SOME ASPECTS OF THE DESIGN OF MODERN PIPING SYSTEMS

By R. N. NEVIN

Introduction

In the selection of either process or power generating plant, engineers recognise the importance of correct design and the need for careful selection of equipment. A great deal of thought is usually given to the choice of material used in construction, to the detailed performance data available and to the advantages and disadvantages associated with different types of plant. Such careful consideration is not always given to the piping systems interconnecting the items of plant. With the increase in pressures and temperatures over the last few years, it is now imperative that piping systems are properly designed in order to reduce shut-downs to a minimum and to avoid possible damage to equipment.

Piping design covers a wide field from the selection of materials to resist pressure, temperature, corrosion and erosion, to problems of regulating flow, but the design aspects of most importance to industry and power generation authorities are those associated with the higher steam and feed water pressures and temperatures now being encountered. For instance, existing boiler plant in the Sugar Industry operates at pressures in the region of 200 lb./sq. in. and temperatures of 500° F., but recent orders are for plant operating at pressures up to 450 lb./sq. in. and temperatures of 750° F. As late as 1957 the maximum working pressures and temperatures of installed plant for power generation did not exceed 685 lb./sq. in. and 900° F.; orders were placed in 1962 for plant operating at 1600 lb./sq. in and 1010° F.

These figures indicate clearly the advances that are being made and the necessity of giving specialised attention to piping design at elevated pressures and temperatures.

Specifications

Except for the petroleum, petro-chemical and, in some cases, the chemical industries, piping in this country is designed to British Standards. Until recently BS.806 was both a material and a design specification for ferrous pipes and piping installations but now separate material specifications have been issued such as BS.3602 covering carbon steel pipes for high duties and BS.3604 covering alloy steel pipes also for high duties.

BS.806 is being revised as a design code only. This has caused a certain amount of confusion but most authorities accept piping manufactured to either the old or the new specification, and design either to the existing BS.806 or to the BS.806 Committee's recommendations for amendments of this specification.

Selection of Materials

The main criterion in the selection of a material for the manufacture of piping is the temperature. The new BS.3602 and 3604 specifies piping materials for steam and boiler feed water as follows:—

Up to 700° F.	35 tons Carbon Steel (for Boiler Feed water).
Up to 800° F.	Fully killed 23 ton or 27 ton Carbon Steel.
Up to 900° F.	Fully killed 23 ton or 27 ton Carbon Steel, but with grain size control.
Up to 1050° F.	1¼% Chrome, ½% Molybdenum Steel.
Up to 1100° F.	2¼% Chrome, 1% Molybdenum Steel or ½% Chrome, ½% Molybdenum, ¼% Vanadium Steel.

Austenitic Steels are used over 1100° F. and BSS. 3605, at present in the course of preparation, will specify details.

The lower limit of temperature at which some of these steels are used has not been stated because economics or other considerations may warrant the use of a higher grade steel at a comparatively low temperature. For instance if one had a very high pressure associated with a relatively low temperature, the thickness of the lower grade steel may be such that it would not be economical to fabricate and manipulate it. The allowable stress of the higher grade steel may be such that the thickness of the pipe could be reduced anything up to 50 per cent.

Design Stresses

In the last 10 years thinking on design stresses and methods of calculating pipe thicknesses has undergone a radical change. Fig. I shows some typical examples of the effect of these changes on pipe thicknesses.

Columns 1 and 2 show the thicknesses calculated in accordance with BS.806/1942 and BS.806/1954 as first issued. Barlows formula with the addition of the corrosion factor is specified. The 1960 amendment to BS.806, in addition to rationalising the design stresses, introduced a formula similar to that specified in the A.S.A. Code for Pressure Piping, which introduces a temperature dependent parameter Y. The latest recommendations once again elevate stresses in most instances and they recommend the use of the mean diameter formulae which obviates the use of Factor Y. These three formulae are given in Fig. II.

There are three criteria for determining design stresses, namely, ultimate tensile, yield and creep rupture stress. The effect of creep is only felt at elevated temperatures and it is based on the mean rupture stress in 100,000 hours at the temperature under consideration.

Velocities and Pressure Drops

After having determined the type of piping materials to be used and the design stresses, the designer must determine the bore of the pipe. Here again modern accepted practice allows the use of velocities far in excess of those of 10 to 20 years ago when steam velocities rarely exceeded 100 ft. per second and feed water velocities were in the region of 6 to 8 feet per second.

It is accepted that higher velocities of saturated steam are undesirable but it is not uncommon to find high pressure superheated steam at velocities of 220 ft.

per second. Velocities in boiler feed systems in modern high pressure power stations frequently exceed 15 ft. per second.

