NORSOK STANDARD

MECHANICAL EQUIPMENT SELECTION

R-100
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CONTENTS

FOREWORD

NORSOK (The competitive standing of the Norwegian offshore sector) is the industry initiative to add value, reduce cost and lead time and remove unnecessary activities in offshore field developments and operations.

The NORSOK standards are developed by the Norwegian petroleum industry as a part of the NORSOK initiative and are jointly issued by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Engineering Industries). NORSOK standards are administered by NTS (Norwegian Technology Standards Institution).

The purpose of this industry standard is to replace the individual oil company specifications for use in existing and future petroleum industry developments, subject to the individual company's review and application.

The NORSOK standards make extensive references to international standards. Where relevant, the contents of this standard will be used to provide input to the international standardisation process. Subject to implementation into international standards, this NORSOK standard will be withdrawn.

INTRODUCTION

This standard replaces R-DP-001, rev. 1, April 1996 and includes some revisions marked with a vertical line in the margin.

1 SCOPE

This standard defines selection criteria and -guidelines for mechanical equipment. The standard shall be used for optimised conceptual work, preliminary and detail design phase for oil production facilities, but is also for verification of selection and sizing of equipment before placement of orders. This standard shall not be used for purchasing of equipment.

The standard covers guidelines for the selection and sizing of rotating machinery and other mechanical equipment in critical service in oil installations, such as:

- Gas or oil processing.
- Power generation.
- Gas or oil export.

2 NORMATIVE REFERENCES

The following standards include provisions which, through reference in this text, constitute provisions of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet or exceed the requirements of the standards referenced below.

2.1 Gas turbine

API 616	Type H Industrial Combustion Gas Turbines for Refinery Services. (Replace with ISO 3977 when issued)

2.2 Compressors

API 617	Centrifugal Compressors for General Refinery Services (Replace with ISO 13711 when issued)
API 11P	Specification for Packaged Reciprocating Compressors for Oil and Gas Production Services.
API 619	Rotary - type Positive Displacement Compressors for General Refinery Service. (Replace with ISO 10440 when issued).

2.3 Centrifugal pumps

API 610	Centrifugal Pumps for General Refinery Services. (Replace with ISO 13709 when issued)
NFPA 20	Firewater Pumps.
Hydraulic Institute	Standards for centrifugal, rotary & reciprocating pumps.

2.4 Heat exchangers

TEMA Class R	Tubular Exchanger Manufacturing Association.

Pressure retaining equipment shall be designed in accordance with one of the following codes:

BS 5500	Unfired Fusion Welded Pressure Vessels.
ASME	Boiler and Pressure Vessel Code, section VIII division 1 & 2.
TBK 1 & 2	General Rules For Pressure Vessels.

3 DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

Can	Can-requirements are conditional and indicates a possibility open to the user of the standard.
Critical service	Critical service is defined as a service where failure of the machine to operate correctly results in an unsafe condition which puts the lives of personnel at risk or jeopardises equipment. Further, it is a service where failure of the machine to operate correctly makes a plant or process unacceptable as a production unit. High criticality requires equipment with high quality, high reliability, stringent testing and eventually redundancy. Alternatively, three half-capacity machines shall be specified, two running in parallel with the third unit as a spare.
May	May indicates a course of action that is permissible within the limits of the standard (a permission).
Shall	Shall is an absolute requirement which shall be followed strictly in order to conform with the standard.
Should	Should is a recommendation. Alternative solutions having the same functionality and quality are acceptable.

3.2 Abbreviations

NFPA	National Fire Protection Association
TBK	Norwegian Pressure Vessel Committee
TEMA	Tabular Exchangers Manufacturers Association
WHRU	Waste Heat Recovery Unit

4 GENERAL REQUIREMENTS

4.1 Reparability and maintainability

The design of mechanical equipment shall prepare for optimum operation and maintainability. Effort shall be made, to standardise the spares stocking by minimising the variety of makes and types of driven equipment, drivers and auxiliary equipment selected for any particular project. This standardisation shall be applied so far as it does not interfere with the selection of an optimal solution for the specified operating conditions.

