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NAVIGATING THE DEPARTMENT OF ENERGY (DOE) ENERGY CONSERVATION STANDARD AND TEST PROCEDURE FOR PUMPS

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ABSTRACT

Following the European Union's (EU) lead, the United States (US) Department of Energy (DOE) began the long process of regulating the energy consumption of pumps in 2011 and, with support from the industry and advocates, published a final Energy Conservation Standard (ECS) and Test Procedure (TP) for Pumps (US Department of Energy 2016a) in January 2016. Compliance to the standard levels set in the ECS is slated for January 27, 2020.

The rulemaking process was very thorough involving many stakeholders; however, the complexity of the standard and inexperience in the United States leaves many pump manufacturers, engineering procurement contractors, consultants, and end users with uncertainty regarding the requirements and impact of the regulation. Since this is a first for the United States, this paper will address the contents of the ECS and TP to provide an understanding of the scope; implications to the manufacturer, end users, and other interested parties; and the benefits of the rule and future voluntary product energy labeling initiatives.

INTRODUCTION

Global energy standards for pumps are new to the industry. European Lot 11 regulations took effect in 2013 and progressed in 2015, and the US regulation for commercial and industrial clean water pumps will take effect in January 2020. Additionally in the United States there are separate rulemakings in process for dedicated-purpose pool pumps and circulator pumps.

The US pump industry has experience complying with safety, design, and other industry standards written by trade associations or end user groups; however, the industry has never dealt with a law regulating the energy consumption of products. The industry must pay close attention to the published regulations and be proactive in future regulations to ensure compliance can be achieved.

As has occurred with electric motors, it is expected that US pump energy standards will progress vertically and horizontally. Evidence of this can be seen in Europe where existing standards have progressed and other pump types outside of clean water and rotodynamic uses are being evaluated for energy conservation standards.

As pump energy conservation standards progress, it will be more difficult to achieve the required energy savings through pump efficiency alone; therefore, an extended product or system approach will be required to achieve the energy savings. More and more, pumps will be sold with motors and controls. Additional training of the specifier, installer, and end user will be required to ensure that published energy savings are achieved and that "intelligent" systems are not misapplied, resulting in reduced functionality, reliability, and potentially increased power consumption when misapplied.

PROBLEM STATEMENT

The US pump industry is not experienced with energy conservation standards, and there is a lack of understanding of the recently released ESC and TP for pumps.

Manufacturers must understand the following:

- Scope of regulated product
- Procedures to accurately and repeatedly measure pump efficiency
- How to determine if products are compliant
- Multiple rating options based on the way the pump or extended product is sold in commerce
- Certification and labeling requirements

End users must understand the following:

- Scope of products
- Impact on available product
- Assumptions made in the calculation that affect energy representation
- Implications of the system interaction

Awareness must be raised and training provided so that the affected parties understand the impacts to the industry and benefits of the regulations.

DOE ENERGY CONSERVATION STANDARD AND TEST PROCEDURE FOR PUMPS – PROCESS AND HISTORY

Title III of the Energy Policy and Conservation Act (EPCA) of 1975, as amended (42 U.S.C. 6291 et seq.) (United States of America in Congress, 2013), sets provisions to improve energy efficiency. Under Part C Section 340 of EPCA, pumps are listed as a type of industrial equipment that meets the definition of "covered equipment." EPCA gives the DOE the statutory authority to regulate the energy consumption of pumps as industrial equipment.

Among the objectives of EPCA are to increase domestic energy supplies and availability, to restrain energy demand, and to prepare for energy emergencies. To this end, and following the standards developed by the EU, on June 13, 2011 DOE enacted its statutory authority to regulate pumps when a Request for Information (RFI) (US Department of Energy, 2011) was issued regarding commercial and industrial pumps.

In the RFI, DOE estimated that commercial, industrial, and agricultural pumps consume 0.63 quadrillion Btus (quads) per year, and that technologies exist that could reduce this consumption by approximately 0.19 quads annually. DOE further asked for information from the public relating to definitions, energy use, and the pump market, including efficiencies and applicable test procedures.

The RFI began a five-year process of communication between the DOE and industry trade associations and the members thereof to develop a Notice of Proposed Rule (NOPR) and subsequent final rules for the ECS and TP for pumps. The ECS and TP development process for pumps is illustrated in Figure 1.

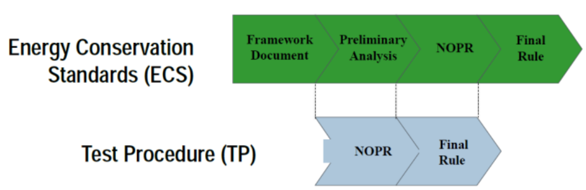


Figure 1. Test Procedure and Standards Rulemaking Process (US DOE 2013b)

As part of the preliminary analysis portion of the rulemaking, the stakeholders agreed that a negotiated rulemaking through the Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) would result in the best outcome for all interested parties. This resulted in a Notice of Intent (NOI) (US DOE, 2013a) to establish a commercial and industrial pumps working group to develop a NOPR for the ECS and TP for pumps.

The ASRAC working group membership was made up of manufacturers, trade associations, energy advocates, end users, an ASRAC designee, and the US DOE representative. The mission of this group was to educate each other, collect required data, and negotiate and agree to a term sheet that would be recommended to the DOE as the basis for a NOPR.

To support the mission of the working group, the Hydraulic Institute worked with the DOE, the ASRAC working group, and its members to facilitate the gathering of performance data on more than 3000 clean water pumps. These data were at the heart of the negotiation and eventual setting of standard levels for pumps. Through hard work and negotiation, the goal was achieved on June 29, 2014 when the working group reached consensus on a term sheet (Commercial & Industrial Pump Working Group, 2014).

When translating the term sheet to proposed and final rules, the requirements of EPCA must be met. The DOE must consider seven factors during the development and analysis of the standards setting to verify that the standards set can be achieved by manufacturers and are economically justified. The following seven factors were analyzed by DOE in consideration of the final regulation:

1. Economic impact on consumers
2. Lifetime operating cost savings compared to the incremental cost of more energy efficiency equipment
3. Utility and performance impacts
4. Energy savings for a specified time period
5. Impact on competition
6. Need for national energy conservation
7. Other factors the Secretary of Energy considers relevant

DOE considered the above factors along with the term sheet and published NOPRs for both the ECS and TP in April 2015. Along with NOPRs, a technical support document (TSD), government regulatory impact model (GRIM), national impact analysis (NIA), and life-cycle cost (LCC) analyses were published to meet the requirements of EPCA and support the proposed rules. The published NOPRs and supporting documents exceeded 1000 pages, which gives an indication of the amount of work required by the DOE and stakeholders to develop the ECS and TP.

