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Electric Submersible Pump Testing

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American Petroleum Institute

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Electric Submersible Pump Testing

1 Scope

1.1 General

This recommended practice provides guidelines and procedures covering electric submersible pump performance testing. These recommended practices are considered appropriate for most pump applications, including gas handlers and high-speed pumps.

1.2 Coverage

This recommended practice covers the acceptance testing of electric submersible pumps (sold as new) by the manufacturer, vendor, or user to the following prescribed minimum specifications. This recommended practice does not include other electric submersible pump system components.

2 Normative Reference

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Recommended Practice 11S8, *Recommended Practice on Electric Submersible System Vibrations*

3 Terms, Definitions and Abbreviations

3.1 Terms and Definitions

3.1.1
affinity laws
Relationships between pump performance and pump speed ratios. For test purposes, the speed ratios are between rated rpm and test rpm.

a) Speed adjusted flow = $\frac{\text{rated rpm}}{\text{test rpm}} \times \text{test flow}$

b) Speed adjusted head = $\left(\frac{\text{rated rpm}}{\text{test rpm}}\right)^2 \times \text{test head}$

c) Speed adjusted brake horsepower = $\left(\frac{\text{rated rpm}}{\text{test rpm}}\right)^3 \times \text{test brake horsepower}$

3.1.2
allowable head-flow rate performance band
A region on either side of a published head-flow rate performance curve (see Figure 1). The limits of this band are defined by a series of vectors with their origin on the published head-flow rate performance curve. The vectors are defined by application of the head and flow tolerances in Table 2.

3.1.3
best efficiency point
BEP
Defines pump performance parameters at the maximum value on the efficiency curve.

3.1.4
brake horsepower
BHP
The power required by the pump corrected for a fluid with a specific gravity of 1.0.

3.1.5
efficiency
EFF
A measure of power out divided by power in. For the pump only:

$$\text{EFF} = \frac{\text{head} \times \text{flow rate}}{C \times \text{BHP}}$$

Where *C* is for units' conversion.

3.1.6
extended operating range pumps
Pump characterized by an advanced configuration or structure, enabling them to operate beyond the recommended operational limits of standard pump designs.

3.1.7
high speed pump
Pump specifically engineered to operate at speeds exceeding 4500 rotations per minute (rpm).

3.1.8
gas handler
Component of an ESP system that conditions multiphase flow without gas separation, to decrease the degradation of pump performance.

3.1.9
new pump
Any pump that has undergone assembly and testing in accordance with the manufacturer's standards, accompanied by full warranty terms applicable to the product.

3.1.10
flow rate
The volumetric rate of fluid delivered by the pump.

3.1.11
recommended operating range
ROR
The range of flow rates over which the manufacturer guarantees Head and BHP performance within the acceptance criteria set forth in this document.
NOTE If the recommended operating range is not defined, use +/- 20% of the rated flow, typically the Best Efficiency Point. Located between the maximum and minimum recommended flow rates.

3.1.12
extended recommended operating range
Located between the extended minimum/maximum recommended flow rate

3.1.13
open flow
The pump flow rate at zero head.
NOTE This value may be limited by test facilities or pump design.

3.1.14
test open flow
The maximum pump flow rate attainable on test. This rate is between the maximum recommended flow rate and open flow.

3.1.15
maximum extended ROR
The maximum recommended flow rate for wide operating range pumps if it applies

3.1.16
maximum base ROR
The maximum recommended flow rate per pump engineering curve

3.1.17
rated flow
The flow rate at the recommended operating point of the pump. The flow rate is generally at BEP.

3.1.18
minimum base ROR
the minimum recommended flow rate per pump engineering curve

3.1.19
midpoint extended ROR
Flow midway between test shut off and minimum base ROR.
NOTE For pumps that do not have an extended ROR the minimum extended ROR and midpoint ROR may be equally spaced between shut off head and minimum ROR.

3.1.20
minimum extended ROR
The minimum allowed flow rate of a pump with an expanded ROR.
NOTE This value may be limited by test facilities or pump design. Some stage types may require that this value be shifted right to support a more realistic head-flow curve overlay.

3.1.21
shut off head
The head at zero flow.

3.1.22
total head
The difference between the pump outlet and inlet head in feet.
NOTE This is the vertical distance, in feet, from the pumping fluid level to the centerline of the pressure gauge, plus the pressure gauge reading converted to feet, plus the friction loss between the pump discharge and pressure gauge in feet.

