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FLAME ARRESTING HIGH VELOCITY VALVES ON CARGO TANKS OF TANKERS FOR INFLAMMABLE LIQUIDS

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Summary

The difference is shown between the various types of flame arresting devices (explosion arresting, long time burning flame arresting and detonation arresting devices) and the requirements to be met in safety aspects by those devices are pointed out. With regard to high velocity valves, which are flame arresting devices as well as conditional flame arresters (e.g. crimped ribbon arresters), the conditions of tests related to flame arresting properties and carried out in the Physikalisch-Technische Bundesanstalt (PTB) are described. Furthermore the conditions for a sufficient carrying-off and diluting of the vented inflammable vapors are explained. Finally the capacity and the facilities of the test plant in PTB are shown.

1. Introduction

A discharged, uncleaned and not gas-free tank of tankers for inflammable liquids with a flash point below the liquid surface temperature (e.g. crude oils) constitutes an increased risk, as — according to the position of the flash point — explosible vapor/air-mixtures may exist in the tank. An ignition then leads to an explosion with increases of pressure with which customary cargo tanks are not able to cope. The safest protective measure against such hazards is to avoid explosible mixtures in the tank by inerting the tank atmosphere. If this is impossible or can be achieved only incompletely, the possible ignition sources which may cause an explosion in the tank must be eliminated. These possible ignition sources comprise — apart from e.g. static discharges during tank washing — also the flash-back of flames from outside through the tank openings which must be provided for venting purposes. As due to this venting system explosible atmosphere may exist also outside the tank (in particular during loading) and as ignition sources cannot always be eliminated in this area, a flash-back into the tank must be avoided. That is, the tank openings must be equipped with flame arresting devices. This is also required on an international level by IMCO [1], JOTTSG [2], IACS [3] and ADNR [4] as well as by national regulations in Germany. For many years, some experience has been gained in the Federal Republic of Germany concerning flame arresting devices on ship tanks as well as on storage tanks as according to the German regulations the prototypes of the flame arresting devices must be experimentally tested and approved [4–6]. The corresponding test work carried out in the Physikalisch-Technische Bundesanstalt (PTB) for many years has resulted in certain requirements as far as safety technique is concerned. With the exception of the requirements concerning high velocity valves the devices have already been dealt with to a large extent [7]. The increase in tanker capacities and loading rates during the loading of the tankers has resulted in the necessity to increase also the capacity of the venting devices on ship tanks. However, large amounts of inflammable vapor/ air-mixtures spilled out from the vent opening create large explosion hazardous areas outside and in the surrounding of the tank. In order to minimize those hazardous areas high velocity venting valves have been developed.

As the flow velocity and the momentum of the vented mixture is high these valves are capable of diluting the mixture and of throwing it up to greater dangerous height. As far as safety is concerned those valves should be of flame arresting type. It should be mentioned at this stage that tests carried out with conventional flame arresting devices whose flame arresting properties are based on flame quenching narrow gaps (such as crimped ribbon flame arresters, have shown that in case of large dimensions such devices cannot be constructed in a sufficiently long time flame arresting manner (see Section 2.2). Furthermore those arresters normally exhibit a high pressure loss at larger volume rates.

As a conclusion high velocity valves offer a combination of the following advantages:

(a) Carrying off and dispersion of the escaping vapor/air-mixtures by means of high flow velocities, high momentum and turbulence near the outlet so that the hazardous area outside the tanks is considerably limited.

(b) Flash-back safety due to their operating method (high flow velocities etc.).

Today two prototypes are manufactured differing in the operating method:

1. So-called relief valves which basically open and close proportionally to the pressure difference (overpressure in the tank), see Fig. 1.
2. So-called safety valves which by means of auxiliary devices (e.g. magneto systems) open or close suddenly and completely; see Fig. 2.

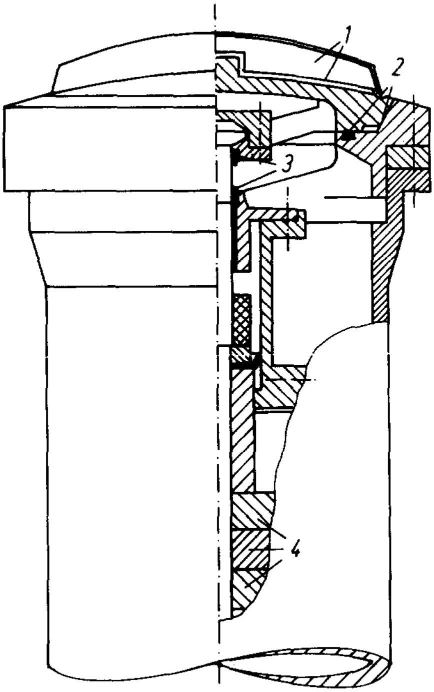
2. Definitions, basic safety requirements

Before going into closer details, the following question must be clarified: What is meant by ‘flame arresting devices’?

