EXPERIMENTAL DETERMINATION OF TEMPERATURE IN ONE STAGE VAPOR COMPRESSION REFRIGERATION CYCLE

Ioan MIHAI, Dan MILICI, Milan CRASI,
"Ştefan cel Mare" University
Str. Universităţii nr. 13, 720 225 Suceava, Romania
mihai.i@fim.usv.ro

Key Words: Joule–Kelvin effect, adiabatic expansion, CoolPack, data acquisition,

Abstract: To determine the parameters of function which characterize the thermodynamic cycle for the cooling system, we used a USB-based multifunction data acquisition and control device. LabJack U12 and sensors LM35. Thanks to the LabWiew software we gathered data in eight points at the entry and the exit of the elements which compose the refrigeration system. The software makes it possible to trace a diagram on which we marked these eight points and their values are given in real time by the computer. It is thus possible either to visualize the values of the temperature at each time, or to memorize data in files/graphic.

1. THE PROCESS OF ADIABATIC COOLING IN A CAPILLARY TUBE THAT ACCOMPANIES THE EXPANSION OF A REAL GAS

It is already known that the variation in the temperature which occurs by the throttling of a gas is called the Joule effect - Thompson. This effect has applications on cooling cycle using vapour compression. In figure 1, one can distinguish the principal methods which are used to decrease the temperature.

For all the situations one speaks about a marked fall of the pressure which is: 1-2s adiabatic, 1-2n polytrophic, 1-2i isenthalpic, 1-2T isotherm.

The equation which corresponds to an isenthalpic relaxation is:

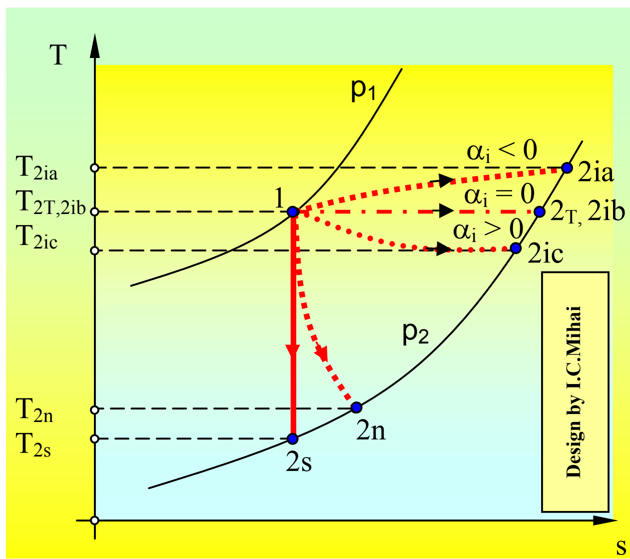


Fig. 1. Des méthodes de détente des gaz

$$dI = TdS + Vdp \tag{1}$$

where I - enthalpy, T - temperature, S - entropy, V - volume, p - pressure. The differential expression of the enthalpy is:

$$dI = \left(\frac{\partial I}{\partial T}\right)_p dT + \left(\frac{\partial I}{\partial p}\right)_T dp = c_p dT + \left(\frac{\partial I}{\partial p}\right)_T dp \tag{2}$$

where c_p- specific heat to constant pressure. In conformity with the first principle of thermodynamics $\delta Q = dI - Vdp$ and then $dI=TdS+Vdp$. Using the Maxwell's equations, one obtains:

$$\left(\frac{\partial I}{\partial p}\right)_T = T\left(\frac{\partial S}{\partial p}\right)_T + V = -T\left(\frac{\partial V}{\partial T}\right)_p + V \tag{3}$$

By the replacement of equation 3 in the differential expression of enthalpy 2 results:

$$dI = c_p dT - \left[T\left(\frac{\partial V}{\partial T}\right)_p - V\right]dp \tag{4}$$

Joule-Thomson cooling is the name given to the drop in temperature that occurs when a real gas such as air or cooling agent expands from high pressure to low pressure at constant enthalpy (i.e., adiabatic expansion).