Once the maximum desirable velocity has been established, pressure drops can be determined and the effect of these pressure drops can be equated against the additional cost of piping at the lower velocities. It must also be remembered that the higher the velocity the greater the need for specialised design of the piping system to avoid excessive vibration or erosion.

Joints

At pressures up to 250 or 300 p.s.i. flanged joints are quite satisfactory. Flanged valves and other fittings are readily available and pipe fitting presents no problem.

of this equipment is relatively small in comparison to the difference in cost between the butt weld valves and the flanged valves.

Modern welding techniques and non-destructive testing techniques are such that the joints should be trouble-free for the life of the plant; consequently maintenance costs are reduced.

The elimination of flanges means a lighter piping system and correspondingly lighter supporting steelwork. Furthermore, lagging costs will also be reduced.

Welding and Non-Destructive Testing of Welds

Welding and non-destructive testing of welds is such a wide field that it is impossible to give more than a brief outline of the modern techniques, as applicable to piping systems.

Fig. I—EFFECT OF CHANGES IN DESIGN CODES ON H.P. PIPE OD's AND THICKNESSES.

		DESIGN CODE			
POWER STATION	DESIGN COND.	B.S. 806 1942—49	B.S. 806 1954	B.S. 806 1954—60	LATEST RECOMMENDATIONS
KOMATI	STEAM AT 1350psi AND 965°F 10" N.B. MIN.	TEMPERATURE OUTSIDE RANGE OF DESIGN CODE.	14" O/D X 1 7/8" d = 10 1/4" B.S. 806 CLASS Q	12 3/4" O/D X 1 3/16" d = 10 3/8" B.S. 806 CLASS Q	12 3/4" O/D X 1" d = 10 3/4" B.S. 3604-HFS 620
	FEED AT 2000psi AND 420°F 10" N.B. MIN.	12 3/4" O/D X 1 5/16" d = 10 1/8" B.S. 806 CLASS B	12 3/4" O/D X 1 5/16" d = 10 1/8" B.S. 806 CLASS B(i)	12 3/4" O/D X 1 1/16" d = 10 5/8" B.S. 806 CLASS B(i)	11 3/4" O/D X 3/4" d = 10 1/4" B.S. 3602 HFS 35
HIGHVELD	STEAM AT 1035psi AND 925°F 12" N.B. MIN.	TEMPERATURE OUTSIDE RANGE OF DESIGN CODE	14" O/D X 15/16" d = 12 1/8" BS 806 CLASS Q	14" O/D X 3/4 d = 12 1/8" BS 806 CLASS Q	14" O/D X 3/4 d = 12 1/8" B S 3604-HFS620
	FEED AT 1425psi AND 385°F 8" N.B. MIN.	9 5/8" O/D X 3/4" d = 8 1/8" B.S. 806 CLASS B	9 5/8" O/D X 3/4" d = 8 1/8" B.S. 806 CLASS B(i)	9 5/8" O/D X 5/8" d = 8 3/8" B.S-806 CLASS B(i)	9 5/8" O/D X 7/16" d = 8 3/4" B.S. 3602-HFS 35
CAMDEN	STEAM AT 1755psi AND 1010°F 12" N.B. MIN.	TEMPERATURE OUTSIDE RANGE OF DESIGN CODE	TEMPERATURE OUTSIDE RANGE OF DESIGN CODE	18" O/D X 2 15/16" d = 12 1/8" B.S. 806 CLASS Q	14 1/2" O/D X 1 3/16" d = 12 1/8" B.S. 3604-HFS 660
	FEED AT 2740psi AND 430°F 12" N.B. MIN.	18" O/D X 2 1/2" d = 13" B.S. 806 CLASS B	18" O/D X 2 1/2" d = 13" B.S. 806 CLASS B(i)	16" O/D X 1 3/4" d = 12 1/2" B.S. 806 CLASS B(i)	14" O/D X 1" d = 12" B.S. 3602-HFS 35

For piping systems operating at higher pressures and temperatures, consideration should be given to butt welding all pipe to pipe joints. Above 600 lb./sq. in. the modern practice is to use butt welded valves as well.

Particularly at the higher pressures and temperatures, butt welded systems, besides being virtually maintenance free, show considerable saving in cost over flanged systems. One objection to butt welding valves into the lines is that it is difficult to remove the valve for maintenance. To obviate this difficulty valve manufacturers can supply lapping equipment which enables the valve seats to be lapped *in situ*. For the average piping installation, the cost.

