THE PRESSURE SEPARATOR

- A DEVICE TO MAKE DISTRICT HEATING SYSTEMS EVEN MORE EFFICIENT -

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INTRODUCTION

Pressure separators contra heat exchangers

When connecting local networks to larger networks, conflicts concerning the pressure levels of the different systems often occur. The reason can be that the local networks have lower design pressures or that the conditions of operation will force the pressures to exceed the safety limits. Conflicts of this kind tend to increase with increasing size and complexity of networks.

Conventional solutions to these problems are either to increase the design pressure of the local network or to keep the pressures of the networks apart by means of heat exchangers.

Heat exchangers, however, are inefficient and will create an unavoidable loss of temperature in the system. The capacity of the network will decrease, favourable heat sources cannot be fully utilized etc. These wellknown facts make the system less effective and will strongly reduce the advantages of network integration.

An alternative to heat exchangers is offered by 'pressure separators'. In this case the different parts of the network are hydraulically connected to each other (they use the same water) but operate at different pressure levels. Thus, there will be no temparture losses but still the advantages with different pressures. The pressure separator will then be responsible for the necessity to keep the pressures apart.

Head

In the following discussion the term **head** is often used instead of pipe pressure. Head is defined as

$$H = \frac{p}{\rho g} + Z$$

where p = liquid pressure (gauge) Pa
ρ = liquid density kg/m^3
g = gravitation (9.81) m/s^2
z = elevation m

Head is advantagous to use when analysing complex pipe networks because - in contradiction to the pressure itself - it is independent of the elevation of the pipes.

THE PRESSURE SEPARATOR - HOW IT WORKS

Structured networks

Guiding for selection of the pressure level in a local network should be the local requirements (elevation, vapour pressure, differential pressure) and not the design pressure for the entire system. To apply the same design pressure all over the system is strongly unfavourable for the costs of network integration and will counteract efforts towards cost-effective and environmental friendly systems.

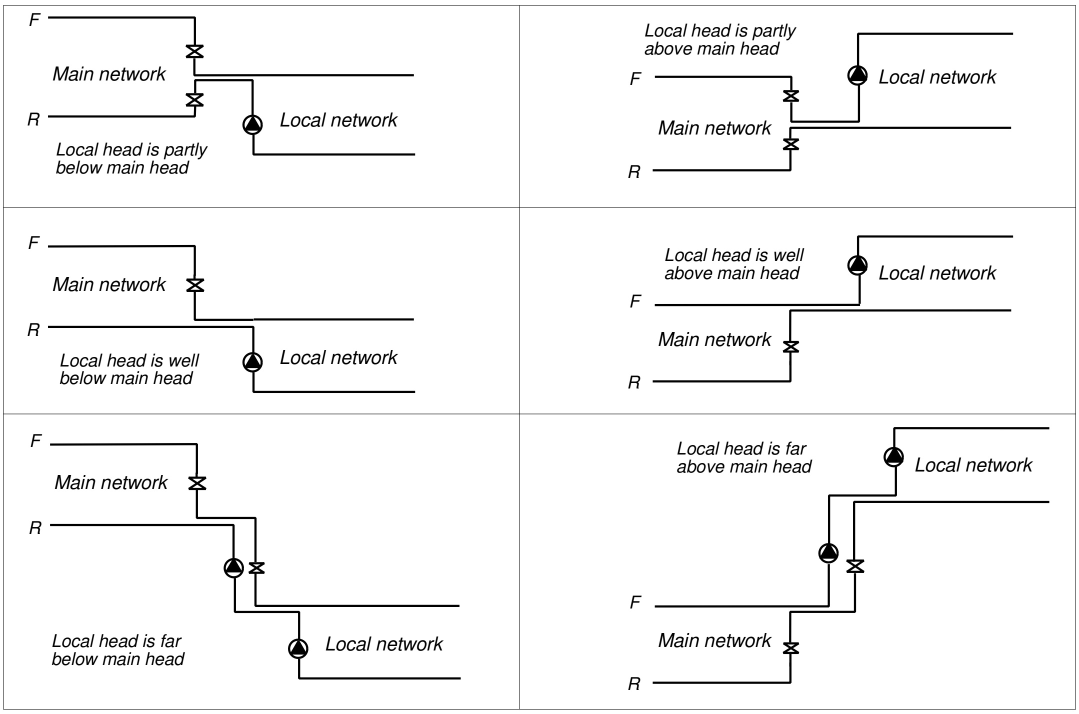


Figure 1. Main and local network at different head levels.

