

TECHNICAL STANDARD SPECIFICATION – Mechanical

Section 03 – Pumps, Compressors, Blowers, and Cutters

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Contents of HAYA Water Technical Standards:

Sr. No	Document Title	Revision No	Revision date
1	HAYA Water Design Manual	03	31/12/2015
2	HAYA Water Standard Specifications Civil Mechanical Electrical ICA	03	31/12/2015
3	HAYA Water Standard Details	03	29/09/2016

Document Prepared by	Document Reviewed by
M/s Halcrow on Behalf of Haya Water	HAYA Water Asset Management / Projects / O&M

i Document Authorisation

This document is authorized for issue.

Document Approval Authority
General Manager Asset Management
Suleiman Al Qasmi

ii Revision History

The following is a brief summary of the most recent revisions to this document. Details of all revisions prior to these are held on file by the issuing department.

Revision No.	Date	Scope / Remarks
0	13/04/2006	Document approved and issued
01	01/06/2008	To incorporate Tender Board and Veolia comments
02	31/12/2010	To incorporate latest changes as per current International standards.
03	29/09/2016	Updated as part of the Haya Water Technical Standards Upgrading project

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1. Introduction

1.1. Purpose

- i. The purpose of this document is to communicate the technical requirements and preferences of Haya Water for pumps, compressors, blowers, and cutters.

1.2. Scope

- i. This Specification has been written in accordance with European and British Standards. Due to the introduction of new European Standards, both British and European Standards may be in force at the same time. In the case of conflict, the European Standard shall apply except where British Standards have been specified in the Contract, and then those shall apply until their official date of withdrawal.
- ii. British Standards and other standards referred to in the Contract shall be deemed to be those current 28 days prior to the date for return of Tenders.
- iii. This Specification shall be applicable for all Haya Water projects and shall be read in conjunction with all other documents of any Contract requirements or the Particular Specification, or both. The clauses in this Specification are applicable in varying degrees to each and every part of the Works. This Specification applies to the entire Works, whether onsite or in yards, workshops, and factories employed elsewhere in connection with the Works. Any clause in this Specification which relates to Works or materials not required by any particular Contract shall be deemed not to apply.
- iv. Strict adherence to all requirements of this Specification shall be maintained at all times and in all circumstances which comply with the previously described scope.
- v. The requirements of this Specification may only be relaxed under extreme circumstances, with each instance of relaxation being strictly controlled, documented, and approved in advance (by hand, not electronically) by the Haya Water General Manager Asset Management. It must be noted that relaxations shall only be allowed under extreme circumstances, and un-warranted requests for relaxation are to be avoided.

1.3. Objective

- i. The objective of this Specification is to ensure that project documents are properly produced, approved, and used in line with the technical requirements and preferences of Haya Water. This Specification is intended for use by Consultants and Contractors who are knowledgeable and experienced in the design of wastewater collection, conveying, and treatment processes. This Specification is a technical guide but it is not necessarily meant to preclude the use of experienced engineering judgement for specific design situations. Consultants and Contractors need to be fully familiar with the contents of this Specification. Incorporating the requirements and criteria of this Specification will ease Haya Water's technical review and approval process in the implementation of projects. Requirements and criteria included in this Specification are not purported to cover all design conditions; Consultants and Contractors shall address all necessary aspects for their particular project.

1.4. Distribution/Target Audience

- i. This document is issued for use by concerned Haya Asset Management and Operations employees, Consultants and Contractors, and Owner Representatives/Engineer.

1.5. Definitions

- i. **Client/Owner/Purchaser:** Oman Wastewater Services Company (Haya Water) for whom the Works are to be undertaken
- ii. **Owner Representative/Engineer:** The firm or company named in the Contract as appointed by the Client to supervise and administer the Contract on behalf of the client or the owner.
- iii. **Consultant:** The firm or company selected by the Client to prepare the engineering design and Particular Specification (the Contract documents) for a given project
- iv. **Contractor:** The company or organisation responsible for the provision of the Works and who have entered into a Contract with the Client
- v. **Site:** The land allocated for the Works
- vi. **Project Documents:** All documents associated with and applicable to the Contract
- vii. **Particular Specification:** The Specification associated with the Contract and prepared at the time of the project by the Engineer specifically for that application
- viii. Technical definitions related to this Specification are to be found within the appropriate technical clauses in the document.

1.6. Abbreviations

ACS	Auto-Coupling System
BEP	Best Efficiency Point
BSP	British Standard Pipe
BSP (T)	British Standard Pipe (Taper)
CLA	Centreline Average
GDP	Guaranteed Duty Point
ISO	International Organisation for Standardisation
MCC	Motor Control Centre
MHEW	Ministry of Housing, Electricity, and Water
NPSH _A	Net Positive Suction Head Available
NPSH _R	Net Positive Suction Head Required
O&M	Operations and Maintenance
PRV	Pressure Relief/reducing Valve
PN	Pressure Number

RMS

Root Mean Squared

- i. Other abbreviations related to this Specification can be found within the appropriate technical clauses in the document.

ii. **Units of Measurement**

°	Degree
µg	Microgram
°C	Degree Celsius
dBA	A-Weighted Decibel
kg	Kilogram
kV/mm	Kilovolt per Millimetre
kW	Kilowatt
L	Litre
L/min	Litre per Minute
L/s	Litre per Second
m	Metre
mbar	Millibar
mA	Milliampere
m ³ /min	Cubic Metre per Minute
mm	Millimetre
mm/s	Millimetre per Second
m/s	Metre per Second
Nm ³ /hr	Normal Cubic Metres per Hour
P _{abs}	Absolute Pressure
rpm	Revolutions per Minute

2. General Procedures

2.1. Roles and Responsibilities

- i. **Author**
- a) Discusses the requirements with line manager

- b) Writes the document using the right template
- c) Requests document number from IMS Section (new document)
- d) Issues document for review
- e) Incorporates comments (as appropriate) and issues document for use
- ii. **Document Reviewer**
 - a) Conducts a formal review of the document and sends comments to author
 - b) Checks that comments from other reviewers are incorporated
 - c) Checks for grammatical and spelling mistakes
- ii. **Document Approver**
 - a) Ensures that control of document is followed
 - b) Accepts final document
- iii. **User**
 - a) Adheres to document control procedure established by Haya Water
 - b) Uses and refers to documents with current revision status only

3. Relevant Standards and Reference Documentation

3.1. General

- i. All workmanship, materials, and components of Haya Water projects shall comply with the applicable Omani Standards where they exist, International Organisation for Standardisation (ISO), American or British Standards and Codes of Practices or other approved standards and codes of practice.
- ii. If there is any conflict between the various standards and codes of practice, then the following hierarchy shall apply:
 - a) Omani Standards
 - b) Haya Water Standards
 - c) International Standards
 - d) ISO
 - e) European Standards
 - f) British Standards
 - g) American Standards
 - h) Codes of practice

3.2. Standards

BS 7854-1:1996	Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. General guidelines.
ISO 10816-1:1995	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 1: General guidelines.
BS ISO 10816-3:2009	Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15000 r/min when measured in situ.
EN ISO 9906:2012	Roto-dynamic pumps. Hydraulic performance acceptance tests. Grades 1, 2 and 3.
EN 10216-1:2002	Seamless steel tubes for pressure purposes. Technical delivery conditions.
EN 10217-1:2002	Welded steel tubes for pressure purposes. Technical delivery conditions. Non-alloy steel tubes with specified room temperature properties.
EN ISO 14847:1999	Rotary positive displacement pumps. Technical requirements.
EN ISO 16330:2003	Reciprocating positive displacement pumps and pump units. Technical requirements.
EN 809:1998+A1:2009	Pumps and pump units for liquids. Common safety requirements.
EN 1092-1:2007	Flanges and their joints. Circular flanges for pipes, valves, fittings and accessories, PN designated. Steel flanges.
EN 1092-2:1997	Flanges and their joints. Circular flanges for pipes, valves, fittings and accessories, PN designated. Cast iron flanges.
EN ISO 12100:2010	"Safety of machinery. General principles for design. Risk assessment and risk reduction".
EN 953:1997+A1:2009	Safety of machinery. Guards. General requirements for the design and construction of fixed and movable guards.
EN 837-1:1998	Pressure gauges. Bourdon tube pressure gauges. Dimensions, metrology, requirements and testing.
EN 10255:2004	Non-alloy steel tubes suitable for welding and threading. Technical delivery conditions.
PD 5500:2012+A1:2012	Specification for unfired fusion welded pressure vessels.
PD 5304:2005	Guidance on safe use of machinery.
BS ISO 1217:2009	Displacement compressors. Acceptance tests.
EN 1012-1:2010	Compressors and vacuum pumps. Safety requirements. Air compressors.

PD ISO/TR 9464:2008	Guidelines for the use of ISO 5167:2003.
BS ISO 10816-3:2009	Mechanical vibration. Evaluation of machine vibration by measurements on non-rotating parts. Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15000 r/min when measured in situ.
EN 1012-1:2010	Compressors and vacuum pumps. Safety requirements. Air compressors.
BS ISO 1217:2009	Displacement compressors. Acceptance tests.
EN 286-1:1998+A2:2005	Simple unfired pressure vessels designed to contain air or nitrogen. Pressure vessels for general purposes.
EN 12483:1999	Liquid pumps. Pump units with frequency inverters. Guarantee and compatibility tests.
EN ISO 12944-1:1998	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. General introduction.
EN ISO 12944-3:1998	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Design considerations.
EN ISO 12944-4:1998	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Types of surface and surface preparation.
EN ISO 12944-5:2007	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Protective paint systems.
EN ISO 12944-6:1998	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Laboratory performance test methods.
EN ISO 12944-7:1998	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Execution and supervision of paintwork.
EN ISO 12944-8:1998	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Development of specifications for new works and maintenance.
EN ISO 12944-2:1998	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Classification of environments.
EN ISO 14713-1:2009	Zinc coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures. General principles of design and corrosion resistance.
EN ISO 14713-2:2009	Zinc coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures. Hot dip galvanizing.
EN ISO 14713-3:2009	Zinc coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures. Sherardizing.

4. Pumps, Compressors, Blowers, and Cutters

4.1. Pumps

4.1.1. General

4.1.1.1. Performance

- i. The pumping installations shall be carried out to the satisfaction and in accordance with the Acts and bylaws of the relevant local Omani authorities).
- ii. Pumps shall be of suitable design for the application.
- iii. All pumps shall be designed to withstand a test pressure of 1.5 times the maximum possible pump shutoff pressure under maximum suction pressure conditions. If a pump can operate at sub-atmospheric suction conditions, the entire pump shall be designed for full vacuum.

4.1.1.2. Materials

- i. Pump materials of construction shall be suitable for application. Replaceable superior grade wear parts shall be included when pumping fluids include grit or sand, or both. The internal parts material in such condition shall be of high hardness (greater than >400 Brinell hardness)
- ii. All pumps and pipework shall be suitably protected against dry running, over-pressure, and low suction pressure. Where pressure relief valves are fitted to the discharge line of any pump, they shall be arranged to feed back to the suction side of the pump or to the wet well.

4.1.1.3. Connections

- i. Common suction and delivery mains shall be provided with two tappings, each fitted with ½ inch (50mm) BSP valves for pressure gauge and transducer connections.
- ii. Tapped bosses shall be provided on the pump casing for air release, draining and suction, and delivery pressure readings. The air release valve and pipework shall be included.
- iii. Pressure sensing devices shall not come into contact with the fluid being pumped unless are made specifically suitable for the application.

4.1.1.4. Seals

4.1.1.4.1. General

- i. The means of sealing shall be dependent upon the application and, unless otherwise required by the Contract, shall be as follows:
 - a) Raw water: Mechanical seal
 - b) Final effluent/irrigation: Mechanical seal
 - c) Potable water/irrigation water: Mechanical seal
 - d) Sewage: Mechanical seal
 - e) Sludge: Soft packed gland

- ii. Adequate access shall be provided to allow maintenance of the shaft sealing arrangement, together with drainage facilities to allow the piped waste of any sealing lubrication water.
- iii. Shaft seals shall be cartridge type bellows mechanical seals. Only where these are not suitable shall packed glands be considered. Any pump fitted with packed glands shall have a replaceable pumping sleeve over the shaft within the gland.

