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Specification for

Testing of positive displacement compressors and exhausters —

Part 2: Methods for simplified acceptance testing for air compressors and exhausters

UDC 621.512:620.1

Co-operating organizations

The Mechanical Engineering Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and professional and industrial organizations:

Associated Offices Technical Committee*
Association of Consulting Engineers*
Association of Hydraulic Equipment Manufacturers Ltd.
Association of Mining Electrical and Mechanical Engineers
British Compressed Air Society*
British Electrical and Allied Manufacturers' Association*
British Gas Corporation*
British Gear Manufacturers' Association
British Internal Combustion Engine Manufacturers' Association
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British Steel Corporation
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The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard.

British Chemical Engineering Contractor's Association
CBMPE
Contractors' Plant Association
Institute of Marine Engineers
Institute of Mining and Metallurgy
Institution of Mining Engineers
South Wales Institute of Engineering
Individual experts

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Foreword

BS 1571 was first published in 1949 under the title "Acceptance tests for positive-displacement compressors and exhausters" and this is the second Part of the metric revision.

The revision is published in two Parts, Part 1 "Acceptance tests" and Part 2 "Simplified acceptance tests for air compressors and exhausters", and it covers the specifications previously contained in BS 726 "Measurement of air flow for compressors and exhausters" and BS 1571, both of which will now be withdrawn.

This Part of the standard complies with annex A of Part 1:1987 and specifies the conditions under which an air compressor or exhauster can be tested provided that a compressor or exhauster of the same series has already been type tested in accordance with Part 1 of this standard.

Such tests will generally be necessary to verify guarantees given for one or more of the following particulars:

a) capacity;

b) shaft input power or specific energy consumption;

c) speed.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 20, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

1.1 General. This standard specifies acceptance tests for positive displacement air compressors and exhausters, the absolute intake pressures of which exceed approximately 1 mbar[1]. In establishing the scope of this standard a positive displacement compressor is considered as a machine where a static pressure rise is obtained by allowing successive volumes of air to be aspired into and exhausted out of an enclosed space by means of the displacement of a moving member. The standard applies to such machines as reciprocating and rotary compressors.

1.2 Guiding principles

1.2.1 Only those measurements necessary to verify any guarantee given by the manufacturer to the purchaser shall be taken, together with any other observations called for when placing the contract or as may be subsequently agreed between the purchaser and the manufacturer.

1.2.2 The test conditions shall be as close as is reasonably possible to the guarantee conditions, and deviations from these shall not exceed the limits specified below:

speed ± 5 %,

absolute intake pressure ± 5 %,

temperature of cooling water ± 8 °C,

pressure ratio ± 1 %.

Where it is not feasible to test a machine within the limitations specified above, special conditions of test or special corrections shall be agreed between the purchaser and the manufacturer.

1.2.3 The compressor on test will be deemed to be acceptable provided the results obtained do not differ from the type test results by more than the allowances given in Table 1.

The need for simplified tests at other than full capacity shall be the subject of agreement between the manufacturer and the purchaser.

2 References

The titles of the British Standards referred to in this standard are listed on the inside back cover.

3 Definitions

For the purposes of this British Standard the following definitions apply.

3.1
total pressure

the pressure measured at the stagnation point when a moving air stream is brought to rest and its kinetic energy is converted by an isentropic compression from the flow condition to the stagnation condition. It is the pressure usually measured by a pitot tube. In a stationary body of air the static and the total pressures are numerically equal

3.2
static pressure

the pressure measured in such a manner that no effect on measurement is produced by the air velocity

3.3
dynamic (velocity) pressure

the total pressure minus the static pressure

3.4
atmospheric pressure

the absolute pressure of the atmosphere measured at the test place

3.5
gauge (effective) pressure

the pressure measured above the atmospheric pressure

[1] 1 mbar = 10^2 N/m^2 = 0.1 kPa.

3.6

absolute pressure

the pressure measured from absolute zero, i.e. from absolute vacuum. It equals the algebraic sum of atmospheric pressure and gauge pressure

3.7

vacuum

the difference between the atmospheric pressure and the absolute pressure when the latter is the smaller

Table 1 — Capacity and specific energy consumption: tolerances for simplified test

Compressor shaft input at normal load	100 % capacity		50 % capacity		
	Capacity	Specific energy consumption	Capacity	Specific energy consumption	No load power
	%	%	%	%	%
Below 10 kW	± 6	± 7	—	—	± 20
10 kW to 100 kW	± 5	± 6	± 7	± 7	± 20
Above 100 kW	± 4	± 5	± 5	± 6	± 20

3.8

standard inlet point

the inlet point considered representative for each compressor. This point varies with compressor design and types of installation

NOTE 1 The standard inlet point of a stationary compressor is generally at the inlet flange.

NOTE 2 The standard inlet point of a portable compressor is a point close to the compressor chosen so that the thermometer is unaffected by the compressor operation.

3.9

standard discharge point

the discharge point considered representative for each compressor. This point varies with compressor design and type of installation

NOTE 1 The standard discharge point of a stationary compressor is generally at the compressor discharge flange.

NOTE 2 The standard discharge point of a portable compressor is the outlet valve on the air receiver.

3.10

inlet pressure

the average absolute total pressure at the standard inlet point

NOTE The absolute total pressure may be replaced by the absolute static pressure if it can be shown that the effect on the test results is insignificant in relation to the accuracy of testing.

3.11

discharge pressure

the average absolute total pressure at the standard discharge point

NOTE The absolute total pressure may be replaced by the absolute static pressure if it can be shown that the effect on the test results is insignificant in relation to the accuracy of testing.

3.12

pressure ratio

the ratio of the discharge pressure to the inlet pressure

NOTE 1 Stage pressure ratio is the pressure ratio for any particular stage in a multistage compressor, the discharge pressure being taken before the intercooler.

NOTE 2 The overall stage pressure ratio is the pressure ratio for any particular stage in a multistage compressor, the discharge pressure being taken after the intercooler (including separators).

3.13

total temperature

the temperature that would be measured at the stagnation point if the air stream were brought to rest and its kinetic energy converted by an isentropic compression from the flow condition to the stagnation condition

3.14
inlet temperature

the total temperature at the standard inlet point of the compressor

3.15
discharge temperature

the total temperature at the standard discharge point of the compressor

3.16
free air

air at the atmospheric conditions of the site and unaffected by the compressor

3.17
capacity of a compressor. (Free air delivered, F.A.D.)

the actual volume rate of flow of air compressed and delivered at the standard discharge point, referred to conditions of total temperature, total pressure and composition (e.g. humidity) prevailing at the standard inlet point.

3.17.1
capacity of a vacuum pump

the actual volume rate of flow of air aspired and compressed by the first stage of a vacuum pump and referred to conditions of total temperature, total pressure and composition (e.g. humidity) prevailing at the standard inlet point

NOTE It is normally assumed that the final stage of the vacuum pump discharges to a pressure of 1 bar[2)] absolute.

3.18
shaft input power (absorbed power)

the power required at the compressor drive shaft. Losses in external transmissions such as gears and belt drives are not included

4 Units and symbols

4.1 General. For the purposes of this standard the units, symbols and subscripts of **4.2** and **4.3** apply. The list takes into account the following requirements.

a) The same symbols shall be used for the same quantities regardless of the units used.

b) For any one quantity a single symbol shall be used with subscripts added to indicate all values other than the primary one.

c) The same symbols shall be used for a given concept regardless of the number of special values which occur.

d) Letter subscripts shall be used to denote values under special conditions.

e) Numerical subscripts shall be used to denote values at different points of a cycle.

f) In general, capital letters denote absolute quantities, unless there are other overriding considerations.