In this connection, some definitions and basic safety requirements of such devices shall be explained.

2.1. Explosion arresting devices

Openings on tanks out of which no larger volume rates of explosible mix-



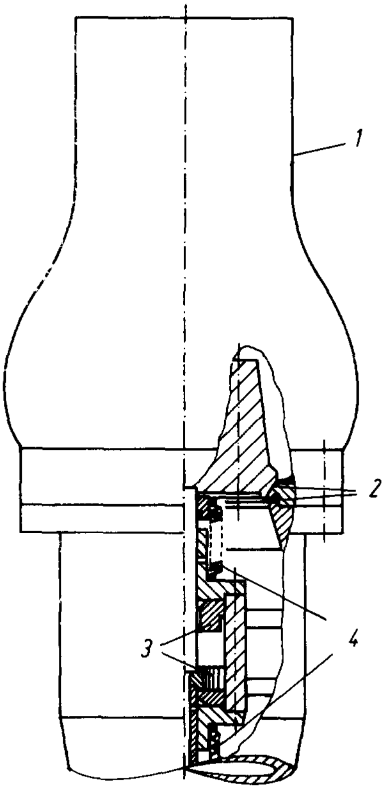


Fig. 1. Scheme of proportionally operating high velocity valve (relief valve); 1 protection against heat radiation, 2 valve seat, 3 scraper ring, 4 supplementary loading.

Fig. 2. Scheme of not-proportionally operaying high velocity valve (safety valve); 1 bonnet, 2 valve seat, 3 magneto system, 4 bellows.

tures escape into the open air over a longer period of time, but in the vicinity of which only clouds of explosible mixtures occur, are exposed after ignition to a short time impact of explosion. Thus, such devices must only prevent the flash-back of individual explosions into the tank and thereby withstand the explosion pressure wave.

Explosion arresting devices often have narrow gaps (e.g. crimped ribbon flame arresters) as quenching elements, having such a small width and such a great length that a flash-back is prevented.

Vacuum devices of non-inerted tanks of liquid tankers should be explosion arresting because of the possible existence of explosible plumes on deck.

2.2. Long-time burning flame arresting devices

In case of venting openings of non-inerted tanks (e.g. during their loading) the escape of larger quantities of explosible atmosphere over a longer period of time must be reckoned with in case of liquids with a low flash point. If the mixtures spreading into the open air are ignited, the mixture which continues to escape from the venting system may possibly burn off. Such openings must therefore be flame arresting not only in case of individual explosions ("explosion arresting", see Section 2.1), but also in case of the burning off of the escaping mixtures over a longer period of time ("long-time burning flame arresting").

2.3. Detonation arresting devices

Especially inside pipes, an explosion can change into a detonation resulting in high impact loads [8]. In order to suppress a flash-back and to prevent the shockwave from entering the tank a "detonation arresting" device must be installed at a suitable place of the pipe. Such devices must be considerably more shock-proof than an explosion arresting equipment. This paper will give no further details concerning detonation arresting devices.

3. Long-time burning flame arresting high velocity valves

3.1. Requirements

3.1.1. The valves must prevent an excessive overpressure in the tank. The opening pressure and the volume rate which is a function of the internal pressure in the tank must not lead to an unduly high overpressure, and moreover the conditions must not be adversely affected by outside influences such as cloggings, even under adverse operating conditions.

3.1.2. In all operating conditions, a flash-back in case of explosions as well as long-time burning flames must be prevented (see Section 2.2). In contrast to international regulations for the transport of inflammable liquids at sea and on inland waterways, in the Federal Republic of Germany the flame arresting devices are already differentiated according to their safety aspects into explosion arresting, long-time burning flame arresting and detonation arresting devices (see Section 2).

3.1.3. When lowering the internal pressure below the reseat-pressure, the high velocity valve must close sufficiently tight in order to avoid leakages as far as possible. In this case, however, attention must be paid to the fact that — for reasons of flash-back safety — the length of the sealing surface of the valve seat is not to short in closed condition (see Section 4).

