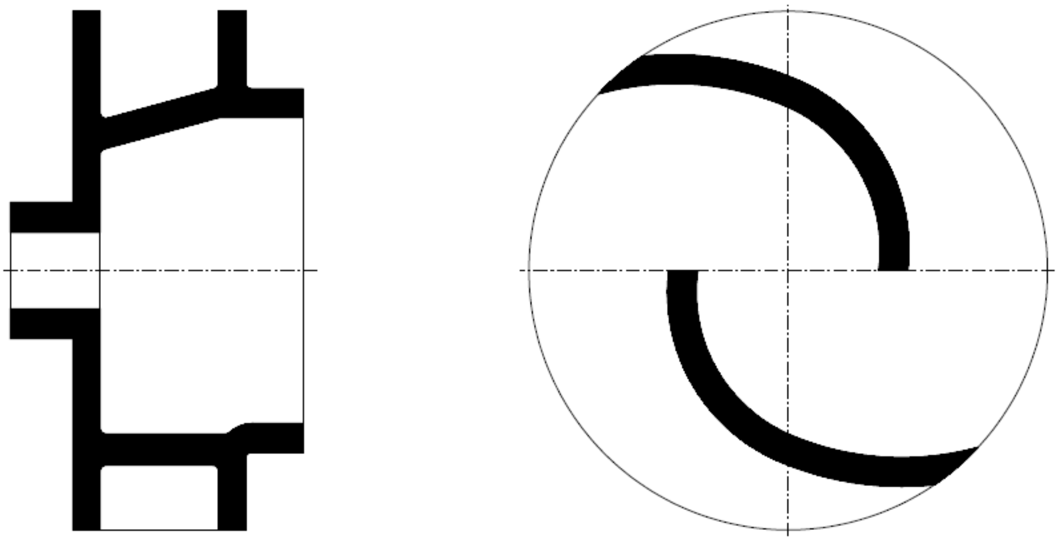

Figure 3: Example of a plan and cross section through a 2-channel impeller (Source Europump)

Multi-vane impellers typically have two or three vanes, and are easier to balance than single-vane impellers. However, they need to be physically larger than to have the same size free passage. They also have two leading edges meaning they have a larger area where debris can collect and have a higher likelihood of clogging.

- **Vortex impellers**

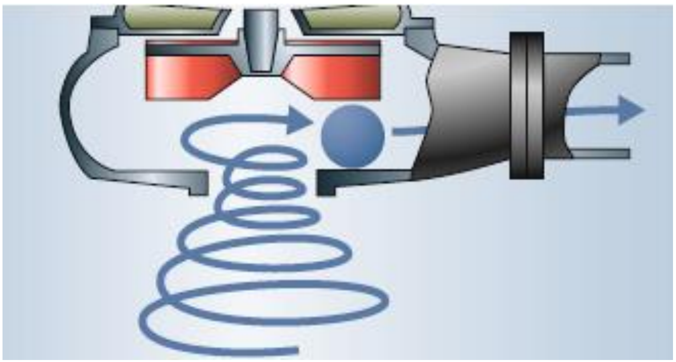

Figure 4 – Example of the operation of a vortex pump[1]

Vortex impellers effectively create a whirling vortex within the pump that can be used to allow some solids to pass through the pump without coming into contact with the impeller.. These are particularly useful when pumping very abrasive solids like grit. These vortex impellers result in a relatively low efficiency compared to most other types, but they do have very good resistance to complete clogging (hard/complete clogging at least end up in tripping the motor protection). Vortex pumps have a hydraulic efficiency range from 26% to 63%.

- **Grinder impellers**

[1] Image courtesy of Xylem Flygt

Grinder impellers are typically fitted on smaller pumps with small-bore pipework, and are used to grind up solid matter in to small, pumpable pieces. The grinder impeller is located on the inlet of the pump and an impeller is used within the pump body.

- Impeller efficiency

The efficiency of these types when used in the applications of the study is shown in Table 1. Note the average efficiency is the mathematical average. Also the hydraulic groups cover a variety in demands, e.g. low and high head applications. Not all hydraulics will be able, to reach the average efficiency.

Table 1: Efficiency spread of impellers with pump types in the study (source – Europump)

Group	Impeller/pump type	ηPmax %	ηPmin %	ηPav %
Radial Sewage Pumps 1 to 10kW submersible & dry installed	Vortex	63	26	43
	Channel	80	39.2	71
Radial Sewage Pumps >10 to 25 kW submersible & dry installed	Vortex	58.5	38.8	45.7
	Channel	87	54	71.5
Radial Sewage Pumps >25 to 160 kW submersible & dry installed	all types average	88.7	55	77.3
Mixed flow & Axial Submersible & dry installed	Activated sludge recirculation Axial (H < 2m)	68.3	35.3	56.5
	Storm water & effluent axial and mixed flow	87.3	68	82.1
Domestic& commercial buildings "once a day operation"	Shredding, grinding pumps	42	22.5	32.3
	Radial sewage pumps 1 to 10kW	78	26	53.5
	Where volute is part of a tank	71	14	27.62
	Centrifugal submersible domestic drainage pump < 40 mm passage	60.8	14.5	35.2
Dewatering pumps, submersible		72	46	64
Slurry pumps	light	82	45	63.5
	heavy	77	35	56

The figures in the table clearly show that the type of impeller used will have an impact on the overall efficiency of the pump. For example, the vortex impellers are on average 25% less efficient than channel impellers when used for the same radial sewage pump. However, as stated previously, this drop in efficiency may be acceptable if resistance to wear and clogging are increased. It is also important to note from the table that the spread of efficiency for any particular type of pump can be significant. For example, the spread of efficiencies for radial sewage pumps 1 to 10 kW is between 39% to 80%. This spread is partly due to the normal differences in impeller designs found between different manufacturers and partly due to the specific requirements of the different applications.

- **Motors**

All the pumps in the study are likely to be used in conjunction with AC electric induction motors. AC motors are rotating electric machines designed to operate from an AC power source. Like other motors, an AC motor has a fixed portion, called the stator and a rotor that spins with a carefully engineered air gap between the two.

- **Induction Motors**

In an AC induction motor, a rotating magnetic field is formed in the stator when an AC supply is connected to the stator windings. The rotating magnetic field induces an Electromagnetic Force (EMF) in the rotor as per Lenz's law, thus generating another set of electromagnets; hence the name – induction motor.

Interaction between the rotating magnetic field and the rotor field generates the motor torque. As a result, the motor rotates in the direction of the resultant torque. One way to produce a rotating magnetic field in the stator of an AC motor is to use a three-phase power supply to feed 3 sets of stator coils, which are a distributed e.g. for a 2-pole motor with 2900 rpm at 120 degree intervals.

The speed of the rotating magnetic field (synchronous speed) in an induction motor depends on the frequency of the supply voltage and on the number of poles in the motor.

$$Sychronous\ speed\ (rmp) = \frac{frequency\ of\ the\ applied\ voltage\ (Hz) \times 60}{number\ of\ pole\ pairs}$$

For example, when a 4-pole motor is supplied with 50 Hz supply, the synchronous speed will be 1500 rpm. Motors with 2, 4 and 6 poles represent the vast majority of the motor market. The rotor speed is slightly lower (a few percent at full power) than the synchronous speed and therefore the induction motor is also called asynchronous motor. The rotor slip increases in a linear manner as the load increases, being almost zero at no-load.

The typical motor for wastewater pumps is the so called squirrel cage induction motor. Main characteristics:

- Low construction complexity,
- High reliability (no brush wear), even at very high achievable speeds
- Driven directly by the grid or by multi-phase Inverter controllers
- Low Electromagnetic Interference (EMI)

- Lowest cost per kW among different motor technologies

Induction motors are by far the most widely used motor in the power range under consideration, using over 90% of the electricity consumed by all motors in that range. Induction motors are robust, inexpensive when compared with other technologies and their efficiency ranges from fair (around 70% for small motors) to very high (over 95% for large motors) depending on the power level and on the design. The efficiency class of motors is defined in IEC 60034-30.

General-purpose induction motors are a commodity type of motor constituting a large majority of the market (they represent 80-85% of the 3-phase induction motor market), whose main characteristics are standardised. This standardisation allows motors to be easily exchanged around the world for motors made by different manufacturers meeting the same requirements. There is a huge variety of special purpose induction motors, the most common being submersible motors. In some applications, these motors may have to comply with strict requirements (e.g. explosion proof motors according to ATEX) in which safety is an overriding concern.

- **Single-Phase Induction motors**

As the name suggests, Single-Phase Induction motors operate with a single-phase power supply. In single-phase induction motors, there is a stator main winding and an auxiliary winding for starting and / or operating purposes. The rotor is of the squirrel cage type.

When the motor is connected to a single-phase power supply, the main winding carries an alternating current. This current produces a pulsating magnetic field. Due to induction, the rotor is energised. As the main magnetic field is pulsating, the torque necessary for the motor rotation is not generated. This will cause the rotor to vibrate, but not to rotate. Hence, the single-phase induction motor is required to have a starting mechanism that can provide the starting kick for the motor to rotate. This is accomplished by the auxiliary stator winding, which normally is connected in series with a capacitor. The combination of the two windings creates a rotating field and the motor torque is generated in the rotor like in a 3-phase induction motor. In cases where a starting capacitor is used for starting, a current respectively voltage sensitive relay is typically used to disconnect the auxiliary winding after starting.

Main characteristics:

- Medium construction complexity due to extra capacitor
- Higher cost than 3-phase induction motors (when relating to the same shaft power)
- High reliability (no brushes)
- Lower efficiency than 3-phase induction motors (When relating to the same shaft power)
- Low EMI
- Driven directly from AC line

Single-phase motors are more expensive and less efficient than equivalent 3 phase motors, being mainly used in residential appliances, and rarely exceeding a few kW. The most relevant electric home appliances are the subject of efficiency assessment regulation in which the efficiency of the whole equipment is regulated. Other integral single-phase motors can be found, mostly in the residential sector, in applications such as submersible pumps and machine tools. In general, terms single-phase motors are used when a three-phase supply is unavailable.

Controls

Pumps are available with a variety of controls to suit a range of pumping operation, such as intermittent batch pumping and variable flow system. The types of controls available are discussed in the following section.