4.2 Units and symbols

Symbol	Description	Unit
h	Nozzle pressure drop	mmH_2O
p	Pressure	bar (in mm Hg for **9.5.2**)
P	Power	W, kW
q	Capacity (volume rate of flow, F.A.D.)	litre/s
T	Thermodynamic temperature, absolute temperature	K
t	Temperature	°C

[2)] 1 bar = 10^5 N/m^2 = 100 kPa.

4.3 Subscripts

0 : condition of ambient atmosphere
1 : condition at standard inlet point
2 : condition at standard discharge point
c : condition of contract (condition of guarantee)
corr: corrected
m : measured conditions
w : condition of cooling water

5 Measuring equipment and methods

5.1 Measurement of temperature

5.1.1 *Methods*

5.1.1.1 In general, mercury-in-glass thermometers with etched stems, graduated with scales suitable for the measurements to be made, shall be employed for all measurements.

5.1.1.2 Commercial or industrial metal-encased thermometers shall not be used.

5.1.1.3 The thermometers shall be inserted directly into the air stream or, when this is not applicable, small thermometer pockets of thin steel tube shall be used. The pockets shall be clean and free from corrosion or oxide. They shall normally be filled with oil; if the temperature is likely to cause evaporation of the oil, mercury shall be used. Where the oblique position of the pockets does not allow liquid filling, copper-powder may be used. The thermometers or the pockets shall extend into the pipe a distance of 100 mm or one third the diameter of the pipe, which ever dimension is the less (see also **9.4.5**).

5.1.1.4 In taking readings, the thermometer shall not be lifted out of the medium being measured, or out of the pocket, when such is used.

5.1.1.5 All thermometers shall be calibrated for their appropriate temperature range.

5.1.1.6 Other methods of temperature measurement may be used and are described in BS 1041.

5.1.2 *Precautions to be observed.* Precautions shall be taken to ensure that:

a) no appreciable quantity of heat is transmitted by radiation or conduction to or from the thermometer, other than that of the medium being measured;

b) the immediate vicinity of the point of insertion and the projecting parts of the connection are well insulated, so that the pocket is sensibly at the same temperature as the medium being measured;

c) the sensitive part of any thermometer or of the thermometer pocket is well swept by the air;

d) the air velocity does not exceed 30 m/s at the point of measurement.

5.2 Measurement of pressure

5.2.1 *Normal and high pressures*

5.2.1.1 For pressures above 2 bar[3)] abs., calibrated Bourdon gauges or dead-weight gauges, mercury manometers or their equivalent shall be employed.

5.2.1.2 Diaphragm gauges shall not be employed.

5.2.1.3 The Bourdon gauges selected shall be of such size that 1 % pressure difference can easily be read and that the pressures to be read shall be between one quarter and three quarters of the total scale reading. Bourdon gauges shall be calibrated at frequent intervals against standard dead-weight test gauges and the calibration certificates shall be made available for inspection.

5.2.2 *Low pressures*

5.2.2.1 For all pressures of 2 bar abs. or below, manometers, columns or vacuum gauges shall be employed.

5.2.2.2 Closed mercury columns known as absolute vacuum gauges should not be used.

3) 1 bar = 10^5 N/m^2 = 100 kPa.

5.2.2.3 Manometers or columns for low pressure measurements should comprise glass tubing of not less than 10 mm bore for single-limb type and not less than 6 mm bore for the double-limb U-type, and with a scale clearly graduated to allow the column to be read within 1.0 mm.

5.2.2.4 Exhauster inlet pressure measurements may be determined by means of columns or manometers.

5.2.2.5 Exhauster inlet pressures shall be measured as close as possible to the inlet flange of the machine in a straight length of pipe.

5.2.2.6 In sloping-limb and other amplifying instruments, the relation between the scale readings and the true inches water column should have been determined previously by calibration against an absolute manometer of suitable sensitivity. The inclination to the horizontal and the density of the manometer liquid should be the same as for the calibration.

5.2.3 *Connections*

5.2.3.1 Connecting piping shall be not less than 6 mm bore for pressure gauges and not less than 10 mm bore for vacuum gauges to minimize the effect of capillarity in the piping.

5.2.3.2 The gauges shall be mounted in a position free from vibration.

5.2.3.3 In cases of pulsating flow, a receiver with an inlet throttling hole shall be provided between the pressure tapping and the pressure measuring instrument.

5.2.3.4 Connecting piping to pressure gauges and manometers shall be as short as possible. The air tightness shall be tested with soap solution and all leaks eliminated.

5.2.3.5 The pressure tapping of the pipe or receiver shall be normal to, and flush with, the inside wall.

5.2.4 *Precautions to be observed*

5.2.4.1 Care shall be taken that the manometer leg subject to atmospheric pressure cannot be influenced by any local atmospheric condition differing from that to which the barometer is subjected.

5.2.4.2 If conditions obtained at the point of measurement vary appreciably from normal than the pressure reading shall be corrected for the following.

a) Temperature, to reduce the mercury reading to the value which would obtain at 0 °C.

b) Gravity, to reduce the reading to the value which would obtain if gravity at the location of the instrument had the international standard value of 9.807 m/s^2.

c) If there is a difference in elevation between the position of the barometer used and the mercury column or manometer, the barometer shall be corrected for this difference, having first been corrected for instrument error, if any.

5.3 Measurement of air flow. The selection of nozzle and calculation of the air flow shall be carried out in accordance with clause **9** of this Part of this standard.

Methods of flow measurement shown in Part 1 of this standard may be used. If other methods of flow measurement are used these should be agreed between the purchaser and the manufacturer and are outside the scope of this test code.

5.4 Measurement of speed. The speed shall be measured at the compressor shaft by tachometer, speed counter, or stop watch and revolution counter. When a tachometer or speed counter is used it shall be checked for accuracy at frequent intervals.

5.5 Measurement of power

5.5.1 If the specified power consumption is that at the input to the driving unit it shall be determined in accordance with the appropriate British Standard as follows:

hydraulic	BS 353	electrical	BS 2613
oil engine	BS 649	gas engine	BS 3109
steam turbines	BS 752		

5.5.2 When the specified power consumption of the machine is that at its coupling, it may be determined by one of the following.

a) An electric motor, the efficiency of which has been determined in accordance with BS 2613.

b) A dynamometer. Cradle electric dynamometers shall not be used below one tenth of their rated torque.

Torsion dynamometers shall not be used below one third of their rated torque. They shall be calibrated after the test with the torsion member at the same temperature as during the test. The calibration shall be conducted with the indicating means in place. Indicator readings shall be made with a series of increasing loads with the precaution that, during the taking of readings with increasing loads, the load shall at no time be decreased.

Similarly, when readings are made with decreasing loads, the load shall at no time be increased. The calculation of output shall be based on the average of the increasing and decreasing loads as determined by the calibration. If the torque difference between increasing and decreasing loads exceeds 1 % the dynamometer shall be considered unsuitable.

c) A driving unit, which has previously been tested in accordance with one of the British Standards mentioned in **5.5.1**.

5.5.3 Where any intermediate form of power transmission, such as a belt drive or gear box, is interposed between the driving unit and the machine, its power consumption shall be taken into account.

5.5.4 As a basis for the efficiency of the transmission the following figures shall be used unless other reliable information is available:

for properly lubricated precision gears:	98 % for each step
for flat belts:	97 %
for V-belt drive	95 %.

5.5.5 When the power consumption is specified in terms of the power supply to the driving unit, allowance shall be made for any variations in its performance due to differences between test and guarantee conditions.

