Safety Considerations in the design of Blow-down Installations

Department of Health and Social Security
Engineering Division

Foreword

In view of the importance of boiler blow-down arrangements it is remarkable that there is a paucity of published information on the subject. One of the most important aspects is that of safety in operation but occurrences over past years have shown that many installations are not only badly designed but virtual death traps, and from that aspect alone this paper is a welcome addition to published information in the field of steam engineering.

It is written primarily for engineers in the Health Service but it should also prove useful to all engineers concerned with the design and operation of steam boiler plant.

JOHN BOLTON, *LL.B.(Lond.), C.Eng., F.I.C.E., F.I.Mech.E., M.Inst.F., Hon.M.I.Hosp.E., F.R.S.H.*

Chief Engineer,

Department of Health and Social Security.

Safety Consideration in the design

of

Blow-down Installations

Department of Health and Social Security

Outline of paper

Appendices

Figures

List of symbols

f	friction factor
q	mass dryness fraction
u ppm	maximum permissible TDS in boiler Solids Content
r ppm	TDS in chemically treated make-up water
H ft	head of water above base of pit orifice
h ft	vertical drop from base of orifice to roof of interceptor
l ft	equivalent length of discharge pipe
L ft	equivalent length of overflow pipe
d in	internal diameter of discharge pipe
D in	internal diameter of overflow pipe
hr	period of discharge
t_1 hr	period of cooling
T hr	time between consecutive discharges from a single boiler
T_1 hr	time between consecutive discharges in multi-boiler installation
W lb	weight of standing water in receptacle
M lb	weight of make-up water supplied to single boiler in T hrs
e lb/hr	instantaneous rate of evaporation
c lb/hr	instantaneous rate of condensate recovery
m lb/hr	instantaneous rate of make-up
b lb/hr	instantaneous rate of discharge from boiler
B lb/hr	constant rate of discharge from boiler
lb/hr	maximum rate of overflow from pit
V ft/sec	velocity
g ft/sec/sec	acceleration due to gravity
v cu ft/lb	specific volume
P lb/in^2 abs	pressure
S Btu/lb	sensible heat in boiler water

Safety consideration in the design of blow-down installations

GENERAL

Boiler water blow-down is required to limit the concentration of dissolved and suspended solids caused by steam losses. It is, if the installation is suitably designed, also useful for rapidly reducing the water level. Sometimes the blow-down can be discharged directly to an open gully but generally the noise, nuisance and danger must be controlled by some such system as that shown in Fig 1.

On opening the valve the pressure drop along the discharge pipe is expended in accelerating the fluid and overcoming friction. At any two adjacent planes along the pipe the excess sensible heat at the lower pressure plane is consumed in changing the phase of a portion of the water which also releases its solids. The pipe thus conveys a mixture in which the reducing water content is balanced by the increasing steam and free solids content. The ever increasing volume of released steam may increase the slip between the phases but it will finally choke the flow.

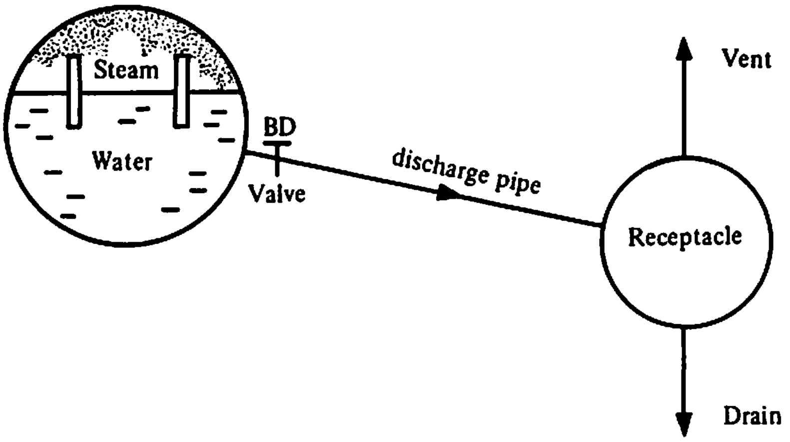

Fig 1

If the discharge is small enough, a critical pressure will be reached at the end of the pipe when the energy released by further pressure drop would be incapable of accelerating the mixture and overcoming friction. The discharge rate is therefore dependent on the dimensions of the discharge pipe and on the difference between the boiler and the critical or end pressure. It does not depend on the pressure in the receptacle unless this is higher than the end pressure.

The receptacle must destroy as quietly as possible the kinetic and pressure energy of the incoming mixture, cool it before passing to the drain where this is a requirement of the local authority and vent the space to prevent build up of pressure unless the receptacle is designed as a pressure vessel. During this process the receptacle must not be allowed to fill with water otherwise the resultant discontinuity of flow will create indeterminate stresses in the system which may be reduced but cannot be eliminated.

The normal chemical composition of the blow-down is such that it is not likely to attack concrete, earthenware, steel or cast-iron. But where ingredients can decompose to form ammonia, non-ferrous metals may be attacked, particularly in the presence of two-phase flow.

DESIGN GUIDANCE

Methods of blow-down

Blow-down may be performed intermittently or continuously or by a combination of these methods. Automation may be necessary when the ratio of manual discharge to evaporation rate is high enough to affect the boiler pressure and indeed some measure of automation may also be necessary for safety and operational reasons. Generally, however, the degree of automation should be based on economic comparisons covering the working of the entire system over the assumed operating range.

With manual periodic blow-down the connection should be made to the base of the boiler at a point remote from the feed. There should be a notice at the valve position forbidding its operation unless the receptacle area is clear. The valve should be opened for a set period at set intervals; e.g., 20 seconds or 1 inch reduction in the gauge glass each shift. Valves should be of the parallel slide type operated by a rack and pinion to give full opening for a half turn of a box key. This can be removed only when the valve is closed (in accordance with the Factories Acts and BS 759). With this kind of valve, scoring is minimised and damage by the bits of scale etc. discharged during cleaning avoided. The 2 inch size is the most common but other sizes are available. This manual system is also used in combination with more automatic systems.

With continuous blow-down the control valve is left open when the boiler is on load. It is designed to give a wide range of adjustment. A pointer on the operating handle works over a graduated scale so that the rate of flow can be set from calibration charts. It is normally attached via ½ inch tubing to a point near the top of the low water level where the salts are most concentrated or to a connection to the main blow-down valve. The latter is operated daily for a short time, preferably at the end of a light load period, to remove settled sludge and to ensure that the valve and the line are clear.

With semi-automatic intermittent blow-down the valve is opened automatically for a fixed period of, say, 10 seconds at 15 minute intervals. These timings are manually adjustable. The valve is powered by steam or air pressure and governed by a controller. It is connected by ½ inch piping in much the same way as the continuous blow-down valve is connected; similarly the main valve is operated in the same way and for the same reasons.

In most hospital installations the variation in load is great and blow-down times or rates should be adjusted frequently. This is normally done by comparing the density of a sample of boiler water against a standard, the sample being taken through a cooler to avoid concentration of solids by evaporation during discharge.

With fully automatic control the valve is modulated by a signal representing the difference between the continuously measured boiler water density and the desired value.

