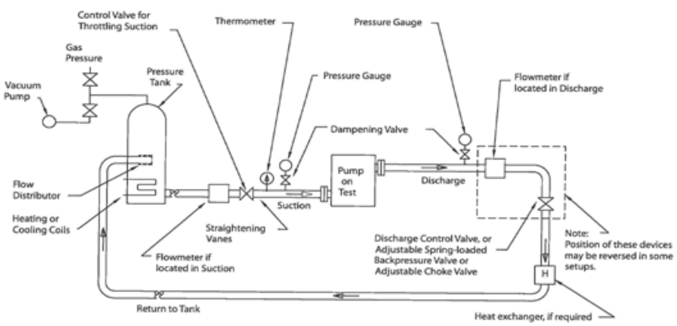


NOTE: Cooling by means of a coil may be replaced by injection of cool water above the free liquid surface and extraction of heated water.

Linked-in Profile

saki.mohsen@gmail.com

WHAT YOU NEED TO KNOW ABOUT

INSPECTION & TESTING of

CENTRIFUGAL PUMPS

NOTES AND REMARKS ACCORDING TO:

- API 610; 2010; Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries
- HI 14.6; 2011; Hydraulic Performance Acceptance Tests
- HI 9.6.7; 2010; Effects of Liquid Viscosity on Rotodynamic (Centrifugal and Vertical) Pump Performance
- ISO 9906; 2012; Rotodynamic pumps - Hydraulic performance acceptance tests - Grades 1, 2 and 3
- ISO 5199; 2002; Technical specifications for centrifugal pumps — Class II
- Centrifugal pumps inspection and testing; By VINOD P. PATEL & JIM BRO
- Pump handbook series; 2000; centrifugal pumps; Fluid Viscosity Effects on Centrifugal Pumps, By: GUNNAR HOLE

February 2017

INSPECTION AND SHOP TESTS FOR CENTRIFUGAL PUMPS

PROJECT :

PUMP NUMBER :

PUMP SERVICE :

1 MATERIALS

COMPONENT (1)	MATERIAL (2)	PMI Req'd (6)	NACE Req'd (7)
BARREL		YES	NACE MR0103
CASING		NO	ANSI/NACE MR0175
SEAL CHAMBER		NO	ISO 15156-1
IMPELLER			Not Applicable
(3) SHAFT			
BOWL			
(4) Gasket & O-Ring			
(5) Bearing Housing			

2 IMPACT TEST

- ☑ Impact test for Carbon Steel materials — Required (8)
- ☑ Hardness Test — Required (8)

3 CASTING & REPAIR

- ☑ Castings Condition — Defect Found (9)
- ☑ Inspection for (major) repair — Required (10)
- ☐ Mill test reports for physical properties and chemical composition property compliance: Checked
- ☑ Post repair heat treatment charts: Checked
- ☐ Nondestructive examination as required and specified: Checked & Witnessed
- ☑ Welding procedures: Checked & Reviewed
- ☑ Procedure/Report for Major Repairs — Approved (11) (12)

GLOSSARY

Peening (repair) is the process of working a metal's surface to improve its material properties, usually by mechanical means, such as hammer blows, by blasting with shot (shot peening), or blasts of light beams with laser peening. Peening is normally a cold work process (laser peening being a notable exception). It tends to expand the surface of the cold metal, thereby inducing compressive stresses or relieving tensile stresses already present.

Plugging (repair); Small porosity leaks can often be plugged with a single pin or tapered plug. Pinning can provide a satisfactory repair on small cracks in non-stressed areas but are usually not recommended for large cracks.

Impregnation (repair); The impregnation process is often considered when dealing with porosity problems in small diecastings. The process for small castings generally takes place in vacuum to first remove the air present in the porosity. Then the cast parts are exposed to a liquid resin. The resin enters the porous areas with the assistance of pressurization that occurs when the vacuum is removed or, in more sophisticated systems, with the assistance of a factory compressed air supply. After impregnation, the parts are washed, and then cured in a heat bath.

Intergranular corrosion (IGC) is a selective attack in the vicinity of the grain boundaries of a stainless steel. It is as a result of chromium depletion, mainly due to the precipitation of chromium carbides in the grain boundaries.
Chromium carbides can be precipitated if the stainless steel is sensitized in the temperature range 550–850°C (1020–1560°F), for example during heat treatment or welding. If the temperature lies in the critical range for too long, chromium carbides will start to form in the grain boundaries, which then become susceptible to intergranular corrosion. The area adjacent to the grain boundaries becomes depleted in chromium (the chromium reacts with carbon and forms carbides) and this zone, therefore, becomes less resistant to intergranular corrosion.

REMARKS

1 Pressure-containing parts shall not be painted (except for anti-crossion primer if required) until the specified inspection and testing of the parts is complete. (API 8.2.1.2)

2 Major pump components' material shall be identified in the pump data sheets with ASTM or ANSI Standards based on API Standard 610, Annex H or equivalent. When such designation is not available, a tabulation of the physical properties and the chemical composition shall be provided by vendor in the proposal. (API 6.12.1.2)

Cast iron material may be offered (mostly for water based services and) only for services with a gauge MAWP not exceeding 17.25 bar (1725 kPa; 250 psi) (API 6.12.1.6). Low carbon steels can be notch-sensitive and be susceptible to brittle fracture, even at ambient (room) temperatures. Therefore, only fully killed, normalized steels made to fine-grain practice shall be used. (API 6.12.1.13)

3 For vertically suspended pumps with shafts exposed to liquid and running in bushings, the standard shaft material is 12 % chrome, except for classes S-9, A-7, A-8 and D-1. The standard shaft material for cantilever pumps (Type VS5) is 4140 alloy steel where the service liquid allows (API Annex H).

4 Radially split casings shall have metal-to-metal fits, with confined controlled-compression gaskets, such as an O-ring or a spiral-wound type. Gaskets other than spiral-wound may be proposed and furnished if proven suitable for service and approved by the purchaser.

Spiral-wound gaskets are generally preferred because they are perceived by users to have had better availability, are more conducive to material identification, have a broader chemical compatibility and temperature range, contact a wider sealing surface (are less susceptible to leakage because of sealing surface irregularities) and are easier to handle and store than O-rings. ISO 21049 and ANSI/API Std 682/ISO 21049, specifically require O-ring gaskets on low-temperature [175 °C (350 °F)] pressure-seal gland plates. (API 6.3.10)
The material specification of all gaskets and O-rings exposed to the pumped liquid shall be identified in the proposal. O-rings shall be selected and their application limited in accordance with ISO 21049. (API 6.12.13)

5 Bearing housings, load-carrying bearing housing covers and brackets between the pump casings or heads and the bearing housings shall be steel except for pumps constructed in accordance with Table H.1, Classes I-1 or I-2. Driver supports for vertical pumps that utilize thrust bearings in the driver to support the shaft shall be steel. (API 6.12.1.15)

6 Tests for physical properties and chemical composition (for pressure parts) are normally recommended if:
- Component is exposed to hydrogen sulfide (H2S) including traces of H2S
- Pumps in highly corrosive service
- Pumps in cryogenic service (below -50°C)

Positive material identification (PMI) is conducted for alloys and not to differentiate between grades of carbon steels (API 8.2.2.8). For material certificates refer to API 6.12.1.8.
Typical agents of concern are hydrogen sulfide, amines, chlorides, bromides, iodides, cyanides, fluorides, naphthenic acid and polythionic acid. Other agents affecting elastomer selection include ketones, ethylene oxide, sodium hydroxide, methanol, benzene and solvents. If chlorides are present in the pumped liquid in a concentration above 10 mg/kg (10 ppm), it is necessary to use caution when applying stainless steel. (API 6.12.1.9)

7 NACE MR0103 applies to oil refineries, LNG plants and chemical plants for materials potentially subject to sulfide stress-corrosion cracking (said onshore in some contexts)
ANSI/NACE MR0175- equivalent to ISO 15156 (all parts)- applies to material potentially subject to sulfide and chloride stress-corrosion cracking in oil and gas production facilities and natural gas sweetening plants (said offshore in some contexts)
Ferrous materials required reduced-hardness but not covered by NACE MR0103/0175, shall have a yield strength not exceeding 620 N/mm2 (90 000 psi) and a hardness not exceeding HRC 22. Components that are fabricated by welding shall be post-weld heat-treated (refer to API 6.12.1.12.4)
If NACE applied, wetted components including pressure casing, shafting (including wetted shaft nuts), pressure-retaining mechanical seal components (excluding the seal ring and mating ring), wetted bolting, and bowls shall have reduced hardness. Double-casing-pump's inner-casing parts that are in compression, such as diffusers, are not considered pressure casing parts.