5.5.6 When the power consumption is specified and the test has to be carried out at reduced power, error will be introduced into the corrected power consumption because of those losses which are not strictly proportional to the total power. If possible an agreed correction should be made for these errors.

6 Arrangement of tests

6.1 General

6.1.1 The arrangement of tests, the test method and the necessary instruments to be used shall be agreed between the purchaser and the manufacturer (see Figure 1 to Figure 4 for diagrammatic arrangements of test layouts). Any special conditions shall be recorded.

6.1.2 It is recommended that a preliminary test should be made for the purpose of checking the test arrangements, instruments and methods of testing under working conditions. The machine to be tested shall be in a satisfactory working condition and the test mains shall be free from leakage. The loading and other test conditions shall be maintained reasonably constant, the governing mechanism shall be maintained in its normal working position and the actual test shall not be commenced until the machine has reached steady working conditions.

6.2 Barometric pressure. The barometric pressure shall be determined by means of a mercury-in-glass barometer. It is permissible to secure a reading, taken at the time of the test, from a local recognized weather bureau provided that a suitable altitude correction is made.

6.3 Cooling water quantity. If the quantity of cooling water is guaranteed it shall be measured in accordance with BS 599.

If the temperature rise of the cooling water is guaranteed it shall be measured by means of thermometers inserted at the inlet and outlet cooling water branches to the machine. Where cooling is effected in stages the inlet cooling water temperature shall be measured in the branch supplying all coolers, and the outlet cooling water temperature shall be measured at the branch accepting the outlet water from all coolers.

7 Test procedure

7.1 General

7.1.1 Preliminary tests should be undertaken for the purposes of:

a) determining whether the compressor and associated systems are in a suitable condition for an acceptance test to be conducted;

b) checking of instruments;

c) training of personnel.

7.1.2 After a preliminary test has been made, this test may, by agreement, be considered the acceptance test, provided that all requirements for an acceptance test have been met.

7.1.3 The governing mechanism shall be maintained in its normal working position.

7.1.4 During the test, the lubricant, the adjustment of the lubricating pumps, lubricators or other lubricating means shall comply with the operating instructions.

7.1.5 During the test no adjustments other than those required to maintain the test conditions and those required for normal operation as given in the instruction manual shall be made.

7.1.6 Before readings begin, the compressor shall be run long enough to assure that steady state conditions are reached so that no systematic changes occur in the instrument readings during the test.

8 Test report

It is recommended that the following type of report should be adopted.

Report

on the trial of a ....

at ....

made at the request of ....

under the direction of ....

on ....

Signature of the engineer directing the test ....

Date ....

The test report should include the following information.

General information

a) Type of machine; e.g. if reciprocating whether:

1) vertical or horizontal,

2) single- or double-acting,

3) cylinders are air or water cooled,

4) intercooled or aftercooled,

5) single-stage, two-stage or multi-stage.

b) Manufacturer's name and number.

c) Date of manufacture.

d) [4]Type of prime mover.

e) [4]Name of manufacturer of prime mover and its number if applicable.

f) [4]Type of speed increasing or reducing gear (if fitted).

g) [4]Name of manufacturer of speed gear and its number.

h) [4]Type of coupling, if any, used for the test.

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[4] This information relates to equipment used during the test and this may not necessarily be that which is supplied with the compressor or exhauster.

Guaranteed performance on test and/or performance on type test

a) Specified intake pressure and temperature.

b) Capacity (F.A.D.).

c) Delivery pressure.

d) Power consumption.

e) Speed.

f) Any other requirements of the standard, e.g. quantity of cooling water or temperature rise of cooling water.

Test observations. Only those measurements necessary to verify any guarantee given by the manufacturer to the purchaser shall be taken, together with any other observations called for when placing the contract or as may be subsequently agreed between the purchaser and the manufacturer.

a) Diameter of nozzle (mm).

Where the diameters and lengths of upstream and downstream pipes do not conform to clause **9**, the fact should be recorded.

b) Speed (rev/min).

c) Barometric pressure (mmHg).

d) Pressure at intake (absolute) (bar[5)]).

e) Pressure drop across nozzle (mmH_2O).

f) Pressure on downstream side of nozzle (mmHg).

g) Pressure at delivery (absolute) (bar).

h) Temperature of air at intake (°C).

i) Temperature of air at nozzle (°C).

j) Power consumption.

k) Any other observations that are required to verify a guarantee quantity of cooling water, inlet and outlet temperatures of cooling water, etc.

Results derived from observations

a) Nozzle constant.

b) Capacity (F.A.D.). This to be calculated in accordance with clause **9**.

Adjustment of results to guaranteed conditions

a) Corrected capacity (F.A.D.)

$$= \frac{\text{test F.A.D.} \times \text{guaranteed speed}}{\text{test speed}}$$

If the speed for a specified F.A.D. is not guaranteed, the correction does not apply provided that the machine gives the specified F.A.D. at a speed which does not adversely affect its service reliability.

b) Pressure at delivery. For positive displacement compressors no correction is necessary as it can safely be assumed that the specified delivery pressure can be obtained with specified intake conditions.

c) Pressure at intake. For exhausters no correction is necessary within the permissible deviation set out in **1.2.2**.

d) Corrected power consumption

= power consumption

$$\times \frac{\text{guaranteed absolute inlet pressure}}{\text{test absolute inlet pressure}} \times \frac{\text{guaranteed speed}}{\text{test speed}}$$

This is the only correction necessary provided that the deviations of test conditions from guarantee conditions do not exceed the values given in **1.2.2**.

5) 1 bar = 10^5 N/m^2 = 100 kPa.

NOTE 1 *The effect of cooling water temperature on the power consumption of a water-cooled compressor.* It has been decided, after careful consideration of the theoretical and practical aspects of this matter, that no corrections are to be made for variations in water temperature from any guaranteed or specified figure within the limits set down in **1.2**.

One method is to correct the figures to those obtained by a strictly theoretical formula for perfect intercooling. From the consideration of several test results it is considered undesirable to adopt this method. Tests were carried out on single- and double-acting two-stage water-jacketed and intercooled machines. The tests were carried out at two water temperatures differing by 17 °C. The performance figures, expressed in values of F.A.D. and based on test figures without correction, were almost identical; when corrected for perfect intercooling, the performance figures differed by as much as 2.5 %.

It is realized that no correction can take into account the change in frictional absorbed power due to changes in oil temperature created by changes in the water temperature, and that this effect is so marked that any corrections based solely on the theoretical indicated power cannot be valid.

NOTE 2 *The effect of inlet pressure and pressure ratio on power.* It can be assumed that, within the limits given in these tests; the efficiency of a machine will not be affected by changes in pressure. The corrected power will therefore be as follows.

a) For single-stage machines cooled and uncooled.

$$P_{corr} = P_m \times \frac{p_{1c}\left[\left(\frac{p_{2c}}{p_{1c}}\right)^{\frac{n-1}{n}} - 1\right]}{p_{1m}\left[\left(\frac{p_{2m}}{p_{1m}}\right)^{\frac{n-1}{n}} - 1\right]}$$

where n is the appropriate index for compression and expansion. For general purposes a value of:

$$n = 1.33 \text{ or } = \frac{n-1}{n} = 1/4 \text{ can be assumed.}$$

b) For multistage machines, the most appropriate equation is:

$$P_{corr} = P_m \times \frac{p_{1c} \cdot \log \frac{p_{2c}}{p_{1c}}}{p_{1m} \cdot \log \frac{p_{2m}}{p_{1m}}}$$

By holding the pressure ratio on test to within ± 1.0 % of the guarantee figure the power correction for all machines can be simplified to:

$$P_{corr} = P_m \times \frac{P_{1c}}{P_{1m}}$$

(See **4.3** for identification of subscripts.)

