ASSESSMENT OF THE SUBCOOLING CAPABILITIES OF A THERMOELECTRIC DEVICE IN A VAPOR COMPRESSION REFRIGERATION SYSTEM

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The paper presents some theoretical results regarding the subcooling capabilities of a thermoelectric device. The refrigeration system taken into account uses the R-134a refrigerant; a constant refrigerant flow of 1.4 m^3/h was considered for all the working variants. The CoolPack refrigeration software was used in order to make the necessary calculations. A TEC 1-12710 type Peltier cooler was considered for subcooling of the liquid refrigerant and its characteristics were evaluated based on experimental tests. The subcooling temperature taken into account was comprised between 0 (no subcooling) and 10K; the cooling capacity, subcooling load and COP were then calculated. The same refrigeration system equipped with a suction gas heat exchanger (SGHX) was considered as reference. The Peltier cooler achieved high COP (5.6…7.7) for low subcooling degrees (1…3K). The overall COP of the refrigeration system with thermoelectric subcooling reached a maximum COP of 2.507 for 5K subcooling and the cooling capacity was comprised between 505 and 557 W. The use of SGHX led to higher overall COP (2.56…2.79); in the meantime, a lower COP and cooling capacity were obtained when no subcooling was applied (COP = 2.45; $\dot{Q}_0$ = 500 W).

***Key words**: refrigeration system, subcooling, thermoelectric module*

Vapor compression systems use the latent heat of vaporization of the working fluid in order to transfer large amounts of heat per unit mass, at a fixed temperature level. The operation principle of a vapor compression system is shown in *fig. 1* [7]: the liquid refrigerant evaporates in the evaporator (V), absorbing heat. The superheated vapors are compressed by the compressor (C) and the vapors turn to liquid state in the condenser (K). The coefficient of performance (COP) of the refrigeration system is defined as the ratio between the useful heat q_0 and the absorbed mechanical work l_c.

Cooling of the condensed liquid leaving the condenser (subcooling), using a subcooler (SR, *fig. 2*), allows the increase of the amount of extracted heat (q_0)

without increasing the power input to the compressor [7].

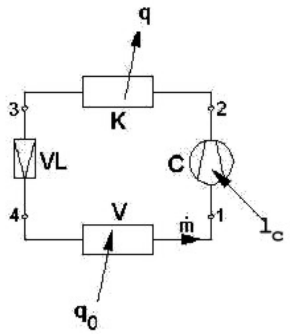


Figure 1 **Operation principle of the vapor compression refrigeration system**
V-evaporator; C-compressor; K-condenser; VL-expansion valve

Usually, subcooling is achieved either with a water cooled heat exchanger (as in *fig. 2*) or by using a suction gas heat exchanger (SR, *fig. 3*). Both these solutions must be taken into account when the refrigeration system is designed and are not applicable when trying to improve an already existent system because of the mechanical procedures involved in order to modify the hydraulic circuits.

Attaching a thermoelectric cooling device at the condenser outlet (*fig. 4*) allows the subcooling of the refrigerant without any modification of the hydraulic

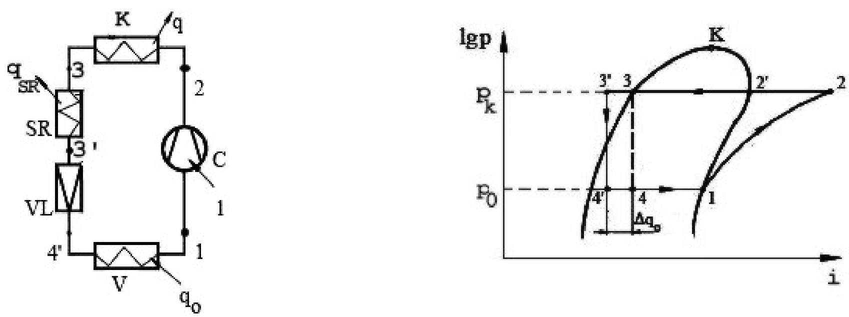


Figure 2 **Effect of liquid refrigerant subcooling**
V-evaporator; C-compressor; K-condenser; SR-subcooler; VL-expansion valve; Δq_0-extracted heat increase.

