Capturing Energy Savings Opportunities for Pumps

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ABSTRACT

Pumps are installed in a number of residential, commercial, agricultural, and industrial applications and are ubiquitous energy-using equipment, consuming approximately 2 quadrillion British thermal units (quads) of energy per year. There have been several voluntary, international, and utility-led efforts to evaluate the performance of pumps and to encourage higher efficiency equipment. Recently, the U.S. Department of Energy (DOE) completed two rulemakings that, together, establish a rating metric, a test procedure, and energy conservation standards for five categories of pumps typically used in commercial and industrial applications. DOE is also currently conducting rulemakings for circulators and pool pumps.

DOE's new metric includes the performance of the bare pump, motor, and controls, and therefore affords utility incentive programs the opportunity to identify energy savings from a variety of improvements to the pump, such as pump efficiency, motor efficiency, and the addition of speed controls. Such information can be used to develop a stream-lined method for estimating the energy savings from pumps in different applications, as is currently being considered as part of the American Council for an Energy Efficiency Economy's (ACEEE) Extended Motor Product Labeling Initiative (EMPLI). There are both simplified and more complex ways in which the new pump metrics and reporting information could be used to estimate savings, depending on the application, pump configuration, and required degree of accuracy and precision, both on a population and site-specific basis.

Introduction

Pumps are installed in a number of residential, commercial, agricultural, and industrial applications, consuming approximately 2 quadrillion British thermal units (quads) of energy per year (DOE 2016b). Opportunities for energy savings include improving pump or motor efficiency, adding controls, and addressing inefficiencies within the pumping system. While pumping system improvements can have the largest impact, work in this area typically occurs through voluntary or incentive programs designed to assess facilities and recommend improvements. On the other hand, given limitations on authority, regulatory programs often focus specifically on pump efficiency, which has a smaller impact.

In recent years, stakeholders, including pump manufacturer groups (Hydraulic Institute [HI] and Europump) and efficiency advocates, have begun exploring ways to broaden the scope of regulations and related programs to encompass pumps inclusive of motors and controls. A carefully designed metric within such a program allows for identification of energy savings from pump and motor efficiency improvements, as well as the addition of speed controls. This offers a significant opportunity for savings while limiting the transaction costs incurred for system-focused or custom programs.

DOE recently published two rulemakings establishing regulations for clean water pumps using such a metric (DOE 2016a; DOE 2016b). These regulations provide a platform for utility and energy conservation programs to further incentivize energy efficiency improvements in pumps through simplified and stream-lined programs.

Discussion

This section (1) reviews existing regulatory and voluntary programs; (2) discusses the history, scope, definitions, metric, test procedure, and standards established by DOE's two recent pumps rulemakings; and (3) explores potential voluntary labeling or incentive programs addressing energy efficiency in pumps.

Existing Programs

When DOE began considering energy conservation standards for clean water pumps, international regulations existed in the European Union, Mexico, and China. These regulations deal primarily with pump efficiency, but in some cases, also include motor efficiency.

The European Commission (EC) established minimum efficiencies for rotodynamic water pumps used in commercial buildings, drinking water pumping, the food industry, and agriculture on January 1, 2013 (EU 2012). The EC regulation is based on pump efficiency at three points along the pump pressure/flow curve at pump's rated speed: the best efficiency point (BEP), 75 percent of flow at BEP, and 110 percent of flow at BEP. This approach accounts for the fact that pumps do not often operate at the BEP and attempts to increase efficiency across a wider range of operating conditions. The minimum pump efficiency is based on an equation based on pump type, rotating speed, flow, and specific speed which was derived from data collected during a 1998 investigation (AEA 2008). A constant in the equation can be adjusted to set lower or higher efficiency levels for specific pump classes (*Id*.). The EC also regulated circulator pumps through a separate regulation with a different metric (EU 2009).

Mexico regulates the minimum energy performance for submersible three-phase deep-well type clean water pumps (Norma Oficial Mexicana 2004). The minimum energy efficiency requirement is the product of minimum pump efficiency (based on ranges of flow) and minimum motor efficiency (based on ranges of motor size). Mexico also regulates certain deep-well water pumping systems, based on nominal bowl diameter and ranges of flow (Norma Oficial Mexicana 1995). Mexico also includes regulations for residential centrifugal clean water pumps less than 1 HP (Norma Oficial Mexicana 2008). China regulates the energy efficiency of several varieties of centrifugal pumps for fresh water, with minimum pump efficiency values at BEP based on ranges of flow and specific speed (GB 19762-2007).

