

Circuit with two-step capillary tube throttling and receiver.

This invention relates to a refrigeration circuit as described in the first part of Claim 1. The purpose of such circuit is to control the flow of refrigerant from receiver to evaporator, by the pressure in the receiver, and in such a way that the evaporator is flooded.

Circuits of this kind are known from several patent applications, all with direct flow in the heat exchanger. In consequence of direct flow the outlet temperatures of the two subjects are drawn towards a common temperature, and that means that the heat exchanger cannot cool the receiver down to a temperature close to the evaporator temperature, and that causes the refrigerant to boil in the capillary tube when throttled to the evaporator. Boiling liquid in a capillary tube has a great influence on the mass flow. Figure 3 is a graph illustrating the calculated mass flow through a capillary tube, assuming the refrigerant is at boiling point when entering the capillary tube. The graph illustrates that the mass flow is an increasing function of the pressure drop, for pressure drop less than 5 Kelvin, but almost fixed for pressure drop higher than 5 Kelvin. The graph is calculated for R134a and with evaporator temperature at -20°C , but the tendency is the same for other evaporator temperatures and for other refrigerants such as R404a, R600a and R22. From this basis it follows that the refrigerant flow cannot be controlled directly by the pressure drop, when the pressure drop is higher than 5 Kelvin, but there are several ways to solve the problem, and three of them are presented in the following.

In US250045 the pressure drop between evaporator and receiver is less than 5 Kelvin and thus the pressure drop can be used without problems to control the flow, but the small temperature difference between suction gas and receiver causes two disadvantages. First, the heat exchanger area has to be large, and secondly, even small swing in temperature will result in big swing in mass flow, with the risk of resonance.

In US2871680 the suction line and the receiver form a heat exchanger with direct flow, from bottom to top. The problem with boiling refrigerant in the capillary tube is solved by separating the refrigerant in liquid and flash gas, and then throttling the two components in separate capillary tubes.

The refrigerant enters at the receiver bottom as flash gas. It moves towards the top, exchanging heat with the suction gas, and leaves through a capillary tube at the receiver top. Flash gas only boils slightly doing throttling and the mass flow will be an increasing function of the pressure drop across the capillary tube. Because of the gravitational pull a part of the liquid will fall to the bottom of the receiver, and here it leaves through a separate capillary tube. The liquid boils heavily during throttling and the mass flow will be constant as illustrated on figure 3.

There are two advantages to this solution: the evaporator is flooded and the heat exchanger area may be small. There are two factors reducing the demands for the area: the temperature difference across the heat exchanger is high and much gas leaves the receiver without charging the heat exchanger.

This method causes two disadvantages. First, a extra capillary tube is required, and secondly, the control of the flow is limited, because the liquid flow is constant.

In DK174179 sub-cooling the refrigerant just before it enters the capillary tube solves the problem. The sub-cooling is carried out by means of a separate heat exchanger, which transfers the heat to the evaporator inlet.

- 5 With this method there is no problem with boiling refrigerant in the capillary tube regardless of how big the pressure drop is between the evaporator and the receiver. However, one of the main purposes of this circuit is to ensure flooding of the evaporator, and that put a limit on the pressure drop, which may be shown, as follows: The first throttling step, from condenser to receiver, adds heat to the receiver, which increases the
10 temperature and thereby the pressure. The suction gas removes heat from the receiver - thereby decreasing temperature and pressure. The pressure and the temperature in the receiver is forced towards an equilibrium between heat added and heat removed, and at the point of equilibrium, relation R1 becomes valid:

$$CP_{\text{liquid}} * (T_{\text{condenser}} - T_{\text{receiver}}) = CP_{\text{gas}} * (T_{\text{receiver}} - T_{\text{evaporator}}) + RT * Y \quad (R1)$$

- 15 where

CP is the heat capacity of the refrigerant. Index for gas or liquid form.

RT is the heat of evaporation

Y is the rate of refrigerant in liquid form at the outlet from the evaporator.

- 20 An essential purpose of the circuit is to keep the evaporator flooded, which implies that Y is positive. This requirement is substituted into R1 and makes R2:

$$R1 \wedge (Y > 0) \Rightarrow$$

$$CP_{\text{liquid}} * (T_{\text{condenser}} - T_{\text{receiver}}) > CP_{\text{gas}} * (T_{\text{receiver}} - T_{\text{evaporator}}) \Leftrightarrow$$

$$(T_{\text{receiver}} - T_{\text{evaporator}}) < (CP_{\text{liquid}} / CP_{\text{gas}}) * (T_{\text{condenser}} - T_{\text{receiver}}) \quad (R2)$$

- 25 Relation R2 sets an upper limit on how much of the total pressure drop may be allowed for the second throttling compared to the first throttling, because the pressure drop during the second throttling also establishes the temperature difference across the heat exchanger. It is essential that this pressure drop is as big as possible to ensure that the heat exchanger area is as small as possible.

- 30 The invention distinguish from the discussed solutions by having counter current flow in the heat exchanger. The suction gas pass the receiver from the bottom towards the top, and sub-cooling the refrigerant in the bottom of the receiver, whereby the refrigerant is enabled to pass the capillary tube without boiling.