9 Measurement of air flow using a nozzle in the pipeline

9.1 General arrangement of the pipeline system

9.1.1 *Receiver capacity.* Reciprocating compressors and exhausters, as well as some rotary types, give rise to pulsations in flow both on the suction and delivery sides. It is necessary to damp these pulsations to obtain accurate flow measurement, and this may be done by fitting a receiver of adequate capacity between the compressor or exhauster and the control valve (see Figure 1 and Figure 2).

Where the pressure drop across the control valve is substantial (not less than 30 % of the upstream absolute pressure), an adequate capacity receiver is one which would contain, at the receiver pressure, the output of the compressor or exhauster during 50 complete pulsations.

Where the pressure drop across the control valve is less than 30 % of the upstream absolute pressure or where no control valve is used between the receiver and the nozzle, a larger receiver may be necessary.

Other damping arrangements may be used provided that it can be shown that no pulsations exceeding ± 2 % of the differential pressure are occurring at the nozzle inlet.

Sensitive low-inertia pressure measuring instruments may be necessary to reveal the presence of these pulsations.

The pipe connecting the machine and the receiver should be as short as possible to minimize the risk of false readings due to resonance effect.

9.1.2 ***Pipeline layout***

9.1.2.1 *General.* The pipes and the nozzle shall be circular in cross section, and arranged generally as shown in Figure 5 and Figure 6. The pipeline may be laid at any convenient angle.

Drains shall be provided at all points where water can accumulate and their entrances shall be flush with the inner surface of the pipe.

Pipe flanges shall preferably be faced so that a metal-to-metal joint is made with the nozzle. If jointing material is used between the flanges and the nozzle its thickness shall not exceed 1.6 mm and the inner diameter of the joint ring shall be not less than the appropriate value of dimension G given in Table 3.

9.1.2.2 *Testing with a nozzle on the delivery side* (see Figure 5). During such testing the air flow shall be steady, any pulsations having been effectively damped by a receiver as explained in **9.1.1**. The control valve may be either the same nominal size as the nozzle approach pipe or smaller. The latter may be preferred for ease of control, and it should then be connected to the nozzle approach pipe by a cone piece. In either case a perforated plate shall be fitted at the inlet flange of the approach pipe to smooth the flow, which leaves the control valve in a violently turbulent condition. The perforated plate shall have a hexagonal pattern of holes drilled in the central portion as indicated in Figure 5 a. The centres of the holes shall be uniformly spaced and shall lie at the corners of equilateral triangles. The number, size and spacing of the holes, and thickness of the plate are specified in Table 2.

The pressure drop across this perforated plate is about four times the nozzle head, hence if it is desired to test up to the maximum nozzle head of 1 000 mmH_2O, the minimum pressure needed would be about 0.5 bar[6)] gauge if discharging to atmosphere. If tests are to be made at lower supply pressures, the nozzle size can be chosen from Table 4 to work at a lower head.

Generally the air pressure on the outlet side of the nozzle is only slightly in excess of atmospheric because the exit pipe discharges either freely to atmosphere or through an exhaust or silencing system to atmosphere (but see **9.6**).

Downstream from the perforated plate, the approach pipe to the nozzle shall be straight and shall have a length not less than 8 pipe diameters. The pipe bore shall be not greater than 2.5 nor less than 2.25 nozzle diameters except for the two smallest nozzle sizes in Table 3 where it shall be 25.4 ± 3.2 mm.

The exit pipeline from the nozzle to atmosphere shall be straight for a distance not less than 4 pipe diameters and shall be of the same diameter as the approach pipe.

The roughness of the internal surface of the pipes need not be reduced below that of ordinary commercial finish, but there shall be no obstructions in the pipelines such as thick welding ridges.

9.1.2.3 *Testing with a nozzle on the intake* (see Figure 6). When the nozzle is on the intake the approach pipe to the nozzle shall have a minimum straight length of 8 pipe diameters and the exit pipe shall have a minimum straight length of 5 pipe diameters. If aspiring from atmosphere, the inlet end may be plain, flanged or flared, but shall not be restricted. As the control valve is on the downstream side of the nozzle a perforated plate is not necessary.

If drawing from another pipe system, special precautions should be taken to avoid swirl or other flow disturbance: the appropriate perforated plate (see **9.1.2.2**) at the entry to the straight pipe of length 8 pipe diameters may be used.

9.2 The rounded nozzle. (see Figure 7 to Figure 10). The nozzle shall be made of bronze or other suitable material and machined so as to be truly parallel in the throat. The inside surface of the nozzle shall be smooth finished. A table of the dimensions of a range of standard nozzles suitable for testing air deliveries from 1 to 14 500 litres of air per second is given in Table 3.

Nozzles with throat diameters smaller than 5.56 mm shall not be used.

6) 1 bar = 10^5 N/m^2 = 100 kPa.

Table 2 — Details of perforated plate

Nominal nozzle diameter *d*		Nominal pipe bore *D*	Details of perforated plate (see Figure 5a)			Thickness of plate
			No. of holes	Diameter of holes	Spacing of holes	
in	mm	mm		mm	mm	mm
7/32	5.56	25	19	1.6	3.2	3.2
3/8	9.53	25	19	1.6	3.2	3.2
5/8	15.88	40	61	1.6	3.2	3.2
1	25.4	65	37	3.2	6.4	3.2
1½	38.1	90	61	3.2	6.4	3.2
2½	63.5	150	217	3.2	6.4	3.2
4	101.6	250	169	6.4	12.7	6.4
6	152.4	375	331	6.4	12.7	6.4
10	254.0	600	217	12.7	25.4	12.7
15	381.0	900	469	12.7	25.4	12.7

Table 3 — Dimensions of nozzles (see Figure 7 to Figure 10)

All dimensions are in millimetres, unless otherwise stated, at the normal temperature of 20 °C.

Nominal size			*d*	*A*	*B*	*C*	*E*	Tolerance[a] on profile	*F*	*G*	*H*	*J*	*K*
Nozzle diameter *d*		Pipe bore *D*											
in													
7/32	5.56	25	5.56 ± 0.01	3.18 ± 0.06	—	—	—	± 0.13	19.05	44.45	—	0.40	—
3/8	9.5	25	9.53 ± 0.01	5.77 ± 0.06	2.87	3.15	1.91	± 0.13	19.05	44.45	—	0.40	—
5/8	15.9	40	15.88 ± 0.01	9.60 ± 0.06	4.78	5.23	3.18	± 0.13	26.19	60.33	—	0.40	—
1	25.4	65	25.4 ± 0.03	15.37 ± 0.08	7.62	8.38	5.08	± 0.13	38.89	85.73	11.11	0.80	29.77
1½	38.1	90	38.1 ± 0.03	23.06 ± 0.10	11.43	12.57	7.62	± 0.18	51.59	111.13	11.11	1.60	44.45
2½	63.5	150	63.5 ± 0.05	38.43 ± 0.13	19.05	20.96	12.70	± 0.25	84.93	177.80	11.11	2.40	74.22
4	101.6	270	101.6 ± 0.05	61.47 ± 0.13	30.48	33.53	20.32	± 0.25	141.29	292.10	12.7	3.20	118.67
6	152.4	375	152.4 ± 0.10	92.20 ± 0.18	45.72	50.29	30.48	± 0.25	206.38	425.45	15.88	4.80	177.80
10	254.0	600	254.0 ± 0.18	153.67 ± 0.25	76.20	83.82	50.80	± 0.25	323.85	660.4	19.05	8.00	293.10
15	381.0	900	381.0 ± 0.25	230.51 ± 0.38	114.30	125.73	76.20	± 0.25	497.43	971.55	19.05	12.20	419.1

[a] The curved surface shall not depart from the nominal profile by more than this tolerance at any point between the cylindrical throat and the upstream face of the nozzle.