3.1.4. During practical use, the reseat-pressure must not drop considerbly in order to maintain the flash-back safety.

3.1.5. The vapor/air-mixtures escaping from the high velocity valve must be carried off in such a way that outside the tanks the occurrence of explosible atmosphere remains restricted to the smallest possible range.

3.1.6. The cleaning and the maintainance work which is necessary to avoid disturbances, should be carried out at certain intervals to be fixed accordingly to experience gained on board. The necessity of such cleaning and maintainance work should be taken into account during the construction of such valves.

3.1.7. Under the practical conditions of maritime navigation the valves should as far as possible remain unaffected by external influences (e.g. by corrosion due to crude oil and sea water, changes in material properties, operating and flash-back safety even during inclinitations (heeling) of the ship and in case of clogging of the forced guides). Furthermore, the mechanical solidity and stability of the detachable connections must be high enough for the stresses occurring.

3.2. Testing of long-time burning flame arresting high velocity valves

The observance of the requirements laid down in Section 3.1, especially section 3.1.2, can be adequately guaranteed only by experimental testing. The following description shows the test procedures at PTB.

3.2.1. Critique of the construction

Before an experimental testing of a prototype, more serious deficiencies, which, for example, can influence the flash-back safety (too large gap widths) or the carrying-off of the mixture (no upward free jet), can be recognized on the basis of the test object and the construction drawings.

3.2.2. Experimental testing of the long-time burning flame arresting property

It is investigated by means of the experimental test whether the valve, under different test conditions corresponding to practice (above all concentration and volume rate), prevents a flash-back during the longtime flame test and in case of explosions from outside during the opening and closing of the valve as well as in open or closed condition. As can be seen in Fig. 3 a flash-back in case of an ignition of the escaping vapor/air-mixtures must be expected if the downward flame velocity λ becomes greater than the upward flow velocity v [9,10]. Due to the relevant radial distribution of these two velocities, a flash-back is most likely to occur near the wall (range A) or near the axis (range B). The test must be carried out with the aid of vapor/air-mixtures of different concentrations taking account of the liquids to be transported or instead with test mixtures guaranteeing comparable flash-back safety. The comparability can be judged on the basis of certain characteristic data such as ignition temperature (according to DIN 51794 or ASTM D 2155—63T or IEC TC 31 publication, resp.), maximum experimental safe gap (according to IEC TC 31, Annex to publ. 79-1) and others.

3.2.2.1. Flash-back near the wall. Within a certain boundary layer near the wall (penetration distance), the existance of a flame is impossible due to the quenching effects of the wall (e.g. due to heat losses and quenching of reaction) [11, 12]. Outside this boundary layer the flame velocity rises abruptly. This penetration distance is not identical with the laminar sublayer of the hydrodynamic flow. A flash-back occurs if within the range A (see Fig. 3) v (A) $<$ λ (A). However, v (A) depends on the maximum flow veloci-

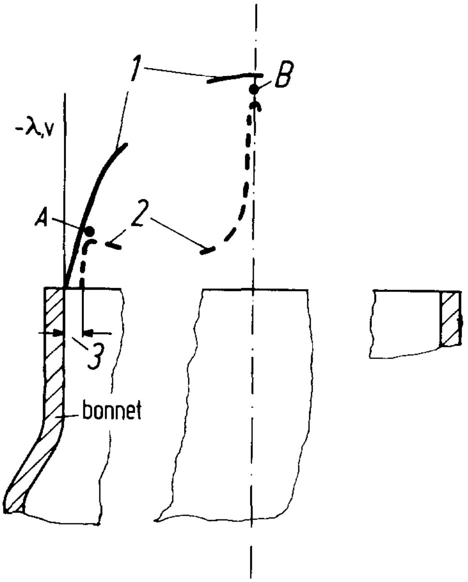


Fig. 3. Distribution of flow velocity v (1) and flame velocity λ (2) near the wall and near the axis; penetration distance (3).