8 For low temperature pump application as -30°C (-20°F) and below, pressure-retaining steels shall meet the minimum Charpy V-notch impact energy requirements at the lowest specified temperature in accordance with paragraph UG-84 of ASME Section VIII, Division 1 (more information at API 6.12.4.5)

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

INSPECTION AND SHOP TEST FOR CENTRIFUGAL PUMPS

PROJECT :
PUMP NUMBER :
PUMP SERVICE :

4 NON-DESTRUCTIVE TESTING

☐ Inspection Class — Class II (13)

No	Component	Methode	Extent (21)	Acceptance (17) (18) (19) (20)
1	CASING Cast/Wrought (14) (15)	RT	Spot (5%)	
		UT	Not Required	
		MT	Spot (10%)	
		PT	Critical Areas	
2	WELDINGS: Main Connections	RT	Full (100%)	
		UT		
		MT		
		PT		
3	WELDINGS: Auxiliary Conn. (16)	RT	Not Required	
		UT		
		MT		
		PT		
4	PIPING: Process Auxiliary Socket-Welded	RT		
		UT		
		MT		
		PT		
5	PIPING: Process Auxiliary Butt-Welded	RT		
		UT		
		MT		
		PT		
6	SHAFT (14)	RT		
		UT		
		MT		
		PT		
6	IMPELLER (14)	RT		
		UT		
		MT		
		PT		

5 VISUAL INSPECTION

Defect Found (22)

☑ Procedure for Major Repairs — Approved

6 WELDING & REPAIR (23) (24) (18)

☑ Welding quality of pressure-containing casings — Acceptable (25)
☐ Welding quality of suction and discharge to casing — Defect Found (25) (26)
☑ Welding quality of auxiliaries to casing — Not Checked (27)

REMARKS

Hardness tests of production welds and of hot bent and hot formed piping are intended to verify satisfactory heat treatment (see note 24). The hardness limit applies to the weld and to the heat affected zone (HAZ) tested as close as practicable to the edge of the weld.
Hardness measurements are taken in the weld, the heat affected zones and the parent metal in order to evaluate the range of hardness values across the welded joint. (refer to ISO 15614-1_2004)

9 Castings shall be free from any defect such as porosity , cracks, blow holes, shrink holes, scale, and similar injurious defects. If any defect observed (See also glossaries) , repair is required.

10 For critical pump services, pumps application in cryogenic services, or for a specialty casting, inspection is recommended for any major casting defect repair.

Major repairs can be defined per ASTM Standards as follows:
- The casting failure to meet hydrostatic test requirements
- Repairs for which the depth of any cavity prepared for repair by welding exceeds 20 percent of the wall thickness or 1.0 in (25 mm), whichever is less.
- The cavity prepared for welding is greater than approximately 10 in2 (65cm2)
- Any repair to cast iron components "may" be considered as major repair.

11 No repairs by peening, plugging or impregnation are allowed to any ferrous pressure containing part and impeller except cast gray iron or nodular iron may be repaired by plugging within the limits of ASTM A278, 536, or 395, respectively. Weldable grades of steel castings may be repaired based on Section VIII, Division 1, and Section IX of the ASME code (Refer to API 6.12.2.3 for more information).
If austenitic stainless steel parts exposed to conditions that can promote intergranular corrosion are fabricated, hard-faced, overlaid or repaired by welding, they shall be made of low-carbon or stabilized grades. Overlays or hard surfaces that contain more than 0.10 % carbon can sensitize both low-carbon and stabilized grades of austenitic stainless steel unless a buffer layer that is not sensitive to intergranular corrosion is applied. (API 6.12.1.7)

12 In general, all major repairs require written acceptance of repair procedure by purchaser prior to proceeding with the repair. The procedure generally should cover:
- Type of defect and how it was discovered
- Sketch or drawing showing location and depth of the defect
- Method of repair (welding, plugging, etc.)
- Step by step procedure of repair including heat treatment where applicable and method of inspection after repair.

13 Inspection classes in accordance to API Table 14:

Class I	Class II	Class III
Minimum Requirement (if not class II or III)	**Max. PT > 200C (392F) & MAWP-margin > 80%**	**SG < 0.5 OR Max. PT > 200C (392F) & SG < 0.7 OR Max. PT > 260C (500F) OR Extremely hazardous services**

Note (1): PT stands for Pumping Temperature and is specified by Purchaser
Note (2): For MAWP-margin, first calculate MAWP-API based on API general rule as follows:

MAWP-API = Maximum Suction Pressure + 1.1 x Maximum Differential Pressure (= MAWP1)

Then compare it with MAWP-OEM (=MAWP2) that is specified by Original Equipment Manufacturer at maximum pumping temperature. If it exceeds 80%, class II may suffice to ensure manufacturing quality.
----> for comparison: MAWP-margin = %{(MAWP2 - AMWP1)/(MAWP1)}

For more information, further to API clause number 6.3.5 (a) & (b), and also 6.3.2 (max. impeller), there are cases in which MAWP-OEM might deviate from the MAWP calculated based on API general rule. Furthermore, referring to API clause 6.3.5, shutoff pressure is to some extend considered in the formula.

14 Wrought materials include forgings, plate and tubular products. Casing includes all items of the pressure boundary of the finished pump casing (e.g. the casing itself and other parts, such as nozzles, flanges, etc. attached to the casing) (API Table 14)
Shaft and impeller as non-pressure parts are not normally addressed by standards regarding NDT. However, with respect to common practices, usually PT for impeller and UT for shaft are recommended to be performed.

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

PROJECT :
PUMP NUMBER :
PUMP SERVICE :

GLOSSARY

Mill Test Report (MTR)
is a quality assurance document used in the metals industry that certifies a material's chemical and physical properties and states a product made of metal (steel, aluminum, brass or other alloys) compliance with an international standards organization (such as ANSI, ASME, etc.) specific standards. Mill here refers to an industry which manufactures & processes Raw Materials. You may also refer to BS DIN EN 10204 for more information about material certificates.

EN 10204:2004 comes with two main categories each one introducing two types of certificate validation as follows;

>> Category 1; Non-Specific Inspection (carried out by the manufacturer in accordance with his own procedures)

+ **Type 2.1;** Manufacture declares (documented) that the products supplied are in compliance with the requirements of the order, without inclusion of test results.

+ **Type 2.2;** Manufacture declares (documented) that the products supplied are in compliance with the requirements of the order. Also, test results are provided carried out in accordance with manufacture standers.

>> Category 2; Specific Inspection (carried out, before delivery, according to the product specification or international standards applied by purchaser)

+ **Type 3.1;** Manufacture declares (documented) that the products supplied are in compliance with the requirements of the order. Also, test results are provided carried out in accordance with product specification, the official regulation and corresponding rules and/or the order. The document is validated by the manufacturer's authorized inspection representative, independent of the manufacturing department.

+ **Type 3.2;** Manufacture declares (documented) that the products supplied are in compliance with the requirements of the order. Also, test results are provided carried out in accordance with product specification, the official regulation and corresponding rules and/or the order. The document is validated by the manufacturer's authorized inspection representative, independent of the manufacturing department and either the purchaser's authorized inspection representative or the inspector designated by the official regulations

Positive Material Identification (PMI)
is the analysis of a metallic alloy to establish composition by reading the quantities by percentage of its constituent elements. Typical methods for PMI include X-RAY FLUORESCENCE (XRF) and OPTICAL EMISSION SPECTROMETRY (OES).

NACE
NACE requirements are applied to different materials ensuring they meet specific hardness limits in order to avoid sulfide stress cracking. Generally, NACE is practicing to keep or lower materials hardness to some discrete amounts and this is why it may be known as reduced-hardness in other contexts. To achieve this, NACE may require controlling the chemistry of base metal or applying different heat treatment methods. (Attention: when NACE applies the weldments, welding procedures, and heat treatment methods might be affected by NACE requirements)

Heat Treatment (PWHT/PRHT)
Heat treating is a group of industrial and metalworking processes used to alter the physical, and sometimes chemical, properties of a material. The most common application is metallurgical. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material. Heat treatment techniques include annealing, case hardening, precipitation strengthening, tempering, normalizing and quenching.

REMARKS

15 For double-casing pumps, the outer casing pressure/temp. should be used to determine the inspection class of the outer casing. The inner casing should be inspected to Class I. (API 8.2.2.2)

16 Due to complex geometry and thickness variations, it may be not practical to RT butt-welded auxiliary casing connections (API Table 14) and UT may be done instead.

17 All inspections (VI/RT/UT/PT/MT) shall be performed after final heat treatment. UT of wrought material shall be performed prior to any machining operations that can interfere with the UT examination. (API 8.2.2.3)

18 If any defect observed, for repair refer to part 3; Casting & Repair.

19 Where the configuration of a casting makes radiography impossible, radiographic examination may be replaced by ultrasonic testing. (API 8.2.2.4)

20 Inspection methods and acceptance criteria shall be in accordance to references reported on API Table 15 as follows:

Type of inspection	Methods	Acceptance criteria	
		For fabrications	For castings
Radiography	ASME BPVC, Section V, Articles 2 and 22	ASME BPVC, Section VIII, Division 1, UW-51 (for 100 % radiography) and UW-52 (for spot radiography)	ASME BPVC, Section VIII, Division 1, Appendix 7
Ultrasonic inspection	ASME BPVC, Section V, Articles 5 and 23	ASME BPVC, Section VIII, Division 1, Appendix 12	ASME BPVC, Section VIII, Division 1, Appendix 7
Liquid-penetrant inspection	ASME BPVC, Section V, Articles 6 and 24	ASME BPVC, Section VIII, Division 1, Appendix 8	ASME BPVC, Section VIII, Division 1, Appendix 7
Magnetic-particle inspection	ASME BPVC, Section V, Articles 7 and 25	ASME BPVC, Section VIII, Division 1, Appendix 6	ASME BPVC, Section VIII, Division 1, Appendix 7
Visual Inspection (all surfaces)	ASME BPVC, Section V, Article 9	In accordance with the material specification and the manufacturer's documented procedures	MSS SP-55

21 Critical areas are inlet nozzle locations, outlet nozzle locations and casing wall thickness changes. The manufacturer shall submit details of the critical areas proposed to receive MT/PT/RT/UT inspection for purchaser's approval.