NOTE 1 Intermediate sizes of nozzles shall conform to intermediate tolerances and shall be proportioned on the dimensions given for 25.4 mm (1 in) or 254 mm (10 in) nozzles.

NOTE 2 The British Standards Institution undertakes, for a fee, to test nozzles to ascertain whether their dimensions conform to those laid down in this specification. Nozzles found to be satisfactory will be marked with the letters BST and date of examination. Enquiries should be addressed to the Director, British Standards Institution, Maylands Avenue, Hemel Hempstead, Herts HP2 4SQ.

Table 4 — Rounded nozzle: nozzle constants and volume flow

Nominal nozzle diameter *d*		Approximate pipe bore *D*	Constant *k*	Approximate volume flow for nozzle outlet pressure near atmospheric			
				h^a = 10 mmH$_2$O	h^a = 100 mmH$_2$O	h^a = 400 mmH$_2$O	h^a = 1 000 mmH$_2$O
in	mm	mm		litres/s	litres/s	litres/s	litres/s
7/32	5.56	25	0.1488	—	1	2	3
3/8	9.53	25	0.4432	—	3	6	8
5/8	15.88	40	1.254	—	8	16	24
1	25.4	65	3.248	—	20	40	60
1½	38.1	90	7.377	14	43	85	140
2½	63.5	150	20.516	38	125	250	380
4	101.6	250	52.429	100	310	620	1 000
6	152.4	375	118.41	220	700	1 400	2 200
10	254	600	328.00	560	1 900	3 900	5 600
15	381	900	737.68	1 450	4 400	8 700	14 500

[a] See **9.5.2**.

Table 5 — Rounded nozzle: tolerances on inlet volume

Nominal nozzle diameter *d*		Tolerances			
		Pressure drop across nozzle *h* mmH$_2$O			
		10 up to and including 25	Over 25 up to and including 100	Over 100 up to and including 400	Over 400 up to and including 1 000
in	mm	%	%	%	%
7/32	5.56	[a]	[a]	± 3.5	± 2.5
3/8	9.53	[a]	[a]	± 2.5	± 2.5
5/8	15.88	[a]	± 3.5	± 2.5	± 2.5
1	25.4	[a]	± 3.5	± 2.5	± 1.5
1½	38.1	± 3.5	± 2.5	± 1.5	± 1.5
2½	63.5	± 2.5	± 2.5	± 1.5	± 1.5
4	101.6	± 2.5	± 1.5	± 1.5	± 1.5
6	152.4	± 1.5	± 1.5	± 1.5	± 1.5
10	254	± 1.5	± 1.5	± 1.5	± 1.5
15	381	± 1.5	± 1.5	± 1.5	± 1.5

[a] Nozzle not to be used in this differential pressure range.

9.2.1 *Nozzle constants.* The constants *k* given in Table 4 include all the coefficients required for each nozzle as well as the factors required for the combination of the units of measurement. The constants are based on air having a density of 1.222 kg/m^3 which corresponds very nearly to the air being dry and having a temperature of 15.5 °C and an absolute pressure of 760 mmHg, the mercury itself being at 15.5 °C. For tile purposes of this British Standard it is not necessary to make corrections for humidity.

9.2.2 *Tolerances on inlet volume.* The tolerances which should be allowed on the values of inlet volume are given in Table 5.

9.3 Selection of nozzle

9.3.1 For the purposes of this standard, heads shall be not less than 10 mmH$_2$O, and shall not exceed 1 000 mmH$_2$O. See Table 5 for special restrictions.

9.3.2 The following empirical rule can be used to ascertain a size of nozzle suitable for a particular test, when the pressure at the nozzle is approximately atmospheric.

Calculate 0.054 times the maximum expected volume flow in litres/s and select from Table 4 the nozzle with the constant *k* next larger than that number.

9.3.3 For other pressures the approximate value of k may be found from the formula for q in **9.5.2** using a value of h within the range given in Table 4.

9.4 Observations and instruments

9.4.1 Instruments shall be calibrated so that their scale errors are known. Pressures and pressure differences shall be determined to within 1 mm of actual scale length and temperatures to within 1 °C. Preliminary observations shall be taken until these show that a steady final state has been reached, after which the test shall be started.

9.4.2 Manometers should be made of glass tubing of not less than 10 mm bore for the single-leg type or not less than 6 mm bore for the double-leg U-tube type.

9.4.3 The manometric liquid should preferably be water, with the addition of up to 0.2 % of a suitable wetting agent to ensure free menisci. To facilitate accurate readings, if heads below 100 mmH_2O are required, sloping tube or other special manometers shall be used. The accuracy of these should be checked by using them in parallel with the double-leg manometer and comparing readings when the head is of suitable magnitude.

9.4.4 The zero of all manometers shall be verified at zero air flow. Instead of double-leg manometers, those of single-leg type may be used, and also other manometric liquids instead of water, but in either case checking against a double-leg water-filled manometer is advisable, and all readings shall be converted into equivalent mmH_2O.

9.4.5 Temperatures shall be obtained by means of a thermometer inserted into the air stream, as specified in **5.1.1.3**. Every precaution shall be taken to ensure that the temperature of the air (not that of the pipe) is taken, and the pipe should be effectively lagged in the vicinity of the thermometer pocket unless the difference between the air temperature and the atmospheric temperature is less than 5 °C.

9.5 Flow measurement. To illustrate the British Standard method of measuring flow, the following outline is given of the procedure which shall be followed when finding the inlet volume for a compressor from the pressure difference, caused by the flow from the machine, across a nozzle arranged as in Figure 1.

9.5.1 *Observations.* The following observations are necessary.

a) *The atmospheric pressure.* Measured in mmHg by means of a barometer. If there is no barometer on site, readings can be obtained from a local recognized weather bureau and corrections applied to allow for the difference in altitude.

b) *At the agreed inlet point:*

1) The difference in pressure between the agreed inlet point and the local barometer reading. For the purposes of calculation the pressure at the inlet point is the barometer pressure less the depression at the agreed inlet point.

2) The temperature of the air at the agreed point in °C. The thermometer shall be so placed that it is not affected by radiant heat from the surroundings.

c) *At the receiver.* The receiver pressure in bar[7)] measured by means of a pressure gauge. This is taken as a record of performance but is not used in the calculation of the flow except where necessary to allow for any small change occurring during the test. Such changes shall not exceed 2 % of the absolute pressure in the receiver.

d) *At the nozzle:*

1) The head across the nozzle, measured as the difference in pressure given by the reading of a double-leg manometer connected as shown in Figure 5.

2) The difference in pressure between the downstream side of the nozzle and the atmosphere. This shall be measured by means of a second manometer connected as shown in Figure 1.

3) The temperature in the pipeline, measured by means of a thermometer as shown in Figure 5. This thermometer shall be placed between three and four pipe diameters downstream from the mouth of the nozzle, and not closer than one pipe diameter to an open end.

7) 1 bar $\doteq 10^5$ N/m^2 = 100 kPa.

