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FOREWORD

This Code of Practice is based upon an investigation carried out by a consortium comprising the Department of Trade and Industry, the National Engineering Laboratory and representatives of pump manufacturers, pump users and manufacturers of pump performance monitoring equipment. The participating organisations are listed in Appendix C.

The document is being published in the present form by The Pump Centre in order to gain experience in its use, and comment on its contents, before it becomes the basis for a British Standard. The consortium recognises as a defficiency the lack of a prescribed method of dealing with the recovery factor in Section 7.2.2. Further experimental work is required before this can be provided.

0 INTRODUCTION

This document deals with the measurement of pump efficiency by the direct thermodynamic method, as an alternative to efficiency testing by the conventional method described in BS 5316 : Part 1 (Class C) and BS 5316 : Part 2 (Class B). BS 5316 : Part 3 covers the application of the thermodynamic method to Precision Class testing.

The method is based on the evaluation of the energy per unit mass of liquid, received by the liquid from the pump shaft, by measurements of the differential head and differential temperature across the pump, using the thermodynamic properties of the liquid.

With the direct thermodynamic method of measuring efficiency, neither the flow rate nor power absorbed by the pump need be measured, but where knowledge of the flow rate at which the pump is operating is required for comparison with the performance specified in the contract, this may be measured with a flow metering instrument, in accordance with the relevant standards.

Alternatively, when the power absorbed by the pump can be determined, in accordance with the relevant standard, the rate of flow may be determined from the shaft power absorbed, the differential head and the efficiency measured by the direct thermodynamic method.

The standard test arrangements and procedures described are those for use when testing pumps either at the manufacturer's works, or on site.

The accuracy with which the efficiency of a pump can be measured by this method is affected by the limitations of the measuring equipment, by measuring conditions at the inlet and outlet sections of the pump and by the uncertainty with which the physical properties of the fluid are known. The level of accuracy with the standard test arrangements is defined by relating the accuracy of the equipment for measuring temperature and pressure differentials across the pump to the resulting uncertainty in computed efficiency.

The method may also be used to monitor long term trends in efficiency performance. In this case it is advisable to carry out a reference test as soon as possible after installation (a 'footprint' test), and to document the test arrangements used to ensure consistency of procedure.

1 SCOPE

This document constitutes a code for the efficiency testing of pumps by use of the direct thermodynamic method.

It defines the terms, the quantities to be measured, and the procedure for the computation of pump efficiency. These methods, by which the pump performance can be established, may be used for comparison with that agreed in a contract.

In general this code applies to any type or size of pumps tested with clean cold water. Other liquids may be used provided that the relevant physical properties are known. It is assumed that the fluid mass flow rates at the inlet and outlet measuring positions of the pump are equal.

This code is not concerned with the structural details of the pump nor with the mechanical properties of its components.

2 SYMBOLS

2.1 Alphabetic List of Symbols Used in the Document

A	Area	m^2
a	Isothermal coefficient	m^3/kg
$\bar{a}$	Mean value of a	m^3/kg
c_p	Specific heat capacity at constant pressure	J/(kg K)
$\bar{c}_p$	Mean value of c_p	J/(kg K)
d	Shaft diameter	m
E	Energy per unit mass of fluid	J/kg
E_h	Hydraulic energy per unit mass of fluid	J/kg
E_m	Mechanical energy per unit mass of fluid	J/kg
E_x	External loss in mechanical energy per unit mass of fluid	J/kg
g	Acceleration due to gravity	m/s^2
h	Enthalpy	J/kg
k	Power coefficient	W min/m^2
H	Pump total head	m
H_1	Total head at inlet	m
H_2	Total head at outlet	m
N	Rotational speed	r/min
p	Pressure	N/m^2
P	Power	W
P′	Heat-transfer coefficient	$W/(m^2 K)$
q_m	Mass flow rate	kg/s
q	Volume flow rate	m^3/s
s	Entropy	J/(kg K)
U	Mean velocity	m/s
V_m	Volume per unit mass	m^3/kg
$\bar{V}_m$	Mean value of V_m	m^3/kg
z	Elevation	m
ΔE_m	Correction term for heat-transfer effects	J/kg
$\Delta\theta$	Differential temperature	K
η	Efficiency	
θ	Temperature	°C

θ_a	Ambient air temperature	°C
ρ	Density	kg/m^3

2.2 Letters and Numbers as Subscripts

1	Inlet
2	Outlet
G	Guarantee
gr	Gross
T	Test
x	External loss

2.3 Definitions of Terms

Term	Definition
Isothermal coefficient, function of temperature and pressure	$a(\theta, p) = \left(\frac{\partial h}{\partial p}\right)_\theta$
Mean isothermal coefficient	$\bar{a} = a\left(\theta_1, \frac{p_1 + p_2}{2}\right)$
Specific heat capacity at constant pressure, function of temperature and pressure	$c_p(\theta, p) = \left(\frac{\partial h}{\partial \theta}\right)_p$
Mean value of c_p	$\bar{c}_p = c_p\left(\frac{\theta_1 + \theta_2}{2}, p_2\right)$
Hydraulic energy per unit mass of fluid	$E_h = \overline{V}_m(p_2 - p_1) + \frac{U_2^2 - U_1^2}{2} + g(z_2 - z_1)$
Mechanical energy per unit mass of fluid	$E_m = \bar{a}(p_2 - p_1) + \bar{c}_p(\theta_2 - \theta_1) + \frac{U_2^2 - U_1^2}{2} + g(z_2 - z_1) + \Delta E_m$
Pump total head	$H = H_2 - H_1$
Total head at inlet	$H_1 = \frac{p_1}{\rho_1 g} + z_1 + \frac{U_1^2}{2g}$

Term	Definition
Total head at outlet	$H_2 = \frac{p_2}{\rho_2 g} + z_2 + \frac{U_2^2}{2g}$
Mean velocity at a pipe section	$U = \frac{q}{A}$
Volume per unit mass of fluid, function of temperature and pressure `	$V_m(\theta, p) = \frac{1}{\rho} = \left(\frac{\partial h}{\partial p}\right)_s$
Mean value of V_m	$\overline{V}_m = V_m\left(\theta_1, \frac{p_1 + p_2}{2}\right)$
Pump efficiency	$\eta = \frac{E_h}{E_m + E_x}$
Static pressure	Force per unit area. Except where otherwise specified pressures are gauge - that is measured with respect to atmospheric pressure.

3 PRINCIPLES OF THE METHOD

This document relates in particular to the Direct Thermodynamic Method of Efficiency Testing - so called because the static pressure readings are taken using wall tappings, and the fluid temperature readings are measured directly at representative positions in the stream of flowing fluid - Fig. 3.1.

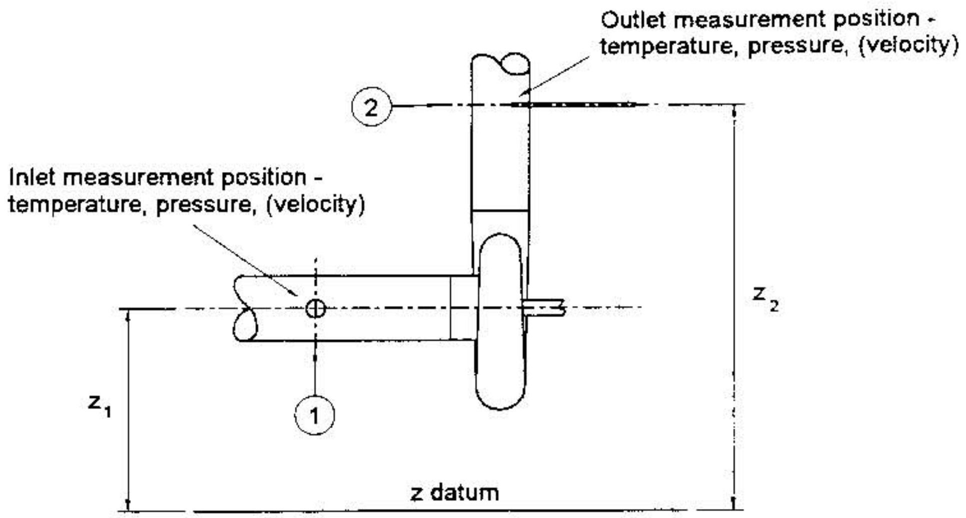

Figure 3.1 Measurement Positions

The hydraulic efficiency is the ratio of two changes in energy per unit mass, each comprising enthalpy, kinetic energy and gravitational terms:

E_h the total enthalpy change in an ideal, reversible, isentropic process between the inlet conditions and the outlet pressure

and

E_m the total enthalpy change in the actual pumping process.

The former is given by:

$$E_h = \overline{V}_m(p_2 - p_1) + \frac{U_2^2 - U_1^2}{2} + g(z_2 - z_1)$$

which is the normal expression for gH where H is the pump total head rise.

The change of total enthalpy in the actual pumping process is:

$$E_m = \bar{a}(p_2 - p_1) + \bar{c}_p(\theta_2 - \theta_1) + \frac{U_2^2 - U_1^2}{2} + g(z_2 - z_1) + \Delta E_m$$

-which, by the First Law of Thermodynamics, is the energy per unit mass fluid transferred to the pump shaft (excluding the external losses, E_x, which do not affect the fluid).

Ignoring the gravitational and kinetic terms, the two processes can be traced on an entropy / enthalpy diagram - Fig. 3.2 - bearing in mind the thermodynamic relations for a pure substance:

$$\left(\frac{\partial h}{\partial p}\right)_s = V_m = \frac{1}{\rho}$$

$$\left(\frac{\partial h}{\partial p}\right)_\theta = a$$

$$\left(\frac{\partial h}{\partial \theta}\right)_p = c_p$$

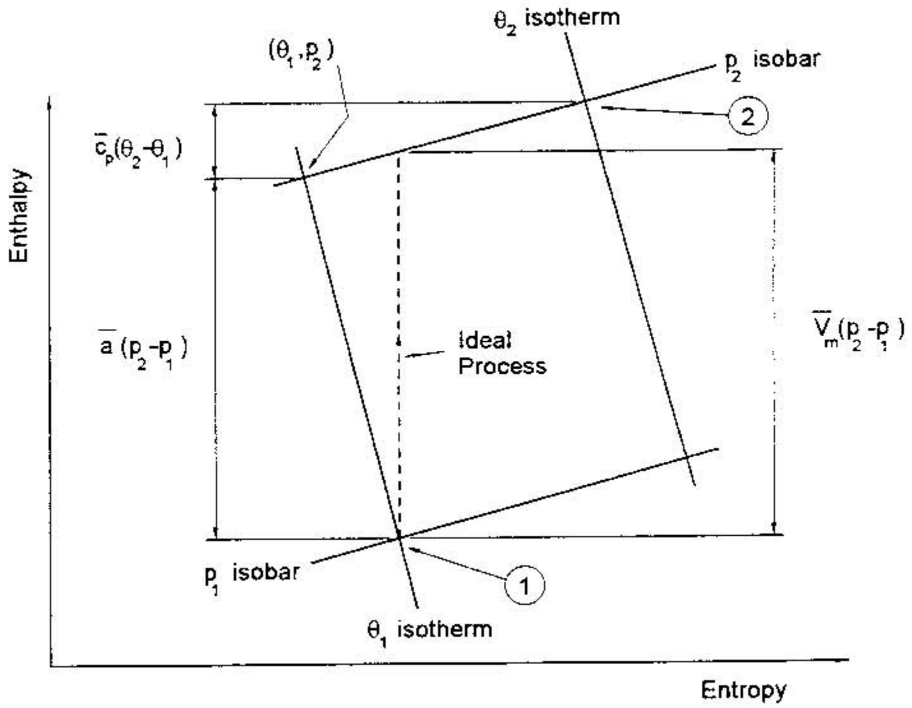

Figure 3.2 Entropy/Enthalpy Diagram of the Processes

The actual process may be regarded as an isothermal process between (θ_1,p_1) and (θ_1,p_2) followed by a constant pressure process between (θ_1,p_2) and (θ_2,p_2) - since the state of the fluid is dependent on the end states of the process and not the path between them.