3.1.23
test curve
A curve is generated by conducting a series of tests where the pump is operated at different flow rates or speeds, and the corresponding head, efficiency, and power consumption are measured. These data points are then plotted on a graph to form the test curve.

3.1.24
published pump performance curve

A standardized graphical representation created by pump design engineers for use in catalogs and technical documentation. This curve illustrates the expected performance characteristics of a pump across a range of operating conditions, typically including parameters such as flow rate, head (pressure or feet), efficiency, and power consumption.

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply

BEP best efficiency point

BHP brake horsepower

BPD barrel per day

EFF efficiency

ROR recommended operating range

rpm revolutions per minute

4 Data and Charts: Pump Performance Curves

4.1 The published curves (Figure 1 and 2) show the discharge head, brake horsepower, and efficiency of the pump as a function of flow rate. Although tests are made on multistage pumps, the published curves represent performance for one or more stages of each pump type. All curves are based on multistage performance tests and do not include horsepower of other components such as gas separators or seal chambers**.**

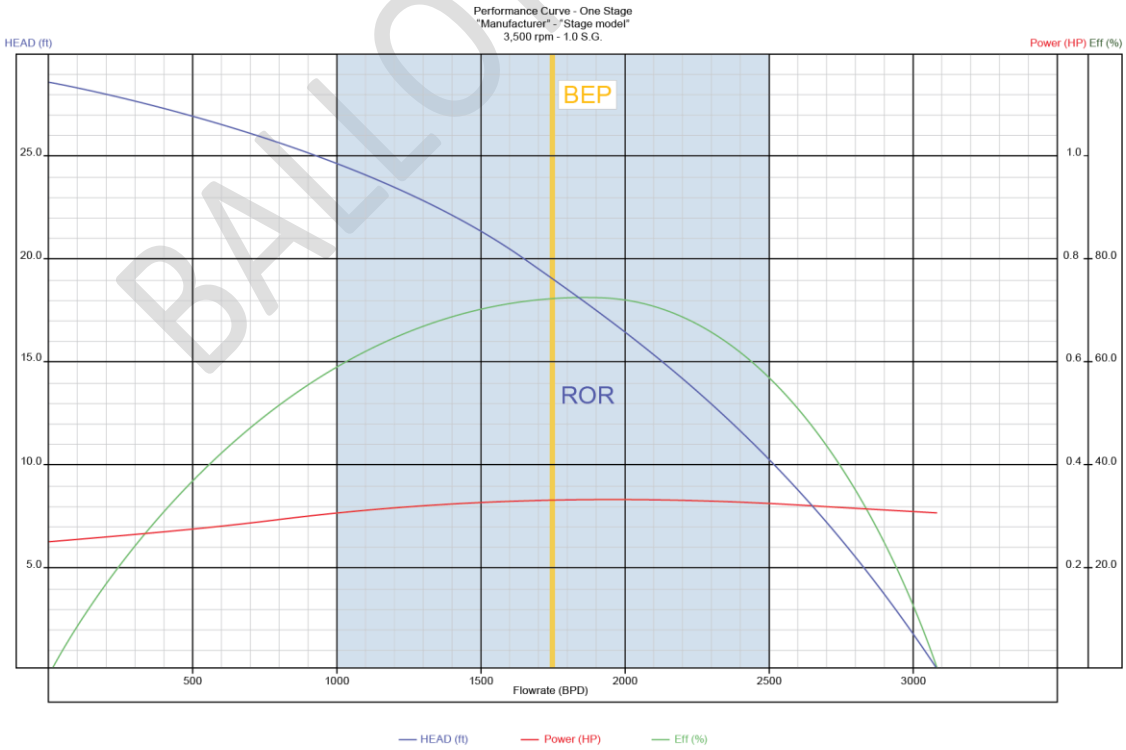

Figure 1. Pump performance curve (Typical)