22 All surfaces of castings including castings for flanges and other piping components, etc., will be visually inspected to ensure conformity with the requirements of MSS SP-55 and will be free from any scale buildup, cracks, hot tears, etc. (See page 2 for Casting & Repair)

23 Welding and weld repairs shall be performed and evaluated in accordance to API Table 11.

Requirement	Applicable code or standard
Welder/operator qualification	ASME BPVC IX or ISO 9606 (all parts)
Welding procedure qualification	Applicable material specification or, where weld procedures are not covered by the material specification, ISO 15609 (all parts), ASME BPVC IX or ANSI/ASME B31.3
Non-pressure-retaining structural welding, such as baseplates or supports	ISO 10721-2 (equivalent to ANSI/AWS D1.1/D1.1M)
Magnetic-particle or liquid-penetrant examination of the plate edges	ASME BPVC VIII, Division 1, UG-93(d)(34)
Post-weld heat-treatment	Applicable material specification, EN 13445-4, ASME BPVC VIII, Division 1, UW 40, or ANSI/ASME B31.3
Post-weld heat-treatment of casing fabrication welds	Applicable material specification, EN 13445-4, or ASME BPVC VIII, Division 1

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

PROJECT :
PUMP NUMBER :
PUMP SERVICE :

GLOSSARY

Nil Ductility Transition Temperature; The temperature above which a material is ductile and below which it is brittle is known as the Nil-Ductility Transition (NDT) temperature. This temperature is not precise, but varies according to prior mechanical and heat treatment and the nature and amounts of impurity elements. It is determined by some form of drop-weight test (ASTM E208). Nil ductility transition temperature of a material represents the point at which the fracture energy passes below a pre-determined point (for steels typically 40J for a standard Charpy impact test).

Gouging/Chipping: as a welding method; is removal of a quantity of metal by completely consuming that portion of the metal removed to form a groove or bevel. Air carbon arc, Plasma arc, mechanical, and oxyfuel are different type of gouging.
Back gouging (chipping) is a process of cutting a groove in the backside of a joint that has been welded. Back gouging can ensure 100% fusion at the root and remove discontinuities of the root pass.

Solution annealing: As a heat treatment process, solution annealing is one of various annealing methods (full, isothermal, inter-critical, subcritical, etc) that is applied commonly to austenitic stainless steels, typically at 1010-1150°C. With unstabilised grades, the treatment must be followed by fast cooling or quenching. It is applied as a softening process during manufacture or to optimize corrosion resistance (e.g. after welding).

Major Casting Defects

Shrinkage; Shrinkage defects can occur when standard feed metal is not available to compensate for shrinkage as the thick metal solidifies. The specific volume of the standard casting metals is larger in the liquid state than in the solid state. For this reason, these metals undergo contraction when solidifying and cooling. This leads to a volume deficit that manifests itself in the form of defects, such as shrink holes, sink marks, microporosity, etc. Shrink holes are thus the result of the interaction between the physical volume deficit during the solidification process and the possibility of compensating it through additional feeding. Shrinkage defects can be split into two different types: open shrinkage defects (on surface) and closed shrinkage defects (inside solid metal).

Porosity; Gas porosity is the formation of bubbles within the casting after it has cooled. This occurs because most liquid materials can hold a large amount of dissolved gas, but the solid form of the same material cannot, so the gas forms bubbles within the material as it cools. Gas porosity may present itself on the surface of the casting or may be trapped inside the metal. Nitrogen, oxygen and hydrogen are the most encountered gases in cases of gas porosity.

Hot Tears; one of the main casting defects is hot tearing or hot cracking, or hot shortness. This phenomenon represents the formation of an irreversible failure (crack) in the still semisolid casting. The fracture has a bumpy surface covered with a smooth layer and sometimes with solid bridges that connect or have connected both sides of the crack.

Mill Scale; often shortened to just scale, is formed on the outer surfaces of plates, sheets or profiles when they are being produced by rolling red hot iron or steel billets in rolling mills. Mill scale is composed of iron oxides mostly ferric and is bluish black in color. It is usually less than 0.1 mm (0.0039 in) thick and initially adheres to the steel surface and protects it from atmospheric corrosion provided no break occurs in this coating. Mill scale is a nuisance when the steel is to be processed. Any paint applied over it is wasted, since it will come off with the scale as moisture-laden air gets under it.

Blowhole; Tiny gas bubbles are called porosities, but larger gas bubbles are called a blowholes or blisters. Vacuum holes caused by metal shrinkage may also be loosely referred to as 'blowholes'

REMARKS

24 Post-weld heat-treatment (PWHT) , if required, shall be carried out after all welds, including piping welds, have been completed.

Heat treatment is used to avert or relieve the detrimental effects of high temperature and severe temperature gradients inherent in welding, and to relieve residual stresses created by bending and forming

Necessity and method of PWHT is relating to pumping liquid (sour services), nominal thickness, welding method, operating temperature, etc. which has been introduced in relating standards such EN 13445-4 (refer to Note 23)

25 For fabricated casings, pressure-containing welds, including welds of the casing to axial-joint and radial-joint flanges, shall be full penetration welds. Accessible surfaces of welds shall be non-destructive inspected after back chipping or gouging and again after post-weld heat-treatment or, for austenitic stainless steels, after solution annealing.

26 Attachment of suction and discharge nozzles shall be by means of full-fusion, full-penetration welds using welding neck flanges. Dissimilar metal weldments shall not be used.

27 Auxiliary piping welded to alloy steel casings shall be of a material with the same nominal properties as the casing material or shall be of low-carbon austenitic stainless steel.

28 Minimum pressure is calculated as: **1.5 x MAWP x f**

MAWP is reported by Vendor at maximum pumping temperature.

f: For pump services which are expected to work in a temperature higher than test temperature, test pressure shall be multiplied by a factor obtained by dividing the allowable working stress for the material at the testing temperature by that at the rated operating temperature. (Refer to API 8.3.2.6) (For Material Properties refer to ASME Section II; Part D; Subpart 1)

29 The test liquid shall be at a temperature higher than the nil-ductility transition temperature of the material being tested. By ISO standard (5199), it shall be perforemd with clean water at ambient temperature and for carbon steel, not less than 15 °C.

30 The hydrostatic test liquid shall include a wetting agent to reduce surface tension if one or more of the following conditions exist (Refer to API 8.3.2.7):
a) The liquid pumped has a relative density (specific gravity) of less than 0.7 at the pumping temperature
b) The pumping temperature is higher than 260 °C (500 °F)
c) The casing is cast from a new or altered pattern
d) The materials are known to have poor castability

31 The chloride content of liquids used to test austenitic stainless steel materials shall not exceed 50 mg/kg (50 ppm). Chloride content is limited in order to prevent stress-corrosion cracking. (API 8.3.2.8)

32 Hydrostatic testing is permitted without the seal-gland plate or removable seal chamber installed. The mechanical seal shall not be included in the hydrostatic test of the pump case. (Refer to API 8.3.2.9)

33 Steam, cooling-water and lubricating-oil piping, if fabricated by welding, shall be tested at 1,5 times maximum operating gauge pressure or 1,050 kPa (10.5 bar; 150 psi), whichever is greater. (Refer to API 8.3.2.13)

34 Cooling passages and components, including jackets for bearings, seal chambers, oil coolers and seal coolers, shall be tested at a minimum gauge pressure of 1,000 kPa (10 bar; 150 psi). (Refer to API 8.3.2.15)

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

PROJECT :

PUMP NUMBER :

PUMP SERVICE :

7 HYDRO-STATIC TEST

HYDRO-STATIC TEST	**Required**	(40)
Minimum Test Pressure	60 barg	(28)
Test Medium Temperature	15 C	(29)
Wetting Agent	Required	(30)
Chloride Content	< 50 ppm	(31)
Parts Tested	Acc. To Code	(32)
proof machined condition	Not Required	(35)
Duration	30 min.	(36)
Segmentally Testing	Not Applicable	(37)
Auxiliry Piping	10.5 barg	(33)
Cooling Components	10 barg	(34)
Test Result	Satisfactory	(38)
After Test Treatment	Acc. To Code	(39)

REMARKS

35 Austenitic or duplex stainless steel pressure-casing components may be hydrostatically tested in the proof (rough) machined condition (API 8.3.2.10). In the proof (rough) machined condition, an additional amount of material remains on areas where machining to critical dimensions and tolerances is required. The additional amount of material removed shall not exceed 1 mm (0.040 in) material stock or 5 % of minimum allowable wall thickness, whichever is less.