The pressure separator offers a way to network structuring without the harmful unavoidable temperature losses related to heat exchangers. According to figure 1 the head level of the local network can be selected above, in between or above the main network depending on the local requirements. This freedom of choice opens the door for less expensive local systems taking advantage of the lower pressure level. As the maximum temperature of the local network is easy to reduce, it is obvious that new materials (f.i PEX) can be used more frequently at least when heat loads from new buildings are connected to the network.

Elimination of hydraulic transients

At steady flow conditions the head levels of different parts of the network can be kept apart by pumping and throttling (figure 1). This will work as long as all equipment (pumps and valves) perform as expected. However, the head levels must be kept apart in **all** situations. In case of disturbancies, for instance pump stops due to power failure, the subnets, therefore, must be hydraulically separated from each other very quickly. This must be done so fast that the pressures will not have time enough to equalize.

To close valves that quickly is in general a very hazardous manoeuvre in a large network and will give cause to strong hydraulic transients (waterhammer effects). Normally such actions are forbidden. The 'pressure separator' is, however, designed to allow arbitrary quick valve manoeuvres without creating any pressure shocks.

Thus, in case of disturbancies the different parts of the network should be momentarily isolated from each other. No pressure waves should propagate out in the network on any side of the sectioning point. The principle way of solving this problem is to short-circuit the forward and the return line, i.e not to stop the flow but to direct it into an alternative flow path. If the flow velocities do not change, no waterhammer effects will occur.

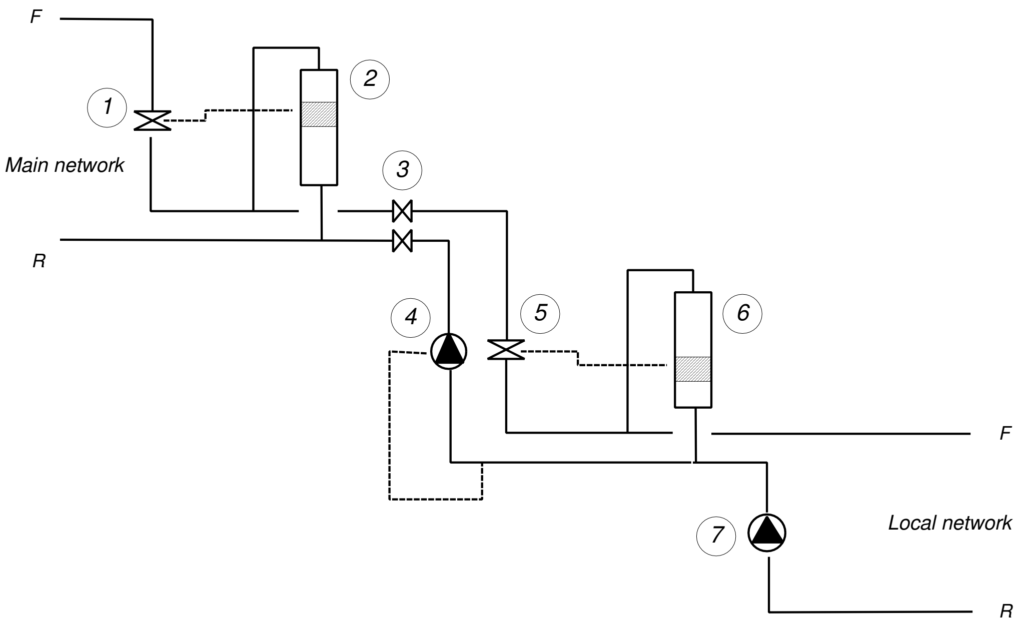
At the location of the section valves there should be no significant pressure difference between the forward and the return line. If a pressure difference exists when the valves close, it will give cause to pressure waves propagating out in the separated networks. Another way of expressing the same criteria is: When the flow is redirected by the section valve activities, it should meet the same flow resistance as in normal conditions of operation.