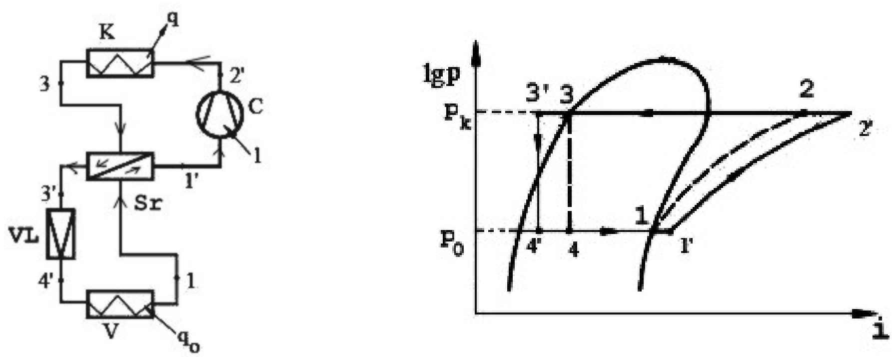
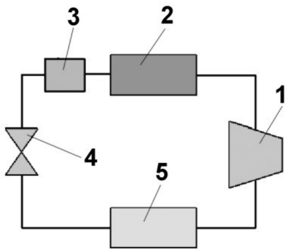


Figure 3 **Subcooling using a suction gas heat exchanger (SGHX)**

circuit; in the meantime, this subcooling method enhances efficiency and cooling capacity without adding moving parts. This method may be taken into account as a simple add-on for an existing system (which was not initially provided with a subcooling heat exchanger), just for the purpose of increasing its capacity.



1-compressor;
2-condenser;
3-thermoelectric module;
4-expansion valve;
5-evaporator.

Figure 4 **Schematic diagram of thermoelectric subcooling**

MATERIAL AND METHOD

Some characteristics of the original refrigeration system are shown in *table 1*.

The effect of subcooling was evaluated for two working variants:

- subcooling by means of a suction gas heat exchanger (SGHX);
- subcooling using a thermoelectric device (TE).

The CoolPack refrigeration software (CoolTools: Design utility) was used in order to make the necessary calculations; 1K to 10K subcooling was taken into account.

Table 1

Characteristics of the refrigeration system

Item	Value
Refrigerant	R134a
Evaporation temperature [^{0}C]	- 10
Evaporation pressure [bar]	2.007
Condensation temperature [^{0}C]	45
Condensation pressure [bar]	11.597
Cooling capacity [W]	500
Refrigerant flow [m^3/h]	1.4

The coefficient of performance (COP) of the conventional refrigeration system was calculated with the relation:

$$COP = \frac{\dot{Q}_0}{P},$$

where $\dot{Q}_0$ is the cooling capacity [W] and P is the compressor power input [W]. When a thermoelectric device is used for subcooling, its power consumption must be accounted for and the relation for COP becomes:

$$COP = \frac{\dot{Q}_0}{P + P_{TE}} = \frac{\dot{Q}_0}{P + \frac{\dot{Q}_{0SC}}{COP_{TE}}},$$

where P_{TE} is the power input to the thermoelectric device, COP_{TE} is the efficiency of the thermoelectric device and $\dot{Q}_{0SC}$ is the cooling capacity required for subcooling (which must be provided by the thermoelectric module).

