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THE INFLUENCE OF CONDENSING PRESSURES OF THE ETHYLENE CARRIER CASCADE CYCLE ON ITS REFRIGERATION CAPACITY

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Abstract

Ethylene, Propane and others liquefied gases as a cargo are transported at sea by temperature below 0°C. It requires sufficient efficiency of reliquefaction plant. Short description of that gas plant is shown including cascade system and its cooling processes are described. Based on Mollier diagrams the refrigeration capacity investigation of gas plant is done. This analysis is focused on condensing pressure which takes place in the condenser. Theoretical cycles are taken into account and real condensers of cargo compressor and screw compressor of refrigerant cycle are considered. Thermostatic expansion valves are employed in cascade cycles and their operation parameters are taken into account as well. Conclusions include some guidelines on condensing pressure and related operation parameters to maintain the gas plant with high efficiency of refrigeration capacity.

Keywords: *refrigeration cycle, reliquefaction plant, condensing pressure, Ethylene gas carrier*

1. Introduction. The gas plan of Ethylene carrier

Boiling point of Ethylene at atmospheric pressure is −103.8°C means that cooling processes are not belong to cryogenics e.g. below 111.1 K when at the same pressure Methane has boiling point. However temperatures below −100°C achieved in Ethylene carriers cargo tanks require using cascade systems, because cooling down the cargo between −60°C till −100°C with multi-stages cycles is very difficult or even impossible [4]. Of course, Ethylene is not only one grade of cargo for these ships [4].

General principles of cargo gas plant operation are being described by using as an example simplified layout of reliquefaction and cascade systems, whereas processes parameters were shown in previous papers [5,6].

Reliquefaction system with reciprocating cargo compressor is shown on Fig. 1. The characteristic points of system and processes are marked by figures 1 to 10. When Ethylene vapour is sucked from the cargo tank by first stage of cargo compressor (point 1), vapour has already left suction drum, where liquid phase could be separated from compressor suction line (to avoid liquid hammering). After discharging by interstage pressure (point 2), before compressing in the compressor second stage, vapour is cooled down by mixing with saturated vapour after its vaporization (from point 9 to 10) in the cargo economizer. By this way vapour temperature in compressor second stage suction is decreased from t_2 to t_3 = 50°C. Second stage compression increases vapour temperature up to t_4 = 130°C, by pressure p_4 = 18.5 bar and Ethylene is directed to LPG condenser.

There is no any Ethylene condensing process in this heat exchanger, but only cooling down of vapour from t_4 to temperature t_5 = 30°C by using sea water as a cooling medium. Condensing process 5-6 takes place in Ethylene condenser.