Time switches

As the name suggests time switches are used to control the operation of pumps based on times. These are not commonly used for wastewater pumping as there is a possibility that pumps could operate when there is not any wastewater in the wet well. Conversely, they may not operate in time to empty a wet well that is full.

They can be used to start pumps which have not been operated for a pre-set length of time, in order to stop any wastewater in a wet well from going septic.

They can also be used to control batch processes in wastewater treatment works that require wastewater to be held in a specific process for a specific length of time.

Level controls

Level controls are amongst the most common type of controls used to wastewater pumping. They are used to switch the pumps on when the amount of wastewater in a wet well reaches a pre-set high level, and switch them off once the waste water level reaches a pre-set low level. Level controls can be used to provide variable flow control in pumping stations with more than one pump, by running a single pump during periods of low flow into the station and multiple pumps during high flow periods.

Process based controls

Certain pumps, such as return activated sludge pumps, are controlled based on the process requirements from a wastewater treatment works. The speed of the pumps, as well as the running times, can be managed by process-based controls. For example if there is a high demand for return activated sludge, the pumps will be operated at full speed; however they might be operated at low speed during periods of low demand.

Intelligent network controls

Intelligent network controls are a relatively new technology that is used to balance the flow of wastewater into a treatment works. They work by maintaining control over all the pumping stations in a wastewater network. The intelligent network controls monitor the level of wastewater in each pumping station and can balance the inflow to a treatment works by controlled operation of pumps in the single collection sumps.. The aim is to reduce the volume of wastewater flowing into the treatment works during peak hours by spreading the flow out during the day.

Flow controls

Flow controls are used to vary the speed of pumps in order to maintain a constant or process controlled outlet flow and flow rate in the pumping system. Although they are not commonly used for wastewater transfer operations, flow controls can be found in certain processes in the wastewater treatment, such as return activated sludge processes, where a constant flow rate is required.

Sensors

The sensors used to control wastewater pumps tend to be level sensors. These are available in a number of different types including pressure transmitters, ultrasonic sensor, level probes and float switches. As well as level sensors, pressure sensors are also used in wastewater pump controls.

Pressure transmitters

Pressure transmitters are suspended in the wastewater wet well, in a protective enclosure down close to the bottom of the well. They use the hydrostatic pressure on a membrane as given by the water above, to determine the water level.

Ultrasonic sensor

Ultrasonic sensors are placed in wet wells above the waste water level. They measure the level of the wastewater by emitting ultrasonic sound waves at the wastewater and measuring the time it take for the ultrasound echo to return to the sensor. The longer it takes the echo to return the lower the waste water level in the wet well.

A key benefit of these types of sensor is that they are never in contact with the wastewater and therefore are unlikely to be soiled by the solids in the wastewater.

Level probes

There are 2 different systems of level probes. The principle of the conductive type is that there are 3 or more electrodes placed within the wet well. A low voltage is applied between the electrodes. When the waste water level in the wet well reaches the height of a probe, an electrical connection in made between the electrodes, and this is used as a signal to turn the pumps on or off. A different system of level probes uses capacitive sensors and by this avoiding malfunction given by grease in the wastewater.

Float switches

Float switches are typically made of plastic and are lightweight balls or boxes filled with air and therefore are able to float on water. There is an electrical switch within the float, which turns on and off depending on the orientation of the float. As shown in Figure 5, when the float switch is floating on the wastewater, it turns upside-down, and the switch is turned on and the control system is sent a signal.

Level probes and float switches give only a start-stop signal at a mechanically prefixed level but pressure transmitters and ultrasonic systems transmit the actual level in the sump to the controls. Transmitting the actual level allows variable level setting at the control panel or by a logic embedded in the controls.

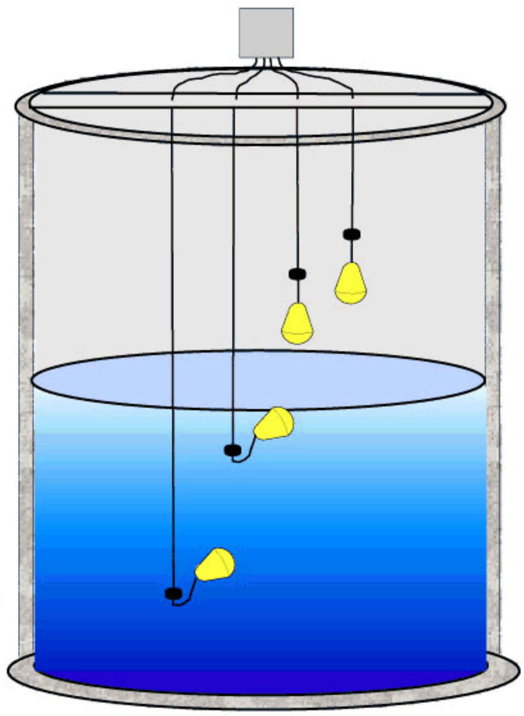

Figure 5 – Example of a wet well with float switches

4.2 Production phase

4.2.1 Bill of Materials (BoM)

The following tables show the BoM for the pumps in the study. The pumps are predominantly made from various metals, as they have to withstand abrasive fluids and relatively high pressures and forces. Ferrous metals tend to be used as the main material in the pumps with steel typically accounting for 5-25% of the pump. The smaller pumps contain plastic elements, but even these are predominantly metal.

The pumps are typically packed in wood however, the small domestic pumps are provided in plastic and cardboard. The weight of the packing materials accounts for a very small percentage (<2%) of the total weight of the pumps.

The BoM does not include any information on VSD. Details of VSD can be found in the Lot 30 study.

Table 2: Bill of Material for pumps in study (Source: Europump)

Pump Type		Steel	Other ferrous metals	Non-ferrous metals	Plastics	Others	Total weight
Centrifugal submersible pump							
	Radial sewage pumps 1 to 10kW	20%	68%	10%	1%	1%	**80 kg**
	Radial sewage pumps >10 to 25kW	20%	68%	10%	1%	1%	200 kg
	Radial sewage pumps >25 to 160kW	25%	58%	15%	1%	1%	1 000 kg
	Mixed flow & axial pumps	25%	58%	15%	1%	1%	400 kg
Centrifugal submersible pump – once a day operation							
	Shredding, grinding pumps	20%	68%	10%	1%	1%	50 kg
	Radial sewage pumps 1 to 10kW	20%	68%	10%	1%	1%	45 kg
	Where volute is part of a tank	15%	40%	10%	34%	1%	40 kg
Centrifugal submersible domestic drainage pump < 40 mm passage		48%	0%	28%	23%	1%	8 kg
Submersible dewatering pumps		34%	14%	44%	1%	7%	50 kg
Centrifugal dry well pump							
	Radial sewage pumps 1 to 10kW	5%	90%	0%	1%	4%	80 kg
	Radial sewage pumps >10 to 25kW	5%	90%	0%	1%	4%	125 kg
	Radial sewage pumps >25 to 160kW	5%	90%	0%	1%	4%	550 kg
	Mixed flow & axial pumps	10%	85%	1%	0%	4%	1 500 kg
Slurry Pumps							
	Light duty	22%	70%			8%	600 kg
	Heavy duty	19%	81%				700 kg

Table 3: Bill of Materials for packing materials (Source: Europump)

<table>
<tr><th colspan="2">Pump Type</th><th>Plastic</th><th>Cardboard</th><th>Paper</th><th>Others, Inc wood</th><th>Total weight</th></tr>
<tr><td colspan="2">Centrifugal submersible pump</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4"></td><td>Radial sewage pumps 1 to 10kW</td><td rowspan="3">1%</td><td rowspan="3">4%</td><td rowspan="3">0%</td><td rowspan="3">95%</td><td rowspan="3">20.8 kg</td></tr>
<tr><td>Radial sewage pumps >10 to 25kW</td></tr>
<tr><td>Radial sewage pumps >25 to 160kW</td></tr>
<tr><td>Mixed flow & axial pumps</td><td>0%</td><td>0%</td><td>0%</td><td>100%</td><td>120 kg</td></tr>
<tr><td colspan="2">Centrifugal submersible pump – once a day operation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3"></td><td>Shredding, grinding pumps</td><td rowspan="3">4.0%</td><td rowspan="3">22.0%</td><td rowspan="3">3.0%</td><td rowspan="3">71.0%</td><td rowspan="3">17.6kg</td></tr>
<tr><td>Radial sewage pumps 1 to 10kW</td></tr>
<tr><td>Where volute is part of a tank</td></tr>
<tr><td colspan="2">Centrifugal submersible domestic drainage pump < 40 mm passage</td><td>0%</td><td>100%</td><td>0%</td><td>0%</td><td>1kg</td></tr>
<tr><td colspan="2">Submersible dewatering pumps</td><td>0%</td><td>100%</td><td>0%</td><td>0%</td><td>1kg</td></tr>
<tr><td colspan="2">Centrifugal dry well pump</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4"></td><td>Radial sewage pumps 1 to 10kW</td><td rowspan="3">1%</td><td rowspan="3">3%</td><td rowspan="3">0%</td><td rowspan="3">96%</td><td rowspan="3">22.7kg</td></tr>
<tr><td>Radial sewage pumps >10 to 25kW</td></tr>
<tr><td>Radial sewage pumps >25 to 160kW</td></tr>
<tr><td>Mixed flow & axial pumps</td><td>0%</td><td>0%</td><td>0%</td><td>100%</td><td>120 kg</td></tr>
<tr><td colspan="2">Slurry Pumps</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2"></td><td>Light duty</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">100%</td><td rowspan="2">120kg</td></tr>
<tr><td>Heavy duty</td></tr>
</table>

4.3 Distribution phase

There can be wide variations in weight and volume of pumps packed for distribution. The Table 4 shows average weights and volumes of pumps that have been derived through consultation with stakeholders.