ΔE_m is the loss of specific energy from the pump casing due to heat transfer - see Section 10.2. Since the thermodynamic method takes no account of external power losses, E_x, which are not manifest as an increase in water temperature (such as external bearing losses) these must be estimated - see Section 10.1 - and included in the expression for η, the pump efficiency:

$$\eta = \frac{E_h}{E_m + E_x}$$

The error involved in using the mean values of V_m, a and c_p, instead of integrating the values along the paths of the processes, is negligible for pressures between 0 and 300 bar and temperatures between 0 and 150 °C. Values of the relevant thermodynamic properties are given in Appendix B.

If the velocity profiles at the measuring positions are far from uniform the use of the mean velocities U_1 and U_2 may be a source of error.

4 GUARANTEES

4.1 Subjects of Guarantees

The pump efficiency may be guaranteed by the manufacturer:

a) At the guaranteed (q_G,H_G) point;

b) Where the flow rate can be measured or assessed to an acceptable degree of accuracy, other points of the flow efficiency curve may be guaranteed at a reduced or increased flow rate, in which case separately agreed tolerances will apply.

Although the guarantees apply to one or more particular flow point(s), the manufacturer's predicted flow efficiency curve should be made available (at the time of agreeing guarantees) for the later analysis of test results.

4.2 Other Conditions of Guarantee

Unless specifically agreed otherwise in the contract, it shall be taken that the following conditions apply to the guarantee values:

a) Unless the chemical and physical properties of the liquid are stated, it shall be taken that the guarantee points apply to clean cold water;

b) The relation between the guarantee values under clean cold water conditions and the likely performance under other liquid conditions shall be agreed in the contract;

c) Guarantees shall apply only to the pump as tested by the methods, and in the test arrangements specified, in this document;

d) The pump purchaser shall be responsible for the specification of the guarantee point.

4.3 Fulfilment of Guarantee

The nominated guarantee for any quantity shall be deemed to have been met if, when tested according to this standard, the measured performance falls within the tolerance specified in Section 5.4 for the particular quantity. Other points on the flow efficiency curve shall not be guaranteed unless the points and tolerances for fulfilment of guarantees are agreed in the contract.

4.4 Verification of Guarantee

4.4.1 Multiple point tests

Where measurements have been taken at a number of flows to an agreed level of accuracy, these points of flow and efficiency are plotted on a graph and a continuous curve drawn through them. The guarantee point (q_G,H_G) is then plotted on the same graph. A comparison is then made between the guaranteed efficiency and the efficiency shown on the curve of the measured points at the guaranteed flow.

4.4.2 Single point tests

Where it is only possible to measure the efficiency at a single flow, this should be as close as possible to the guarantee flow. This point is then plotted onto a graph. The guarantee point is then plotted onto the same graph and a curve with the same slope as that of the manufacturers predicted (q,H) curve is then drawn through the guarantee point. A comparison is then made between the efficiency on this curve at the test flow and the measured efficiency.

4.4.3 Correction for speed

The pump shall be tested at a speed in the range of the specified speed ±20 per cent. If the test is made at a value of pump rotational speed which is different from that specified for the particular guaranteed values, the test values shall be corrected to the specified speed of rotation in accordance with Section 10.3. Similarly, if the test is made at a value of electrical supply frequency different from that specified for the particular guaranteed values, the tests shall be corrected to the specified frequency.

5 GENERAL REQUIREMENTS FOR TESTS

5.1 Organisation of Tests

5.1.1 Place of testing

Efficiency tests shall be carried out at the manufacturer's works or, alternatively, at a place agreed between the manufacturer and the purchaser.

Both purchaser and manufacturer shall be entitled to have representatives present at all tests and calibrations in order to verify that they are performed in accordance with this document and any prior written agreements.

5.1.2 Time of testing

The time of testing shall be agreed by the manufacturer and the purchaser.

5.1.3 Staff

Accurate measurements depend not only on the quality of the measuring instruments used but also on the ability and skill of the persons operating and reading the measuring devices during the tests. The staff entrusted with effecting the measurements shall be selected just as carefully as the instruments to be used in the test.

A chief of tests possessing adequate experience in measuring operations shall be appointed. Normally, when the test is carried out at the manufacturer's works, the chief of tests is a staff member of the manufacturing firm.

When the test is carried out elsewhere under Section 5.1.1 the chief of tests shall be a person possessing adequate experience, subject to agreement between manufacturer and purchaser.

All persons charged with effecting the measurements are subordinated during the tests to the chief of tests, who conducts and supervises the measurements, reports on test conditions and the results of the tests and then drafts the test report. All questions arising in connection with the measurements and their execution are subject to his decision.

The parties concerned shall provide all assistance that the chief of tests considers necessary.

5.1.4 State of pump

When guaranteed efficiency testing is to be carried out at a place other than the manufacturer's works, both parties shall have the opportunity to make preliminary adjustments to the pump and its system.

5.1.5 Test programme

Only the specified operational data shall form the basis of the test; other data determined by measurement during the tests shall have only an informative function, and this shall be stated if they are included in the test programme.

5.1.6 Test equipment

When deciding on the measuring procedure, the measuring and recording apparatus required shall be specified at the same time.

The chief of tests shall be responsible for checking the correct installation of the apparatus and its proper functioning. All measuring apparatus shall be covered by reports showing by calibration or by comparison with British or International Standards, that it complies with the requirements of Section 5.4. These reports shall be presented if required.

The measuring devices used shall have valid calibration. Periodic calibration shall be performed to traceable standards.

Generally after site testing or in case of dispute, new calibrations shall be performed as soon as possible.

5.1.7 Test report

After actual scrutiny the test results shall be summarised in a report signed either by the chief of tests alone, or by him and representatives of the manufacturer and of the purchaser.

All parties to the contract shall receive a copy of the report as an essential condition for the completion of the contract.

The test report shall contain the following information:

a) Place and date of the performance test;

b) Manufacturer's name, type of pump, serial number, impeller diameter and year of construction;

c) Specified characteristics, operational conditions during the performance test;

d) Specification of the pump drive;

e) Description of the test procedure and the measuring apparatus used including calibration data;

f) Observed readings;

g) Evaluation and analysis of test results with calculations of measuring uncertainties;

h) Conclusion, including comparison of the test results with the specified duties.

All test records and record charts shall be initialled by the chief of tests and by the representatives of both the purchaser and the manufacturer, each of whom shall be provided with a copy of all records and charts.

The evaluation of the test results shall be made as far as possible while the tests are in progress and in any case before the installation and instrumentation are dismantled, in order that measurements regarded as suspect can be repeated without delay.

5.2 Test Arrangements

5.2.1 Ideal arrangements

The outlet measuring section should ideally be of the same diameter as the inlet measuring section since this avoids the need to consider recovery factor - Section 7.2.2. Both outlet and inlet measuring sections should provide straight pipe giving a minimum of 2 diameters upstream and 2 diameters downstream of the measuring position. The flow through the inlet measuring section should be such that there is:

a) An axially symmetric velocity distribution;

b) A uniform static pressure distribution;

c) Freedom from swirl induced by the installation;

d) Ample Net Positive Suction Head (NPSH) to avoid cavitation in the region of the inlet side instruments.

5.2.2 Site tests

For the purposes of this document a site test comprises a thermodynamic test carried out on the pump after it has been installed in the system for which it was purchased.

A site test may be required by the purchaser immediately after commissioning to check that the pump is performing near its best efficiency point, or to establish that the specified design parameters are correct. The requirement for the test may also be to record the initial performance (a 'footprint test'), so that tests can be carried out subsequently to monitor trends in performance.

5.2.2.1 Site test arrangements

Where possible the ideal arrangements of Section 5.2.1 should be used; the pipework design should incorporate tappings in accordance with Section 6.1, fitted into straight inlet and outlet measuring sections 4 diameters long, and of equal diameter.

Where this is not possible the tappings, in accordance with Section 6.1, should be incorporated into the pipework in straight lengths of pipe, preferably but not necessarily of equal diameter. Where these lengths of pipe are more than 6 diameters from the pump some correction for the effect of losses in the pipework may be needed. It is acceptable for footprint testing to allow longer pipe runs, valves and fittings between the measurement positions but the valves shall be retained in the fully open position. In such a test the pipework and fitting configuration shall be documented for future reference. Any flow variation shall be brought about by throttling downstream of the measuring position at the outlet from the pump, or by varying the outlet head by some other means.

Experimental work indicates that tapping points closer than 2 diameters to the pump are likely to give less accurate and possibly less consistent results.

5.2.3 Installation effects

The presence of bends, diffusers and other fittings may affect the pump head/flow rate and efficiency performance, calculated from conventional test results. When the thermodynamic method of efficiency testing is used, any effect of fittings on the head measurement will have some effect on the efficiency calculated.

It is less likely that the temperature differential will be affected since the temperature profile across the pipe is usually more uniform than the velocity and pressure profiles.

Any problems with temperature measurement are much more likely to be the result of probe vibration due to high fluid velocities or turbulence. Such problems can best be avoided by ensuring that stable operation of the thermometers is proven by calibration at velocities at least as high as those experienced on test - as recommended in Section 7.2.1.

5.2.3.1 Cavitation

It is essential that cavitation is avoided in the vicinity of the measuring probes. To ensure this the available NPSH shall be in excess of 0.5 m above the pump's required NPSH. If the available NPSH is less, the temperature reading of the upstream thermometer may be affected and meaningful test results not obtained.

5.3 Test Conditions

5.3.1 Execution of tests

The duration of the test shall be sufficient to obtain consistent results having regard to the uncertainty to be achieved. Where multiple readings are taken to reduce the random uncertainty (see Section 5.3.2), they shall be taken at unequal intervals of time. All measurements shall be made under steady conditions of operation but a decision to make measurements when such conditions cannot be obtained shall be at the discretion of the chief of tests. Verification of the guaranteed point requires that flow rate be measured, estimated or assessed and test data shall be recorded at at least five points of measurements closely and evenly grouped around the guaranteed point, for example between $0.9q_G$ and $1.1q_G$.

Where it is required to determine performance over a range of operating conditions, a sufficient number of measurement points shall be taken to establish the performance within the uncertainty stated in Section 5.4.

5.3.2 Stability of operation

5.3.2.1 Fluctuations and variations - definitions

For the purpose of this document the following definitions apply:

Fluctuations: Short period changes in the measured value of a physical quantity about its mean value during the time that a single reading is being made;

Variations: Those changes in mean value which take place between one reading and the next.

5.3.2.2 Damping

Where the construction or operation of a pump is such that fluctuations of great amplitude are present, measurements may be carried out by means of an instrument capable of providing an integration over at least one complete cycle of fluctuations. The calibration of such an instrument shall comply with the provisions of Tables 5.2 and 5.4.

If an automatic data acquisition system is used then the sampling time for each reading should extend over at least one complete cycle of fluctuations. In order to obtain a reliable mean value, it is recommended that the maximum permissible fluctuation in the signal shall be less than that specified in Table 5.1 for 3 readings.

Averaging may be introduced in measuring systems where necessary to reduce the amplitude of fluctuations to within acceptable values. For head measurement, this limit is ±3 per cent; the limits for flow, torque and power measurements are to be taken from the appropriate standards. (Fluctuations of speed measurements will have no significant influence on the efficiency results but may have an effect on the estimation of the guarantee point.) Where it is possible that damping will significantly affect the accuracy of the readings, the tests shall be repeated using a symmetrical and linear damping device, for example a capillary tube.

5.3.2.3 Number of sets of observations

5.3.2.3.1 Steady conditions

In steady and well controlled test conditions, only one set of readings of individual quantities shall be recorded for the specified test condition. This set shall be recorded only after the observers have been satisfied that the fluctuations have settled down within the limits specified in Sections 5.3.2.2 and 5.3.2.3.2.

5.3.2.3.2 Unsteady Conditions

In cases where the unsteadiness of test conditions gives rise to doubts concerning the accuracy of the tests, the following procedure shall be followed. Repeated readings of the measurements shall be made at the guarantee point, only speed and fluid bulk temperature being allowed to be controlled. Throttle valve, water level, gland adjustment, balance water settings etc. shall be left completely unaltered. The difference between these repeated readings of the same quantities will be a measure of the unsteadiness of the test conditions, which are at least partly influenced by the pump under test as well as the installation.