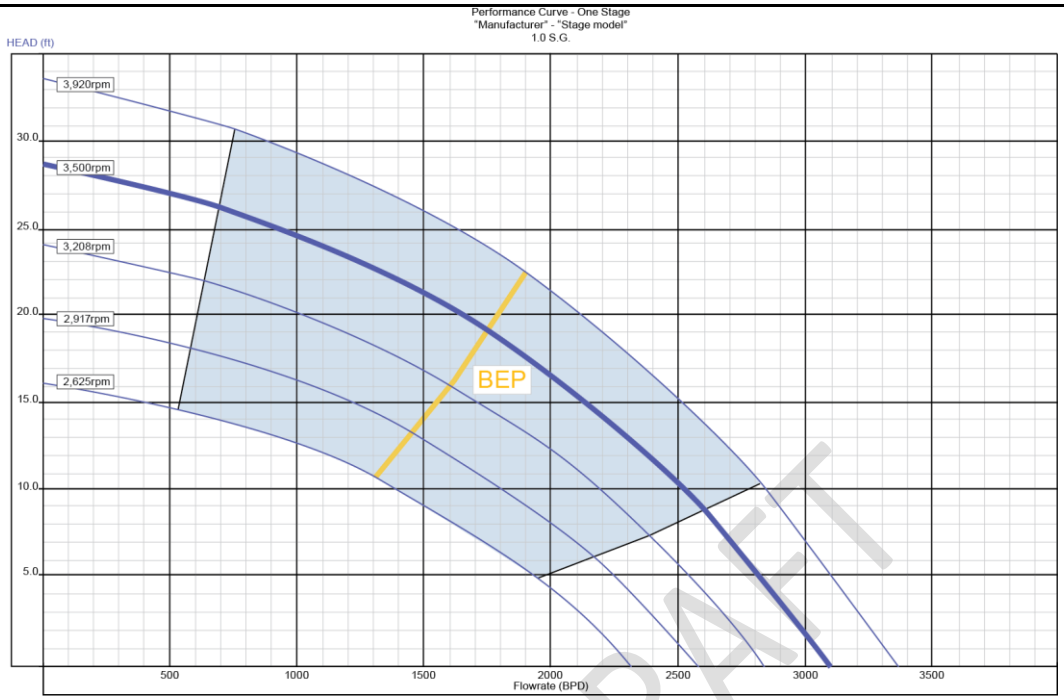

Figure 2. Pump performance multi-frequency curve (Typical)

4.2 The curves are based on fresh water at 60°F (S.G. = 1.0), give a recommended operating range for the pump, and are commonly available for both 50 Hertz (2916rpm) and 60 Hertz (3500rpm) operation. For high-speed pump, the curve should be provided at the design speed. The curve may be adjusted by speed using centrifugal pump affinity calculations (or other established correlation). Note that some gas handlers' stage designs might not follow centrifugal pump affinity laws.

4.3 Manufacturers shall publish head and brake horsepower curves. Numerical representation for efficiency is a calculated value from these curves at a given flow rate. Using polynomial equations is preferred rather than using published curves; therefore, when possible, polynomials should be used to verify conformity with certified test points.

5 Test Procedure

5.1 Test Points

Performance tests shall be conducted at the following minimum points: 1, 3, 4, 5, and 7.
Optionally, tests can be performed at all points (1–7). Any deviations from this should be agreed upon by both the operator and the provider.
Refer to Figure 3 for details on the test points:

- Point 1 Test open flow.

  NOTE This value may be limited by test facilities or pump design

- Point 2 Maximum extended ROR (extended operating pumps only if applicable)

- Point 3 Maximum base ROR

- Point 4 Rated flow (generally BEP).
- Point 5 Minimum base ROR
- Point 6 Minimum extended ROR (extended operating pumps only)
- * Point 7 Shut off head