Table 4: Distribution phase input data (Source: Europump)

Pump Type		Total weight
Centrifugal submersible pump		
	Radial sewage pumps 1 to 10kW	100.8 kg
	Radial sewage pumps >10 to 25kW	220.8 kg
	Radial sewage pumps >25 to 160kW	1 020.8 kg
	Mixed flow & axial pumps	520 kg
Centrifugal submersible pump – once a day operation		
	Shredding, grinding pumps	67.6 kg
	Radial sewage pumps 1 to 10kW	62.6 kg
	Where volute is part of a tank	57.6 kg
Centrifugal submersible domestic drainage pump < 40 mm passage		9 kg
Submersible dewatering pumps		51 kg
Centrifugal dry well pump		
	Radial sewage pumps 1 to 10kW	102.7 kg
	Radial sewage pumps >10 to 25kW	147.7 kg
	Radial sewage pumps >25 to 160kW	572.7 kg
	Mixed flow & axial pumps	1 500 kg
Slurry Pumps		
	Light duty	720 kg
	Heavy duty	820 kg

4.4 Use phase (product)

4.4.1 Data on Use Phase for Pumps in Scope

The data for the use phase energy consumption of the pumps is shown in Table 5

Table 5: Data on use phase for ENER Lot 28 pumps (Source: Europump)

Pump Type		Load factor %	Annual operating hours hours	Annual energy consumption GWh
Centrifugal submersible pump				
	Radial sewage pumps 1 to 10 kW	85	1000	3808
	Radial sewage pumps >10 to 25 kW	85	1500	2295

Pump Type		Load factor %	Annual operating hours hours	Annual energy consumption GWh
	Radial sewage pumps >25 to 160 kW	85	2000	8925
	Mixed flow & axial pumps	70	5000	858
Centrifugal submersible pump – once a day operation				
	Shredding, grinding pumps	75	30	13
	Radial sewage pumps 1 to 10 kW	80	30	44
	Where volute is part of a tank	80	30	14
Centrifugal submersible domestic drainage pump < 40			80	30
Submersible dewatering pumps			75	2000
Centrifugal dry well pump				
	Radial sewage pumps 1 to 10 kW	85	1000	765
	Radial sewage pumps >10 to 25 kW	85	1500	717
	Radial sewage pumps >25 to 160 kW	85	2000	1785
	Mixed flow & axial pumps	85	250	64
Slurry pumps				
	Light duty	100	2600	7800
	Heavy duty	80	2000	888

4.4.2 The Extended Product Approach

The Extended Product Approach is summarised in Task 1, and described in detail in Annex 3 of Task 4 in the description written by Europump. The purpose of this section is to give a more detailed technical review, and then to describe the approach within the context of this study.

- **Why the Extended Product Approach is needed**

The 100% load efficiency figures for the pump and motor could be used to calculate for example the minimum allowable energy consumption for a pump (and pump product), and/or the target energy consumption for "Best in class" pump product. Using this simple method, the regulator could then define the minimum allowable efficiency of a pump+motor combination, assuming that it uses the MEPS applicable to that motor and pump. So simply multiplying the two efficiencies together would give a single combined MEPS for the pump+motor product.

However, this method does not take account of real life operating conditions that will include time at different load points, and so is not adequate for giving an accurate indication of the actual operating costs. This occurs where the more detailed approach of the EPA is of benefit.

- **Deriving values for the EPA**

Existing regulations for the Pump product (only) are based on MEPs for a particular pump size, which are defined with reference to a Minimum Efficiency Index or "MEI" value. The Extended Product Approach energy consumption is distinguished from this by being defined in terms of the Energy Efficiency Index or "EEI" value.

The term EEI comes from the EUP Circulator regulations, where the annual energy consumption is based on the energy used by pump + motor + VSD control over a typical annual operating profile. The advantage of this EEI method is that it considers the real life operating profile of the extended product, and so gives the best representation of the actual costs of using that product.

Creating load profiles that are representative of the different types of application that will be powered by the pumps in scope is critical, but work to date suggests that just three profiles will be adequate:

- Closed loop variable flow.
- Open loop variable flow
- Constant flow[2] (open and closed loop)

The profile just gives the proportion of the time that is spent at each load point, with the actual annual operating time for each application being used to establish energy consumption. The pumps in this lot concern mainly constant flow (open and closed loop).

The following factors are needed for calculating the EEI:

- Pump efficiency at different load points
- Motor efficiency at different load points
- VSD efficiency at different load points in as far as VSD is applicable
- Applicable load profile
- Efficiency of controls (contactors) is neglected, because this is less than 0,1 % of the motor losses

It is very important to note that the majority of the pumps in scope of Lot 28 study are used in constant flow applications and the use of VSDs will only reduce the overall energy efficiency. Therefore, it is not recommended for VSDs to be part of the EPA for most of the pumps in scope of this study.

Unlike existing pump and motor regulations, these values are required at a range of load points. These can either be collected for each load point for each product, or by using a new Semi Analytical Model (SAM) that allows key data to be used to predict product efficiency at part load points.

The need for this information means that in order to devise an EEI value for a pump product, it will be essential to know the efficiency of the pump. Therefore, while the key outcome of this Preparatory study is expected to be EEI values related to the Extended Product Approach, it is still essential for this study to produce efficiency values for the pump alone in order for these EEI values to be calculated.

More specifically, in order that the EEI value can be calculated for every pump size, it is actually important to know what the desirable efficiency is for the selected pump duty. As with the ENER Lot 11 pump regulations, this will vary with head, flow and shaft speed. It is expected that the same type of calculation method as used in existing regulations will again be used for the other types of pump considered in ENER Lot 28 study.

[2] The large majority of waste water pumps follow this profile.

This means that MEPs for pumps of each head, flow and shaft speed will be required in order that corresponding minimum EEI values can be calculated. For the motor, the existing regulated MEPs may be used.
In addition, as with the Circulator regulations, a load profile is required that will state the proportion of time that a pump will operate at a particular load point over a typical operating cycle.
In Tasks 1-4, the work is focussed on the different types of pump in scope. In Task 5, the base case energy consumption of each type of pump is actually based on the first estimates of the Extended Product Approach energy consumption. However, it should be noted that the real life energy consumption of a pump product is the same as that of the EPA it is part of. Where the differences will become more important is in subsequent analysis in Task 6 onwards.

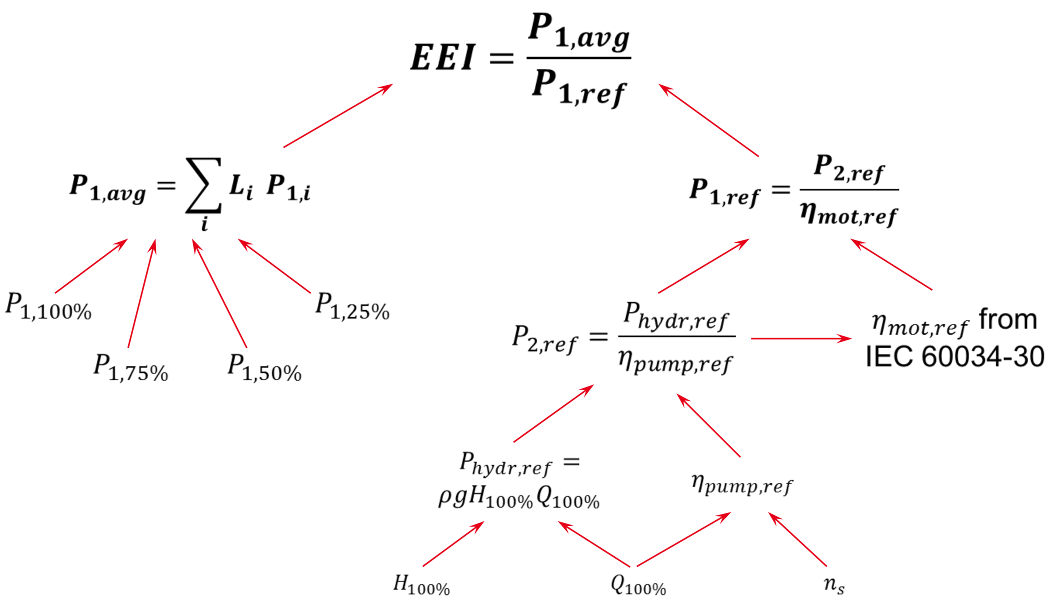

Figure 6 – Graphical presentation of the EEI calculation[3]

In principle, each pump type might be used in more than one EPA load profile, similarly each EPA load profile may be used with more than one pump type, and so there is not a simple relationship between the energy consumption of different pump types and the different load profiles associated with them. However, Annex 2, Table 4 shows that in practice the majority of pump types in this study only have the one load profile, which makes subsequent analysis much simpler

4.5 End-of-life phase

The high metal content of ENER Lot 28 pumps means that they are likely to be sold for scrap at the end of their lives. However, wastewater pumps may need cleaning to remove pathogens prior to being moved to the scrap yard.

The BOMs for the pumps in this study shows that the proportion of non-metallic components by weight is typically less than 1% for larger pumps. Pumps are heavy items, and have both a

[3] Source – Europump Extended Product Approach paper – See Annex 2

positive scrap value and an avoided disposal cost, and so it is to a company's advantage to send old pumps for scrap. In practice, it is the norm for pumps to be sent for scrap. To a good approximation, it is assumed that all of the metallic and none of the non-metallic components are recycled. The percentage (by weight) of the product destined to landfill is estimated to be 8% and is coherent with the value used for pumps in the ENER Lot 11 study.

The lifetime of a wastewater 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. The lifespan of ENER Lot 28 pumps will often be related to the solids they are required to pump.

It should be noted that 100% separation of copper, iron and aluminium metal parts is not achieved during scrap treatment, leading to fractions of lower recycling quality due to remaining impurities.

4.6 Recommendations on mandates

It is important that any standards produced for the Lot 28 product group has appropriate mandates to allow meaningful testing to be undertaken. The clean water test standards, ISO 9906:1999 Grade 2 for larger pumps and ISO:9906:1999 Annex A for mass produced pumps, can be used to determine the 'as new' hydraulic efficiency, (this is the hydraulic efficiency of the pump as soon as it is manufactured), however it is not appropriate for testing other key factors associated with efficient wastewater pumping. Therefore, it is recommended that the following issues be addressed by the European standardisation organisations for standards for wastewater pumps through the creation of appropriate tests:

- Ability to handle wastewater of a specified classification
- Ability to resist clogging/blocking shall be tested
- Ability to resist wear to the pump

EUROPUMP has made efforts to prepare such standards.