4.1.1.4.2. *Soft-Packed Gland*

- i. Gland packing shall be graphite impregnated poly-tetra-fluoro-ethylene (PTFE), of approved manufacture. Asbestos based packing shall not be permitted.
- ii. The gland design shall incorporate the following:
 - a) A tapered "lead-in" at the mouth of the gland entry shall facilitate packing replacement and obviate the risk of damage on assembly.
 - b) The surface finish of the adjacent metal parts shall be 0.4 μm centreline average (CLA) on the shaft gland sleeve and 1.6 μm CLA on the stuffing box bore.
 - c) Where running clearances are excessive, the packing shall be protected by an independent ring of suitably robust material which reduces the clearance to a minimum.
 - d) The packing shall not be used as a bearing.
 - e) All studs, dowels, and adjustable nuts shall be manufactured from stainless steel 316.
 - f) Lantern rings shall be of gun metal, bronze, or stainless steel for irrigation and shall be split for ease of removal. Stainless steel 316 lantern rings shall be used for all aggressive applications.
 - g) Pumped water supplies to the lantern ring shall be free from abrasive solids.

4.1.1.4.3. *Mechanical Seals*

- i. Mechanical seals shall be designed to operate with a positive suction head and delivery head, as specified and also to operate at all pump curve points at $\text{NPSHA} > \text{NPSHR}$. The seals shall, not under normal conditions, permit any controlled leakage from the pump. The seal system shall be a zero-leakage double-seal system that actively prevents liquid from entering the motor cavity, thereby reducing the risk for bearing and stator failure. An inner seal can act as a micro-pump and an outer seal that prevents leakage of pumped media into the buffer chamber.
- ii. The Contractor shall specify the type, size, and material of the mechanical seal he intends to supply in accordance with the actual service or application. It shall be the responsibility of the Contractor to ensure, and to demonstrate in supporting technical information submitted for design approval, that the tolerances required by the seal manufacturer are not exceeded. Checks shall be carried out on the pump casing and shafting for the following:
 - a) Shaft straightness
 - b) Rotational balance
 - c) Shaft run-out
 - d) Bearing clearance: lateral and radial movement
 - e) Shaft tolerance and ovality

- f) Concentricity
 - g) Seat squareness
 - h) Coupling alignment
- iii. The Contractor shall ensure and demonstrate in supporting technical information submitted for design approval, that the seat, face, and component materials of the mechanical seal are suitable for the media being sealed. Under operational conditions, thermal loading of the seal components shall be within the capacity of the seal to ensure that wear rate is minimised.

4.1.1.4.4. Seal/Gland Drainage

- i. Except for submersibles, seal/gland drainage shall be collected in a collecting tray formed integrally with the pump casing stuffing box. The tray shall not extend high enough to submerge the gland in the event of drain hole blockages. Drainage shall be piped to the bed plate tundish located at the non-driven end of the pump. A water thrower shall be fitted to the shaft between the pump seal and the motor.

4.1.1.5. Bearings

- i. Bearing housings shall be grease retaining and dust-proof. Each bearing shall be grease lubricated.

4.1.1.6. Motors

- i. Motors shall be sized in accordance with the following table:

Absorbed Power at Duty Point (P_{abs})	Motor Installed Power
Less or equal to 10 kW	$P_{abs} + 25\%$ or end of curve power + 10%, whichever is greater
More than 10 kW and less or equal to 50 kW	$P_{abs} + 10\%$ or end of curve power + 5%, whichever is greater
More than 50 kW and less or equal to 100 kW	$P_{abs} + 10\%$
More than 100 kW	$P_{abs} + 5\%$

4.1.2. Hydraulic and Constructional Requirements

- i. On sewage pumps, hydraulic efficiency may be reduced in order to ensure freedom from blockage. Where practicable, all pumps shall be capable of passing a sphere, sized equivalent to the bore of the outlet flange. For an outlet flange bore of 100 mm and above, the minimum sphere size shall be 75 % of the outlet flange bore. Where a closed impeller is unable to achieve this, an alternative design of impeller, pump, or pumping system suitable for the application may be offered and shall be subject to review and approval by the engineer.

- ii. Vortex type pumps shall only be used with the permission of the Engineer, unless for pumping liquids with a high grit content. Sewage pump hydraulic efficiency shall be more than 70%.
- iii. Consideration shall be given to pumps with reduced through inlets if cutting devices or innovative designs are proposed, with the written permission of the Engineer. Cutting devices shall not be used due to the high cost of maintenance and spares unless approved by the Engineer.
- iv. The pump outlet flange bore and Impeller passageways shall be as large as possible consistent with good design.
- v. For sewage and sludge applications, common suction and delivery mains shall be provided with two 1" BSP tappings fitted with valves for fitment of diaphragm type pressure gauges.
- vi. The Contractor shall:
 - a) Carry out a full assessment of the total pump head and suction conditions at the duty point, submitting calculations for the station and system friction losses. Losses shall be evaluated for pipework in both new and estimated worn conditions to ensure the suitability of pump selection. The pump should always operate as close as possible to its BEP.
 - b) Ensure that the pump selected is suitable for the net positive suction head available (NPSH_A).
 - c) Submit a graphical plot of system characteristics and pump performance curves (including efficiency, power, and net positive suction head required [NPSH_R]) superimposed on each other. Pump shall be selected for highest efficiency (lowest motor size required to pump the required flow)
 - d) Ensure that, for optimum performance and economic considerations, the duty point on the head/flow curve shall lie between 80 and 105 % of the best efficiency point (BEP).
 - e) Ensure that, for pump sets with variable speed drives, the best overall efficiency shall be obtained. However, variable speed shall not match natural frequency of the pump body.
- vii. To ensure the pump sump, benching, and baffling is designed correctly, computational modelling shall be considered for all pump stations ≥ 300 l/s and compulsory for pumping stations ≥ 500 l/s unless physical modelling is carried out. Physical modelling shall be considered for all pump stations $\geq 1,000$ l/s and compulsory for pumping stations $\geq 1,500$ l/s.
- viii. Minimum or maximum size impellers for the casing are not permitted. The Contractor shall confirm duty diameters as well as maximum and minimum diameters in the pump technical schedule.
- ix. The closed valve head shall be a minimum of 110 % of the duty head.

4.1.3. Vibration and Balancing

- i. Following completion of assembly, all rotating parts shall be statically and dynamically balanced. Balancing certificates shall be submitted to the Engineer for acceptance. The Contractor shall supply all required vibration isolation systems as follows.
- ii. All pipework and ducting shall be isolated from plant born vibration.
- iii. Intermediate shaft lengths shall not exceed 3 m and shall run below their first critical speed, and vibration shall be within the limits stated in the approved datasheet.
- iv. The vibration of machinery, when installed onsite and operating within its normal operational duty range, shall meet the requirements of BS 7854:1996, evaluation zone B or ANSI/HI 9.6.4 standard or ISO 10816 standard. The Contractor shall carry out tests to confirm this.

- v. During operation, should the machinery require remedial action to reduce the level of vibration to the previously described requirements, the Contractor shall be responsible for rectifying any problems.

4.1.4. Pump Works Testing

- i. All pumps with an installed power of 30 kW and above shall be factory tested.
- ii. All test curves and certificates shall be included within the Operations and Maintenance (O&M) Manuals.
- iii. As a minimum requirement, the performance testing of pumps shall be carried out as follows:

4.1.4.2. Hydraulic Performance Testing

- i. All pumps shall be tested in accordance with BS EN ISO 9906:2012.
- ii. All pumps with motors between 30 and 75 kW, inclusive, shall be factory tested without witness to Grade 2.
- iii. All pumps with motors of between 75 and 150 kW, inclusive, shall be factory tested with witness to Grade 2.
- iv. All pumps with motors of above 150 kW shall be factory tested with witness to Grade 1.
- v. The pump shall be selected such that the $NPSH_A$ always exceeds the $NPSH_R$ (including the relevant safety margin) at all potential operating points.
- vi. Net positive suction head tests shall be carried out on all pumps or as advised by the pump manufacturer.

4.1.4.3. Mechanical Vibration Testing

- i. All pumps shall be tested in accordance with BS7854-1:1996 or ISO 10816-1:1995.
- ii. Vibration tests shall be carried out on pumps with motors 75 kW and above, and shall not exceed vibration levels in Evaluation Zone B. (5.1mm/s for ≤ 100 kW and 7.1mm/s for > 100 kW motors)
- iii. Vibration velocity measurements shall be taken on the casing adjacent to the drive bearing housing with the pump unit operating in the range 70 to 120 % of the BEP. For variable speed pump units, testing shall be performed across the full range of pump unit operating speeds. Preferred operation region shall be 3.0mm/s (RMS) as per API 610.
- iv. For pump units with multi-vane or vortex impellers, the maximum value of the root mean squared (RMS) vibration velocity shall be < 6.6 mm/s. For pump units with a single channel or screw centrifugal impeller, the maximum value of the RMS vibration velocity shall be 8.6 mm/s.
- v. The following table is summarising a range of pump vibrations for various sizes and applications and shall be considered for estimating the maximum allowable vibration RMS limits for each pump type and in accordance with the particular application and type of installation. Tested pumps shall successfully exhibit or demonstrate lower vibration results than what is shown in this table. Deviation from the vibration levels shall not exceed 1%, otherwise the pump will not be accepted. Vibration sensors shall be permanently fitted on all pumps above 75kW motor.

Pump Type	Pump Motor Size	Vibration limits RMS
End suction ANSI/B73	< 15 kW >75 kW	3.0 mm/s 4.6 mm/s
Vertical Inline long Coupled ANSI B73.2	< 15 kW >75 kW	3.0 mm/s 4.6 mm/s
End suction, & Vertical inline Close coupled	< 15 kW >75 kW	3.6 mm/s 5.3 mm/s
End suction frame mounted	< 15 kW >75 kW	3.6 mm/s 5.3 mm/s
End suction, API610	Preferred operation Region Allowable operation Region	3.0 mm/s 4.1 mm/s
End suction, Solid handling - Horizontal	< 7.5 kW >300 kW	3.6 mm/s 5.3 mm/s
End suction, Solid handling – Vertical	< 7.5 kW >300 kW	6.6 mm/s 8.6 mm/s
Between Bearing, Single & Multistage	< 15 kW >150 kW	6.6 mm/s 8.6 mm/s

4.1.4.4. Compatibility/String Testing for Variable Speed Pumping Duties

4.1.4.4.1. Manufacturer's Shop Testing

- i. The pump units shall be tested in accordance with the test regime specified in the approved datasheet.
- ii. Testing shall not be performed until the pump unit has been performance tested in accordance with BS EN ISO 9906:2012, and the associated test report has been received, reviewed, and accepted by the Engineer.
- iii. Testing shall be performed at the following pump unit operating speeds for a minimum period of 20 minutes. The pump unit shall be stopped and re-started at each change of speed.
 - a) Minimum operating speed
 - b) Main duty point operating speed (that is, the speed at which the pump unit is likely to operate for the majority of the time)
 - c) Maximum operating speed
 - d) Intermediate operating speeds (as required)

- iv. The overall system efficiency at the guarantee point shall demonstrate the tolerance on the quoted efficiency which is stated in the approved datasheet.
- v. Vibration velocity levels measured during testing shall not exceed the maximum vibration levels specified for a fixed speed pump unit of the same design/rating.
- vi. Bearing temperatures measured during testing shall not exceed the maximum values expected for a fixed speed pump unit of the same design/rating.
- vii. The electrical tests confirming compatibility/stability shall include over-current monitoring and a demonstration that the inverter is not prone to cut-outs caused by excessive temperature rise in the inverter enclosure or repeated motor starting.

4.1.4.4.2. Site Testing

- i. After installation and before commissioning, the Contractor shall carry out site tests, to be witnessed by the Engineer. Any problems/defects detected during these tests shall be promptly rectified by the Contractor at no additional cost to the Client.
- ii. The pump unit and contact inverter shall be tested in accordance with BS EN 12483 to demonstrate that all elements of the overall system (that is, the pump, motor, supply cable, inverter, and all auxiliary items) function together smoothly and are free from difficulties/instabilities over the intended operating range (taking into account such characteristics as hydraulic performance, noise, vibration, and electrical phenomena).
- iii. Prior to testing, it shall either be demonstrated that all elements of the overall system have reached their normal steady state operating temperature, or that the overall system shall have been be operated at maximum speed for a minimum period of 2 hours.