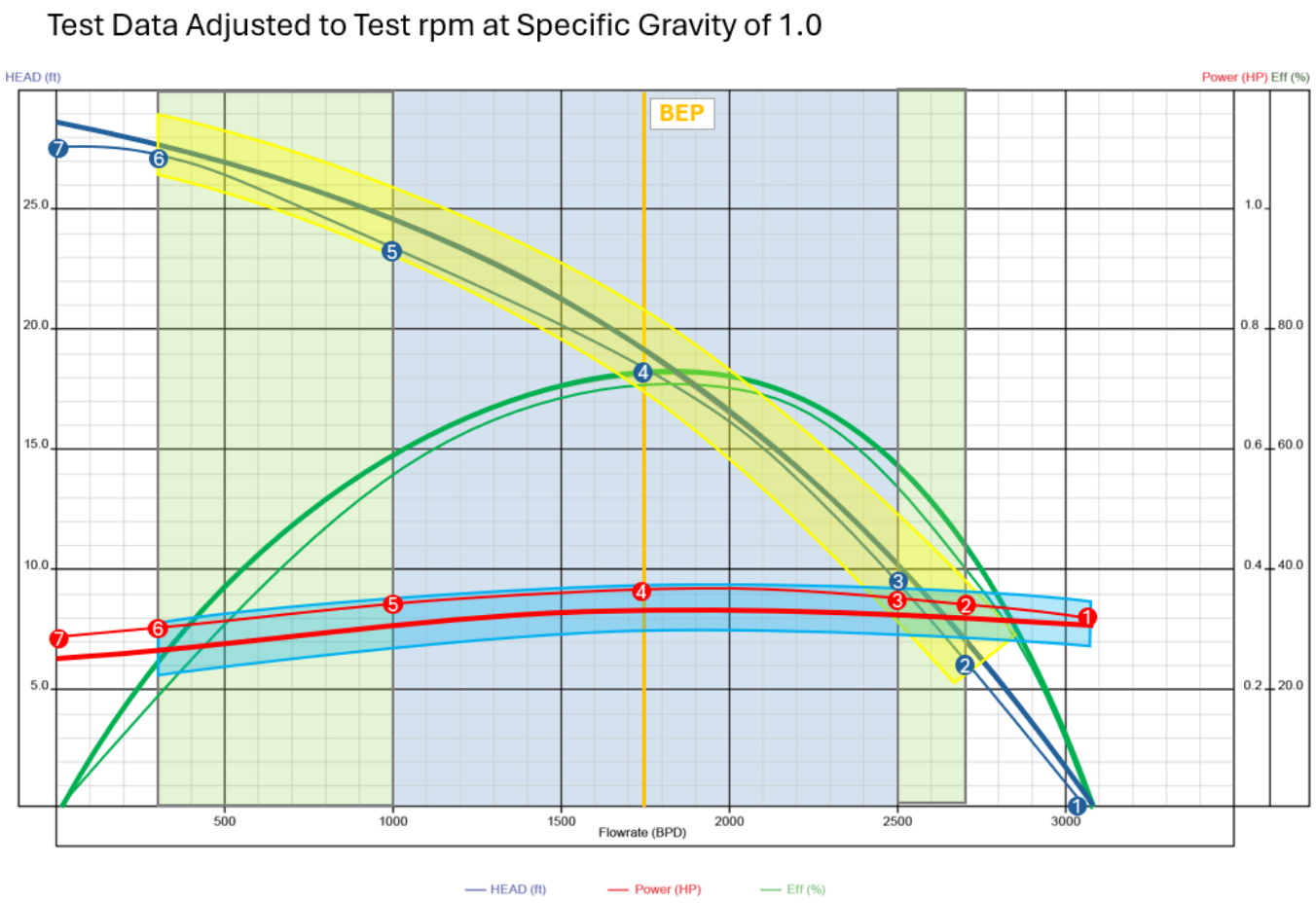

Fig 3. Pump test points (engineering) curve (Typical)

5.2 Certified Data

Data for Items in 5.1 can be certified.

Tests for these points shall be conducted within ± 2 percent of the specified flow. The following exceptions may be applied. For 400 series pumps with test flow rates higher than 6000 bpd, points may be conducted within ± 5 percent of the specified flow. For all lower flow pump types with required test rates lower than 200 bpd, points may be conducted within ± 5 percent or a minimum of ± 10 bpd of the specified flow.

The head and brake horsepower will be reported at the actual test flow rate rather than the specified flow rate.