Measuring the performance of wastewater pumps against these criteria should give a more accurate representation of their overall in use efficiency. However, as discussed, the lack of these standards does not mean that regulations cannot be introduced soon, with refinement to the regulations possible at a time of subsequent revision once these new standards are introduced.

It is also recommended that the hydraulic efficiency test should be made coherent with the present version of ISO9906:2011

4.7 Conclusion

Pumps used to transfer wastewater are available in a variety of sizes and configurations to suit the various pumping applications. The vast majority of waste water pumping is undertaken by centrifugal pumps where a continuous flow of liquid is forced through a rotating impeller. There are a range of impellers available for pumping waste water, including single vane impellers which have large free passages to allow solids through, and vortex impellers which create a powerful swirl within the volute, allowing the solids to pass through the pump without coming into contact with the impeller.

The vast majority of waste water pumps are coupled with an AC induction motor, which provides efficient performance, even at part load. Waste water pumps are typically controlled based on the fluid level in the wet well, but they are also found to be controlled on timers or as required by the waste water treatment controllers. Intelligent network controllers are used to manage many pumping stations at the same time in an attempt to provide a steady flow of water into a waste water treatment works.

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

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

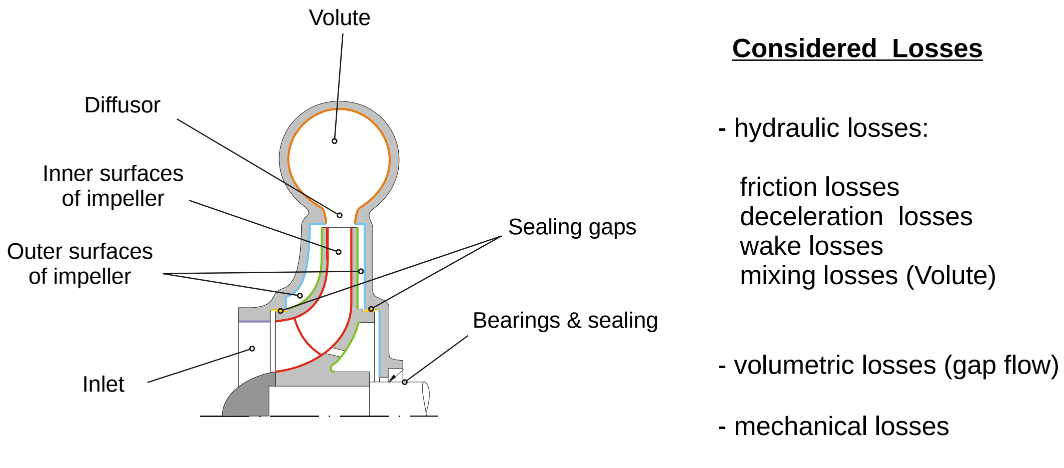

Figure 7 – Loss-causing components of a centrifugal pump.

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 5 (where n is the speed of rotation, Q the rate of flow and H the pump head).

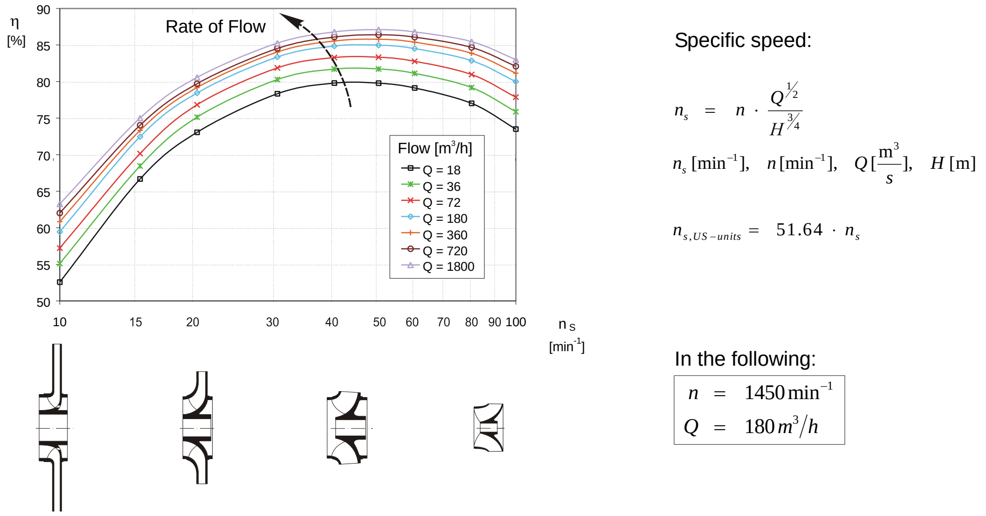

Figure 8 – The influence of rate of flow

As shown in Figure 5 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 5 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 were generated for operating conditions characterized by a flow rate of 180 m3/h and a speed of rotation n = 1450 min-1.

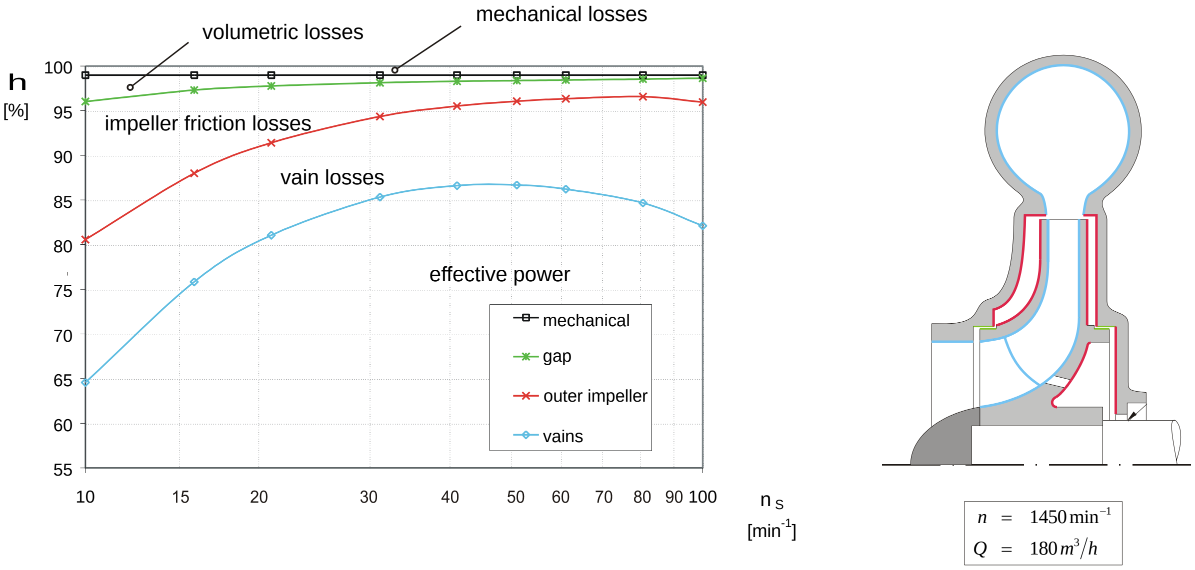

Figure 9 – Partial losses within a centrifugal pump

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

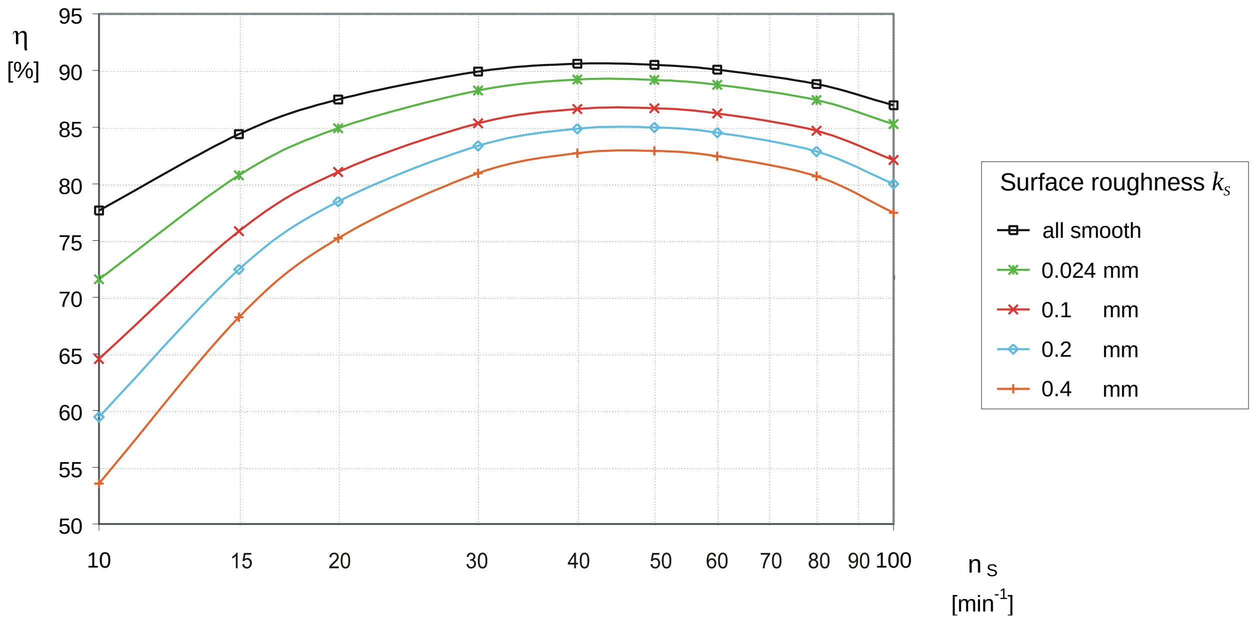

Figure 10 – The influence of surface roughness

Figure 5 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.q. 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 5 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.