The pressures at a certain location in the network are during normal operation determined by the heat load situation and selected production units. As the distribution conditions vary over the season, the pressures will also vary. Thus, some kind of measures must be taken in order to bring the pressure difference as close to zero as possible at all conditions of operation the year around.

From a security point of view the quick section valves must be allowed to close at any condition of operation at any circumstancies. Therefore, an **always open** connection is provided on both sides of the section valves. A continuously controlling device will prevent the flow to short-cut from the forward to the return line through the connecting pipe. These are the unique and most important characteristics of the pressure separator.

Design and working principle

An example of the design of a 'pressure separator' is shown in figure 2. The example illustrates a case where the local network operates at a lower head-level than the main network.



Figur 2. Principle design of a pressure separator.

The forward and the return lines are always hydraulically connected to each other. The open connections (2) and (6) through the completely water-filled tanks will force the differential pressure between the forward and the return lines to be zero.

The forward line is connected to the upper part of the tank and the return line to the lower part. The temperature at the top will be close to the forward temperature and the temperature at the bottom close to the return line temperature. In between a temperature gradient is created. This is illustrated in figure 2 by the so called temperature layers.

The control valve (1) in the forward line of the main network will keep the temperature layer in the high pressure tank at correct position and will thereby stop hot forward water to enter the return line. In a similar way the control valve (5) will keep the forward and return water apart in the low pressure tank.

The return-pump (4) of the pressure separator will keep the local network at the prescribed head-level and the local pump (7) will take care of the distribution in the local network.

When the sectioning valves (3) are instantaneously closed, water from the forward line of the main network will enter the top of the high pressure tank and water from the the bottom region will flow out in the return line. The stored water volume will prevent the return line from a temperature shock. The stored water volume is selected large enough to create sufficient manoeuvre time for next action. Next action can, for instance, be a normal shut down.

A similar - but not identical - process will take place in the low pressure tank (6).

When designing a pressure separator for practical use, the pipes between the two tanks should be made as short as possible. The pipes in the adjacent networks can be of arbitrary length.

Alternative designs

The pressure separator can be shaped in many different ways to serve different purposes. The connected networks can be large or small. The head-level differen-cies as well. The pressure separator can be single-sided or double-sided. If no risks for unwanted pressures or temperatures exist on one side of the pressure separator when the quick section valves close, then a single-sided pressure separator will do.

In cases where temperature shocks are harmless, the stored volume can be eliminated and the size of the tanks can be reduced. Such a pressure separator is illustrated in figure 3.

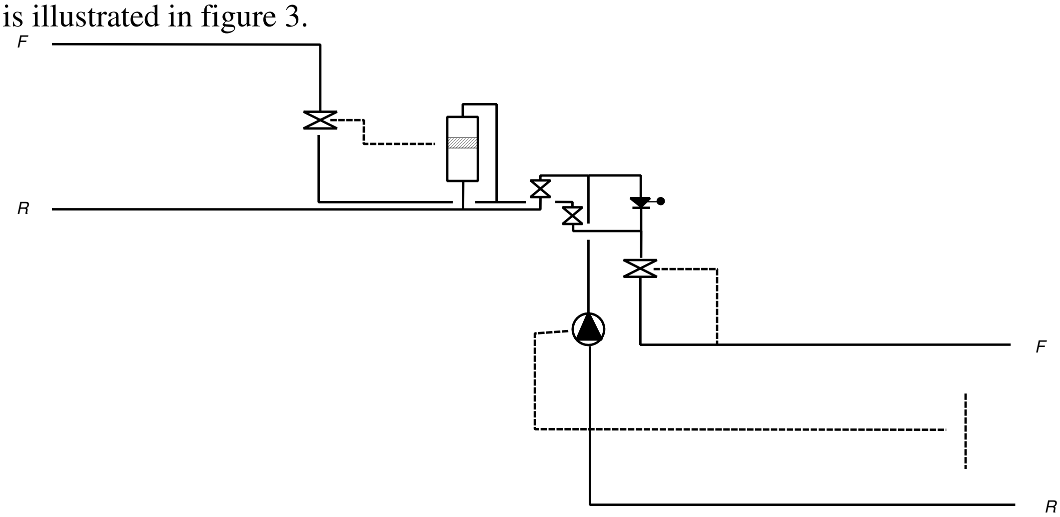


Figure 3. Single-sided pressure separator with special checkvalve.