Stakeholders reviewed the proposed rules, documentation provided, attended a public hearing on the proposed rule, and then submitted comments regarding the proposed rules. DOE considered all of the stakeholder's comments and addressed them in the final TP and ECS, which were published in the Federal Register on January 25, 2016 and January 26, 2016, respectively.

SCOPE

The term "pump" is listed in EPCA; however, it was undefined. For the purpose of the rulemaking scope, a definition was created as follows: Pump means equipment that is designed to move liquids (which may include entrained gases, free solids, and totally dissolved solids) by physical or mechanical action and includes at least a bare pump and, if included by the manufacturer at the time of sale, mechanical equipment, driver, and controls. DOE noted that this broad definition for "pump" would provide DOE with flexibility to make any necessary adjustments to its regulations to address potential scoping changes in the future that DOE may consider.

As noted by the DOE, the definition of pump is broad and designed to include all conceivable pump types. As recommended in the term sheet, the scope of the ECS and TP was limited to rotodynamic pumps designed for clean water that fall into five specific equipment categories and further limited by performance and design features.

Table 1 provides a summary of the pump types, DOE and industry nomenclature, and scope inclusions and exclusions. To view larger images and full definitions for each pump type, visit the following link:

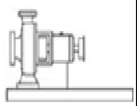
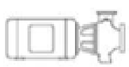
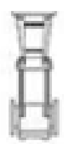
http://www.pumps.org/DOE_Pumps.aspx

The refined scope of the ECS and TP for pumps is inclusive of five pump equipment classes designed for clean water:

1. End suction frame mount (ESFM)
2. End suction close coupled (ESCC)
3. In-line (IL)

4. Radially split multistage vertical in-line diffuser casing (RSV)
5. Submersible turbine (ST), with 6-in or smaller bowl diameter

Table 1. ESC & TP for Pumps Final Rule Scope Summary

Pump Type Diagram	Nomenclature (DOE)/[Industry]	Scope Refinement
	End Suction Frame Mount (ESFM) [OH0, OH1]	**Included** Clean Water 1 – 200 hp Flow ≥ 25 gpm Head ≤ 459 ft 14°F to 248°F 3600/1800 rpm Ns ≤ 5000 **Clean water excluded** Sanitary spec Nuclear spec Mil spec Mag-drive Fire pump Self-priming Prime assist Circulators Pool pumps **Nonclean water** Wastewater Slurry API – 610 ASME B73
	End Suction Close Coupled (ESCC) [OH7]	
	In-line (IL) [OH3, OH4, OH5]	
	Radially Split Multistage Vertical In-line Diffuser Casing (RSV) [VS8]	
	Submersible Turbine (ST) [VS0]	

The scope is further bounded by power, performance, and design characteristics as follows:

- Clean water pump design
- 1 – 200 hp (150 kW) at best efficiency point (BEP) rate of flow for full impeller diameter
- BEP rate of flow ≥ 25 gpm (1.57 L/s) for full impeller diameter
- Head ≤ 459 ft (140 m) at BEP rate of flow for full impeller diameter
- Design temperature range of 14°F to 248°F (-10°C to 120°C)
- Nominal speed of rotation of 3600 rpm (2880 – 4320 rpm) or 1800 rpm (1440 – 2160 rpm)
- Specific speed (Ns) ≤ 5000 (US customary units)

The basis of the scope for each pump equipment category is that the pump is designed for clean water. A clean water pump is defined as a pump that is designed for use in pumping water with a maximum nonabsorbent free solid content of 0.016 lb/ft^3 (0.25 kg/m^3), and with a maximum dissolved solid content of 3.1 lb/ft^3 (50 kg/m^3), provided that the total gas content of the water does not exceed the saturation volume and disregarding any additives necessary to prevent the water from freezing at a minimum of 14°F (-10°C).

The clean water design requirement specifically excludes the pump types that are designed for chemical processing, oil and gas, wastewater, or slurry applications.

Additionally specific kinds of clean water pumps that would otherwise meet the defined scope were excluded as follows:

- Sanitary spec. pumps
- Nuclear spec. pumps
- Military spec. pumps
- Magnetically driven pumps
- Fire pumps
- Self-priming pumps
- Prime-assist pumps
- Circulator pumps
- Dedicated-purpose pool pumps

These specific kinds of clean water pumps were excluded for various reasons ranging from little energy savings potential, safety, unique designs, or for consideration under a separate standard. Two application-type pumps that were excluded are circulator pumps and dedicated-purpose pool pumps, which currently have ASRAC working groups negotiating ECSs and TPs.

THE TEST PROCEDURE

The final TP for pumps establishes the requirements to test equipment within scope, methods to calculate performance metrics, as well as associated definitions and parameters that establish the scope of applicability of the TP and how to determine and certify compliance.

The Hydraulic Institute worked with the DOE to develop a normative industry test standard that could be referenced in the final TP.

HI 40.6-2014 Methods for Rotodynamic Pump Efficiency Testing was completed in June of 2014 (Hydraulic Institute, 2014) and was incorporated by reference in the final TP.

HI 40.6-2014 is derived from ANSI/HI 14.6-2011, extracting the material that pertains specifically to the determination of the efficiency of a rotodynamic pump with no criteria for acceptance because it was developed as a normative standard solely for the consistent determination of rotodynamic pump efficiency.

THE NEW STANDARD

Differing from previous EU regulations for clean water pumps that only considered the bare pump, the ECS is inclusive of a driver and controls when applicable.

The ESC sets standard levels and the TP lays out a methodology to determine if equipment is compliant as follows:

- Determine the Pump Energy Rating (PER), in which the weighted average power consumption of the equipment is being rated inclusive of the driver and controls when applicable. PER can be constant load (CL) or variable load (VL) and;
- Determine the Pump Energy Rating Standard (PER_{STD}), which is the standard weighted average power consumption for a minimally compliant pump inclusive of a minimally compliant bare pump and a minimally compliant driver and;
- Determine Pump Energy Index (PEI), which is the constant load (CL) or variable load (VL) PER divided by the PER_{STD}. PEI is the final metric used to determine if the rated equipment is compliant with the standard. For rated equipment to be compliant the PEI must be 1.0 or less.

$$\mathrm{PEI_{CL}} = \frac{\mathrm{PER_{CL/VL}}}{\mathrm{PER_{STD}}} \leq 1.00$$

Table 2 is a summary of all the performance metrics outlined in the TP for pumps.