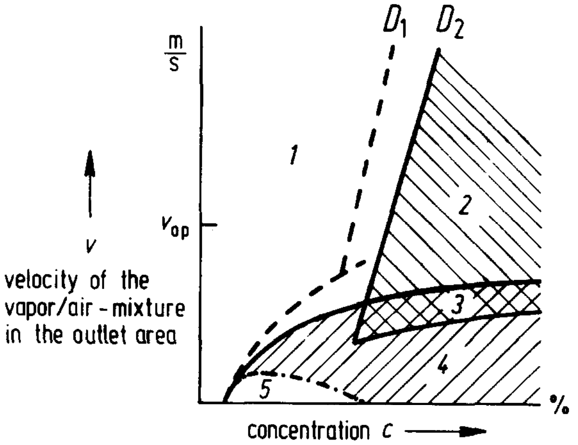


Fig. 4. Schematic diagram of the characteristic regions of flame stability; D_1, D_2, outlet diameter $D_1 > D_2$, 1 flame blown out, 2 lifted flame, 3 lifted flame or flame at outlet area, 4 flame at outlet area only, 5 flash-back near the wall.

ty in the axis. Thus in case of a hydrodynamic flow, the maximum flow velocity in the axis can also be used as criterion for a possible flash-back. When indicating a lower limit for the flow velocity in order to avoid a flash-back it should be noted that due to separation of the boundary layer (e.g.

in case of increased enlargement of the cross section) the flow velocity within the range A may considerably decrease and thus consequently a flash-back may occur.

It should be noted that the wall temperature may rise due to the influence of the flame and that thus the penetration distance decreases [13]. Then the flame velocity increases in this area and can possibly exceed the flow velocity. This procedure may result in a slow movement of the zone of flame contrary to the flow of vapor/air-mixtures due to a heating of the wall, thus causing a flash-back. Fig. 4 schematically shows various regions of the flame depending on the flow velocity v in range A (see also Fig. 3) and on the concentration c. If v increases, the flame lifts up from the outlet area (region 2 in Fig. 4) or is even blown out in case of lower concentrations (region 1) [12]. The high velocity valves so far tested at PTB had a velocity (v_{op}) of at least 30 m/s in the axis (that is a mean velocity of 25 m/s for a pipe) for the purpose of efficient removal of the escaping mixtures. In case of these valves, the flow velocity v is higher than v_{op} and is therefore sufficient to lift the flame up in the free jet and to blow it out in case of concentration below the upper explosion limit (region 1 or 2 in Fig. 4); see [12,14].

3.2.2.2. Flash-back near the axis. Some authors [15, 16] describe a flash-back to occur near the axis under certain test conditions (e.g. large outlet diameters, nozzle-type outlet-area). Reasons for this are among others a local increase of the flame velocity due to the concave flame front possibly in combination with a flow at the outlet which is hydrodynamicly not fully developed and which leads to a lower flow velocity on the axis of the free jet [17]. When testing the high velocity valves, these possibilities of a flash-back did not yet occur on the valves tested so far but other types of flash-back (see Sections 3.2.2.1, 3.2.2.3, and 3.2.2.4).

3.2.2.3. Flash-back during opening and closing of the high velocity valves. Especially during the closing of the valve, the flow velocity in the outlet cross-section decreases and the flame may flash back into the bonnet (see Fig. 2). When the flame contacts the valve seat, this must already be closed to such an extent that the remaining, still open gap permits no further flash-back into the tank. Decisive for preventing such a flash-back through the gap of the valve seat is the velocity with which the valve is closed. The velocity of the closing motion depends on the ullage space of the tank as well as the loading rate of the tank loading. Furthermore, safety valves especially tend to pulsation (open-closed) in case of low volume rate and small ullage. These influences are examined during the experimental test, in particular with regard to a possible flash-back. The velocity of the closing motion is lowered by friction in the forced guides; as according to experience the velocity is increased when inclining the valve (in case of heelings of the ship), the valve is inclined by 10 degree during the test.

3.2.2.4. Flash-back due to heating (hot surface). A flame — even if it does not flash-back due to high flow velocities — may lead, due to radiation and conduction, to a heating of surfaces, which are in direct contact with the atmosphere in the tank and which can ignite it [18]. Therefore this question is clarified in a long-time burning flame test under various conditions of concentration and volume rate. But also with closed valves, dangerous heat accumulation may result from the burning of small, often unvoidable leakages, as in this case the flame is usually burning directly at the valve seat. Furthermore, possibly existing soft seals can be destroyed by mechanical damage and by prolonged exposure to flames; before starting the tests those soft seals are therefore removed. Attention must further be paid to the fact that when suddenly closing the valve after longer burning a heat accumulation may result due to a lack of cooling flow of the mixture which can lead to a local excessive heating of surfaces under the valve seat and thus to an ignition of the explosible tank atmosphere.