In this case the local network is protected against water hammering by a special checkvalve. The checkvalve is kept closed during normal operation by a weight. The weight must then balance the pressure drop over the section valves, which can be made very small by selecting suitable valve size and type. At sectioning the checkvalve is opened by the flow forces and the flow in the local network has found a way to escape. No temperature protection is provided as the return water enters the forward line in the local network.

A heat exchanger can be used to create the always open connections and also to reduce the temperature shock. In cases when a heat exchanger already exists, this design can be suitable (figur 4).

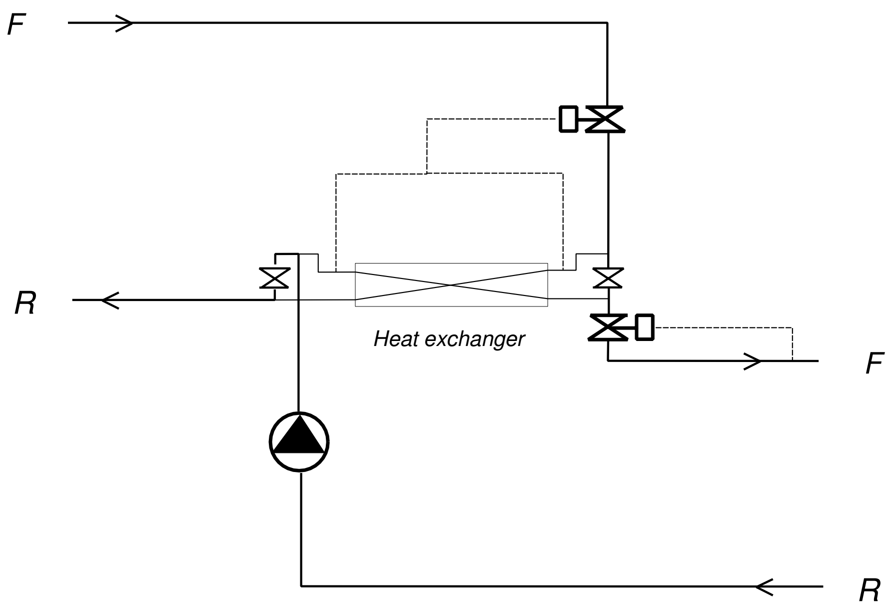


Figure 4. The pressure separator as a by-passed heat exchanger.

The primary and secondary (always open) flowpaths through the heat exchanger are cross-coupled over the section valves. This means that the headlines cross each other as small flows are passing through the heat exchanger. The main flows take the way through the section valves. Thus, the heat exchanger is by-passed and the temperature losses almost eliminated. The control valve balancies the crossflows to equal size. At sectioning the full flow is forced to pass through the heat exchanger. Sectioning thus means to go back to the 'old way' of operation.

The next alternative design take advantage of a 'pressure reference'. The pressure reference can take the shape of an atmospheric open tank or a pressurized closed tank. In the illustration below (figure 5) the pressure reference consists of an open atmospheric accumulator. To allow the main network to operate above 100 ºC and still take advantage of an open tank, the temperature is reduced by mixing forward water with low temperature return water. The following main components can be recognized. The control valve (RV11) keeps the temperature layer in position. The quick section valves prevent the main network from loosing water and pressure in case of an emergency. RV12 controls the forward temperatur of the accumulator and RV13 the stored energy. Pump P12 delivers return water back to the main network and P21 creates required differential pressure in the local network.