Table 2. Performance Metric Summary

Performance Metric		Constant Load	Variable Load
Standard Level	C-Value	Independent	
Standard Pump Efficiency	$\eta_{pump,STD}$	Independent	
Standard Pump Energy Rating	PER_{STD}	Independent	
Pump Energy Rating (Product)	PER	PER_{CL}	PER_{VL}
Pump Eneryg Index (Product)	PEI	PEI_{CL}	PEI_{VL}

The following will be expanded on in the upcoming sections, but simplistically the metrics can be described as follows:

- **C-value** - Along with bare pumps' BEP rate of flow and specific speed, the C-value sets the standard pump efficiency ($\eta_{pump,std}$) for an equipment class.
- **$\eta_{pump,std}$** – Used with the hydraulic power at the bare pump load points along with standard driver losses to calculate the PER_{STD}.
- **PER_{STD}** – The minimally compliant weighted average power consumption for an equipment class inclusive of the minimally compliant driver. PER_{STD} is the basis to compare the power consumption of the equipment being rated.
- **$PER_{CL/VL}$** –The weighted average power consumption of the equipment being rated inclusive of standard or actual driver and control losses if applicable.
- **$PEI_{CL/VL}$**– Is either constant load or variable load depending if the equipment is supplied without or with controls. PEI is the ratio of $PER_{CL/VL}$ and the PER_{STD}.

STANDARD PUMP EFFICIENCY ($\eta_{pump,std}$)

In line with the EU, but using an adapted equation for US surveyed data, the standard efficiency for pumps ($\eta_{pump,std}$) is determined based a constant value (C) and other known variables that impact bare pump efficiency, which are pump specific speed (Ns) and rate of flow at BEP ($Q_{100\%}$). The equation for $\eta_{pump,std}$ is a quadratic polynomial describing a three-dimensional surface as shown in Figure 2. Figure 2 illustrates how the standard efficiency level changes based on the equation variables and compares the DOE surface to the EU surface.

$$\eta_{pump,STD} = -0.85\times\ln(Q_{100\%})^2 - 0.38\times\ln(N_S)\times\ln(Q_{100\%}) - 11.48\times\ln(N_S)^2 + 17.80\times\ln(Q_{100\%}) + 179.80\times\ln(N_S) - (C+555.60)$$

Where at nominal speed of rotation (n_{sp}):
$Q_{100\%}$ = Rate of flow, in gpm at the BEP
N_S = Pump specific speed = $N_S = \frac{n_{sp}*\sqrt{Q_{100\%}}}{(H_{100\%})^{0.75}}$
$H_{100\%}$ = Head, in ft at the BEP rate of flow

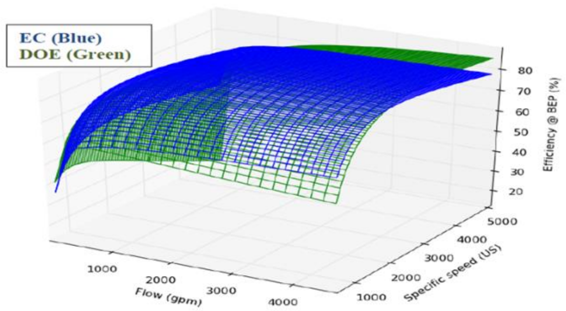


Figure 2. $\eta_{pump,std}$ Three-dimensional Surface, DOE Compared to EU

A data survey along with the $\eta_{pump,std}$ equation was used to calculate C-values for the equipment classes. Figure 3 is a summary of C-value data for 1800 rpm ESCC pumps surveyed as a function of specific speed. Note that percentile lines are overlaid on the chart. These lines represent the baseline level (5th percentile) and the negotiated standard level (25th percentile).

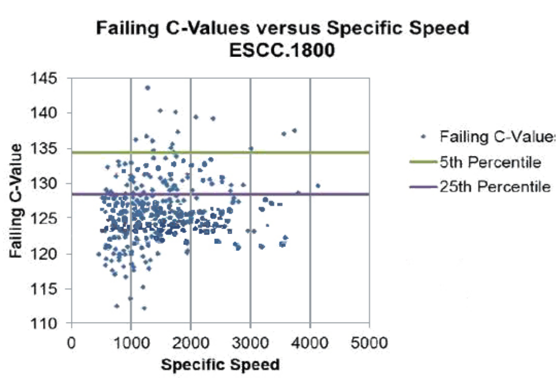


Figure 3. Failing C-value sample for ESCC Pump with 1800 rpm Nominal Speed of Rotation

Based on the survey data, a summary of C-values by pump types and percentile level is provided in Table 3. The $\eta_{pump,std}$ equations illustrate that the C-value is directly proportional to pump efficiency. For example, for two ESCC 1800 pumps of identical specific speed and BEP rate of flow, the efficiency of the 25th percentile (C-value – 128.47) would be 5.96 percent more efficient than the baseline level (C-value – 134.43).

Table 3. Pump Type C-value Summary by Percentile Standard Level Set

Equipment Class	EL0	EL2	EL4	EL5
	Baseline	25th Eff Percentile	55th Eff Percentile	70th Eff Percentile
ESCC 1800	134.43	128.47	125.07	123.71
ESCC 3600	135.94	130.48	127.35	125.29
ESFM 1800	134.99	128.85	125.12	123.71
ESFM 3600	136.59	130.99	127.77	126.07
IL 1800	135.92	129.3	126	124.45
IL 3600	141.01	133.84	129.38	127.35
RSV 1800	129.63	-	-	124.73
RSV 3600	133.2	-	-	129.1
ST 1800	138.78	-	-	127.15
ST 3600	138.78	134.85	129.25	127.15

The ECS published C-values (standard level) that set the minimally compliant efficiency for each equipment class as designated by the highlighted cells in Table 3. To arrive at the C-values, data was surveyed for all pump types except RSV 1800/3600 and ST 1800 pumps; therefore, in the ECS, the standard level for RSV 1800/3600 and ST 1800 pumps was set at the baseline level and for the remaining equipment classes the standard level was set at the 25th percentile, which is the level at which the least efficient 25% of pumps would be eliminated from commerce. Based on the standard levels set, DOE estimated 0.27 quads of energy will be saved from 2020 through 2050.

US data were not sufficiently surveyed for RSV types, so the standard level for RSV is harmonized with the EU level and designated as the baseline level.

The ST pumps included in the scope of the ECS are primarily well-type that are of 3600 rpm nominal speed design. Since 1800 rpm nominal speed models are not manufactured, data were not surveyed. To prevent a potential loophole, where 1800 rpm well pumps could be developed, DOE included a standard value for 1800 rpm ST pumps based on the baseline value for 3600 rpm ST pumps.

PUMP ENERGY RATING STANDARD (PER_{STD})

In the TP, standard load points for consideration are designated as 75 percent, 100 percent, and 110 percent of BEP rate of flow and they are equally weighted. The equipment is tested per HI 40.6-2014 to determine the BEP rate of flow and head, and to determine the rate of flow and head at 75 percent and 110 percent of BEP as shown in Figure 4. When determining the PER_{STD}, the pump power input and driver losses are not directly measured; they are determined from the hydraulic power at each load point divided by the standard pump efficiency and default driver losses at each load point as described below.