Equipment should be accessible to obtain and maintain. Equipment should be capable of being removed for maintenance. Equipment should be prepared for condition monitoring. Equipment should be capable of being isolated from pressure for maintenance and any gas/liquid inside the isolation be capable of being bled off and flushed out.

Environmental protection should be considered such as capturing accidental and intentional drainage and venting from the equipment.

4.2 Driver selection

A selection study shall be made in the conceptual project phase in order to define the primary selection of drivers for the largest compressors and pumps.

4.3 Availability and sparing

An availability and sparing evaluation shall be undertaken by the purchaser to evaluate the benefit of increased equipment availability against the cost of purchasing and installing spare equipment. Vendors experience of the equipment shall be obtained to ensure that the equipment selection does not include prototype equipment. Proven experience is considered having at least one year in service with good record of two comparable units.

Generally, all rotating equipment in critical service shall have installed spare units. However, units with intermittent service or high investment costs e.g. pumps driven by gas turbine, may dictate against sparing. Rotating equipment shall be standardised to minimise spare parts inventory as far as it does not interfere with the selection of an optimal unit for the specified operating conditions.

4.4 Pinch analysis

Energy-conservation is of concern, and innovative energy-conserving approaches shall be pursued. Equipment efficiencies and utility energy consumption shall be optimised. Due to the current/future emphasis on the environmental and imposition of energy/CO_2 taxes, the choice of high efficiency systems and components is imperative. Equipment manufacturers shall be encouraged to suggest alternatives when such approaches achieve improved energy effectiveness and reduced total life costs without sacrifice of safety or reliability.

4.5 Prime vendor and vendor prequalification

Compressors, pumps, drivers and mechanical equipment that make up a complete unit shall be ordered from the manufacturer of one of these components, and this prime vendor shall become responsible for the satisfactory performance of the complete unit. Further, this manufacturer shall warrant and guarantee all equipment and component parts as stipulated in the relevant specifications and purchase order.

When prequalifying and selecting rotating machinery for critical services, the Vendors operating experience of the equipment shall be obtained to ensure that the equipment selection does not include prototype equipment. Prototypes shall not be used without Company approval and in such cases show considerable benefits with respect to technical properties, economy and/or safety. Selection of a prototype would require extensive work tests under full load conditions. Major redesign or newly developed main components, such as impellers, shall be regarded as prototype.

Furthermore Company experience, operating costs and standardisation requirements for identical or similar equipment shall be checked and taken into consideration when comparing bids. Life-cycle costs shall be estimated and used as selection criteria.

4.6 Codes and standards

The equipment covered by this standard shall be designed and supplied in accordance with the codes and standards listed in section 2 Normative references.

4.7 Technical documents

The preparation of inquiries on mechanical equipment shall only include the direct relevant and main functional standards for purchasing in accordance with NORSOK.

5 GAS TURBINES

5.1 Selection

5.1.1 Gas turbine type

A two-shaft gas turbine should preferably be selected for mechanical drives because a variable power turbine speed is an advantage for capacity control. Attention shall be given to gas turbines which allow direct coupling to the driven equipment eliminating the requirement for a gearbox.

5.1.2 Operating experience

In general, only gas turbines with a minimum of 2 years proven experience are acceptable (16000 running hours on a single machine). This is applicable for new turbines and larger redesigns. The Supplier shall be inquired with regard to information about recent technical changes. A new combination of a gas generator and a power turbine, which both can show proven experience as individual machines, requires normally a judgement of operating experiences in order to ensure that the design is reliable together with test results.

5.1.3 Exhaust gas emissions

All new gas turbines shall have provisions for easy modifications for future NO_x-reduction systems. Only proven and tested systems shall be used. The reliability shall be documented from other installations.