There are also several existing voluntary programs, including utility programs, many of which are focused on more of a system basis and on the use of controls in pumping systems. For example, ASHRAE Standard 90.1 includes requirements for variable speed control in certain hydronic variable flow systems and for impeller trimming or speed adjustment in certain hydronic systems. Many utility programs offer incentives for certain clean water pumps, particularly related to installing pumps with variable speed drives (VSDs). (*e.g.*, Inland Power and Light Company, Hawaii Energy.)

DOE General Pumps Rulemakings

Under authority from the Energy Policy and Conservation Act of 1975 (EPCA), as amended, DOE recently finalized two final rules adopting definitions, metrics, and a test procedure for certain varieties of clean water pumps (January 2016 general pumps TP final rule; DOE 2016a), as well as energy conservation standards for those varieties of pumps (January 2016 general pumps ECS final rule; DOE 2016b). The following sections describe the history and specifics of those rules.

History. DOE initiated the general pumps rulemaking with a Request for Information (RFI) published on June 13, 2011 (DOE 2011). Subsequently, HI and the Appliance Standards Awareness Project (ASAP) initiated discussions between pump manufacturers and efficiency advocates regarding potential energy conservation standards. On February 1, 2013, DOE announced the availability of a Framework Document pertaining to energy conservation standards for commercial and industrial pumps (DOE 2013a). Subsequently, based on feedback from stakeholders, DOE announced the establishment of the Commercial and Industrial Pump (CIP) Working Group established through the Appliance Standards Rulemaking Federal Advisory Committee (ASRAC) to negotiate standards and test procedures for pumps (DOE 2013b). The CIP Working Group initiated meetings in December 2013 and concluded its negotiations on June 19, 2014, with a consensus vote to approve recommendations to DOE on appropriate standard levels for pumps as well as aspects of the metric and test procedure ("CIP Working Group recommendations").[1] The recommendations focused on clean water pumps and developed a new metric, pump energy index (PEI), designed to capture the benefits of pump and motor improvements as well as the addition of controls. DOE published a notice of proposed rulemaking (NOPR) on April 2, 2015 (DOE 2015a), based on the recommendations of the CIP Working Group (CIP Working Group 2015),[2] and in January 2016, following public comment, published the general pumps TP and ECS final rules.

Scope and Definitions. In the January 2016 pumps TP final rule, DOE defined "pump" as "equipment designed to move liquids (which may include entrained gases, free solids, and totally dissolved solids) by physical or mechanical action and includes a bare pump and, if included by the manufacturer at the time of sale, mechanical equipment, driver, and controls" (DOE 2016a). Given this definition, DOE's test procedure and energy conservation standards for general pumps are applicable to pumps distributed in commerce as a bare pump, with a motor, or with a motor and continuous or non-continuous controls. Therefore, DOE's test procedure is able to evaluate the energy use of the pump as it would be installed in the field and, in particular, the significant energy savings that may be available through the use of continuous and non-continuous controls on pumps.

The test procedure and standards adopted in the January 2016 general pumps TP and ECS final rules apply only to a certain subset of pumps, specifically end-suction close-coupled (ESCC); end-suction frame mounted/own bearings (ESFM); in-line (IL); radially split, multi-stage, vertical, in-line, diffuser casing (RSV); and submersible turbine (ST) pumps that are "clean water pumps" (as defined, except fire pumps, self-priming pumps, prime-assist pumps, magnet driven pumps, nuclear pumps, and pumps meeting the design and construction

[1] The term sheet containing the Working Group recommendations is available in the CIP Working Group's docket (Docket No. EERE-2013-BT-NOC-0039, No. 92).
[2] Information on the ASRAC, the CIP Working Group, and meeting dates is available at http://energy.gov/eere/buildings/appliance-standards-and-rulemaking-federal-advisory-committee.

requirements set forth in any relevant Military Specifications) and meet several other flow, head, temperature, speed, and bowl diameter characteristics.

Based on the recommendations of the CIP Working Group, DOE elected to reserve circulator pumps and dedicated-purpose pool pumps for separate rulemakings (CIP Working Group 2015) and has pursued these in two negotiations (DOE 2015b; DOE 2016c).