Because of the residual stresses resulting from final liquid quenching and relatively low proportional limits inherent in these materials, small amounts of permanent deformation can occur at critical dimensions during hydrostatic testing. By allowing a small amount of material to remain at these critical areas during hydrostatic testing, the necessity to add material by welding to restore close-tolerance dimensions after hydrotest is avoided.

36 Base time duration for hydrotest by API is minimum 30 minutes (8.3.2.11), but for large and heavy pressure-containing parts, it can require a longer testing period as agreed upon by the purchaser and the vendor.

By ISO 5199; 6.3.3.1, minimum test duration is 10 minutes.

By HI 14.6; Table B.1; test duration depends on pump's pressure rating:

Rated above 2500 kPa (360 psi)	30 min.	Hydrostatic test is **optional** by **HI** standard.
Rated above 1000 kPa (145 psi) and not above 2500 kPa (360 psi)	10 min.	
Rated up to 1 000 kPa (145 psi)	5 min.	

Note For pumps with a shaft power of less than 10 kW (13 hp) and a pressure rating of less than 1000 kPa (145 psi), the minimum test time shall be 1 minute.

37 If approved by purchaser, vertically suspended, double-casing, integral gear-driven and horizontal, multistage pumps may be designed for dual pressure ratings. Accordingly, they may be segmentally tested. In such case, Seepage past internal closures required for testing of segmented cases and operation of a test pump to maintain pressure is acceptable. (API 8.3.2.12)

38 The hydrostatic test shall be considered satisfactory if neither leaks nor seepage through the pressure containing parts and joints occur. The purchaser's written approval is required prior to any repairs performed because of a failed hydrostatic test.

39 To prevent deposition of chlorides as a result of evaporative drying, all residual liquid shall be removed from the tested parts at the conclusion of the test

REMARKS

40 Need to be mentioned that hydrotest is optional by HI standard. (HI 14.6; Annex B)

41 Shop running test in general (including performance, NPSH, and mechanical run) is conducted to verify pump performance, vibration level, and mechanical integrity.

42 Performance test is mandated for each pump by API (followed here) but might not be necessary in all standards and specifications. So, it is of paramount importance to make reference-standard clear before contract.

API 610, 2010	ISO 5199, 2002	HI 14.6, 2011	Remarks
Mandatory	Mandatory (ISO 9906, 2012)	Mandatory	by ISO and HI, testing all identical pumps is not mandatory and the number of pumps tested shall be agreed in advance

43 Contract (purchased) bearings shall be used during pump shop tests. (API 8.3.3.2)

44 According to API, purchased mechanical seals shall be used unless otherwise approved by purchaser. Not using purchased mechanical seal(s) during shop test might be either for preventing damage to seal or when test liquid is not compatible with seal material.
In case of using purchased seal and with regard to differences between pumping fluid and test liquid, modified seal faces might be required during performance test which shall be supplied by seal manufacturer. After successful test, modified seal faces will be replaced with purchased seal faces.

Always after performance test, mechanical seal (with purchased faces or in case of shop seal, after replacing with purchased seal) shall be air tested (refer to API 610; 2010; 8.3.3.7 d)- or ISO 21049; 2004; 10.3.4). Only if purchased seal (without modified seal faces) has been used during performance test and passed shop test successfully, air test is not required.
Seal satisfactory operation in performance test is achieved when no leakage is observed during test (for more detail information refer to API 610; 2010; 8.3.3.2 c) & d)- also ISO 21049; 2004; A.1.3). in case of leakage, seal shall be disassembled, repaired, and air tested. Pump rerun would be required until seal satisfactory operation is achieved.

45 Applying contract (purchased) Motor (Driver) is not mandatory in performance test.

46 Unless otherwise agreed, performance tests shall be performed using water at a temperature not exceeding 55 °C (130 °F). (API 610; 2010; 8.3.3.2 i)

47 According to API, all lubricating-oil pressures, viscosities and temperatures shall be within the range of operating values recommended in the vendor's operating instructions for the specified unit being tested. (Refer to API 610; 2010; 8.3.3.2 e) & f))

48 All joints and connections shall be checked for tightness and any leaks shall be corrected. (Refer to API 610; 2010; 8.3.3.2 g)

49 At the beginning and end of test, oil temperature for ring and splashed-oil systems or bearing metal temperature for oil pressurized system shall be recorded according to API 610; 2010; 8.3.3.5. During test, for ring or splashed-oil systems, sump oil temperature rise shall not exceed 40K. For pressurized oil system, bearing oil temperature rise shall not exceed 28K. (for more information please refer to API 610; 2010; 6.10.2.4)

50 According to API, if specified, the performance test shall be conducted with test stand NPSHA controlled to no more than 110 % of the NPSHA specified on the data sheet. It is the purpose of this test to evaluate pump performance with the specified NPSHA at pump suction. (API 610; 2010; 8.3.3.6)

51 If it is necessary to dismantle a pump after the performance test for the sole purpose of machining impellers to meet the tolerances for differential head, no retest is required unless the reduction in diameter exceeds 5 % of the original diameter. The diameter of the impeller at the time of shop test, as well as the final diameter of the impeller, shall be recorded on a certified shop test curve that shows the operating characteristics after the diameter of the impeller has been reduced. (API 610; 8.3.3.7-a)

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

INSPECTION AND SHOP TEST FOR CENTRIFUGAL PUMPS

PROJECT :

PUMP NUMBER :

PUMP SERVICE :

8 PERFORMANCE TEST — Required (41) (42)

CAUTION: green and red highlighted cells include formula.

Contract bearing to be used	YES	(43)	Lube oil characteristics	In Range	(47)	Test Stand NPSHA: Not More than 110% DSH's NPSHA	Not Specified	(50)
Contract mechanical seal to be used	YES-Modified Seal Faces	(44)	Leakage from joints and connections	Yes (but corrected)	(48)	Impeller Diameter @ Beginning of Test		(51)
Contract Motor to be used	Not Mandatory	(45)	Lube oil/ bearing metal temp. (C)	20 @ Beginning of Test	(49)	Impeller Diameter @ End of Test		(51)
Test Liquid	Clean & Cold Water (<55C)	(46)	Lube oil/ bearing metal temp. (C)	50 @ End of Test	(49)	Pump dismantling after test & Retest	Dismantled with Retest	(68)

Pump Tag No.:		Suction Size (mm):	250	Rated Capacity (m3/h):	462	Nominal Power (kW):	1250	Pum. Liq. Vapor Pres. (bar):	1.7
Pump Serial No.:		Discharge Size (mm):	200	Rated Head (m):	682.4	Pumping Liq. SG:	1	Water Temp. (C):	30 (@ Shop)
Pumping Liquid:	HP Boiler Feedwater	Nominal RPM:	2977	Shutoff Head (m):	800	Pum. Liq. Visco.(cP):	0.29 (@ 115C)		
Stage(s) No.:	2 (& Double)	NPSHA (m):	11.51	Rated Efficiency (%)	82%	Test Liquid SG.:	1		
Impeller Dia. (mm):	270 / 394 (1st/2nd)	NPSHR (Predicted) (m):	8.5	Rated Power (kW)	1008	Test Liq. Visco.(cP):	0.8 (@ 30C)		

Water Viscosity (cP)		
1.79 @ 0C	0.8 @ 30C	0.40 @ 70C
1.52 @ 5C	0.65 @ 40C	0.36 @ 80C
1.31 @ 10C	0.55 @ 50C	0.32 @ 90C
1.00 @ 20C	0.47 @ 60C	0.28 @ 100C

Testing Points (52) (53) (54)		Flow(m3/hr) (55)		Press. (barg)		Head (m) (56)				RPM (57)		Current (A) & Volt. (V) (58)				Motor Data (59)		Power (kW) (60)				effic. (%) (61)		Vibration (mm/s) Drive End			Non-Drive		
		points	Cor'ed	Suc.	Dis.	Predi.	Dyn.	Static.	Total	Tst	C. Fact	I1	I2	I3	V	CosΦ	effic.	Predi.	Hydro.	Test	Cor'ed	Predi.	Test	Axi.	Hor.	Ver.	Axi.	Hor.	Ver.
1	Shutoff		0.0			800.0	0.000	0.0	0.0		0%							415	0	0	0	0%	0%	(63) (64) (65)					
2	MCSF	179.6	179.6	4.12	82.01	790.0	0.076	793.2	793.3	2977	100%	82.4	82.4	82.4	5935	0.88	95.45	740	388	712	712	53%	55%	0.4	1.6	0.8			
3	Midpoint 95-99% of Rt'd	420.5	420.5	3.85	73.58	710.0	0.416	710.1	710.5	2977	100%	112.0	112.0	112.0	5935	0.91	95.88	990	814	1005	1005	81%	81%	0.3	1.6	0.8			
4	Rated Up to 105%	462.6	462.6	3.79	71.31	682.4	0.503	687.6	688.1	2977	100%	117.2	117.2	117.2	5937	0.91	95.89	1008	867	1052	1052	82%	82%	0.3	1.6	0.7			
5	BEP	494.4	494.4	3.67	69.26	655.0	0.575	667.9	668.5	2977	100%	120.8	120.8	120.8	5938	0.91	95.90	1020	901	1084	1084	83%	83%	0.3	1.5	8.0			
6	MAF	592.8	592.8	3.51	61.82	560.0	0.827	593.8	594.6	2977	100%	130.8	130.8	130.8	5935	0.92	95.92	1077	961	1186	1186	81%	81%	0.3	1.6	1.0			