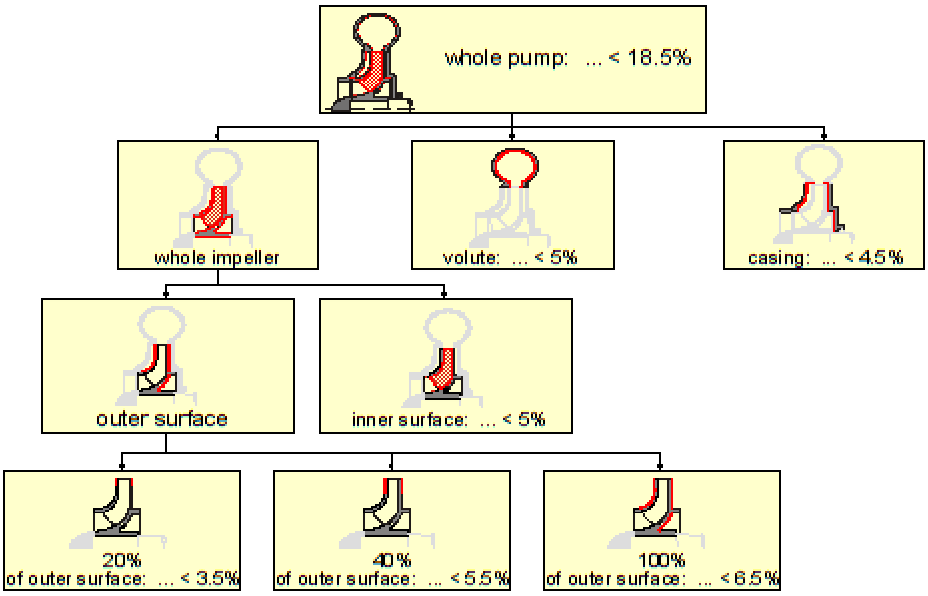

Figure 11 – Theorical estimation

Volumetric losses are mainly caused by the existence of a suction-sided sealing gap which serves as a throttle in order to reduce the secondary flow from the impeller out- to inlet as well as a an additional pressure-sided sealing gap which usually belongs to the axial thrust balancing system of a single-stage centrifugal pump. This internal leakage flows strongly depend on the clearance of the sealing gaps. Figure 5 shows the change in efficiency due to a variation of the gap clearance (the change in efficiency refers to a smooth gap with a radial gap clearance of 0.6 mm).

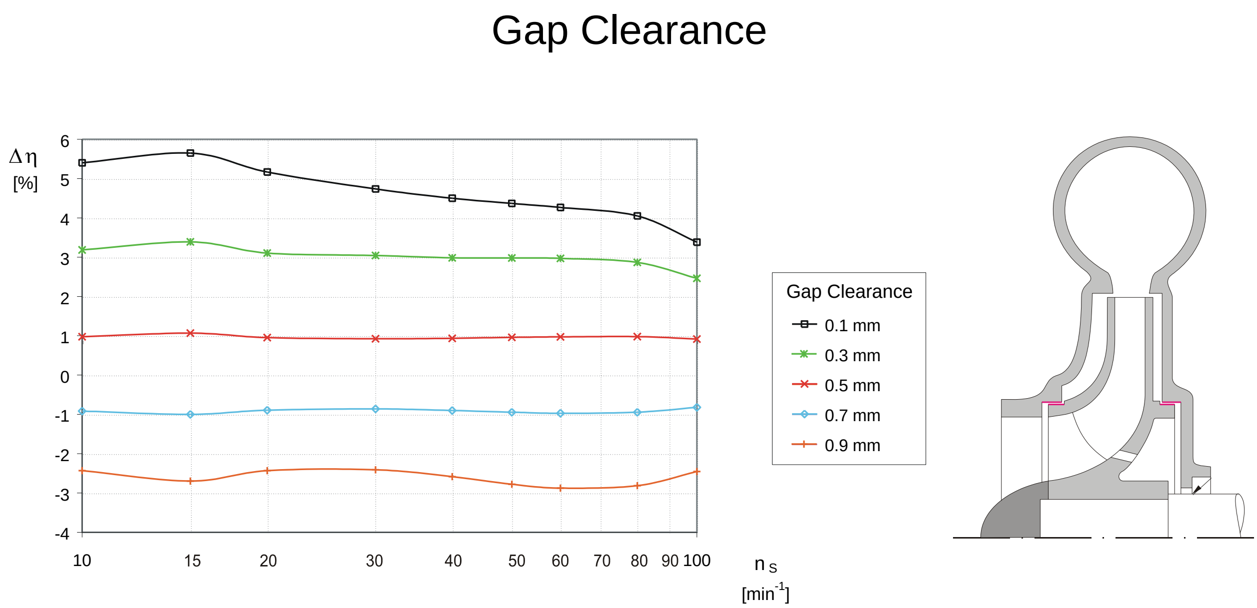

Figure 12 – The influence of secondary flow through the sealing gaps

The above diagrammed estimation results demonstrate that a reduction of gap clearance for instance from 0.6 mm to 0.3 mm can improve the pump efficiency about 3 per cent points. A possible additional treatment to reduce the internal leakage flows is to furnish one or both gap surfaces with circumferential notches (Figure 5).

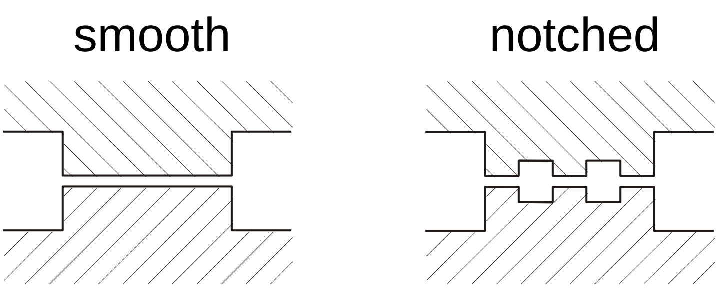

Figure 13 – Different types of sealing gaps

The theoretically carried out parameter study showed, that notching gaps of the type usually used in standard centrifugal pumps (cylindrical gaps with a relatively short gap length), only leads to a slight improvement of the pump efficiency.

- **Conclusions**

The presented results show, that for single-stage standard centrifugal pumps within a range of specific speed n_s = 10 min^{-1} up to n_s = 100 min^{-1} (corresponding to values from 520 min^{-1} up to 5200 min^{-1} in US-Units), the highest potential for an efficiency improvement can generally be found in the region of low specific speeds. All efforts aimed at an improvement of the surface quality of several parts of the pump which are in contact with the flow cause a gain of efficiency. With regard to the manufacturing costs, which result from such additional surface treatments the smoothing of the outer front and back shroud of the impeller can be proposed as a cost-efficient procedure to improve the efficiency. Furthermore, it could be shown that it is recommendable to reduce the clearance of the sealing gaps to the smallest possible value in order to increase the volumetric efficiency.

It should also to be mentioned, that the conditions of the surfaces as well as the sealing gaps within a centrifugal pump normally depend on the time of operation, which means that there is a strong necessity to check these parameters at reasonable intervals during the lifetime of a pump.

Annex 2: Draft description of the Extended Product Scheme, (Europump)

Foreward

This working document is prepared by a subcommittee of the Europump Standards Commission which consists of the following members:

- Dr. Niels Bidstrup, Grundfos
- Mr. Markus Teepe, WILO
- Mr. Gerhard Berge, KSB
- Dr. Gerhard Ludwig, TU Darmstadt

The working document will serve as a communication tool towards the European Commission during the legal process concerning the ecodesign requirements based on the extended product approach (EPA) for pumps. At a later stage this working document will be elaborated into a Europump guide, as an aid for pump manufacturers and users to ensure compliance with the future regulation on the extended product approach (EPA) for pumps.

This working document for a future Europump guide on the Extended Product Approach is prepared by a subcommittee of the Europump Standards Commission. It has not been presented or discussed in the Europump Standards Commission or the joint working group for EuP/ErP and currently does not reflect the position of Europump.

Europump's answer to the ecodesign directive for pumps is based on three pillars as shown in Figure 5. The Product Approach focuses on the efficiency of the pump alone. The Extended Product Approach is focused on the extended product (pump, PDS, controls) and the System Approach focuses on optimising the pumping system. The purpose of this guide is to describe the methodology for future implementing measures (i.e labelling, legislation etc.) for extended pump products (EPs).

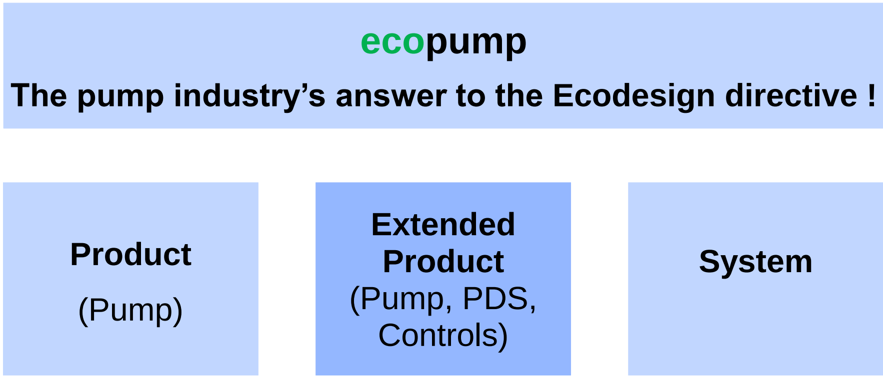

Figure 14 – Europump Ecopump initiative

Figure 5 shows the difference between a Product Approach and an Extended Product Approach. Implementing measures based on a Product Approach take only the efficiency of the product into account, whereas the Extended Product Approach via the load profile and control method curve also takes the reductions in pump head into account.