The modern practice is to weld pipes up to approximately 2½ inch bore by oxy-acetylene and above 2 inches by metallic arc. A sound root run is essential for the satisfactory welding of the joint and, to this end, special techniques have been evolved.

One of these techniques is the "E.B. root weld insert" which is illustrated in Fig. III. The E.B. insert wire is inserted as shown between the ends of the pipes to be welded and the internal surface of the pipe is purged with argon gas. A Tungsten non-consumable electrode, argon arc shielded, is then applied to the external surface of the insert and, when molten, the insert fuses with the pipe ends, at the same time being drawn into the gap by capillary action so that there is no protrusion in the bore of the pipe. This technique has been used with marked success in most power stations in the Republic operating at over 600 lb./sq. in.

The welds of all carbon steel pipes ½ inch thick or greater and all alloy steel pipes must be heat treated. This entails the correct pre-heating, where necessary, heating during welding and finally stress-relieving. Where possible induction heating coils, or a similar method, are used and temperatures are recorded on a chart. Shop welding is stress relieved in a furnace where again temperatures are recorded but at site the induction heating coils have to be used for the stress relieving as well.

Butt welds, particularly those done at a construction site, are frequently non-destructively tested. Either gamma-ray or X-ray examination gives the clearest definition of a defect in the weld. Although ultrasonic testing is invaluable in other fields, it is difficult to determine the exact nature of the defect in a butt weld and magnetic particle testing will only reveal cracks near the outer surface of the pipe. Although X-ray gives a better definition than gamma-ray, gamma-radiography is generally used on construction sites because of the compact nature of the equipment.

Piping Flexibility

After having determined the pipe materials, the pipe size, the type of joint, the welding technique and heat treatment and the testing procedure, the piping designer must turn his attention to the physical layout of the piping system.

The object should be to arrange the piping such that it can absorb its own expansion without being overstressed and without imposing excessive thrusts or moments on plant to which it is connected. The complexity of the analysis is such that it has become essential to resort to the use of an electronic digital computer—it is estimated that the average high pressure flexibility analysis, if done manually, would take one man six months.

Besides determining the stresses in the pipes and the moments and forces which would be imposed on plant to which the piping system connects, and the moments and forces at anchor and restraint points so that these can be designed, the analysis gives deflections at any point in the system. This enables spring supports to be designed and a check to be made that, due to expansion movement, no fouls occur with other pipes, structural steelwork or items of plant. Furthermore, the designer can ensure that joints do not occur at points of high bending moment, thus ensuring that the erector does not have undue difficulty in lining up the joint for welding (or flanging).

Support and Anchor Design

Incorrect design of spring supports can lead to excessive stresses in the piping and possible damage to plant through the imposition of high moments and thrusts. Essential information which should be available before spring calculations can be made are:

(1) The deflections at the points of support.

(2) Accurate loads to be carried by the supports.

If the spring design is not accurate, springs may become either fully compressed or the pipe may actually lift off the supports so that no load is being carried by that support. In either case excessive stresses may be set up in the pipe or additional damaging moments and thrusts may be imposed on items of plant. Generally open coil springs should only be used when the deflection is not excessive, that is up to approximately 2 inches deflection. Even with comparatively small deflections, the load loss characteristic of open coil springs is such that the pipe, although correctly supported when hot will not be ideally supported when erected cold but, within certain limits, this is acceptable.

For larger vertical movements constant load supports should be used to reduce the load loss. Where moments and forces on equipment is critical, it is advisable to use constant load supports to ensure that there is negligible load loss under all conditions of temperature.

Drainage

At elevated temperatures correct drainage of steam lines is of major importance. Condensate lying in contact with a pipe under stress, or the repeated sudden cooling of a localized area of pipe due to the impingement of condensate can cause corrosion fatigue cracking.

Some of the important points to remember when considering drainage at the design stage, and when operating plant, are as follows:—

(1) Avoid dead legs wherever possible.