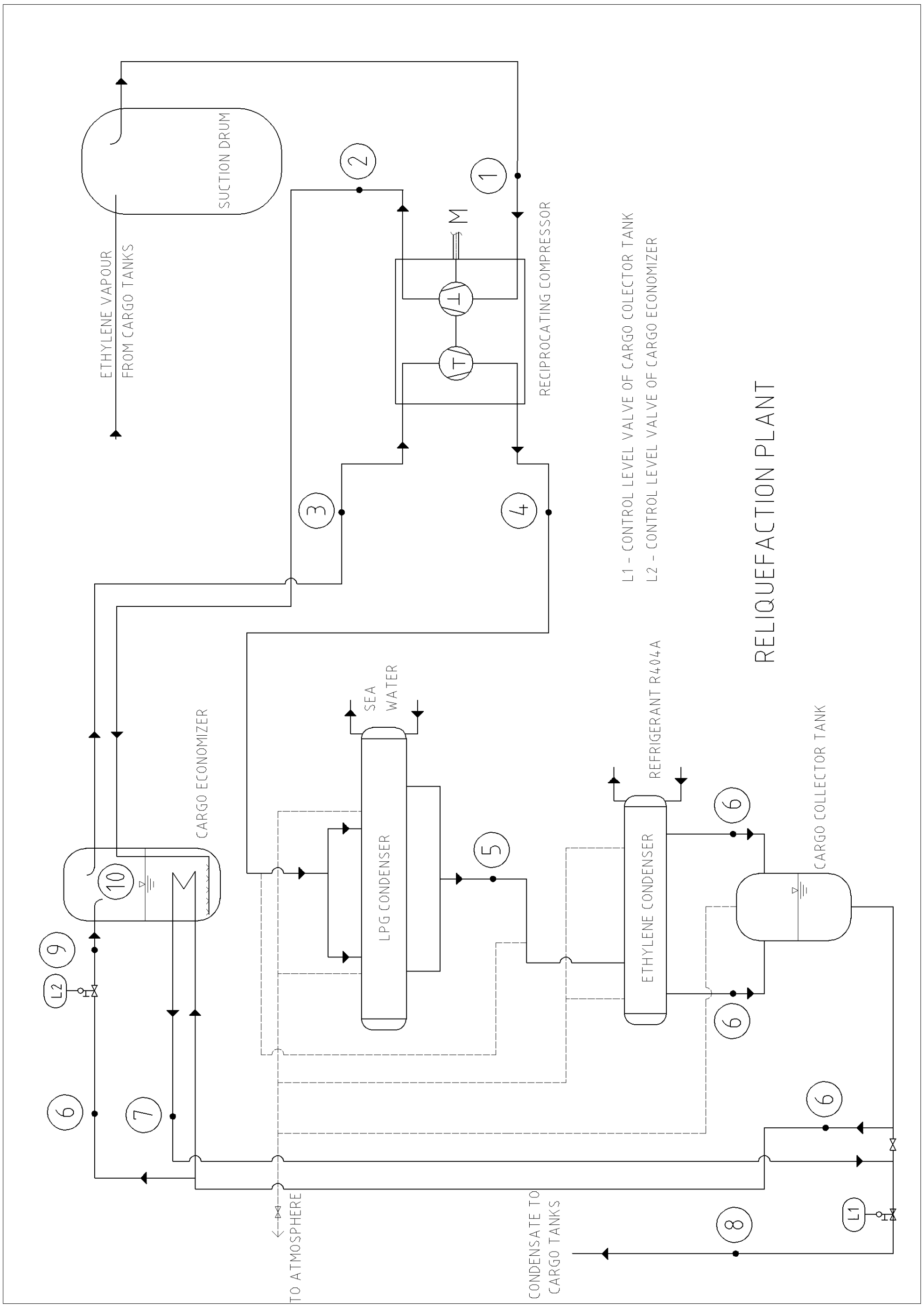

Fig. 1. Layout of reliquefaction plant [6]

In this heat exchanger are connected two systems: reliquefaction (Fig. 1) and refrigerant (Fig. 2), because Ethylene condensing process is carried out by vaporization of refrigerant R404A or Propylene in Ethylene condenser, common heat exchanger of both systems: reliquefaction and refrigerant, as a one cascade system. By high gauge pressure $p_4 = 18.5$ bar is possible to condense Ethylene and cooling down to temperature $t_6 = -30$°C by means of R404 of which evaporating temperature is −40°C. In next step, flowing through the cargo economizer coil Ethylene condensate is subcooled in process 6-7 to temperature $t_7 = -63$°C with the use of Ethylene, which evaporates (process 9-10) by interstage pressure $p_2 = 5$ bar and temperature $t_9 = -72$°C in the cargo economizer.