9.5.2 *Method of calculation*. The capacity q, expressed in litres/s, shall be calculated from the formula:

$$q = k.\frac{T_1}{p_1}\sqrt{h.\frac{p_2}{T}}$$

where

- q is the inlet volume in litres/s;
- h is the pressure drop across the nozzle in mmH_2O;
- k is the constant for the nozzle (see Table 4);
- T_1 is the absolute temperature at the agreed inlet point;
- T is the absolute temperature downstream from the nozzle;
- p_1 is the absolute pressure at the agreed inlet point in mmHg;
- P_2 is the absolute pressure at the downstream side of the nozzle in mmHg.

These absolute pressures are obtained by adding or subtracting from the atmospheric pressure, as given by the barometer, the water-gauge reading obtained from the appropriate manometer. The water-gauge readings are converted to mmHg by dividing by **13.6**.

9.6 Alternative tests

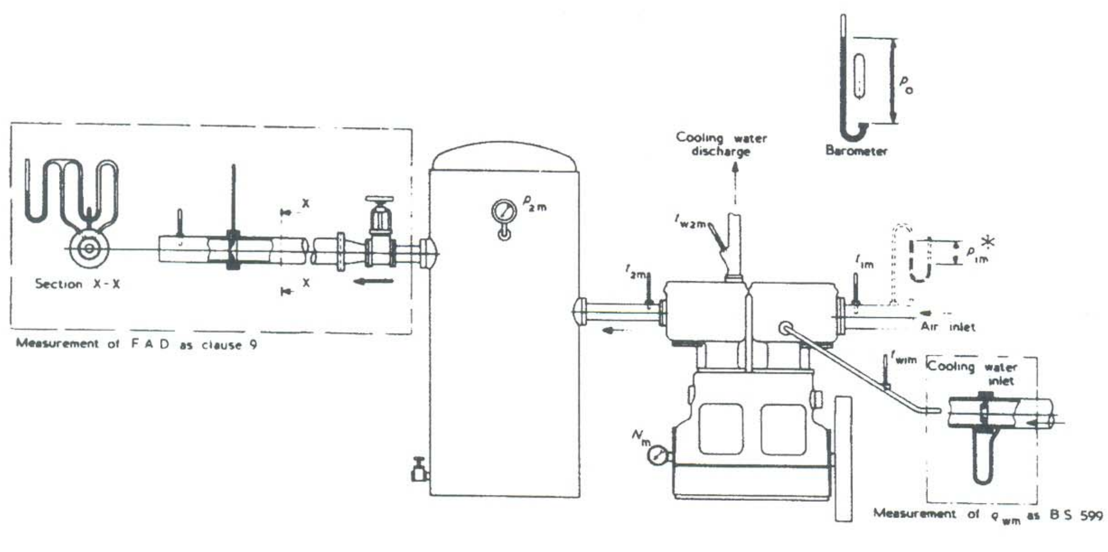
9.6.1 The discharge may have to be made into a pipeline under pressure instead of into the atmosphere, or it may be desirable to measure the flow at the delivery pressure in order to reduce the dimensions of the pipeline required. The test layout should then be the same as that described in **9.1** with the addition of a second perforated plate across the downstream pipe at least five pipe diameters away from the nozzle and before the flow reaches any bends, valves or obstructions. The pressure at the downstream side of the nozzle is measured by a pressure gauge substituted for the second manometer (see **9.5.1**) and the reading converted to mmHg.

Bourdon gauges shall be mounted vertically and shall be readable to 0.5 % of the full scale reading. They shall be used only between one quarter and three quarters of their full scale reading. They shall be calibrated against a dead-weight gauge before and after the test.

Care shall be taken to ensure that the high pressure pipeline into which the air is discharged is free from pulsations.

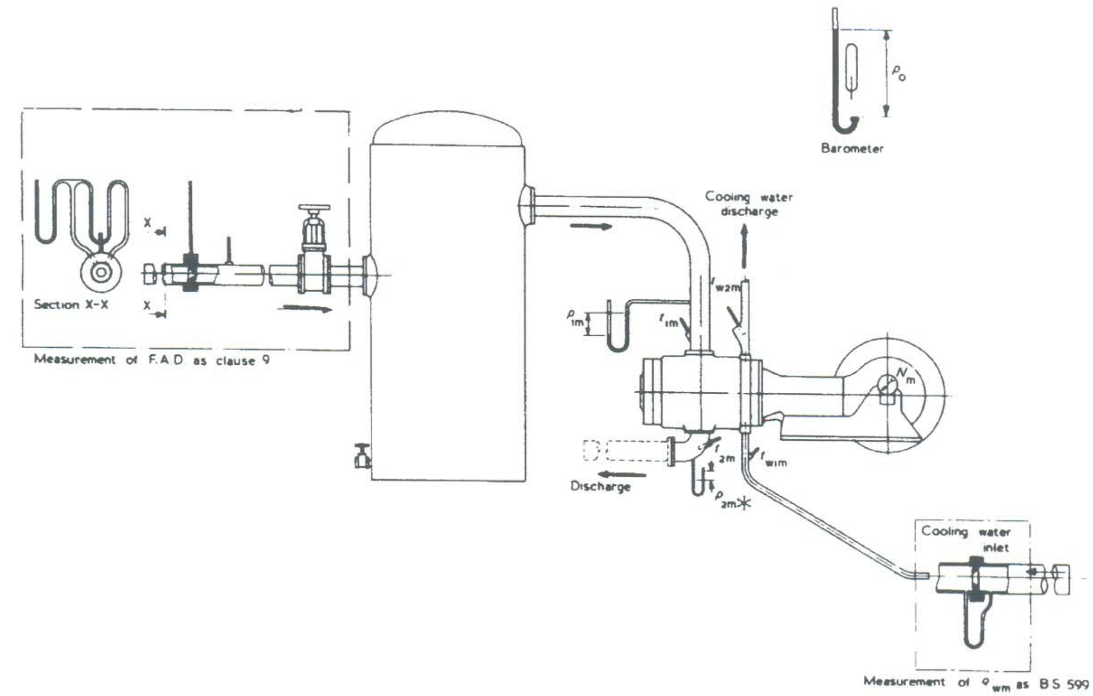
The calculations are made in the same manner as for discharge to atmosphere.

Tests have shown that this test layout and procedure give results in agreement with the method described in **9.1**.



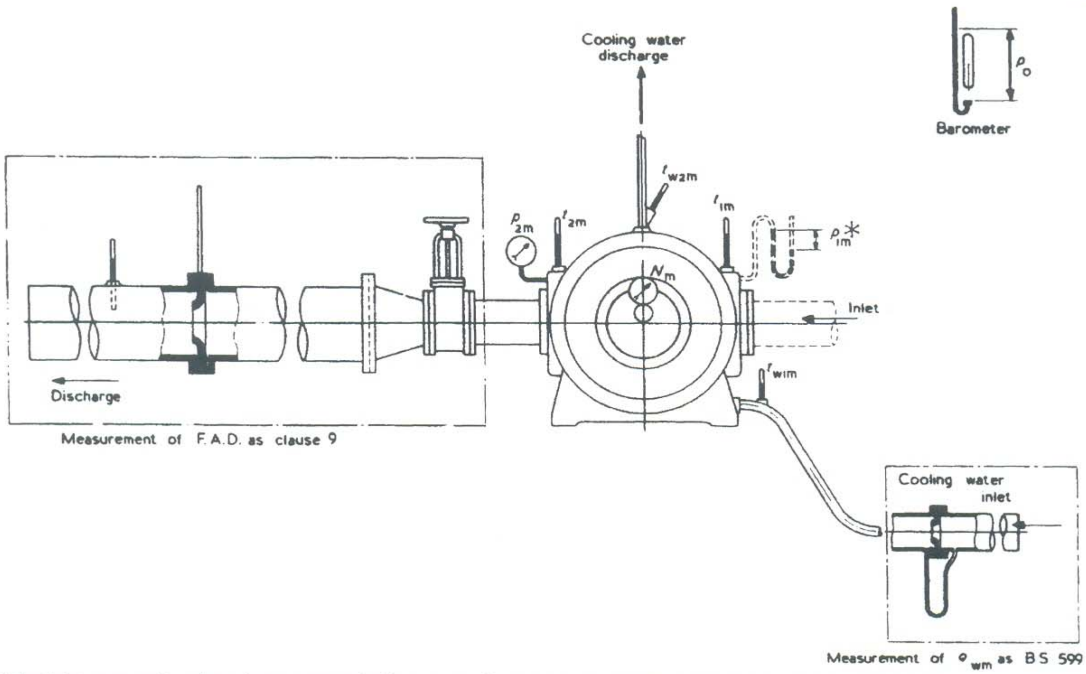
*The inlet pressure is to be taken as atmospheric, except when an agreed resistance is imposed at the suction inlet.