Amount of blow-down

Fig 2 shows instantaneous flow rates for a modulated system in which the TDS in the boiler must not exceed u ppm and in the raw water after treatment r ppm. Assuming no carry-over of solids by the steam and that the solids are uniformly distributed in the boiler water:

rate of solids leaving the boiler = rate of solids entering

$$b\,u = m\,r$$

$$\text{hence, rate of blow-down} \quad b = \frac{r}{u}\,m \text{ lb/hr} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

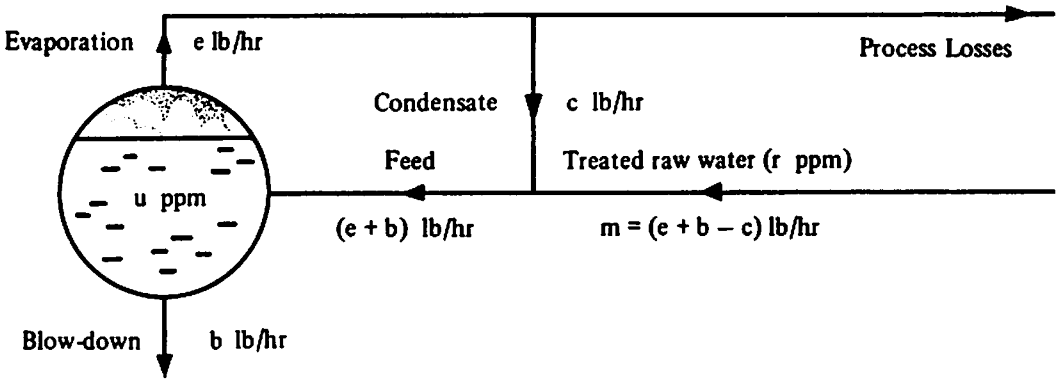

Fig 2

The blow-down rate b lb/hr must therefore follow slavishly the rate of demand for make-up water. If the boiler uses M lb of make-up water during an operating period of T hours and if S Btu/lb is the sensible heat in the boiler water at saturation temperature:-

Weight of solids in blow-down (much of which will be precipitated in the receptacle as the water cools and must therefore be removed from time to time to preserve the water space) is:- $Mr\,10^{-6}$ lb

Minimum water lost to blow-down which must be made up and chemically treated is:- Mr/u lb

Minimum heat lost in blow-down if not recovered is:- MSr/u Btu's

With periodic blow-down b will normally be zero in the above illustration. When the TDS in the boiler have risen to u ppm the blow-down valve should be opened and if discharge takes place at a constant rate of B lb/hr for t hours, Btu 10^{-6} lb of solids will leave the boiler. In replenishing the lost water the feed will supply Btr 10^{-6} lb of solids, but not at the same rate, hence

$$\text{effective weight of solids lost by blow-down} = (u-r)Bt\ 10^{-6}\ \text{lb}$$

The calculation is not affected by the different input and output rates; indeed, it assumes the best practice of shutting off the feed during blow-down as well as avoiding operation at peak loads.

After the blow-down valve has been shut and the boiler water level restored, the solid content will rise at the rate of mr 10^{-6} lb/hr. If it takes T hr to reach the limiting concentration of u ppm and during this time a total of M lb (including previous blow-down) of make-up has been fed to the boiler

$$(M - Bt)r = (u-r)Bt$$

$$\text{hence, amount of blow-down} \quad Bt = \frac{r}{u} M\ \text{lb} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

This means that blow-down can be carried out at any time but it must be continued for a period t dependent on the amount of make-up water used since the last blow-down.

It would seem that if this equation can be satisfied manually the heat loss incurred by periodic blow-down would be no greater than that incurred by modulated blow-down. It would indeed be more effective because the average solid content in the boiler, and consequently the amount of carry-over in the steam would be less.

The limiting concentration of solids u ppm can be obtained from the boiler manufacturer. The following is representative of practice for shell boilers:-

Lancashire	-	17,000 ppm
Packaged	-	3,500 ppm
Economic	-	4,500 ppm

All natural waters require treatment before being fed into a boiler and most of the chemicals used in this process add to the TDS. Since the ingredients of raw waters vary from season to season and sometimes from day to day, the TDS after treatment r ppm is also likely to vary slightly.

The flow rates e and c which help to determine the amount of make-up water in the above equations vary considerably with time. The evaporation rate e may vary from zero to rather more than the maximum rating of the boiler, whilst the condensate carries this variation plus others dependent on the use of process steam. An assumed analysis of the average raw water and a careful study of the entire operating range of the plant is therefore necessary before applying the above equations to establish provisional blow-down policies for the different methods of blow-down - policies which strive to minimise the losses and are practicable.

Whatever the method, blow-down can be avoided only by condensing all the steam ($e - c = o$) or by demineralisation ($r = o$) which really amounts to the same thing. The difference in costs between blow-down and demineralisation is gradually reducing and economic comparisons between these alternatives should be repeated from time to time.

Waste-heat recovery

With modulated control, at any instant mr/u lb/hour of water at boiler saturation temperature are being lost. This not only represents a considerable loss of water which has to be made up and chemically treated, but also a loss of heat. The loss of heat alone can be significant and again the more inefficient the system the greater the heat loss and incidentally the greater the hazard. With the common practice of periodic blow-down it is difficult to apply any heat recovered to useful purposes, but with modulated blow-down, any waste-heat recoverable is related to the load on the boiler and is therefore available for continuous processes, particularly feed heating.

