GESTRA Steam Systems

GESTRA Information A 1.7

Automatic Deaeration of Steam-Heated Heat Exchangers

Preface

For optimum efficiency of steam-heated heat exchangers several requirements should be fulfilled, the most important being:

1. Saturated steam should be used. The rate of heat transfer from superheated steam is lower. If wet steam is used the thick water layer being formed will impair heat transfer.
2. It is essential that the design steam pressure is maintained so that the effective temperature difference is preserved.
3. Banking-up of condensate into the heating surface should be avoided. This is achieved by correct choice, sizing and arrangement of steam traps.
4. The heating surface should be clean. It may be necessary to clean it from time to time.
5. Air-venting during start-up and during continuous operation is necessary.

Quite frequently the latter point is not considered adequately. This information sheet therefore treats this subject in some detail.

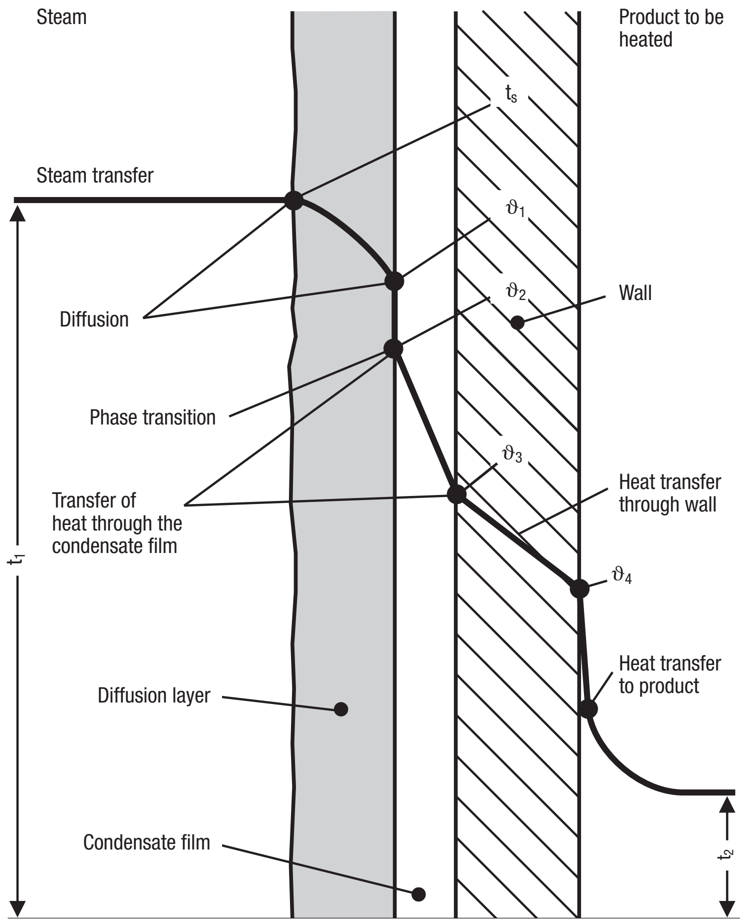

Fig. 1 *Temperature gradient during film condensation of a steam/air mixture*

Basic Concepts

The rate of heat exchange ($\dot{Q}$) from the heating fluid through a partition wall to the product to be heated depends on several individual processes expressed by the following equation:

$$\dot{Q} = k \cdot A \cdot \Delta t_m \quad [W]$$

where

Δt_m = mean temperature difference between steam and product [K]

A = heating surface area [m^2]

k = coefficient of overall heat transfer $\left[\frac{W}{m^2 K}\right]$

calculated for a clean heating surface by the equation

$$\frac{1}{\frac{1}{\alpha_1} + \frac{\rho}{\lambda} + \frac{1}{\alpha_2}} = k$$

where

α_1 = coefficient of heat transfer $\left[\frac{W}{m^2 K}\right]$

heat transfer steam to wall

α_2 = coefficient of heat transfer $\left[\frac{W}{m^2 K}\right]$

heat transfer wall to product

ρ = wall thickness [m]

λ = coefficient of thermal conductivity $\left[\frac{W}{m^2 K}\right]$

heat flow through the wall.

Incondensable gases, mainly air, penetrate into the heating surface by several means, in particular during periods of standstill. These gases considerably impair the heat exchange since they form an insulating layer (diffusion layer) between the steam and the condensate film on the heating surface.

