EXPERIMENTAL STAND FOR ECO-REFRIGERANTS TESTING

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Rezumat. În prezent protecția mediului înconjurător a devenit o prioritate la nivelul Uniunii Europene. Această prioritate, prin aquis-ul legislativ European de mediu, se regăseşte şi în domeniul tehnicii frigului şi din acest motiv în ultimii ani s-a intensificat activitatea de cercetare la nivel internațional pentru a găsi soluții alternative de substituția agenților frigorifici poluanți. În acest context, din 2004, la Catedra de Termotehnică, Maşini Termice şi Frigorifice, din Facultatea de Inginerie Mecanică şi Mecatronică – UPB, s-au derulat câteva contracte de cercetare importante. În această lucrare este prezentat un stand experimental integral dedicat cercetărilor asupra agenților ecologici de substituție. Standul permite: compararea performanțelor experimentale ale unei instalații frigorifice cu comprimare de vapori folosind diferiți agenți frigorifici; stabilirea compatibilității dintre agenții frigorifici ecologici alternativi şi cei poluanți; observarea problemelor tehnice ce apar în cazul funcționării cu agenții frigorifici de substituție, precum şi teste de anduranță şi de fiabilitate. Pentru a asigura corectitudinea cercetărilor experimentale, standul a fost proiectat astfel încât să permită folosirea, în paralel, a două metode pentru determinarea unuia dintre parametrii funcționali importanți ai sistemului frigorific: o metoda principală, pentru măsurarea directă debitului masic de agent frigorific din sistem şi una secundată, pentru validare.
Cuvinte cheie: Aquis-ul legislativ european de mediu, cercetare experimentală, sisteme frigorifice cu comprimare de vapori, agenți frigorifici ecologici alternativi, coeficient de performanță.

Abstract. In the present, the environment protection has become a priority in European Union. This priority, through the European environmental legislation aquis, directly involves the field of refrigerants and for that reason an intense research activity is carried out at international level in order to find substitution alternatives for pollutant refrigerants. In this context, since 2004, the Chair of Applied Thermodynamics, Thermal and Refrigeration Systems from the Faculty of Mechanical and Mechatronics Engineering, University Politehnica of Bucharest develops several important research grants. This paper presents an experimental stand which is entirely dedicated for alternative eco-refrigerants researches. The stand allows: experimental performance comparison of a vapor compression refrigeration system working on various refrigerants; to establish the compatibility between alternative and pollutant refrigerants; the observation of technical problems that appear during the process of replacement and also, endurance and reliability tests. To ensure accuracy of experimental investigation, the stand was designed to allow the use, in parallel, of two methods for determining one of the functional parameters of the refrigeration system: a main method for direct measuring of the refrigerant mass flow rate through the system and a secondary one, for validation.
Keywords: European environmental legislation aquis, experimental investigation, vapor compression refrigeration systems, alternative eco-refrigerants, coefficient of performance.

1. INTRODUCTION

Lately, issues concerning environmental protection have become a priority at European and national level [1]. The strategy consists of drastically reducing the emissions of gasses that lead to the greenhouse effect amplification, but, also, of those that lead to ozone layer depletion. Refrigerants are included in the last category [2]. From this point of view, the goal is to gradually replace polluting refrigerants with eco-refrigerants organic or synthetic substances [3-4].

The substitution of pollutants refrigerants with eco-refrigerants involves the following steps:

– determination of the compatibility between the substitution refrigerants and pollutant refrigerants, from a thermodynamic point of view;

– establishing the application range;

– observing and solving the technical problems which occur when pollutant refrigerants are replaced in existing refrigeration systems, or when new refrigeration systems are designed to work on eco-refrigerants.

Some research activities of the Chair of Thermodynamics, Refrigeration and Thermal Systems of the Faculty of Mechanical Engineering and Mechatronics - UPB are part of this general framework. To achieve the objectives of the research in the field of refrigerants, in a dedicated laboratory; an experimental stand which consists of a refrigeration chamber fitted by one stage mechanical vapor compression refrigeration system was built. The experimental investigation stand allows the determination of the: cooling load, the compressor energy consumption and heat exchangers fans, the refrigerant mass flow rate, the thermal operating regime of the system and, not at least, the coefficient of performance. The testing stand offers the possibility to compare the overall performance obtained when the system operates with various refrigerant types. In this context, expe-

rimental research can be performed to find the most appropriate refrigerants to substitute the pollutants ones [5].