A minimum of three sets of readings shall be taken at the guaranteed point and the value of each separate reading and of the efficiency derived from each set of readings shall be recorded. The percentage difference between the largest and smallest values of each quantity shall not be greater than that given in Table 5.1. It will be noted that a wider tolerance is permitted if the number of readings is increased up to the maximum requirement of nine readings.

These tolerances are designed to ensure that the random uncertainty determined from the random scatter, taken together with the systematic uncertainties given in Tables 5.2 and 5.4, will result in overall measurement uncertainties not greater than those given in Table 5.3 and 5.5.

Table 5.1 Maximum Permissible Range of Readings

Number of sets of readings	Maximum permissible difference between largest and smallest readings of each quantity				
	Differential temperature mK		Head per cent		Fluid bulk temperature K
	BS 5316 Part 1 (Class C)	BS 5316 Part 2 (Class B)	BS 5316 Part 1 (Class C)	BS 5316 Part 2 (Class B)	
3	H/20	H/50	1.8	0.8	0.1
5	H/10	H/25	3.5	1.6	0.1
7	H/7.5	H/19	4.5	2.2	0.1
9	H/6.3	H/15	5.8	2.8	0.1

(H is pump total head in metres)

The arithmetic mean of all the readings for each quantity shall be taken as the actual value for the purposes of the test. If the values given in Table 5.1 cannot be reached, the cause shall be ascertained, the conditions rectified and a new complete set of readings made, all the readings in the original set shall be rejected. No reading in the set of observations may be rejected because it lies outside the limits.

In the case where the excessive variation is not due to procedure or instrumentation errors and cannot therefore be eliminated, the uncertainties may be calculated by statistical analysis.

5.4 Uncertainty of Measurement

For the purpose of this document, the uncertainty on the measurement of a variable is defined as twice the standard deviation of this variable. The uncertainty shall be calculated and indicated as such for any measurement in accordance with this document. When component uncertainties, the combination of which gives the uncertainty, are independent one from the other, are small and numerous and have a Gaussian distribution, there is 95 per cent probability that the true value will lie within the range of the measured value ± the uncertainty.

This test code specifies the standard methods of measurement and instruments, to be used for the determination of inlet and outlet total head, or pump total head, and differential temperature. Any device or method which by calibration or comparison with ISO standards has been demonstrated to be capable of measuring with systematic uncertainties not exceeding those given in Table 5.2 or 5.4 may be used. The devices or methods shall be agreed upon by the parties concerned.

Where tests are required to meet the limits associated with BS 5316 : Part 1 : 1976 (Class C) the values shown in Tables 5.2 and 5.3 shall apply.

Table 5.2 BS 5316 : Part 1 (Class C)
Permissible Systematic Uncertainties of Measuring Instruments

Measured quantity	Permissible limit
Pump total head	±2.5 per cent
Fluid temperature	±0.1 °C
Speed of rotation	±1.4 per cent
Differential temperature	± H/10 mK (H in metres)

If the recommendations concerning the systematic errors of instruments as given in Table 5.2 and those concerning the actual test procedure are followed, it shall be assumed that the overall limits of error will not exceed those given in Table 5.3 for pump total heads greater than 20 m.

Table 5.3 BS 5316 : Part 1 (Class C)
Resulting Overall Uncertainties

Measured quantity	Error limit
Pump total head	±3.5 per cent
Speed of rotation	±2.0 per cent
Pump efficiency	±5.0 per cent

Where tests are required to meet the limits associated with BS 5316 : Part 2 : 1977 (Class B) then the values shown in Tables 5.4 and 5.5 shall apply.

Table 5.4 BS 5316 : Part 2 (Class B)
Permissible Systematic Uncertainties of Measuring Instruments

Measured quantity	Permissible limit
Pump total head	±1.0 per cent
Fluid temperature	±0.1 °C
Speed of rotation	±0.35 per cent
Differential temperature	± H/25 mK (H in metres)

If the recommendations concerning the systematic errors of instruments as given in Table 5.4 and those concerning the actual test procedure are followed, it shall be assumed that the overall limits of error will not exceed those given in Table 5.5 for pump total heads greater than 35 m.

Table 5.5 BS 5316 : Part 2 (Class B)
Resulting Overall Uncertainties

Measured quantity	Error limit
Pump total head	±1.5 per cent
Speed of rotation	±0.5 per cent
Pump efficiency	±2.8 per cent

6 MEASUREMENT OF HEAD

6.1 Pressure Tappings

Static pressure tappings shall comply with the requirements shown in Fig. 6.1 and shall be free from burrs and irregularities and flush with, and normal to, the inner wall of the pipe. The diameter of the pressure tappings shall be between 2 and 6 mm or equal to 1/10 of the pipe diameter, whichever is the less. The length of a pressure tapping hole shall not be less than two and a half times its diameter.

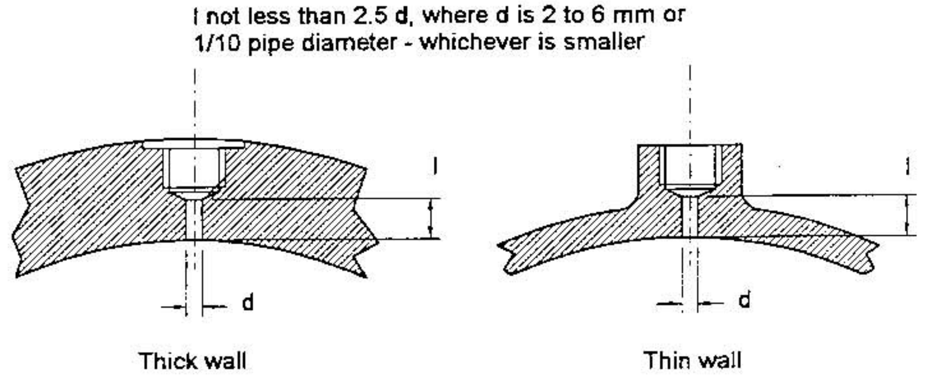

Figure 6.1 Requirements for Static Pressure Tappings

The bore of the pipe containing the tappings shall be clean, smooth and resistant to chemical reaction with the liquid being pumped. Any coating such as paint applied to the bore shall be intact. If the pipe is welded longitudinally, the tapping hole shall be displaced as far as possible from the weld.

Pipes connecting pressure tappings to possible damping devices and to instruments shall be at least equal in bore to the bore of the pressure tappings. The system shall be free from leaks. It is recommended that transparent tubing be used so as to allow determination of the amount of fluid or air in the tubing. ISO 2186 gives indications as to the connecting tubes.

These tappings shall be located at a distance of 2 pipe diameters upstream of the pump inlet flange when the length of this pipe allows it and at a distance of 2 pipe diameters downstream of the pump outlet flange. When the distance of 2 pipe diameters upstream cannot be reached (for example in the case of a rather short inlet bellmouth) the available straight length shall be divided so as to take the best possible advantage of the local conditions between the upstream and downstream

6.1.1 Combined pressure and temperature tappings

Where a single tapping point is used for the measurement of pressure and the insertion of a temperature probe it is recommended that tappings are a minimum of 1/2 inch BSP with a through bore to suit the requirements of the probe. Fig. 6.2 shows such a fitting. A valve may be fitted between the pipe boss and the tee-piece fitting.

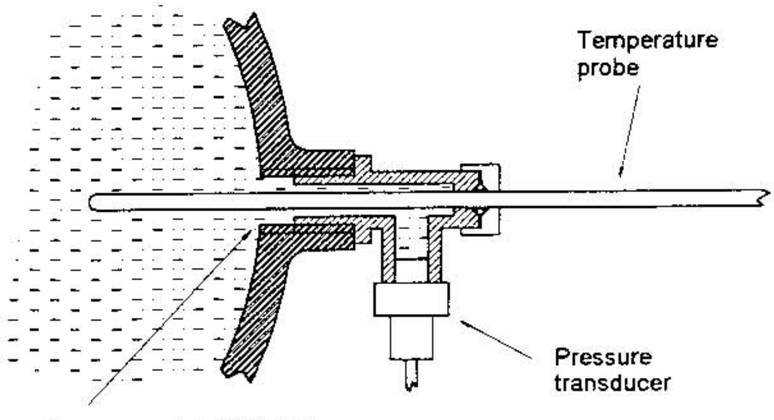

Figure 6.2 Combined Pressure and Temperature Tapping

6.2 Measurement of Head - BS 5316 : Part 1 (Class C)

Fig. 6.3 shows the arrangement of tappings and pressure transducers for a test to meet the uncertainty levels associated with BS5316 : Part 1 (Class C) - which are given in Table 5.3. Single inlet and outlet tappings conforming to Section 6.1.1 may be used for Class C testing.

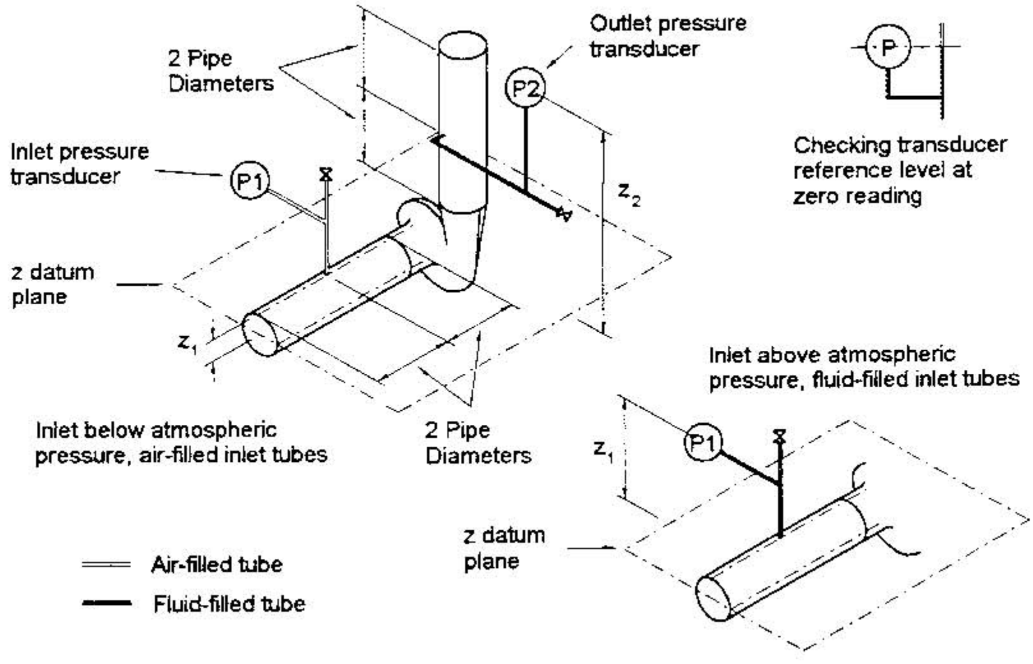

Figure 6.3 Arrangements for Measurement of Head
BS 5316 : Part 1 (Class C)

The elevations, z, are measured upwards from the datum plane which shall be chosen at any convenient level. If the pump is operated with the inlet pressure below atmospheric pressure the inlet pressure measurement tubes may be operated full of air. In this case the inlet measurement point elevation, z_1, is the height of the tapping point. Where the pressure measurement tubes are full of fluid, the elevation is that of the transducer. Both cases are shown in Fig. 6.3.

The inlet and outlet total heads are defined as:

$$H_1 = \frac{p_1}{\rho_1 g} + z_1 + \frac{U_1^2}{2g}$$

$$H_2 = \frac{p_2}{\rho_2 g} + z_2 + \frac{U_2^2}{2g}$$

6.3 Measurement of Head - BS 5316 : Part 2 (Class B)

When a test is required to meet the uncertainty levels associated with BS5316 : Part 2 (Class B) - which are given in Table 5.5 - the arrangement described in this section, and illustrated in Fig. 6.4, shall be used.

