Problems of energy efficiency of pumps and pumping systems

I Tverdokhleb¹, A. Kostyuk¹, S. Sokolov²

¹ HMS Group Management Company LLC, 7, Chayanova st., Moscow, 125047, Russia
² Subsidiary of JSC «HMS Livgidromash» in Moscow, 7, Chayanova st., Moscow, 125047, Russia

E-mail: tib@hms.ru

Abstract. The total energy consumption of various types of pumps is significant and the energy saving potential in this area is also huge. The transition from consideration of the characteristics of a separate pump to the features of its operation with a drive, taking into account the operation in different modes in conditions of a specific hydraulic network, allows obtaining a much greater potential for reducing energy consumption, significantly increasing the efficiency and reliability of pumping equipment.

Efficiency of pumps and pumping systems is a key factor of for presence on the world market. Application of efficient pumps allows cut cost of operation. In addition, reduction of energy consumption helps to solve ecological problems.

Until recent days the main approach for increasing efficiency of pumps was the upgrading of hydraulics of pumps and increasing of efficiency of drives. This traditional approach among the experts was named as a Product approach because considers an improving of properties only a product.

Today the design of most widely used type of pumps manufactured by leading companies have efficiency very close to the maximum achievable efficiency.

The estimated potential of energy saving for these types is approximately 3 ÷ 5 %. The situation with electric motors and drives is the same. The Product approach can give up to 3% of energy reduction.

European experts estimate the energy consumption of pumps for water in Europe Union as a 226.2 TW*h per year [1] what at price for kWh costs 226.2 TWh year.

The potential of energy saving is huge. That is why since the 2000 the work of pumps efficiency has been going on.

In Europe since 2009 with the methodological and organizational support of Europump, the Directive 2009/125 / EC, Commission Regulation No. 622/2012 and the European Standard EN 16297: 2012, have been implemented. These standards define the energy efficiency requirements for low-capacity circulating pumps used in the EU.

The draft of European standard EN 16480 "Pumps - Minimum required efficiency. Centrifugal pumps for water "[2] has been developed. The standard defines the efficiency requirements of pumps for clean water by introducing the required minimum efficiency index MEI.

The scope of the standard includes end suction pumps, monoblock pumps, vertical multistage and borehole multistage pumps. The introduction of national standards based on this standard is being
planned in Europe countries. The actual objective of the standard is to increase the requirements for pump efficiency, which are presented on the market by step-by-step banning of sales of low-efficiency pumps.

In the standard as low efficiency pumps considered pumps with efficiency in three points with flows $Q=QBEP$ (best efficiency point), $QPL=0.75QBEP$ (part load) and $QOL=1.1QBEP$ (overload) lower than defined values. Standard EN 16480 defines values of efficiency in these points (house of efficiency). Lower values of efficiencies for these points are not allowed for sale (Figure 1). Formulas (1). (3) for calculation of efficiency levels are included in standard.

\[ \eta_{BEP} = -11.48x^2 - 0.85y^2 - 0.38xy + 88.59x + 13.46y - C \]  
\[ (\eta_{PL})_{min, requ} = 0.947 \cdot (\eta_{BEP})_{min, requ} \]  
\[ (\eta_{OL})_{min, requ} = 0.987 \cdot (\eta_{BEP})_{min, requ} \]

where $x = \ln(n_Q)$, $y = \ln(Q_{BEP})$.

In order to take into account the current technical level of the pumps produced by European manufacturers, in formula the correction factor $C$ is used (1), by the amount of which the required minimum value of the efficiency is reduced.

The coefficient is given in the standard in tabular form and depends on the pump type, speed and MEI index (minimum efficiency index).

The MEI index reflects the quantitative ratio of products of different technical level presented on the market, and in fact determines the levels of efficiency of these types of pumps for the next few years. Based on the results of the review of all pumps of these types on the market since the introduction of the above-mentioned EU regulations in 2013, 10% of pumps with low efficiency have been excluded from the market. (MEI = 0.1), then from 2015. - 40% of the pumps (MEI = 0.4).

Practice shows that the switch over from the characteristics of only pump to the evaluation of its operation, taking into account specific conditions in a particular system, allows to obtain a much greater potential for reducing of energy consumption.

It can be achieved by the correct selection of a pump in accordance with system parameters, the application of efficient drives, control methods and control algorithms. This glance on efficiency of pump systems has been named as Extended Product Approach. In this case as the object for energy saving considered the pump unit with the drive and the control system. The potential of energy saving at EPA is 15 ÷ 25%.