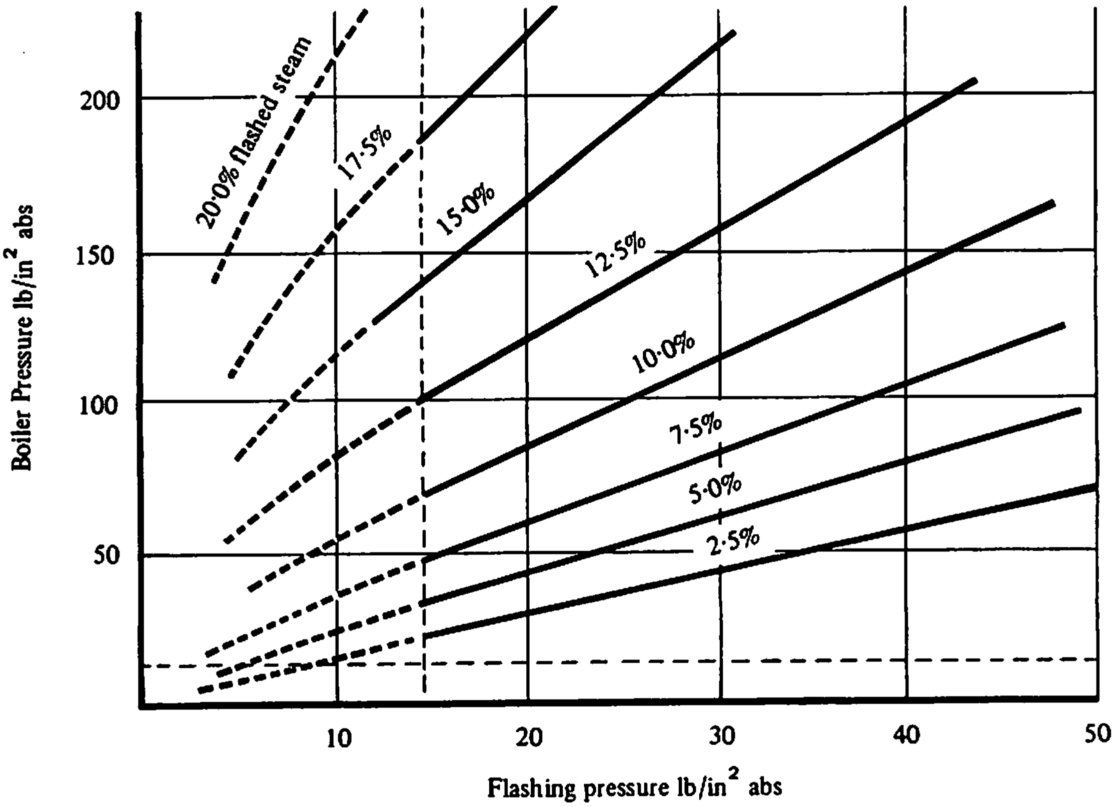

Fig 3

Although most of the heat in the blow-down above the raw water temperature can be extracted, the flashing steam is most easily harnessed and of the most valuable grade. The percentage of blow-down available as flashed steam is easily calculated, but Fig 3 is useful and instructive. It brings out clearly how the amount of flashed steam increases with reduction of the flashing pressure. Unfortunately the lower the flashing pressure the greater the size and expense of the waste-heat equipment required. The flashed steam can be used for low-pressure purposes or its latent heat extracted directly or in heat exchangers and the condensate fed to the feed system to reduce the requirement for chemical treatment of the make-up water. The heat from the heat exchangers can be used for feed water heating, thermal de-aerators, space heating etc.

The sensible heat in the remaining blow-down liquid can also be extracted, but it is of low grade and the main purpose of extracting it would be to simplify the cooling of this water before exhausting to the drains. The water contains a high solids content and associated waste-heat equipment must be capable of dealing with the sludge which separates out under comparatively static conditions. Fig 4 illustrates diagrammatically a complete waste-heat recovery system.

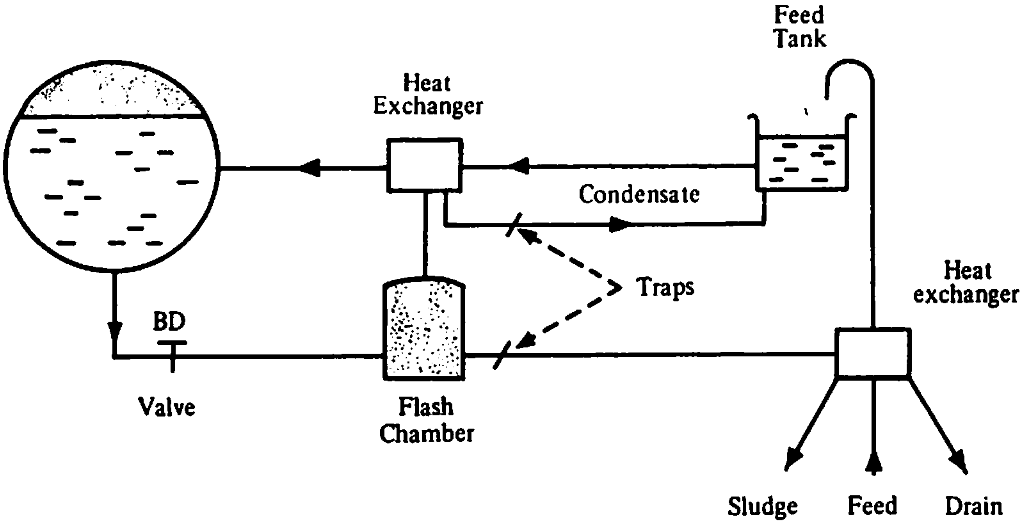

Fig 4

The extent of waste-heat recovery adopted requires a study of the entire operating range of the boiler in conjunction with the other principles established in this paper. The economic calculations involved are quite straightforward and it is not intended to pursue them further.

Discharge pipe

The pipe for conveying the blow-down to the receptacle also restricts the rate of flow. If the boiler pressure is high enough and the receptacle pressure low enough a critical pressure somewhere between the two is developed at the end of the pipe. This is the end pressure. The degree of choking depends on the difference between the boiler pressure and this critical pressure, the pipe dimensions, the amount of freed solids and the friction of two-phase flow. This latter depends on the pipe surface, its dimensions and the ratio of steam to water and its growth along the pipe. Similar problems are experienced in the cascade drain lines from turbine bleed points, the throttled flow of refrigerants, the flow in boiling water reactors, the low pressure flow between stages of flash evaporators, in oil pipe lines and chemical processing plant. The literature between 1931 and 1962 on two-phase flow was reviewed by D. Chisholm in NEL Report No. 103 published in August 1963. In January 1969 the NEL issued Reports 385, 6, 7 and 8 on "Designing for two-phase flow". Engineers designing blow-down systems may find it helpful to consult these works.

Appendix I gives discharge rates B lb/hr which may be used for provisional calculations but actual discharge rates should be measured when each installation is commissioned so that safe blow-down policies can be developed for subsequent operation.

The pipe bore should be as small as necessary to restrict the flow to something less than that which the receptacle space, vent, and drain can deal with, to prevent the deposition of solids and to ensure maximum heat loss per unit area of discharge pipe. Whilst the heat loss can also be increased by extending the length of the blow-down pipe, the actual length must be limited to restrict expansion, thermal shock and vibration. To facilitate drainage, the pipe should be laid with a continuous fall of, say, 1 in 12 towards the receptacle. Bends and other obstructions should be made as easy as possible to reduce erosion by the high velocity steam and free solids and to prevent the lodgement of scale and sludge. Where bends are necessary, replacements of eroded parts are simplified by the use of flange joints. Bends should also be braced against "whip" as a result of the reaction due to change of direction.

Expansion should be taken by natural flexion and preferably without additional loops. Where this is not possible a stainless steel axial expansion joint with a heavy gauge internal sleeve should be selected. It should be anchored, pre-stressed and guided in accordance with the maker's instructions, flange connected and accessible for inspection and replacement. Anchorage to a concrete receptacle should preferably be made by a cast-iron puddle flange capable of sustaining expansion forces and the reaction of discharge.

When the receptacle takes the form of a pit, the pipe must discharge vertically downwards into the standing water so that the kinetic, pressure and sound energy of discharge can be absorbed. The end portion or dip pipe should be detachable and should project at least 6 inches below the surface of the standing water.

The vacuum created in the pipe on closing the valve and the subsequent filling of the pipe with water from the receptacle can be avoided by a small drilled hole in the dip pipe above the standing water level. If the position of the hole is properly chosen the high speed discharge during blow-down may tend to reduce pipe vibration but it will erode nearby masonry unless protected by a cast-iron shield.