Fig. 1 shows the influence of the air layer and the condensate film on the temperature gradient. The predominently negative influence is a result of the enormous reduction of the coefficient of heat transfer α_1.

Fig. 2 shows clearly that this heat transfer coefficient reduces with increasing gas percentage. It is worst at very low flow velocities.

The inclusion of incondensable gases in the steam reduces the partial steam pressure and consequently the temperature. Although the pressure gauge indicates the full pressure the temperature is lower than the saturated steam temperature relative to the applied pressure. This implies a reduction in the mean temperature difference between steam and product, i.e. the rate of heat exchange is reduced. Compensation is possible by increasing the pressure until the desired temperature is reached. On the other hand, the temperature drop enables us to vent the system automatically as a function of pressure and temperature.

Gauge pressure = total pressure (P_t) = partial steam pressure (P_S) + partial gas pressure (P_G).

Without the inclusion of gases in the steam $P_t = P_S$. At an absolute pressure of 6 bar the temperature is 158.8 °C.

If, however, 20 % by weight of air are present in the steam, we obtain in accordance with the above equation, $P_t = P_S + P_G$ or $6 = 4.8 + 1.2$, i.e. a partial steam pressure of 4.8 bar, the corresponding temperature is only 150.3 °C.

The connection between total pressure, percentage of air present and temperature is shown in the chart **(Fig. 3)**.

Below is an example of the use of this chart: A total pressure of 11 bara and a temperature of 180 °C were measured in a heat exchanger. This implies that the heat exchanger is fed with 10 % of air and 90 % of steam. At the same total pressure, but a temperature of only 170 °C the air/steam mixture contains as much as 35 %. This illustrates that for the same total pressure the concentration of air is highest at the coolest spot. This should be considered when deciding on the position of the air vents.

What about standard practice?

As far as heat exchangers that are already operating are concerned the coolest spot can be determined by measurement. As these measurements require some time and effort they quite often remain undone. Efficient deaeration should already be provided on new heat exchangers. The question, however, remains where to install the air vent. The determination of the venting capacity and of the place of installation is always difficult. One has to rely on practical experience.

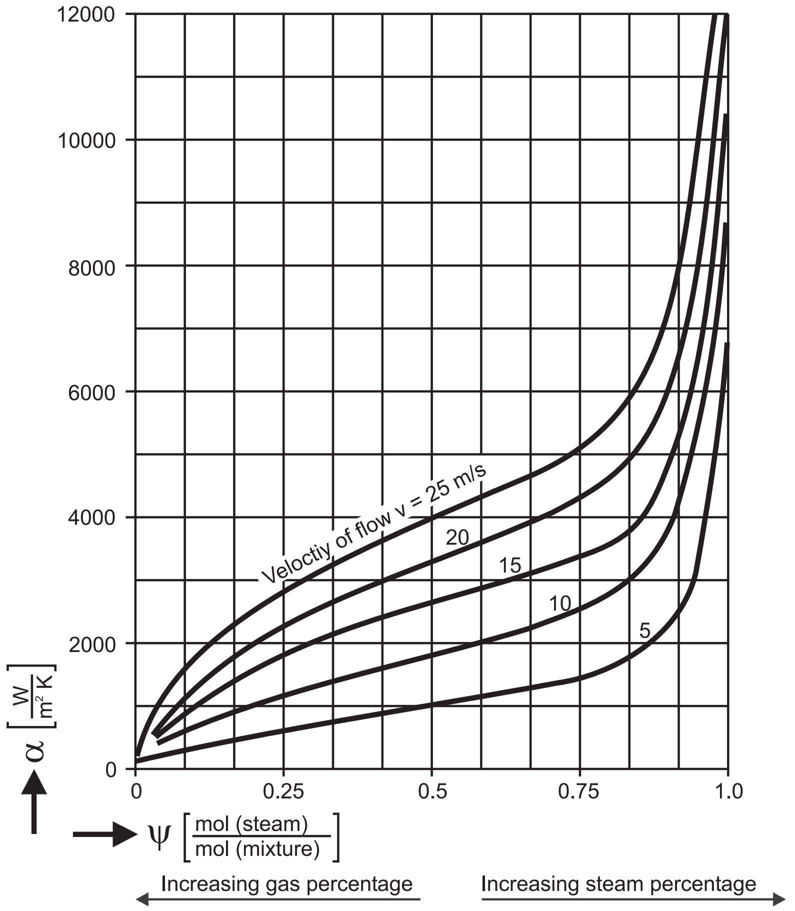

Fig. 2 *Coefficient of heat transfer α in the case of condensation of water from a steam/air mixture as a function of the molar percentage ψ of the steam and the velocity of flow at a total pressure of 2 bar a.*