A TEC1-12710 thermoelectric cooler was considered as subcooling device; the following expressions were used to calculate the fundamental TEC parameters form the set of data given by the manufacturer [3]:

- the Seebeck coefficient: $\alpha = \frac{U_{max}}{T_H}$ [V/K],

- the electrical resistance: $R = \frac{U_{max}}{I_{max}} \cdot \frac{T_H - \Delta T_{mx}}{T_H}$ [Ω],
- the thermal resistance: $\theta = \frac{\Delta T_{max}}{I_{max} \cdot U_{max}} \cdot \frac{2 \cdot T_H}{T_H - \Delta T_{max}}$ [K/W],

where U_{max} is the maximum DC voltage [V] that will deliver the maximum possible temperature drop ΔT_{max} [K] at the supplied current I_{max} [A] and at the temperature T_H of the hot junction [K].

The figure of merit of the thermoelectric module was determined with the relation [1]:

$$Z = \frac{\alpha^2 \cdot \theta}{R} \text{ [K}^{-1}\text{]}.$$

The coefficient of performance of the TEC module was evaluated with the relation [4]:

$$COP_{TE} = \frac{T_C}{T_H - T_C} \cdot \frac{\sqrt{1 + Z \cdot \frac{T_H + T_C}{2}} - \frac{T_H}{T_C}}{\sqrt{1 + Z \cdot \frac{T_H + T_C}{2}} + 1},$$

where T_H is the hot plate temperature (50^0C) and T_C is the cold plate temperature.

Some characteristics of the TEC1-12710 thermoelectric module are presented in *table 2*.

Table 2

Characteristics of the TEC1-12710 thermoelectric module

Item	Value	Observations
No. of thermocouples	127	
I_{max} [A]	10.5	for $T_H = 50^0$C
U_{max} [V]	17.4	for $T_H = 50^0$C
ΔT_{max} [^{0}C]	75	for $T_H = 50^0$C
Z [K^{-1}]	$2.4 \cdot 10^{-3}$	for $T_H = 50^0$C

The cooling capacity required for subcooling was calculated using the relation:

$$\dot{Q}_{0SC} = \dot{m} \cdot c_p \cdot \Delta T_{SC} \text{ [W]},$$

where $\dot{m}$ is the refrigerant mass flow [kg/s], c_p is the specific heat of the refrigerant [J/kg·K] and ΔT_{SC} is the degree of subcooling [K].

RESULTS AND DISCUTIONS

As shown in *fig. 5*, the thermoelectric cooler achieves high coefficients of performance at low temperature differences between the two plates of the device; therefore using TEC for subcooling seems to be a reasonable choice.

Fig. 6 presents a comparison between SGHX subcooling and TE subcooling. It is clear that both methods lead to an increased efficiency compared to the one of original system (COP = 2.449). The COP of the refrigeration system constantly increases with the degree of subcooling when a heat exchanger is used; for TE subcooling, COP reaches the maximum value of 2.507 for 5K subcooling. This is due to the fact that while the required subcooling capacity increases with the degree of subcooling (*fig. 7*), the COP of the thermoelectric device decreases

(COP_{TE} = 7.68 for 1K subcooling; COP_{TE} = 2.693 for 10K subcooling) because of the higher temperature difference between the two junctions of the thermoelectric module.

