Section 10

Fluid Equipment

10.1 Turbines

Both steam and gas turbines are in common use for power generation and propulsion. Power ranges are:

Steam turbines	*Gas turbines*
Coal/oil generation: Up to 1000 MW	Power generation: Up to 230 MW
Nuclear generation: Up to 600 MW	Aircraft: Up to about 30 MW
Combined cycle application: Up to 30 MW	Warships: Up to about 35 MW
	Portable power units: Up to about 5 MW

Both types are designed by specialist technology licensors and are often built under licence by other companies.

Table 10.1 Gas turbine propulsion terminology

Gas turbine (GT)	Engine comprising a compressor and turbine. It produces jet thrust and/or shaft ‘horsepower’ output via a power turbine stage.
Turbojet	A GT which produces only jet thrust (i.e. no power turbine stage). Used for jet aircraft.
Turboprop	A GT that produces shaft output and some jet thrust. Used for propeller-driven aircraft.
Afterburner	A burner which adds fuel to the later stages of a GT to give increased thrust. Used for military aircraft.
Pulse-jet	A turbojet engine with an intermittent ‘pulsed’ thrust output.
Ramjet	An advanced type of aircraft GT which compresses the air using the forward motion (dynamic head) of the engine.
Rocket motor	A ‘jet’ engine that carries its own fuel and oxygen supply. Produces pure thrust when there is no available oxygen (e.g. space travel).

Engineers’ Data Book, Fourth Edition. Clifford Matthews.

USEFUL STANDARDS

Steam turbines

1. API 611: 2008: General purpose steam turbines for refinery services (American Petroleum Institute).
2. API 612: 2003: Special purpose steam turbines for refinery services (American Petroleum Institute).
3. ANSI/ASME Performance Test Code No 6: 2004 (American Society of Mechanical Engineers).
4. BS EN 60953: 1996: Rules for steam turbine acceptance tests.
5. BS EN 60045-1: 1993: Guide to steam turbine procurement.
6. BS EN 45510-5-1: 2008: Steam turbines.

Gas turbines

1. BS 3863: 1992 (identical to ISO 3977: 1991): Guide for gas turbine procurement.
2. BS 3135: 1989 (identical to ISO 2314): Specification for gas turbine acceptance test.
3. ANSI/ASME Performance Test Code 22: 2005 (The American Society of Mechanical Engineers).
4. API 616: 1998: Gas turbines for refinery service, (American Petroleum Institute).
5. BS ISO 11042: 1996: Gas turbines – exhaust gas emissions.
6. BS ISO 11086: 1996: Gas turbines – vocabulary.
7. BS EN 45510-5-2: 2001: Gas turbines.

10.2 Refrigeration systems

The most common industrial refrigeration plant operates using a vapour compression refrigeration cycle consisting of the standard components of compressor, evaporator, expansion valve, and condenser connected in series.

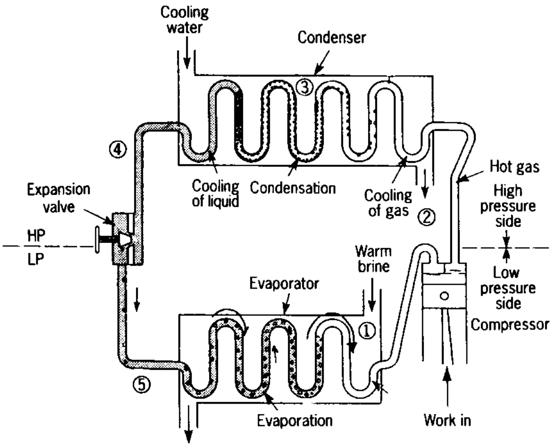

Figure 10.1

The process can be shown on $T-s$ or $P-v$ cycle charts.

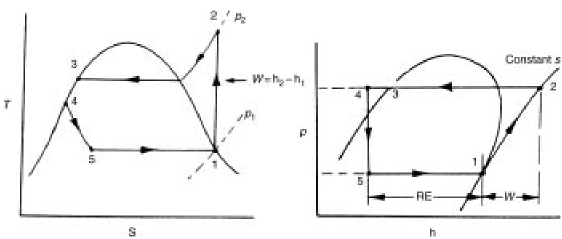

Figure 10.2

Performance characteristics are:

- Refrigerating effect $= \text{RE} = h_1 - h_5$
- Coefficient of performance $(\text{COP}) = \dfrac{\text{RE}}{W} = \dfrac{\text{RE}}{h_2 - h_1}$

Common refrigerants such as R12 and R22 still use halogenated hydrocarbons. These are being replaced with other types because of environmental considerations.