When a refrigerant is replaced with another one in an existing refrigeration system, the thermal regime and system performances are changing. Also, problems may occur regarding the: compatibility with the compressor lubrication oil and with certain materials used in the refrigeration system, such as sealing elements (e.g. incompatibility with rubber - HFC or CO2) and the material of the compressor electromotor (e.g. incompatibility ammonia - copper); changes of the refrigerant flow regime through pipes, evidenced by speed variation, which, in turn, causes problems regarding oil returning to the compressor and, respectively, heat transfer worsening at the condenser and evaporator, the modification of refrigerants mass flow rate, cooling load and compressor power consumption. All of these lead in the end to different coefficient of performance. These changes need to be carefully tracked to determine the compatibility between the refrigeration system and alternative eco-refrigerants. If the compatibility has been established endurance and reliability tests must be performed [6].

To achieve these goals, as detailed below, the testing stand is equipped with devices for measuring and control (automation), but, also, with a data acquisition system that allows remote monitoring and controlling of the functional parameters through a network (e.g. INTERNET).

To ensure accuracy of experimental investigation, the stand was designed to allow the use in parallel of two methods for determining the performance of the refrigeration system, namely:

– indirect method: determination of refrigerant mass flow rate based on the refrigeration system thermodynamic cycle calculus and energy consumed by the compressor electromotor measuring;

– direct method: measurement of liquid refrigerant mass flow using an electronic flow meter.

Finally, the aim is that the results obtained by the two methods are consistent [7].

2. TEST STAND DESCRIPTION

The testing stand consists of: *1* – refrigeration chamber; *2* – condensing unit; *3* – control panel; *4* – electricity meter; *5* – liquid refrigerant flow meter; *6* – the link pipeline between the condensing unit and evaporator; *7* – acquisition data console.

Figure 1 presents the overall picture of the experimental stand.

The refrigeration chamber is the refrigeration space, inside which the evaporator of the refrigeration system is mounted. From the construction point of view the refrigeration chamber is characterized by:

– useful volume – $V = 1$ m^3;

– the walls are made of polyurethane panels;

– the chamber is provided with a single access door.

The condensing unit consists of: *1* – hermetic compressor; *2* – condenser; *3* – condenser fan; *4* – liquid receiver; *5* – electrical connections box; *6* – high and low pressure controller; *7* – suction line; *8* – discharge line. A picture of the condensing unit is shown in Figure 2.

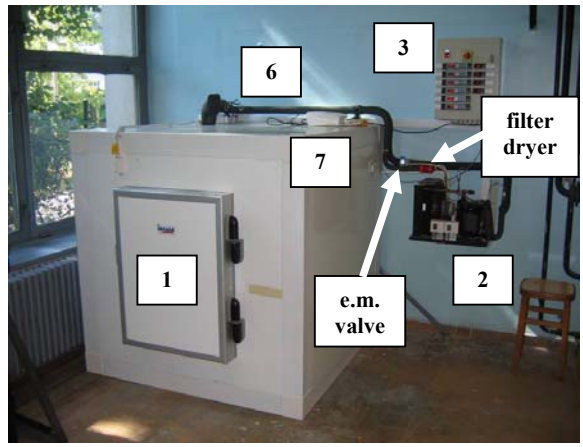


Fig. 1. Overall view of the experimental stand.