4.1.5. Pump Pipework

- i. Long radius bends, radial tees, and swept junctions shall be used wherever possible to reduce friction losses and improve flow characteristics. However, this shall not require an increase in the size of civil structures (for example, valve chambers, pump sumps, or similar components).
- ii. Care shall be taken to ensure that the suction pipework rise to the inlet of the pump, thus preventing air pockets from forming. Eccentric "flat top" tapers shall be used on horizontally mounted suction pipework.
- iii. Flange adaptors and couplings shall be installed, as necessary, to facilitate the removal of plant and components without disturbance to the system. These shall be tied, as necessary, to resist thrust loadings. "Uni-flanges" or "Flex locks" adaptors shall not be acceptable for this purpose.
- iv. Isolation valves shall be installed, as necessary, to enable any pump (in a two or more pump installation) to be isolated and removed without isolating the whole installation. Thus, care shall be taken when selecting wafer type valves, sandwiched between two flanges with through bolts. (One of the flanges may need to be withdrawn to facilitate removal of the pump.)
- v. Drain connections with valves shall be fitted to the suction and discharge pipework.
- vi. For more information regarding pipework, see Technical Standard Specification – Mechanical Section 06 – Piping and Accessories, and Wastewater Design Manual Section 4 – Sewage Pump Stations and Force (Pressure) Mains.

4.1.6. Centrifugal Pumps

4.1.6.1. Submersible Sewage Pumps

4.1.6.1.1. General

- i. Pumps shall be high efficiency (>67%) vertical spindle unshakeable single-stage centrifugal type having radial or mixed flow impellers and shall be suitable for continuous running under complete or partially submerged conditions. They shall be specifically designed to handle sewage water containing 100 mm diameter spheres, rags, fibrous materials, grit, and other wastes.
- ii. The maximum allowable rotation speed shall be 1,500 rpm.
- iii. The pumps shall be equipped with stator temperature guards as well as water leakage guards to oil and stator housing.

4.1.6.1.2. Casing

- i. The casing shall be high-grade cast iron (fine grained mechanite), at a minimum, free from blow-holes or imperfections, of ample proportions throughout, with all internal passages finished smooth, and shall be abrasive-resistant, capable of taking shock loads, and shall incorporate lifting eyes located for removal of the pump.

4.1.6.1.3. Impeller

- i. The impeller shall be single or double-shrouded semi open, channel, screw or vortex type for sewage application, statically and dynamically balanced, with interchangeable bearings and a ball clearance of at least 100 mm, of the non-clogging type. Back vanes shall be provided on the discharge side shroud to minimise the ingress of abrasive matter into the shaft seal.
- ii. The impeller shall be manufactured of high-grade cast iron or duplex stainless steel 2205 at a minimum and shall be keyed to the shaft and secured by locking screws. Ni-hard cast iron shall be used where high grit content is likely. Material shall be minimum 400 Brinell hardness.
- iii. All studs, bolts, nuts, washers, and screws used in the construction of the pump units shall be of stainless steel 316, as a minimum.

4.1.6.1.4. Pedestal

- i. Pump supports shall be a cast iron duck-foot bend with pump coupling and sliding flange coupling for connection to the discharge pipe. A pump consisting of two guide rods from duck-foot bend to pump deck (stainless steel 316) shall be installed. Hoisting cables (stainless steel 316 with a lock fixed to the pump) shall be provided.

4.1.6.1.5. Cooling

- i. Motor cooling shall either be by pumped coolant in a cooling jacket or by heat transfer through the stator casing. The use of sewage or effluent as a pumped media coolant is not permitted only if the cooling jacket is made of fully anti-corrosion materials with non-clogging passages.
- ii. If cooling is effected by heat dissipation, then the motor rating shall be suitably de-rated.

4.1.6.1.6. Seals

- i. Unless otherwise specified, seal protection shall be provided on all pumps with motors of 7 kW and above. Level sensors shall be configured to alarm in all cases.

4.1.6.1.7. Guides, Guiderrails, and Auto-Coupling System (ACS)

- i. The pump unit shall be positively guided during installation and removal from the wet well by a guide system.

- ii. The guide system shall be designed and installed to ensure straight, vertical lifting/lowering of the pump unit.
- iii. The guide system shall allow the pump unit to be raised to the top of the wet well without the need to undo any fixing arrangements or enter the wet well.
- iv. The guide system shall comprise twin smooth circular cross-sectional tubes and all necessary fixtures and fixings.
- v. The guiderail material, all brackets, and fasteners (that is, nuts, bolts, and similar items) shall be stainless steel 316L as a minimum.
- vi. Guiderails shall be of single piece construction up to a maximum length of 3 m.
- vii. The guide tubes shall be supported along their length by suitably designed brackets. The maximum length of any unsupported guide tube span shall be 3 m. The tops of the guide tubes shall finish a maximum of 150 mm below the underside of the wet well cover.
- viii. Hooks shall be provided at the top of the guiderails for securing the cable support sleeves and for hanging the lifting chain.
- ix. If specified, the pump unit shall be provided with an auto-coupling system (ACS) to interface it with the outlet pipework/rising main. If an ACS is required, the following requirements shall apply:
 - a) The ACS shall typically comprise a duck foot bend, guide claw, and all necessary seals/gaskets and fixings.
 - b) The guiderail material, all brackets, and fasteners (nuts, bolts, and similar items) shall be stainless steel 316L as a minimum. The duck-foot bend, guide claw, and all fixings shall be manufactured from cast iron as a minimum. The outlet connection of the duck-foot bend shall terminate with flange type PN 16.
 - c) The ACS shall be designed so that the pump unit is positively located onto the duck-foot bend during pump installation.
 - d) The ACS shall be designed so that the interface between the duck-foot bend and guide claw is effectively sealed during pump installation.
 - e) The duck-foot bends shall include suitable provisions for locating and fixing the guide tubes and, if necessary, shall be galvanically isolated from the guide tubes.
 - f) The duck-foot bends shall include suitable provisions for securing it to the base of the wet well.

4.1.6.1.8. *Drywell Application*

- i. The casing shall be provided with adequate access for internal inspection and removal of trapped debris from the impeller. Where inspection hole covers are fitted, these shall be shaped to conform to the interior profile of the casing and be secured with stainless steel fixings.
- ii. If noise testing is not part of the pump unit test regime, the expected noise levels generated by the pump unit when it is installed onsite and operating at the guarantee point shall be as stated. The noise levels generated by the pump unit shall not exceed 80 dBA at 1 m distance.
- iii. Air release pipework complete with a non-return valve to ensure self-priming shall be provided.
- iv. Motor cooling shall be required for immersible pumps installed in dry well conditions; unless motors are suitably de-rated for the maximum ambient air temperature. The motor design shall include an integral cooling jacket constructed of steel, A283, Grade D. The cooling medium shall be the pumpage. Re-circulation through the jacket shall be achieved by discharging the pumpage

into the cooling jacket from periphery, high pressure area of the impeller and returning it into the low pressure behind the impeller at the hub. Riser pipes within the jacket shall be utilised to facilitate circulation. The cooling passages shall be non-clogging by virtue of the dimensions; screening solids from entering the jacket. The jacket shall have external NPT connections to be used for external cooling as an option, as well as for venting the jacket. The jacket cooling system shall provide heat dissipation for the motor whether the unit is submerged or dry operating in air.

4.1.6.2. Dry Well Centrifugal Sewage Pumps

4.1.6.2.1. General

- i. For open coupled pumps, the motor shall be mounted on either a cast iron or fabricated stainless steel 316 stool at motor room level. The stool shall incorporate access holes to the motor coupling.
- ii. Pumps shall be supplied complete with suction bends, each incorporating a large hand hole and cover. Pumps shall be mounted on substantial cast iron or fabricated stainless steel 316 stools, suitable for fixing to concrete plinths. All bolt holes shall be drilled to ensure complete interchangeability when removals are necessary.
- iii. Access into the pump casing for inspection and cleaning purposes shall be provided in the form of a large hand hole and cover.
- iv. Pressure gauges, if required, shall be remotely mounted to avoid vibration damage.
- v. The pump set shall be suitable for the environment in which it is to be installed including any hazardous areas.
- vi. The maximum allowable operating speed of the pump set shall be 1,500 rpm.

4.1.6.2.2. Hydraulic Performance

- i. The pump set hydraulic performance at the guaranteed duty point (GDP) shall be as specified.
- ii. The pump set shall be capable of continuous operation within the specified operating envelope.
- iii. The pump set shall have stable characteristics against the system curve.
- iv. The pump efficiency and absorbed power (bare shaft) at the GDP and maximum flow rate shall be as stated, in the coated and/or uncoated conditions. Hydraulic efficiency shall be >70%.
- v. The pump set shall be capable of operating against a closed valve (zero flow rate) without damage for a minimum time period.

4.1.6.2.3. Drive Assembly

- i. The pump set may be mounted in either the vertical or horizontal orientation. Motor drives for vertical pumps shall be mounted in accordance with one of the following methods:
 - a) Directly onto the pump casing using an adaptor stool
 - b) Onto a free standing stool fixed rigidly to the floor and connected to the pump using a flexible spacer coupling
 - c) Remotely and connected to the pump by line-shafting
- ii. Motor drives for horizontal pumps shall be mounted on a base plate.

- iii. To allow the removal of the rotating components, the casing shall be designed so that the top half casing can be removed without disturbing the bottom half casing and system pipework.
- iv. The drive shaft shall have flexible couplings at both ends. The pump operating speed shall be below the first critical speed of the shafting. Provision shall be given for access to the flexible coupling for maintenance and removal of the disc elements.
- v. The pump shaft shall be supported in an external bearing housing constructed in cast iron forming the cover of the pump, there being no internal bearings in the pump. Bearings shall be fitted to accommodate thrust in either direction, in addition to journal load and shaft weight. The driven end of the shaft shall be keyed to suit the coupling. Adjustment for positioning the impeller within the casing shall be by means of two thrust collars threaded onto the shaft at the driven end.
- vi. The pump shaft shall be constructed from stainless steel 316 or higher grade. A renewable sleeve shall be fitted to the shaft from the impeller extending through the seal area.

4.1.6.2.4. Casing

- i. The casing halves shall be accurately aligned during assembly to match the volute profiles and be doweled to ensure certain repositioning during re-assembly. Means shall be provided to facilitate the separation of the casing halves. On larger castings, this shall be by two or more stainless steel jacking screws.
- ii. The inlet and outlet flange of the pump shall terminate with flange type PN 16 (minimum). All casing surfaces having a fine clearance between fixed and rotating components shall incorporate renewable wear parts that are easily removable for refurbishment or replacement.
- iii. The direction of rotation of the impeller shall be clearly and indelibly marked on the pump casing with an arrow.
- iv. Connections shall be provided on the pump set flanges or casing for connection of inlet and outlet pressure gauges, venting, drain, and seal flushing pipework. These shall consist of bosses appropriately drilled and tapped, with a minimum size of 3/8 inch (10mm) BSP (T). Venting connections shall be positioned on the highest practicable point on the casing. All unused, tapped holes shall be fitted with solid, corrosion resistant metal plugs.
- v. A drilled and tapped boss shall be provided in the top of the pump casing to accommodate air release pipework which the Contractor shall supply. A drain cock shall be fitted to the lowest point.

4.1.6.2.5. Impeller

- i. The impeller type shall be selected to provide the required hydraulic and physical requirements.
- ii. Each impeller shall be a one-piece casting manufactured from corrosion resistant and/or suitable materials selected for the fluid being pumped.
- iii. The impellers shall not be pinned to the shaft; neither shall shaft rotation be relied upon to ensure that the impeller is locked in position.
- iv. Each impeller shall be dynamically balanced in two planes to prevent the pump set exceeding the maximum specified vibration levels. Balancing shall be achieved by machining, not by addition of weights.
- v. If impeller wear rings are not fitted, a machining allowance shall be provided on the impeller to accommodate the future fitment of wear rings.

- vi. If the shaft is exposed to the pumped liquid, it shall be manufactured from a corrosion-resistant material or be protected by the use of a sleeve.
- vii. The first critical speed of the rotating element (shaft, impeller, or similar components) shall be at least 25 % above the maximum operating speed.

4.1.6.2.6. Seals

- i. Seals shall be mechanical gland type.
- ii. Where accepted, packed gland seal drains shall incorporate a tundish and pipe into a dry well sump.

4.1.6.2.7. Vertical Extended Spindle Pumps

- i. The prime mover shall be provided with either a support mounting plate or stool suitable for bolting in place.
- ii. The motor stool or mounting plate shall have a machined register on the topside to match a similar register which shall be provided on the base of the motor, so that the motor may be removed and replaced without disturbing the alignment.
- iii. Intermediate steel shafting between pump and prime mover shall be provided with universal couplings at the bottom and top ends. The coupling on the pump shaft shall be fitted on a sliding splice to allow vertical adjustment of not less than 25 mm.
- iv. All shafting shall be guarded up to the underside of the motor floor. Guards shall be demountable to facilitate shaft changes. Individual sections of guards shall not weigh more than 10 kg.
- v. Shafting shall be dynamically balanced.
- vi. Intermediate shaft lengths shall not exceed 3 m and shall run below their first critical speed, and vibration shall be within the limits stated in the approved datasheet.