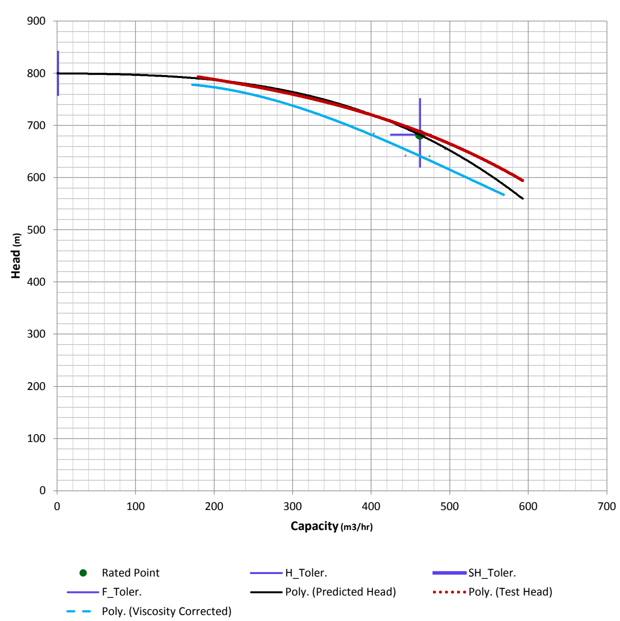
Tolerance Band (62)	Flow Rate		Rated Head		Shutoff Head		Power		Efficiency	
	Upper	3%	Upper	10%	Upper	5%	Upper	9%	Upper	0%
	Lower	-8%	Lower	-9%	Lower	-5%	Lower	0%	Lower	-7%

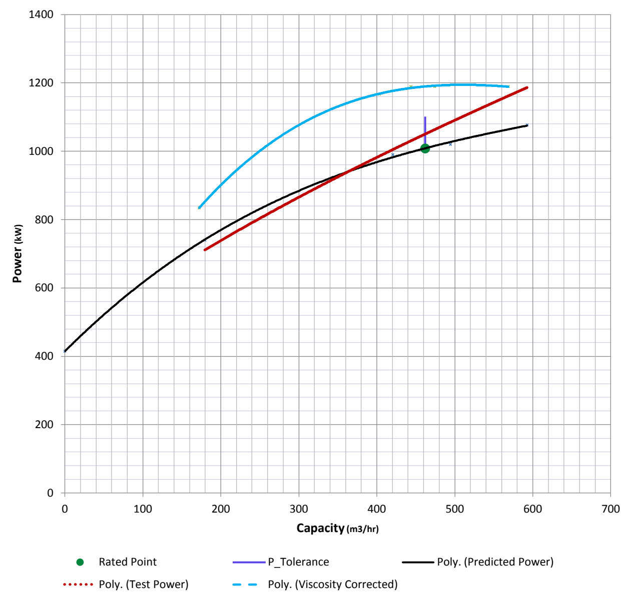
In case of "No-Limit" or "Not Applicable" please select 0%.

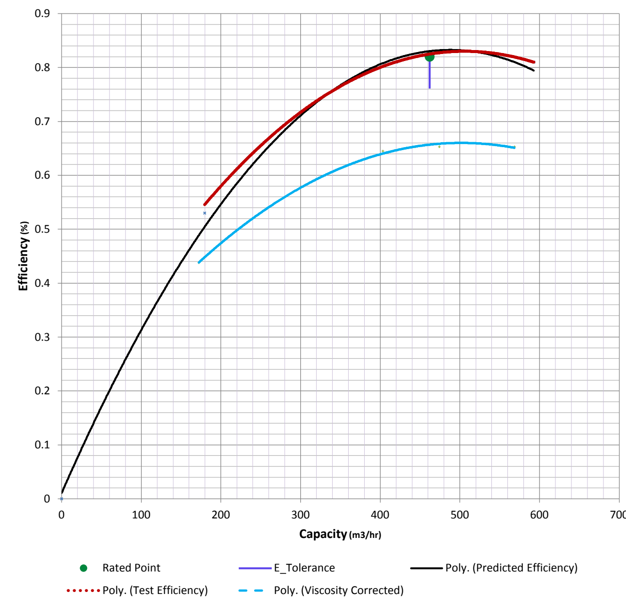
Correction for Viscosity is Required (66) **YES**

Visc. =	200.0	cSt (For viscous pumping liquid)	Stage No. =	2
Q =	494.4	m3/hr (For water curve @ BEP)	S.G. =	1.00
H =	668.5	m (For water, per stage @ BEP)	Visc. cP =	200.0
N =	2977	RPM		
B =	4.436	B Factor ->	Refer to Note (67)	

			read from test curve			corrected for viscosity			
			Q-w	H-w	η-w	Q-act.	H-act.	η-act.	p-act.
C-Q = 0.959									
C-η = 0.796									
$C\text{-}H_1$ = 1.000	Shutoff	1	0.0	0.0	0%	0.0	0.0	0%	#N/A
$C\text{-}H_2$ = 0.981	MCSF	2	179.6	793.3	55%	172.3	778.1	44%	834
$C\text{-}H_3$ = 0.964	Mid Point	3	420.5	710.5	81%	403.3	684.8	64%	1167
$C\text{-}H_4$ = 0.961	Rated	4	462.6	668.1	82%	443.7	642.1	65%	1189
$C\text{-}H_{BEP}$ = 0.959	BEP	5	494.4	668.5	83%	474.2	641.2	66%	1254
$C\text{-}H_6$ = 0.953	MAF	6	592.8	594.6	81%	568.6	566.7	64%	1361







Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

PROJECT :

PUMP NUMBER :

PUMP SERVICE :

REMARKS

52 According to API, test data shall be recorded as minimum in 5 points which are normally from followings;
1) Shutoff
2) Minimum continuous stable flow (MCSF)
3) Between 95 % and 99 % of rated flow (Mid Point)
4) Between rated flow and 105 % of rated flow
5) Approximately the best efficiency flow (BEP)
6) End of allowable operating region. (MAF)

>> ISO 9906; 2012 and HI 14.6; 2011 share the same criteria.

53 If rated flow is in 5% of BEP, BEP is not required to be recorded and another point might be slected instead.

54 For multi-stage and high-speed pumps, test at shutoff may be not feasible (high temperature rise is possible at shutoff). (For high-energy density pumps refer to API 610; 2010; 6.1.15)

55 If required, flow rate shall be corrected to the rated speed; $Q_2 = Q_1 \times (N_2 / N_1)$

56 Predicted head to be read from pump performance curve.

Dynamic head is due to liquid velocity and is calculated as $H_{Dyn} = V^2 / 2g = (1/2g)\,(4Q/pi)^2\,[1/(D_2)^2 - 1/(D_1)^2]$

D_1 and D_2 are suction and discharge diameter respectively.

Static head is calculated from static pressure measured by pressure gauges installed at suction and discharge: $H_{St} = \rho g / (P_2 - P_1)$

Total head is sum of dynamic and static head and if required, corrected for speed: $H_2 = H_1 \times (N_2 / N_1)^2$ (Height of pressure gauges might also be considered if are installed high enough)

57 According to API, test speed shall be within 3% of rated speed indicated on pump's datasheet. Test results shall be corrected to rated speed by affinity laws. If contract motor is used in test, no correction for speed is required.

By ISO and HI, deviation within range of 50 to 120% of rated speed is allowed. Also it has been cautioned that speed has an effect on pump efficiency, but it could be neglected within range of 20% of rated speed.

58 The current to each phase of Motor and Voltage are normally recorded in performance test which could be used for calculation absorbed power. However, with respect to test facilities, Vendor may measure input power by other methods (For more information refer to ISO 9906; 2012; D.4.3 & HI 14.6; 2011; 1.4)

59 Motor power factor and efficiency are read from motor load curve prepared by original motor manufacturer which are applied for power calculation. (see Note 60)
Motor curves are normally plotted based on motor load percent. By recorded current in test, load percent could be realized from curve and then, other parameters could be read accordingly.

60 Predicted power is read from submitted performance curve.

Hydraulic power is calculated from speed-corrected flow and total head: $P_{Hy} = Q \times \rho \times g \times h$

Test (/absorbed) power is calculated from recorded data during test: $BHP = (3^{0.5})\, I \times V \times \cos\Phi \times$ (Motor effic.) average recorded current could be applied in calculation.