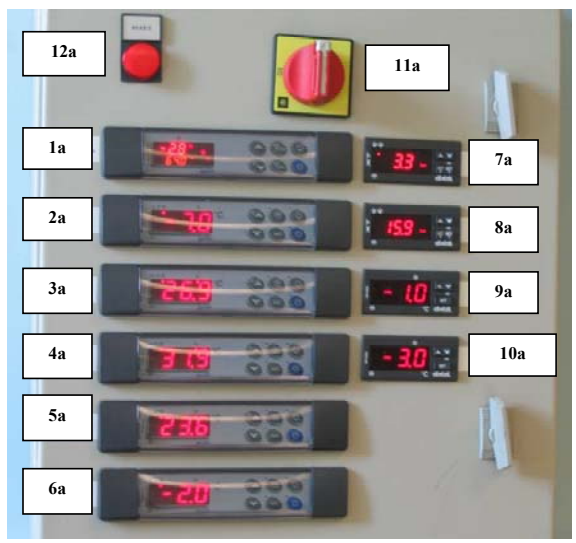


Fig. 2. Picture of the condensing unit.

Control panel consists of: *1* – temperature and relative humidity controller of the air inside the refrigeration room; *2a* – air temperature display at evaporator outlet; *3a* – air temperature display at condenser inlet; *4a* – air temperature display at condenser outlet; *5a* – display of subcooled refrigerant temperature (at the expansion valve inlet); *6a* – display of overheated refrigerant temperature (at the compressor suction line); *7a* – controller of compressor suction pressure; *8a* – controller of condensing pressure; *9a* – display of air temperature inside the refrigeration chamber near the evaporator; *10a* – display of air temperature inside refrigeration chamber near the door; *11* – switch; *12* – damage light indicator. The control panel is presented in Figure 3.

Pressure and temperature measurement are done by means of pressure and temperature transducers mounted at the cold circuit. Air temperature and air relative humidity of the cooling chamber are measured through specialized probes.

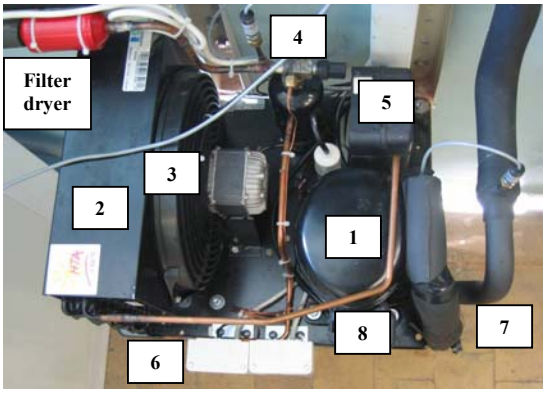


Fig. 3. Picture of the control panel.

The electricity meter is used to measure the energy consumed by the compressor electromotor.

Electronic flow meter of refrigerant is mounted on the pipe which connects the condensing unit and evaporator. For flow meter operation is used a 24 V source, DC voltage.

Link pipeline which connects the condensing unit (*2*, Fig. 1) and the evaporator of the refrigeration system is equipped with a dryer filter (Fig. 1 and Fig. 2), mounted at outlet of the liquid receiver, and with an electromagnetic valve (Fig 1). The dryer filter retains the moisture and any impurities, and the electromagnetic valve stops feeding the evaporator with liquid refrigerant, when the minimum set temperature has been reached. Also, on this pipeline the refrigerant flow meter and expansion valve are mounted.

Acquisition data console records and stores all data provided by the control pane controllers, liquid refrigerant flow rate and electricity meter. Through dedicated software, the console can be configured to record data at a certain time. By remotely accessing the console (e.g. via the Internet), acquisition and functional parameters of the refrigeration system can be changed.

Figures 4,*a* and *b* presents the *interface* of the *software* used for data acquisition, for console controlling, which can be done remotely. Therefore, in Figure 4,*a* it is shown the console software interface accessed remotely via TCP/IP network. Figure 4,*b* shows an image capture which shows how the console can be remotely accessed. Also all 13 points of measurement and control pursued during testing are shown.

3. ESTABLISHING THE PERFORMANCES OF THE REFRIGERATION SYSTEMS

The performances of the refrigeration system can be experimentally determined using two methods: a main method (or the direct determination method) and a secondary method (or indirect determination method) used to confirm the results obtained through main method.

3.1. Indirect method

The indirect method involves the following steps:

● *1st stage: Determination of working temperatures and pressures.* To obtain the working temperatures and pressures it is necessary, in a first phase, to represent the thermodynamic cycle of the refrigeration system in *p-h* coordinates (Fig. 5) [8].