For Centrifugal Pumps (>100kW or those at main pumping stations):

Each pump shall be equipped with **suction valve, discharge valve, check valve, pressure switch, pressure gauge, & (dry protection) device** to trip the pump in case of drive/flow failure.

The instrumentation for the safety monitoring of pumps shall include (SENSORS+TRANSMITTERS):

1. Pressure measuring devices at inlet and outlet.
2. Flow meter measurement devices.
3. Stator temperature guard and water leakage guard to oil & stator housing. (for submersible pumps)
4. Seal protection shall be provided on all pumps larger than 7 kW.
5. Level sensors shall be configured to alarm in all cases.
6. Vibration level sensing device (shall be fixed type).
7. Bearing monitoring equipment shall be fitted to all pumps > 100kW to monitor bearings wear.
8. All 3 RTD or 6 RTD signals for motor protection shall be successfully connected to control system.
9. Instruments shall provide signals for the shutting down of pump if unsafe conditions arise and for visual indication of the fault.
10. Contractor shall provide all necessary instrumentation for measuring the flow from each pump.

4.1.6.3. Archimedean Screw Pumps

- i. A full-life cost analysis shall be done before using an Archimedean screw pump in any design proposal. If there is any specific technical reason why an Archimedean screw pump should be used, then prior approval shall be obtained from the Engineer.

4.1.6.3.1. Materials

- i. The screw pump body shall consist of a centre tube constructed of mill-certified BS EN 10216-1: 2002 or BS EN 10217-1: 2002 steel (or equivalent), sealed at each end with rigidly designed steel end plates of the same quality steel. The centre tube shall be designed such that the pump deflection between the bearing centrelines does not exceed 4 mm under all static and dynamic loads. Where two or more centre tube sections must be welded together to make the full length of the pump body, the additional sections shall be added equally to the two ends of the centre tube.
- ii. The tube ends shall be machined with registers to precisely locate the upper and lower bearing assemblies. Each of the bolt holes in the end plates for the bearing assemblies shall have a sealing plate welded to the inside face of the end plate to provide a watertight pump body.
- iii. Each torque tube shall be precision-machined to ensure that the end plates are perpendicular to the pump's centreline axis. Each end face shall not exceed ± 0.15 mm from the true perpendicular to the pump axis, and ± 0.15 mm out of parallel to one another.
- iv. The screw flight shall be constructed from cold form steel to the same grade material as the pump body. The screw flights shall be continuously welded to the centre tube on both sides with full penetration welds. All radial welds between adjacent flight segments shall be full penetration welds on both sides of the flight. Each flight segment shall be positioned and welded in place such that each flight is perpendicular to the centre tube. The outside pump diameter at the pump flights shall be machined to a uniform diameter that varies no more than 2 mm from the theoretical radius measured from the centreline axis.
- v. Reinforced EN 10216-1: 2002 or BS EN 10217-1: 2002 (or equivalent) removable steel profile plates of a minimum 5 mm thickness shall be supplied in approximately 1,500 mm sections for mounting on the uptake side of the screw pump. The profile plates shall act as an extension of the trough periphery and be designed to contain spillage.

4.1.6.3.2. Bearings

- i. The lower bearing assembly shall be constructed to allow continuous operation when fully submerged. The bearing shall be designed to remain in true axial alignment of the screw pump centreline through the lower and upper bearings for all operating conditions, and allow for the expected free axial expansion of the screw pump. The bearing arrangement shall consist of either the sleeve type phosphor bronze bearing bush and high carbon content steel shaft, or spherical roller bearing. In both cases, the bearing assembly shall be of adequate dimensions with a design life of not less than 100,000 hours.
- ii. The bearing assembly shall be completely protected by a stationary shroud to prevent material in the wastewater from becoming wrapped around its rotating parts. The shroud shall be manufactured in two halves to facilitate its removal from the bearing housing. The design of the lower bearing shall be such that it can be replaced without removal of the base anchorage or the screw pump body.
- iii. The bottom bearing shall be grease-lubricated by means of an automatic grease lubricator unit driven from the gearbox output shaft. Means shall be provided for adjusting the rate at which grease is supplied to the bearing. Grease piping shall be stainless steel. Provisions shall be made

for manual lubrication of the bearing with grease and for clearing the grease piping of dry air pockets.

- iv. The upper bearing assembly shall consist of either a self-aligning double spherical roller bearing or a combination of spherical roller and thrust bearings, mounted in a cast iron housing designed to withstand thrust and radial loads under all operating conditions. The bearing assembly shall be designed with a L10 life expectancy of not less than 100,000 hours. The upper bearing drive shaft shall be manufactured of a solid steel stub shaft fitted with either a cast iron hub flange or gusseted steel plate which matches the register on the screw pump end plate.
- v. Bearing monitoring equipment shall be fitted to all pumps over 100 kW to monitor upper and lower bearing wear; the lower bearing monitor shall be of a submersible type.

4.1.6.3.3. *Drive System*

- i. Each pump shall be driven by a totally enclosed, oil lubricated, air cooled, foot mounted helical/bevel speed reducing gearbox. The gears and bearings shall be design for continuous operation and shall have design L10 life expectancy of not less than 200,000 hours at the rated power and speed. The gears and bearings shall be either splash- or force-lubricated to suit the size and mounting orientation of the reducer. The housing shall be complete with removable inspection covers, oil filler, drain, and breather.
- ii. The output shaft of the gearbox shall be connected to the screw pump upper bearing shaft by means of a low speed flexible coupling. The coupling shall be designed to compensate for shocks, vibration, and shaft miss-alignment. The coupling shall consist of two cast iron housings separated by flexible, non-metallic rubber or elastomeric bushes. Replacement of the flexible elements shall not necessitate disassembly of the screw pump drive chain.
- iii. The gearbox and coupling shall be suitable for continuous duty with moderate shock loading and sized for not less than the greater of either 1.5 times the absorbed power or 1.0 times the motor rated torque at the screw pump design rpm.
- iv. The electric motor shall be connected to the gearbox via a V-belt drive and shall be mounted on a robust adjustable motor slide base. The motor shall be of sufficient capacity to operate the screw pump under all conditions and shall operate at less than 90 % of its power rating when the pump is discharging at its maximum capacity and lift. The motor speed shall be a maximum of 1,500 rpm.

4.1.6.3.4. *Guards*

- i. Guards and splash plates shall be provided to protect equipment and personnel from spray and the rotating elements of the screw pumps. The guards shall be fabricated in a neat and substantial manner and shall be easily removable for inspection and maintenance purposes.

4.1.6.3.5. *Anti-Rotation*

- i. The screw pump shall be equipped with an anti-rotation device to prevent back rotation on power failure or stopping of the screw.

4.1.7. **Positive Displacement Pumps**

4.1.7.1. **Progressive Cavity Pumps**

4.1.7.1.1. *Casing*

- i. The pump casing shall be designed to resist corrosion, abrasion, and mechanical shock loads imposed by constituents in the pumped liquid.

- ii. A clean-out cover shall be provided on the suction casing.

4.1.7.1.2. *Rotor/Stator*

- i. The Contractor shall select suitable materials for the rotor and stator with due consideration to the material to be pumped. Aluminium shall not be used in the fabrication of the pump's wetted parts. The rotor shall be stainless steel but may be coated to increase durability, should the Contractor deem this required in order to attain the design life stated in the Particular Specification.
- ii. The pumping element shall consist of a single helix rotor revolving eccentrically within a double helix resilient stator.
- iii. The suction chamber shall be capable of rotation to any of three positions 90° apart so that the simplest piping arrangement can be devised. A drain plug shall be fitted to suit the chosen orientation.

4.1.7.1.3. *Speed*

- i. The pump speed shall be carefully selected to ensure a long service life. On no account, shall the speed exceed 350 rpm for light sludge and 250 rpm for primary and heavier sludge. In all cases, the rubbing velocity between the rotor and stator shall not exceed 1.5 m/s.

4.1.7.1.4. *Drive System*

- i. The connection between the motor and pump shall be either a flexible drive shaft or a sealed rugged universal joint with a metal/rubber protection sleeve.
- ii. The pump shall be driven either through a gearbox or by piggyback "V" belt drive. Pump components and materials shall be suitable for the pumped medium. The pump casing shall be capable of being fitted with a replacement rotor and stator, ensuring that either can be withdrawn within the confines of the surroundings. Tapped bosses shall be provided for drain and suction and delivery gauge connections.

4.1.7.1.5. *Pipework*

- i. The pipework shall include bends or dismantling joints to minimise dismantling of adjacent pipework.

4.1.7.1.6. *Bearings*

- i. Minimum L10 bearing life shall be 100,000 hours at GDP.

4.1.7.2. **Ram/Plunger Pumps (Reciprocating Pumps)**

4.1.7.2.1. *Casing*

- i. Pumps shall be designed for easy dismantling with separate castings for the body and stuffing box, permitting the removal of wearing parts such as pistons, connecting rods, and cylinder liners, without disturbing the pump body, chambers, or manifold.

4.1.7.2.2. *Cylinder/Barrel and Crankshaft*

- i. The pump cylinder/barrel shall be supplied with a wear-resistant coating.
- ii. The crankshaft, crosshead assembly (if required), and connecting rods shall possess sufficient torsional and axial stiffness to prevent excessive distortion under all operating conditions.
- iii. All the pump passages shall be capable of passing solids up to at least 75 mm diameter.

4.1.7.2.3. *Bearings*

- i. For oil lubricated bearings, the reservoir of oil attached to each pump, from which oil is pumped to the eccentric bearings, shall be fitted with a contents gauge with contacts arranged in conjunction with the pump starter such that the pump is prevented from operating when there is insufficient lubricant in the reservoir.

4.1.7.3. Rotary Lobe Pumps

4.1.7.3.1. General

- i. The pumpset shall be in accordance with BS EN ISO 14847:1999.
- ii. The unit shall be designed to allow pumping in either direction with minimum reversed flow of the pumped liquid.

4.1.7.3.2. Casing

- i. The casing/housing shall include an access cover in the front of the casing to allow easy access to the wetted parts. Front covers weighing over 25 kg shall be hinged or have lifting eyes fitted to allow safe lifting.
- ii. The casing shall incorporate integrally cast mounting feet with machined faces.
- iii. The casing shall incorporate easily accessible oil filling and drainage points that shall allow in situ oil replacement/replenishment. An oil level window/sight glass shall be supplied.

4.1.7.3.3. Rotor/Lobes

- i. Pump units shall be of twin rotor design with lobed rotors mounted on separate parallel shafts, counter-rotating within the pump casing.
- ii. Rotors shall be replaceable without the need to replace inlet outlet pipework and the mechanical seals. Any special tools required to carry out this task shall be supplied with the pump.
- iii. The rotors/shafts shall be marked to ensure correct installation/synchronisation on re-installation.

4.1.7.3.4. Shaft

- i. Shaft rotation shall be synchronised to ensure that there is no contact between lobes or lobes and casing.
- ii. Shafts shall be high grade stainless steel of one-piece construction, machined all over.
- iii. Shafts shall be sized to accommodate all possible loads over the specified operating range of the pump. The first critical shaft speed shall be in excess of the maximum shaft speed.
- iv. Shafts shall be individually withdrawable for maintenance.
- v. The pump unit shall incorporate mechanical type cartridge seals. Seal fixing screws shall not make direct contact with the shafts.

4.1.7.3.5. Gears and Belts

- i. Timing gears shall be precision-manufactured involute form, spur (straight cut), or helical gears. The gearbox shall be designed to accommodate any thrust forces generated by the timing gears.

- ii. The timing gears shall be supplied with a separate oil chamber for the bearings.
- iii. The maximum speed reduction allowable using belts/pulleys shall be 3:1.
- iv. Belts shall have a minimum service factor of 1.5.

4.1.7.3.6. *Bearings*

- v. All bearings shall have an L10h bearing life of 100,000 hours at GDP.
- vi. Bearing housings shall be designed to prevent the ingress of dust and water.