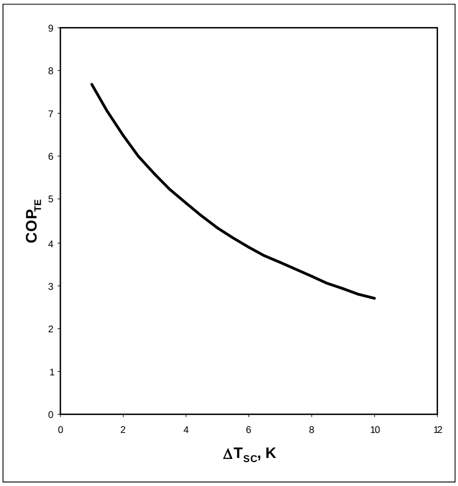


Figure 5 **TEC coefficient of performance**

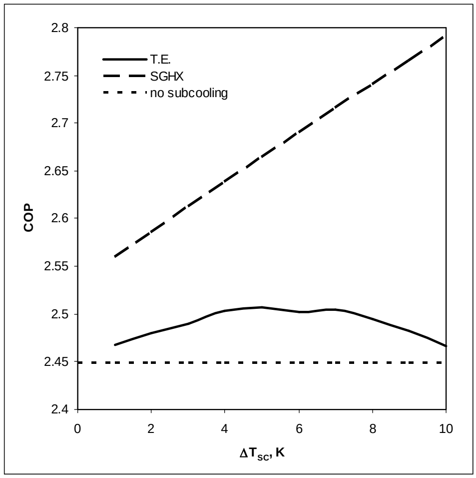


Figure 6 **COP of the refrigeration system**

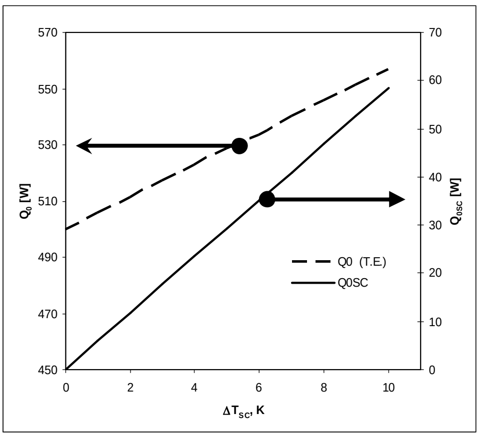


Figure 7 **Cooling capacity and required subcooling load (TEC)**

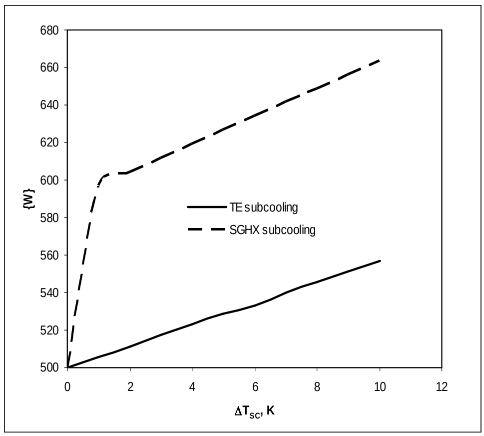


Figure 8 **Cooling capacity**

Fig. 7 also shows that the cooling capacity of the TE subcooled system increases when the subcooling degree increases (from the initial value of 500 W to 557 W, when subcooling reaches 10K).

A comparison between the two subcooling methods in terms of cooling capacity (*fig. 8, tab. 3*) shows that higher cooling capacities are achieved when a suction gas heat exchanger (SGHX) is used.

Table 3

Comparison between subcooling methods

Item		SGHX subcooling	TE subcooling
COP	1K subcooling	2.560	2.468
	5K subcooling	2.664	2.507
	10K subcooling	2.791	2.467
$\dot{Q}_0$ [W]	1K subcooling	597.1	505.8
	5K subcooling	626.8	528.7
	10K subcooling	663.6	557.0

CONCLUSIONS

A thermoelectric cooling device, placed at the outlet of the condenser, was taken into account in order to subcool the liquid refrigerant in a vapor compression refrigeration system.

Two working variants were considered in order to evaluate the cooling capacity and coefficient of performance: thermoelectric (TE) subcooling and SGHX subcooling.

TE subcooling allowed an increase of COP and cooling capacity; the COP rise reached a maximum value of 2.507 for 5K refrigerant subcooling, while cooling capacity increased by 11.4%.

Although the SGHX subcooling led to higher COP (8.7% increase for 5K subcooling) and cooling capacity (25.4% increase for 5K subcooling) then TE subcooling, the latter method has the advantage of enhancing efficiency and cooling capacity without adding moving parts and may be applied to a system which was not initially provided with subcooling capabilities.

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