Metric and Test Procedure. In the 2016 general pumps TP final rule, DOE established a new metric, the pump energy index (PEI), to rate the energy performance of general pumps inclusive of motor and controls. DOE adopted a similar metric for all pump configurations (*i.e.*, bare pumps, pumps sold with a motor, and pumps sold with a motor and continuous or non-continuous controls) to allow for better comparability and more consistent application of the rating metric for all general pumps. This way, the benefit of speed control can be reflected in the measurement of energy use or energy efficiency. Specifically, DOE adopted the constant load pump energy index (PEI_{CL}) for pumps sold without continuous or non-continuous controls and the variable load pump energy index (PEI_{VL}) for pumps sold with either continuous or non-continuous controls. Both PEI_{CL} and PEI_{VL} describe the weighted average power consumption of a rated pump inclusive of an electric motor and, if applicable, any integrated continuous or non-continuous controls, normalized with respect to the performance of a minimally compliant pump without controls as shown in equation 1 (DOE 2016a):

$$PEI_i = \frac{PER_i}{PER_{STD}} \qquad \textbf{Eq. 1}$$

Where:

PER_i = the constant load pump energy rating (PER_{CL}) for bare pumps or pumps sold with motors or the variable load pump energy rating (PER_{VL}) for pumps sold with motors and continuous or non-continuous controls (hp), and
PER_{STD} = the PER_{CL} for a pump of the same equipment class with the same flow and specific speed characteristics that is minimally compliant with DOE's energy conservation standards serving the same hydraulic load (hp).

For pumps sold as a bare pump or pumps sold with motors, PER_{CL} is calculated as the weighted average input power to the motor at load points corresponding to 75, 100, and 110 percent of flow at the BEP of the pump (BEP flow),[3] as shown in Eq. 2**Error! Reference source not found.**:

$$PER_{CL} = \sum_{i=75\%,100\%,110\%} \omega_i P_i^{in,m} = \omega_{75\%}\left(P_{75\%}^{in,m}\right) + \omega_{100\%}\left(P_{100\%}^{in,m}\right) + \omega_{110\%}\left(P_{110\%}^{in,m}\right) \qquad \textbf{Eq. 2}$$

Where:

ω_i = weighting at load point i (equal weighting or 0.3333 in this case),
$P_i^{in,m}$ = measured or calculated driver power input to the motor at load point i (hp), and
i = load point corresponding to 75, 100, or 110 percent of BEP flow as determined in accordance with the DOE test procedure.

[3] DOE's test procedure evaluates pumps at full impeller diameter, nominal speed, and a specific number of stages for RSV and ST pumps. The BEP for the pump is defined as "the pump hydraulic power operating point (consisting of both flow and head conditions) that results in the maximum efficiency" and all references to the BEP in this document refer to BEP as determined in accordance with the DOE test procedure. 10 CFR 431.464.

Similarly, for pumps sold with a motor and continuous or non-continuous controls, PER_{VL} is calculated as driver power input to the continuous or non-continuous controls at load points corresponding to 25, 50, 75, and 100 percent of BEP flow, as shown in Eq. 3:

$$PER_{VL} = \sum_{i=25\%,50\%,75\%,100\%} \omega_i P_i^{in,c} = \omega_{25\%}\left(P_{25\%}^{in,c}\right) + \omega_{50\%}\left(P_{50\%}^{in,c}\right) + \omega_{75\%}\left(P_{75\%}^{in,c}\right) + \omega_{100\%}\left(P_{100\%}^{in,c}\right) \quad \textbf{Eq. 3}$$

Where:

ω_i = weighting at load point i (equal weighting or 0.25 in this case),

$P_i^{in,c}$ = measured or calculated driver power input to the continuous or non-continuous controls at load point i (hp), and

i = load point corresponding to 25, 50, 75, or 100 percent of BEP flow as determined in accordance with the DOE test procedure.