In a multi-boiler installation where each blow-down pipe discharges into a common header, the safety of men working in boilers under repair must be considered. The Factories Acts require there to be only one blow-down valve key which should not be removable from a blow-down valve in the open position. When the installation includes different types of blow-down valves it may be necessary to weld or chain together the different keys in order to meet the requirement of the Factories Acts. It may be wise to reduce the effects of this problem by using a separate blow-down pipe between each boiler and the receptacle. This should be repeated for each intermittent automatic or continuous blow-down pipe.

The "Specification for ferrous pipes and piping installations for and in connection with land boilers" BS 806 - 1967 should be followed. Para 1.4.4 of this specification reads:- "The design conditions for blow-down pipes, whether run separately into a tank or sump, or into a common header, shall be the design boiler pressure and the corresponding saturated steam temperature. The design basis for a blow-down header common to a number of boilers and discharging freely into an adequately vented receptacle shall be half the design boiler pressure and the saturated steam temperature corresponding to this lower pressure, provided that under maximum flow conditions this pressure is not exceeded".

Drainage

Para 27(1)b of the Public Health Act prohibits the flow of waste steam or liquid above 110°F to any drain or sewer communicating with a public sewer. This is to protect men working in sewers against scalds or discomfort. The regulations covering the discharge of effluence to sewers vary from one authority to another but for provisional design purposes it may be assumed that the suspended solids should not exceed 1000 ppm. Where practicable the blow-down should be mixed with large quantities of domestic effluent before discharge into the public sewers or waters under the control of a statutory authority.

The requirements of River Authorities are being more stringently enforced and treatment of the blow-down may be required to control the alkalinity, the solids content and the biological oxygen demand before discharging direct to a river or stream. The following limits have been set by Royal Commission:-

Temperature	90°F
pH	beween 6 and 9
Suspended solids	30 ppm
Biological Oxygen Demand	20 ppm
Oil, grease and fat	10 ppm
Metallic ions	1 ppm
Cyanides	1 ppm
Hydrogen sulphide	0.1 ppm as H_2S

In hospital sewage systems it may be possible to relax the temperature rule but temperatures above 150°F are detrimental to PVC and plastic jointed clay-ware pipes; modifications to the hospital sewage treatment installation may be necessary.

Storm drains should not be used; they may get choked or may back-up when running full and discharge into them under either condition would be hazardous. Discharge into a foul drainage system requires a thorough examination of that system. The maximum pressure is fixed by the relative invert levels and failure to apply simple rules may at the least result in the lifting of foul drainage manhole covers, overflow at surface grids and the backing up of nearby WC pans - a static pressure of .15 feet will blow back through a WC seal.

The flow capacity of overflow pipes from the receptacle to the drainage system depends on the relationship between the slope and the friction slope, and between the friction factor and the static head. Appendix II gives sufficient information for the provisional sizing and positioning of overflow pipes so that they are compatible with the blow-down rates and times chosen.

Overflow pipes should be made of cast-iron to BS 1211 - 1958 Class C. Bends should be avoided if possible and an access interceptor below frost level provided by the sewer manhole.

Receptacle

Assuming perfect operation, the total blow-down over any long period of, say, 1 day, is the same regardless of the method of blow-down used. But the rate of blow-down is very different. Manual periodic blow-down once per shift gives rise to a considerably higher rate of flow than intermittent blow-down once every 15 minutes or so (equation (2) on page 8) and this in turn to something considerably greater than the maximum rate which may be developed during modulated blow-down (equation (1) on page 7).

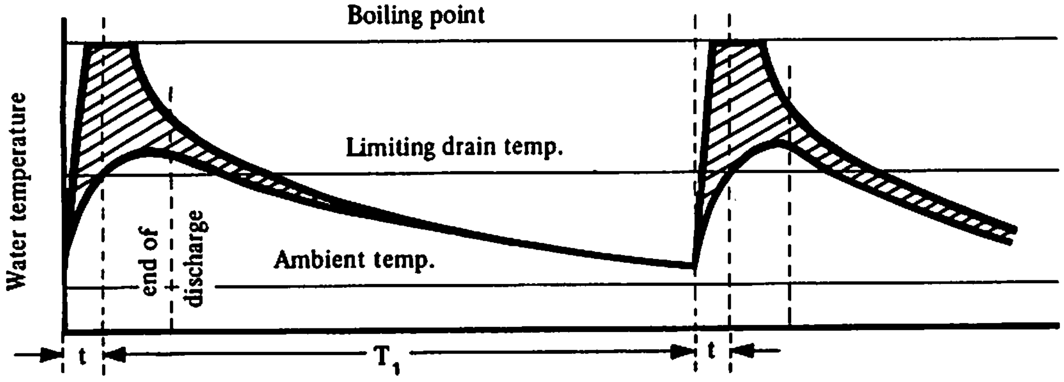

Fig 5

The function of the receptacle - to receive the blow-down and safely absorb much of its energy before exhausting it to the drain and atmosphere - is more easily achieved at the lower than at the higher rates of blow-down. Consequently it is necessary to consider only the handling of manually operated periodic blow-down, more especially as this is also used in addition to the other methods.

In automatic systems any standing water in the receptacle soon attains a steady temperature. With manual systems the standing water receives heat during blow-down but must then reject it so that it is ready at the start of the next blow-down of any boiler in the system to repeat its function efficiently. This cycle is shown in figure 5 - the shaded areas representing temperature variation within the standing water. The cooling effect during both these phases can be improved by the introduction of circulating water or by the deliberate extraction of waste heat. Indeed, some such method may be necessary if the objective cannot otherwise be achieved by reasonably economic design. The normal traditional method of dealing with this problem is in the blow-down pit below ground level. With boilers in the basement, the pits may still have to be constructed at ground level in order to obtain gravity discharge.

(a) Blow-down Pits

In the arrangement shown in Fig 6 the standing water level would reach the lower level of the overflow pipe. The mass W lb should be sufficient to absorb the shock of blow-down, condense the steam phase and disperse the pressure and heat. It should also be sufficient to reduce the mean temperature at the end of blow-down to something very much less than boiling point. That is:

$$W \gg \frac{\text{Boiler water temperature above } 212^{\circ}\text{F}}{\text{Steady pit water temperature below } 212^{\circ}\text{F}} \cdot \frac{r}{u} M \text{ lb}$$

The air space should be at least twice that necessary to receive the maximum possible calculated blow-down, i.e. rM/31u cu ft.