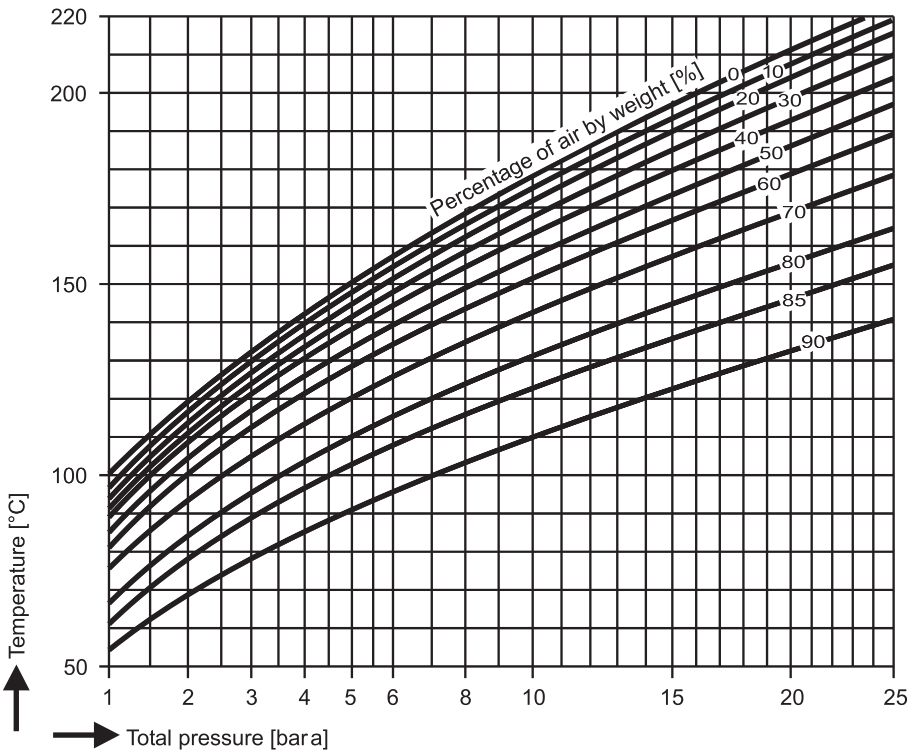

Fig. 3

Air-Venting of Heat Exchangers

The following types of heat exchangers should be considered separately for air venting:

1. **Heat exchangers with tube systems, such as heat exchangers with tube bundles or heating coils, where the steam is flowing through the tubes and the condensate discharged by steam traps.**

   In this case air-venting is effected by the steam traps. For this purpose, however, steam traps with air-venting capacity are required, such as thermostatic traps, stage-nozzle traps or ball-float traps with additional thermostatic deaeration. Other trap types are unsuitable.

   The steam traps are always installed at the end of the heating tubes (condensate outlet). The incondensable gases are transported through friction produced by the flow energy of the steam and the condensate to the end of the tube system and are there discharged by the trap.

   Air-venting problems hardly occur.

2. **Heat exchangers with the steam circulating around the tubes or in steam chambers, such as jacketed heat exchangers, autoclaves etc., i.e. heat exchangers with large calandria which are also drained by steam traps.**

   In the large calandria the flow velocities towards the condensate outlet are low, so that little turbulence is present.

   Differences in the heat flow density on the heat-exchange surface may occur.

   Condensate may accumulate depending on the steam admission, the design of the heating surface and the different heat flow density.

   And all these conditions may vary at different loads.

   Incondensable gases having different densities may also be present, e.g. in heat exchangers heated with flash steam.

   As a result of these influences the gases might not be transported to the condensate outlet at all or only partly or only at times. The gases concentrate at certain points where they reduce the rate of heat transfer since they prevent the steam from reaching these parts. These are also the coolest parts that should be vented separately, provided they are known. It is, however, to be expected that the gases concentrate at the calmest spots, one of them being the furthermost from the steam inlets.