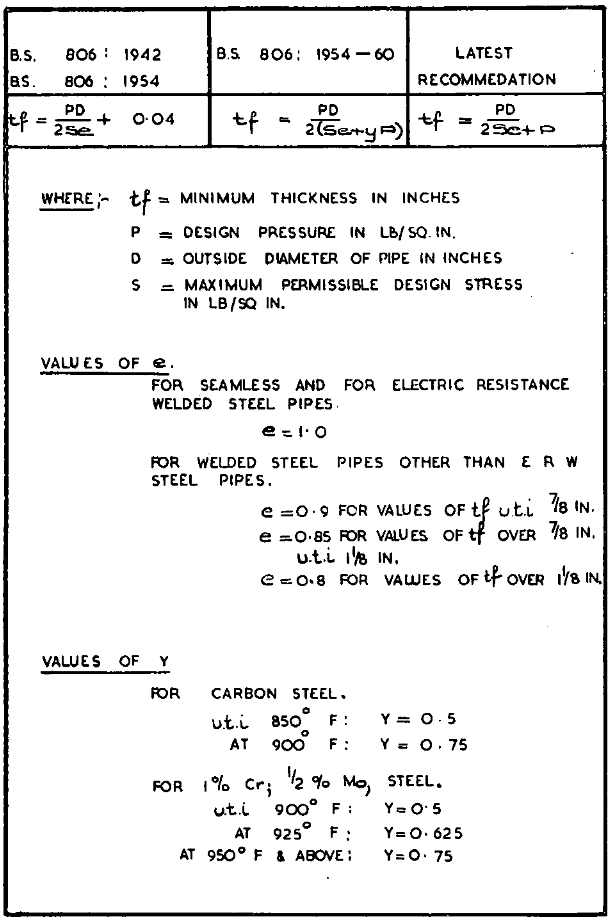
(2) Where it is not possible to avoid dead legs, ensure that they drain away from the hot end and ensure that the leg is adequately trapped.

(3) Avoid sectioning valves in vertical pipelines. The valve should be repositioned in the horizontal or the pipeline should be re-routed.

Valves so positioned are invariably affected by the condensate that is trapped in the vertical pipe leg and this leads to leaking flange joints, lid joints and damage to the seats due to the sudden cooling effect.

Small bore drain valves are invariably positioned in vertical lines but the selection of materials and general design caters for this rigorous duty.

FIG II—PIPE DESIGN FORMULAE



B.S. 806 : 1942 B.S. 806 : 1954	B.S. 806: 1954—60	LATEST RECOMMEDATION
$t_f = \frac{PD}{2Se} + 0{\cdot}04$	$t_f = \frac{PD}{2(Se+yP)}$	$t_f = \frac{PD}{2Se+P}$

WHERE:- t_f = MINIMUM THICKNESS IN INCHES
P = DESIGN PRESSURE IN LB/SQ. IN.
D = OUTSIDE DIAMETER OF PIPE IN INCHES
S = MAXIMUM PERMISSIBLE DESIGN STRESS IN LB/SQ IN.

VALUES OF e.

FOR SEAMLESS AND FOR ELECTRIC RESISTANCE WELDED STEEL PIPES

e = 1·0

FOR WELDED STEEL PIPES OTHER THAN E R W STEEL PIPES.

e = 0·9 FOR VALUES OF t_f u.t.i 7/8 IN.
e = 0·85 FOR VALUES OF t_f OVER 7/8 IN. u.t.i 1 1/8 IN.
e = 0·8 FOR VALUES OF t_f OVER 1 1/8 IN.

VALUES OF Y

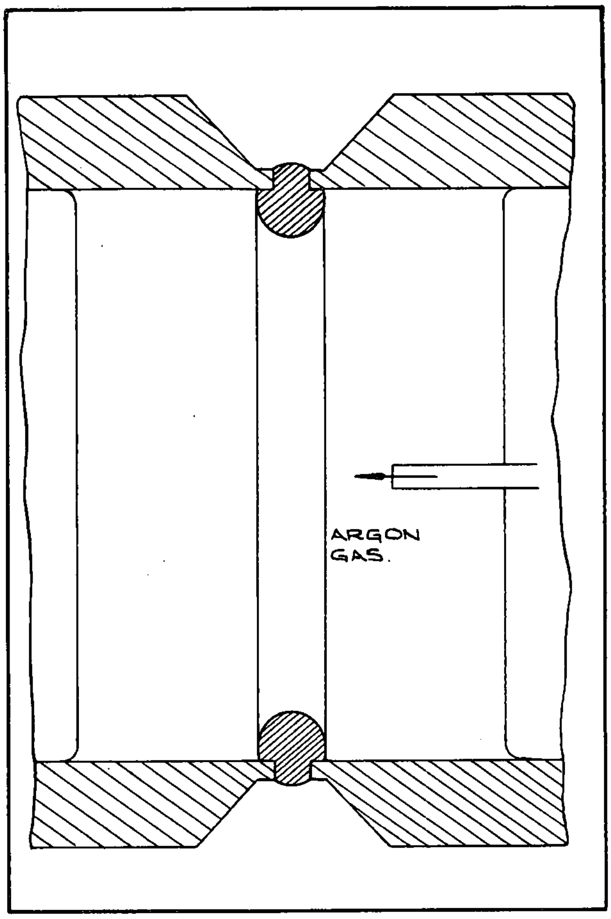
FOR CARBON STEEL.