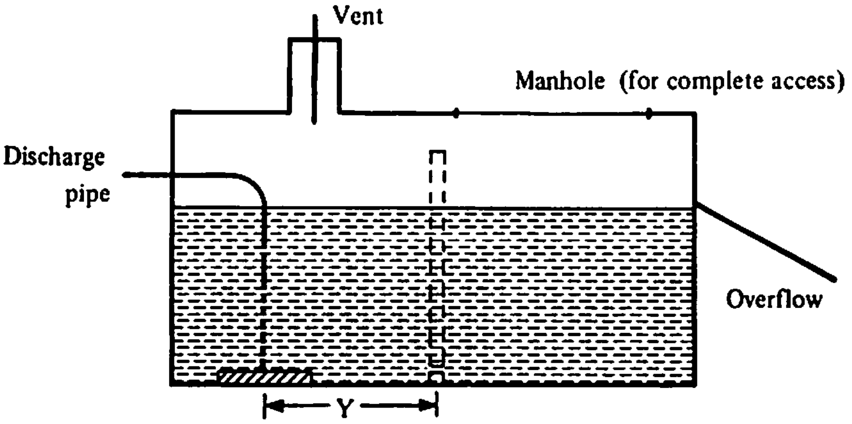

Fig 6

During blow-down the water level would rise but the rate of rise would be retarded by the increasing head on the drain and the increasing evaporation rate. This is illustrated in Fig 7. Since the equation (2) on page 8 gives complete freedom of choice between blow-down rate B and the ratio of cooling to heating time T/t it s always possible to ensure that the head in the pit stabilises before the tank is full. That is when:-

rate of blow-down - rate of evaporation = rate of drainage.

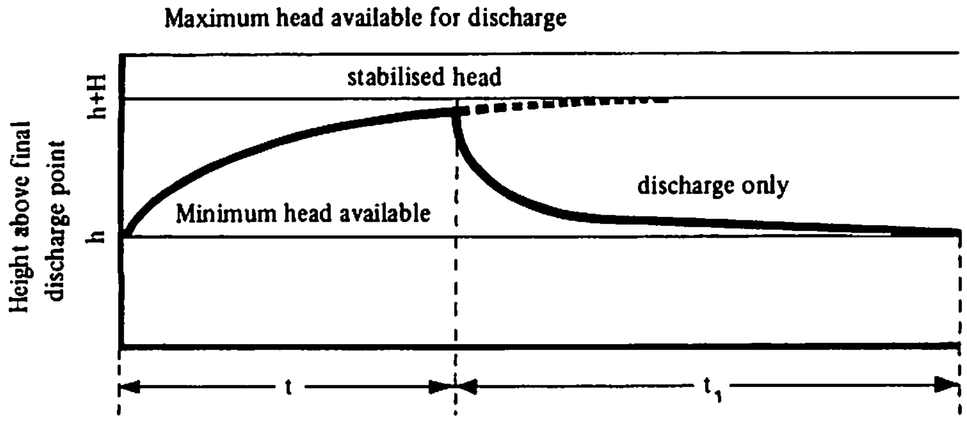

Fig 7

But the choice of dimensions to satisfy this condition must, so far as possible, facilitate natural cooling. The time t_1 available for cooling before all the blow-down is drained away is given in Appendix III for different critical dimensions. The curves there illustrate quantitatively:

(i) the direct proportion existing between discharge time t_1 and the surface area of the water being discharged;

(ii) the negligible effect of head on discharge time t_1 for the larger drain sizes in spite of the increased volume discharged.

The dimensions having been chosen, the temperature of the water entering the drain can only be further reduced by reducing the heat transmission between the dip pipe and the overflow; that is, by increasing the shaded area in Fig 5. This can be achieved by the construction of a partition wall at some point distance Y from the dip pipe and with a water way at its base (shown dotted in Fig 6).

There are several ways of increasing the drainage rate and ostensibly reducing the temperature of the water entering the drain. The most typical is that shown in Fig 8. It incorporates a baffle or blank partition wall which acts as a weir between the two sides. The position of the wall Y and the height of the overflow X depend on flow rates and cooling required and the ability of the drainage system to withstand the head. By depicting the standing water level, Fig 8 demonstrates how a greater head can be placed on the drainage system. Unfortunately the specific discharge time t_1 is reduced considerably by this arrangement because the maximum head and the maximum surface area (above the weir) coincide. The reduction can be gauged from Appendix III and must be compared against possible increased cooling during blow-down when the water flowing over the weir will be that which has just provided latent heat of evaporation and is continuing to do so as it is sliced into comparatively thin sheets.

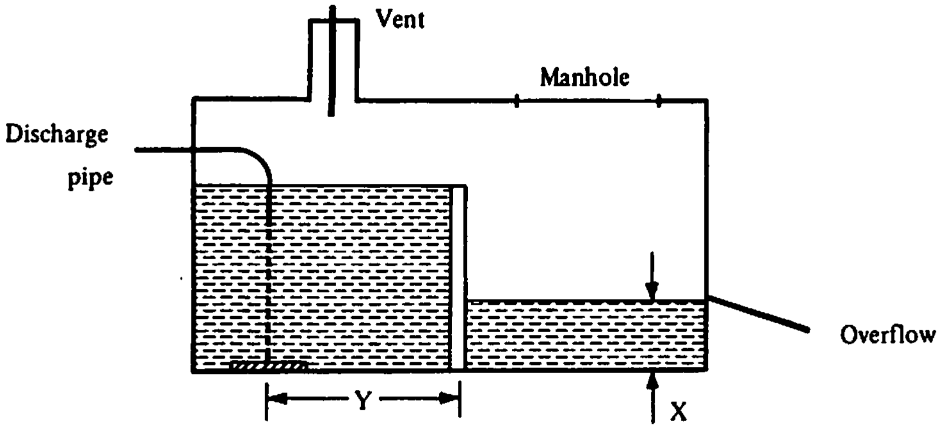

Fig 8

More complex arrangements of baffles may be justified in an attempt to reduce the temperature and possible rate of flow through the drains. Unfortunately the more complex the arrangement the more intractable the assessment of flow rates and temperatures. In fact in all pit designs it is necessary to measure actual temperatures and flow rates during commissioning in order to formulate safe blow-down procedures.

Additional cooling of the standing water between successive operations (during time T_1) can only be effected by increasing the ratio of the surface area to the volume of the pit and particularly the surface area of the water. This will add to the expense of the pit and must be taken into account in economic comparisons with other methods.

In the event of a partly blocked drain and to a lesser extent vent pipe, the head in the pit may not stabilize; and if for some reason blow-down is continued there would be a discontinuity of flow the moment the pit filled. This would cause an instantaneous rise in pressure limited only by the resilience of the pit unless e critical pressure is exceeded. Under normal hydraulic flow conditions this pressure would immediately fall until it was just sufficient to accelerate up the vent pipe an amount of water equivalent to the blow-down rate less anything escaping through the drains or past the manhole cover. But this is not just hydraulic flow. The water temperature is continually rising yet free flashing can take place only over the surface of the vent and at the manhole gap. A potentially dangerous situation therefore exists which can only be contained by:

(i) rigid planned maintenance ensuring that drains, vents, manholes and blow-down valves are always free;

(ii) rigid blow-down policies ensuring that maximum permitted blow-down is never exceeded either by a single boiler or by several boilers in a multi-boiler installation.

The resilience of the pit may be increased by the elasticity of trapped air. Fitting the vent into a recess and allowing it to project below the surface as shown in Figure 6 may help. As the main water level rises above the base of the vent pipe the water inside the pipe rises faster due to the gradually increasing pressure in the receptacle. Just before the tank fills the manhole cover would lift momentarily to release the air. The final shock at the instant of filling would be absorbed by the air trapped in the recess and discharge would continue up the vent pipe until or unless the water pressure is sufficient to lift the manhole cover.