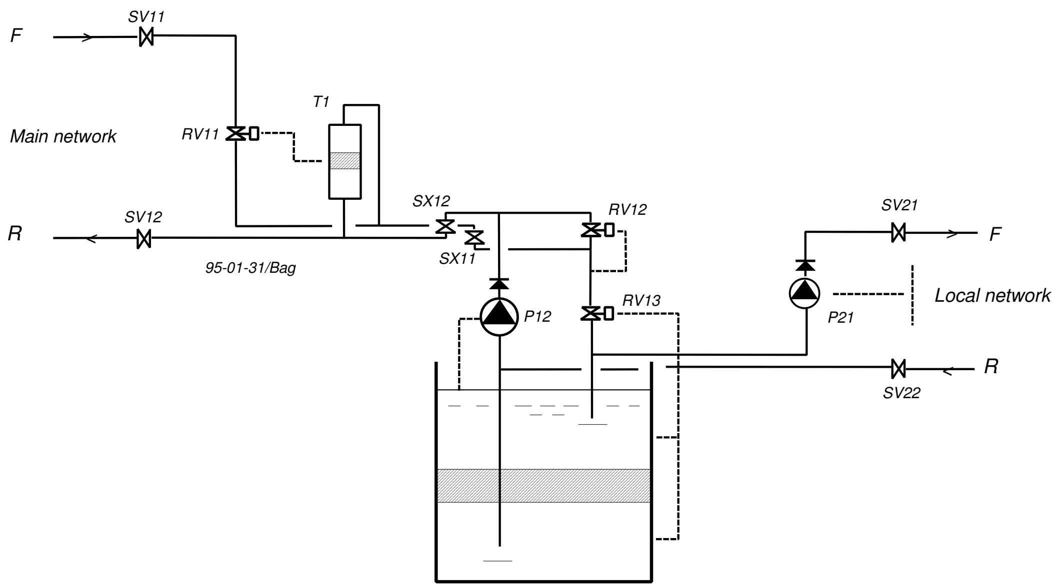


Figure 5. The pressure separator taking advantage of a pressure reference

Behind the accumulator the local network operates with very favourable conditions concerning pressure and temperature. It is easy to imagine how these favourable conditions can be utilized for cost-effective layout of the local network. Even the main network will benifit from the distributed accumulator. It does not have to deal with the varying heat loads in the local network any more.

Most of the alternative designs of pressure separators - although not illustrated here - can be arranged to include an accumulator. It is just to increase the size of the tanks. For instance, if the stored volume in the low pressure tank of figure 2 is enlarged, the local network suddenly is equipped with an accumulator.

However, all the thrilling possibilities provided by the pressure separators go back to the fact that the pressure levels can be kept apart at any operational conditions and at any emergency situations by quick sectioning. It is left to the imagination of the reader to create more alternative designs.

EXISTING PLANTS

Two plants equipped with pressure separators exist in the real world today. One is a small test facility (200 kW) and the other is a full-scale unit (60 MW) in commercial operation. Both are located in the district heating system of Göteborg.

The test facility

The local network of the test facility consists of one single substation serving around 20 apartments with heat and hot water. The main network is very large and is in fact the entire district heating system of Göteborg. A great advantage with the test facility is, that it has to operate under typical conditions for a real plant. It has to meet with varying pressures and temperatures as they appear in the main network and they have to meet with the varying load following the customers demands.

A flow sheet with all components included are reproduced in figure 6.