Figure 1 — Diagrammatic arrangement of test layout for reciprocating compressor



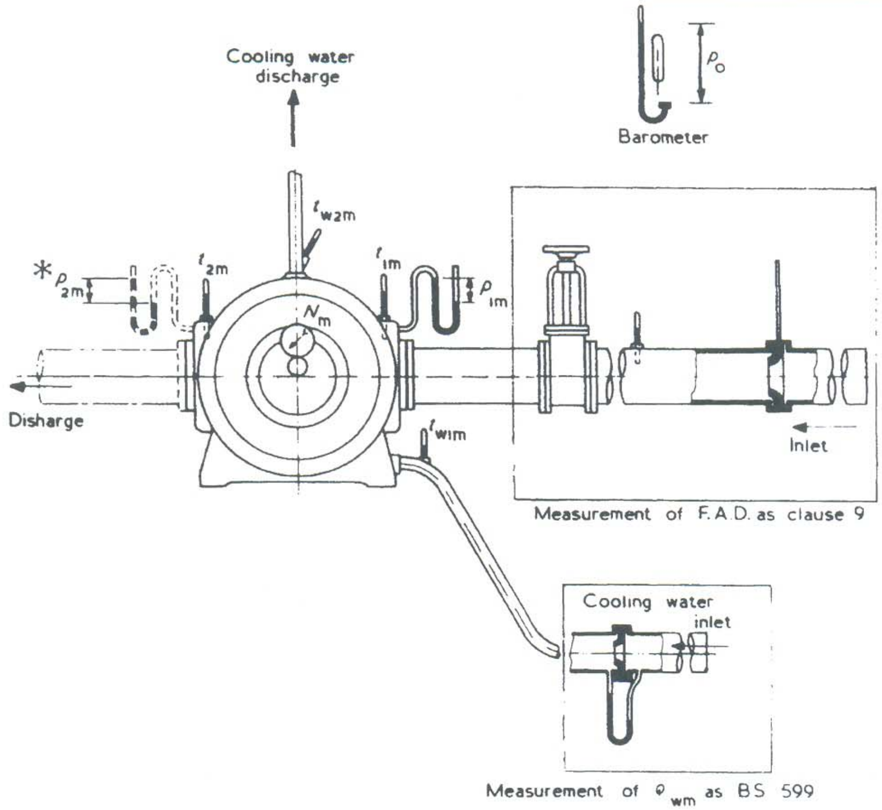
*The outlet pressure is to be taken as atmosph ric, except when an agreed resistance is imposed beyond the delivery flange

Figure 2 — Diagrammatic arrangement of test layout for reciprocating exhauster



*The inlet pressure is to be taken as atmospheric, except when an agreed resistance is imposed at the suction inlet.

Figure 3 — Diagrammatic arrangement of test layout for rotary compressor



*The outlet pressure is to be taken as atmospheric, except when an agreed resistance is imposed beyond the delivery flange.

Figure 4 — Diagrammatic arrangement of test layout for rotary exhauster

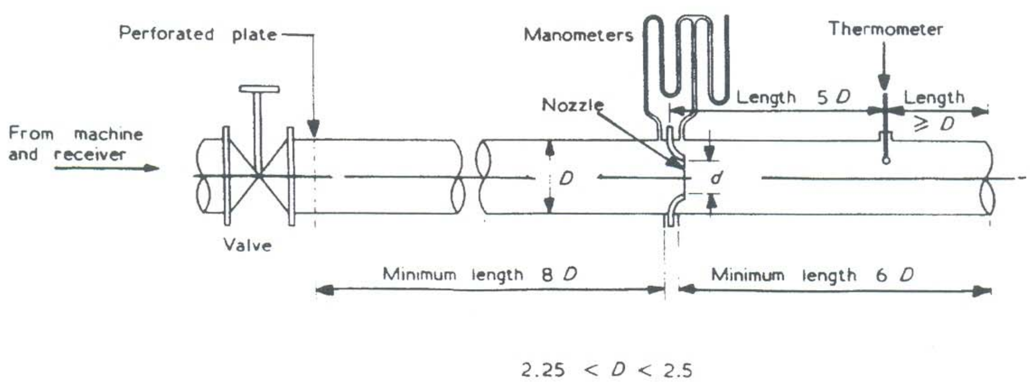
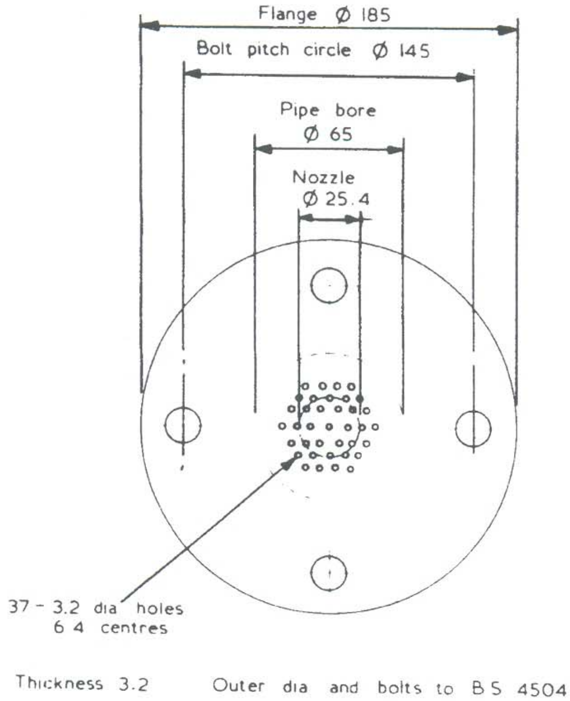


Figure 5 — Arrangement for testing with a nozzle on the delivery side (see 9.1.2.2)



Dimensions in millimetres

Figure 5a — Perforated plate for 25.4 mm (1 in) nozzle (for other sizes see Table 2)