Pits should not be positioned in front of boilers, in the firing aisle or in any escape routes through or external to the boiler room. The vicinity of the manhole cover should be restricted by a guard rail or, if necessary, a surrounding wall. A bold notice should be displayed forbidding persons to enter this area when boilers are being blown-down.

Pits should be designed and constructed as single structures - the base being secured to the walls by tie-bars or by continuous reinforcement - and the internal surface rendered with water-tight cement at least $\frac{3}{4}$ inches thick when engineering bricks are used for walls. A 1 inch cast-iron plate at least 2 feet square should be fitted below the dip pipe to prevent erosion of the concrete. Similar plates may be necessary on concrete or brick walls lying within 18 inches of discharging points.

A heavy cast-iron or steel manhole cover should be attached to the top by a non-ferrous hinge so that the weight is evenly supported on a simple seal which is broken when the internal pressure rises above the unit pressure of the manhole cover. It may be necessary to fit a safety stop or set screw to control the opening of the manhole cover if this cannot be achieved by gravity. The manhole cover should permit easy access to all parts of the pit and it should be designed in a manner which will prevent the ingress of surface water, dirt and rubbish.

In deep pits cast-iron or steel step-irons may be required for cleaning purposes. Where semi-automatic intermittent or continuous blow-down is practised some provisions must be made for rapid cleaning since it will be necessary to isolate the pit.

The pit must be designed as a pressure vessel if pressure is required to lift the cooled blow-down into the drainage system. Under these circumstances insurance may be necessary and if the Factories Acts apply, inspection will be required every 26 months.

(b) Surface mounted blow-down tanks

When it is difficult to obtain adequate cooling in a pit, a surface mounted steel tank may offer a sound economical solution. Indeed, in the U.S. and Canada these have recently become mandatory.

Tanks available for this purpose are little more than ventilated settling tanks or flash vessels. They are usually pressure tested but they are not certified as pressure vessels. Nor are they designed as coolers but their cooling capacities can be accurately assessed and improved by suitable siting. The manufacturers usually offer gilled tube coolers to be used in conjunction with the tanks. The combination gives a system in which the total performance can be accurately predicted from design figures.

Ventilation

The purpose of the vent pipe is to allow the escape of air to avoid pressure rise, and to allow the escape of vapour to reduce the heat content of the fluid in the receptacle. In a properly designed and operated system there is no other function. But if something goes wrong, if the drain becomes blocked and blow-down fails to stop, the vent, like the manhole cover, must act as a safety device or forced drain.

Under the worst conditions, with the drain blocked and the receptacle full of boiling water, the vent pipe would be required to discharge $(1 - q)B = (1 - q)rM/ut$ lb/hr of water and to release $qB = qrM/ut$ lb/hr of steam (q is the flashing fraction obtained from Fig 3). The vent pipe dimensions should be such that this discharge can occur when the receptacle pressure rises to not more than 1 lb/in^2 above atmosphere.

The vent pipe should be of cast-iron to BS 1211 - 1958 - at least Class B. It should be adequately supported with the minimum number of bends and terminated in a galvanised anti-bird device in such a position that the issuing steam will not cause a nuisance or danger.

A simplified example illustrating the use of the charts in Appendices I, II and III is given at Appendix IV.

C. Copple

13/9/71

Boiler blow-down discharge rates

Appendix I

In a horizontal pipe of uniform section the pressure drop dP between two planes dx ft apart is expended in overcoming friction and accelerating the fluid

$$-(12)^2\, v\,dP = \left[\frac{4}{25\pi}\right]^2 \left\{ \frac{1}{g} \left[\frac{B}{d^2}\right]^2 v\,dv + \frac{12f}{2gd} \left[\frac{B}{d^2}\right]^2 v^2\,dx \right\}$$

Between two planes 1 equivalent feet apart and subject to terminal pressures P_b and P_r

$$\int_{P_r}^{P_b} \frac{1}{v}\,dP = \left[\frac{1}{75\pi}\right]^2 \left[\frac{B}{d^2}\right] \frac{1}{2g} \left\{ 2\log\left[\frac{V_r}{V_b}\right] + 12\,\frac{fl}{d} \right\}$$

Choking will occur if the integral quantity can reach a maximum before expansion is complete, i.e. if

$$\frac{d}{dP} \int_{P}^{P_b} \frac{1}{v}\,dP = 0 \text{ is satisfied by } P = P_c \text{ where } P_c > P_r$$

The critical mass flow consequent on this critical pressure is:-

$$B = 1{\cdot}893\; 10^3\, d^{5/2} \sqrt{\frac{\int_{P_c}^{P_b} \frac{1}{v}\,dP}{2d\log\left[\frac{V_c}{V_b}\right] + 12\,fl}} \quad \text{lb/hr}$$

Assuming isentropic expansion and no pipe entry losses the graph below gives the solutions to this equation for a friction factor f = •013. The simplest method of reducing the effects of the above assumptions is to follow the procedure outlined on p. 336-342 of Nuclear Science Engineering 41 (1970) NASA.

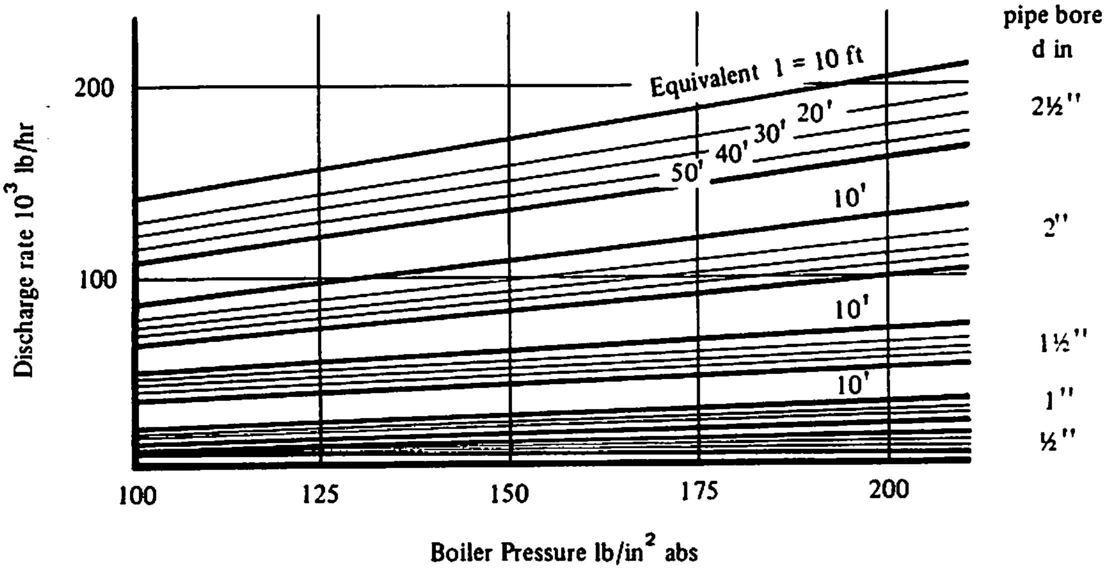

Fig 9

Blow-down pit overflow pipe discharge rates Appendix II

The thick horizontal lines on the graph below - deduced from Blaisdell's paper on Flow in Culverts, Vol 92 No HY2 Proc ASCE March '66 - represent free flow discharge controlled by flush circular orifices.