4.1.7.4. **Diaphragm Pumps**

4.1.7.4.1. *General*

- i. The pumpset shall be in accordance with BS EN ISO 16330:2003.
- ii. Pump units shall be self-priming and capable of dry running without damage.
- iii. Pump units shall be designed so that the design assembly and the diaphragm can be removed without disturbing the inlet/outlet pipework.

4.1.7.4.2. *Casing*

- i. Components in the body/casing that may be prone to wear shall be easily removable for refurbishment or replacement. Material hardness shall be more than that of solid particles might be accompanied with the pumped liquid.
- ii. All mating surfaces shall be accurately machined and be provided with deep registers, dowels, and spigots, where necessary to ensure alignment.

4.1.7.4.3. *Valves*

- i. Ball and flap valves shall be supplied with removable covers to facilitate the removal of worn valve components or the removal of debris and blockages. Covers shall be perfectly sealed.
- ii. Valves shall be designed to prevent chatter. A method of adjusting the valve response to hydraulic fluctuations in the system shall be supplied.
- iii. Ball valves shall be designed to create bias flow conditions.

4.1.7.4.4. *Drive Assembly*

- i. The pump gearbox shall incorporate easily accessible oil filling and drainage points that shall allow in situ oil replacement/replenishment without excessive spillage. A means of checking the oil level shall be supplied.
- ii. All bearings shall have an L10h bearing life of 100,000 hours at GDP.
- iii. An adjustable crank stroke facility shall be provided to allow for changes in flow rate. If specialist tools are required for this action, they shall be supplied with the pump.
- iv. The connecting rod shall be spring-loaded to prevent hydraulic lock or cushion forces (or both) applied to the diaphragm due to solids trapped beneath it.

- v. Solid connecting rods shall not be used.
- vi. The drive end of the connecting rod shall incorporate rolling element bearings. Plain bearings shall not be used. The bearing shall be supplied with an accessible lubrication point.
- vii. The pump shall be driven by a dedicated, self-contained, hydraulic power unit.
- viii. The hydraulic system shall be a “single pass” “open loop” design.
- ix. The hydraulic power unit shall be factory assembled and shall comprise the following:
 - a) Hydraulic system
 - b) Electric motor
 - c) Base frame
 - d) Water or air blast oil cooler
 - e) Control panel
- x. The hydraulic system shall include but not be limited to the following:-
 - a) Oil reservoir
 - b) Hydraulic pump
 - c) Valve stack with directional flow control valve
 - d) Pressure relief valve
 - e) Full flow return filter and suction strainer
 - f) Hoses and hydraulic pipework
- xi. All filter elements shall be easily accessible and replaceable.
- xii. The final connections between the pump and the hydraulic power unit shall be by flexible hydraulic hoses.

4.1.7.5. Double Disc Pumps

4.1.7.5.1. General

- i. The technical requirements of the pump unit shall comply with BS EN ISO 16330:2003.
- ii. The safety requirements of the pump unit shall comply with BS EN 809:1998+A1:2009.
- iii. The following information shall be provided with the datasheet:
 - a) A drawing of the pump unit, indicating its overall dimensions. This shall indicate, where appropriate, the minimum clearance distance required for the removal of components (for refurbishment or replacement) with the pump unit in situ.
 - b) A typical sectional drawing of the pump, detailing the arrangement of the pump components.
 - c) A schedule of spares required for 2 years of operation (plus associated costs and lead times).
- iv. The pump unit shall be self-priming and capable of dry running without damage during priming.
- v. The pump unit shall be designed such that the drive assembly, diaphragms and trunnions can be replaced without disturbing the inlet/outlet pipework.
- vi. The auxiliary connections required/provided on the pump unit (for example, for the connection of inlet/outlet pressure gauges, venting, drain pipework, or similar components) shall consist of

bosses, appropriately drilled and tapped. Vent connections shall be positioned on the highest practicable point on the pump body/casing/flanges.

- vii. The process inlet and outlet connection details shall terminate with flange type PN 16, in accordance with the relevant part of BS EN 1092-1:2007 and BS EN 1092-2:1997.
- viii. Guarding shall comply with BS EN ISO 12100:2010 and BS EN 953:1997+A1:2009.

4.1.7.5.2. *Pump Body/Casing*

- i. The body/casing shall be designed to perform as follows:
 - a) Withstand any pressure or dynamic loading that may be generated during normal pump operation, including intermittent physical shock loadings caused by solids in the flow.
 - b) Resist corrosion and abrasion imposed by constituents in the pumped medium.
- ii. Components in the body/casing that may be subject to wear shall be easily removable for refurbishment or replacement. Material hardness shall be more than that of solid particles might be accompanied with the pumped liquid.
- iii. All mating surfaces shall be accurately machined and provided with deep registers, dowels, and spigots where necessary, to ensure alignment.

4.1.7.5.3. *Driveshaft, Eccentric Bearings, and Support Bearings*

- i. The driveshaft shall possess adequate torsional and axial stiffness to prevent excessive distortion under all operating conditions.
- ii. All bearings shall be adequately lubricated to prevent excessive wear/seizure under all operating conditions.
- iii. All bearings shall be rated for a minimum L10h life of 100,000 hours at the GDP.

4.1.8. **Water Pumps**

4.1.8.1. **Submersible Borehole Pumping Equipment**

4.1.8.1.1. *General*

- i. Borehole pumps shall be high efficiency multi-stage mixed flow or centrifugal pumps suspended below the motor/thrust bearing/head gear which shall be mounted under cover.
- ii. Electro-submersible pumps shall be used in deep well applications and where borehole casing sleeves are less than 350 mm internal diameter. They may also be used horizontally as “in-line booster” applications where required by the Contract in pipes of 150 mm diameter or less.

4.1.8.1.2. *Materials*

- i. Impellers shall be fabricated from stainless steel 316 or bronze of suitable grade for the nature of the water being pumped. Plastic impellers/casings shall not be accepted. The pump shaft and wear ring shall be fabricated from stainless steel 316. Mechanical seals shall be employed with faces of tungsten carbide or ceramic. Shaft bearings shall be sealed and lubricated for life.
- ii. Pumpsets in casings below 100 mm diameter may be fabricated from stainless steel 316 construction inclusive of shaft casings, impellers, and check valve.

- iii. Pump shafts shall be stainless steel, and bearings shall be water lubricated bronze or stainless steel 316L. Rubber water lubricated bearings are permitted provided there is no possibility of the pump running “dry”.

4.1.8.1.3. *Rising Main*

- i. The pump and associated rising main pipe column shall be supported separately from the motor and thrust bearing stools.
- ii. The rising main shall be flanged, and provision made for cabling to borehole sensors or intermediate bearing lubrication lines, or both, where applicable.

4.1.8.1.4. *Strainer*

- i. Pump inlets shall be fitted with stainless steel inlet strainers employing 12 mm diameter holes, unless otherwise specified in the approved datasheet. The outlet shall be fitted within a positively seating bronze check valve (this is in addition to the reflux valve associated with the headgear pipework).

4.1.8.1.5. *Non-Return Valve*

- i. Each borehole pump shall be fitted with a mushroom type non-return valve bolted directly to the pump. The mushroom shall be drilled with a 6 mm bypass to allow draining of the rising main.

4.1.8.1.6. *Motors*

- i. In borehole and in-line applications, the motor shall be arranged upstream of the pump inlet, and cooling water flow over the motor shall be unimpeded.
- ii. In horizontal applications, the pump and motor shall be fully supported by adjustable radial supports at 1200 mm centres, with not less than two sets per pumpset.

4.1.8.2. **End Suction Water Pumps**

4.1.8.2.1. *General*

- i. End suction pumps with back-pull-out facility shall combine the pump and drive motor as a single compact unit. The pump shall be a single stage high efficiency type directly coupled to its drive motor through a spacer coupling.
- ii. The unit shall be mounted on a robust, combined base plate. The back-pull-out facility shall permit removal of the shaft with its bearing housing, back cover, shaft seals, and impeller in a single assembly without disturbing the suction and delivery pipework or drive motor.
- iii. The back plate shall be fitted with jacking screws to enable it to be eased out of the pump casing. The positioning of the support foot, if required, on horizontal pumps for the bearing housing and bolted connections to the volute casing shall positively locate the pump rotor assembly so that on reassembly the spacer and pump shaft couplings are truly aligned.

4.1.8.2.2. *Volute*

- i. The volute casing shall be supported on integral feet to eliminate distortion. Replaceable wear rings shall be fitted to all volute castings. Replaceable back cover wear rings shall be fitted if the impeller is fitted with hydraulic balance holes. Suction and delivery flanges shall be provided with tapplings for pressure gauge connections. Air release and drain tapplings shall be provided on the

volute casing. Material hardness shall be more than anticipated solid particles that might be accompanied with the pumped liquid.

4.1.8.2.3. *Impellers*

- i. Impellers shall be overhung, single entry, and fully shrouded and fitted with replaceable wear rings, including back rings if the impeller is provided with hydraulic balance holes. Alternatively, rear balance vanes may be fitted. Impellers shall be secured to shafts through shaft keys and shaft nuts, the nuts being threaded to the opposite hand to the direction of rotation. The shaft nut shall be secured to the shaft by a locking device.

4.1.8.2.4. *Bearings*

- i. Bearings shall be oil or grease-lubricated and shall be capable of accepting the full unbalanced thrust. Bearing oil or grease seals shall provide adequate protection against bearing contamination. Shaft seals shall be cartridge type mechanical seals. Couplings shall be flexible spacer type on horizontal pumps.

4.1.8.3. **Hydro-Pneumatic Booster Sets**

4.1.8.3.1. *General*

- i. Hydro-pneumatic booster sets shall comprise a hydraulic accumulator and pump sets all mounted on a skid.
- ii. At least two pumps shall be provided, arranged on a duty/assist basis.
- iii. Pumps shall be controlled by pressure switches arranged to start and stop the units on falling and rising pressure.
- iv. Each pump unit shall be selected so that its hydraulic efficiency at a given operating point is within +/-10 % of its best hydraulic efficiency under all booster set operating conditions. The hydraulic efficiency of each pump unit at the minimum, mean and maximum flow rates required shall be as stated on the datasheet.

4.1.8.3.2. *Net Positive Suction Head Required (NPSH_R)*

- i. Each pump unit shall be selected so that the minimum inlet pressure exceeds the pump NPSH_R (including the relevant safety margin) under all booster set operating conditions.
- ii. If specified, the booster set shall be capable of discharging into an empty main. The maximum allowable operating time under these conditions shall be as stated on the approved datasheet.
- iii. For each different pump unit incorporated into the booster set, characteristic curves of pump total generated head, pump efficiency, pump power input, motor power input, and pump NPSH_R versus flow rate at the minimum (if relevant) and maximum speed shall be supplied.

4.1.8.3.3. *Accumulator*

- i. Hydraulic accumulators shall be of internal/external coated steel incorporating a diaphragm all suitable for potable water, inspection hatch, inlet air self-sealing charge valve, and pressure gauge to BS EN 837-1:1998. As an alternative, on large sets, the Contractor may propose, for the approval of the Engineer, permanently installed air compressors with suitable filtration and oil removal to maintain air pressure within the accumulator.

- ii. Accumulators shall be constructed, certified, and marked in accordance with Statutory Pressure Vessel Regulations and PD 5500:2012+A1:2012 or ASME VIII.
- iii. Accumulator vessels shall be sized in accordance with the following equation:

$$V = \frac{7.5 \times P_a \times (Q_e + Q_a)}{Z \times (P_a - P_e)}$$

Where:

V = Vessel volume (l)

Pe = Cut-in pressure (bar absolute)

Pa = Cut-out pressure (bar absolute)

Qe = Flow at cut-in pressure Pe (l/min)

Qa = Flow at cut-out pressure Pa (l/min)

Z = Number of motor starts per hour allowed

The capacities of the accumulator vessels provided shall be as stated on the approved datasheet.

4.1.8.3.4. *Materials*

- i. Pumps shall have a cast iron casing with stainless steel 316 impellers and shafts. Pumps shall be fitted with mechanical seals.

4.1.8.3.5. *Pipework*

- i. Pipework shall be of galvanised steel to BS EN 10255:2004, fusion bonded epoxy coated steel, high performance polyethylene (HPPE), ductile iron, or stainless steel.
- ii. Suction and delivery isolating valves and pump delivery non-return valves shall be fitted together with a delivery pressure gauge to BS EN 837-1:1998.