- 35 The invention is made up of a pipe shaped receiver and extended with a capillary tube at both ends. Refrigerant is throttled in two steps: first from the condenser to the top of the receiver and subsequently from the bottom of the receiver to the evaporator. The suction line is placed in thermal contact with the pipe shaped receiver - oriented so that the suction gas passes from the bottom towards the top, forming a heat exchanger with counter current flow. The liquid in the bottom of the receiver will be sub-cooled close to the evaporator
40 temperature and the suction gas will be super-heated to close to the receiver temperature. At equilibrium between added and removed heat relation R3 is valid:

$$CP_{\text{liquid}} * (T_{\text{condenser}} - T_{\text{evaporator}}) = CP_{\text{gas}} * (T_{\text{receiver}} - T_{\text{evaporator}}) + RT * Y \quad (R3)$$

- A main purpose of the circuit is to keep the evaporator flooded, which implies that Y is positive. This requirement is substituted into R3 and makes R4:

45 $R3 \wedge (Y > 0) \Rightarrow$

$$CP_{\text{liquid}} * (T_{\text{condenser}} - T_{\text{evaporator}}) > CP_{\text{gas}} * (T_{\text{receiver}} - T_{\text{evaporator}}) \Leftrightarrow$$

$$(T_{\text{receiver}} - T_{\text{evaporator}}) < (CP_{\text{liquid}} / CP_{\text{gas}}) * (T_{\text{condensor}} - T_{\text{evaporator}}) \quad (\text{R4})$$

The heat capacity of liquid is always higher than the heat capacity of gas. This relation is substituted into R4 making R5:

$$R4 \wedge (CP_{\text{liquid}} / CP_{\text{gas}}) > 1 \Rightarrow$$

$$(T_{\text{receiver}} - T_{\text{evaporator}}) < (T_{\text{condensor}} - T_{\text{evaporator}}) \Leftrightarrow$$

$$T_{\text{receiver}} < T_{\text{condensor}} \quad (\text{R5})$$

Relation R5 is always true - and the evaporator will be full-flooded without any restrictions on the temperature in the receiver, in contrast to DK174179, which is restricted by R2. It, therefore, follows that the temperature in the receiver may be set at a higher temperature and the heat area will be similarly reduced.

Because the liquid is sub-cooled in the bottom of the receiver, it may be throttled directly to the evaporator without any further cooling - but it is important to fulfil the requirement of sub-cooled liquid. The requirement is fulfilled when the evaporator is flooded - because then the evaporator is "bleeding" with liquid refrigerant. Relation R5 ensures that the evaporator is flooded at equilibrium - so it is a matter of ensuring that the evaporator is flooded before equilibrium. If the evaporator inlet is placed at the evaporator bottom, then most of the refrigerant will be accumulated in the evaporator during standstill - and consequently the evaporator will be flooded at start-up.

Manufactures of small household freezers and refrigerators normally use a capillary tube with thermal contact to the suction line as throttling device, as illustrated in Figure 1. This construction results in superheated suction gas, which yields two advantages: the COP (Coefficient Of Performances) increases (for most refrigerants) and the warm suction gas prevents water from condensing on the suction line, which otherwise might cause damage behind freezers and refrigerators. With the invention the same advantages may be obtained by placing the first capillary tube in thermal contact with the suction line as illustrated on Figure 2 at mark (12).

30 Description of illustrations:

Figure1 roughly illustrates the circuit normally used for small freezers and refrigerators. The circuit is composed of: compressor (1), condenser (2), liquid line (3), evaporator (4), suction line (5), capillary tube (6), thermal contact between capillary tube and suction line (7).

Figure 2 roughly illustrates the invention, which only differs from Figure 1 by the tube shaped receiver - splitting the capillary tube in two parts.

The invention is made up of: compressor (1), condenser (2), liquid line (3), evaporator (4), suction line (5), capillary tube (8), receiver (9), capillary tube (10), thermal contact between receiver and suction line (11), thermal contact between capillary tube and suction line (12).

Figure 3 illustrates the graph of the calculated mass flow of R134a in a capillary tube. The outlet of the capillary tube is fixed at -20C and the inlet temperature is varying from -20C to +25C. On entering the refrigerant is at boiling point.

Implementation of the invention:

The invention is composed of 4 parts, a suction line, a pipe shaped receiver and 2 pieces of capillary tubes. As an example suitable dimensions are calculated for a 100Watt freezer with Danfoss compressor NLY9KK. The temperature in the receiver has been chosen to +10C.