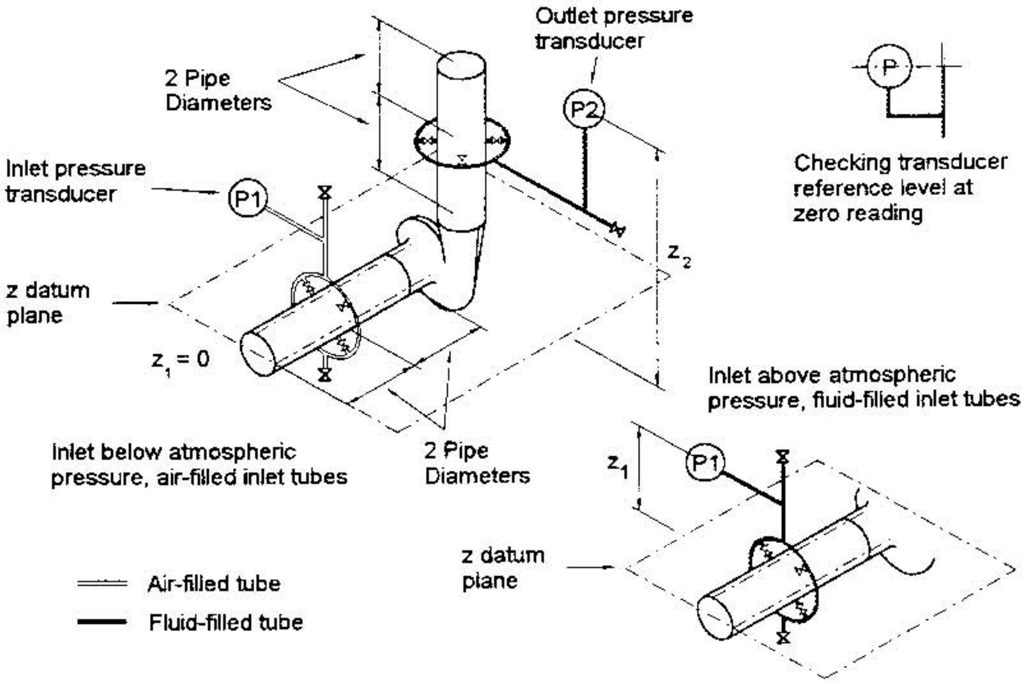

Figure 6.4 Arrangements for Measurement of Head
BS 5316 : Part 2 (Class B)

Four static pressure tappings are to be provided, symmetrically disposed around the circumference of the inlet and of the outlet pipes.

The elevations, z, are measured upwards from the datum plane which shall be chosen at any convenient level. If the pump is operated with the inlet pressure below atmospheric pressure the inlet pressure measurement tubes may be operated full of air. In this case the inlet measurement point elevation, z_1, is the height of the inlet pipe centre line at the measuring position. Where the pressure measurement tubes are full of fluid, the elevation is that of the transducer. Both cases are shown in Fig. 6.4.

The pressure tappings shall be connected through shut-off cocks to a ring manifold of cross-sectional area not less than the sum of the cross-sectional areas of the tappings, so that the pressure from any single tapping may be measured if required. Before making testing, the pressure with each tapping alone open shall be taken, at the normal test condition of the pump, for each of the four tappings at inlet and outlet. If one of the readings shows a difference of more than 0.5 per cent of the total head with respect to the arithmetical mean of the four measurements, or if it shows a deviation of more than the velocity head in the measuring section, the cause of the spread shall be ascertained and the measuring conditions rectified before the test proper is started.

The inlet and outlet total heads shall be determined from the pressure heads measured at the ring manifolds, the gravitational heads of the points of measurement and the velocity heads calculated as though there were uniform velocity at the measuring positions:

$$H_1 = \frac{p_1}{\rho_1 g} + z_1 + \frac{U_1^2}{2g}$$

$$H_2 = \frac{p_2}{\rho_2 g} + z_2 + \frac{U_2^2}{2g}$$

6.4 Instrumentation

6.4.1 Pressure transducers

Use of an electronic data acquisition system is preferable when testing pumps by the thermodynamic method. This requires the use of electronic pressure measuring devices referred to in this document as pressure transducers. The calibration of these devices shall be checked for each test.

6.4.2 Bourdon dial gauges

When this type of gauge is used for inlet and outlet pressure measurements to ascertain pump total head, it is recommended that the difference between two consecutive scale graduations be within 1.5 and 3 mm for both measurements, and that this difference corresponds to not more than 5 per cent of the pump total head. The calibration of these measuring devices shall be checked for each test.

6.4.3 Calibration

Bourdon gauges and pressure transducers shall be calibrated against a deadweight tester or a reference pressure transducer. The overall uncertainty of the calibration shall enable pressure measurements to be made within the uncertainty specified in Section 5.4.

6.5 Effect of Pre-swirl Induced by the Pump

Errors in the determination of the inlet total head can occur if the pump induces a pre-swirl of the flow at the inlet measurement position. The following method shall be used to detect the presence of pre-swirl induced by the pump.

If the pump draws from a free surface reservoir, where the water level and the pressure acting on it are constant, the head losses between this reservoir and the inlet measuring section follow a quadratic law with the flow rate and therefore the same holds true for the inlet total head. At higher rates of flow where there is no pre-swirl induced by the pump at the inlet measuring section, measuring points ranged along a straight line $H_1 = m + n\,q^2$ (where m and n are constants), will be obtained - Fig. 6.5. However, with lower flow rates the appearance of pre-swirl induced by the pump will cause errors in pressure measurement resulting in deviations from this straight line. The corrected value for H_1 shall be taken from the straight line.

If the pump does not draw from a constant head reservoir, another measuring section shall be selected sufficiently far upstream where pre-swirl induced by the pump is known to be absent. It is then possible to use the same reasoning for the head losses between the two sections (but not directly for the inlet total head).

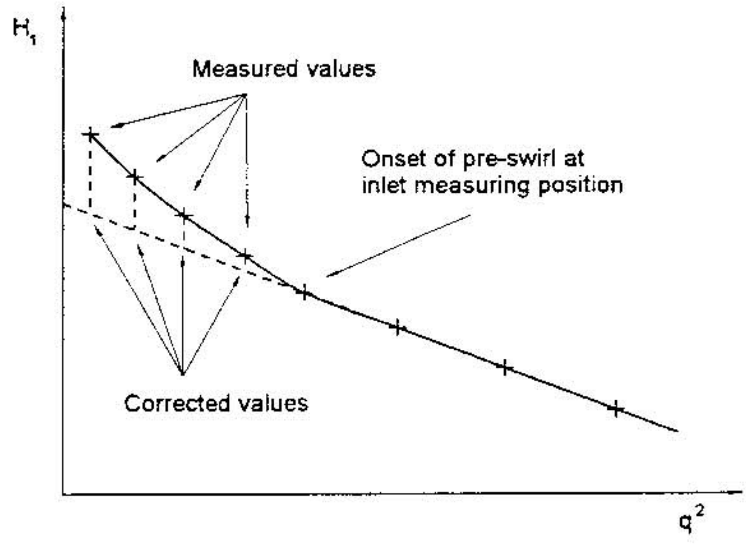

Figure 6.5 Correction of the Measured Total Head at Inlet for Pre-swirl Induced by the Pump

7 Measurement of Temperature

7.1 Thermometers

Any sensitive and accurate thermometers can be used for the thermodynamic method provided their calibration and stability ensure the desired accuracy in the measurement of the temperature difference. The uncertainty in temperature measurement shall meet the limits given in Tables 5.2 and 5.4 at fluid velocities at least as high as those encountered in the pump testing.

The thermometers shall be stable over a range of ±5 K about the mean temperature to be measured.

7.1.1 Calibration

For the measurement of fluid temperature the thermometer shall be calibrated against a traceable standard. The overall uncertainty of the calibration shall enable temperature measurements to be made within the uncertainty specified in Section 5.4.

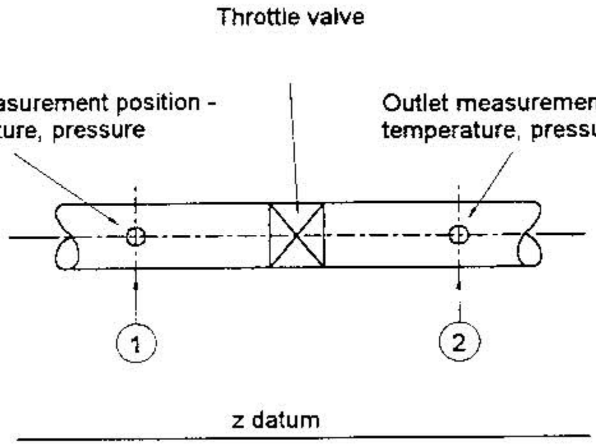

Figure 7.1 Throttling Calorimeter

The system for the measurement of differential temperature shall be calibrated using a throttling calorimeter - Fig. 7.1. In this device a flow of fluid is throttled using a valve or similar device. Since there is no transfer of mechanical energy to the fluid:

$$E_m = \bar{a}(p_2 - p_1) + \bar{c}_p(\theta_2 - \theta_1) + \frac{U_2^2 - U_1^2}{2} + g(z_2 - z_1) + \Delta E_m = 0$$

If the calorimeter is well insulated ΔE_m is zero and, if the test section is horizontal and the inlet and outlet measuring positions are in pipes of equal diameter, $z_1 = z_2$ and $U_1 = U_2$. Under these conditions:

$$\theta_2 - \theta_1 = \frac{\bar{a}(p_1 - p_2)}{\bar{c}_p}$$

Thus if p_1, p_2 and θ_1 are measured the differential temperature can be calculated and compared with the measured value.

This calibration should be carried over a range of differential temperature, fluid temperature, fluid velocity and probe insertion depth corresponding to the pump test situation.

If the operation of the temperature probes and the calorimeter is satisfactory the calibration will be unchanged when the upstream and downstream probes and their associated equipment are swopped.

As part of the project under which this document was developed, a throttling calorimeter has been established at NEL, and is available for the calibration of differential temperature measurement systems. The test sections are 150 mm in diameter. Differential temperatures from 5 to 130 mK and water velocities up to 7 m/s are attainable in the calorimeter. The rig operates at close to ambient temperature and the rate of rise of temperature during operation is less than 1 K/hr.

7.2 Probe Position

Only one thermometer is required at the inlet measurement position and one at the outlet position. For large pumps - particularly those with horizontal pipes of diameter greater than 2 m at the measurement positions - more than one thermometer may be used at each position by agreement between the parties. The thermometer(s) and the pressure measurement tapping(s) at each position shall be in the same plane cross-section normal to the pipe axis.

Insertion probes are recommended for pump total heads less than 100 m.

Probes should be inserted to a minimum depth of 50 mm beyond the pipe wall, subject to several observations to confirm that stable readings are being obtained.

Probes may be susceptible to vibration due to turbulence in the flowing fluid or vortex shedding from the probe. Increasing fluid velocity aggravates this problem. If vibration of a temperature probe is detected a new location should be found for it.

7.2.1 Velocity effects

The accuracy of temperature measurement can be seriously reduced if the fluid velocity at the measuring positions is sufficiently high to induce vibration of the probes. Measurement under such conditions should be avoided. The operation of the probes should be proven at fluid velocities and insertion depths at least as severe as those encountered in the tests.

7.2.2 Recovery factor

The recovery factor is applied to the velocity heads at the measuring positions to correct the measured temperatures for the viscous and momentum heating effects of the fluid moving past the stationary probes.

Where the inlet and outlet measuring section diameters are equal, the differential velocity head is zero and the recovery factor has no effect on the differential temperature - provided that the inlet and outlet probes are of the same design.

The recovery factor depends on the design of the temperature probes. As a general guide correction will be necessary where the differential velocity head is greater than 0.5 per cent of the pump total head.

7.3 Effect of Flow Recirculating from the Pump Inlet

At flow rates well below the best efficiency flow rate for the pump, fluid may recirculate back from the pump inlet and past the inlet measuring position. This fluid will be heated during its turbulent passage into and out of the impeller, and may include fluid which has been through the impeller and has returned via the wear rings. In these circumstances the reading of the inlet thermometer will be higher than the temperature of the upstream fluid and the measured differential temperature will be in error. The inlet temperature reading may also become much less steady when recirculation reaches the inlet measuring position.