USEFUL STANDARDS

1. BS 3122: Part 1: 1990: Refrigerant compressors – methods of test for performance (similar to ISO 917).
   Part 2: 1990: Methods for presentation of performance data (similar to ISO 9309).
2. BS EN 378-1: 2008: Specification for refrigeration systems and heat pumps. Safety and environmental requirements.
3. BS 4434: 1995: Specification for safety and environmental aspects in the design, construction and installation of refrigeration appliances and systems.

10.3 Diesel engines

10.3.1 Categories

Diesel engines are broadly divided into three categories based on speed.

Table 10.2

Designation	*Application*	*(Brake) Power rating (MW)*	*Rpm*	*Piston speed (m/s)*
Slow speed (2 or 4 stroke)	Power generation, ship propulsion	Up to 45	<150	<9
Medium speed (4 stroke)	Power generation, ship propulsion	Up to 15	200–800	<12
High speed (4 stroke vee)	Locomotives, portable power generation	Up to 5	>800	12–17

10.3.2 Performance

Performance criteria are covered by manufacturers' guarantees. The important ones, with typical values are:

Maximum continuous rating (MCR): 100 percent
Specific fuel consumption: 220 g/kW h (brake)
Lubricating oil consumption: 1.5 g/kW h (brake)
NO_x limit: 1400 mg/Nm^3

Note that many of these vary with the speed and load of the engine.

USEFUL STANDARDS

The main ones covering diesel engine design, testing and performance are:

1. ISO 3046: Reciprocating internal combustion engines: performance.
   This is identical to BS 5514. It contains the following parts (separate documents):
   ISO 3046/1: Standard reference conditions
   ISO 3046/2: Test methods
   ISO 3046/3: Test measurements
   ISO 3046/4: Speed governing
   ISO 3046/5: Torsional vibrations
   ISO 3046/6: Overspeed protection
   ISO 3046/7: Codes for engine power

10.4 Heat exchangers

Heat exchangers can be classified broadly into parallel and counterflow types. Similar equations govern the heat flow. The driving force is the parameter known as log mean temperature difference (LMTD).

For the parallel flow configuration

$$LMTD(\theta_{\mathrm{m}}) = \frac{\theta_1 - \theta_2}{\ln \theta_1/\theta_2}$$

where:

U = overall heat transfer coefficient (W/m^{2}K)
A = tube surface area (m^2)
θ = temperature difference (°C)
Heat transferred, $q = UA\theta$ (Watts)

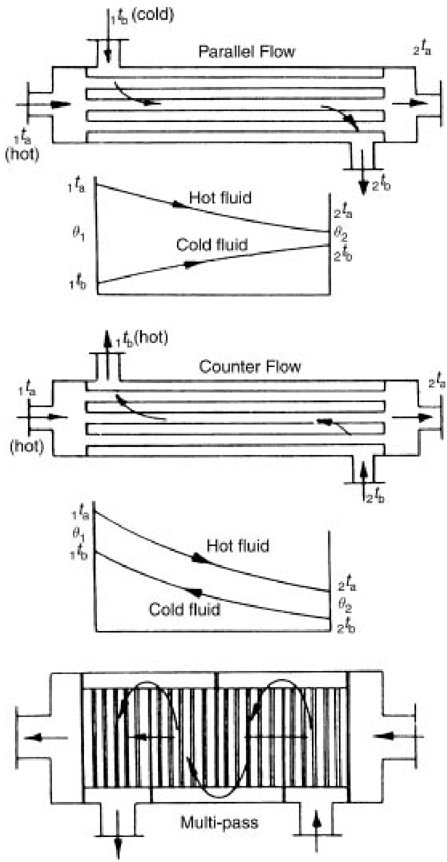

Figure 10.3

For counterflow the same formulae are used.

For more complex configurations, such as cross flow and multi-pass exchangers, LMTD is normally determined from empirically derived tables.

Useful Standards

1. TEMA: 2007: Standards for design and construction of heat exchangers (Tubular Exchangers Manufacturers Association).
2. BS 853 Part 2: 1996: Tubular heat exchangers and storage vessels for buildings and industrial services.
3. BS 2871 Part 3: 1971: Tubes for heat exchangers.
4. BS EN 3274: 1998: Specification for tubular heat exchangers for general purposes.
5. BS 3606: 1992: Specification for steel tubes for heat exchangers.
6. BS EN 247: 1997: Heat exchangers – terminology.