3. **Heat exchangers with a level control for the condensate discharge.**

   Heat exchangers provided with a level control for the condensate discharge preclude any possibility of discharging the air through the condensate outlet. A special provision for a deaerator connection just above the max. level is therefore essential.

In practice – as with other aspects of steam plant – we have to distinguish between start-up conditions and normal running conditions.

During the start-up process large volumes of air have to be discharged from the calandria. As the process approaches optimum load the lowest volume is reached. All deliberations in respect of optimum deaeration are relative. Strictly speaking it is hardly possible to establish exact data on the required air-venting capacity. It is necessary to rely on estimation and experience as concerns air quantities as well as the places where air collects.

Automatic Deaeration with Thermostatic Steam Traps

If air-venting is effected by fixed orifice plates either the air-venting capacity during start-up is insufficient or the steam loss in continuous operation too large. The use of manually operated valves for deaeration offers some advantage compared with fixed orifice plates. The valves can be fully opened during start-up and throttled later. It is, however, hardly possible to determine the degree of opening or throttling. In most cases they are opened too far.

It is therefore recommended to deaerate as a function of the temperature of the steam/air mixture. Thermostatic steam traps are well suited for this purpose.

The main function of a steam trap is to hold back the steam and to let the condensate pass. The traps open in the presence of undercooled condensate (undercooling means that the temperature of the condensate is lower than the temperature relative to the applied steam pressure). When the amount of undercooling decreases the traps move in a throttling position and are closed before steam passes.

Thermostatic traps are not controlled by the fluid but by the temperature and the pressure. As the inclusion of air reduces the temperature so that it is no longer the saturation temperature relative to the applied pressure, the traps open and release an air/steam mixture. The larger the air proportion, the more the traps open and vice versa.

The following traps from our range are suited as air vents:

**GESTRA Duo Steam Traps,
Series BK, (Fig. 4)
GESTRA Steam Traps,
Series MK (Figs. 5 and 6)**

For more details on the design and operation of these traps refer to the respective leaflets.

For normal air-venting purposes BK with factory setting and MK with "N" (standard) membrane can be used. If the process requires very exact deaeration the BK is better suited in that it can be readjusted so that a larger air-venting capacity or a continuous flow can be obtained. The MK cannot be readjusted.

Fig. 4 *GESTRA Rhombusline® BK 45*

Fig. 5 *GESTRA Rhombusline® MK 45*

Fig. 6 *GESTRA Steam Trap MK 36/51*

Installation of Air Vents

The vent point should be provided in the part of the calandria that has to be deaerated. The vent line should always rise, ideally vertical. By this means the condensate forming in that part of the pipeline can flow back and water pockets upstream of the air vent that would prevent air discharge are avoided.

The air vent should be installed on the top of an uninsulated pipe having a length of at least 1 m (separating pipe). As a result of the partial condensation of the steam in this pipe the partial steam pressure is reduced. This leads to a temperature drop and consequently to an increased air discharge **(Fig. 7)**. The continual condensation of a slight amount of steam also produces a flow in the direction of the air vent.

The line downstream of the air vent should be as short as possible to avoid the formation of a condensate column that would reduce the differential pressure available for the air vent and consequently the air-venting capacity. This is particulary detrimental if the pressure in the calandria is very low.

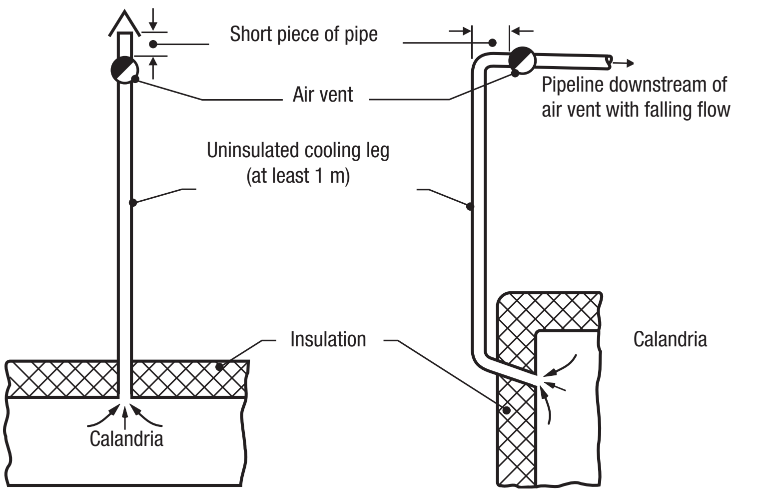

Fig. 7 *Correct mounting position of air vents*

Application of Air Vents

The following examples show heat exchangers requiring additional air venting and indicate the parts where, in accordance with experience, the air vents should be fitted.