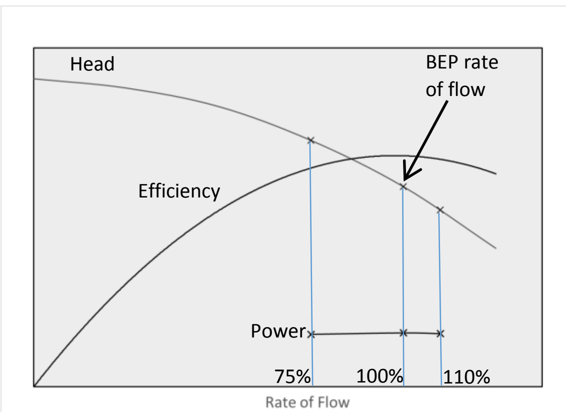


Figure 4. Graphical Representation Measurements and Standard Load Points to Determine PER_{STD}

The PER_{STD} is a function of the pump standard pump efficiency, the hydraulic power, and the standard driver losses at the designated load points at the nominal speed of rotation as expressed below.

$$\mathrm{PER_{STD}} = \sum \omega_i \left(P_{i,std}^{in}\right) = 0.3333 \times \left(\frac{P_{u75\%}}{0.947 \times \frac{\eta_{pump,STD}}{100}} + L_{75\%}^{std}\right) + 0.3333 \times \left(\frac{P_{u100\%}}{\frac{\eta_{pump,STD}}{100}} + L_{100\%}^{std}\right) + 0.3333 \times \left(\frac{P_{u110\%}}{0.985 \times \frac{\eta_{pump,STD}}{100}} + L_{110\%}^{std}\right)$$

Where:

$\boldsymbol{P_{i,std}^{in}}$ = Driver power input to minimally compliant pump

$\boldsymbol{\omega_i}$ = Weighting at load points, this is equal to 0.3333

$\boldsymbol{P_{u,i}} = \frac{Q_i * H_i}{3956}$ = Bare pump hydraulic power at the load point

$\boldsymbol{\eta_{pump,std}}$ = Standard bare pump efficiency

$\boldsymbol{L_i^{std}}$ = Standard driver part load losses at the load points

$\boldsymbol{i}$ = Load points 75%, 100%, and 110% of BEP

The standard driver losses applied are a function of the 120 percent of BEP rate of flow power consumption for a bare pump or the nameplate motor power rating for a pump sold with a driver or driver and controls. With the exception of ST pumps, the driver losses are based on the default minimum of the open or closed nominal full-load motor efficiency ($\eta_{motor,full}$) listed for two- and four-pole NEMA design B motors listed in 10 CFR 431.25(g).

Since ST pumps use motors that are not listed in 10 CFR 431.25(g), DOE surveyed motor manufacturers and published in the TP a default motor efficiency table for submersible motors.

In consideration of the PER_{STD} equation, the following calculations are made.

1. The standard default full-load motor losses($L_{full,std}$) are determined

$$L_{full,std} = \frac{Motor\ HP}{\frac{\eta_{motor,full}}{100}} - Motor\ HP$$

2. The standard part-load loss factors (y_i^{std}) at each load point

$$y_i^{std} = -0.4508 \times \left(\frac{P_i^{std}}{Motor\ HP}\right)^3 + 1.2399 \times \left(\frac{P_i^{std}}{Motor\ HP}\right)^2 - 0.4301 \times \left(\frac{P_i^{std}}{Motor\ HP}\right) + 0.6410$$

3. The part-load losses (L_i^{std}) at each load point are calculated based on the part-load loss factors and the standard full-load motor losses

$$L_i^{std} = y_i^{std} \times L_{full,std}$$

PUMP ENERGY RATING CONSTANT LOAD (PER_{CL})

For constant load ratings, the standard load points for consideration are identical to the PER_{STD} of 75 percent, 100 percent, and 110 percent of BEP rate of flow and they are again equally weighted. The equipment is tested per HI 40.6-2014 to determine the rate of flow (Q_i), head (H_i), and the bare pump power input (P_i) or the driver power input ($P_i^{in,m}$) at each load point at the nominal speed of rotation (n_{sp}).

Figure 5 illustrates the test curves and load points required to calculate the PER_{CL}. Note that the power input measurement is either for the bare pump or driver depending on how the manufacturer wishes to rate the pump and distribute it in commerce.

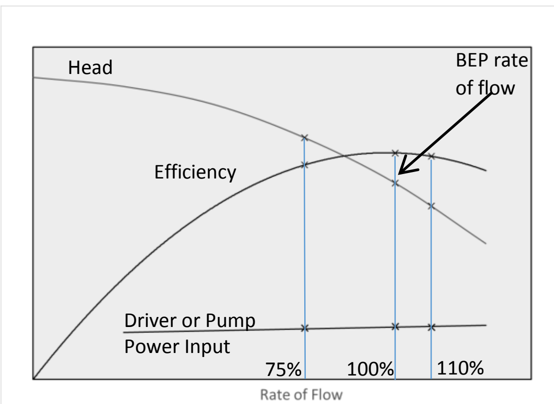


Figure 5. Graphical Representation Measurements and Standard Load Points to Determine PER_{CL}

As noted in Table 4, there are three methods to determine the PER_{CL}. The method used is dependent on the manufacturer's needs and how the pump will be distributed in commerce as described below. "Calculated" is listed in quotes because a physical bare pump test is still required and "calculated" refers to calculating and applying default loss factors for the driver in lieu of testing in a wire-to-water configuration.

- Method A.1 – PER_{CL} for a bare pump "calculated"
  - Bare pump test + standard driver loss calculations to determine PER_{CL}
- Method B.1 – PER_{CL} for a bare pump + driver "calculated"
  - Bare pump test + actual driver loss calculations to determine PER_{CL}
- Method B.2 – PER_{CL} for a bare pump + motor (tested)
  - Bare pump + actual driver wire-to-water test to determine PER_{CL}

In short, if the equipment will be sold in commerce as a bare pump or with a nonelectric driver, then method A.1 is the only option. If the equipment will be sold in commerce with an electric motor covered under 10 CFR 431.25(g) or a submersible motor, then methods A.1, B.1, or B.2 can be used depending on the requirements of the manufacturer.