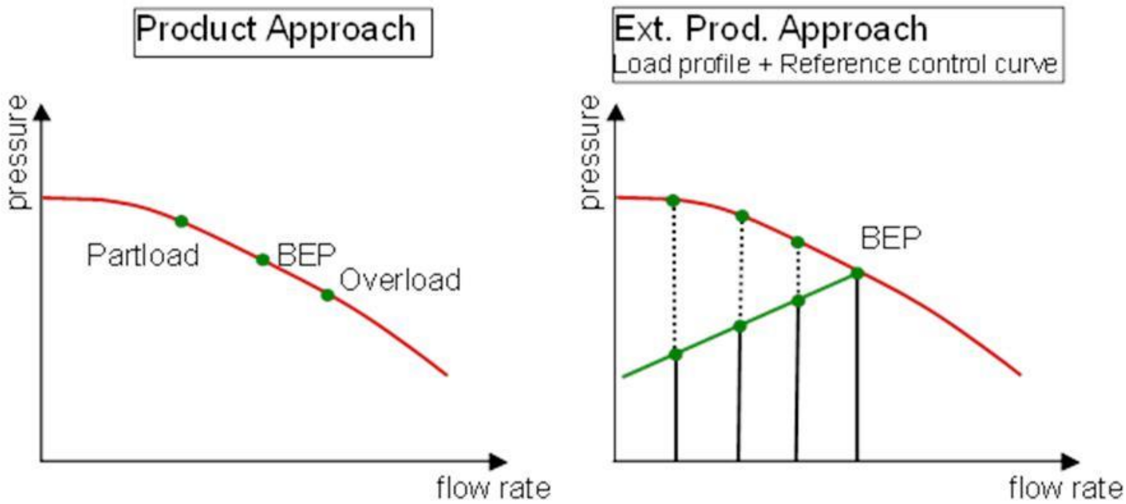

Figure 15 – Difference between a Product Approach and an Extended Product Approach

- **Pumps in scope**

The Extended Product Approach (EPA) has already been applied for circulators and forms the basis for the ecodesign requirement for these products today[4]. Figure 5 shows the road map for ecodesign requirements for pumps.

[4] *Commission Regulation 641/2009 (EC)*, Brussels: European Commission, 2009.

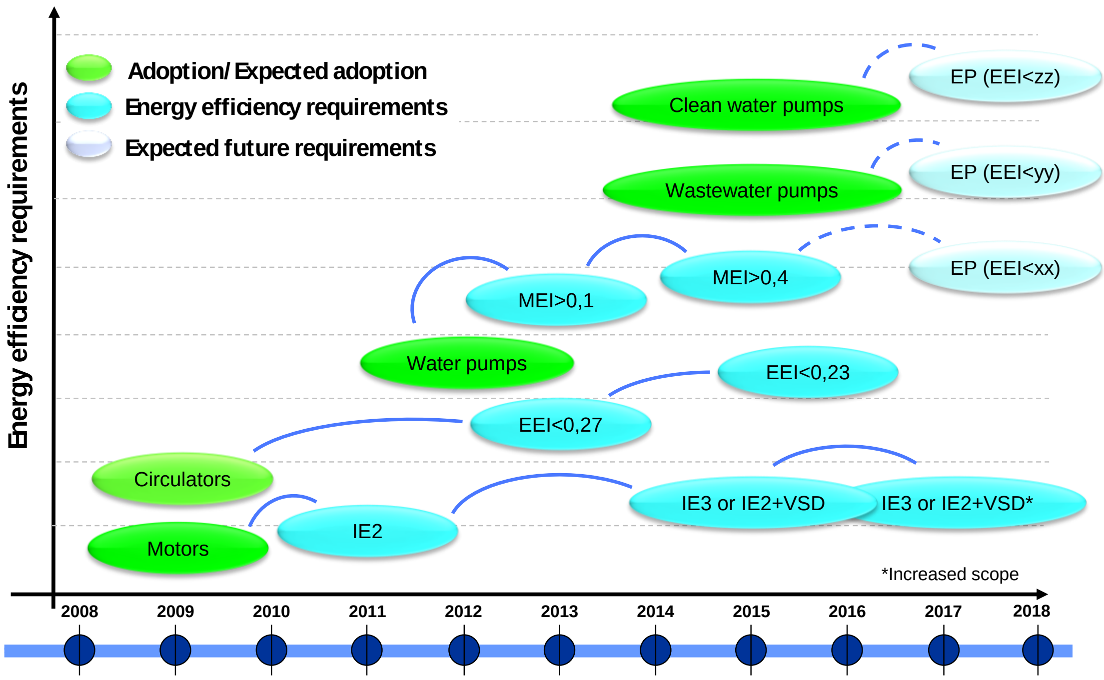

Figure 16 – Road map for energy efficiency regulation on pumps in EU

Ecodesign requirements based on extended products (EPs) are expected to be introduced during the next 5 years and the requirements will be based on an Energy Efficiency Index (EEI) as for circulators. The following pump products are expected to be targeted:

- Water pumps as defined[5]
- Booster systems (directly or indirectly)
- Wastewater pumps as defined in (to be determined)...up to 150 kW?
- Clean water pumps as defined in (to be determined)...up to 150 kW?

Energy savings

The main driver for the Extended Product Approach is the huge energy saving potential. Europump estimates that a marked transformation based on the EPA for water pumps in the scope of Commission Regulation 547/2012 only will lead to energy savings of 35 TWh per year, which is approximately ten times greater than the saving in 2020 achieved by the current regulation for water pumps.

Task 4: Extended Product Approach for pumps

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

- Extended Product Approach (EPA): a methodology to calculate the Energy Efficiency Index (EEI) of an Extended Product (EP), which incorporates load profiles and control method.

[5] *Commission Regulation 547/2012 (EU)*, Brussels: European Commission, 2012

- Extended Product (EP): consists of physical components

The EPA is a methodology or procedure which can be used to qualify an extended product for a certain efficiency level, whereas the EP is the actual product. This is shown graphically in Figure 5.

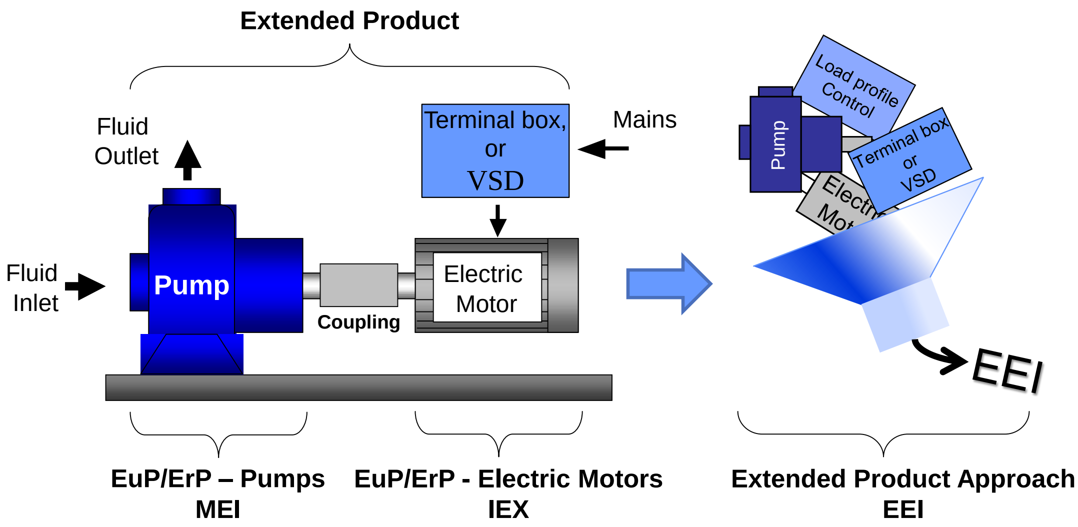

Figure 17 – Definition of Extended Product Approach

Extended pump products are placed on the market as integrated units i.e. a pump, a motor with or without VSD, which is supplied by one manufacturer as a complete unit. They are also placed on the market as separated units i.e. where the pump, motor and VSD are separate products supplied by one or more manufacturers. The EPA must be able to handle both integrated and separated extended pump products.

This leads to the following general definition for an extended pump product

> *Extended pump product means a pump driven by an electric motor with or without a variable speed drive (VSD)*

This definition is valid for all extended pump products in the scope, including circulators. The speed control is based on a system feedback which can come from sensors in the system or in the pump or from sensorless feedback transmitted by the motor.

Load Profiles and reference control curves

Extended pump products are used in a variety of applications with different load profiles and control methods. For the purpose of the EPA methodology, these load profiles and control methods are grouped into the following:

- Closed loop systems or open loop systems
- Constant flow systems or variable flow systems

- Sensorless speed control possible, (although complex to achieve)

When combined they cover all applications in the scope.

- Closed loop variable flow system

In a closed loop system, the purpose of the pumps is to produce enough head to overcome friction losses in the system and satisfy the requirement for actuators (valves etc.). A typical closed system is a hydronic distribution system of a heating and/or air conditioning system (HVAC-system). The purpose of these pumps is to distribute energy from the energy supply (boiler, chiller etc.) to the emission systems (radiator, coils, air handling units etc.) by circulating a pumped media. The load profile for these systems is shown in Table 4.

Table 6: Load profile for closed loop variable flow systems

	Flow (%)	Time (%)
L_1	100	6
L_2	75	15
L_3	50	35
L_4	25	44

At part load, the pump head can be reduced due to reduction in friction losses in the system. The control method must consider those. Figure 5 below shows the load points from and the reference control curve as defined for these systems (green line).

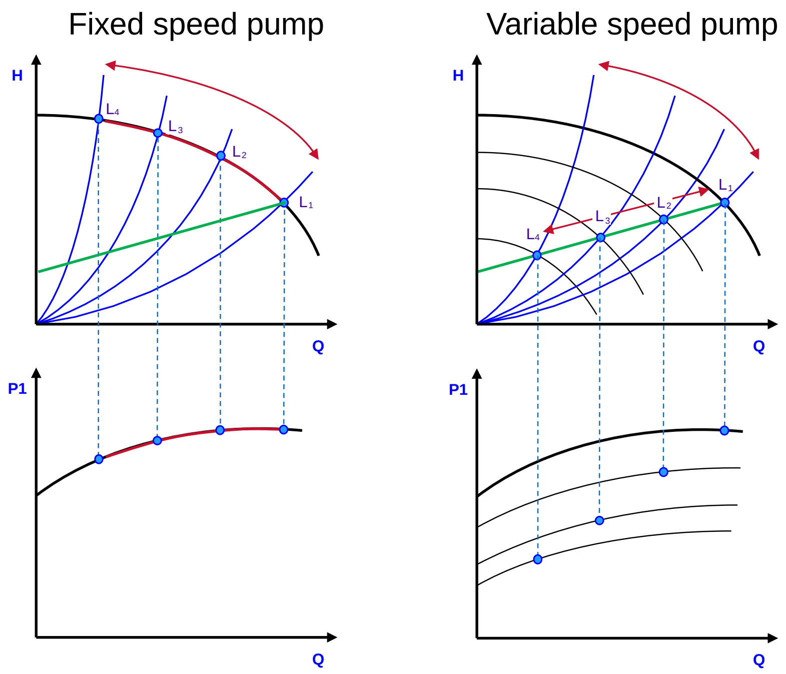

Figure 18 – Load points and control curve for closed loop variable flow systems

The EEI calculation of all pumps (fixed speed or variable speed) used in closed loop variable flow systems will be evaluated according to this reference control curve and load profile.