In both cases, PER_{STD} is determined as the PER_{CL} of a baseline, minimally-compliant pump, inclusive of a minimally-compliant default motor. The pump efficiency at each load point for the minimally-compliant pump is determined based on a calculation that is defined as a function of flow and specific speed of the rated pump, as shown in Eq. 4:

$$\eta_{pump,STD} = -0.8500 * \ln(Q_{100\%})^2 - 0.3800 * \ln(Ns) * \ln(Q_{100\%}) - 11.480 * \ln(Ns)^2 + 17.800 * \ln(Q_{100\%}) + 179.800 * \ln(Ns) - (C + 555.60) \quad \textbf{Eq. 4}$$

Where:

$Q_{100\%}$ = BEP flow rate (gpm),

Ns = specific speed at 60 Hz and calculated using U.S. customary units, and

C = a constant that is set for the two-dimensional surface described by Eq.5,[4] which is set based on the speed of rotation and equipment variety of the pump model. The values of this constant, or “C-values,” are used for determining pump efficiency for the minimally-compliant pump and are established in the pump energy conservation standard rulemaking (see “Standards” section).

Based on the equation for pump efficiency at BEP for the minimally-compliant pump, shown in Eq. 4, the general pumps test procedure then describes how to calculate the input power at each load point based on the measured hydraulic power of the rated pump, an assumed hydraulic efficiency offset, a default motor efficiency, and an assumed relationship of motor efficiency to motor load, as shown in Eq. 5:

$$P_i^{in,m} = \frac{P_{u,i}}{\alpha_i \times \left[\eta_{pump,STD}/100\right]} + L_i \quad \textbf{Eq. 5}$$

Where:

$P_{u,i}$ = the measured hydraulic output power at load point i of the tested pump (hp);

α_i = hydraulic efficiency offset of 0.947 for 75 percent of the BEP flow rate, 1.000 for 100 percent of the BEP flow rate, and 0.985 for 110 percent of the BEP flow rate;

$\eta_{pump,STD}$ = the minimally-compliant pump efficiency, determined in accordance with Eq. 4;

L_i = the motor losses at load point i, determined based on a default motor efficiency and assumed motor loss curve; and

i = load point corresponding to 75, 100, or 110 percent of BEP flow.

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[4] A visualization of this 2-dimensional surface described by Eq. 5 can be found in DOE 2013a.

The default motor efficiency values are based on the minimum nominal full load motor efficiency values for polyphase, NEMA Design B motors from 1 to 500 hp, defined in 10 CFR part 431, subpart B for medium and large electric motors, except for submersible motors. DOE defined a unique table of submersible motor efficiencies to use when calculating the PER_{STD} for ST pumps (and PER_{CL} for ST pumps sold as bare pumps). The nominal full load motor efficiency value is then used to determine the full load losses, in horsepower, associated with that motor. The full load losses are then adjusted using an algorithm to reflect the motor performance at partial loads, corresponding to the load points specified in the DOE test.

Standards. The energy conservation standards established for pumps are expressed as a maximum PEI of 1.00, which means that the PER for any given pump must be less than or equal to the PER_{STD} corresponding to flow and specific speed of the given pump. PER_{STD} (Eq. 4) is fully specified using the C value, which differs by equipment class.

In evaluating standards, DOE considered efficiency levels representing various efficiency percentiles, including 10, 25, 40, 55, and 70. The adopted C value, recommended by the CIP Working Group, was designed to represent the 25^{th} efficiency percentile (DOE 2016b). This means that DOE estimated, using a database it compiled of the performance of existing pumps within the scope of its rulemaking, that 25% of pump models in the market have lower efficiency than the defined efficiency function.

The efficiency levels represent only available improvements resulting from hydraulic design. DOE did not consider the addition of a speed control (*i.e.*, continuous or non-continuous controls) as design options because there are many application types and load profiles that would not benefit from a VSD, and even some for which energy use would increase (*i.e.*, constant load situations for which the VSD would only add power consumption with no benefit) (DOE 2016b). However, manufacturers may choose to invest in either hydraulic redesign or motor and control improvements or additions when seeking to meet the new standards.

Potential Opportunities for Increasing the Energy Efficiency of Pumps.

DOE's new PEI metric allows for the development of equipment performance ratings and standardizes the quantification and comparison of energy savings from a variety of efficiency improvements to the pump performance. Currently, pumps are often incentivized as a custom measure, which may reduce widespread participation in such incentive programs and also makes implementation more cumbersome. Creating approaches that do not require unique calculations and metering for each pump application and enable pumps to be treated more like a "deemed" measure[5] could help address these barriers. Specifically, while requirements vary based on the specific utility or program, energy efficiency incentive programs typically require two key inputs for each measure: (1) a specification that describes the required attributes of the measure and (2) an estimate of energy savings associated with each "unit" of the measure that is installed. The description of these measures vary from "deemed measures" to unique, one-off custom measures. Deemed measures, which rely on upfront analysis, estimate the average savings associated with each given installation of the product in a given application and provide a fixed amount of incentive for each unit based on the estimate. Once the specifications and estimated

[5] A deemed measure is an energy efficiency measure that has pre-determined, validated estimates of energy and peak demand savings attributable to it in a particular application.

savings are established, these programs are easy both to implement and for customers to participate in, typically resulting in greater market penetration. For situations where savings are more variable or harder to predict, there are custom programs that can have various amounts of standardization, from simplified calculators to completely custom test-in/test-out programs.