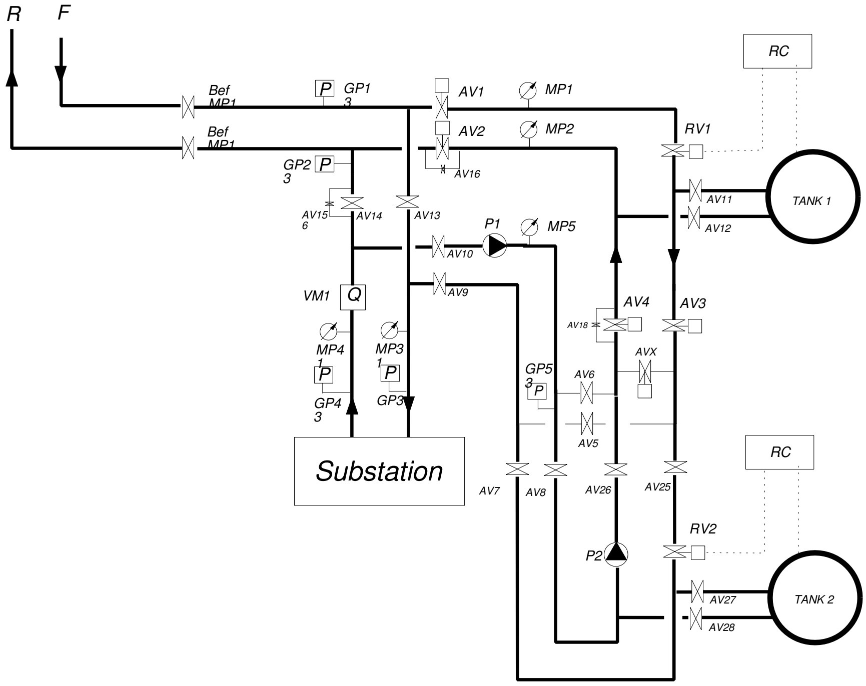


Figure 6. The pressure separator test facility

The test facility permits operation in many ways. By closing the on/off-valves AV1, AV2, AV9 and AV10 the substation is back to the original connection to the main network. By closing AV13, AV14, AV7, AV8, AV25 and AV26 a system according to the single-sided pressure separator in figure 3 is set up. With AV5, AV6, AV13 and AV14 closed the double-sided pressure separator in figure 2 is realized.

A lot of measurements have been performed in the test facility. Most of them focusing on the behaviour of the temperature layer and the pressure transients following a fast closure of the section valves. Some results from early tests are reported in ref 1 and some are still to be reported. However, no doubts exist about the working principle.

Musikvägen

The very first full-scale plant in commercial operation is located at Musikvägen in Göteborg. The ever-lasting effort of low cost operation and friendly treatment of the environment asked for heat power delivery based on waste heat sources into the local network of Frölunda. Thereby local oil-fired production units could be forced back and be shut off most of the season. The problem was that Frölunda was designed for 10 bar as maximum pressure and had to meet the 16 bar system of Göteborg. In 1992 a heat exchanger was installed in order to keep the different pressure levels apart. The heat exchanger was designed for 60 MW heat power at maximum flow (1800 m^3/h) and temperature losses of 7 ^oC on primary as well as on secondary side.

This was apparently a case for a pressure separator. It was designed according to figure 4 using the existing heat exchanger as the allways open connections. In 1994 (November 9, 8.05 pm) the section valves were opened up for the very first time and the plant at Musikvägen experienced its first seconds of operation as a pressure separator. This historical moment (at least for the author of this report) was followed by further tests and security controls. From the middle of december up to now (end of March) Musikvägen has been in commercial operation. Operational experiencies are good so far. The temperature losses have been reduced to around 0.3 ^oC. The pay-off time of the installation is estimated to be slightly more than a year and the environmental benifits are obvious. The plant at Musikvägen is described in more detail in ref 2.

CONCLUDING REMARKS

Tests with the pressure separator have confirmed the working principle. The basic concept has shown to be correct. Experiencies from the test facility and from the full-scale plant are undoubtly very encouraging. The commercial application points out an economic potential as well as environmental advantages. Both plants, the test facility at Öckerögatan and the full-scale unit at Musikvägen, have been investigated by the 'Swedish Plant Inspectorate' (Svensk Anläggningsprovning)
to meet with the safety regulations according to 'Pressure Vessel Code' and 'Swedish Piping Code'.

Further applications discussed above (for instance the system layout in figure 4) are, however, 'pure armchair speculations' and has not yet been realized. The reader is encouraged to use his/hers imagination to find the right places for the pressure separator in his/hers network.

The pressure separator is applied for patent. Swedish patent has been granted. International application through EPO is under examination.

ACKNOWLEDGEMENTS

The birth of the pressure separator has a long history. The pressure separator would never have seen the light of day without solid background knowlegde of district heating systems, network operation, control activities and particularly hydraulic transients. The most important tools for design and for learning are the computer programs **pfcsf** (Pipe Flow Calculations - Steady Flow) and **pfctf** (Pipe Flow Calculations - Transient Flow).
The development of these programs and the confrontations with real networks have been going on for several years now. Encouraging and supporting - in particular concerning the pressure separator - have been Göteborg Energi AB, Stockholm Energi AB and Stiftelsen för Värmeteknisk forskning (Thermal Engineering Research Institute). Also Malmö Energi AB, Trollhättan Energi AB and NUTEK (National Board for Technical Development) have encouraged and supported the platform from which the pressure separator has emanated. Friendly thougths are sent to all of you.

MORE TO READ ABOUT THE PRESSURE SEPARATOR

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2. B-A Gustafson — The Pressure Separator
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3. B-A Gustafson — Tryckväxlare - en anordning för effektivisering av
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