The onset of this condition shall be detected by plotting the measured inlet temperature against the square of the flow rate (Fig. 7.2) and noting the point at which the temperature deviates from the almost constant value noted at high flow rates. In closed loop test rigs care should be taken to distinguish between an inlet temperature rise due to recirculation and the rise in temperature with time as the rig is run.

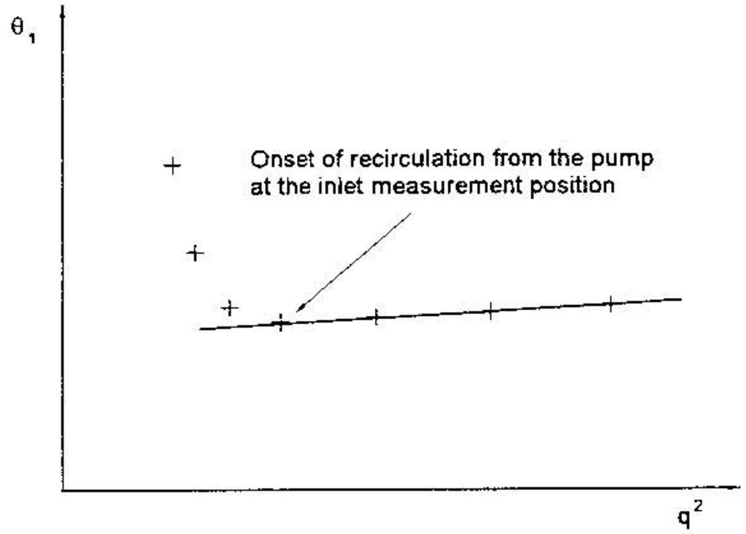

Figure 7.2 Detection of the Onset of Recirculation from the Pump at the Inlet Measurement Position

The thermodynamic method of efficiency measurement shall not be applied in flow conditions where this recirculation is affecting the inlet temperature measurement.

8 MEASUREMENT OF POWER INPUT

If required, the shaft input power to the pump shall be measured by one of the following methods:

a) Indirectly by subtracting the various electrical and mechanical losses from the measured electrical power input to the driving motor;

b) Directly by determination of the speed and torque at the pump shaft.

8.1 Indirect Method

The indirect method is normally used. In this method the electrical input power to the motor, P_{gr}, is measured, and the pump input power, P, is the product of P_{gr} and the efficiency of the motor, less any drive train losses between the motor and the pump - for example gear box losses.

Ideally the electrical power should be measured at the motor terminals. If this cannot be done the measured power shall be decreased by the losses occurring between the location of the power meter and the motor terminals. These losses shall be determined by calculation. The losses should include cable losses and starter and controller losses.

Measurement of electric power shall be by a Class 0.5 wattmeter (IEC Publication 51) using either a two wattmeter or three wattmeter method.

8.2 Direct Method

The power input to the pump may be determined by measurement of shaft torque and shaft speed. BS 5316 : Part 3 gives more details of this procedure.

9 DETERMINATION OF FLOW RATE

9.1 Direct Measurement

The preferred method of determination of flow rate is by direct measurement using equipment in accordance with the relevant standards. Possible methods are:

a) Weighing tank method (ISO 4185);

b) Volumetric tank method (ISO 8316);

c) Orifice plates, venturi tubes and nozzles (ISO 5167, ISO 2186);

d) Thin plate weirs (ISO 1438/1, ISO 4373);

e) Velocity area methods (ISO 3354, ISO 3966);

f) Tracer methods (ISO 2975);

g) Electromagnetic meters (ISO 9104);

h) Turbine meters and ultrasonic meters when suitably calibrated and operated in appropriate conditions.

9.2 Calculating the Flow rate From Measured Power Input

Where the flow rate can not be measured directly it can be deduced from the input power to the pump, P, measured as described in Section 8, and the thermodynamic method efficiency measurement, η. The flow rate is then given by:

$$q = \frac{\eta P}{\rho g H}$$

where H is the pump total head.

The flow rate calculated by this method is affected by any errors in the pump head and differential temperature measurements caused by installation effects.

10 CORRECTIONS

Where the sum of the corrections for heat transfer and bearing and shaft seal losses, as estimated according to Sections 10.1 and 10.2, exceed 1% of the shaft input power the limits of uncertainty given in 5.4 can not be guaranteed.

10.1 Power Losses in Bearings and Shaft Seals

The efficiency measured by the thermodynamic method does not take account of external losses in bearings and shaft sealing devices, where the heat generated by these losses is not removed by the pumped fluid. These losses are generally small compared to the total power absorbed, but will be more significant in a low power machine - especially if it is fitted with a complex sealing system.

In certain mechanical seal arrangements a recirculation flush is provided by taking pumped fluid from a high pressure point on the casing, through the seal cavity and returning it to the main flow - through balance holes for example. In such cases it may be assumed that the frictional heat from the seals contributes to the temperature rise across the pump and no additional external seal loss allowance need be made. Sealing systems to API 610 Plan 11 fall into this category.

Table 10.1 gives coefficients for the estimation of bearing and seal losses for various combinations of components. These coefficients are used in the following formula to calculate the external loss:

$$P_x = k_x N d^2$$

- where d is the shaft seal diameter.

Table 10.1 Bearing and Seal Loss Coefficients

Configuration	k_x (W min/m^2)
End suction, overhung impeller:	
Two ball bearings, packed gland	48
Two ball bearings, mechanical seal (Plan 11)	28
One ball, one roller bearing, packed gland	54
One ball, one roller bearing, mechanical seal (Plan 11)	34
One angular contact bearing and one roller bearing double balanced mechanical seal	13
Double entry impeller between bearings:	
Two ball bearings, two packed glands	68
Two ball bearings, two mechanical seals (Plan 11)	28
One angular contact bearing and one roller bearing, two mechanical seals (Plan 11)	40

The specific energy loss is then given by:

$$E_x = \frac{P_x}{q_m}$$

Alternative means may be used to estimate these losses subject to agreement between the parties.

10.2 Heat Transfer

Where the pumped fluid is at a similar temperature to the ambient temperature, the correction for heat lost through the casing walls will generally be negligible, but where there is a significant temperature difference a correction may be necessary. The the loss of mechanical energy by heat transfer, per unit mass of fluid flowing is given by:

$$\Delta E_m = \frac{1}{q_m} P' A(\theta_1 - \theta_a)$$

- where A is the exposed surface area of the pipework and the pump casing between the inlet and outlet temperature measurement positions. The heat-transfer coefficient, P′, through metallic pipework and pump casing, is typically 10 $W/(m^2 K)$.

Alternative means may be used to estimate the heat-transfer coefficient by agreement between the parties. Cases where heavy condensation is occurring may require special treatment.

Where bearings and seals are supplied by external lubricant and coolant systems it may be possible to determine the consequent heat losses from the flow rates and temperature rises of these fluids. Otherwise estimated values shall be agreed by the parties.

10.3 Speed

The pump shall be tested at a speed in the range of the specified speed ±20 per cent. The efficiency is not significantly affected by variations of speed in this range. However, if it is required to correct the test results from the test speed, N_T, the specified speed, N_G, the following relations shall be used:

$$q = q_T\left(\frac{N_G}{N_T}\right)$$

$$H = H_T\left(\frac{N_G}{N_T}\right)^2$$

$$P = P_T\left(\frac{N_G}{N_T}\right)^3$$

$$\eta = \eta_T$$

ANNEX A - REFERENCES

BS 5316 : Part 1 : 1976 Acceptance tests for centrifugal, mixed flow and axial pumps. Part 1. Class C tests. (ISO 2548 - 1973)

BS 5316 : Part 2 : 1977 Acceptance tests for centrifugal, mixed flow and axial pumps. Part 2. Class B tests. (ISO 3555 - 1977)

BS 5316 : Part 3 : 1988 Acceptance tests for centrifugal, mixed flow and axial pumps. Part 3. Precision class tests. (ISO 5198 - 1987)

ISO 1438/1 Water flow measurement in open channel using weirs and venturi flumes. Part 1: Thin-plate weirs.

ISO 2186 Fluid flow in closed conduits - Connections for pressure signal transmissions between primary and secondary elements.

ISO 2975 Measurement of water flow in closed conduits - Tracer methods. Parts 1, 2, 3, 6 and 7.

ISO 3354 Measurement of clean water flow in closed conduits - Velocity -area methods using current-meters in full conduits and under regular flow conditions.

ISO 3966 Measurement of fluid flow in closed conduits - Velocity -area methods using Pitot static tubes.

ISO 4185 Measurement of liquid flow in closed conduits - Weighing method.

ISO 4373 Measurement of liquid flow in channels - Water level measuring devices.

ISO 5167 Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full.

ISO 8316 Measurement of liquid flow in closed conduits - Method by collection of the liquid in a volumetric tank.

ISO 9104 Measurement of liquid flow in closed conduits - Methods of evaluating the performance of electromagnetic flowmeters for liquids.

IEC Publication 51 Recommendations for direct acting electrical measuring instruments and their accessories.

ANNEX B - THERMODYNAMIC PROPERTIES OF WATER

Values of the coefficients a, ρ ($V_m = 1/\rho$) and c_p are given in Tables B1, B2 and B3 respectively, as functions of temperature and pressure at intervals from 0 to 275 °C and from 0 to 300 bar gauge (1 bar = 10^5 Pa).

Table B1 Isothermal Coefficient, a (10^{-3} m^3/kg)

Pressure	Temperature (°C)							
(bar gauge)	0	5	10	15	20	25	30	35
0	1.018 6	0.995 9	0.975 4	0.957 1	0.941 1	0.926 5	0.912 4	0.899 0
20	1.015 3	0.993 2	0.973 1	0.955 2	0.939 4	0.925 0	0.911 1	0.897 9
40	1.012 1	0.990 5	0.970 8	0.953 2	0.937 7	0.923 5	0.909 8	0.896 7
60	1.008 9	0.987 8	0.968 6	0.951 3	0.936 0	0.922 0	0.908 6	0.895 6
80	1.005 8	0.985 2	0.966 3	0.949 4	0.934 3	0.920 6	0.907 3	0.894 5
100	1.002 7	0.982 6	0.964 1	0.947 4	0.932 7	0.919 1	0.906 0	0.893 4
120	0.999 7	0.980 0	0.961 9	0.945 6	0.931 0	0.917 6	0.904 7	0.892 3
140	0.996 8	0.977 4	0.959 7	0.943 7	0.929 4	0.916 2	0.903 5	0.891 2
160	0.993 8	0.974 9	0.957 6	0.941 8	0.927 7	0.914 7	0.902 2	0.890 1
180	0.990 9	0.972 4	0.955 4	0.940 0	0.926 1	0.913 3	0.900 9	0.889 0
200	0.988 1	0.970 0	0.953 3	0.938 1	0.924 5	0.911 9	0.899 7	0.887 9
220	0.985 3	0.967 6	0.951 2	0.936 3	0.922 9	0.910 5	0.898 5	0.886 9
240	0.982 5	0.965 2	0.949 1	0.934 5	0.921 3	0.909 1	0.897 2	0.885 8
260	0.979 8	0.962 8	0.947 1	0.932 7	0.919 7	0.907 7	0.896 0	0.884 7
280	0.977 2	0.960 5	0.945 1	0.930 9	0.918 2	0.906 3	0.894 8	0.833 7
300	0.974 5	0.958 2	0.943 0	0.929 2	0.916 6	0.904 9	0.893 6	0.882 6