Fig. 7: Heat exchangers with large calandria drained by steam trap

a) Heat exchangers with tube bundles are used as storage calorifiers, preheaters, air heaters etc.

b) Jacketed heat exchangers are boiling pans, agitator vessels, brewing pans, driers, heating beds, stills etc.

c) Autoclaves are vessels with steam-tight closure for heating products under pressure, for example block curers, boiling vessels, sterilizers, vulcanizers, textile finishers etc. Depending on the steam admission into the autoclave it might become necessary to fit s everal air vents, particulary if during the heating process other gases besides air are released.

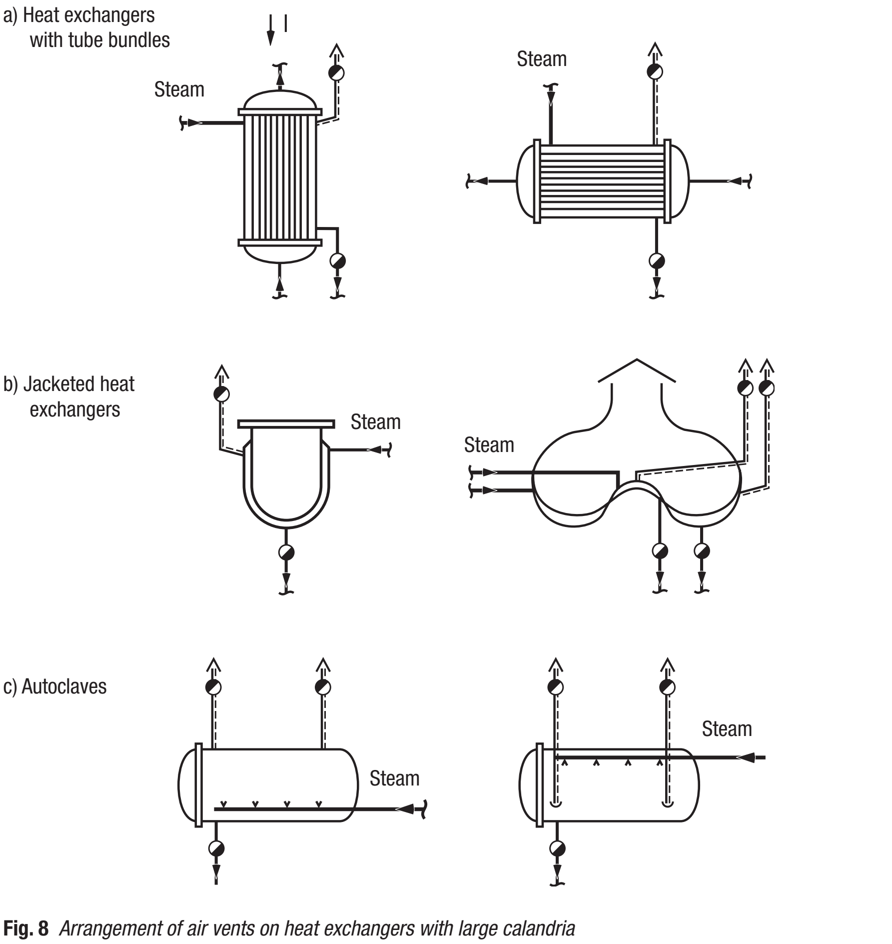

Fig. 8 *Arrangement of air vents on heat exchangers with large calandria*

Fig. 8: Deaeration of evaporators heated with flash steam

Flash steam is secondary steam produced by flashing (e.g. downstream of steam traps) or, as in the case of evaporators, by the vaporization of the water from the product.

Evaporating plants are usually of multi-stage design, for example in the sugar industry. The first stage is heated with live steam.