4.1.8.3.6. *Header/Break Tanks*

- i. Where installed in sewage pumping stations or treatment works and used in conjunction with a header tank feeding from a potable water supply, the tank shall incorporate a double-check valve and an inlet ball valve arrangement.
- ii. The break tank shall be open-topped with a removable cover and shall incorporate a type "A" air gap.
- iii. Header tanks shall be manufactured from approved non-toxic materials with the following as a minimum:
 - a) Inlet connection and isolating valve
 - b) Ball-cock

- c) Overflow connection
- d) Outlet connection and isolating valve
- e) Drain connection and isolating valve
- f) Level sensing device to signal low tank water level

4.1.8.3.7. *Variable Speed*

- i. As an alternative to a hydro-pneumatic set, the Contractor may propose, for the approval of the Engineer, a variable speed pump set with integral or remote mounted inverters. The surge vessel shall be of steel incorporating a diaphragm suitable for potable water, inspection hatch, inlet air self-sealing charge valve, and pressure gauge to BS EN 837-1:1998.

4.1.8.4. **Screw Type Impeller Pumps**

- i. Dry well of high hydraulic efficiency (>80%) screw centrifugal pumps shall be specifically designed to pump raw unscreened sewage, bio-solids/activated-flocculated sludge up to 8 % consistency, or other media containing solids or rags (or both) and other fibrous materials without clogging.
- ii. The pumps shall be designed for continuous operation and shall be operated continuously under normal service. To minimise operation power costs, the hydraulic efficiencies listed for each pump are the minimum acceptable, and shall be guaranteed by the Contractor.
- iii. Single-passage screw centrifugal impellers shall have proven ability to handle sewage flow containing solids as well as rags and long fibrous materials without clogging.
- iv. Pump size of 50 to 80 mm connections: Free passage for non-compressible solids shall be minimum 50 mm.
- v. Pump size of 100 to 150 mm connections, subject to its proven success of pumping raw unscreened sewage or sludge (or both), with a range of impellers having free passage for non-compressible solids of 75 to 115 mm.
- vi. Pump sizes above 150 mm connections: Free passage for non-compressible solids shall be minimum 100 mm, with generally larger free passage for larger bore pump design such that a 500 mm bore pump would have 230 mm of free passage.
- vii. Pumps selected for sludge applications shall be capable of operation at high consistency; with up to at least 8 % dissolved solids, without any significant drop or collapse from their standard water performance curve.
- viii. Screw centrifugal pump impellers shall be designed such that it is able to pump activated/biological sludge without damage to the delicate and costly flocculants.
- ix. Rotational speed shall not exceed 1,500 rpm.
- x. The basic design shall be a single-passage, clog-free pump, utilising a screw-centrifugal impeller. The impellers shall comprise a single vane, with a large open passage. The overall pump design shall combine high efficiency, low required NPSH, a large solid passage, and the ability to handle rags or other fibrous material without blocking.
- xi. Suction and discharge flanges shall be drilled to meet BS EN 1092-1:2007 and BS EN 1092-2:1997.

- xii. The pump volute, back plate, and suction piece and impeller shall be of stainless steel 316 or optional duplex stainless steel 2205 for severe corrosion applications.

4.1.9. Sump Pumps

- i. Where specified, sump pumps shall be provided in dry wells where natural drainage is not possible, and in wet sumps which are required to be fully drained down after a pump cycle (for example, storm pump sump).
- ii. Sump pumps shall be fully automatic with integral non-mercury level control switches. Integral level float switches shall not operate on mains voltage. They shall be free-standing and suitable for use with 300 x 300 x 300mm drainage sumps.
- iii. Delivery pipework shall be acrylonitrile butadiene styrene (ABS) terminating with a ball type reflux valve and isolating valve adjacent to the drainage sump. For dry well applications, a 3,000 mm long flexible hose shall connect the pump to the pipework, complete with hand tightened threaded pipe union to facilitate removal of the pump without affecting the pipework.
- iv. Sump pumps mounted in wet sumps shall be guiderail-mounted and comply fully with the submersible pump specification.

4.1.10. Inspection and Testing

- i. Haya Water reserves the right for shop inspection/stage inspection by their authorised representatives.
- ii. The surge vessels shall be subjected to heat treatments and tests (including non-destructive testing (NDT)), as required by the specific applicable code of construction.
- iii. The material certificates indicated in the previous details shall be inspected and certified by the Engineer prior to starting shop tests of the component.
- iv. The Contractor shall provide full assistance and co-operation for any such inspection, when required by the Engineer.
- v. The vessels shall be hydro-tested to a pressure 1.5 times the design pressure.
- vi. The Contractor shall make suitable provisions for detailed shop testing of the surge vessels and notify the Engineer sufficiently in advance to enable the Engineer to witness the tests.
- vii. The Engineer and, if required, a third-party inspection authority, shall be informed of all defects arising during manufacture and fabrication of the surge vessels, and only those parties shall authorise repair or rejection of faulty material or workmanship.
- viii. The programme for the tests shall be prepared by the Contractor and shall be subject to the Engineer's approval.
- ix. The Contractor shall produce material test certificates for all components making up the surge vessels in accordance with ISO 10474 3.1B certificate.
- x. If any defect is detected during the tests before completion or during the warranty period, the faulty equipment shall then be rectified immediately by the Contractor at his expense. If the fault cannot be rectified, the Contractor shall then replace the defective equipment which shall also be proven to be free from defect.
- xi. The factory tests for each surge system shall include, but shall not be limited to, the following:
 - a) Visual examination of the surge vessels to ensure compliance with the Specification

- b) Hydrostatic test of the surge vessels
 - c) High voltage test for rubber lining before vulcanisation at 5 kV/mm
 - d) After vulcanisation, the following tests shall be conducted on rubber lining:
 - Visual inspection
 - Adhesion test
 - Dielectric test with sparking device
 - Shore D hardness test
 - Thickness test by electronic device
 - e) Coating thickness check
- xii. The requirements described as follows shall apply to the Quality Control Plan/Inspection Test Plan, which shall be submitted by the Contractor and approved by the Engineer.
- a) Mill certificates to ISO 10474 3.1B shall be submitted for the steel plates indicating the following:
 - Heat treatment (if any)
 - Chemical analysis
 - Physical analysis
 - Welding procedure specifications, together with procedure qualification records
 - Welder qualification records
 - Non-destructive testing procedure
- xiii. The previously mentioned certificates shall be subject to review and approval by a third-party inspection agency or the Engineer
- a) The following tests shall be included in the quality control plan as witness/hold points for a third-party inspection agency or the Engineer
 - b) Tests on rubber lining before vulcanising
 - c) Tests on rubber lining after vulcanising
 - d) Hydrostatic test
 - e) Coating thickness checks
- xiv. Certificates of type 3.2 to ISO 10474 shall be issued for all previously mentioned tests.
- xv. The previously mentioned certificates shall be reviewed and certified by the respective inspection authority.
- xvi. After shop test, the surge vessels shall be opened, and visual inspection shall be carried out for any possible defects/deformations. Any defects/faults/deformations detected shall be promptly repaired/replaced, prior to dispatch. The Engineer's decision in this regard, within Tender specifications, shall be final and binding on the Contractor.

4.1.11. Spare Parts

Spare parts shall be supplied and delivered at the same time as the equipment to which they relate. Spare parts shall be new and completely intact and free of any defects or damages. Any damaged part observed at the delivery shall be rejected and replaced by new item.

Long-term storage requirements shall be included in the supplied spare parts lists (for example, temperature controlled).

The following are minimum spares required for sewage pumps (or more if provided by vendor)

S.N.	Item	Unit	Quantity
1	Ball Bearings (upper and lower)	No.	2
2	O-Rings and Gasket	Set	1
3	Mechanical Seal	Set	1
4	Impeller Wearing and casing Wearing	No.	1 each
5	Oil Seals	Set	1
6	For every 2 similar pumps (of same model): a) Shaft b) Impeller	No. No.	1 1
7	Cable Entry Kit	Set	1

4.1.12. Vacuum Vessels

- Sewage from the vacuum mains shall be transferred to a vacuum station and collected in a steel tank vacuum vessel. The vessel shall be provided with a flanged manhole access (minimum 600 mm diameter) to permit man-entry for inspection and maintenance of the interior.
- The vessel shall be internally and externally protected.
- A tanker with valve connection, of preferably 100 mm diameter Bauer coupling, shall be provided from the vase of the vacuum vessel. Pipework shall be provided to an accessible point, 1 m above finished ground level (FGL), on the outside of the building for connection of a mobile tanker connection to prevent the tanker discharging into the vessel.
- A 25 mm tapping and boss complete with a suitable isolation valve shall be fitted below normal sewage level for chemical dosing.
- To collect sewerage from the rising main and to store the sewerage prior to being pumped to the next stage of the process, one steel collection vessel shall be supplied.
- The operating volume of the vessel shall be equal to the volume delivered by the vacuum generating pumps in 3 minutes.
- The length of the vessel shall be such as to accommodate the incoming rising mains.

- viii. The sewage collection vessel shall be in accordance with AM-ENG-SS-02-01, General Technical Standard Specification.
- ix. The collection vessel shall be supplied with all necessary connections to facilitate the installation of the required instrumentation associated with the full operation of the vacuum pumps and sewerage pumps.
- x. The Contractor shall ensure there is a sufficient clear air path above the maximum high high alarm level of the sewage in the sewage collection vessel to the vacuum sewers to ensure an efficient vacuum operation.
- xi. There shall be sufficient liquid above the sewage pumps to ensure that they do not cavitate, maintain prime and to minimise the likelihood of a vortex forming.
- xii. Sewage pump suction connections shall be supplied at the invert of the collection vessel.
- xiii. Sewer inlets shall be provided with short radius bends inside the vessel to force the flow away from the sewage pump connections.
- xiv. A drain connection with valves shall be fitted to the vessel invert. The drain valve shall be a resilient seat gate type.
- xv. A DN 600 access hole and cover shall be fitted to the side or the top of the collection vessel. The cover shall be fitted with a lifting eye.
- xvi. The collection vessel shall be fitted with lifting lugs, supports, and all connections to ensure correct operation.
- xvii. A graduated sewage level gauge polycarbonate tube with stainless steel tube guard shall be fitted to the collection vessel. The level gauge shall be fitted with isolation and drain valves that are capable of being cleaned without removal from the collection vessel.

4.2. Air Blowers and Compressors

4.2.1. General

- i. Pipework air flow velocity shall not exceed 10 m/s. The pipework system shall have a horizontal fall of not less than 1 in 50 in the direction of air flow and incorporate drainage points at distances of not less than 30 m. Drainage points shall comprise equal tees with a down-pointing leg fitted, preferably, where changes of direction occurs. Branch take-offs shall be from the top of the main, and the lowest point of any falling pipes shall be drained.
- ii. Exposed pipework shall be insulated for personnel safety and protection where outer surface temperatures exceed 70°C.
- iii. All moving parts, where accessible to operations personnel, shall be protected and suitably guarded in accordance with PD 5304:2005. All guards shall be designed to facilitate easy removal.
- iv. Units shall have anti-vibration mountings, be statically and dynamically balanced, and run free from vibration. The critical speed of the rotor shall be above the operational running speeds.
- v. Where noise levels generated by the blower or compressor exceed 80 dBA at 1 m or other noise limitations apply, they shall be installed in an acoustic enclosure having an outer skin of mild steel, or glass-reinforced plastic (GRP), and an inner skin of perforated steel. Between the outer and inner skins shall be a filling of mineral wool or similar material, with a thin film of plastic between the mineral wool and the perforated sheet to preclude dirt and grease. A neoprene rubber strip shall be used to seal the lower edge of the enclosure.

- vi. A schedule of spares shall be required for 2 years of normal operation (plus associated costs and lead times).