If the slope of the overflow pipe is reduced until it is less than the friction slope, i.e.

$$\frac{h}{L} < \left[\frac{4}{25\pi}\right]^2 \frac{12f}{2gD} \left[\frac{Cv}{D^2}\right]^2$$

the pipe will run full. The limits of free flow, or the beginnings of the horizontal lines are shown for pipes of ·01 inch average roughness discharging fluid of density 61·2 lb/cu ft and viscosity 4·7 x 10^{-6} ft^2 sec and using friction factors from Moody or 1969 HRS charts. If the head or possibly the slope of the overflow pipe is increased it may also fill and cause the discharge to increase, but the precise condition under which this happens cannot be evaluated. The total head across the overflow pipe when running full is converted to kinetic and frictional heat energy, i.e.

$$H + h = \left[\frac{4}{25\pi}\right]^2 \left\{ \frac{1}{2g} \left[\frac{Cv}{D^2}\right]^2 + \frac{12\,fL}{2gD} \left[\frac{Cv}{D^2}\right]^2 \right.$$

$$\text{and } C = 9{\cdot}625\ 10^3\ D^{5/2} \sqrt{\frac{H + h}{D + 12fL}} \ \text{lb/hr}$$

Discharge is thus controlled by the pipe dimensions and geometry and cannot be represented on the graph. It is roughly indicated by the shaded areas.

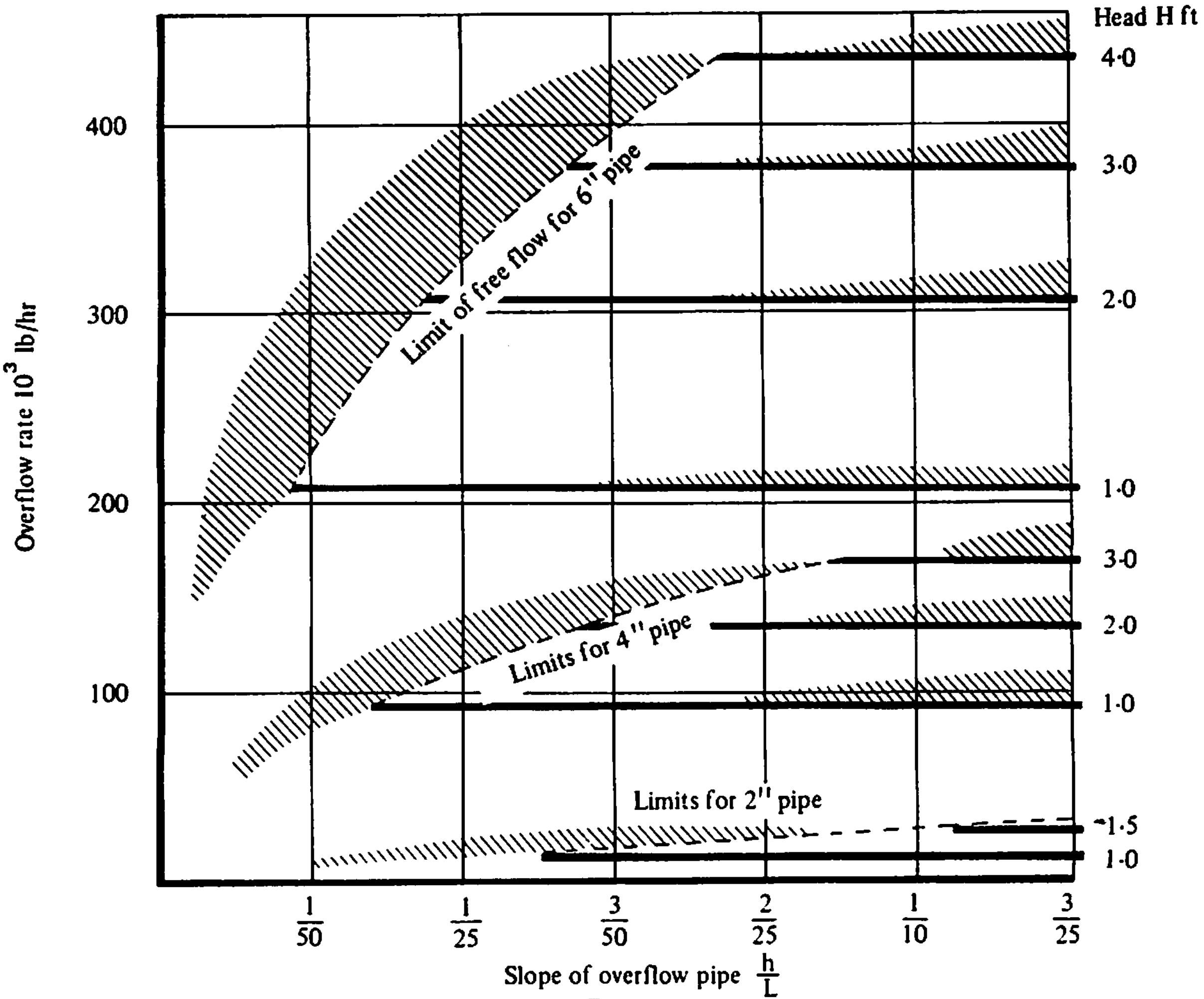

Fig 10

Blow-down pit cooling period

The total period of discharge includes the heating period t during which the head above the orifice increases to H ft and the cooling period t_1 during which the head falls to say H_0 ft above the base of the orifice, i.e.

$$\text{Total period of discharge } t + t_1 = t + \frac{25\pi}{v}\left[\frac{D}{24}\right]^2 \int_{H_0}^{H} \frac{dh}{C} \text{ hr}$$

The latter expression for t_1 includes a period of orifice and a period of weir control and both are minimal when the flow is free. The graph below therefore again makes use of Blaisdell's figures in demonstrating the minimum (free flow) periods t_1 per sq ft of surface area for a flush pipe to reduce the head from H to H_0 ft or ½ inch above the base of the orifice. To obtain actual cooling times the figures on the horizontal axis must be multiplied by the area of the water in sq. ft. e.g. if the surface area is A from H to H_1 and A_1 from H_1 to H_0 the cooling time t_1 is A times the horizontal axis reading from H to H_1 plus A_1 times the horizontal axis reading at H_1