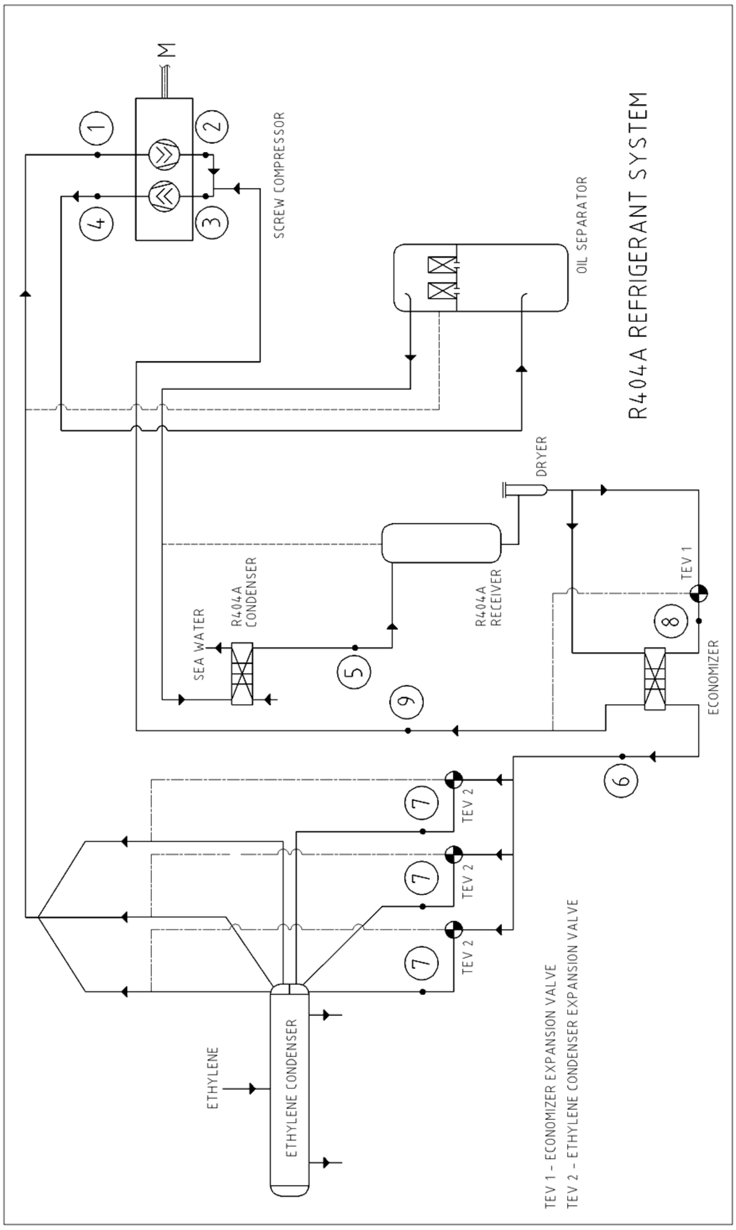

Fig. 2. Layout of refrigerant system[6]

Isenthalpic expansion of refrigerant 6-7 (Fig.2) is carried out by means of three TEVs, which operate as a controllers for supplying R404A to Ethylene condenser. More details about this cycle were described in previous papers [6].

2. The cargo compressor theoretical Mollier pressure-enthalpy diagram

Condensing pressure of counter clockwise cycle is one of the most important parameters in order to maintain high efficiency ratio of refrigeration capacity. But sometime this ratio is higher when condensing pressure is higher, sometimes when it is as low as possible.