5.2 Sizing and performance rating

5.2.1 ISO rated power

For mechanical drive turbines, the power output shall be defined at the turbine coupling, before any gearbox losses. For generator drive, the power output shall be defined at the generator terminals, and therefore includes all losses in the unit.

5.2.2 Site rated power

The site rated power is the power delivered by the gas turbine when fitted with inlet filters, inlet and exhaust silencers including waste heat recovery unit (WHRU) when applied, operating at the specified ambient temperature, pressure and humidity for the site. A site rated performance shall be calculated from the manufacturers ISO rated performance using correction curves for the turbines concerned. The pressure losses used for intake and exhaust systems shall be obtained from the supplier for fully fouled and worn conditions.

The **base load rating** shall normally be used. The base load rating is to be based on ambient conditions.

Exceeding base load operating temperatures for short excursions, when the ambient temperature is high, turbine rating can be compensated by running below these temperatures for longer periods when the ambient temperature is low. This **flat rated power** is achieved with no reduction of turbine life or reduction in time between overhauls when compared with an turbine operating continuously at maximum base load output.

Flat rating shall not be used, unless a guaranteed and fixed value on maximum power turbine inlet temperature or firing control temperature can be given.

5.2.3 Power margin between compressor and gas turbine

API 617 specifies that the margin between the greatest power required by the compressor and the rating of a steam turbine or electric motor should be at least 10%.

The power margin for the gas turbine must be sufficient to cover the following contingencies:

1. A 2% tolerance (50% of API 617 para.) on compressor power during testing compared with the guaranteed value.
2. An average compressor deterioration and power reduction of 3% is appropriate for a 'normal' compressor.
3. Gas turbine performance deterioration. The power reduction is estimated to be 7% for an aeroderivative type gas turbine, between the as new condition and the point where the turbine is withdrawn for overhaul.

A minimum margin of 12% (=2+3+7) for aeroderivative gas turbines is required between compressor rated power and the gas turbine site rating to allow for normal service deterioration.

5.2.4 Power margin between electrical generator and gas turbine

The generator performance deterioration is regarded to be negligible.

5.2.5 Gearbox losses

For performance calculations, the gearbox mechanical losses shall be considered as 2.5% of the input power.

6 GAS COMPRESSORS

6.1 Selection of compressor type

The centrifugal compressor type shall be used wherever possible, provided the centrifugal compressor can handle the required flow with a reasonable efficiency.

6.1.1 Reliability, sparing and standardisation

High availability and reliability are considered as primary criteria for selecting this type of machinery.

6.2 Centrifugal compressor

6.2.1 Selection

A compressor selection study shall be made in the conceptual engineering phase i.e. by use of computerised selection programs and data bases. The results from the preliminary selection may include some or all of the following variables:

- Number and types of compressor casings.
- Number of impellers in each casing.
- Rotational speeds.
- Type of seals.
- Frame size.
- Performance data.
- Rating and operating conditions.
- Rotor stability.
- Rotordynamic and aerodynamic behaviour.
- Sparing alternatives.
- Rewheeling strategy.
- Advanced seals and bearings.
- Type of base plate.
- Weight & space requirements.

6.2.2 Compressor design basis and selection criteria

The selected compressor configuration shall be based on the following parameters:

- Polytropic head per impeller shall be limited to 3600 meter.
- To qualify, the vendor should have delivered at least two impellers to identical size to those offered and for these to be operating successfully with the same thermodynamic conditions on a gas of the same molecular weight in one year.
- The maximum number of impellers per casing shall preferably be limited to 8 but shall not exceed 9 for straight through design, and shall not exceed 8 for back to back machines, to keep bearing span to a minimum, and critical speeds as high as possible.
- Gas discharge temperature shall preferably be below 160°C to limit thermal problems.
- Radial split barrel type compressors are required for offshore services irrespective of pressure level.
- Tips speeds should be limited to 270 m/s.
- Compressor blade tip Mach numbers shall preferably be below 0.95. Higher tip Mach numbers may be unavoidable for low pressure compressors handling heavy gases.