System approach considers a complete hydraulic system and takes into account changes in the characteristics of pipelines, requirements of technological processes, as well as application of effective valves. System approach can additionally give 10-15% of energy savings.
But it is necessary to notice that the System Approach usually is out of scope of responsibility of pump manufacturers and usually is the responsibility of end users of pump systems. This approach is more complicated for implementation.

To evaluate the efficiency of pump equipment by using the extended product approach for different types of pumps, it is necessary to calculate the index of extended product approach $EEI_{EP}$ in accordance with formula (4)

\[ EEI_{EP} = \frac{P_{\text{avg}}}{P_{\text{ref}}} \]  

The index is calculated taking into account the load profile and control method.

The power consumption of the pump $P_{\text{avg}}$, is defined during its operation for a given load profile for a specified period of time.

The referenced (or calculated) power $P_{\text{ref}}$ of the pump is fixed legislatively and is determined on the basis of the analysis of high-efficiency pumps and electric motors taking into specific speed of the pump and flow.

In accordance with extended product approach a pump unit is considered as a high efficient, if the value of $EEI_{EP}$ is higher than the value defined for same system.

The value of $EEI_{EP}$ is used as a criteria of pump efficiency. The pump unit considered as high efficient in accordance with the extended approach if it has $EEI_{EP}$ higher then certain by the standard for a system of this type. Otherwise, restrictive sanctions determined by law can be applied.

The experience of the USA in increasing the efficiency of pumps is very interesting. HI with support of DOE has developed the standards on energy savings.

In 2016 Standard [3] of energy saving of pumping equipment was adopted. The scope of the standard includes pump types included in the standard EN 16480. The performance of the pumping unit is characterized by the dimensionless $PEI$ coefficient calculated for the operating modes with constant and variable flow according to formulas (5.1) and (5.2), respectively.

\[ PEI_{CL} = \frac{PER_{CL}}{PER_{STD}} \]  

\[ PEI_{VL} = \frac{PER_{VL}}{PER_{STD}} \]

In accordance with HI/ANSI the average value of pump power is calculated. The calculation is made on base of test results at either constant or changing load.

For every pump, a certain standard average power consumption of the motor is calculated $PER_{STD}$ at operation on different modes at constant load (CL). At operation in different modes at constant load or with VSD with variable load (VL).

For the constant load the formula has

\[ PER_{STD} = \sum_{i=75\%,100\%,110\%} \omega_i \left\{ \frac{P_{\text{avg}}}{a_i \eta_{\text{pump},STD}} + L_i \right\} \]  

where

- $\omega_i$ – weight load factor at each point (for this case it is assumed equal to 0,3333),
- $P_{\text{avg}}$ – measured hydraulic output power at $i^{th}$ mode of the pump in question (hp)
- $a_i$ – 0,947 for operating point with flow 75% $Q_{\text{BEP}}$, 1,000 for operating point 100% $Q_{\text{BEP}}$, and 0,985 for operating point 110% $Q_{\text{BEP}}$.
- $L_i$ – losses in electric motor at $i^{th}$ mode calculated in accordance with DOE approach.
i – points of loads, corresponding to modes with 75,100 и 110% $Q_{BEP}$.

Minimum allowable efficiency of a pump $\eta_{pump,STD}$ defined as function of specific speed $nq$ and value $Q_{100\%}$ at BEP.

$$\eta_{pump,STD} = -0.85 \cdot \ln(Q_{100\%})^2 - 0.38 \cdot \ln(Ns) \cdot \ln(Q_{100\%}) - 11.48 \cdot \ln(Ns)^2 + 17.8 \cdot \ln(Q_{100\%}) + 179.8 \cdot \ln(Ns) - (C + 555,6)$$

(7)

Coefficient C is defined by the legislation [3]. Its physical meaning and order of application is similar to the coefficient of formula (1).

A mandatory condition for the sale in the United States is $PEI < 1,0$

The next step on the way of increasing the efficiency of pumps is the introduction in the US of the so-called high energy efficiency labeling (hereinafter referred to as MVE) with an energy rating of ER.

Any company that manufactures and sells pumps, follows requirements and procedures specified in the HI Guidelines for the High Energy Efficiency Labeling Program [4], may use this marking to inform the buyer of the high energy-saving properties of the products supplied.