4.2.2. Air Blowers

4.2.2.1. General

- i. Positive displacement, high efficiency, low-noise (preferably screw type) blowers shall be used as standard for medium capacities, while centrifugal turbo-blowers shall be used for large flow rates as specified in the Particular Specification (individual blower flow $>100 \text{ m}^3/\text{min}$, or $6,000 \text{ m}^3/\text{h}$).
- ii. A component/system schedule or asset list shall be provided to the Engineer including, for each major component/system, the component/system manufacturer and all relevant technical specifications (including details of materials).
- iii. A lubrication schedule shall be provided to the Engineer detailing all components/systems requiring lubrication, the method and frequency of lubrication, and the type and manufacturer of the lubricants.
- iv. Components weighing over 25 kg, that will be removed for maintenance (with the exception of rotors and impellers), shall incorporate clearly identified, permanent lifting points located to give a safe, balanced lift. If lifting points are not designed for lifting the whole blower, they shall be clearly marked accordingly.
- v. Blower cylinders and head-plates shall be cast iron. Impellers shall be spheroidal graphite or mehanite.
- vi. All blower components and associated pipework (including valves and fittings) shall be designed and assembled to avoid galvanic corrosion.
- vii. Guarding shall comply with BS EN ISO 12100:2010 and BS EN 953:1997+A1:2009.
- viii. Guarding of machinery (for example, belt drives) shall be independent of the acoustic enclosure, if provided.
- ix. Blower components and associated pipework that present a burn hazard shall be insulated/guarded.
- x. Components that require regular inspection, cleaning, or maintenance shall be readily and safely accessible and, where appropriate, easily replaceable.
- xi. Components shall be designed to avoid the need for the use of special tools for maintenance. If special tools are required, they shall be provided.
- xii. Couplings (if required/provided) shall be replaceable without disturbing the blower or its drive, or both (that is, spacer-type couplings shall be fitted). Couplings shall be designed with a service factor of 1.6 (based on the maximum absorbed power at the blower shaft stage).
- xiii. Unless otherwise specified/stated on the approved datasheet, pulley and V-belt transmissions (if required/provided) shall incorporate an automatic belt tensioning device. V-belt drives shall be designed with a service factor of 1.6 (based on the maximum absorbed power at the blower shaft stage).
- xiv. Guards fitted to pulley and V-belt transmissions shall incorporate facilities for inspecting V belt condition (for example, mesh sections or inspection covers).
- xv. The blower shall be provided with one or more information plates, permanently fixed to one of its main components. The plates and their fixings shall be manufactured from corrosion resistant,

non-degradable materials. As a minimum, the information plates shall include the following information:

- a) Blower manufacturer
 - b) Blower model/type
 - c) Blower serial number
 - d) Flow rate (Nm³/hr)
 - e) Head/pressure (m or bar)
 - f) Operating speed (rpm)
 - g) Year of manufacture
 - h) CE mark
- xvi. "Walk-in" type acoustic enclosures shall be provided with all appropriate warning signs/notices.
- xvii. Bearing design life shall be 100,000 hours based on L10 parameters.

4.2.2.2. Centrifugal Blowers

- i. Blower sets shall be low noise, high efficiency reliable, energy-efficient and preferably certified 100% oil free to ISO 8573-1 Class 0 (2010), comprised of modulating powered inlet and outlet guide vanes, stainless steel impeller with integrated seals to achieve high efficiency plus gearbox, lubrication system, electric drive motor, magnetic bearing, and suction and discharge flexible stainless steel connection compensators, all mounted on a common base plate. The sets shall be installed on flexible machine mounts.
- ii. The volume flow rate from the blowers shall have modulated control on the inlet and outlet guide vanes, which shall be capable of varying the delivery rate down to 45% of the rated output without causing the blower to go into surge when operating either singly or in parallel. A high operating efficiency shall be maintained throughout the flow range.
- iii. Materials and equipment of construction shall give a design running life of at least 100,000 hours before major maintenance is necessary.
- iv. The impeller shall be statically balanced, and the whole rotor shall be dynamically balanced. The first responsive critical speed of the rotating assembly shall be at least 10 % above the maximum operating speed.
- v. The gearboxes shall be of the parallel shaft high speed helical type. The gears shall have a minimum American Gear Manufacturer's Association (AGMA A4/DIN5) with service factor of 1.5. A labyrinth oil seal shall be fitted to each shaft to prevent oil seepage from the casing under operating and static conditions. The seals shall be designed to ensure there is no contamination of the process air.
- vi. Each gearbox shall be fitted with an oil level sight glass and a drain plug which shall be readily accessible in operation.
- vii. The base plate shall be provided with lifting points to allow the complete set to be handled using chain slings.
- viii. Instrumentation for the safety monitoring of air blowers shall include *oil temperature, oil level, air temperature* at inlet and outlet from the blower, *outlet air pressure, surge conditions, bearing temperature* and *vibration*, and *motor running current*. The instruments shall provide signals for the shutting down of air blowers if unsafe conditions arise and for visual indication of the fault.

Additionally, the Contractor shall provide all necessary instrumentation for measuring the airflow from each blower.

- ix. Each blower shall be equipped with an inlet air filter, automatic unloading device, pressure relief valve, pressure switch, and under-load (no flow) detection device to trip the blower in case of drive/flow failure.
- x. Each blower shall be performance-tested at the manufacturer's premises, using the control motors, to BS ISO 1217:2009. Air flow measurement for these tests shall be carried out in accordance with PD ISO/TR 9464:2008. Blower casings shall be hydrostatically tested at the manufacturer's premises to 1.5 times the maximum working pressure.
- xi. Unless specified in the approved datasheet, vibration levels shall not exceed 2.8 mm/s, in accordance with BS ISO 10816-3:2009.
- xii. The impeller shall be machined from a single forging.
- xiii. The impeller shall be secured to the impeller shaft and retained against circumferential movement. The impeller shall not be pinned to the shaft, and shaft rotation shall not be relied upon to ensure that the impeller is locked in position.
- xiv. The rotating element (impeller and shaft) shall be dynamically balanced in two planes to prevent the blower exceeding the maximum vibration levels specified. Balancing shall be achieved by machining, not addition of weights.
- xv. The design of the rotating element shall ensure that the first critical speed does not occur within +/-20 % of the operating speed range of the blower.
- xvi. The impeller shall be suitable for an over-speed of at least 115 %.
- xvii. The impeller shaft shall be provided with seals to prevent the ingress of oil and contaminants into the volute casing and avoid contamination of the gearbox oil.
- xviii. The gearbox shall incorporate a pressurised oil lubrication system to lubricate the gears and bearings. The system shall incorporate the following items, as a minimum:
 - a) Oil reservoir with thermostatically controlled oil heater.
 - b) Main oil pump (mechanically driven) with suction strainer.
 - c) Auxiliary oil pump (electrically driven) with suction strainer.
 - d) Oil cooler.
 - e) Oil filter with visual condition indicator.
 - f) All necessary pressure relief valves, non-return valves, fittings, pipework, and similar components to ensure effective, fail-safe operation.
 - g) All necessary instrumentation and protective devices to ensure effective, fail-safe operation.
 - h) Readily accessible oil drain and fill/vent points to allow oil removal/replacement in situ without excessive spillage and without disturbing blower mountings or ancillary equipment (or both). An effective oil mist vent filter shall be provided.
- xix. The auxiliary oil pump shall ensure effective gearbox lubrication during blower start-up and run-down. It shall also act as a standby unit if the main oil pump fails.
- xx. Unless otherwise specified in the Particular Specification or approved datasheet, the blower shall be provided with the following items:
 - a) Actuated blow-off/unloading valve with open/closed limit switches and silencer.

- b) Surge detection/prevention system.
- c) Non-return valve.
- d) Isolating valve.
- e) Outlet pressure gauge with isolating valve. The gauge full scale deflection shall be between 1.5 and 2.0 times the maximum outlet pressure.
- f) Outlet air temperature sensor with high level switch.
- g) Outlet silencer.
- h) Inlet air temperature sensor with high level switch (to detect reverse flow/stalling).

Centrifugal Blowers shall require conditional monitoring as classified below:

For Centrifugal Blowers (>355kW):

Each blower shall be equipped with **inlet air filter, automatic unloading device, pressure relief valve, check valve, pressure switch** and **under load (no flow) detection device** to trip the blower in case of drive/flow failure. Instrumentation for the safety condition monitoring of air blowers shall include (SENSOR+TRANSMITTERS) for:

1. Oil temperature.
2. Oil level.
3. Air temperature at inlet and outlet from the blower.
4. Air pressure at the outlet.
5. Surge conditions.
6. Bearing temperature.
7. Vibration level sensing elements.
8. Motor running current. Plus all 6 RTD motor protection signals.
9. Instruments shall provide signals for shutting down of air blowers if unsafe conditions arise and for visual indication of the fault.
10. Contractor shall provide all necessary instrumentation for continuous measuring of airflow from each blower.

For PD Blowers (100 - 355kW):

Each blower shall be equipped with **inlet air filter, automatic unloading device, pressure relief valve, check valve, pressure switch** and **under load (no flow) detection device** to trip the blower in case of drive/flow failure. Instrumentation for the safety condition monitoring of air blowers shall include (SENSOR+TRANSMITTERS) for:

1. Air temperature at inlet and outlet from the blower.
2. Outlet air pressure.
3. Bearing temperature.
4. Vibration level sensing devices.
5. Motor running current. Plus 3 RTD motor protection signals.
6. Instruments shall provide signals for shutting down of air blowers if unsafe conditions arise and for visual indication of the fault.

7. Contractor shall provide all necessary instrumentation for continuous measuring of airflow from each blower.

4.2.2.3. Positive Displacement Blowers

- i. The blowers shall be low noise, high efficiency (preferably screw type) complete with all ancillary equipment required to enable the units to operate correctly. Blowers shall be incorporating proven screw technology, and designed, manufactured and tested in accordance with ISO 9001,
- ii. Blowers shall be air-cooled of screw or triple rotor positive displacement rotary type, delivering oil-free air. The 100% oil-free air, certified according to ISO 8573-1 CLASS 0 (2010) shall be absolutely essential to avoid contamination and keep the production running smoothly
- iii. Each blower shall be complete with an automatic unloading device, a dead-weight pressure relief valve, a spring type pressure relief valve, a pressure gauge, a pressure switch, and non-return valve of the wafer or nozzle ring check pattern.
- iv. The blower speed shall not exceed 70% of the maximum designed speed or 2,300 rpm, whichever is lower.
- v. Each blower shall have an under-load detection relay or other similar device to trip the blower in the event of a drive or flow failure.
- vi. The blower casing shall be high-grade cast iron adequately ribbed to assist cooling and avoid distortion. The rotors shall be spheroidal graphite iron with integral shafting. Timing gears shall be of nickel cast iron positively keyed to the rotor shafts; they shall be accurately ground with close clearances to prevent interference between rotors.
- vii. The blower shall be fitted with an oil lubrication system for the bearings and timing gears. The blower shall be fitted with mechanical seals to prevent the ingress of oil into the rotor chamber.
- viii. The lubrication system shall include filling and drain plugs and oil level indicators visible from outside the acoustic cover.
- ix. The drive between the blower and motor shall be of the V-belt or flat toothed belt type and of approved design.
- x. The complete blower assembly shall be mounted on steel section frame which shall incorporate a blower mounting plate, motor adjustment slides, and guard support brackets; the frame shall be supported on anti-vibration mounts.
- xi. An outlet silencer shall be fitted to maintain noise levels as low as possible. A flexible coupling shall be fitted to prevent vibration transmission to the air supply system.
- xii. Silencers are to be of the reactive type; absorptive type silencers shall not be permitted. Components likely to wear in the course of normal operation shall be capable of replacement with readily available replacement components.
- xiii. The maximum operating speed for the specified duty shall be as follows:
 - a) Less than < 2,300 rpm for machines above 50 kW
 - b) Less than < 3,200 rpm for machines below 50 kW
- xiv. The blower shall be capable of satisfactory operation in parallel with a number of other blowers.
- xv. Both single and multistage units shall be provided with the following:
 - a) Low oil level cut out switch

- b) Crank case oil sight glass
- c) Air inlet filter
- d) Silencer complete with pressure gauge and low pressure cut-out (filter blockage protection)
- e) Pressure gauge tapping after each stage for compressors up to 15kW, and gauges and safety valves on compressors over 15kW
- f) Oil pressure indicator on compressors over 100 kW
- g) Final air temperature indicator on compressors over 100 kW
- xvi. The rotor shafts shall be provided with seals to prevent the ingress of oil into the casing and avoid the contamination of the timing gearbox oil.
- xvii. All bearings shall have a minimum L10h life (or equivalent) of 100,000 hours.
- xviii. The gear case shall incorporate readily accessible oil filling and drain plugs to allow oil removal/replacement in situ without excessive spillage and without disturbing blower mountings or ancillary equipment, or both. An oil level window/sight glass shall be provided.
- xix. If oil-lubricated bearings are provided, bearing housings shall incorporate readily accessible oil filling and drain plugs to allow oil removal/replacement in situ without excessive spillage and without disturbing blower mountings or ancillary equipment, or both. Oil level windows/sight glasses shall be provided.
- xx. Unless otherwise specified in the Particular Specification, the blower shall be provided with the following items, at a minimum:
 - a) Blow-off/unloading valve and silencer.
 - b) Pressure relief valve (PRV), set at 110 % of the maximum operating pressure and rated to pass the maximum blower flow rate (the PRV shall discharge outside the acoustic enclosure).
 - c) Non-return valve.
 - d) Outlet pressure gauge with isolating valve. The gauge full scale deflection shall be between 1.5 and 2.0 times the maximum outlet pressure.
 - e) Flexible connections to the inlet/outlet pipework, as appropriate.
 - f) Inlet and outlet silencers.
- xxi. The following shall be required, unless specified in the approved datasheet:
 - a) Vibration levels from the blower stage shall not exceed 12 mm/s.
 - b) Vibration levels from the blower package shall not exceed 30 mm/s.