4. Explosion arresting high velocity valves

At present, the view is held in the Federal Republic of Germany that on inerted tanks venting devices for the loading and ballasting as well as for the breathing during the journey should be explosion arresting because of the possibility of failures in the inert gas system.

As results from the requirements explained in Section 2.1, an explosion ar-aresting high velocity valve is not designed to prevent flash-back in case of a long-time burning flame test, but it must be capable of suppressing flash-back from individual explosions from outside and withstand the thereby occurring explosion pressure wave. Therefore under test, in closed condition, the valve is exposed to an explosion from outside. For this purpose, the valve is surrounded by a cloud of explosible mixture (in a plastic foil) of at least 2 m^3 and is connected to a test tank which is equipped with a bursting diaphragm and filled with an explosible mixture. For the test the explosible mixture is chosen in a concentration most favourable for ignition, i.e. with the smallest maximum experimental safe gap. After igniting the outside mixture cloud, flash-back into the tank must not occur. The test experience has shown that in case of fuel vapor/air- and crude oil vapor/air-mixtures, metallic gaps of at least 10 mm length and a maximum width of 0.5 mm can be regarded as explosion arresting. Apart from flash-back safety, explosion arresting high velocity valves must also satisfy the requirements according to Sections 3.1.1, 3.1.3, 3.1.5, 3.1.6 and partly 3.1.7.

5. Carrying-off of vapor/air-mixtures

When compared with conventional venting devices high velocity valves have the advantage that a relatively fast mixing with the surrounding air takes place due to high flow velocities, great momentum in the outlet area and turbulence in the free jet. Thus the explosible atmosphere outside the tank is limited to a relatively small area. Based on the knowledge of the dispersion processes in a turbulent free jet, PTB assumes a sufficient carrying-off of the mixtures if, in case of a diameter of 100 mm of the bonnet, the maximum outlet velocity on the axis amounts to at least 30 m/s. (In case of smaller diameters or other geometric outlet cross-sections, an equally great momentum should be taken as basis in order to guarantee a sufficiently dynamic rise of the jet [19,20]. An exception being the opening and closing condition of relief valves.) A mean flow velocity of at least 25 m/s should be provided for all geometric outlet forms and dimensions. Moreover, reference shall be made to the following facts:

(1) The outflow opening of the valve should lie sufficiently high over the ship deck [3]. It must be possible to carry off the mixtures upwards in the free jet in an undisturbed way.

(2) In case of very low wind velocities and an unfavourable thermal stratification of the atmosphere, attention should be paid to the fact that due to their normally higher density, when compared with air, the vapor/air-mixtures may possibly fall back onto the deck without being sufficiently diluted and may lead to explosion hazards [21—25].

(3) Because of the possible dispersion procedure (horizontal deflection by wind) of the escaping mixtures, a horizontal separation should be observed between the high velocity valves and bulky superstructures of the ships [26—28, 31].

The relations for the distribution of the concentrations behind a mixture source discussed in literature are statistical (Gaussian distribution) [29]. Thereby the indicated concentrations are average values because of the spreading and meandering process in the cloud. As far as safety technique is concerned the occurring maximum values are interesting [30, 31]. Thus, these relations have only a limited importance for safety purposes.

6. Volume flow rate/pressure differents diagram

In order to avoid unduly high internal pressures inside the tank during loading and ballasting due to excessive loading rates, it is necessary to know the volume flow rate as a function of the internal tank pressure. Based on these relations the minimum closing pressure of the valve has to be fixed and is among others of great importance for the flash-back safety. In case of cargo tanks of crude oil tankers, today a test pressure of 0.25 bar and an allowable working pressure of 0.2 bar is usual. When determining the pressure loss Δp, friction and acceleration losses in the valve itself and in the supply standpipe must be considered. When fixing the loading rate on the basis of the volume flow rate, experimentally determined with atmospheric air, the higher density of the vapor/air-mixtures ('density factor' f_s) when compared with air, must be taken into account. As far as its magnitude is concerned, the vapor density factor of crude oils and other liquids can be assumed to be $f_s \simeq 1.2$. It must be furthermore taken into account that from liquid cargo, light components may flash or evaporate (e.g. C_3 - and C_4 -hydrocarbons from crude oil); the effect can be determined, as far as its magnitude is concerned, by a 'flash-factor' $f_g = 1.25$. Therefore the loading rate L_a (m^3 /h) for loading and ballasting can be written as follows:

$$L_a = \frac{L_1}{f_s \cdot f_g} \approx 2/3\, L_1$$

where l_1 in m^3 /h is the experimentally determined volume flow rate for atmospheric air at 20° C. Special attention must be paid to the strong flashing of hydrocarbon gases from spiked crude oils.