The key factor in the application of MVE is the comparison of the PEI index of the pump to be marked and the base index of the pump that meets the minimum energy efficiency requirements. In accordance with formula (5.1), the base index is calculated as:

$$PEI_{Baseline} = \frac{PER_{Baseline}}{PER_{STD}}$$

(8)

$PER_{Baseline}$ is the weighted average power consumption of the unit (with the electric motor) with efficiency of basic level, determined uniquely for each pump by formulas (6) and (7) at nominal speed and flow $Q_{BEP}$, hydraulic power at 75,100 и 110% $Q_{BEP}$, and given in [4] in a table for the base level of energy efficiency coefficient "C".

The energy rating of ER is calculated by the formula:

$$ER = (PEI_{Baseline} - Rated - PEI_{CL/VE}) \times 100$$

(9)

Thus, ER is a tool for calculating energy savings when operating a pump in comparison to a "basic" pump that meets the minimum energy efficiency requirements. The main idea of the introduction of ER is the use of a user-friendly marking (Figure 2), which makes it possible to estimate the energy savings of the acquired equipment.

![Figure 2. Labeling of ER and QR code.](image-url)
It is possible to calculate the energy savings of a pump relatively to pump with low (basic) to level of energy efficiency by using the ER labeling according to formula (10).

\[
\text{Saving (kW} \cdot \text{h)} = \frac{ER}{100} \times P_M \times h
\]  

(10)

where \( P_M \) – power of a motor (kW)

h – time of operation (h)

For example, for a pump with the label shown in Figure 2 with an electric motor 37 kW, the forecasted savings for 1 year (8760 hours) of continuous operation will be

\[
\frac{22}{100} \times 37 \times 8760 = 71306.4 \text{kW} \cdot \text{h}
\]

In Russia, the legislative approach to energy efficiency differs from the US and European countries. Documents which limit the energy consumption of pumping equipment, includes only recommendations.

For example, the Decree of the Government of the Russian Federation of June 17, [5] provides tax benefits to enterprises and organizations operating energy-efficient equipment and systems. The standard defines requirements of efficiency to centrifugal multi-stage sectional, oil trunk and retaining, as well as piston and rotary pumps.

The efficiency of pump was selected as an indicator of energy efficiency. The value of pump efficiency should be not less than the values specified for different types of pumps in the Decree. This decision caused an ambiguous reaction among pump industry specialists, as the same requirements are imposed on pumps for various purposes and design schemes, the specific speed of the pumps was not taken into account. Often these requirements are either overstated or vice versa, underestimated.

The Russian association of pump manufacturers applies efforts to perform work in of increasing the pumps efficiency within the framework of world legislative initiatives.

National standard 16297 parts 1, 2, 3 Pumps. Rotodynamic pumps. Glandless circulators. . General requirements and procedures for testing and calculation of energy efficiency index (EEI)

At the stage of acceptance in the Comission of standardization there is a modified GOST EN 16480 "Minimum required index of energy efficiency (MEI) for water pumps", developed on the basis of the above-mentioned European standard.

On the basis of the international standard, ISO/ASME 14414 "Evaluation of the energy efficiency of the pumping system" is prepared, which integrates and makes available for a wide range of specialists the basic elements for assessing the energy efficiency of pumping equipment. The standard is useful from a practical point of view, since it is focused on pumping equipment and is developed taking into account the world experience in conducting assessments of pumping systems.

Throughout the world, work has been going on for a long time to improve the efficiency of pumping systems, the key element of which is to reduce their energy consumption. The application of the extended approach, in which the pump is considered in conjunction with the drive and control system, can significantly improve the efficiency and reliability of pumping equipment.

References
[1] Ecodesign Pump Review. Study of Commission Regulation (EU) No. 547/2012 incorporating the preparatory studies on 'Lot 28' and 'Lot 29' (Pumps). Final Progress report. December 2015. Annex 4
[2] prEN 16480:2014. Pumps - Minimum required efficiency of rotodynamic water pumps
[3] Energy Conservation Program: Energy Conservation Standards for Pumps [Docket Number EERE–2011–BT–STD–0031]
[4] Hydraulic Institute Program Guide for HI Energy Rating Program (HI 40.5-2016)
[5] Decree of the Government of the Russian Federation of June 17, 2015. No. 600 "On approval of the list of objects and technologies that relate to objects and technologies of high energy efficiency"