Pressure	Temperature (°C)							
(bar gauge)	40	45	50	55	60	65	70	75
0	0.886 1	0.873 9	0.862 3	0.851 1	0.840 0	0.828 8	0.817 8	0.806 7
20	0885 2	0.873 1	0.861 7	0.850 6	0.839 5	0.828 5	0.817 6	0.806 7
40	0.884 2	0.872 3	0.861 0	0.850 0	0.839 1	0.828 2	0.817 4	0.806 6
60	0.883 3	0.871 5	0.860 3	0.849 5	0.838 7	0.827 9	0.817 2	0.806 6
80	0.882 3	0.870 7	0.859 7	0.848 9	0.838 3	0.827 6	0.817 1	0.806 5
100	0.881 4	0.869 9	0.859 0	0.848 4	0.837 8	0.827 3	0.816 9	0.806 4
120	0.880 4	0.869 1	0.858 3	0.847 8	0.837 4	0.827 0	0.816 7	0.806 4
140	0.879 5	0.868 3	0.857 6	0.847 3	0.837 0	0.826 7	0.816 5	0.806 3
160	0.878 5	0.867 5	0.857 0	0.846 7	0.836 5	0.826 4	0.816 3	0.806 2
180	0.877 6	0.866 7	0.856 3	0.846 2	0.836 1	0.826 1	0.816 0	0.806 1
200	0.876 7	0.865 9	0.855 6	0.845 6	0.835 7	0.825 7	0.815 8	0.806 0
220	0.875 7	0.865 1	0.855 0	0.845 1	0.835 2	0.825 4	0.815 6	0.805 9
240	0.874 8	0.864 3	0.854 3	0.844 5	0.834 8	0.825 1	0.815 4	0.805 7
260	0.873 9	0.863 5	0.853 6	0.844 0	0.834 3	0.824 7	0.815 1	0.805 6
280	0.873 0	0.862 7	0.853 0	0.843 4	0.833 9	0.824 4	0.814 9	0.805 5
300	0.872 1	0.862 0	0.852 3	0.842 8	0.833 4	0.824 0	0.814 7	0.805 3

Table B1 Isothermal Coefficient, a (10^{-3} m^3/kg) (continued)

Pressure (bar gauge)	Temperature (°C)							
	80	85	90	95	100	105	110	115
0	0.795 8	0.784 9	0.774 1	0.763 1	0.751 8	-	-	-
20	0.795 9	0.785 1	0.774 4	0.763 6	0.752 4	0.740 8	0.728 9	0.716 6
40	0.795 9	0.785 3	0.774 7	0.764 0	0.753 0	0.741 6	0.729 8	0.717 7
60	0.796 0	0.785 5	0.775 0	0.764 4	0.753 5	0.742 3	0.730 7	0.718 7
80	0.796 0	0.785 6	0.775 3	0.764 8	0.754 1	0.742 9	0.731 5	0.719 7
100	0.796 1	0.785 8	0.775 6	0.765 2	0.754 6	0.743 6	0.732 3	0.720 6
120	0.796 1	0.785 9	0.775 8	0.765 6	0.755 1	0.744 2	0.733 0	0.721 5
140	0.796 2	0.786 1	0.776 1	0.766 0	0.755 5	0.744 8	0.733 8	0.722 4
160	0.796 2	0.786 2	0.776 3	0.766 3	0.756 0	0.745 4	0.734 5	0.723 3
180	0.796 2	0.786 3	0.776 5	0.766 6	0.756 5	0.746 0	0.735 2	0.724 1
200	0.796 2	0.786 4	0.776 8	0.767 0	0.756 9	0.746 5	0.735 9	0.724 9
220	0.796 2	0.786 5	0.776 9	0.767 3	0.757 3	0.747 1	0.736 5	0.725 7
240	0.796 2	0.786 6	0.777 1	0.767 6	0.757 7	0.747 6	0.737 2	0.726 5
260	0.796 1	0.786 7	0.777 3	0.767 8	0.758 1	0.748 1	0.737 8	0.727 3
280	0.796 1	0.786 8	0.777 5	0.768 1	0.758 5	0.748 6	0.738 4	0.728 0
300	0.796 1	0.786 8	0.777 6	0.768 3	0.758 8	0.749 0	0.739 0	0.728 7

Pressure (bar gauge)	Temperature (°C)							
	120	125	130	135	140	145	150	155
0	-	-	-	-	-	-	-	-
20	0.704 0	0.690 9	0.677 5	0.663 6	0.649 4	0.634 6	0.618 9	0.602 5
40	0.705 2	0.692 3	0.679 1	0.665 4	0.651 4	0.636 8	0.621 5	0.605 3
60	0.706 4	0.693 7	0.680 6	0.667 2	0.653 4	0.639 0	0.623 9	0.608 1
80	0.707 5	0.695 0	0.682 1	0.668 9	0.655 3	0.641 1	0.626 3	0.610 7
100	0.708 6	0.696 3	0.683 6	0.670 5	0.657 1	0.643 2	0.628 6	0.613 3
120	0.709 7	0.697 5	0.685 0	0.672 1	0.658 9	0.645 2	0.630 9	0.615 8
140	0.710 7	0.698 7	0.686 4	0.673 7	0.660 7	0.647 2	0.633 0	0.618 2
160	0.711 8	0.699 9	0.687 7	0.675 2	0.662 4	0.649 1	0.635 2	0.620 6
180	0.712 7	0.701 1	0.689 0	0.676 7	0.664 1	0.651 0	0.637 3	0.622 9
200	0.713 7	0.702 2	0.690 3	0.678 2	0.665 7	0.652 8	0.639 3	0.625 2
220	0.714 6	0.703 3	0.691 6	0.679 6	0.667 3	0.654 6	0.641 3	0.627 4
240	0.715 6	0.704 3	0.692 8	0.681 0	0.668 8	0.656 3	0.643 2	0.629 6
260	0.716 4	0.705 3	0.694 0	0.682 3	0.670 3	0.658 0	0.645 1	0.631 6
280	0.717 3	0.706 3	0.695 1	0.683 6	0.671 8	0.659 6	0.646 9	0.633 7
300	0.718 1	0.707 3	0.696 2	0.684 9	0.673 2	0.661 2	0.648 7	0.635 7

Table B1 Isothermal Coefficient, a (10^{-3} m^3/kg) (continued)

Pressure (bar gauge)	Temperature (°C)							
	160	165	170	175	180	185	190	195
0	-	-	-	-	-	-	-	-
20	0.585 3	0.567 2	0.548 3	0.528 5	0.507 4	0.484 3	0.459 4	0.432 5
40	0.588 4	0.570 7	0.552 1	0.532 8	0.512 1	0.489 6	0.465 4	0.439 2
60	0.591 4	0.574 1	0.555 9	0.536 9	0.516 7	0.494 8	0.471 1	0.445 6
80	0.594 4	0.577 3	0.559 5	0.540 9	0.521 1	0.499 7	0.476 6	0.451 8
100	0.597 3	0.580 5	0.563 0	0.544 8	0.525 4	0.504 5	0.481 9	0.457 8
120	0.600 1	0.583 6	0.566 5	0.548 6	0.529 6	0.509 1	0.487 1	0.463 5
140	0.602 8	0.586 6	0.569 8	0.552 2	0.533 6	0.513 6	0.492 1	0.469 1
160	0.605 4	0.589 6	0.573 0	0.555 8	0.537 6	0.518 0	0.496 9	0.474 5
180	0.608 0	0.592 4	0.576 2	0.559 3	0.541 4	0.522 2	0.501 7	0.479 7
200	0.610 5	0.595 2	0.579 2	0.562 7	0.545 1	0.526 3	0.506 2	0.484 8
220	0.613 0	0.597 9	0.582 2	0.565 9	0.548 7	0.530 3	0.510 7	0.489 7
240	0.615 3	0.600 5	0.585 1	0.569 1	0.552 3	0.534 2	0.515 0	0.494 5
260	0.617 7	0.603 1	0.588 0	0.572 3	0.555 7	0.538 0	0.519 2	0.499 2
280	0.619 9	0.605 6	0.590 7	0.575 3	0.559 0	0.541 7	0.523 2	0.503 7
300	0.622 1	0.608 0	0.593 4	0.578 2	0.562 3	0.545 3	0.527 2	0.508 0

Pressure (bar gauge)	Temperature (°C)							
	200	205	210	215	220	225	230	235
0	-	-	-	-	-	-	-	-
20	0.403 7	0.372 8	0.339 9	-	-	-	-	-
40	0.411 2	0.381 3	0.349 4	0.315 5	0.279 5	0.241 5	0.199 4	0.150 9
60	0.418 4	0.389 3	0.358 4	0.325 5	0.290 7	0.254 0	0.213 3	0.166 9
80	0.425 3	0.397 0	0.367 0	0.335 1	0.301 4	0.265 8	0.226 6	0.182 0
100	0.432 0	0.404 5	0.375 3	0.344 3	0.311 6	0. 277 1	0.239 2	0.196 4
120	0.438 4	0.411 6	0.383 2	0.353 2	0.321 4	0.288 0	0.251 3	0.210 1
140	0.444 6	0.418 5	0.390 9	0.361 7	0.330 9	0.298 4	0.262 9	0.223 2
160	0.450 6	0.425 2	0.398 3	0.369 9	0.340 0	0.308 4	0.274 1	0.235 7
180	0.456 4	0.431 7	0.405 5	0.377 9	0.348 7	0.318 1	0.284 8	0.247 7
200	0.462 1	0.437 9	0.412 4	0.385 5	0.357 2	0.327 4	0.295 1	0.259 3
220	0.467 5	0.444 0	0.419 2	0.392 9	0.365 4	0.336 4	0.305 0	0.270 4
240	0.472 8	0.449 9	0.425 6	0.400 1	0.373 3	0.345 1	0.314 6	0.281 1
260	0.478 0	0.455 6	0.431 9	0.407 0	0.380 9	0.353 4	0.323 9	0.291 4
280	0.482 9	0.461 1	0.438 0	0.413 7	0.388 2	0.361 5	0.332 8	0.301 3
300	0.487 8	0.466 4	0.443 9	0.420 2	0.395 4	0.369 3	0.341 4	0.310 8

Table B1 Isothermal Coefficient, a (10^{-3} m^3/kg) (concluded)

Pressure (bar gauge)	Temperature (°C)							
	240	245	250	255	260	265	270	275
0	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
40	0.095 9	0.034 4	-	-	-	-	-	-
60	0.114 5	0.056 1	-0.008 4	-0.079 2	-0.156 3	-0.239 9	-	-
80	0.132 0	0.076 4	0.015 2	-0.051 8	-0.124 6	-0.203 4	-0.288 3	-0.379 3
100	0.148 5	0.095 5	0.037 2	-0.026 4	-0.095 4	-0.169 9	-0.250 0	-0.335 8
120	0.164 2	0.113 5	0.057 9	-0.002 6	-0.068 1	-0.138 8	-0.214 6	-0.295 7
140	0.179 1	0.130 5	0.077 4	0.019 8	-0.042 6	-0.109 7	-0.181 7	-0.258 6
160	0.193 3	0.146 7	0.095 9	0.040 8	-0.018 6	-0.082 6	-0.151 0	-0.224.0
180	0.206 9	0.162 2	0.113 5	0.060 8	0.004 0	-0.057 0	-0.122 2	-0.1917
200	0.219 9	0.176 9	0.130 2	0.079 7	0.025 3	-0.032 9	-0.095 1	-0.161 3
220	0.232 4	0.191 0	0.146 1	0.097 6	0.045 6	-0.010 1	-0.069 5	-0.132 7
240	0.244 4	0.204 5	0.161 3	0.114 8	0.064 8	0.011 5	-0.045 4	-0.105 8
260	0.255 9	0.217 4	0.175 8	0.131 1	0.083 1	0.031 9	-0.022 5	-0.080 4
280	0.267 0	0.229 8	0.189 7	0.146 6	0.100 5	0.051 4	-0.000 9	-0.056 3
300	0.277 6	0.241 6	0.202 9	0.161 4	0.117 1	0.069 8	0.019 7	-0.033 5

Table B2 Density, ρ (kg/m^3)