Calculated absorbed power shall be corrected to rated speed: $P_2 = P_1 \times (N_2 / N_1)^3$

61 Predicted pump efficiency should be read from submitted pump performance curve. Test pump efficiency is calculated by pump hydraulic power and pump absorbed power calculated (and speed-corrected) from test: $Eff._P = P_{Hy} / BHP$

REMARKS

62 Refeering to API 610; 2010, acceptance crteria for performance test is as follows;

Condition	Rated Point (%)	Shutoff (%)
Rated differential head		(a)
0 m to 75 m (0 ft to 250 ft)	± 3	± 10
> 75 m to 300 m (250 ft to 1 000 ft)		± 8
> 300 m (1 000 ft)		± 5
(Maximum) Rated Power	4 (b)	
(Minimum) Efficiency	(c)	
(Maximum) Rated NPSH	0	

(a) If a rising head flow curve is specified (see PAI 610; 6.1.11), the negative tolerance specified here shall be allowed only if the test curve still shows a rising characteristic.

(b) With test results corrected to rated conditions [see 8.3.3.3 b)] for flow, speed, density (specific gravity) and viscosity, it is necessary that the power not exceed 104 % of the rated value, from all causes (cumulative tolerances are not acceptable).

(c) The uncertainty of test efficiency by the test code specified is 2,5 %; therefore, efficiency is not included in the pump's rated performance. In those applications where efficiency is of prime importance to the purchaser, a specific value and related tolerance should be negotiated at the time of the order (see 8.3.3.4).

\+ **The test data by this booklet are fitted to polynomial equation with orders as follows: Head(3), Power(3), Efficiency(2), and NPSH(2). Certified data needs to be read from curve trough intersection of rated flow and generated test curve. (Refer to API 8.3.3.3 b)**

ISO 9906; 2012 & HI 14.6; 2011 share identical acceptance criteria with three major grades (1, 2, & 3) divided to unilateral and bilateral sub-grades as following. API acceptance criteria are in compliance with HI/ISO grade 1B, but with no tolerance for efficiency.

Grade	1			2		3	
ΔτQ (%)	10			16		18	Guarantee requirement
ΔτH (%)	6			10		14	
Acceptance Grade	**1U**	**1E**	**1B**	**2B**	**2U**	**3B**	
τQ (%)	+10	±5		±8	+16	±9	Mandatory
τH (%)	+6	±3		±5	+10	±7	
τP (%)	+10	+4		+8	+16	+9	Optional (HI: or/either)
τη (%)	≥ 0		-3	-5		-7	

\+ In above table U, B, & E stand for unilateral, bilateral, & Energy-Efficiency respectively. Specifically 1E is important for purchasers concerned about energy consumption.

\+ HI and ISO are open to purchaser selection regarding which grade should be used for performance verification. However, if it has been omitted before contract, ISO/HI offer default test acceptance grade (ISO 9906; 2012; 4.5 & HI 14.6; 2011; 14.6.4).

\+ Despite API, both HI & ISO do not mandate any criteria for shutoff point. But it has been explained that any duty point other than rated should be specified by purchaser and its acceptance criteria shall be agreed between purchaser and vendor. If purchaser specify other test points but fail to clarify acceptance criteria, grade 3B (ISO: Grade 3) will be applied by default. (ISO 9906; 2012; 4.1 & HI 14.6; 2011; 14.6.3.1)

\+ API is mute regarding test flow rate tolerances. However, according to HI/ISO, a test is accepted when at either guarantee flow or head, the other factor is (or both are) within accepted tolerance band. (by next revision of API, ±3% allowable tolerance for flow might be expected)

\+ By HI/ISO, power and efficiency tolerances are optional meaning that one of them could apply but not both. API in this regard has made its choice and is only applying power tolerance.

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

PROJECT :

PUMP NUMBER :

PUMP SERVICE :

REMARKS

62 Continued .....

Worth to be noted that tolerances are adopted based on test uncertainties. In fact tolerances should be higher than uncertainties unless successful test result might be not achieved practically. There are two different types of uncertainties, “random” and “systematic”. Random uncertainty could be reduced by increasing the number of measurements but systematic uncertainty remains constant as far as same measuring instruments are used. Overall uncertainties are derived from both factors. (for more information refer to ISO 9906; 2012; 4.3 Measurement Uncertainty)

Power and efficiency are calculated but not directly measured. Accordingly, their uncertainty is calculated based on maximum and minimum uncertainty for affecting parameters (ISO 9906; 2012; 4.3.3.4). Referring ISO and with respect to method of power calculation, minimum and maximum amount of uncertainty band for grade 1, 2 & 3 would be as following:
[Grade 1 (Min., Max.); Grade 2 & 3 (Min., Max.)] : [(±2.9 , ±3.2) ; (±6.1 , ±6.4)]
Finally it should be pointed out that API is probably omitting efficiency tolerance because HI/ISO tolerances for efficiency are not based on calculated uncertainties but more practical. As HI says “The power and efficiency tolerances are not the result of an exact calculation using the maximum values of a related column. They are instead reflecting real life experience. For grade 1 E and 1 U, no negative tolerance on efficiency is allowed.”

However, no tolerance for efficiency, makes API not appropriate test standard for energy-efficiency sensitive cases like very large size pumps. (refer to API 610; 2010; 8.3.3.4). According to API, considering tolerance for efficiency might affect pump cost and delivery.

+ By HI/ISO, for small pumps (shaft power input < 10kW), more lenient tolerances should be considered as: $\tau Q = \pm 10$ % and $\tau H = \pm 8$ %.
Also for power and efficiency, formulas are defined. (ISO 9906; 2012; 4.4.2)

63 According to API, vibration levels shall be measured during performance test at each test point except for shutoff. No vibration record is required following HI & ISO standards.

64 Acceptance criteria for vibration has been regulated by API and categorized for horizontal, vertical, and high energy pumps. It has been tabulated hereunder briefly, but for more detail information refer to API 610; 2004; 6.9.3.

Location of vibration measurement	
Bearing housing	Pump shaft
Pump bearing type	
All	Hydrodynamic journal bearings
Vibration limits for overhung and between-bearings pumps (@ preferred region)	
vu < 3.0 mm/s (0.12 in/s)	Au < (5.2 x 10^6/n)^0.5 µm [(8,000/n)^0.5 mils]
	Not to exceed: Au < 50 µm (2,0 mils)
Vibration limits for vertically-suspended pumps (@ preferred region)	
vu < 5.0 mm/s (0.20 in/s)	Au < (6.2 x 10^6/n)^0.5 µm [(10,000/n)^0.5 mils]
	Not to exceed: Au < 100 µm (4.0 mils)

+ "vu" is the measured overall velocity (RMS)
+ "Au" is the amplitude of measured overall displacement (peak-to-peak)
+ "n" is the rotational speed, expressed in r/min
+ Foregoing limits are for preferred operating region, for any other operating point out of preferred but within allowable region, 30% increase is allowed. In fact, the points at which level of vibration exceeds this limit are reference for MCSF and MAF.
+ For pumps running above 3600 rpm or absorbing more than 300 kW (400 hp) per stage, above limits are not applicable and API curve (API 610; 2010; Figure 34) shall apply.

REMARKS

65 Pump vibration shall be measured at each bearing housing in term of RMS (root mean square; mm/s or in/s) unless for hydrodynamic bearings which should be measured on shaft in term of peak-to-peak displacement (µm or mils). (API 610; 2010; 6.9.3.2)

66 There is no absolute margin to decide at which viscosity (different from water) correction should apply. It is known that as much as fluid viscosity deviates from water, pump curve also deviate from those generated by manufacturers for water. In general, viscosity effects are matter of concern when pumping liquid viscosity is higher than water. Generated curves for water are adequate for use when the actual fluid that we are interested in pumping has a viscosity that is less than or equal to that of water.

There should be different empirical and theoretical methods that could be used for viscosity effects estimation. For years, HI guidelines have been used by most of pump users and designers. It was first based on generalized curves, derived from test data available from individual pumps tested up to 1960 and were thus not of a generic nature.

Working with HI graphs were not much user-friendly. Hence, a set of polynomial equations were intruduced by GUNNAR HOLE which have been developed to replace the nomograph presented in old HI version Figure 72. (Refer to The Pump Handbook Series, CENTRIFUGAL PUMPS, GUNNAR HOLE, Fluid Viscosity Effects on Centrifugal Pumps, 2000)

Later, HI introduced calculation method and formulas (HI 9.6.7 2010) which are supposed more precise and cover a wider range of test data collection up to 1999. Accordingly, HI method is applied here by this guidline.

It should be realized that performance estimates using the HI method are only approximate. There are many factors for particular pump geometries and flow conditions that the method does not take into account. It is nevertheless a dependable approximation when only limited data on the pump are available and the estimate is needed. Theoretical methods based on loss analysis may provide more accurate predictions of the effects of liquid viscosity on pump performance when the geometry of a particular pump is known in more detail.