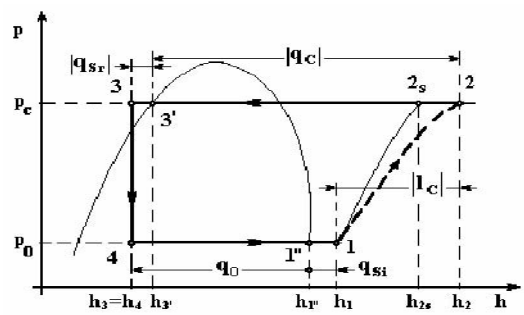
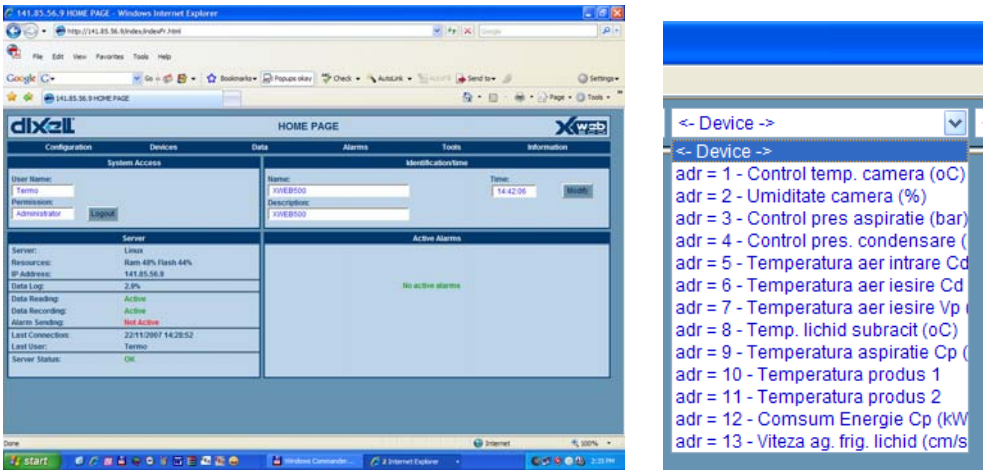


Fig. 6. Thermodynamic theoretic cycle of the refrigeration system in the *p* - *h* coordinates.



a b

Fig. 4. Image capture of remote data acquisition console accessing:
a – software interface; *b* – functional parameters controlled and stored by data acquisition console.

Accordingly to this cycle, through the control panel of the testing stand or through data acquisition console the following parameters are read: the compressor suction pressure, which is, actually, the evaporating pressure; the discharge pressure, which is actually the condensing pressure; overheated refrigerant temperature (refrigerant temperature in the suction line); subcooled refrigerant temperature .

● *2nd Stage: State parameters of the working fluid in the characteristic state points of the thermodynamic cycle and energy balances.* State parameters (enthalpy, entropy and specific volume) in the characteristic points of the theoretic refrigeration cycle can be obtained using a pressure-enthalpy chart or by using specialized programs. Further, the specific mass energy exchanges are obtained.

Refrigerant temperature at the compressor suction state is determined as follows:

$$t_1 = t_{asp} + \Delta t_{si}. \text{ [°C]} \quad (1)$$

where Δt_{si} takes into account the overheating process that occurs when the refrigerant passes over the compressor's electromotor;

– Mass cooling load

$$q_0 = q_{4-1''} = h_{1''} - h_4 \text{ [kJ/kg]} \quad (2)$$

– The volume cooling load:

$$q_{0V} = q_0 / v_1 \text{ [kJ/m}^3\text{]} \quad (3)$$

where v_1 [m^3/kg] is the specific volume of refrigerant at the compressor inlet.