6.2.3 Rotordynamic and rotorstability evaluation

For high pressure applications having an average gas density above 50 kg/m^3, an Aerodynamic cross coupling stiffness and log decrement analysis has to be made.

6.2.4 Anti-surge control system selection

The preliminary definition of anti-surge protection strategy shall be made in the conceptual phase based on operating requirements. The anti-surge control system is a protection system and shall not be used as a process control system.

6.2.5 Reciprocating compressors

Reciprocating compressors are selected when the volumetric flow is small and the thermodynamic head is high. For offshore applications it is important to ensure high reliability and ability for the compressor to be controlled automatically/remotely.

The use of gearbox shall be avoided. Where process requirements dictate a variation in flow, capacity control should be achieved preferably by a by-pass loop. Suction valve unloading and clearance pockets may only be used with company approval. For continuous service with varying loads/capacities consideration shall be given to variable speed drivers.

6.3 Screw compressors

Screw compressors should be selected where low pulsations and surge free operation are desirable. The pressure limit is approximately 25 bara. Dry Screw compressors shall be considered where the system characteristic requires a constant volumetric flow between 3000-20000 m^3/h and pressure ratios between 1.3 to 2.5. For higher pressure ratios multi-staging can be considered. Process applications where screw compressors may be selected are:

- When gases contain liquid droplets.
- As vapour blowers.
- Compression of light gases.

Dry type oil free compressors are preferred. Oil of liquid injected compressors shall not be selected for handling hydrocarbon gases.

For oil free helical screw compressors the configuration shall be based on the following criteria:

- Pressure ratio per stage shall be limited to 2.5. For higher pressure ratios extra stages shall be considered.
- Gas discharge temperatures should be limited to 150°C.
- Peripheral speeds for helical screw compressors shall be 50 to 100 m/s.
- Mach. numbers based on suction conditions shall not exceed 0.24.

7 CENTRIFUGAL PUMPS

7.1 Pump selection

A pump selection shall be made during the conceptual phase to establish an optimum pump type and configuration with regards to cost, hydraulic performance, operating efficiency and reliability. Care shall be taken when establishing the pump suction conditions to ensure that adequate NPSH is provided under all operating conditions, including the pump in the worn condition (2xAPI clearance). Variations in flow and/or head requirements or special operating conditions, which can affect the choice of pump and driver, shall be clearly indicated.

Preference shall be given to pumps which incorporate modular construction, to simplify platform on-site maintenance. Barrel type pumps are preferred for multistage pump applications. For pumps in critical service and shaft power exceeding 500 kW, proximity probes for shaft vibration monitoring shall be installed.

7.2 Performance and energy conservation

Equipment efficiencies and utility consumption shall be optimised for pumps with output above 200 kW. For large pump installations, variable speed drivers or transmissions shall always be considered due to energy conservation.

7.3 Transient analysis

Unduly high or low pressures in pipeline systems shall be avoided by means of suitable pressure surge protection devices, such as surge tank stand pipes at intermediate points, breakaway of the liquid column, venting the line downstream from suction tank, etc. On above basis, a transient analysis shall be carried out for the pumping system.

7.4 Requirements to design

For new/unproven pumps larger than 1MW, some or all of the following features shall be verified:

- Bearing design.
- Thrust balance including measurement of residual loads in worktests/field.
- Acceptable vibration levels.
- Calculation methods for rotor dynamics.
- Instrumentation.
- Both accelerometer & proximity sensors to be evaluated.
- Condition monitoring system.
- Stool/baseplate design.
- Preliminary structural design including pump unit.
- Maintenance handling cranes and laydown facilities.

7.4.1 Offshore installations of sea water lift pumps

The various elevations of the pump set, relative to the platform and pump support structure, shall be clearly illustrated on a sketch provided with the pump data sheet. When establishing the required pump submergence, the effect of wave motion, superimposed on LAT (Lowest Astronomical Tide), plus the effects of platform settlement and drawdown shall be taken into consideration.