Table 4. Applicability of Testing and "Calculation" Methods to Determine PER_{CL}

Pump Configuration	Pump sub-configuration	Calculation based test method	Testing based method
Bare Pump	Bare Pump	A.1: Tested Pump Efficiency of Bare Pump + Default Nominal Full Load Motor Efficiency + Default Motor Part Load Loss Curve	Not Applicable
Pump + Motor	Pump + Motor covered by DOE's Electric Motor Energy Conservation Standards OR Pump + Submersible Motor	B.1: Tested Pump Efficiency of Bare Pump + Represented Nominal Full Load Motor Efficiency for Actual Motor Paired with Pump + Default Motor Part Load Loss curve	B.2: Tested Wire-to-Water Performance
	Pump + Motor Not Covered by DOE's Electric Motor Energy Conservation Standards (Except Submersible Motors)	Not Applicable	B.2: Tested Wire-to-Water Performance

Determining PER_{CL} using Method A.1 is identical to the calculation of PER_{STD}, except the pump power input (P_i) is determined through testing instead of being calculated by the hydraulic power and the standard pump efficiency, as shown below.

1. Calculate full-load driver losses

$$L_{full,std} = \frac{Motor\ HP}{\frac{\eta_{motor,full}}{100}} - Motor\ HP$$

2. Calculated part-load loss factors

$$y_i^{std} = -0.4508 \times \left(\frac{P_i}{Motor\ HP}\right)^3 + 1.2399 \times \left(\frac{P_i}{Motor\ HP}\right)^2 - 0.4301 \times \left(\frac{P_i}{Motor\ HP}\right) + 0.6410$$

3. Calculated part-load losses

$$L_i^{std} = y_i^{std} \times L_{full,std}$$

4. Calculate the PER_{CL}

$$\mathrm{PER_{CL}} = 0.3333 \times \sum \left(P_i + L_i^{std}\right)$$

Determining PER$_{CL}$ using Method B.1 is only applicable for pumps distributed in commerce with motors under 10 CFR Part 431.25(g) or submersible motors. Pumps distributed in commerce with other motors must use method B.2. Identical to method A.1, the pump power input (P_i) is determined through testing; however, the nameplate nominal motor efficiency is used instead of the default table.

Exception: ST pumps do not use motors under an ECS; therefore, default motor efficiencies outlined in the TP must be used, but the nameplate motor power is used.

1. Calculate full-load driver losses

$$L_{full,NP} = \frac{MotorHP,NP}{\frac{\eta_{motor,full,NP}}{100}} - MotorHP,NP$$

2. Calculated part-load loss factors

$$y_i^{std} = -0.4508 \times \left(\frac{P_i}{Motor\ HP,NP}\right)^3 + 1.2399 \times \left(\frac{P_i}{Motor\ HP,NP}\right)^2 - 0.4301 \times \left(\frac{P_i}{Motor\ HP,NP}\right) + 0.6410$$

3. Calculated part-load losses

$$L_i^{std} = y_i^{std} \times L_{full,NP}$$

4. Calculate the PER$_{CL}$

$$\mathrm{PER_{CL}} = 0.3333 \times \sum\left(P_i + L_i^{std}\right)$$

Determining PER$_{CL}$ using Method B.2 eliminates the calculation of motor losses because the driver input power ($P_i^{in,m}$) is measured directly as shown below.

$$\mathrm{PER_{CL}} = 0.3333 \times \sum\left(P_i^{in,m}\right)$$

PUMP ENERGY RATING VARIABLE LOAD (PER$_{VL}$)

The TP states that equipment distributed in commerce with continuous or noncontinuous controls can be rated in a variable-load configuration. This is a rating advantage over equipment sold without these controls because the variable-load rating considers load points achieved by reducing the pump speed.

A continuous control is defined as a control that adjusts the speed of the pump driver continuously over the driver operating speed range in response to incremental changes in the required pump flow, head, or power output. As an example, variable speed drives, including variable frequency drives and electronically commutated motors, would meet the definition for continuous controls.

For pumps sold with continuous controls as identified above, a variable-load rating can be applied (PER$_{VL}$). The standard load points for consideration are 25 percent, 50 percent, 75 percent, and 100 percent of BEP rate of flow as determined by the intersection of the reduced speed pump curve and a standard control curve as shown in Figure 6.

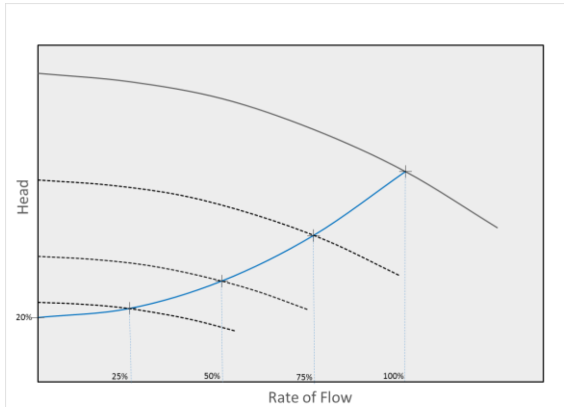


Figure 6. Graphical Representation of Measurements and Continuous Control Standard Load Points to Determine PER$_{VL}$

A noncontinuous control is defined as a control that adjusts the speed of a driver to one of a discrete number of noncontinuous preset operating speeds and does not respond to incremental reductions in the required pump flow, head, or power output. As an example, multispeed motors, such as two- or three-speed motors, meet the definition.

For pumps sold with noncontinuous controls as identified previously, a variable load rating can be applied (PER$_{VL}$). The standard load points for consideration are 25 percent, 50 percent, 75 percent, and 100 percent of BEP rate of flow; however, the head point considered is dependent on where the reduced speed pump curve intersects the control curve. Figure 7 illustrates a three-speed motor example as a noncontinuous control. The speed cannot be adjusted to meet the control curve target points; therefore, for this example, the 100 percent and 75 percent load points are taken from the full-speed pump curve, the 50 percent flow point is taken from the middle-speed pump curve, and the 25 percent flow point is taken from the low-speed curve.

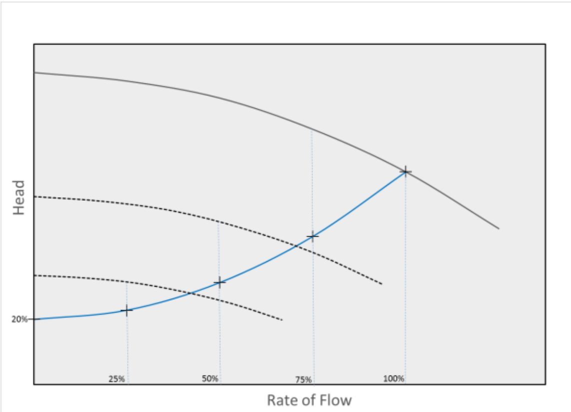


Figure 7. Graphical Representation Measurements and Noncontinuous Control Standard Load Points to Determine PER$_{VL}$

Table 5. Applicability of Testing and "Calculation" Methods to Determine PER$_{VL}$