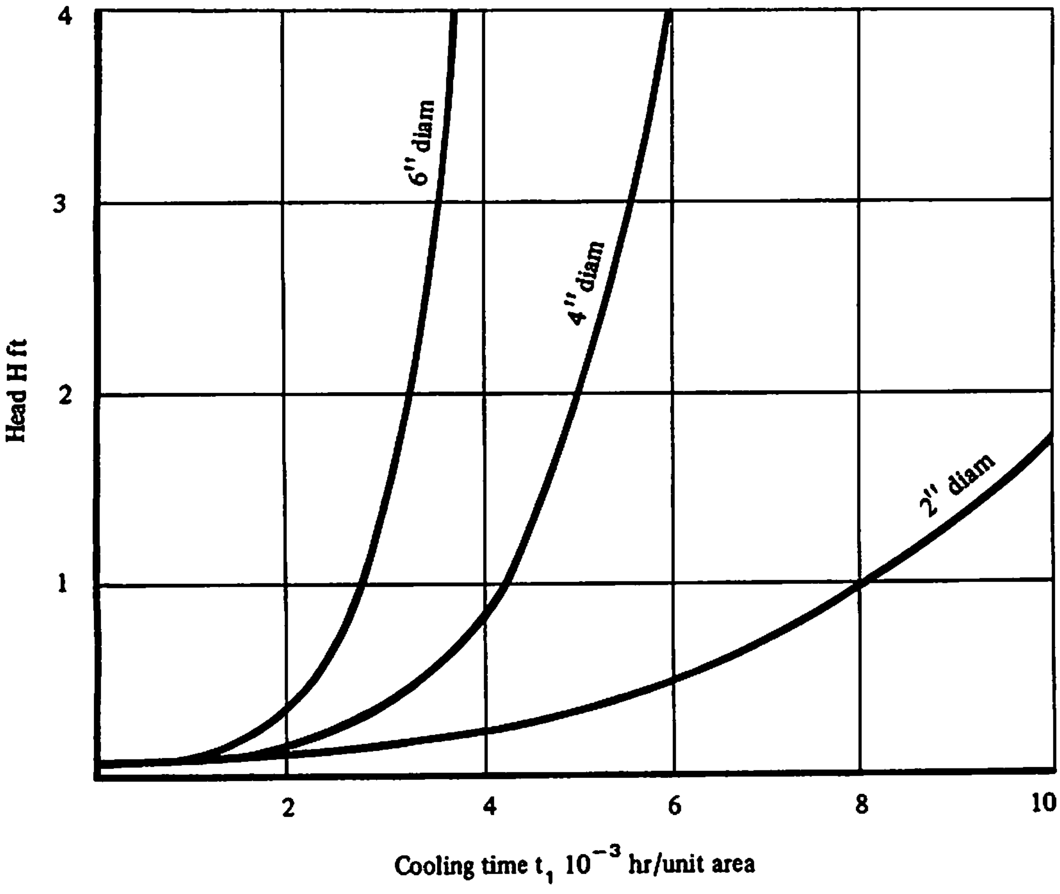

Fig 11

Illustrative example

Make-up water with a TDS content of 200 ppm is fed to a boiler producing heating and process steam at 150 lb/in² gauge (366°F). Heating is required for 24 hrs a day but process steam, which is not returned to the boiler as condensate, is consumed only during the 8 hr day shift at a uniform rate of 5,000 lb/hr.

The solids content of the boiler must not exceed 3,500 ppm. The boiler is positioned some 20 ft from a suitable blow-down pit location which in turn lies at a slope of 1 in 20 to 25 from the drain. The exact slope will depend on the actual inlet position of the overflow pipe.

It is required to estimate the major dimensions for manual periodic blow-down for feasibility and costing purposes before considering alternative and possibly more economic methods.

$$u = 3500 \text{ ppm}$$

$$r = 200 \text{ ppm}$$

$$l = 20 \text{ ft}$$

$$M = (5000\,T + Bt) \text{ lb}$$

$$S = 338 \text{ Btu/lb}$$

Discharge pipe

Equation 2 on page 8 can be written

$$Bt = \frac{r}{u} M = \frac{200}{3500} (5{,}000\,T + Bt)$$

from which $\frac{T}{t} = 3{\cdot}3\,B \times 10^{-3}$

Fig 9 at Appendix I shows that a 2 inch pipe 20 ft long will discharge at a rate B of 100 x 10^3 lb/hr. With this standard pipe therefore

$$\frac{T}{t} = 330$$

giving rise to the following combinations

T hrs	2	4	6	8
3600 t sec	22	44	66	88

With a single boiler installation using process steam during one shift only, the 8 hr blow-down can be divided into 3 similar operations - one immediately following the process shift and the other two at any suitable intervals during the remaining 16 hrs. In this case each operation needs to be continued for only 88/3 sec. Using this policy the amount of blow-down at each operation is

$$Bt = (100 \times 10^3 \times 88) \div (3 \times 3600) = 815 \text{ lb}$$

This quantity contains

$$\text{(a)}\quad 815 \times 3{,}500 \times 10^{-6} \doteqdot 3 \text{ lb of solids}$$

$$\text{and}\quad \text{(b)}\quad BtS = 274{,}000 \text{ Btu of wasted heat.}$$

Standing Water

If between operations the pit water drops to 85° F the minimum standing water required (page 14) is given by

$$W = \frac{\text{Boiler water temperature above } 212^\circ\text{F}}{\text{Steady pit water temperature below } 212^\circ\text{F}} \cdot \frac{r}{u}\, M \text{ lb}$$

$$= \frac{366 - 212}{212 - 85} \cdot 815 = 990 \text{ lb} \doteqdot 17 \text{ cu ft}$$

and the minimum air space $rM/31u \doteqdot 2 \times 14$ cu ft

If W is increased beyond 17 cu ft both the heat loss by local boiling and the average temperature will be reduced. There will be other reasons for increasing the pit size, e.g. possible future increase in the use of process steam, need to drain the boiler during annual cleaning etc., but each case must be treated on its merits.

Overflow pipe

Fig. 10, Appendix II, indicates that a 4 inch pipe subjected to a head of 1 ft would discharge 95×10^3 lb/hr provided the slope were not less than 1 in 35. A 4 inch overflow pipe under a 15 inch head would therefore stabilize the flow regardless of the exact position of its inlet.

Pit dimensions

In a pit with a simple barrier to reduce heat transfer the head should rise 15 inches above the base of the outlet during blow-down

$$(\text{length} - \text{barrier thickness}) \times \text{width} \times 1\tfrac{1}{4} = 17 \text{ cu ft}$$

and this is satisfied by a 6 ft by 2 ft 6 in pit 4 ft deep

Fig 11, Appendix III gives a cooling time $t_1 = 4\frac{1}{2} \times 6 \times 2{\cdot}5 \times 10^{-3}$ hr $\doteqdot$ 4 min.

In a similar sized pit with a weir barrier at its centre and y in above the previous standing water level, the outlet would need to be lowered by this same amount. The stabilizing head would therefore lie (15 + y) in above the base of the outlet orifice. With y = 9 in Fig 11, Appendix III gives a cooling time

$$t_1 = \left\{(5 - 4{\cdot}65)\ 6 \times 2{\cdot}5 + 4{\cdot}65 \times 3 \times 2{\cdot}5\right\} 10^{-3} \text{ hr} \doteqdot 2\tfrac{1}{4} \text{ min.}$$

With this arrangement the slope of the overflow pipe is reduced by 9 inches and the cooling time t_1 nearly halved but it does give a few more inches above and/or below the discharge pipe to improve condensation and reduce erosion.