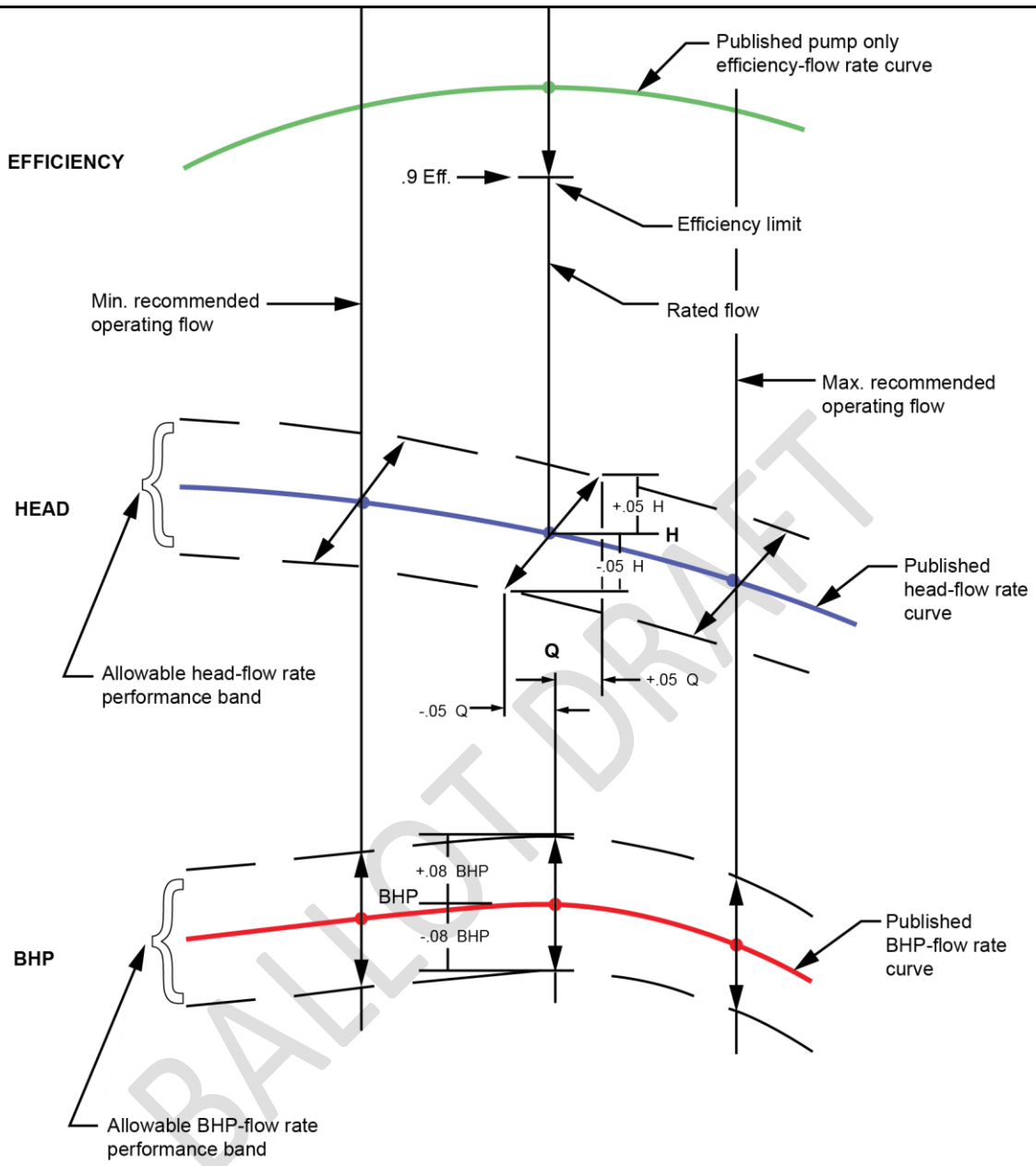

Figure 4. Pump Test Acceptance Limits From Published Curve

5.3 Efficiency

5.3.1 The efficiency of the pump will be calculated at the rated flow test point**.**

5.3.2 An example of an efficiency calculation using a typical published pump performance curve (see Figure 1):

Flow rate = 1160 BPD

Head = 28.7 feet

Horsepower = 0.386 HP

Specific gravity = 1.0

Unit conversion = $\frac{1{,}440 \text{ min/day} \times 33{,}000 \text{ ft-lb/HP-min}}{350 \text{ lbs/bbl}} = 136{,}000 \text{ bbl ft/HP day}$

$$\text{Eff.} = 1160 \text{ BPD} \times 28.7 \text{ ft} / (136{,}000 \times 0.386 \text{ HP}) = 0.634$$

5.4 Special Testing Considerations

5.4.1 Where sections of tandem pumps are tested as individual units, each section should be evaluated as an independent pump. Testing two pump sections as an assembly is a permissible deviation from standard procedures, particularly when one of the pump sections is too short to be mounted to the test bench. This approach should be agreed upon by both the manufacturer and the operator. By testing the two sections together, it ensures that the performance and functionality of the entire pump system can be properly evaluated.