u.t.i	850° F:	Y = 0·5
AT	900° F:	Y = 0·75

FOR 1% Cr; 1/2 % Mo, STEEL.

u.t.i	900° F:	Y = 0·5
AT	925° F:	Y = 0·625
AT	950° F & ABOVE:	Y = 0·75

FIG III—CONSUMABLE ROOT WELD INSERT



(4) When isolating a boiler or a portion of a main between sectioning valves, if more than one valve will effect the isolation, ensure that the sectioning valve nearer the section under pressure is closed. For instance, frequently a boiler is isolated by means of the boiler stop valve, but the valve on the boiler lead adjacent to the main or interconnector is left open—this creates ideal conditions for corrosion fatigue.

(5) Design and operate in such a way that the minimum number of steam traps is necessary. In high temperature superheated steam piping systems, no condensate should exist in the mains after correct warming up; consequently a trap will merely discharge condensate which has collected in the drain pipe, thus providing a source of loss of energy. In addition, the cost of maintenance cannot be ignored, in spite of advancement in steam trap design.

(6) Ensure that a hand drain is supplied in steam lines between adjacent sectioning valves so that, when starting up, the pipes can be warmed up correctly.

Summary

The aspects of design of piping systems presented should indicate clearly the need for giving specialised attention to these matters. Correct design will reduce plant outages and maintenance costs. Too frequently piping considerations play second fiddle to the consideration of other plant, the result being that the piping is "thrown together" just before the commissioning of the major plant. If due recognition is given to its importance and design, manufacture and erection are properly planned, a saving in initial capital cost can be made in many instances.

Acknowledgments

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References

Blair, J. S. (1963). The Design of High Temperature Steam Pipes: Proc. Joint International Conference on Creep, 4-77.

Mr. Bentley (in the chair): As regards steam piping, this gives very little trouble in the sugar industry, no doubt due to the forethought that goes into the design of our installations. But as regards some of our other piping this industry must be one of the pipe manufacturers' best customers. We have no sooner put it in one place than we cut it out and put it elsewhere. It is soon attacked by juice and we have to replace it. I have discussed with an associate of Mr. Nevin's the possibility of using stainless steel tubing in evaporators. There might be advantages, although stainless steel tubing has a lower coefficient of heat transfer than the brass tubing at present used. But from the point of view of scaling, which is a major problem in the industry, might it be possible to develop a stainless steel tubing which would enable one to run evaporators without having to clean them once a week, as we do now? Maybe Mr. Nevin or someone else present would care to comment on this.

Mr. Ashe: I have not had experience of stainless steel tubing in evaporators, but we have at Umfolozi a vacuum pan so fitted. Two pans were installed last year, one fitted with stainless steel tubes, exactly half the thickness of the tubes in the other. The tubes are expanded and welded top and bottom. Both pans are boiling "C" Massecuites and we find the pan with the stainless steel tubing takes longer to boil an equal volume of massecuite. We have had very little scaling trouble in either pan.

Mr. Renton: Are the two pans of identical design?

Mr. Ashe: Almost identical — the pan with stainless steel tubing has a conical bottom, the other a flat bottom.

Mr. Nevin: I must point out to you what the effects of these design changes have been. If we just take Camden alone we see up to 1954 it was not possible to design all those walls for that temperature. Even from 1954-1960 to now, we have a difference in the O/D thickness of the steam piping from 18" O/D by nearly 3" thick down to something we can handle, 14$\frac{1}{2}$" O/D by 1$\frac{3}{16}$" In the one case the 18" O/D is based on one per cent. chrome and $\frac{1}{2}$ per cent. "Moly" Steel, but the latest recommendations are for the $\frac{1}{2}$ per cent. Chrome, $\frac{1}{4}$ Molybdenum and $\frac{1}{4}$ Vanadium. So there is an advance not only in design, but also in materials. The same applies to the feed, whereas in 1942 we were 18" O/D by 2$\frac{1}{2}$" thick, it has come right down to 14" O/D by 1 inch. Again it is a different material, that is the 35 ton carbon which due to the grain size is not suitable for steam. There are other pipings being developed now with thinner walls.

Mr. Bentley: The information Mr. Nevin has given will be most useful to those faced with future installations. The ranges quoted in the paper are certainly outside the pressures we are likely to use in the sugar industry for some time. I do not think that even Illovo are considering super-critical boilers at this stage but if they are I am sure Mr. Nevin will help them in the design of the steel piping.