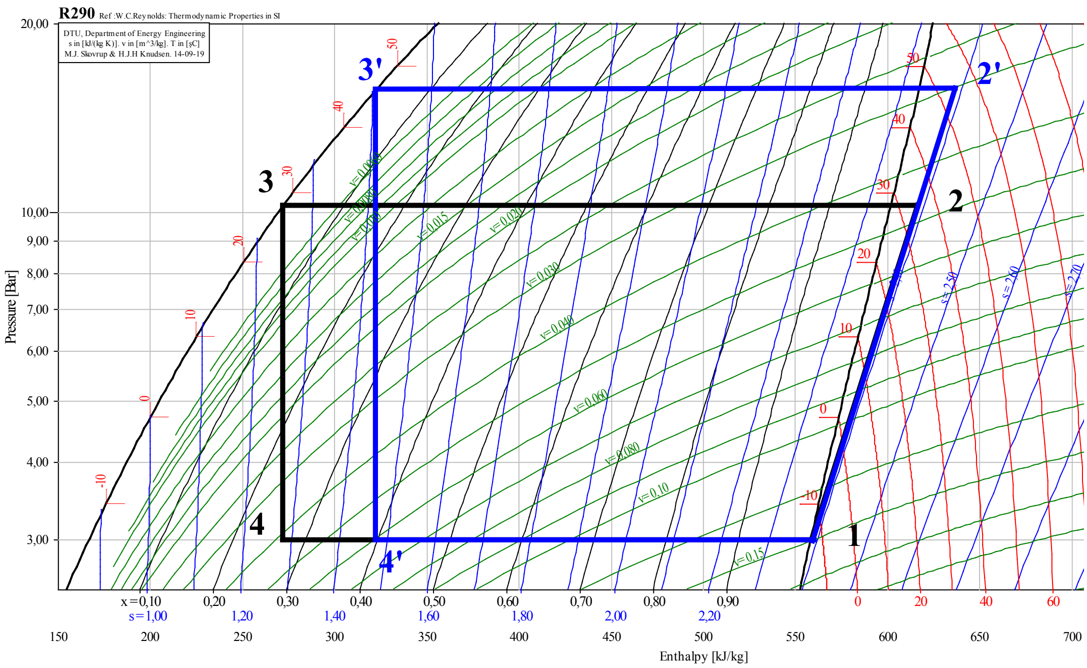

Fig. 3. Mollier diagram of Propane [2]

Above on Fig. 3 is shown the difference of Propane specific refrigeration capacity caused by different sea water temperature as a coolant of condensers. The reliquefaction plant shown on Fig. 1 operates as two stage without intercooling. Cycle 1-2-3-4-1 operates with sea water temperature 28°C and specific refrigeration capacity h_1-h_4, whereas 1-2'-3'-4'-1 with temperature 45°C and reduced specific refrigeration capacity h_1-$h_{4'}$. According to data of Burckchardt cargo compressor 2K160-2H volume capacity, it can be calculated that by 3 bars absolute pressure in suction line total refrigeration capacity is:

$$Q_1 = m_{1*} (h_1 - h_4) = 554[kW]. \quad (1)$$

This equation is for a cycle 1-2-3-4-1 where m_1 is mass flow of cargo through compressing process 1-2 and:

$$Q_2 = m_{2*} (h_1 - h_{4'}) = 432[kW]. \quad (2)$$

for a cycle 1-2'-3'-4'-1 with Propane mass flow m_2 in process 1-2'. It means because of higher temperature of sea water refrigeration capacity of reliquefaction unit is less approx. 22%. Mass flow m_1 is higher than m_2 because this calculation takes into account less volume capacity of the compressor caused by higher discharge pressure [1,3]. Of course the same loss of refrigeration capacity is if there is higher pressure of condensing because the condenser is not properly clean.

3. Refrigerant cycle

On Fig.4 are shown two cycles of refrigerant system (Fig.2) with different condensing pressure. First one operates with 8 bar abs and second cycle 15 bars abs condensing pressure. Analogous to cycles described on Fig.3 it seems that cycle 1-A-B-C-D-E-1 has higher refrigeration capacity than cycle 1-2-3-4-5-6-1 because of higher specific refrigeration capacity as a difference between enthalpies:

$$h_1 - h_E > h_1 - h_6)\ [\text{kJ/kg}]. \qquad (3)$$

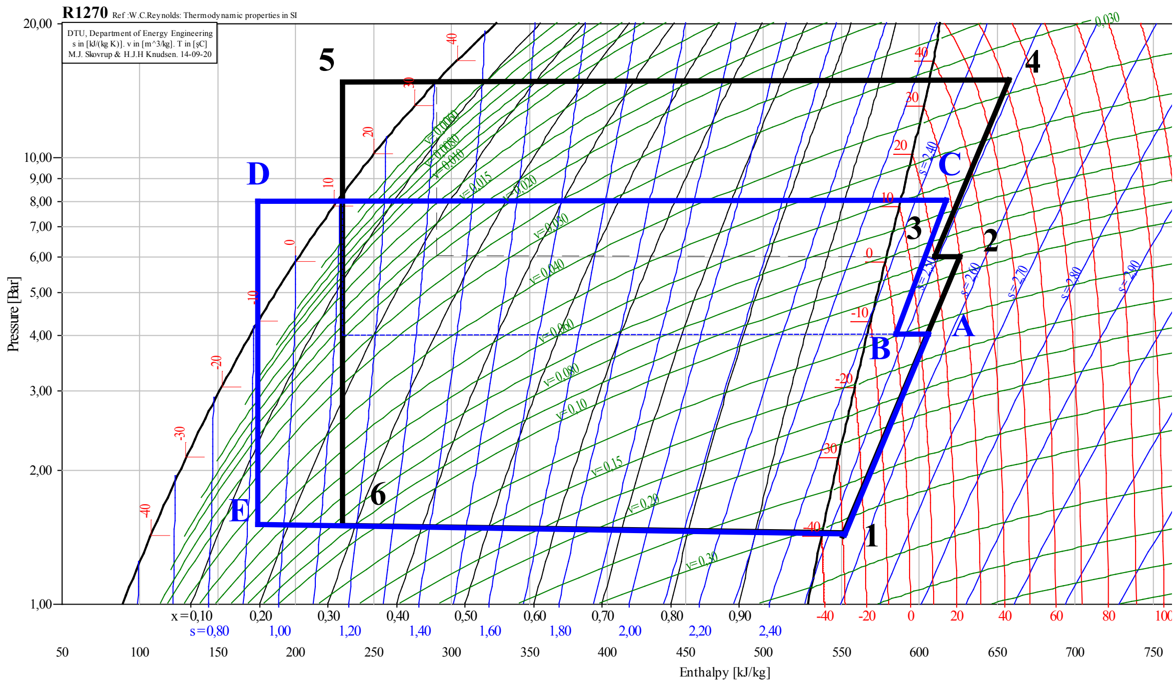

Fig. 4. Mollier diagram of refrigeration cycle [2]

In this plant with old design of TEVs it is not true. According to manufacturer manual condensing pressure should be kept approx. 14.0 bar abs in order to achieve required mass flow of refrigerant through thermostatic expansion valves (TEV). Tab.1 shows refrigeration capacity of thermostatic valves TES 12 (R404A) related to drop of refrigerant pressure during a flow through valve.

Tab. 1. TEV refrigeration capacity kW related with refrigerant pressure drop

Thermostatic expansion valve type	Pressure drop through expansion valve [bar]					
	6	8	10	12	14	16
Danfoss TES 12-13.4 Catalouge year 2009	**21,6**	**23,8**	**25,3**	**26,1**	**26,3**	**26,5**
Danfoss TES 12-20 Catalouge year 2014	**29,6**	**29,3**	**28,3**	**26,9**	**25,2**	**23,5**

It can be noted that difference between inlet and outlet pressure of refrigerant (before expansion valve and after) is important for old TEV`s constructions (year 2009). Increase of refrigerant capacity may change from 21,6 kW to 26,5 kW – approx. 20% depends on refrigerant pressure difference. It means that condensing pressure is an essential parameter of refrigerant plant in order to achieve high refrigeration efficiency.

4. Conclusions

Refrigeration cycles used at sea are not only as a provision plant, air conditioning systems or reefers. This refrigeration system is used on LPG and Ethylene carriers, where very often total refrigeration capacity of reliquefaction plants are higher than 1000 kW or 2000 kW and 20% drop od refrigeration efficiency means delays in cargo transportation and lost money.

Very easy is to notice when refrigeration system operates with improper, to high condensing pressure, but it is important to know that sometimes too low pressure is disadvantage as well. As was shown in Tab.1 especially old TEV`s constructions require accurate condensing pressure to provide high efficiency of plants. High difference between TEV's inlet and outlet pressure provides required refrigerant mass flow and oil back to the compressor.

New solutions employed in these systems:

- new design of thermostatic expansion valves
- electrically operated expansion valves
- valves with PLC controlers

These devices operate properly with wide range of condensing pressure in refrigeration systems.

5. References

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