5.4.2 When testing pumps with few stages (usually less than 10), the intake losses should be considered. If the short pump test yields results differing from those in the catalog, the vendor should provide an explanation, supported by calculations involving the test loop, pump design, and any other pertinent factors. Alternatively, as mentioned earlier, conducting a test on the short pump with a longer assembly is an option. If the combined assembly test aligns with the catalog specifications, it can be inferred that the deviation observed in the shorter pump test was likely due to intake losses.

5.4.3 The use of fresh water for testing can result in damage caused by freezing or corrosion during shipping and storage. Pumps should be flushed with an environmentally safe corrosion inhibitor and antifreeze solution after testing and shipping caps installed on both the head and base. Alternative methods of sealing the pump will be required when the pump includes an integral discharge head or intake.

5.5 Test Orientation

The published performance curves are based on horizontal testing. Additionally, industry experience has shown that pumps tested in one orientation routinely meet the specifications of Section 6 when tested in the other orientation. The pump performance test may be conducted either vertically or horizontally, using the appropriate published performance curve. If the test orientation differs from horizontal testing, the published performance curve should indicate this.

5.6 Test Fluid

The published pump performance curves are based on reasonably clean fresh water at 60°F by filtering, fluid settling or other means. If alternate fluids are used for testing, performance test results may be corrected to the freshwater performance as stated below. Other fluids introduce factors (such as viscosity and specific gravity) that require the test data to be corrected. Typically, viscosity changes up to 5 cSt (approximately 42 SSU) and specific gravity changes below 1% do not require corrections. The relationships to convert from one test fluid to a standard water test are illustrated as follows:

$\text{Head}_{water} = \text{total head}_{test} \times H_{vis}$

$\text{Flow}_{water} = \text{flow}_{test} \times Q_{vis}$

$\text{BHP}_{water} = \frac{\text{BHP}_{water}}{\text{Sp. Gr.}} \times \text{BHP}_{vis}$

Viscosity corrections (H_{vis}, Q_{vis}, BHP_{vis}) for fluids other than water are empirically derived. Correction factors may be agreed upon for a range of temperatures, viscosity variations above 5 cSt, non-newtonian fluids, etc.

5.7 Test Run-In Time

The test should be established within the recommended operating range, and the equipment should run long enough to achieve stable flow, head, and horsepower readings at each certified test point. A stable reading is considered achieved when a flow, head, or horsepower data point remains consistent and unchanging (as defined by the manufacture), as per the instrumentation accuracy stated in Table 1 in Section 5.9.

5.8 Speed Variations

5.8.1 Pumps may be tested with standard, calibrated motors dedicated to the test apparatus. As a result, there may be speed variations from the nominal value of 3500 rpm for 60 Hz power. In addition, there may also be test loop capacity limits (flow rate, test motor HP, operating frequency, electrical load, etc.) that require testing to be performed at lower shaft rpm / operating frequency**.**

All pump tests should be corrected back to the nominal speed of 3500 rpm. The affinity laws are used to correct the rated value or for other power line speeds.

High speed pump shall be tested at the nominal speed defined by the manufacturer.

5.8.2 An example of speed correction calculations using test data and rated rpm is shown:

Test flow = 1160 BPD

Test head = 27.7 feet

Test brake horsepower = 0.36 BHP

Test rpm = 3520

Rated rpm = 3500

Using the definition of affinity laws (see 3.1.2), the following equations can be established:

Speed adjusted flow = (3500 rpm/3520 rpm) ´ 1160 BPD= 1153 BPD

Speed adjusted head = (3500 rpm/3520 rpm)^{2}´ 27.7 feet = 27.39 feet

Speed adjusted brake horsepower = (3500 rpm/3520 rpm)^{3} ´ 0.36 BHP = 0.354 BHP

5.9 Inlet Pressure Requirements

The inlet pressure to the pump must be above the minimum required by the manufacturer. If there are any inlet or discharge pressure limitations, these should be specified by the manufacturer.

5.10 Instrumentation Accuracy

All measurements are inevitably subject to inaccuracies. Table 1 provides the maximum tolerance for instruments used during the test.