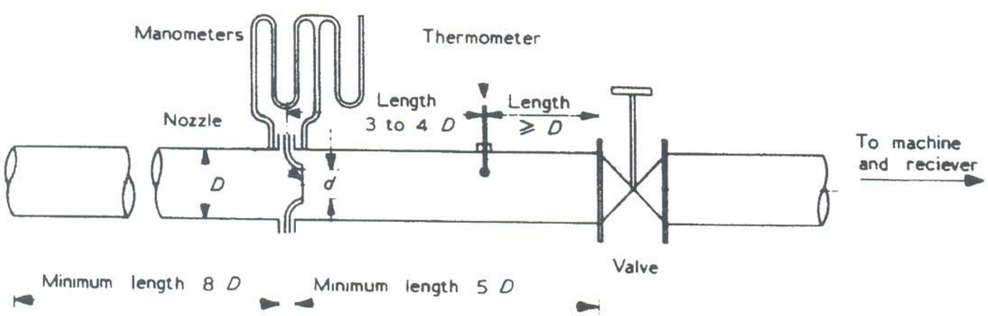
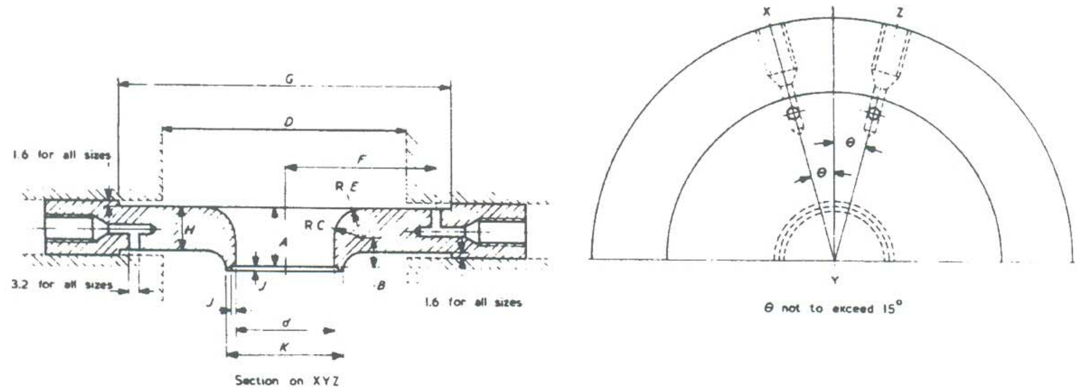
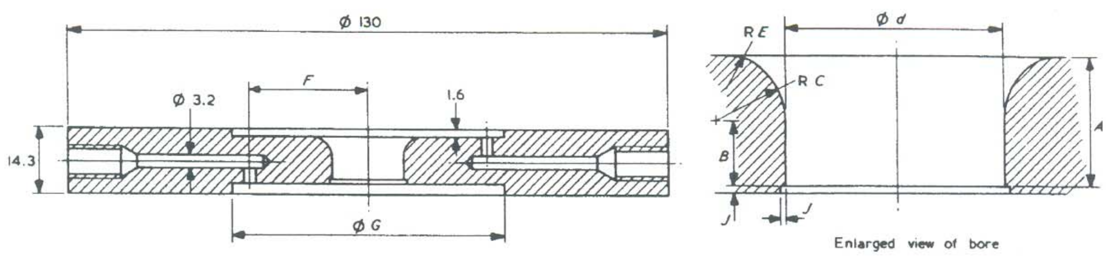


Figure 6 — Arrangement for testing with a nozzle on the intake (see 9.1.2.3)



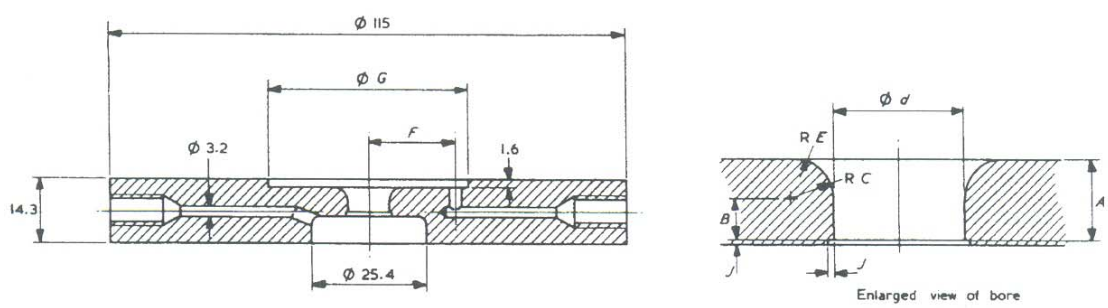
Dimensions in millimetres

Figure 7 — Nozzles 25.4 mm (1 in) and larger (for dimensions see Table 3)



Dimensions in millimetres.

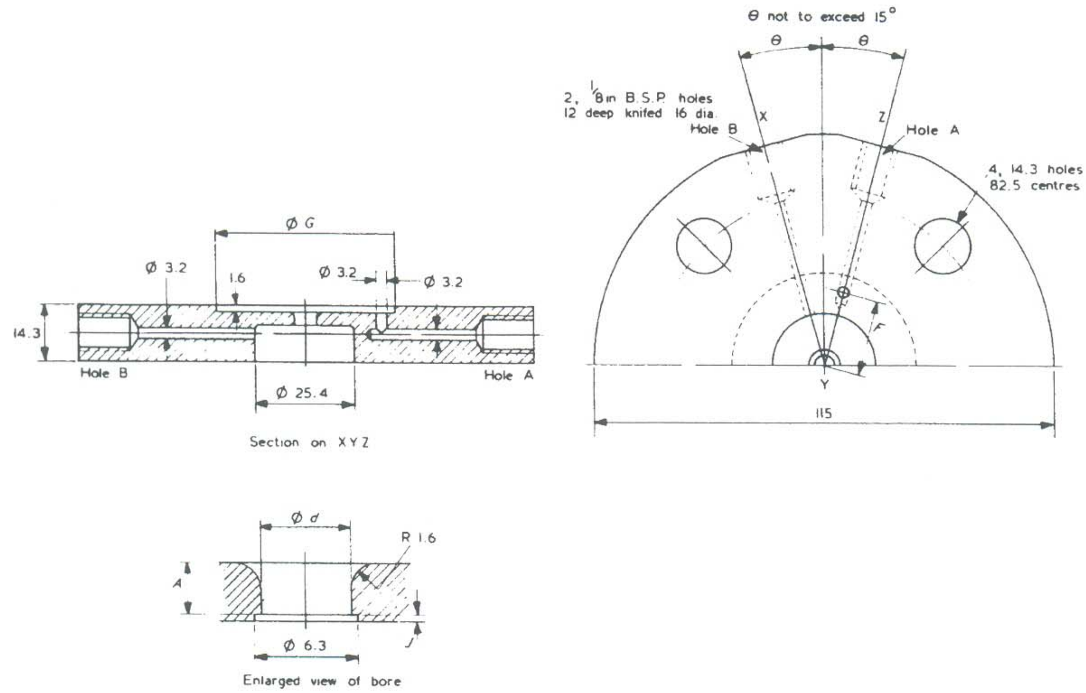
Figure 8 — 15.88 mm (5/8 in) nozzle



Dimensions in millimetres.

NOTE Angle between pressure tapping as in Figure 7.

Figure 9 — 9.53 mm (3/8 in) nozzle



Dimensions in millimetres

Figure 10 — 5.36 mm (7/32 in) nozzle

Publications referred to

This standard makes reference to the following British Standards:

BS 353, *Methods of testing water turbine efficiency.*

BS 599, *Methods of testing pumps.*

BS 649, *The performance of reciprocating compression-ignition (diesel) engines, utilizing liquid fuel only, for general purposes.*

BS 752, *Test code for acceptance tests for steam turbines.*

BS 1041, *Code for temperature measurement.*

BS 1571, *Testing of positive displacement compressors and exhausters.*

BS 1571-1, *Acceptance tests.*

BS 2613, *Electrical performance of rotating electrical machines.*

BS 3109, *Gas and dual fuel engines.*

BS 4504, *Flanges and bolting for pipes, valves and fittings. Metric series.*

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