Open loop variable flow system

Pumps in open loop variable flow systems must deliver a certain static pressure and, in addition, enough head to overcome friction losses in the system. A typical open loop variable flow system is a water distribution system in cities and buildings. A load profile for these systems is shown in Table 4.

Table 7: Load profile for open loop variable flow systems

	Flow (%)	Time (%)
L_1	100	1
L_2	90	2
L_3	80	3
L_4	70	4
L_5	60	6
L_6	50	12

L_7	40	19
L_8	60	26
L_9	20	21
L_{10}	10	6

At part load, the pump head can also be reduced in these systems due to reduction in friction losses and the control method must take that into account. Figure 5 shows the load points from table above and the reference control curve as defined for these systems (green line).

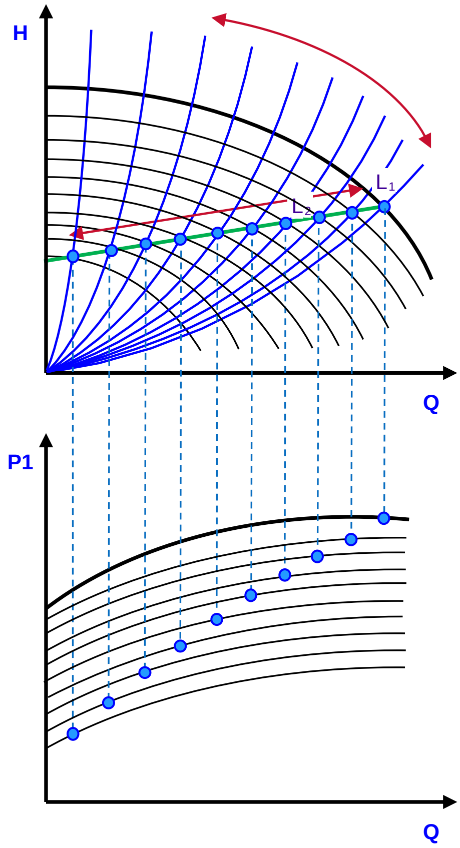

Figure 19 – Load points and control curve for open loop variable flow systems

The EEI calculation of all pumps (fixed speed or variable speed) used in open loop variable flow systems will be evaluated according to this reference control curve and load profile.

- **Constant flow system (open and closed loop)**

In a constant flow system, the pump must overcome a certain static pressure in an open loop system or overcome a certain friction loss in a closed system which is designed to give a certain constant flow. A typical application of an open loop constant flow system is where the purpose of the pump is to move liquid from one reservoir to another. A typical example of a closed loop system could be a boiler feed pump. In a real system, the flow is very seldom constant. For example, it will vary due to the level of the reservoirs etc. Therefore, it makes sense to define a load profile with a load point around the best efficiency point. Such a load profile is shown in Table 4 below.

Table 8: Load profile for constant flow systems (open and closed loop)

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

These are the same load points as those used for MEI calculation for water pumps, where a time profile has been added.

In these systems, variable speed is not a benefit and no reference control curve is defined.

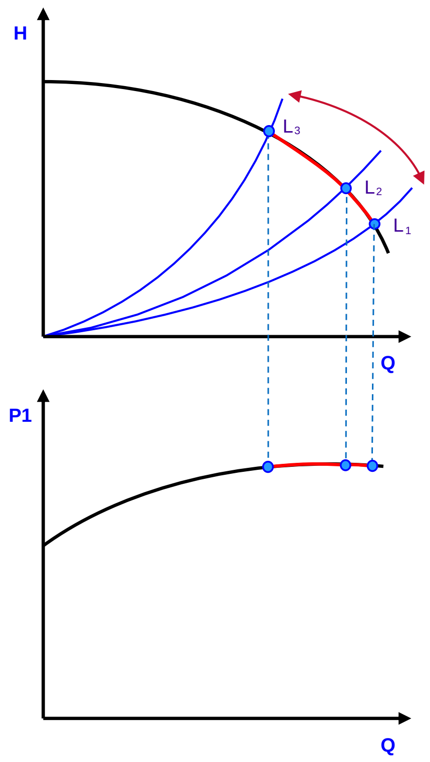

Figure 20 – Load points constant flow systems (open and closed loop)

The EEI calculation of all pumps (fixed speed or variable speed) used in constant flow systems (open loop and closed loop) will be evaluated according to this load profile.

- **Relation between system types and pump types**

There is no one-to-one mapping between system types and pump types. Some pump types are used in different systems. Table 4 shows the relation between system types and pump types.

Table 9: System type vs. pump type

Pump type	Relation to EuP/ErP	System type		
		Variable flow		Constant flow
		Closed loop	Open loop	Closed and open loop
Circulators	Lot 11	X		
ESCCI	Lot 11	X	X	O
ESOB	Lot 11	X	X	X
ESCC	Lot 11	X	X	X
MS	Lot 11	O	X	O
MSS	Lot 11	O	O	X
Wastewater	Lot 28	O	O	X
Clean water pumps	Lot 29 (except Lot 11 pump types)	O	O	X

For pump types used in more than one system type, more than one EEI value will be calculated. The *product information requirements* must ensure that the EEI is calculated and documented for all the entries in the table marked with an 'X'. Calculation and documentation of an EEI are optional for the entries marked with an 'O' in the table.

The *energy efficiency requirements* must specify that when putting an extended product into service, the energy efficiency requirements (in terms of EEI) for a particular pump type used in a particular system type must be met.

- **Task 4: Methodology for calculation of EEI for extended products**

The Energy Efficiency Index (EEI) is based on the same methodology as for circulators. Basically, it consists of an average power input calculated on a load-time profile divided by a reference power input.

Figure 5 shows how the power in an extended product is defined. P_1 is the electrical power input from the grid. P_2 is the mechanical power from the motor shaft. P_{hydr} is the hydraulic power produced by the pump.

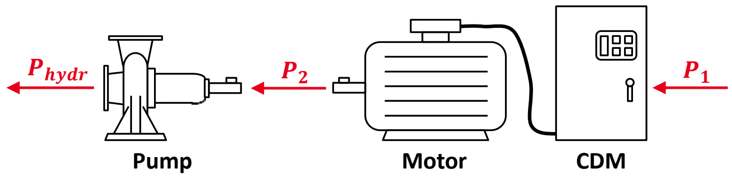

Figure 21 – Definition of Powers in an extended pump product. The combined motor and CDM (VSD) is referred to as a Power Drive System (PDS)

A graphical presentation of the EEI calculation is shown in Figure 5 below. The left side shows the calculation of average power input i.e. the numerator of the EEI index. The right side shows how to calculate the reference power i.e. the denominator of the EEI index.

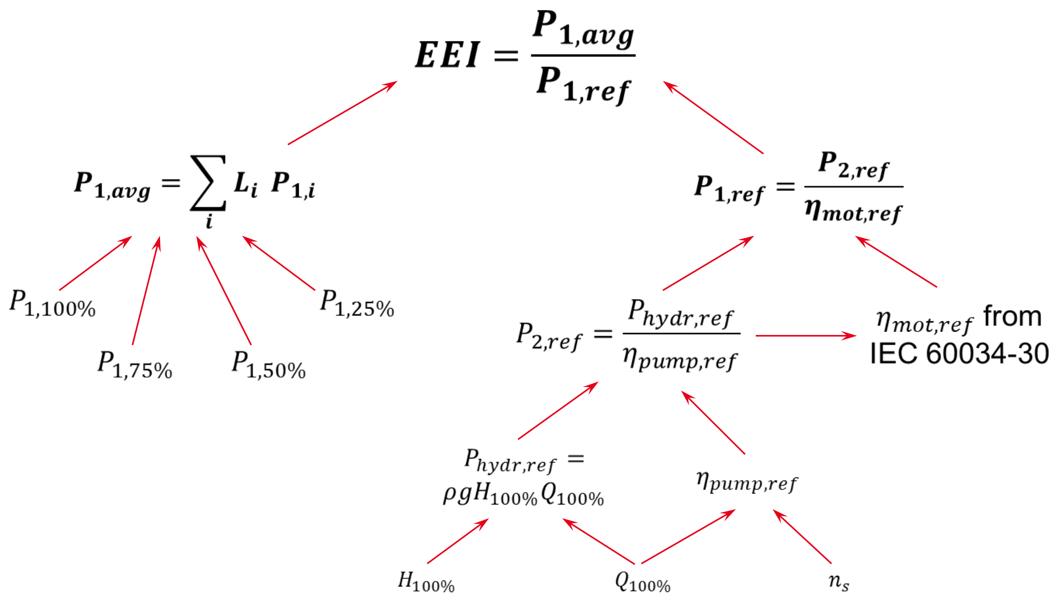

Figure 22 – Graphical presentation of the EEI calculation

The power input values $P_{1,I}$ in Figure 5 above can be measured, but this is not possible in most cases especially not for separated units. The $P_{1,I}$ values will then be calculated from Semi Analytical Models as described in the next section.

The reference power input based on actual efficiency of the pump as defined in the EC regulation for water pumps[6] and later on for the other pump types in the scope in Lot 28 and Lot 29. Based on actual measurements of the pump, the head and the flow, the best efficiency point (H100%, Q100%) is determined and from that the specific speed (ns) is calculated. Based on the hydraulic power and the efficiency, the reference shaft power $P_{2,ref}$ is calculated, which can via the IEC 600034-30 for motors be converted onto a reference power input. The reference efficiency of the VSD is set to 100% by definition. The actual efficiency of the specific VSD is captured by the power input values $P_{1,I}$ as is the case for pump and motor.