Table 1—Overall Instrument Accuracy

Quantity	Limit (Percent of Full Scale)
Flow rate	±0.2%
Total head/pressure	±0.5%
Electrical power input	±0.1%
RPM	±0.5%
Torque	±0.1%
Temperature	±0.1%

Each instrument must undergo calibration throughout its entire range spectrum, covering intervals of 0%, 25%, 50%, 75%, and 100%. The calibration schedule should occur annually. New instruments should undergo bi-annual calibration during their first year to ensure stability.

The testing range of the instrument should be appropriately matched to the specifications of the testing equipment. Any light loading below 10% is discouraged to maintain the accuracy of the test results. The Test instrumentation loading should be between 10% and 90% of full scale. Loading above or below this range is discouraged.

A copy of the current calibration record to include the certificate and worksheets shall be available onsite for inspection.

Certification of the instruments used to calibrate the system shall be maintained and available as a part of the calibration record. Pump brake horsepower will have a ± 3.0 percent instrument accuracy. Calculated pump efficiency, being a composite of other accuracies, should not exceed ± 5.0 percent.

6 Test Certification

6.1 Limits

The limits listed in Table 2 shall apply to manufacturer's published pump performance curves. The limits are graphically shown in Figure 4 and shall apply to pumps tested in vertical or horizontal orientation.

6.2 Acceptance

6.2.1 The pump head-flow rate performance is acceptable if the certified test points are within the allowable head-flow rate performance band (see 3.1.3 for definition).

6.2.2 For gas handler head-flow rate performance, limits may be widened based on agreement between operator and manufacturer.

6.2.3 The pump brake horsepower performance is acceptable if the pump horsepower is within the tolerance limits at the certified test points**.**

Table 2—Pump Test Acceptance Limits From Published Curve

Curve	Limits	Where Applicable
Head—flow rate	±5% Head ±5% Flow rate	Over recommended operating range[a]
BHP—flow rate	±8% BHP	Over recommended operating range[a]
Pump efficiency—flow rate	90% of efficiency	At rated flow
[a]The recommended operating range is defined as the manufacturer's published extended operating range. If this range is not defined, use ±20% of the rated flow.		

6.2.4 The pump efficiency calculated from test results is acceptable if it is greater than the specified limit at rated flow**.**

6.2.5 Vibration acceptance values shall in accordance with API 11S8**.**

6.2.6 Pumps shall be visually inspected. All pumps must meet the following criteria:

a) External appearance on housing, head, and base should be free of any visual defect
b) Welding quality (if it applies) should meet manufacturer standards
c) Smooth shaft rotation
d) Shaft ends play measurements that meet manufacturer’s tolerances as per the manufacturer specifications.
e) Acceptable radial shaft plays as per manufacturer specifications.

6.2.7 When tests are conducted using instruments meeting the accuracy criteria, and the values observed during the test meet test certification criteria, the pump test is acceptable**.**

6.3 Validity Period

A pump test shall remain valid for a period of one calendar year from date of acceptance, after which time a new pump test is required to evaluate pump test acceptance. Storage conditions should be in accordance with manufacturer guidelines and be communicated to the operator.

6.4 Test Data Reporting

The test report for the acceptance test shall contain the following information. Additional information may be included in the test report.

a) Company name and address where the test was conducted
b) Date of acceptance
c) Unique pump identifier, i.e. Serial Number
d) Manufacturer pump description and part number
e) Indication if the pump is new manufacture or used
f) Pump stage designation and stage quantity
g) Test speed and orientation
h) Data for test points. The data shall be reported for actual test flow rate points, not the specified flow rate on the published pump performance curves. The efficiency shall be calculated using the actual flow rate data.
i) Percent deviation for each of the data points within the recommended operating range. Any data points not meeting the specified acceptance criteria shall be designated.
j) Calculated Efficiency deviation at rated flow.
k) Any corrections to the data for speed, specific gravity, etc. shall be noted.
l) A statement that the data is normalized for a single stage or for multiple stages.
m) Test report output (test curve overlaid on published pump performance curve)
NOTE See Figure 3. Pump performance over laid published curve (Typical)
n) Vibration data

Bibliography

BS EN ISO 15551-1:2015, *Petroleum and natural gas industries — Drilling and production equipment Part 1: Electric submersible pump systems for artificial lift*