Pressure (bar gauge)	Temperature (°C) 0	5	10	15	20	25	30	35
0	999.8	999.9	999.7	999.1	998.2	997.0	995.6	994.0
20	1 000.8	1 000.9	1 000.6	1 000.0	999.1	997.9	996.5	994.9
40	1 001.8	1 001.9	1 001.6	1 000.9	1 000.0	998.8	997.4	995.8
60	1 002.8	1 002.8	1 002.5	1 001.8	1 000.9	999.7	998.3	996.6
80	1 003.8	1 003.8	1 003.4	1 002.7	1 001.8	1 000.6	999.1	997.5
100	1 004.8	1 004.8	1 004.4	1 003.7	1 002.7	1 001.5	1 000.0	998.4
120	1 005.8	1 005.7	1 005.3	1 004.6	1 003.6	1 002.3	1 000.9	999.2
140	1 006.8	1 006.7	1 006.2	1 005.5	1 004.5	1 003.2	1 001.7	1 000.1
160	1 007.8	1 007.6	1 007.2	1 006.4	1 005.4	1 004.1	1 002.6	1 000.9
180	1 008.8	1 008.6	1 008.1	1 007.3	1 006.2	1 005.0	1.003.5	1 001.8
200	1 009.7	1 009.5	1 009.0	1 008.2	1 007.1	1 005.8	1 004.3	1 002.6
220	1 010.7	1 010.5	1 009.9	1 009.1	1 008.0	1 006.7	1 005.2	1 003.5
240	1 011.7	1 011.4	1 010.8	1 010.0	1 008.9	1 007.6	1 006.0	1 004.3
260	1 012.6	1 012.3	1 011.7	1 010.9	1 009.7	1 008.4	1 006.9	1 005.2
280	1 013.6	1 013.3	1 012.6	1 011.7	1 010.6	1 009.3	1 007.7	1 006.0
300	1 014.6	1 014.2	1 013.5	1 012.6	1 011.5	1 010.1	1 008.6	1 006.8

Pressure (bar gauge)	Temperature (°C) 40	45	50	55	60	65	70	75
0	992.2	990.2	988.0	985.7	983.2	980.5	977.7	974.8
20	993.1	991.0	988.9	986.5	984.0	981.4	978.6	975.7
40	993.9	991.9	989.7	987.4	984.9	982.3	979.5	976.6
60	994.8	992.8	990.6	988.2	985.8	983.1	980.4	977.4
80	995.7	993.6	991.4	989.1	986.6	984.0	981.2	978.3
100	996.5	994.5	992.3	990.0	987.5	984.8	982.1	979.2
120	997.4	995.3	993.2	990.8	988.3	985.7	982.9	980.1
140	998.2	996.2	994.0	991.7	989.2	986.6	983.8	980.9
160	999.1	997.0	994.8	992.5	990.0	987.4	984.6	981.8
180	999.9	997.9	995.7	993.3	990.9	988.2	985.5	982.6
200	1 000.8	998.7	996.5	994.2	991.7	989.1	986.3	983.5
220	1 001.6	999.6	997.4	995.0	992.5	989.9	987.2	984.3
240	1 002.4	1 000.4	998.2	995.8	993.4	990.8	988.0	985.2
260	1 003.3	1 001.2	999.0	996.7	994.2	991.6	988.9	986.0
280	1 004.1	1 002.0	999.8	997.5	995.0	992.4	989.7	986.8
300	1 004.9	1 002.9	1 000.7	998.3	995.8	993.2	990.5	987.7

Table B2 Density, ρ (kg/m³) (continued)

Pressure (bar gauge)	Temperature (°C) 80	85	90	95	100	105	110	115
0	971.7	968.6	965.3	961.8	958.3	-	-	-
20	972.6	969.5	966.2	962.8	959.2	955.6	951.9	948.0
40	973.5	970.4	967.1	963.7	960.2	956.6	952.8	949.0
60	974.4	971.3	968.0	964.6	961.1	957.5	953.8	950.0
80	975.3	972.1	968.9	965.5	962.0	958.4	954.7	950.9
100	976.2	973.0	969.8	966.4	962.9	959.4	955.7	951.9
120	977.0	973.9	970.7	967.3	963.8	960.3	956.6	952.8
140	977.9	974.8	971.5	968.2	964.8	961.2	957.5	953.8
160	978.8	975.7	972.4	969.1	965.7	962.1	958.5	954.7
180	979.6	976.5	973.3	970.0	966.5	963.0	959.4	955.6
200	980.5	977.4	974.2	970.9	967.4	963.9	960.3	956.6
220	981.3	978.2	975.0	971.7	968.3	964.8	961.2	957.5
240	982.2	979.1	975.9	972.6	969.2	965.7	962.1	958.4
260	983.0	980.0	976.8	973.5	970.1	966.6	963.0	959.3
280	983.9	980.8	977.6	974.3	971.0	967.5	963.9	960.2
300	984.7	981.6	978.5	975.2	971.8	968.4	964.8	961.1

Pressure (bar gauge)	Temperature (°C) 120	125	130	135	140	145	150	155
0	-	-	-	-	-	-	-	-
20	944.0	940.0	935.8	931.5	927.0	922.5	917.9	913.2
40	945.0	941.0	936.8	932.5	928.1	923.6	919.0	914.3
60	946.0	942.0	937.8	933.6	929.2	924.7	920.1	915.5
80	947.0	943.0	938.8	934.6	930.2	925.8	921.2	916.6
100	948.0	944.0	939.8	935.6	931.3	926.9	922.3	917.7
120	948.9	944.9	940.8	936.6	932.3	927.9	923.4	918.8
140	949.9	945.9	941.8	937.7	933.4	929.0	924.5	919.9
160	950.8	946.9	942.8	938.7	934.4	930.0	925.6	921.0
180	951.8	947.9	943.8	939.7	935.4	931.1	926.7	922.1
200	952.7	948.8	944.8	940.7	936.4	932.1	927.7	923.3
220	953.7	949.8	945.8	941.7	937.5	933.2	928.8	924.3
240	954.6	950.7	946.7	942.6	938.5	934.2	929.8	925.3
260	955.5	951.7	947.7	943.6	939.4	935.2	930.8	926.4
280	956.5	952.6	948.6	944.6	940.4	936.2	931.9	927.5
300	957.4	953.5	949.6	945.5	941.4	937.2	932.9	928.5

Table B2 Density, ρ (kg/m³) (continued)

Pressure (bar gauge)	Temperature (°C) 160	165	170	175	180	185	190	195
0	-	-	-	-	-	-	-	-
20	908.3	903.3	898.3	893.1	887.7	882.3	876.7	871.0
40	909.5	904.6	899.5	894.3	889.1	883.6	878.1	872.4
60	910.7	905.8	900.7	895.6	890.4	885.0	879.5	873.9
80	911.8	906.9	902.0	896.9	891.7	886.3	880.9	875.3
100	913.0	908.1	903.2	898.1	892.9	887.6	882.2	876.7
120	914.1	909.3	904.4	899.3	894.2	889.0	883.6	878.1
140	915.3	910.5	905.6	900.6	895.5	890.3	884.9	879.5
160	916.4	911.6	906.8	901.8	896.7	891.5	886.2	880.8
180	917.5	912.8	907.9	903.0	897.9	892.8	887.5	882.2
200	918.6	913.9	909.1	904.2	899.2	894.1	888.8	883.5
220	919.7	915.0	910.2	905.4	900.4	895.3	890.1	884.8
240	920.8	916.1	911.4	906.5	901.6	896.5	891.4	886.1
260	921.9	917.2	912.5	907.7	902.8	897.8	892.6	887.4
280	922.9	918.3	913.6	908.8	904.0	899.0	893.9	888.7
300	924.0	919.4	914.8	910.0	905.1	900.2	895.1	890.0

Pressure (bar gauge)	Temperature (°C) 200	205	210	215	220	225	230	235
0	-	-	-	-	-	-	-	-
20	865.1	859.1	852.9	-	-	-	-	-
40	866.6	860.6	854.5	848.2	841.8	835.2	828.4	821.4
60	868.1	682.2	856.1	849.9	843.5	837.0	830.3	823.4
80	869.6	863.7	857.7	851.5	845.2	838.8	832.1	825.3
100	871.0	865.2	859.3	853.2	846.9	840.5	834.0	827.2
120	872.5	866.7	860.8	854.8	848.6	842.2	835.8	829.1
140	873.9	868.2	862.3	856.3	850.2	843.9	837.5	831.0
160	875.3	869.6	863.8	857.9	851.8	845.6	839.3	832.8
180	876.7	871.1	865.3	859.4	853.4	847.3	841.0	834.6
200	878.1	872.5	866.8	860.9	855.0	848.9	842.7	836.3
220	879.4	873.9	868.2	862.4	856.6	850.5	844.4	838.1
240	880.8	875.3	869.7	863.9	858.1	852.1	846.0	839.8
260	882.1	876.6	871.1	865.4	859.6	853.7	847.6	841.4
280	883.4	878.0	872.5	866.8	861.1	855.2	849.2	843.1
300	884.7	879.3	873.9	868.3	862.6	856.7	850.8	844.7

Table B2 Density, ρ (kg/m³) (concluded)

Pressure	Temperature (°C)							
(bar gauge)	240	245	250	255	260	265	270	275
0	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
40	814.2	806.8	-	-	-	-	-	-
60	816.3	809.0	801.4	793.6	785.4	777.0	-	-
80	818.3	811.1	803.7	795.9	788.0	779.7	771.2	762.3
100	820.3	813.2	805.9	798.3	790.4	782.3	773.9	765.3
120	822.3	815.3	808.0	800.5	792.8	784.9	776.6	768.2
140	824.2	817.3	810.1	802.7	795.2	787.3	779.3	770.9
160	826.1	819.2	812.2	804.9	797.4	789.7	781.8	773.6
180	828.0	821.2	814.2	807.1	799.7	792.1	784.3	776.3
200	829.8	823.1	816.2	809.1	801.9	794.4	786.7	778.8
220	831.6	825.0	818.2	811.2	804.0	796.7	789.1	781.3
240	833.4	826.8	820.1	813.2	806.1	798.9	791.4	783.8
260	835.1	828.6	822.0	815.2	808.2	801.1	793.7	786.2
280	836.8	830.4	823.9	817.1	810.3	803.2	795.9	788.5
300	838.5	832.2	825.7	819.1	812.3	805.3	798.1	790.8

Table B3 Specific Heat Capacity at Constant Pressure, c_p J/(kg K))

Pressure	Temperature (°C)							
(bar gauge)	0	5	10	15	20	25	30	35
0	4 207.5	4 202.7	4 196.7	4 189.7	4 181.6	4 182.1	4 182.0	4 181.6
20	4 198.1	4 194.1	4 189.0	4 182.9	4 175.7	4 176.4	4 176.6	4 176.3
40	4 189.0	4 185.8	4 181.5	4 176.2	4 169.9	4 170.8	4 171.2	4 171.2
60	4 180.1	4 177.6	4 174.1	4 169.6	4 164.2	4 165.3	4 165.9	4 166.1
80	4 171.4	4 169.6	4 166.9	4 163.1	4 158.5	4 159.8	4 160.6	4 161.1
100	4 162.9	4 161.8	4 159.8	4 156.8	4 153.0	4 154.4	4 155.4	4 156.1
120	4 154.6	4 154.2	4 152.8	4 150.5	4 147.5	4 149.1	4 150.3	4 151.2
140	4 146.4	4 146.7	4 146.0	4 144.4	4 142.1	4 143.9	4 145.3	4 146.4
160	4 138.5	4 139.3	4 139.3	4 138.4	4 136.8	4 138.8	4 140.4	4 141.6
180	4 130.7	4 132.2	4 132.7	4 132.5	4 131.5	4 133.7	4 135.5	4 136.9
200	4 123.1	4 125.1	4 126.3	4 126.7	4 126.3	4 128.7	4 130.6	4 132.3
220	4 115.7	4 118.2	4 120.0	4 120.9	4 121.2	4 123.8	4 125.9	4 127.7
240	4 108.4	4 111.5	4 113.8	4 115.3	4 116.2	4 118.9	4 121.2	4 123.2
260	4 101.2	4 104.9	4 107.7	4 109.8	4 111.3	4 114.1	4 116.6	4 118.8
280	4 094.2	4 098.4	4 101.7	4 104.4	4 106.4	4 109.4	4 112.0	4 114.4
300	4 087.4	4 092.0	4 095.9	4 099.0	4 101.6	4 104.8	4 107.5	4 110.0