From NLY9KK data sheet:

- Refrigerant: R600A
- Cooling effect at 30C/-30C (condenser/evaporator) 100W
- Mass flow: 1.37kg/h = 0.34g/s

Heat is transferred to the suction line at three locations:

1. From capillary tube:

$$Q_{\text{capillary}} = \text{Flow} \times CP_{\text{gas}} \times 20K = 0.34g/s \times 1.7J/g/K \times 20K = 12W$$

2. From condensing of gas in top of the receiver:

$$Q_{\text{gas}} = \text{Flow} \times CP_{\text{liquid}} \times 20K - Q_{\text{capillary}} \\ = 0.34g/s \times 2.3J/g/K \times 20K - 12W = 16W - 12W = 4W$$

3. From sub-cooling of liquid at the bottom of the receiver

$$Q_{\text{liquid}} = \text{Flow} \times CP_{\text{liquid}} \times 40K = 0.34g/s \times 2.3J/g/K \times 40K = 31W$$

A heat exchanger is capable of transferring this quantity of heat:

$$Q = U \times A \times \text{LMTD}$$

(R6)

where

U : heat transfer coefficient

A: heat transfer area

LMTD: Logarithmic Mean Temperature Difference

For a tube heat exchanger like this:

$$U = 0.1W/cm^2/K$$

$$\text{LMTD} = (dT_1 - dT_2) / \ln(dT_1 / dT_2)$$

where

dT_1 and dT_2 are the temperature difference at the heat exchanger inlet and outlet. For simplicity the temperature difference at the heat exchanger outlet is here chosen as:

$$dT_2 = 1K$$

The bottleneck of the heat transfer is the inside area of the suction line, and the minimum of this area is calculated from a rearrangement of R6 into R7;

$$Q = U \times A \times \text{LMTD} \Leftrightarrow$$

$$A = Q / (U \times \text{LMTD})$$

(R7)

By substitution into R7, the minimum thermal contact areas are calculated for the three locations on the suction line:

1. Along the capillary tube, se Figure 2 mark 12:

$$dT_1 = [20K \times (1 - CP_{\text{gas}} / CP_{\text{liquid}})] = 5.5K \wedge (dT_2 = 1K) \Rightarrow$$

$$\text{LMTD} = (dT_1 - dT_2) / \ln(dT_1 / dT_2) = 4.5K / \ln(5.5) = 2.6K$$

$$A_{\text{capillary}} = Q_{\text{capillary}} / (U \times \text{LMTD}) = 12W / (0.1W/cm^2 / K \times 2.6K) = 46cm^2$$

The length of the capillary tube heat exchanger has to be no less than:

$$L_{\text{capillary}} > 46cm^2 / 1.5cm = 31cm$$

2. Condensing at the receiver top:

$$(dT_2 = 40K) \wedge (dT_2 = 1K) \Rightarrow$$

$$LMTD = (dT_1 - dT_2) / \ln(dT_1 / dT_2) = 39 / \ln(40) = 10.6K$$

$$A_{condensing} \geq Q_{condensing} / (U * LMTD) = 4W / (0.1W/cm^2/K * 10.6K) = 4cm^2$$

5 Hence it follows that the suction line contact with receiver top must be no less than:

$$L_{Receiver\ top} > 4cm^2 / 1.5cm = 3cm$$

3. For sub-cooling at the receiver bottom

$$(dT_1 = 40K) \wedge (dT_2 = 1K) \Rightarrow$$

$$LMTD = (dT_1 - dT_2) / \ln(dT_1 / dT_2) = 39 / \ln(40) = 10.6K$$

$$10 \quad A_{condensing} \geq Q_{condensing} / (U * LMTD) = 31W / (0.1W/cm^2/K * 11K) = 28cm^2$$

and thus the suction line contact with receiver bottom must be no less than:

$$L_{Receiver\ bottom} > 28cm^2 / (150cm^2/m) = 19cm$$

The calculations show:

1. The thermal contact between capillary tube and suction line must be no less than 31cm.
- 15 2. The contact between receiver and suction line must extend no less than (3cm + 19cm
=>) 22cm.

When choosing a receiver of 50 cm length the level of refrigerant may vary by 28cm - and still comply with the basic requirement: that at least 22 cm is available for heat transfer.

20 When choosing the receiver diameter 22 mm the volume of refrigerant may vary with 75 ml corresponding to 45g of refrigerant. The part list will be as follows: Please refer Figure 2:

- Suction line: 6 mm x 120 cm copper tube (5,11,12)
- Receiver: 22 mm x 50 cm (9)
- 25 • First throttling: 0,7 mm x 90 cm capillary tube with no less than 31cm thermal contact to suction line (12)
- Second throttling: 0,7 mm x 90 cm capillary tube (10)

30 The invention provides an effective and cheap regulator as an alternative to the traditional capillary tube throttling for small household freezers and refrigerators. The regulator makes freezers and refrigerators more effective in operation and better suited for varying temperatures. It is simple for manufacturers to adapt the invention - a look at Figures 1 and 2 shows that the only difference is a small receiver placed at the middle of the capillary tube.

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Claims:

- 5 Claim 1: A closed refrigeration circuit comprising compressor (1), condenser (2), evaporator (4), receiver (9), and with capillary throttling (8) between condenser and receiver and with capillary throttling (10) between receiver and evaporator and thermal contact (11) between suction line and receiver characterized by the refrigerant in the receiver flows from the top towards the bottom and the suction line is oriented so that the suction gas passes the receiver from receiver bottom towards receiver top.
- 10 Claim 2: A closed refrigeration circuit as claimed in Claim 1 characterized by thermal contact (12) between suction line and the capillary tube (8) connecting condenser and receiver.