– Specific work input required for the compression process:

$$|l| = |l_{1-2}| = h_2 - h_1 \text{ [kJ/kg]} \quad (4)$$

To evaluate the discharge state parameters, the compression efficiency is considered as ratio between the saturation temperatures corresponding to suction and respectively, discharge pressures:

$$\eta_c = \frac{|l_{1-2s}|}{|l_{1-2}|} = \frac{h_{2s} - h_1}{h_2 - h_1} \cong \frac{T_0}{T_c} \text{ [-]} \quad (5)$$

– Condenser mass heat load:

$$|q_C| = |q_{2-3`}| = h_2 - h_{3`} \text{ [kJ/kg]} \quad (6)$$

– Heat absorbed in the overheating process:

$$q_{si} = q_{1''-1} = h_1 - h_{1''} \text{ [kJ/kg]} \quad (7)$$

- Heat rejected in the subcooling process:

$$|q_{sr}| = |q_{3`-3}| = h_{3`} - h_3 \text{ [kJ/kg]} \quad (8)$$

Energy balance on the cycle:

$$q_0 + q_{si} - |q_C| - |q_{sr}| = -|l| \quad (9)$$

● *3rd Stage: Determination of the coefficient of performance.* The Indirect method is based on the results obtained for the liquid refrigerant flow rate, through data processing provided by all measurement devices that define the operating regime of the refrigeration system, including measured data of compressor energy consumption.

Thus, the refrigerant mass flow rate will be calculated according to the compressor electric power consumption ($|P_{cp}|$) and the specific work input consumed in the compression process ($|l|$), using the relationship:

$$\dot{m} = \frac{P_{cp}}{|l|} \text{ [kg/s]} \quad (10)$$

The power consumed by the refrigeration compressor, will be calculated based on the data acquired by the energy meter (E_{cp}) and the duration of acquisition (τ_{cp}), using the relationship:

$$P_{cp} = \frac{E_{cp}}{\tau_{cp}} \text{ [kW]} \quad (11)$$

The Coefficient of performance is obtained:

$$COP_{indir} = \dot{Q}_0 / P_{cp} \text{ [-]} \quad (12)$$

where $\dot{Q}_0$ is the cooling load of the refrigeration system and is obtained using the relationship

$$\dot{Q}_0 = \dot{m} \cdot q_0 \text{ [kW]} \quad (13)$$

Finally, using the indirect method, the coefficient of performance, refrigerant mass flow rate and cooling load are obtained.

3.2. Direct method

In the direct method, unlike the indirect method, the refrigerant mass flow rate is obtained using the flow meter mounted on the link pipe between the refrigeration system and evaporator.

The values for specific mass energy exchanges of the cycle (q_0 and $|l|$) are the same with the values obtained using the indirect method.

The relation of the coefficient of performance is:

$$COP_{dir} = \dot{Q}_0 / \dot{P}_{cp} \text{ [-]} \quad \mathbf{(14)}$$

for which the cooling load is determined using measured mass flow rate, as follows

$$\dot{Q}_0 = \dot{m} \cdot q_0 \text{ [kW]} \quad \mathbf{(15)}$$

and the power required to run the compressor is determined as shown in the indirect method.

In order to consider that the experimental results are correct, the error between the values of the *COP* obtained through the two methods must be less than 5%.

4. CONCLUSIONS

The testing stand presented in this paper is integrated in the refrigeration laboratory of the Chair of Applied Thermodynamics, Thermal and Refrigeration

Systems of the Faculty of Mechanical Engineering and Mechatronics - UPB. This stand was used to complete, in good conditions, the activities of the research in the field of refrigerants. The components of the testing stand are: refrigeration chamber, condensing unit, control panels, electricity meter; liquid refrigerant flow meter; pipeline link between the refrigeration system and evaporator of the refrigeration system; data acquisition console. The stand allows: to compare the overall performance obtained when the system operates with various refrigerant types, to find the most appropriate refrigerants to substitute the pollutants ones, the observation of the technical problems that occur during the substitution process, endurance and reliability tests. The performances of the refrigeration can be determined using two methods.

The first method, called indirect method, is based on the results obtained for the liquid refrigerant flow rate, through data processing provided by all measurement devices that define the operating regime of the refrigeration system, including measured data of compressor energy consumption. The second method, or the direct method, is based on the refrigerant mass flow rate obtained using the flow meter mounted on the pipe which connects the refrigeration system and the evaporator. The aim is that the results obtained by the two methods are consistent.

Once the possibility to substitute a pollutant refrigerant with an ecological one has been established, endurance and reliability tests must be conducted.

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