- **Semi Analytical Models (SAMs)**

[6] *Commission Regulation 547/2012 (EU)*, Brussels: European Commission, 2012

A methodology for an extended pump product cannot be based on measurement only although this is an option, which can be applied in some cases.

Separated extended pump products are in many cases built on site, which makes a determination of EEI based on measurements of the extended product impossible. Therefore, a methodology based on Semi Analytical Models (SAMs) has been developed to overcome this problem[7].

A SAM is a model which is based on measurement combined with physical and empirical knowledge of the product. Based on SAMs of the pump, motor and VSD it is possible to calculate the EEI of the extended product based on a few measurement points (supporting points) of the individual products (pump, motor and VSD).

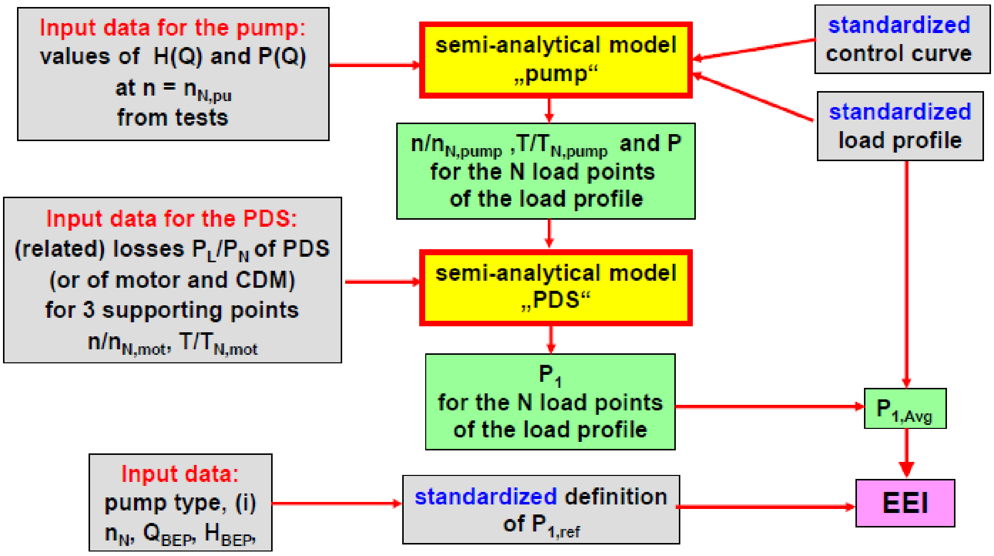

Figure 23 – Flow chart for calculating EEI of an Extended Pump Product

Based on the SAM for the pumps, the torque and rotational speed at the part load point is calculated.

Based on SAMs of the Power Drive System (PDS) the power losses at these part load point can be calculated and used to determine the power input to the extended product.

The SAM for the PDS is decribed in prEN50589-2[8] [4]. Figure 5 shows the eight load points which are defined in this standard. These eight points are chosen to cover all PDS applications.

[7] B. Stoffel, *Semi Analytical Models SAM's for Pumps*, Technical University of Darmstadt, 2013

[8] *prEN 50589-2 Energy efficiency indicators for power drive systems and motor starters*, CENELEC, 20xx.

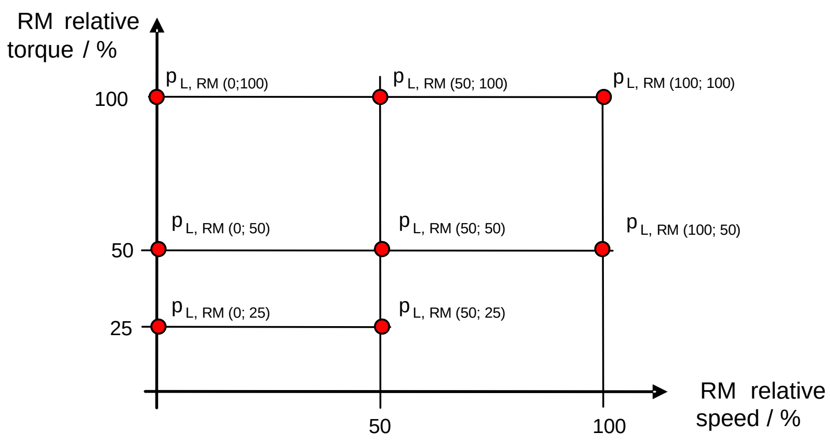

Figure 24 – Related losses of a PDS at different part load points[9]

Figure 5 shows the three supporting points for pump applications. All pump applications in the scope will be within the green shaded area.

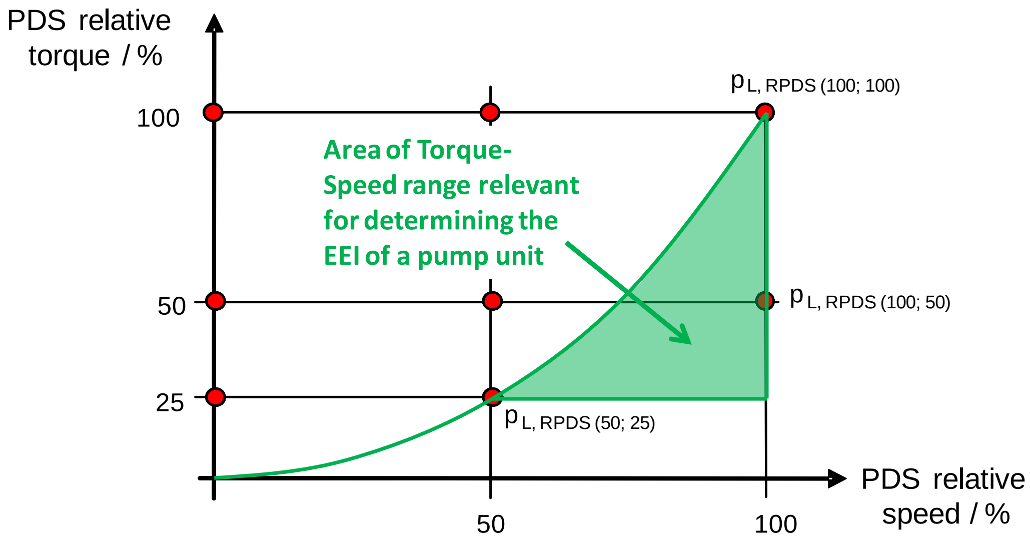

Figure 25 – Three points of related losses and shaded area of interest for pump manufacturers when calculating the EEI (Energy Efficiency Index) of a pump unit[8]

The actual losses will be based on interpolation based on these supporting points. Part One of the PDS standard[10] will cover the generic application of the standard for extended products. A specific measurements standard must be written for all products. A draft standard for pumps is already under development.

[9] *prEN 50589-2 Energy efficiency indicators for power drive systems and motor starters,* CENELEC, 20xx.

[10] *prEN 50589-1 Procedure for determining the energy efficiency indicators or motor driven applications by using the extended product approach and semi analytical model,* CENELEC, 20xx

Annex 3: Extract from the Lot 11 Preparatory study - The "House of Efficiency" scheme[11]

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:

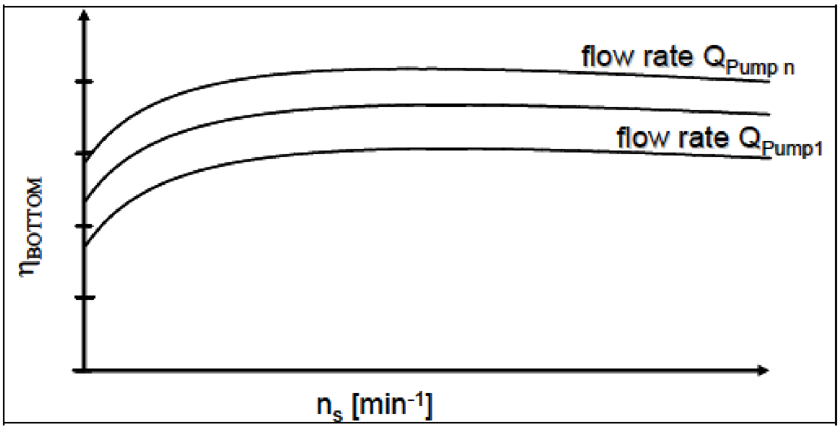

Figure 26 – Bottom lines for different geometrical pump sizes (defined for nominal flow rate Qn > Q1) within one pump type

That leads to bottom lines specific to each pump type at a certain flow (see Figure 5) which have to be defined, based on statistical data.

[11] This section is included for reference, and is an extract from the Lot11 Preparatory report section 8.1.12.3).

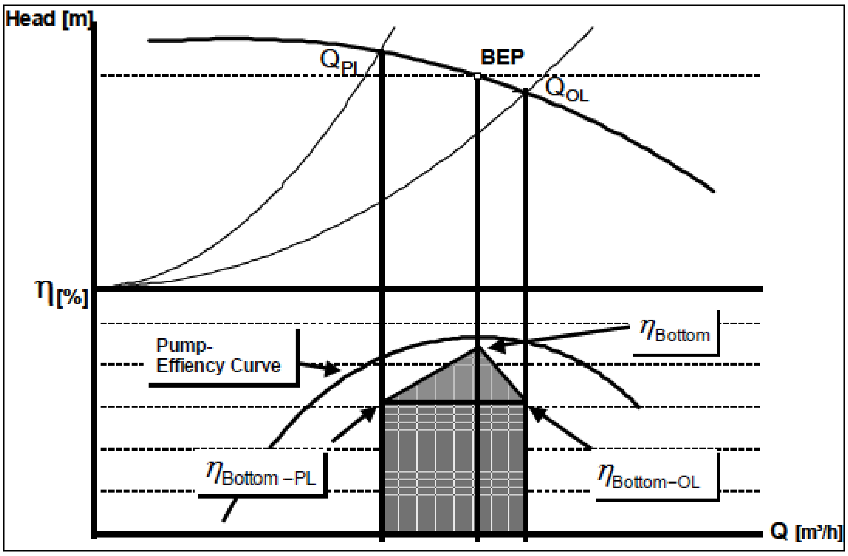

Figure 27 – "House of Efficiency" - explanatory representation of the scheme in a η (Q): flow-Plot

In Figure 5 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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