The flash steam produced in the first stage provides the heating fluid for the second and so on. More often than not the flash steam includes a large proportion of incondensable gases (not only air, but N, NH_3, CO_2 etc.) which severely impair the heating capacity in the subsequent stages. As the gases have different molecular weights each evaporator needs several vent points at different levels and in different places. Each vent point should be fitted with a separate air vent at the end of the vent pipe as shown in schematic diagram a). If the individual pipes downstream of the air vents are to be led to an elevated level (e.g. over the roof) they can be grouped in a common header as shown in schematic diagram b). The header, however, requires draining. To avoid the nuisance of odour in closed rooms it is recommended to introduce the vent pipe into a water tank below the level, or to provide a water loop in the header. The header may also be led directly into the open with falling flow, see schematic diagram c).

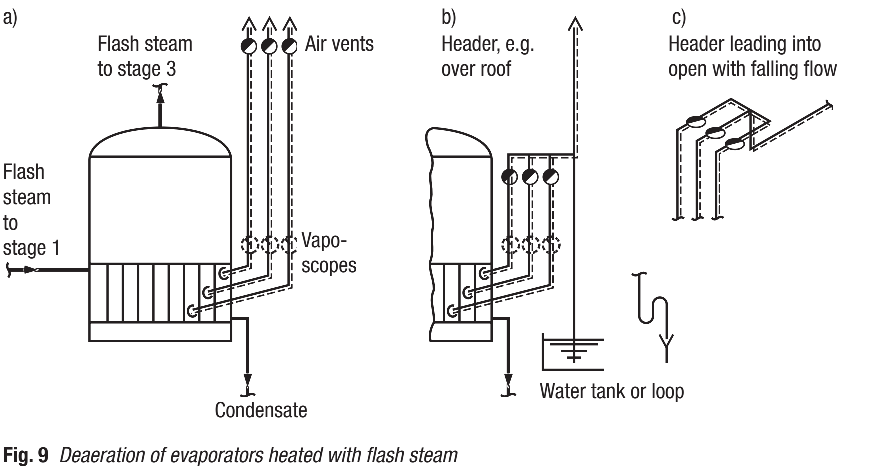

Fig. 9 *Deaeration of evaporators heated with flash steam*

Fig. 9: Heat exchangers with level control

The vent connection should always be provided just above the maximum level. As the air cannot escape through the water seal it will collect at this part of the heat exchanger. If the air is not discharged, it will not only reduce the heating capacity but also cause corrosion on the vessel wall at the level of the boundary layer.

Fig. 10: Heat exchangers operating on the thermosiphon principle

If the thermosiphon principle is applied when heating and draining a heat exchanger because there is no other possibility of utilizing the flash steam, an air vent has to be fitted upstream and downstream of the heat exchanger. Otherwise a thermosiphon circulation would not start.

Fig. 11: Deaeration of a flash vessel in a closed steam/condensate system

Flash vessels are pressure vessels for separating the flash steam from the condensate. They are applied if the flash steam from high-pressure heat exchangers is used for heating low-pressure heat exchangers. If the one or the other of the high-pressure heat exchangers is frequently shut down a large amount of air will penetrate into the flash vessel. The air would be fed with the flash steam into the low-pressure heat exchangers and considerably impair the heat transfer. The air should therefore be discharged as far as possible beforehand which is best effected with an air vent.

Fig. 12: Large, extended steam plants

Frequent start-up and shut-down of extended steam plants will lead to accumulation of air in the system. If the air is to be prevented from entering the heat exchangers the steam line should be vented.

To ensure that the air reaches the air vent and is not entrained by the steam beyond the vent connection, it is recommended to install the air vents in pipe bends and at the end of the pipeline. The air-venting effect is improved if an air collecting pipe or vent dome is provided at the vent point and if the pipe leading to the air vent is fitted at these points.