DOE's new metric can be used to both easily communicate the desired energy performance of a pump under an energy efficiency program, as well as estimate the likely energy savings associated with the program. The PEI is a normalized metric, which results in a value that is indexed to the standard (*i.e.*, a value of 1.0 for a pump that is minimally compliant, and a value less than 1.0 for a pump that is more efficient than the standard requires). Programs can easily provide tiers or rankings based on PEI to specify the desired performance of qualified pumps above the market baseline. For example, a PEI below ~0.70 would effectively differentiate pumps with continuous or non-continuous controls from single-speed pumps.[6] Such an approach could achieve the same result as many existing custom utility energy efficiency programs that incentivize the use of VSDs in certain applications, but with a more flexible and technology-neutral approach.

DOE's new metric and reporting information can also be used to develop methods for estimating the energy savings from pumps in different applications, with potential methods varying in degree of complexity, depending on the application, pump configuration, and required degree of accuracy and precision, both on a population and site-specific basis. These include (1) a simple PEI-based estimation (method 1), (2) a PEI-based estimation with an adjustment factor (method 2), (3) a PER-based approach (method 3), and (4) a calculation based on the input power to the pump at each load point (method 4), as summarized in Table 1.

Table 1. Summary of Energy Savings Estimation Methods for Pumps

Method	Inputs	Summary	Increasing Complexity
(1) PEI difference	PEI_{CL} or PEI_{VL}, MotorHP (or η_{motor})	Simple difference between PEI value for rated pump and PEI baseline	↓
(2) PEI difference with adj. factor	PEI_{CL} or PEI_{VL}, MotorHP (or η_{motor}), Adjustment factor	Difference between PEI value for rated pump and PEI baseline with an application-specific adjustment factor	↓
(3) PER difference (with or without adj. factor)	PER_{CL} or PER_{VL}, Adjustment factor	Difference between PER value for rated pump and PER baseline with an application-specific adjustment factor	↓
(4) Input power calculation	P_i^{in}, weights for each load point	Weighted average input power at different load points for the rated pump compared to a baseline	↓

[6] This value was derived based on the value of PEI_{CL} and PEI_{VL} for a similar bare pump and motor without and with continuous controls, respectively, calculated using the calculation-based approaches in the DOE test procedure (DOE 2016a). The underlying bare pump data was from DOE's pump performance database.

To give context to the discussion and to compare the different methods, first consider the key variables of the energy savings calculation, shown in Eq. 6:

$$S_j = \sum_i \left(P_{i,pre} - P_{i,post}\right) \times H_i \qquad \textbf{Eq. 6}$$

Where:

S_j = the expected energy savings from the measure in each application j (kWh),
$P_{i,pre}$ = input power to the baseline pump (kW),
$P_{i,post}$ = input power to the new, efficient pump at each load point i (kW),
H_i = operating hours at each load point i (hr), and
i = load points of operation.

Eq. 6 provides a method of estimating the energy savings for any given application j. An average (or weighted average) of the savings in each application can then be determined and applied to all applications to provide a simple, consistent estimate of the energy savings associated with each efficient pump installation. However, depending on the variability of the load profile and operating hours associated with each application, it may make sense to consider and incentivize each application uniquely.

The pump PEI reflects the weighted average input power to the pump as representative operating points divided by the representative power consumption of a minimally-compliant pump. Therefore, the PEI of a rated pump can be used to easily estimate the post-retrofit power consumption of the pump, as compared to a baseline pump, by subtracting the PEI of the rated pump from that of the baseline product and multiplying by the pump input power, as in Eq. 7:

$$P_{i,pre} - P_{i,post} = \left(PEI_{baseline} - PEI_{efficient}\right) \times P_{in} = \left(1.00 - PEI_{efficient}\right) \times (MotorHP \times 0.7457) \qquad \textbf{Eq. 7}$$

Where:

$P_{i,pre}$ = input power to the baseline pump (kW),
$P_{i,post}$ = input power to the new, efficient pump at each load point i (kW),
$PEI_{baseline}$ = the PEI of the baseline pump (dimensionless),
$PEI_{efficient}$ = the PEI of the efficient pump (dimensionless), and
MotorHP = the horsepower of the motor with which the pump is being sold (hp).