8 SHAFT-SEALING AND BEARING SYSTEM

8.1 Selection of seals and bearings types

Sealing and bearing systems can be grouped as follows:

- *Wet systems* (lube- and seal oil systems), incl. oil film seals or oil mechanical seals and oil lubricated bearings.

- *Dry systems*, incl. dry running gas seals and magnetic bearings. Active magnetic bearings can be use in conjunction with any gas seals and dry couplings enabling certain compressors to be made oil free.
- *Combination of dry and wet system* with dry running gas seals and oil lubricated bearings. This is the preferred systems for new compressors and shall be considered for all installations. However, a special review shall be on rotordynamics and stability constraints.

8.2 Seal oil systems

If the wet system has to be used, the choice has to be made between separate lube oil system and seal oil system for the compressor train or a combined lube and seal oil system for the complete train. Combined lube and seal oil systems are used for pipeline or other applications compressing clean and sweet dry gas at relatively low pressure where significant contamination of the lube oil does not occur.

Separate seal and lube oil systems are preferable for sour gas with considerable amounts of condensate C_4 and above. By removing the lube oil from the contaminating source, bearing failure due to viscosity reduction shall be avoided. In order to avoid low seal oil flash points, it is normally required to install supplementary degassing facilities when heavy components are present in the gas. An atmospheric degassing tank will generally only release contaminants up to C_3, and supplementary degassing facilities are required for C_4 plus removal. Two principal routes have been found to be effective:

1. Vacuum reclamation.
2. Gas sparging.

8.3 Dry gas seal for compressors

Compressor seals and sealing systems shall be selected based on the availability and proven technology, with the objective to have the most cost effective solution. Triple seals shall only be used where strictly necessary, for example due to very high pressures. In such cases, an extensive rotor dynamic evaluation shall be agreed with company.

O-ring materials shall be evaluated for high pressures and rapid decompressions. For pressures above 100 bara alternative materials to standard elastomer O-rings shall be evaluated. Seal type and system shall be proven by at least two comparable operating references.

The seal must be able to withstand seal pressure fluctuations down to under atmospheric. If backwards rotation can occur, it is required to select a seal which has the ability to rotate in both directions.

8.3.1 Settle-out pressure, shaft seals and oil systems

Settle-out pressure and off-design process pressure conditions, which occur during start-up, shutdown and upset must be defined on the compressor data sheet.

8.4 Magnetic bearings

Initial design studies for installation and rotor dynamic analysis shall be made if magnetic bearings are arranged.