The following are minimum spares required for Air blowers (or more if provided by vendor)

S.N.	Item	Unit	Quantity
1	Roller and Ball Bearings (at both ends)	Set	2
2	O-Rings and Gasket	Set	1
3	Seal assembly	Set	1
4	Lip seal	No.	1
5	Seal wear ring	No.	1
6	For every 2 similar blowers (of same model): rotor & shaft	Set	1
7	Inlet Air filter elements	Set	2
8	Oil filter elements	Set	2

4.2.3. Compressors

4.2.3.1. General

- i. The design and installation of the compressed air system shall be in accordance with the requirements of the British Compressed Air Society's Code of Practice and the Pressure Systems and Transportable Gas Containers Regulations, 1989.
- ii. Compressors shall be rated to achieve the duty at optimum efficiency and shall be selected from one of the following types unless otherwise specified in the Particular Specification:
 - a) Reciprocating single stage
 - b) Reciprocating multi-stage
 - c) Rotary screw
- iii. Other technologies may be considered and shall be submitted to the Engineer for approval. Compressors or blowers shall be deemed to be compressors if the normal continuous output pressure exceeds 1,100 mbar.
- iv. Compressors shall be provided on a duty/standby basis and shall be capable of continuous automatic operation whilst requiring the minimum of maintenance, and shall supply dry, oil free compressed air.
- v. Equipment to be furnished hereunder shall be the standard product of a manufacturer who is regularly engaged in the design and construction of fully automatic air compression system.
- vi. Compressors shall be designed to BS EN 1012-1:2010 and tested to BS ISO 1217:2009 for the defined duty.

- vii. For continuous ratings to 25 l/s and 7 bar, air compressors for instrument and general service air purposes shall be single-stage reciprocating. Unless there is a single duty requiring oil in air, compressors shall be oil-free.

4.2.3.2. Reciprocating Compressors

- i. Reciprocating single-stage compressors shall be of inherently oil free design. The compressor shall be low noise and high efficiency of cast iron construction with aluminium cylinder heads and shall be air-cooled. The unit, complete with electric motor, shall be mounted on a rigid bedplate incorporating anti-vibration mountings. The drive arrangement shall be belt or shaft driven and shall be fully guarded. A suitable means of achieving alignment shall be provided and, where appropriate, flexible couplings shall be used.
- ii. Reciprocating multi-stage compressors shall be as previously described but shall incorporate inter-stage cooling and be of the short stroke design for low piston speeds.
- iii. Both single- and multi-stage units shall be provided with the following:
 - a) Low oil level cut out switch
 - b) Crank case oil sight glass
 - c) Air inlet filter
 - d) Silencer complete with pressure gauge and low pressure cut-out (filter blockage protection)
 - e) Pressure gauge tappings after each stage for compressors up to 15k W, and gauges and safety valves on compressors over 15 kW
 - f) Oil pressure indicator on compressors over 100 kW
 - g) Final air temperature indicator on compressors over 100 kW
 - h) Unloader valve unit
 - i) Air dryer system (dehumidifier) where dry air is required

4.2.3.3. Rotary Compressors

- i. Rotary screw compressors shall be low noise and high efficiency of inherently oil free design and shall be either the single- or multi-stage type depending on the duty.
- ii. The separate stages shall be enclosed in individual housings, the male rotor being gearbox driven, whilst the female rotor shall be driven via a timing gear.
- iii. The rotor shafts shall be supported by precision-made ball and roller bearings.
- iv. Lubrication to the driving gear, bearings, and timing gear shall be via an oil pump driven by the main shaft. The lubrication system shall be complete with oil filter and cooler, pressure gauge, and fail-safe pressure switch.
- v. On multi-stage units, air cooling shall be undertaken by an intercooler.
- vi. The compressor shall be motor driven via a flexible coupling and gearbox common to both stages. A suitable means of alignment shall be provided.
- vii. The complete compressor set (compressor, motor, gearbox, and associated cooling equipment) shall be supplied on a rigid bed plate suitable for floor mounting via anti vibration mountings.

4.2.3.4. After Cooler

- i. All types of compressor shall be fitted with an after cooler. These shall be of the air cooled type comprising an air to air heat exchanger. The after cooler shall cool the process air to a temperature of 10°C above ambient. The after cooler shall be fitted with an automatic condensation drain which shall be provided with a manual bypass.
- ii. Delivery lines from the compressor sets shall be fitted with the following equipment:
 - a) Oil trap/filter prior to entry into the air receiver. The filter shall be fitted with an auto drain and manual bypass.
 - b) Adjustable safety valve (lockable).
 - c) Solenoid valve for unloading (dependent upon compressor size) for applications where the compressor is directly coupled to a surge vessel.
 - d) Non return valve.
 - e) High-efficiency coalescing oil filter (0.001 micron filtration).

4.2.3.5. Air Receivers

- i. Unless otherwise stated, one air receiver shall be provided, normally being online, but with the capacity to be isolated from the system.
- ii. Air receivers shall be manufactured from fusion welded steel and shall comply with BS EN 286-1:1998+A2:2005 or equivalent for the appropriate pressure class.
- iii. Air receivers greater than 1,000 l capacity shall be designed and manufactured in accordance with PD 5500:2012+A1:2012 or equivalent.
- iv. Each integral air receiver shall have sufficient capacity to damp out air pulses from the compressor and to prevent pressure drops on process valve actuations.
- v. The air receivers shall be connected such that the duty compressor delivers into either or (if two air receivers are specified) both of the air receivers. Diaphragm isolation valves shall be provided for isolating either of the receivers from the system.
- vi. The air receivers shall be suitable for floor mounting and shall be supplied with two inspection ports. The inspection ports shall be of the elliptical type and pressure sealed.
- vii. All instrument tappings shall be via suitable bosses welded to the tank structure. The vessel shall be supplied with the following:
 - a) Pressure gauge
 - b) Pressure relief valve
 - c) Drain valve
 - d) Lifting lugs
- viii. The vessel shall be corrosion protected to give maintenance-free service for a period of 20 years minimum, as defined in the relevant British Standards.
- ix. Full certification in triplicate shall be supplied with the vessel. The vessel shall also feature a stainless steel nameplate containing the following details.
 - a) Manufacturer's name
 - b) Date of manufacture

- c) Standard to which the vessel was built
- d) Maximum design pressure
- e) Minimum design pressure where it is other than atmospheric
- f) Design temperature
- g) Test pressure
- x. The safe working pressure shall be written in 80 mm indelible characters in colour contrasting to the main vessel on one side of the vessel facing the operator working area.

4.2.3.6. Instrument Air Equipment

- i. The air distribution system design shall consist of a header ring main, which shall be sufficiently sized to minimise pipe losses, off which branch lines shall be taken to serve the equipment.
- ii. Moisture separators shall be incorporated into the ring main at suitable intervals to reduce the moisture content of the compressed air. The separators shall be equipped with an automatic drain trap facility. Automatic drain cocks shall be provided, preceded by strainers, at low points in the system. Trace heating shall be provided where necessary.
- iii. Branch lines shall be taken off the top of the header ring main to minimise the risk of moisture ingress into the branch.
- iv. The branch lines shall be manufactured from thermoplastic or nylon reinforced polyvinyl chloride (PVC) material and shall include an isolating valve which shall be located in an accessible position.

4.2.3.7. Air Filters

- i. Two main airline filter units shall be provided, each unit comprising of a duty/standby filter.
- ii. One filter unit shall be a pre-filter and shall be installed between the receiver and the air dryer. The other shall be a main filter and shall be installed after the air drier.
- iii. Each filter unit shall be supplied complete with isolating valves and a lockable bypass valve, and complete with a padlock and key.
- iv. Pressure gauges shall be provided to indicate the differential pressure across each filter.
- v. The pre-filter shall filter large particles from the air to protect the main filter and the air driers.
- vi. The main filter shall filter the air to a maximum particle size of 3 microns.

4.2.3.8. Air Driers

- i. Two air driers (one duty, one standby) shall be provided and positioned before the main filter.
- ii. Each dryer shall be capable of providing dry compressed air with a minimum compression dew point of 35°C
- iii. Absorption/desiccant type driers shall be designed for continuous operation, having two absorption columns operating in a run and regeneration cycle alternately. Switching and regeneration shall take place automatically. Condensate draining shall also be automatic, and the condensate shall be piped to a suitable drain for disposal.

- iv. When specified in the Particular Specification, refrigerated driers shall be provided, as a duty unit only, and shall include integral filters for particle removal in excess of 3 microns, fully hermetically sealed compressors, and hot gas bypass for constant dew-point control. A separate pressure switch shall be provided for fan and safety control.
- v. The driers shall be arranged in parallel and isolating valves, and a bypass shall be provided. The bypass valves shall be lockable, and a padlock and key shall be provided. The bypass shall also contain a blank brass spade inserted between a pair of flanges.
- vi. The air driers shall be controlled by a local wall mounted control panel. The incoming supply fuse switch shall be lockable in the OFF position. The panel shall be supplied from the motor control centre (MCC).
- vii. The panel shall include the following facilities:
 - a) Duty selector switch:
 - Air dryer 1 duty, air dryer 2 standby.
 - Off.
 - Air dryer 2 duty, air dryer 1 standby.
 - The mode selected shall also be signalled to the MCC.
 - b) Failure of the duty or standby dryer shall be signalled to the plant interposing relay signals marshalling section to provide separate signals to the MCC annunciator panel and telemetry section.
 - c) A pushbutton reset, together with a duty and standby dryer failed indication, shall be incorporated on the door.
 - d) Isolation switches, padlockable in the OFF position, shall be provided on the panel door for each dryer to allow for maintenance work to be undertaken when the duty dryer is required to remain operational.
- viii. The duty air dryer regeneration shall only be permitted to run when the duty air compressor is running. Visual indication shall be included on the control panel to indicate whether the duty or standby dryer is running.
- ix. The air driers shall operate in conjunction with an air moisture monitor/alarm panel located adjacent to the air driers control panel and include a moisture sensor at the air sampling point. The high moisture alarm shall be signalled to the plant interposing relay signals marshalling section to provide separate signals to the MCC, annunciator panel and telemetry section. The moisture monitor shall include facilities for an isolated 4 to 20 mA output.

4.2.3.9. Silencers

- i. The inlet silencers shall incorporate replaceable filter elements and a visual restriction indicator which shall warn of filter blockage.
- ii. The discharge silencers or air blowers shall maintain noise levels at the acceptable levels specified in the Technical Standard Specification – Mechanical Section 01 – General and include a flexible coupling to prevent vibration transmission to the air supply manifold.

4.2.3.10. Air Supply

- i. Air supplies shall discharge into a common air supply manifold via non-return and isolating valves. Each discharge shall also incorporate a pressure relief valve, a pressure operated under-pressure switch which shall trip the blower on loss of air supply, and unloading valves of the centrifugal or solenoid type. A discharge pressure gauge shall be provided on the delivery branch of the air supply manifold.
- ii. Non-return valves shall be of the duo-check or nozzle ring check pattern, with valve bodies of high grade cast iron with stainless steel fulcrum points, stainless steel stops, and inconel return springs.
- iii. A compressed air filter shall remove oil, liquid water, and solid particles from the air. The filter shall have greater than 99.99 % efficiency in removing both 0.5 micron-diameter solid particles and 0.5 micron-diameter oil aerosol. The compressed air filters shall employ three-stage filtration, including mechanical separation, coalescence, and adsorption, in a single housing. A separate pre-filter and moisture separator shall only be required for the removal of solids and normal amounts of condensed moisture in air supplies to instrumentation, as detailed later in this section. The filters shall have replaceable oil-removing filter element which turns colour to indicate saturation with oil, and which shall be mounted in a transparent tube for visibility and inspection whilst on-line. Replacement shall be indicated when the colour reaches the top of the transparent portion of the housing. The transparent tube shall be protected by expanded steel safety shield.