In this example (method 1), the $PEI_{baseline}$ is estimated as 1.00, which is the Federal minimum standard level beginning on January 27, 2020. However, for programs today, it would be more appropriate to select a higher value that is more representative of the market baseline. In DOE's January 2016 general pumps ECS final rule, DOE found the least efficient pumps to have a PEI between 1.40 and 1.10. Eq. 7 also demonstrates how the input power (kW) to the motor could be estimated based on readily available information (*e.g.*, motor horsepower). Since changes in motor efficiency are already captured in PEI, using the horsepower of the motor will give a reasonable estimate of the likely change in power consumption. However, to improve the accuracy, one could also divide the motor horsepower by the known efficiency of the baseline motor or the Federal minimum standard for electric motors. Such an approach is currently being considered by the HI as part of the ACEEE EMPLI (Rogers 2014).

This simplified calculation is likely to be accurate on a population-basis, but may not be accurate for any given pump application. The degree to which the PEI estimation approach accurately estimates the energy savings associated with any given pump, or a population of pumps, depends on the degree to which the load points and weights assumed in the PEI metric are representative of the operating load profile of any given pump in any given application. Given the wide variation in system operation and applications for the general pumps subject to the DOE test procedure, the PEI_{CL} assumes load points of 75, 100, and 110 percent of BEP flow, and assumes that the pump spends, on average, equal amounts of time at each load point. The PEI_{VL} assumes load points of 25, 50, 75, and 100 of BEP flow and, similarly, assumes the pump spends an equivalent amount of time at each load point. If the load profile in a given application is significantly different than that in the PEI_{CL} and PEI_{VL} metrics, the energy use and subsequent energy savings achieved in the field may be more or less than that estimated based on PEI.

A sensitivity analysis of the PEI metric and savings estimates to the variability in load profiles and weights suggests that PEI_{CL} is not very sensitive to variations in load profile, while PEI_{VL} is much more sensitive due to the cubic relationship of power to operating speed and, therefore, large spread in input power values between the 25 and 100 percent of BEP flow load points. Specifically, for PEI_{CL}, the energy savings estimates varied, on average, 0.96 percent over a population of 1,500+ unique pump models (with a maximum variance of 29 percent) when considering four unique variations from the constant load profile.[7] Conversely, the energy savings estimates calculated based on PEI_{VL} (for pumps sold with continuous or non-continuous controls) varied an average of 58 percent (with a max variance over 100 percent for profiles that assumed significant operating hours at high load points). Therefore, it may be acceptable to determine the energy savings for pumps sold as bare pumps or with motors based on a simplified PEI calculation, as in method 1, but additional considerations may be necessary when estimating the energy savings associated with continuous or non-continuous controls in any given application (method 2).

To develop more accurate estimates of energy savings for applications with load profiles significantly different than that assumed in the calculation of PEI, a utility could develop application-specific savings estimates based on the load profiles in those specific applications they were considering incentivizing. For example, if a utility knew that pumps installed in cooling water applications operated or could operate the majority of hours at load points of 25 and 50 percent of BEP flow and very few hours at higher load points, the energy savings from installing a variable speed pump would be greater than that estimated by PEI, and an adjustment factor of 1.44 could be applied to account for those additional savings.[8] This example is illustrative, and could be performed for any weights associated with any of the PEI_{CL} or PEI_{VL} load points. Such a factor will significantly improve the accuracy of the estimated savings for a given application; however, the specific performance of any given pump at the relative load points will not be captured. That is, if a certain pump has the same PEI as another pump but performs better at lower loads, that pump would likely yield more energy savings in the cooling water example above; this would not be captured by the adjustment factor since it would be representative of the average change in PEI across many pump models.

Either PEI-based approach discussed above (simple or adjusted) could also be performed with the pump's PER and, since the PER is the non-normalized weighted average input power to the pump, no assumption or information regarding the input power to the motor or motor efficiency would be required (method 3). However, PER is not required to be on the label for participating pumps, while PEI is (see 10 CFR 431.466).