9 DRIVER TRAIN TRANSMISSION

9.1 Transmissions with speed control

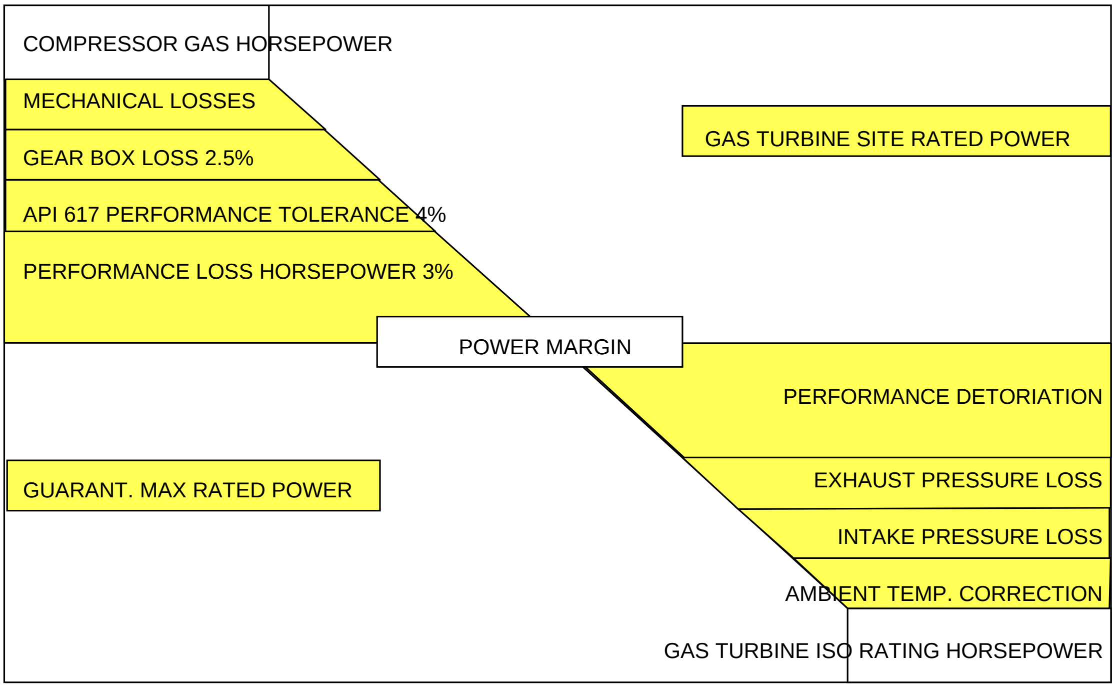
Combined hydraulic torque converter and planetary gear units are acceptable for moderate powers/speeds up to 10000 kW/12000 rpm. 2 types of gear/coupling units with speed control shall be considered:

1. Hydrodynamic torque converter, or variable speed hydrodynamic coupling efficiency.
2. A combined superimposing planetary gear and a hydrodynamic torque converter (or an external motor/pump) which activates the gear. The efficiency is high.

The selection shall be based on evaluation of the following aspects:

- A compact unit design with integrated gear stage.
- Motor starting under no load - stopping of the turbocompressor while the motor continues to run (rapid emptying).
- Variable speed control range.
- Damping of shock loads through hydrodynamic power transmission.
- Use of standard mineral oils as working medium.
- Efficiency.

Figure 1: Diagram presentation of power margin between gas turbine and compressor



10 WASTE HEAT RECOVERY UNITS (WHRU)

10.1 WHRU Selection

WHRU's for gas turbines are used for the following applications:

Simple heat recovery:	Heat generation in a closed loop heating medium system.
Cogeneration:	Steam generation for utility and/or process use.
Combined cycle:	Combined heat and power generation.

Firetube units are mainly applied for diesel (or duel flue) engines, and for high pressure processes. These units may operate with process gas streams up to 30 barg and 1200°C, and heating medium pressure up to 120 barg. Firetube units may be used where gas leakage must be eliminated, and where purity of the steam is not critical.

Watertube units are very flexible. The units may be composed of vertical or horizontal tubes with natural or forced circulation. Watertube units may handle high heating medium pressures and are suitable for very high gas flow rates.

A multiple pressure boiler design is applicable only for very large combined cycles or special cogeneration cases. For preliminary calculations the following figures may be used:

Pinch point:	20°C
Approach temp. (eco):	12°C
Approach temp. (SH):	30°C

Surface area and pinch point are subject for optimisation with respect to pressure drop, weight and thermal efficiency. WHRU's shall be have their dedicated heater within the heating medium system. Induct burners upstream of waste heat boilers shall only be used with approval.

10.2 Functional requirements

Thermal design shall be based upon the available waste heat for all operating modes accounting for variations to ambient conditions, number of engine units operating and range of output.

WHRU shall not be designed for running dry. A by-pass system with required automatic dampers shall be installed and is used when WHRU is out of operation.

For dual flue gas turbines, consideration must be given to the minimum flue gas temperature to avoid acid condensation on the heating surfaces.