Pump Configuration	Pump sub-configuration	Calculation based test method	Testing based method
Pump + Motor + Speed Controls	Pump + Motor Covered by DOE's Electric Motor Energy Conservation Standards + Continuous Control OR Pump + Submersible Motor + Continuous Control	C.1: Tested Pump Efficiency of Bare Pump + Represented Nominal Full Load Motor Efficiency for Actual Motor Paired with Pump + Default motor/Control Part Load Loss Curve + Assumed System Curve	C.2: Tested Wire-to-Water Performance
	Pump + Motor Covered by DOE's Electric Motor Energy Conservation Standards + Non-Continuous Control OR Pump + Submersible Motor + Non-Continuous Control	Not Applicable	C.2: Tested Wire-to-Water Performance
	Pump + Motor Not Covered by DOE's Electric Motor Energy Conservation Standards (Except Submersible Motors) + Continuous or Non-Continuous Controls	Not Applicable	C.2: Tested Wire-to-Water Performance

The TP outlines two methods to determine PER$_{VL}$ as illustrated in Table 5. The method used is dependent on the manufacturer's needs and how the pump will be distributed in commerce and are described below. "Calculated" is listed in quotes because a physical bare pump test is still required and "calculated" refers to calculating or applying default loss factors for the driver and controls instead of testing in a wire-to-water configuration.

- C.1 – PER$_{VL}$ for a bare pump + motor + continuous control "calculated"
  - Bare pump test + standard driver and control loss calculations to determine PER$_{VL}$
- C.2 – PER$_{VL}$ for a bare pump + motor + control (tested)
  - Bare pump + actual driver and control wire-to-water test to determine PER$_{VL}$

Method C.1 is only applicable for pumps distributed in commerce with continuous controls, with motors under 10 CFR Part 431(g), or submersible motors. Pumps distributed in commerce with other motors must use Method C.2. Method C.1 requires that the equipment is tested per HI 40.6-2014 to determine the rate of flow ($Q_{100\%}$), head ($H_{100\%}$), and the bare pump power input ($P_{100\%}$) at the nominal speed of rotation. The bare pump data are at nominal speed of rotation and are corrected to consider the reduced speed pump power input and driver and control losses at the load points.

1. Standard calculations are conducted to determine the pump input power at the load points as shown below.

$$P_i = \left(0.8 \times \frac{(Q_i)^3}{(Q_{100\%})^3} + 0.2 \times \frac{Q_i}{Q_{100\%}}\right) \times P_{100\%}$$

2. Driver and control losses are calculated based on standard equations utilizing a, b and c constants based on the rated power of the motor as shown in Table 6.

$$Z_{100\%} = a \times \left(\frac{P_i}{Motor\ HP, NP}\right)^2 + b \times \frac{P_i}{Motor\ HP, NP} + c$$

Table 6. Motor and Control Loss Coefficients

Motor power	Coefficient for motor & control part-load loss factors Z_i		
	a	b	c
Motor HP,NP ≤ 5	-0.4658	1.4965	0.5303
5 < Motor HP,NP ≤ 20	-1.3198	2.9551	0.1052
20 < Motor HP,NP ≤ 50	-1.5122	3.0777	0.1847
Motor HP,NP ≤ 50	-0.8914	2.8846	0.2625

3. The full-load motor losses are determined and the part-load losses motor and control ($L_i^{M,C}$) are calculated using the following equation.

   For pumps distributed in commerce with a motor under, 10 CFR Part 431.25(g):

$$L_{full,NP} = \frac{MotorHP,NP}{\frac{\eta_{motor,full,NP}}{100}} - MotorHP,NP$$

$$L_i^{M,C} = Z_i \times L_{full,NP}$$

For pumps distributed in commerce with a submersible motor:

$$L_{full,std} = \frac{Motor\ HP}{\frac{\eta_{motor,full}}{100}} - Motor\ HP$$

$$L_i^{M,C} = Z_i \times L_{full,std}$$

4. Calculate PER_{VL} based on the equally weighted average of the pump power input and driver and control losses at the load points.

$$PER_{VL} = 0.25 \times \sum(P_i + L_i^{M,C})$$

Method C.2 is applicable for pumps distributed in commerce with continuous or non-continuous controls. The TP specifies that in addition to wire-to-water constant load testing as outlined in HI 40.6-2014, there is a requirement to test the equipment as distributed in commerce and measure the control power input ($P_i^{in,C}$) at the load points as identified in Figures 6 and 7. This method requires no driver and control loss calculations because they are measured directly; therefore, the PER_{VL} can be calculated directly in one step as shown.

$$PER_{VL} = 0.25 \times \sum(P_i^{in,C})$$

PUMP ENERGY INDEX (PEI)

The PEI is the final metric that determines compliance with the ECS. As outlined above it considers the weighted average power of a minimally compliant pump (PER_{STD}) and the weighted average power of the pump being rated ($PER_{CL/VL}$). The ratio of these values creates the index. For rated equipment to be compliant, the PEI must be 1.00 or less as described below.

$$PEI_{CL/VL} = \frac{PER_{CL/VL}}{PER_{STD}} \leq 1.00$$

When a basic model is not compliant, there are several options for the manufacturer.

- The pump efficiency of the basic model can be improved,
- A more efficient motor can be applied, or
- Controls can be added to the basic model

Table 7 summarizes these three options and shows representative $PEI_{CL/VL}$. In this example, the bare pump as tested fails the PEI criteria, but increasing the efficiency of the pump or motor or adding continuous controls results in a compliant rating.

Table 7. $PEI_{CL/VL}$ Rating Examples

In-line 3600	1 - Bare pump	2 - Bare pump, increase efficiency	3 - Bare pump, high-efficiency motor	4 - Bare pump, motor, controls
$Q_{100\%}$	358.30	358.30	358.30	358.30
$H_{100\%}$	89.34	89.34	89.34	89.34
η_{pump}	73.36	74.86	73.36	73.36
$P_{100\%}$	11.03	10.81	11.03	11.03
η_{motor}	90.20	90.20	92.00	90.20
MotorHP	15	15	15	15
PER_{STD}	12.09	12.09	12.09	12.09
$PER_{CL/VL}$	12.26	12.12	11.99	6.17
$PEI_{CL/VL}$	1.01	1.00	0.99	0.51

The examples shown in Table 7 illustrate the benefit of rating a product inclusive of continuous controls, as can be seen by the reduction in the PEI from 1.01 to 0.51 without improving the efficiency of the pump or motor. The reduction in PEI is the result of the reduced power consumption at the standard variable load points and not increased pump, driver, or drive efficiency; however, the reduced PEI rating considers the improved system efficiency that will result from a reduction is system pressure or elimination of the need to bypass flow to control the system.

PEI is a ratio of rated power to the minimally compliant (baseline); therefore, it can easily be used to estimate power consumption over the baseline product. Also two PEI-rated products can be compared and the difference in power consumption can be estimated. If the example in Table 7 is examined, the following estimations for power consumption over or under the DOE compliant pump can be made respective of the PEI ratings using the following equation.