67 Where applying HI 9.6.7; 2010, you must be aware that:

+ Reference test data is from conventional single-stage and multistage pumps which cover the following range of parameters: closed and semi-open impellers; kinematic viscosity 1 to 3000 cSt; rate of flow at BEP with water $Q_{BEP\text{-}W}$ = 3 to 410 m3/h (13 to 1800 gpm); head per stage at BEP with water $H_{BEP\text{-}w}$= 6 to 130 m (20 to 430 ft).
+ The generalized method may be applied to pump performance outside the range of test data indicated above. Empirical data are based on viscosities up to 3000 cSt, but the procedure may be used up to 4000 cSt with increased uncertainty.
+ The correction factors are applicable to pumps of hydraulic design with essentially radial impeller discharge ($N_{s\text{-}METRIC} \leq 60$, $N_{s\text{-}US} \leq 3000$), in the normal operating range, with fully open, semi-open, or closed impellers. Do not use these correction factors for axial flow type pumps or for pumps of special hydraulic design.
+ Use correction factors only where an adequate margin of NPSH available (NPSHA) over NPSH3 is present in order to cope with an increase in NPSH3 caused by the increase in viscosity.
+ Performance guarantees are normally based on water performance. All methods for viscous corrections are subject to uncertainty and adequate margins need to be considered, especially with respect to the pump driver rating.
+ Pumps in the range of $20 \leq N_{s\text{-}METRIC} \leq 40$ ($1000 \leq N_{s\text{-}US} \leq 2000$) can be expected, based on available data, to give the highest efficiencies when viscous liquids are being pumped.
+ HI provides viscosity performance corrections only for the pumping element. Pumps that incorporate external piping, a suction barrel for vertical can type pumps, a discharge column, or other appurtenances for liquid conveyance to or from the pumping element, require additional consideration for viscous losses.

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

INSPECTION AND SHOP TEST FOR CENTRIFUGAL PUMPS

PROJECT :
PUMP NUMBER :
PUMP SERVICE :

9 NPSH3 TEST — **Required** (69) (70)

CAUTION: green and red highlighted cells include formula.

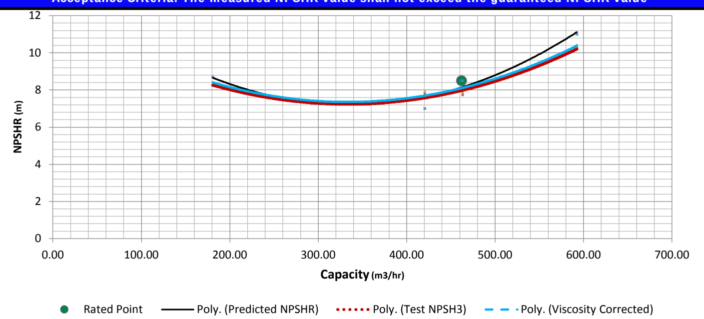
Test Facility — **Closed Loop** (71)

Pump Tag No.:			Rated Capacity (m3/h):	462	NPSHA (m):	11.51
Pump Serial No.:			Rated Head (m):	682.4	NPSHR (Pred.) (m):	8.5
Pumping Liquid:	HP Boiler Feedwater		Nominal RPM:	2977	NPSHA @ Test Setup (m):	(72)
Stage(s) No.:	2	(& Double)	Suction Size (mm):	250	Suc. Guage Height (m)	1.04 (73)
Barometric (Atm/bar):	1.00	1.01	Discharge Size (mm):	200	Retest (74)	Performed

Water Vapour Pressure (bar)			
@ 5 C	0.00873	@ 10 C	0.01228
@ 15 C	0.01706	@ 20 C	0.02339
@ 25 C	0.03170	@ 30 C	0.04247
@ 35 C	0.05629	@ 40 C	0.07385
@ 45 C	0.09595	@ 50 C	0.12352

	Testing Points (52) (53) (54)	Flow (m3/hr) (55)		Dyn. Head (m)		PERFORMANCE RECORD				Max H Drop (77)		NPSH TEST RECORD				RPM (78)	Test Medium		S.G.	Result (m) (62) (79)		
						Press. (barg)		Head (m) (76)		With 3% of 1st Stage	Total Drop	Press. (barg)		Head (m) (76)			Temp. (C)	Vapour (bar)				
		points	Cor'ed	Suc.	Dis.	Suc.	Dis.	Static.	Total			Suc.	Dis.	Static.	Total					H. Drop	NPSH3	Pred.
1	Shutoff	(75)																				
2	MCSF (43)	180.70	180.70	0.053	0.130	4.10	81.54	792.91	792.98	781.09	1.50%	-0.26	75.52	775.94	776.02	2977	33	0.0503	0.99	2.14%	8.25	8.70
3	Midpoint 95-99% Rt'd	420.50	420.50	0.289	0.705	3.82	73.08	709.85	710.27	699.62	1.50%	-0.32	66.90	689.05	689.46	2977	36	0.0594	0.99	2.93%	7.80	7.00
4	Rated Up to 105%	463.30	463.30	0.350	0.855	3.53	70.49	685.57	686.08	675.79	1.50%	-0.34	64.68	665.79	666.30	2977	33	0.0503	0.99	2.88%	7.74	8.50
5	BEP (44)																					
6	MAF (45)	592.50	592.50	0.573	1.399	3.49	61.45	593.64	594.47	585.55	1.50%	-0.12	56.30	577.87	578.70	2977	34	0.0532	0.99	2.65%	10.25	11.00

Acceptance Criteria: The measured NPSHR value shall not exceed the guaranteed NPSHR value



Correction for Viscosity is Required (66) (80) **YES**

Visc. =	200.0	cSt (For viscous pumping liquid)
Q =	494.4	m3/hr (For water curve @ BEP)
H =	668.5	m (For water, per stage @ BEP)
N =	2977	RPM
B =	4.436	B Factor --->
C-Q =	0.959	= $C\text{-}H_{BEP}$
Suc. Geometry	Side Inlet	
A =	0.5	A Factor
NPSH-w =	9.3	@ BEP
C-NPSH =	1.02	

Stage No. =	2
S.G. =	1.00
Visc. cP =	200.0

Refer to Note (67)

		NPSH-w	NPSH-corr.
MCSF	2	8.2	8.4
Mid Point	3	7.8	7.9
Rated	4	7.7	7.9
BEP	5	9.3	9.5
MAF	6	10.3	10.4

REMARKS

68 After Performance test: Disassembly, reassembly and retest (API)

+ Unless otherwise specified, pumps shall not be disassembled after final performance testing. The pump, including the seal chamber, shall be drained to the extent practical, filled with a water-displacing inhibitor within 4h of testing and redrained.
+ If it is necessary to dismantle a pump after the performance test for the sole purpose of machining impellers to meet the tolerances for differential head, no retest is required unless the reduction in diameter exceeds 5 % of the original diameter. (impeller diameter shall be reported on test sheet before and after trimming) (Also ISO 9906; 2012; 6.2.2)
+ If specified, disassembly of multistage pumps for any head adjustment (including less than 5 % diameter change) after test, shall be cause for retest.
+ If it is necessary to dismantle a pump for any other correction, such as hydraulic performance, NPSH or mechanical operation, the initial test shall not be acceptable, and the final performance test shall be run after the correction is made.

69 NPSH margins should be specified on purchaser's specification clearly defining conditions on which NPSH test becomes necessary. For information, HI 9.6.1; 2012 is giving some recommendations and rules regarding NPSH margin for pumps in different services.

70 API 610; 2010; 8.3.4.3.3 might be followed as a procedure for conducting NPSH test. Worth to be noted that during NPSH test; for each test point, several data recording would be required. Some criteria for consecutive data recording are described by API. Normally, the last data recorded just before head-drop exceeds 3% (or agreed total head-drop) would be ignored, and NPSH3 is calculated based on the next to last recorded data.

71 Test facilities arrangement could be divided in two main categories; closed loop and open sump. In closed loop, pump is installed in a closed pipe loop, in which by controlling pressure, temperature, or level of liquid at constant flow and head, pump is forced into cavitation. In open sump, pump draws liquid from a sump by its suction piping in which cavitation occurs by controlling free liquid level or liquid pressure at pump suction. For more information regarding test setup and facilities, you may refer to ISO 9906; 2012; Table 10 & Annex B.

There is no priority imposed by standards regarding which type of test arrangement should be used and it is mainly depended on manufacturer available facilities. However, considering the method conducted to achieve NPSH3, there would be more sub-division for NPSH test. Referring ISO 9906; 2012; table 10, nine methods are introduced depending on which parameter is controlled and which characteristic is kept constant (eg. inlet throttle, outlet throttle, water level, pressure in the tank, temperature). Also more detail information has been regulated by ISO 9906 (Annex A) regarding the installation of measuring instrumentations.