10.5 Centrifugal pumps

Pumps are divided into a wide variety of types. The most commonly used are those of the dynamic displacement type. These are mainly centrifugal (radial) but also include mixed flow and axial types. The performance of a pump is mainly to do with its ability to move quantities of fluid. The main parameters are:

- Volume flowrate, q_ν (m^3/s).
- Mass throughput, q_m (kg/s).
- Head, H (m). This represents the useable mechanical work transmitted to the fluid and is measured in metres. Together, q and H define the *duty point* of a pump – a key part of its acceptance guarantee.
- Pump efficiency, η (%) is a measure of the efficiency with which the pump transfers useful work to the fluid.

$$\eta = \frac{\text{pump power output}}{\text{pump power input}} = \frac{q_m g H}{\text{pump power input}}$$

For most centrifugal pumps the q/H characteristics are as shown.

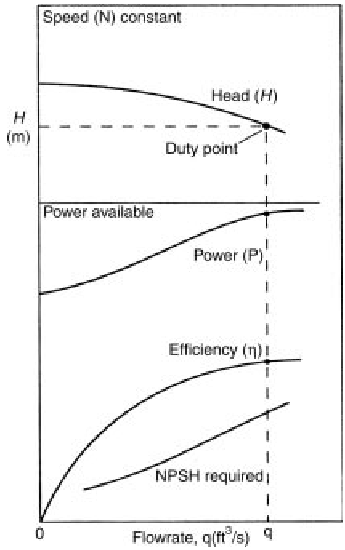

Figure 10.4

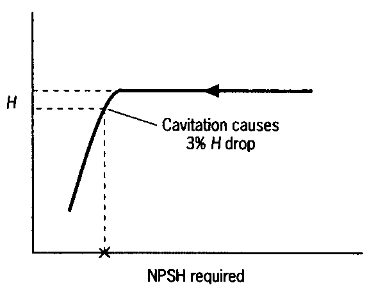

Figure 10.5

A further performance requirement of a centrifugal pump is its net positive suction head (NPSH), a measure of suction performance at various volume throughputs.

The hydrodynamic performance of centrifugal pumps is covered by the equation:

$$\text{Total head, } H = Z_2 - Z_1 + \frac{p_2 - p_1}{\rho g} + \frac{v_2^2 - v_1^2}{2g}$$

where

$Z =$ distance to a reference plane
$\rho =$ density
$g =$ acceleration due to gravity

$$\text{NPSH} = H_1 + \frac{P_{\text{atmos}}}{\rho g} - \frac{\text{vapour pressure}}{\rho g}$$

where

$$H_1 = \frac{p_1}{\rho g} + Z_1 \frac{v_1^2}{2g}$$

10.6 Impeller types

The impeller shape used in a pump is related to the pump's efficiency and a dimensionless 'specific speed' (sometimes referred to as 'type number') parameter which is a function of rotational speed, q_v and H. Figure 10.6 shows approximate design ranges.

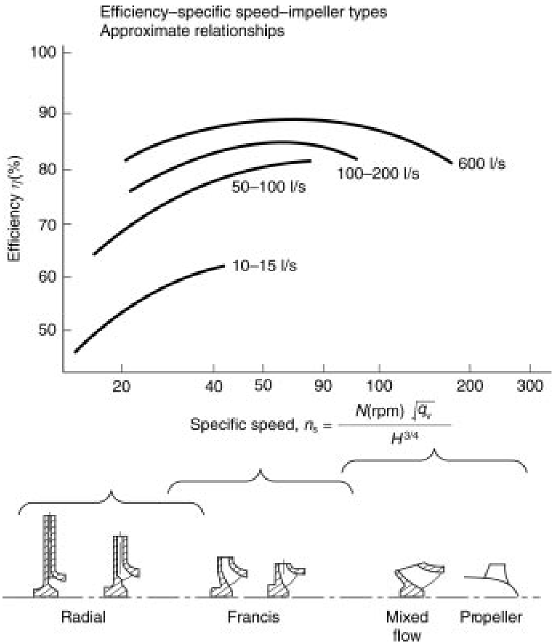

Figure 10.6

Useful Standards

1. ISO 2548: 1973: (is identical to BS 5316) Part 1: 1976: Specification for acceptance tests for centrifugal mixed flow and axial pumps – Class C tests.
2. ISO 3555: 1977: (is identical to BS 5316) Part 2: 1977: Class B tests.
3. ISO 5198: 1999: Precision class tests.
4. DIN 1944: Acceptance test for centrifugal pumps (VDI rules or centrifugal pumps) (Verein Deutscher Ingenieure).
5. API 610: 10th Edition, 2011: Centrifugal pumps for general refinery service (American Petroleum Institute).
6. BS 5257: 1975: Specification for horizontal end-suction centrifugal pumps (up to 16 Barg).
7. ISO 5199: 2002: Technical specifications for centrifugal pumps – Class 2.