Power savings (hp) = (1 – PEI) × MotorHP

In the above equation, MotorHP is used as the standard power consumed, but it should be understood that PER_{STD} is more accurate; however, PER_{STD} is not be readily available to the user of the equipment, so MotorHP is subsituted for convenience. Following are examples of the power consumption or savings over baseline for the four configurations outlined in Table 7.

1. Power savings (hp) = (1 – 1.01) × 15 = -0.15 hp
2. Power savings (hp) = (1 – 1.00) × 15 = 0 hp
3. Power savings (hp) = (1 – 0.99) × 15 = 0.15 hp
4. Power savings (hp) = (1 – 0.51) × 15 = 7.35 hp

The user should be aware that the power savings calculation is an estimate based on the standard load points and weighting thereof and the actual power consumption depends on the operational load points. Two examples where the estimated power consumptions can be inaccurate are:

1. If a variable load rated pump is installed in a constant flow application resulting in the actual weighting values at each load point being different than the weighting values specified in the TP.
2. An application in which the actual load profile curve differes significantly from the load profile curve specified in the TP.

The most extreme illustration of example 1 is if a user does not understand the PEI_{VL} rating system and makes a decision to purchase the bare pump + motor + continuous controls option (example 4 shown in Table 7) because it has a lower PEI rating, but the actual application requires a constant flow. As illustrated in Figure 8, the PEI_{VL} pump does not vary speed to achieve reduced flow rates because the system demands 100 percent rate of flow. The resultant PEI is 1.12 instead of 0.51 per the TP-assumed load profile. In this extreme case the estimated power savings are 63 percent more than actual. Furthermore, the user would be paying a premium for continuous controls, but would have a pump that consumes as much as 12 percent more power than without controls, based on the TP motor and control default loss assumptions.

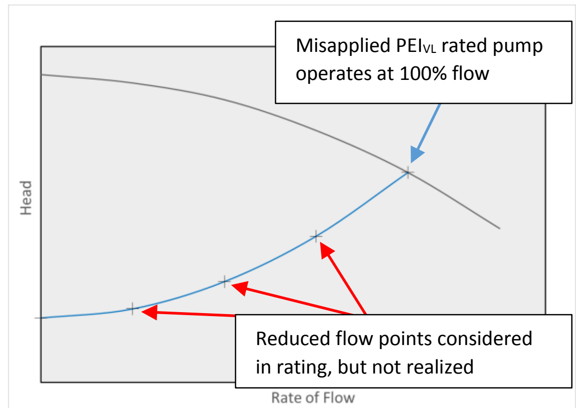


Figure 8. PEI_{VL} Rated Pump Applied in Constant Load Application

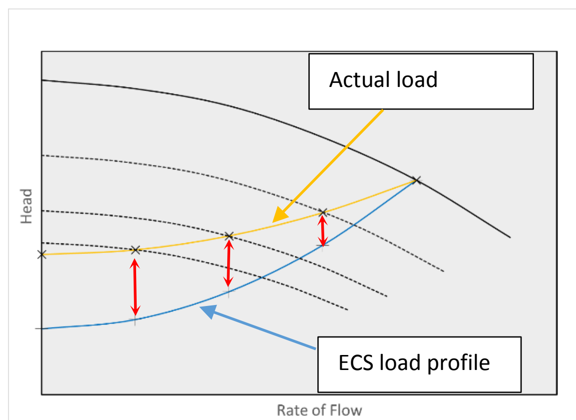


Figure 9. PEI_{VL} Rated Pump Applied in System with Different System Curve than DOE Assumed Load Profile Curve

If a rated pump is applied in a system with a different load profile than the TP-specified load profile curve, estimated power savings will be less accurate. Figure 9 illustrates a PEI_{VL} example where the load profile results in higher required system head at the reduced flow rates. The arrows represent additional energy consumed by the pump due to the higher head requirement than if the pump was operating on the TP-assumed load profile. Assuming the weighting at each load point remains 25 percent and applying the actual load profile in Figure 9 to example 4 shown in

Table 7, the resultant PEI_{VL} is 0.62 instead of 0.51. This is 11 percent more power consumption than is calculated using the TP-assumed load profile curve.

The PEI is a great tool for estimating power and energy savings in a general manner, but the user of the pump must understand the system in which it is applied to accuratly determine the power savings that will be realized. This is more important when considering pumps with a variable load rating because system conditions may not warrant the use of variable speed to regulate the system flow and, in misapplied cases, the power consumption could be more than if a constant load rated pump was applied.

LABELING, CERTIFICATION, AND COMPLIANCE

Labeling requirements of the ECS are that a permanent nameplate on the pump and all catalog and marketing material that represents the energy consumption of the pump will display the following:

- PEI_{CL} or PEI_{VL}
- Bare pump model number
- Impeller diameter or space left for it if final trim is determined later in the commerce stream

The ECS and TP became effective on March 28, 2016 and compliance is required on January 27, 2020. Annual filing is required, with certification reports due September 1st of each year; however, the submittal procedure and data portal has not been specified by DOE. Certification reports require the following data at the pump BEP and nominal speed of rotation:

- The pump configuration as distributed in commerce
  - Bare pump equipment category
    - i. with driver
    - ii. with driver and controls
  - Or, must otherwise provide sufficent information to identify the specific driver model and/or control models with which the bare pump is distributed
- Basic model number descriptive of the bare pump and driver and controls if applicable
- PEI_{CL} or PEI_{VL}
- Whether PEI is calculated or tested
- Pump total head
- Flow, in gpm
- Calculated driver power input at each load, in hp
- Full impeller diameter
- Number of stages for RSV and ST pumps
- Bowl diameter for ST pumps
- For pumps supplied with motors:
  - Nominal motor efficency
  - Motor hp
- Optional reporting:
  - Pump efficiency at BEP
  - PER_{CL} or PER_{VL}

VOLUNTARY INDUSTRY LABELING AND THE EXTENDED MOTOR PRODUCT LABELING INITIATIVE (EMPLI)

In addition to pumps, the DOE is working on ECSs for other motor-driven systems. Currently fans and compressors are in different stages of the process, with rules expected to be published in the 2016/2017 time frame. Benefits of these ECSs to the motor-driven systems industry are:

- Defined products and scope
- Standard efficiency levels
- Performance metrics and test procedures to arrive at consistent representations of energy consumption.

Since energy conservation standards are being developed across multiple motor-driven systems, it gives the industries an opportunity to develop a common-themed labeling program for motor-driven equipment.