REMARKS

72 The NPSH3 test shall start with at least the same NPSHA as the performance test and at least twice the NPSH3 shown on the proposal curve.
(Refer to API 610; 2010; 8.3.4.3.3 and its NOTE)

73 If pressure reading instrument is installed in a considerable height from measuring section, its effect should be considered accordingly. (ISO 9906; 2012; A.4.4)

74 Dismantling to correct NPSH3 performance requires a retest (refer to API 610; 2010; 8.3.4.3.4).

75 Testing NPSH3 at shutoff is not required.

76 Total head needs to be corrected for speed deviations.

77 According to HI definition, Cavitation effects may be detected as a drop in head or power at a given rate of flow. As an accepted industry practice, 3% drop in head is used to determine NPSHR known as NPSH3. For very low head pumps, a head drop larger than 3% may be agreed on.

According to standard, head drop shall be measured for first stage (in case of multi-stage pumps). If feasible, a separate connection to the first stage discharge should be used for measuring head drop. If it is not possible and total head is measured, 3% head drop should be considered only for first stage which results to lower (than 3%) total head drop. As a rule of thumb, each stage head could be derived from dividing total head to the number of stages as far as pump stages share same diameter impellers.

For more information refer to [API 610; 2010; 8.3.4.3.2] or [HI 14.6; 2011; 14.6.5.8.1] or [ISO 9906; 2012; 5.8.1.1]

78 API does not directly refer to speed for NPSH test but considering the fact that NPSH3 test is normally conducted after performance with same test setup, API criteria (test speed within 3% of rated speed) should apply here.

By HI/ISO, the speed of rotation should lie within the range 80 % to 120 % of the specified speed of rotation, provided the rate of flow lies within 50 % and 120 % of the rate of flow corresponding to the maximum efficiency at the test speed of rotation. (ISO 9906; 2012; 5.7.2)

79 Result head-drop is calculated as a fraction of NPSH3 test recorded head and performance test recorded head.

NPSH3 is calculated at suction side as follows: $H_{static} + H_{dynamic} + H_{guage\ height} - H_{vapour}$
NPSH3 may also be corrected for rated speed: NPSH2 = NPSH1 (N2/N1)^2
(For more discussion on speed effects, refer to ISO 9906; 2012; 6.1.1)

As acceptance criteria; NPSHR shall not exceed predicted one at rated/guarantee point.

80 It should be noticed that the HI generalized method is provided for approximation purposes but the user is cautioned that it is based on an analytical approach and is not based on actual NPSH3 test data. When pumping highly viscous liquids, ample margins of NPSHA over the NPSH3 are required and the advice of the pump manufacturer should be sought.

There is a dual influence of the pumped liquid viscosity on NPSH3. With increased viscosity the friction goes up, which results in an increase of NPSH3. At the same time, higher viscosity results in a decrease of air and vapor particle diffusion in the liquid. This slows down the speed of bubble growth and there is also a thermodynamic effect, which leads to some decrease of NPSH3.

Rate of flow is not corrected in this NPSH3 correction method. For rate of flow corresponding to corrected values of $NPSH3_{vis}$, use uncorrected values of Q_w.

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253

INSPECTION AND SHOP TEST FOR CENTRIFUGAL PUMPS

PROJECT :
PUMP NUMBER :
PUMP SERVICE :

10 RUNNING TEST — Required (81)

Test Started at	10:00	A.M.	Test Ended at	2:30	P.M.

		No.	1	2	3	4	5	6	7	8	9	10	
		Time (Min)	Start	30	60	90	120	150	180	210	240	270	(82)
		FLOW (m3/hr)											(83)
		RPM											(84)
		Dis. Pres. (barg)											
VIBRATION (mm/s or µm: peak-to-peak amplitude) (85)	PUMP DE	A											
		V											
		H											
	PUMP NDE	A											
		V											
		H											
	MOTOR P-SIDE	A											
		V											
		H											
	MOTOR END	A											
		V											
		H											
TEMPERATURE (C) (86)	Oil-in												
	Amb.												
	Water												
	PUMP DE	J_{DE}											
		Th_{DE}											
	P-NDE	J_{NDE}											
	MOTOR WINDINGS	W1											
		W2											
		W3											
	P-SIDE	J											
	END	J											
		NOISE(dbA)											(87)

Suction Pressure (barg)		(88)
Leakage condition during test	Leak Observed; But Corrected	(89)
11 Complete Unit Test	Not Specified	(90)
Disassembly After Test	No Need	(91)

REMARKS

81 Mechanical running is not mandatory by standards. However, it is normally requested by purchasers want to make sure of pump satisfactory operation at rated condition. By running test, vibration, leaks, temperatures, and sound level are checked to be in acceptable condition.

82 According to HI 14.6; 2011, pump shall be running for at least 10 minutes. (Annex E, E.5)

API 610; 2010 offer longer running time that could be categorized as follows:

+ Running until oil temperature stabilization
+ Running for 4 hours
+ Running for 4 hours after oil temperature stabilization

As a common practice, end users interested in of API, normally ask for 4 hours running (/after oil temperature stabilization). Test data to be recorded every 30 minutes.

It is worth to note that Pumps equipped with ring-oiled or splash lubrication systems normally do not reach temperature stabilization during performance tests of short duration and sometimes not even in 4 h tests. (API 610; 2010; 6.10.2.4)

83 Pump shall be running at rated flow. Running at other flows required purchaser approval. (HI 14.6; 2011; E.3 b)

84 Pump shall be running at rated speed. Running at other speeds required purchaser approval. (HI 14.6; 2011; E.3 a)

85

Vibration at three directions shall be measured on each bearing housing or in case of hydrodynamic bearings, peak-to-peak amplitude might be recorded by proximity probes (provision for proximity probes must have been stated during detail design and manufacturing stage). Vibration at motor bearing housing is not normally part of running test. However, if contract motor is used in test or in case of complete unit test, it is worth to also record motor vibration.

For acceptance criteria refer to REMARK 64. For motor vibration you may refer to API 541 for vibration limits on electric motors.

86 Bearings' temperatur at both inboard and outboard bearings shall be measured. Same as vibration, temperature at motor bearings or windings are not part of running test. However, in case of complete unit or contract motor, it is recommended to be recorded.

For pressurized oil system, oil-in temperature should be recorded on each reading.

For ring-oiled or splash systems during shop testing, the sump oil temperature rise shall not exceed 40 K (70 °R) above the ambient temperature in the test cell measured at the time of each reading and (if bearing-temperature sensors are supplied) outer ring temperatures shall not exceed 93 °C (200 °F).
For pressurized systems during shop testing, and under the most adverse specified operating conditions, the bearing-oil temperature rise shall not exceed 28 K (50 °R). (API 610; 2010; 6.10.2.4)

87 Noise level to be recorded during running test. On each reading, better to be recorded at a different direction and about one meter far from test skid.
Considering the fact that shop conditions cannot completely resemble site conditions, noise readings are just for record and could hardly be guaranteed.
Rubbing of rotating parts may be detected by indications of structure-borne noise (in some instances, this may be audible). The coast down of the pump, when power is cut off, should be observed. Rubbing of rotating parts should not be apparent from excessive noise during operation nor abrupt stopping of the pump when power is cut off. (HI 14.6; 2011; E.5 d) & E.6 d))

88 As available from the test facility, suction pressure shall be sufficient to prevent cavitation.

89 In general, following components/areas are prone to leakage;

+ Pump pressure-containment components
+ Pump gaskets
+ Mechanical seal piping
+ Mechanical seal(s) or packing
+ Bearing housing(s)

During test, there should be no visible leakage through pressure-containment parts, gaskets, seal recirculation piping, bearing housing, etc. Visual observation is sufficient for all leakage. Mechanical seals may have an initial small leakage, but should have no visible leakage when running at test operating conditions during running (minimum of 10 minutes for HI design). There are seal designs that may exhibit a prescribed level of leakage during test and this can be confirmed with the seal manufacturer. When shut down, there should be no visible leakage from seals for 5 minutes with the test suction pressure applied. The purpose of this test is to ensure that the entire seal (cartridge) has been properly installed.
Soft packing typically should have no more than 12 drops per minute leakage for a 25-mm (1-in) shaft up to 3500 rpm. For larger shafts or higher test speeds and pressures, allowable leakage will be increased proportionately with shaft diameter, speed, and pressure or as agreed to, by the purchaser.

90 Complete unit test is not normally specified except for extremely critical pumping systems, and when driver size and voltage level are compatible with that available in the vendor's shop. Also, it should be investigated if contract motor could run with water (test liquid) instead of pumping liquid.
Performing complete unit test, does not replace those test that are normally conducted for auxiliaries (gear unit, oil system, etc) unless agreed with purchaser.

91 Pump Disassembly After Test
After shop tests, Pump Disassembly for bearings and seal inspection is generally not required or recommended except in special circumstances such as inconsistent test results, prototype pump design, etc.
The most common causes of failures are: Incorrect impeller diameter, rotating elements incorrectly balanced, poor pump-to-motor alignment, uncalibrated instrumentation, poor quality surface finish on impeller and cases, testing errors and misinterpretation of test requirement, or acceptance criteria.

Email: saki.mohsen@gmail.com
Linked-in: https://www.linkedin.com/in/mohsen-saki-81770253