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[7] The sensitivity analysis assumed the following load profiles: very low, low, BEP, high, and highest, all of which adjusted the weights to skew the distribution of hours low or high (or extremely central) depending on the scenario.
[8] The value 1.44 was estimated based on adjusting the weights from 0.25 at all PEI_{VL} load points to 0.40 at load points of 25 and 50 percent of BEP flow and 0.1 at load point of 75 and 100 percent of BEP flow for all the pumps in DOE's pump performance database.

Finally, for situations with application-specific information or where high confidence is required, DOE's regulations also include certification reports that contain detailed and comprehensive information on pump performance for each measured load point that could be used to estimate savings for any given pump model uniquely (method 4). Specifically, in the January 2016 general pumps ECS final rule, DOE specified that the certification report for each basic model must, among other things, contain the driver input power to the motor or motor and controls (P_i^{in}), as applicable. With such information and a good understanding of the load profile for any given pump or application, one could precisely calculate the weighted average power consumption for that case. However, pump manufacturers are not required to submit such information to DOE until after the compliance date (specifically, September 1, 2020; see 10 CFR 429.12(d)). Pump manufacturers are also not required to certify the PEI of applicable pump models until that time, but may elect to do so early to support such efficiency programs. Also, once such information is available, PEI will be listed on the label of each pump (see 10 CFR 431.466), while other information may not be as standardized.

It is worth noting that, regardless of the method used to estimate the change in power consumption between the baseline pump and the efficient pump, an estimation of operating hours is still required on a site-specific or application-specific basis. As little such information exists, and the operating hours are quite variable even within a given application, it is likely that the variability in the estimated operating hours will significantly affect the accuracy of any energy savings estimate for a given application or installation, regardless of the method selected.

Conclusion

As pumps consume approximately 2 quads of energy per year, energy-efficient pumps present a significant opportunity for utilities and energy efficiency programs to pursue energy savings. Since existing pump incentive programs are typically custom or specific to a given application, widespread participation and market uptake has not been as high as it could be with a more stream-lined or "deemed" approach.

DOE's new PEI metric evaluates the energy use of the pump, including any motor or controls and, therefore, affords the opportunity to identify energy savings from a variety of pump and motor efficiency improvements as well as the addition of speed controls. The PEI can be used to easily communicate the desired energy performance of a pump under any energy efficiency program, as well as estimate the likely energy savings associated with the program based on a variety of potential methods (Table 2).

Table 2. Summary of Energy Savings Estimation Methods for Pumps

Method	Inputs	Benefits	Issues
(1) PEI difference	PEI_{CL} or PEI_{VL}, MotorHP (or η_{motor})	Simple to calculate and implement	May be inaccurate for load profiles significantly different from those assumed in the PEI calculation (larger issue for variable load applications); input power estimated based on motor information
(2) PEI difference with adj. factor	PEI_{CL} or PEI_{VL}, MotorHP (or η_{motor}), Adjustment factor (based on variation in load profile from PEI assumption)	Relatively simple to calculate and implement; accounts for variation in savings due to variation in load profiles for different applications	Does not account for differences in performance at different load points among equipment; input power estimated based on motor information
(3) PER difference (with or without adj. factor)	PER_{CL} or PER_{VL}, Adjustment factor (based on variation in load profile from PEI assumption)	Same as method (2); directly measures input power to motor	PER is not required to be on the pump label
(4) Input power calculation	P_i^{in}, weights for each load point (based on the specific application)	Most accurate in characterizing efficient pump performance (assumptions still required for baseline pump)	Most burdensome calculation, P_i^{in} information may not be available until September 1, 2020

While the necessary accuracy for any pumps energy saving estimate will vary based on the specific utility or program, the PEI provides an important foundation for standardization and accessibility of information. However, any energy savings estimate typically requires two key inputs: (1) the estimated reduction in power consumption between the baseline and efficient cases and (2) the operating hours of the equipment, potentially disaggregated by application or other factor. It is likely that the variability in operating hours and/or load profile by application will impact the accuracy of any savings estimate as much or more than the difference in pump performance. Therefore, future efforts on behalf of the utilities to develop and validate such programs should focus resources on collecting operating data to supplement existing estimates regarding relative pump performance provided by PEI and the new DOE regulations.

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