10.3 Supplementary firing

Duct burners may raise the temperature to 700-750°C, and increase the duct draught loss moderately. *Intertube burners* may raise the temperature to 1200-1400°C. The draught loss is higher than for a duct burner. *Register/Rejector burners* require a furnace, and may be duel-flue. Only proven burner technology shall be applied

The NO_x emission shall be reduced by using low-NO_x burner technology such as:

- Staged combustion (staged air or staged flue).

- Divided air supply combined with swirl to enhance turbulence.
- Internal or external flue gas recirculation.

11 HEAT EXCHANGERS

11.1 Shell and tube heat exchangers

11.1.1 Maintenance aspects

Special consideration shall be given to determine if the heat exchanger shall be located in a horizontal or vertical position due to maintenance and inspection requirements. Space for tubebundle withdrawal, access for platform crane, inspection requirements may also affect the choice of heat exchanger type.

11.1.2 Tubeside and shellside fluid allocation

The criteria for fluid allocation shall be:

- The most corrosive to be tubeside.
- The higher pressure fluid to be tubeside.
- Severe fouling fluids shall be allocated the side which is accessible.
- Shellside boiling or condensation is usually preferred.
- Specific pressure drop.

When pressure drop is critical, shellside flow is preferred as baffle arrangement can be adjusted to fit specified pressure drop.

11.1.3 Pressure drop

For initial sizing purposes maximum allowable pressure drop shall be:

- 0.5 bar for recompression gas coolers.
- 1.0 bar for medium to high pressure gas coolers.
- 1.0 bar for liquids.

11.1.4 Fixed tubesheet type/shell and tube exchanger

Fixed tubesheet heat exchanger, is the preferred type when operating conditions allow this design. Limiting factors are shellside fouling conditions and differential temperature between the tubes and the shell during normal operation, start up, shut down or other conditions. Multiple tubeside passes shall be avoided

Tube to tubesheet joints shall be checked for expansion stresses. As a guide metal temperature difference of 50°C can usually be accommodated.

11.1.5 U-Tube type

As the U-bends internally are not accessible for mechanical cleaning, fluid subject to fouling shall not be on the tube side. TEMA BEU-type is preferred for gas cooling and heating duties with cooling- or heating medium on the shellside.

11.1.6 Internal floating head type

There is no limitation in temperature difference between tubeside and shellside streams. Split ring (S-type) type and floating head is preferred due to less tube bundle by-pass. Shell and tube heat exchanger with internal floating head design is suitable for fouling service combined with large temperature differences. This design is preferred for crude heating duties.

11.2 Plate heat exchangers

For moderate design temperatures/pressures and liquid cooling/heating purposes PHE offer a favourable design with regard to investment cost, heat transfer area, flexibility, space and weight requirements. Thermal design is normally performed by the vendors, however different cooling/heating medium flow rates shall be evaluated. Approach temperature as small as 5°C is normal. Additional heat transfer area to cover fouling shall be: 20%

Plates welded to form cassettes are not accessible for manual cleaning so the fluid should be non-fouling. The risk of scaling should also be considered.

Typical applications are cooling medium cooling and crude cooling with seawater coolant. Welded plates should be considered for crude coolers operating at the upper pressure limit. Semiwelded and fully welded plates should be considered for gas cooling. Utility cooling like lube oil cooling is normally performed in plate heat exchangers.

11.3 Matrix type heat exchangers (Compact heat exchangers with bonded plates)

Compact heat exchangers with bonded plates have no gaskets or tightening bolts i.e. a single material construction. They are capable of withstanding very high pressures and temperatures. Special care shall be taken to avoid fatigue introduced cracking of the core, due to pressure variations.

Due to small passages they should be used in clean service only. Devices for chemical injection are recommended. Matrix heat exchangers are suitable for high pressure gas cooling and for high pressure liquids. They are of special interest for process integration purposes as several heating/cooling duties can be accommodated in one unit.

When one of the media to be used is hydrocarbon gas, special consideration shall be given for the hydrate temperature. If the heat exchanger is cooled with sea water, special considerations shall be given for hydrate formation and scaling.