Early in the rulemaking processes, an extended motor product labeling initiative (EMPLI) was created. The initiative is a joint effort between the American Council for an Energy Efficient Economy (ACEEE), energy advocates, utility power administrators, and trade associations that represent fans (Air Movement & Controls Association [AMCA]), compressors (Compressed Air & Gas Institute [CAGI]), pumps (Hydraulic Institute [HI]), and drives, drivers, and controls (National Electrical Manufacturers Associations [NEMA]).

The goal of EMPLI is to accelerate the adoption of high-performance equipment into the marketplace ahead of the compliance date in the respective ECSs. Users of motor-driven systems should expect the voluntary labeling programs as the first noticable impact of the respective ECS and TP.

To accomplish this, the trade associations are working together with utility representatives to develop common-themed, third-party labels that build on the ECSs, and communicate relative enegy consumption of the motor-driven system in an easy and understandable way.

The programs and label or rating must communicate energy savings verification to meet the requirements of the public service commissions in order for power utility administrators to design incentive programs based on the label, thereby accelerating the adoption of more efficient equipment.

The ECS and TP for pumps allowed the HI pump committee to move forward with developing a rating system, label, and program to adminster it. The program is currently under development, going through committee approval processes. The HI pump committee understood the label must provide utility program administrators the required information to justify incentives based on power reduction from a base case. To that end, the HI pump committee considered several rating ideas, but is ultimately proposing a "yardstick" approach called the HI Energy Rating, which is similar to EnergyGuide ratings seen on appliances. It is understood that for commercial and industrial products a label may not be required and that the developed rating and label may or may not be applied to the product, but will be placed in marketing and submittal information used to make purchasing decisions.

To develop the energy rating, the HI committee evaluated data published by DOE in the Technical Support Document (TSD) (US Department of Energy, 2015) to the ECS. The TSD presented the scatter plots of C-values for each pump equipment category. These data were evaluated to understand the expected range of $PEI_{CL/VL}$ for an equipment category from the base case to the maximum surveyed, allowing the maximum and minimum energy consumption to be illustrated on a scale. Table 8 is a summary of the analysis done and shows the average PEI for each pump equipment category from baseline to maximum.

Table 8. Preliminary Average PEI Baseline to Maximum

Average PEI Constant Load Range Chart				Average PEI Variable load Range Chart	
DOE Type	Baseline	DOE	Max	Low Range	Max
ESCC 1800	1.10	1.00	0.81	0.53	0.39
ESCC 3600	1.09	1.00	0.81	0.54	0.41
ESFM 1800	1.10	1.00	0.80	0.53	0.39
ESFM 3600	1.09	1.00	0.79	0.54	0.40
IL 1800	1.11	1.00	0.82	0.54	0.39
IL 3600	1.13	1.00	0.82	0.56	0.41
RSV 1800	1.00	-	0.93	0.49	0.45
RSV 3600	1.00	-	0.94	0.50	0.47
ST 1800	1.00	-	0.84	0.57	0.48
ST 3600	1.07	1.00	0.81	0.64	0.49

This makes PEI a very useful tool to develop an energy rating system; however, the HI committee decided a derivative of the PEI metric that allows for whole numbers on an increasing scale to indicate better performance was easier to understand and communicate. The PEI derivative value is defined as the HI Energy Rating (ER). The ER represents the percent power savings over the base case and is calculated using the equation below, which uses the baseline PEI for each DOE equipment category listed in Table 7.

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

Using the ER equation and the data in Table 8, Table 9 is generated, which summarizes the average ER for each equipment class from the baseline to maximum surveyed.

Table 9. Preliminary Average ER Baseline to Maximum Surveyed

Average ER Constant Load Range Chart				Average ER Variable load Range Chart	
DOE Type	Baseline	DOE	Max	Low Range	Max
ESCC 1800	0	10	29	56	70
ESCC 3600	0	9	27	54	68
ESFM 1800	0	10	30	57	71
ESFM 3600	0	9	30	55	69
IL 1800	0	11	29	57	72
IL 3600	0	13	31	56	72
RSV 1800	0	-	7	51	55
RSV 3600	0	-	6	50	53
ST 1800	0	-	16	43	52
ST 3600	0	7	26	43	57

Figure 10 represents a draft ER label that depicts the yardstick concept. The rating label includes information to calculate power savings over the base case or another ER. Since ER represents the percent power savings over the baseline, it is very simple to calculate power savings compared to the baseline case and is shown below. The accuracy of the power savings calculations are limited to the load profile curve and weighting assumptions outlined in the TP.

$$Power\ Savings = \frac{ER}{100} \times Rated\ Motor\ power$$

In addition, power savings over another ER can be calculated as shown below.

$$Power\ Savings\ = \frac{ER1 - ER2}{100} \times Rated\ Motor\ power$$

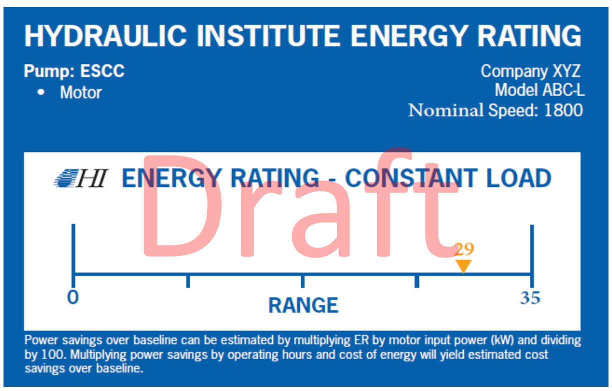


Figure 10. Draft HI ER Label

SUMMARY AND CONCLUSIONS

Compliance to the new ECS and TP for pumps is required January 27, 2020 and the estimated energy savings over the next 30 years is 0.27 quads, which, based on 2014 US Energy Information Administration data (US Energy Information Administration, 2015), is the equivalent annual energy use of approximately 7 million US households.

Manufacturers of pumps are bearing the burden of compliance to the ECS and TP, which is designed to eliminate the least efficient 25 percent of pumps sold today. Compliance to the rule is complex and is requiring manufacturers to upgrade testing facilities, to test and evaluate long-standing product lines, and to invest in redesigning or eliminating products that are not compliant.

There are opportunities for pump manufacturers as well, through voluntary labeling initiatives aimed at accelerating the application of more efficient pumping solutions. The voluntary labeling programs are being developed to more easily communicate power consumptions of rated products. This will enable educated purchasing decisions based on credible data and enable utility incentives to be made available in a deemed capacity for pumps.

It is important, however, that pump users and specifiers of newly rated pumps understand what the ratings mean, the assumptions made, and have a good understanding of the system in which the pump and power drive system will be installed. Continued training of pump users is essential to maximize the potential of the new ECS for pumps and voluntary labeling programs. Educated end users will limit the misapplication and subsequent dissatisfaction that will occur due to not understanding how to properly apply the constant load and variable load rating systems.

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