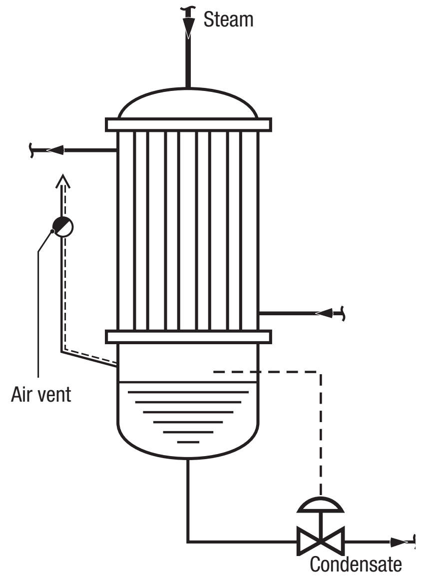

Fig. 10 *Deaeration of a heat exchanger with level control*

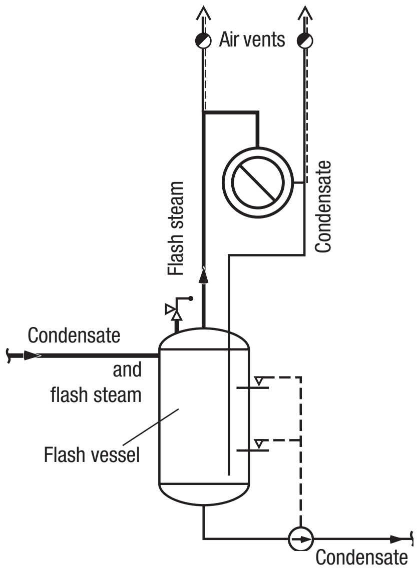

Fig. 11 *Deaeration upstream and downstream of a heat exchanger operating on the thermosiphon principle*

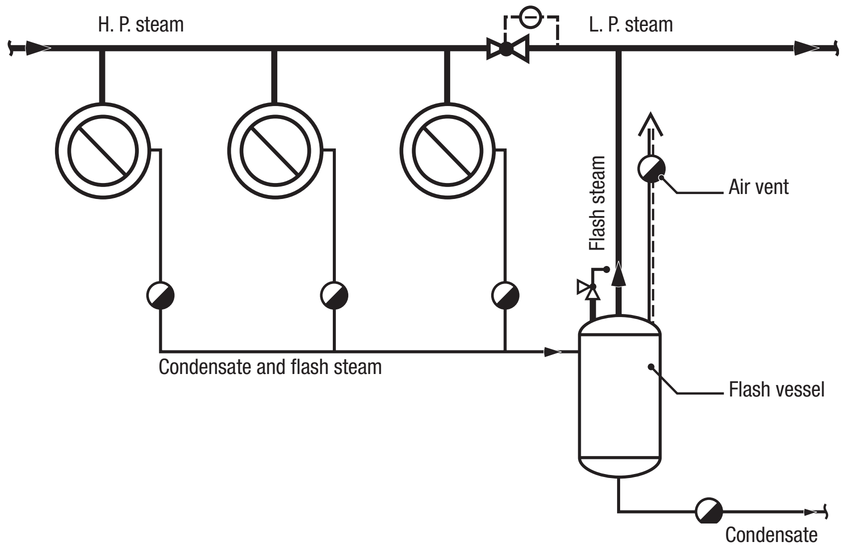

Fig. 12 *Schematic diagram of a flash steam recovery system with deaeration of flash vessel*

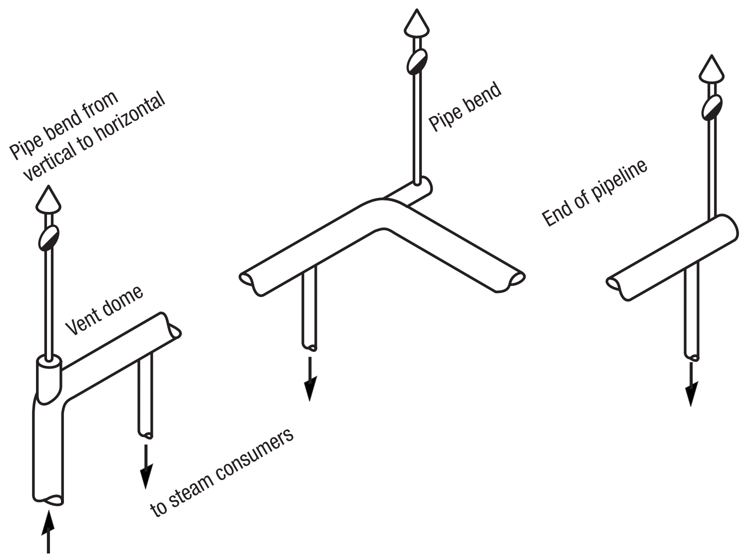

Fig. 13 *Examples of effective arrangement of air vents in a long pipeline*

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