7. Test equipment at PTB

At its test plant, PTB has the possibility to carry out experiments with explosions, detonations and long-time burning flames. No closer details shall be given here concerning the production of mixtures as well as measuring procedures and test equipments for experiments with explosions and detonations, but reference is made to the existing publications [7, 8]. For the testing of devices with large volume flow rates (e.g. high velocity valves for crude oil tankers) a large scale experimental plant has been constructed (see Fig. 6), the capacity of which can be seen in Fig. 5. The hatched working range in Fig. 5 can be realized with the plant. Due to suitable possibilities of control (continuous control of fan speed, continuous control of regulating valves and by-pass), the plant is flexible enough to adapt itself to the multiple requirements. At this time the plant is capable of producing 2500 kg/h pure inflammable vapor (e.g. gasoline vapor). The following examples may give an idea of the capacity of the test plant; at 14000 m^3 /h

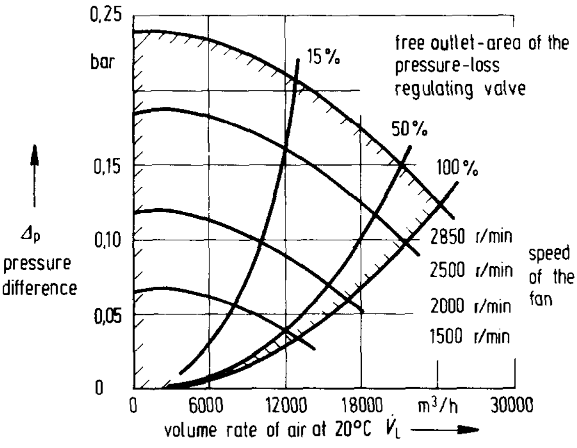


Fig. 5. Operating range of the test plant at PTB.

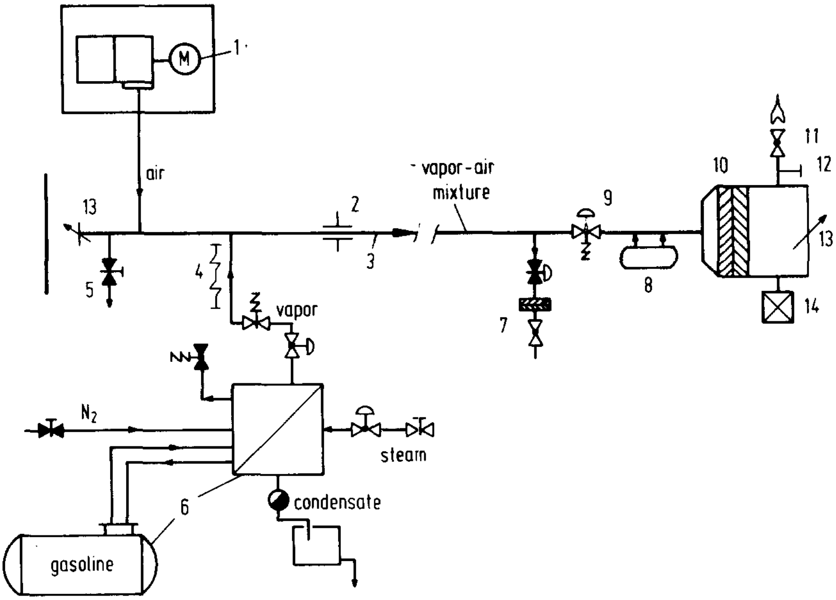


Fig. 6. Schematic plan of the test plant at PTB; 1 fan with variable speed, 2 volume rate indicator, 3 pipe (500 mm diameter), 4 heated vapor pipe, 5 air bypass, 6 evaporator and liquid storage tank, 7 vapor/air-mixture bypass, 8 extinguishing agents, 9 control and quick action stop valve, 10 explosion arresting crimped ribbon, 11 high velocity valve to be tested, 12 flame detector, 13 bursting diaphragm, 14 concentration indicator.

and 0.15 bar overpressure a concentration of gasoline vapor in the mixture of 5% is reached and a mixture above the upper explosion limit can be produced at a lower air flow rate of approximately 7000 m^3 /h.

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