Pressure	Temperature (°C)							
(bar gauge)	40	45	50	55	60	65	70	75
0	4 180.8	4 179.8	4 178.8	4 181.3	4 183.7	4 186.2	4 188.8	4 191.6
20	4 175.8	4 175.1	4 174.3	4 176.8	4 179.3	4 181.8	4 184.4	4 187.2
40	4 170.9	4 170.4	4 169.9	4 172.4	4 174.9	4 177.4	4 180.1	4 182.9
60	4 166.1	4 165.8	4 165.5	4 168.1	4 170.6	4 173.1	4 175.8	4 178.6
80	4 161.3	4 161.3	4 161.2	4 163.8	4 166.3	4 168.9	4 171.5	4 174.4
100	4 156.5	4 156.8	4 156.9	4 159.5	4 162.1	4 164.6	4 167.3	4 170.2
120	4 151.8	4 152.3	4 152.7	4 155.3	4 157.9	4 160.5	4 163.2	4 166.1
140	4 147.2	4 147.9	4 148.5	4 151.2	4 153.7	4 156.3	4 159.1	4 162.0
160	4 142.7	4 143.6	4 144.4	4 147.1	4 149.6	4 152.3	4 155.0	4 157.9
180	4 138.2	4 139.3	4 140.4	4 143.0	4 145.6	4 148.2	4 151.0	4 153.9
200	4 133.7	4 135.0	4 136.3	4 139.0	4 141.6	4 144.2	4 147.0	4 150.0
220	4 129.3	4 130.9	4 132.4	4 135.0	4 137.6	4 140.3	4 143.1	4 146.1
240	4 125.0	4 126.7	4 128.4	4 131.1	4 133.7	4 136.4	4 139.2	4 142.2
260	4 120.7	4 122.6	4 124.5	4 127.2	4 129.8	4 132.5	4 135.4	4 138.4
280	4 116.5	4 118.6	4 120.7	4 123.4	4 126.0	4 128.7	4 131.6	4 134.6
300	4 112.4	4 114.6	4 116.9	4 199.6	4 122.2	4 124.9	4 127.8	4 130.9

Table B3 Specific Heat Capacity at Constant Pressure, c_p (J/(kg K)) (continued)

Pressure	Temperature (°C)							
(bar gauge)	80	85	90	95	100	105	110	115
0	4 194.6	4 198.0	4 201.8	4 208.4	4 215.2	-	-	-
20	4 190.2	4 193.6	4 197.5	4 204.0	4 210.6	4 217.4	4 224.6	4 232.0
40	4 185.9	4 189.4	4 193.2	4 199.6	4 206.1	4 212.8	4 219.8	4 227.1
60	4 181.7	4 185.2	4 189.1	4 195.3	4 201.6	4 208.2	4 215.0	4 222.2
80	4 177.5	4 181.0	4 184.9	4 191.0	4 197.2	4 203.6	4 210.3	4 217.4
100	4 173.3	4 176.9	4 180.8	4 186.8	4 192.8	4 199.1	4 205.7	4 212.6
120	4 169.2	4 172.8	4 176.8	4 182.6	4 188.5	4 194.7	4 201.1	4 207.9
140	4 165.2	4 168.7	4 172.8	4 178.4	4 184.3	4 190.3	4 196.6	4 203.3
160	4 161.2	4 164.8	4 168.8	4 174.4	4 180.1	4 186.0	4 192.2	4 198.7
180	4 157.2	4 160.8	4 164.9	4 170.3	4 175.9	4 181.7	4 187.8	4 194.2
200	4 153.3	4 156.9	4 161.0	4 166.3	4 171.8	4 177.5	4 183.4	4 189.7
220	4 149.4	4 153.0	4 157.2	4 162.4	4 167.7	4 173.3	4 179.1	4 185.3
240	4 145.5	4 149.2	4 153.4	4 158.5	4 163.7	4 169.2	4 174.9	4 181.0
260	4 141.7	4 145.4	4 149.6	4 154.6	4 159.8	4 165.1	4 170.7	4 176.7
280	4 137.9	4 141.7	4 145.9	4 150.8	4 155.8	4 161.1	4 166.6	4 172.4
300	4 134.2	4 138.0	4 142.2	4 147.0	4 151.9	4 157.1	4 162.5	4 168.2

Pressure	Temperature (°C)							
(bar gauge)	120	125	130	135	140	145	150	155
0	-	-	-	-	-	-	-	-
20	4 239.9	4 248.3	4 257.2	4 266.7	4 276.8	4 289.4	4 302.5	4 316.4
40	4 234.8	4 243.0	4 251.8	4 261.1	4 271.1	4 283.3	4 296.2	4 309.7
60	4 229.8	4 237.8	4 246.4	4 255.6	4 265.4	4 277.4	4 289.9	4 303.2
80	4 224.8	4 232.7	4 241.2	4 250.2	4 259.9	4 271.5	4 283.8	4 296.7
100	4 219.9	4 227.7	4 236.0	4 244.9	4 254.4	4 265.8	4 277.8	4 290.4
120	4 215.1	4 222.7	4 230.9	4 239.6	4 249.0	4 260.1	4 271.8	4 284.2
140	4 210.3	4 217.8	4 225.8	4 234.4	4 243.7	4 254.6	4 266.0	4 278.1
160	4 205.6	4 213.0	4 220.9	4 229.3	4 238.5	4 249.1	4 260.3	4 272.1
180	4 201.0	4 208.2	4 216.0	4 224.3	4 233.3	4 243.7	4 254.6	4 266.2
200	4 196.4	4 203.5	4 211.1	4 219.4	4 228.2	4 238.3	4 249.1	4 260.4
220	4 191.9	4 198.9	4 206.4	4 214.5	4 223.3	4 233.1	4 243.6	4 254.7
240	4 187.4	4 194.3	4 201.7	4 209.6	4 218.3	4 227.9	4 238.2	4 249.0
260	4 183.0	4 189.7	4 197.0	4 204.9	4 213.4	4 222.9	4 232.9	4 243.5
280	4 178.6	4 185.3	4 192.5	4 200.2	4 208.6	4 217.8	4 227.7	4 238.1
300	4 174.3	4 180.9	4 187.9	4 195.6	4 203.8	4 212.9	4 222.5	4 232.7

Table B3 Specific Heat Capacity at Constant Pressure, c_p (J/(kg K)) (continued)

Pressure	Temperature (°C)							
(bar gauge)	160	165	170	175	180	185	190	195
0	-	-	-	-	-	-	-	-
20	4 330.9	4 346.2	4 362.3	4 379.4	4 401.4	4 424.1	4 447.6	4 471.8
40	4 323.9	4 338.9	4 354.7	4 371.4	4 392.7	4 414.7	4 437.4	4 460.8
60	4 317.1	4 331.7	4 347.2	4 363.5	4 384.1	4 405.4	4 427.4	4 450.2
80	4 310.3	4 324.7	4 339.8	4 355.8	4 375.8	4 396.4	4 417.7	4 439.8
100	4 303.7	4 317.8	4 332.6	4 348.3	4 367.7	4 387.6	4 408.3	4 429.6
120	4 297.2	4 311.0	4 325.5	4 341.0	4 359.7	4 379.0	4 399.0	4 419.8
140	4 290.8	4 304.3	4 318.6	4 333.7	4 351.9	4 370.6	4 390.0	4 410.2
160	4 284.6	4 297.8	4 311.8	4 326.6	4 344.2	4 362.4	4 381.2	4 400.8
180	4 278.4	4 291.4	4 305.1	4 319.7	4 336.7	4 354.4	4 372.7	4 391.6
200	4 272.3	4 285.1	4 298.5	4 312.9	4 329.4	4 346.5	4 364.3	4 382.7
220	4 266.4	4 278.9	4 292.1	4 306.2	4 322.2	4 338.8	4 356.1	4 374.0
240	4 260.5	4 272.8	4 285.8	4 299.6	4 315.1	4 331.3	4 348.0	4 365.4
260	4 254.8	4 266.8	4 279.5	4 293.1	4 308.2	4 323.9	4 340.2	4 357.1
280	4 249.1	4 260.9	4 273.4	4 286.8	4 301.4	4 316.7	4 332.5	4 349.0
300	4 243.5	4 255.12	4 267.4	4 280.5	4 294.8	4 309.6	4 325.0	4 341.0

Pressure	Temperature (°C)							
(bar gauge)	200	205	210	215	220	225	230	235
0	-	-	-	-	-	-	-	-
20	4 496.9	4 522.8	4 549.6	-	-	-	-	-
40	4 485.1	4 510.2	4 536.3	4 563.2	4 591.1	4 620.1	4 664.7	4 712.3
60	4 473.7	4 498.1	4 523.3	4 549.5	4 576.6	4 604.7	4 646.9	4 692.1
80	4 462.6	4 486.2	4 510.7	4 536.1	4 562.5	4 589.8	4 629.8	4 672.8
100	4 451.8	4 474.7	4 498.5	4 523.2	4 548.8	4 575.4	4 613.4	4 654.2
120	4 441.3	4 463.6	4 486.7	4 510.7	4 535.6	4 561.5	4 597.6	4 636.5
140	4 431.0	4 452.7	4 475.1	4 498.5	4 522.8	4 548.0	4 582.3	4 619.4
160	4 421.0	4 442.1	4 463.9	4 486.7	4 510.3	4 534.8	4 567.5	4 602.9
180	4 411.3	4 431.8	4 453.0	4 475.1	4 498.1	4 522.1	4 553.2	4 587.1
200	4 401.8	4 421.7	4 442.4	4 463.9	4 486.3	4 509.7	4 539.4	4 571.8
220	4 392.6	4 411.9	4 432.1	4453.0	4 474.9	4 497.6	4 526.0	4 557.0
240	4 383.5	4 402.4	4 422.0	4 442.4	4 463.7	4 485.9	4 513.0	4 542.7
260	4 374.7	4 393.0	4 412.2	4 432.1	4 452.9	4 474.5	4 500.4	4 528.9
280	4 366.1	4 383.9	4 402.6	4 422.0	4 442.3	4 463.4	4 488.2	4 515.5
300	4 357.7	4 375.1	4 393.2	4 412.2	4 432.0	4 452.6	4 476.3	4 502.6

Table B3 Specific Heat Capacity at Constant Pressure, c_p (J/(kg K)) (concluded)

Pressure (bar gauge)	Temperature (°C) 240	245	250	255	260	265	270	275
0	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
40	4 763.0	4 817.0	-	-	-	-	-	-
60	4 740.3	4 791.7	4 846.3	4 904.3	4 965.7	-	-	-
80	4 718.7	4 767.8	4 820.0	4 875.6	4 934.5	4 996.9	5 062.8	5 132.4
100	4 698.1	4 745.0	4 795.0	4 848.3	4 905.0	4 965.1	5 028.7	5 095.9
120	4 678.3	4 723.2	4 771.2	4 822.5	4 877.0	4 935.0	4 996.4	5 061.4
140	4 659.4	4 702.4	4 748.6	4 797.9	4 850.5	4 906.4	4 965.8	5 028.8
160	4 641.3	4 682.6	4 726.9	4 774.4	4 825.2	4 879.3	4 936.8	4 997.9
180	4 623.8	4 663.5	4 706.2	4 752.0	4 801.1	4 853.5	4 909.2	4 968.5
200	4 607.0	4 645.2	4 686.3	4 730.6	4 778.1	4 828.8	4 882.9	4 940.5
220	4 590.8	4 627.6	4 667.3	4 710.1	4 756.1	4 805.3	4 857.9	4 913.9
240	4 575.2	4 610.6	4 649.0	4 690.4	4 735.0	4 782.8	4 833.9	4 888.4
260	4 560.2	4 594.3	4 631.4	4 671.5	4 714.7	4 761.2	4 810.9	4 864.1
280	4 545.6	4 578.6	4 614.5	4 653.3	4 695.3	4 740.5	4 788.9	4 840.8
300	4 531.6	4 563.4	4 598.1	4 635.8	4 676.6	4 720.6	4 767.8	4 818.4

ANNEX C - PARTICIPATING ORGANISATIONS

This Code of Practice was written as part of a project on the thermodynamic method of pump testing. The members of consortium which undertook the project were:

Advanced Energy Monitoring Systems Limited
Anglian Water Services Limited
British Steel Swinden Laboratory
Development Engineering International
Engineered Products (Manchester) Limited
Ingersoll-Dresser Pumps (UK) Limited
Kvaerner Boving Limited
National Engineering Laboratory
Scottish Hydroelectric PLC
Southern Water Services Limited
SPP Limited
Sulzer (UK) Pumps Limited
UK Department of Trade and Industry
Welsh Water
Yorkshire Water Services Limited