One can define "the differential coefficient $\alpha_{i,}$ Joule-Thompson" with the relation:

$$\alpha_i = \left(\frac{dT}{dp}\right)_i = \frac{1}{c_p}\left[T\left(\frac{\partial V}{\partial T}\right)_p - V\right] \tag{5}$$

If:

$\alpha_i < 0$ =>the temperature increases;

$\alpha_i = 0$ => the temperature remains constant;

$\alpha_i > 0$ => the temperature drops with applications in refrigeration.

The phenomenon of cooling of a gas to the limited variations of pressure is named "the integral effect Joule - Thompson". After the integration of equation 5, the variation in the temperature becomes:

$$\Delta T = T_1 - T_{2i} = \int_{p_2}^{p_1} \frac{1}{c_p}\left[T\left(\frac{\partial v}{\partial T}\right)_p - v\right]dp \tag{6}$$

This relation makes it possible to determine the variation of the temperature of a laminated gas (refrigerating agent) in a capillary tube

2. DETERMINATION OF THE TEMPERATURES IN THE CORNERS OF A CYCLE USING COOLPACK SOFTWARE

To determine the values of the temperature in the corners of a cycle one can use a specialized software developed by the Department of Mechanical Engineering (MEK), Section of Energy Engineering (ET) at the Technical University of Denmark (DTU). The CoolPack software makes it possible to determine by calculation, in these same points, the values of the temperatures. It only remains to compare these values obtained for the theoretical case with the experimental data.

This software can be downloaded on the site www.et.dtu.dk/CoolPack. CoolPack is a whole package of simulation programs which can be used for the design, dimensioning, the analysis and the optimization of the refrigeration systems. The programs in CoolPack are divided into three main groups: Refrigeration Utilities, EESCoolTools, and Dynamic.

The main group EESCoolTools has been divided further into four subgroups: Cycle analysis, Design, Evaluation, and Auxiliary.

- ***Refrigeration Utilities***: - The group **Refrigeration Utilities** consist of 3 refrigerant oriented programs, primarily used for calculating the properties of primary and secondary refrigerants, creating property plots for primary refrigerants (like p-h, T-s and h-s diagrams) and for calculating the pressure drop for flow of secondary refrigerants in pipes.

- ***Cycle analysis*** – for the analysis of the cycles;
- ***Design*** – This package of tools enable the design of a system of refrigeration. The first level of the tool is the analysis of cycle (starting by default), the second level is the dimensioning of the components and the third represents the simulation containing of the specific components
- ***Evaluation*** – Each program of this category allows the evaluation of the evaporator, the compressor with constant capacity or evaporator and of the compressor with variable capacity ;
- **Auxiliary** - allows the evaluation by elements: **COMPRESSOR** - isentropic evolution and volumetric effectiveness, **EVAPORATOR** - UA Value **CONDENSER** - UA Value, **Cooler with air** - the cooling and the dehumidification of the humid air, **PIPES**: Gas pipelines - the fall of pressure and transfer of heat, Liquid pipes - the fall of pressure and heat transfer , **PROPERTIES**: Refrigerants properties: physical, thermodynamics and transport. **HUMID AIR** - physical thermodynamics and thermo (transport) properties, Comparison of the refrigerants: Comparison of the three cooling agents in a simple cycle of refrigeration, **AMOUNT OF COOLING**: Cold room, Liquid cooling, refrigerating shop window, air-conditioned rooms, **ECONOMY**: Cost of the cycle of life.
- ***Dynamic*** – The group named **Dynamic** contains the dynamic programs in CoolPack. With this program it is possible to simulate the cooling down of an object/room under various conditions and with on/off-capacity control of the compressor.

A thermodynamic cycle traced by the authors in Log (p) - H using CoolPack and the parameters determined by the software are depicted in the fig. 2.

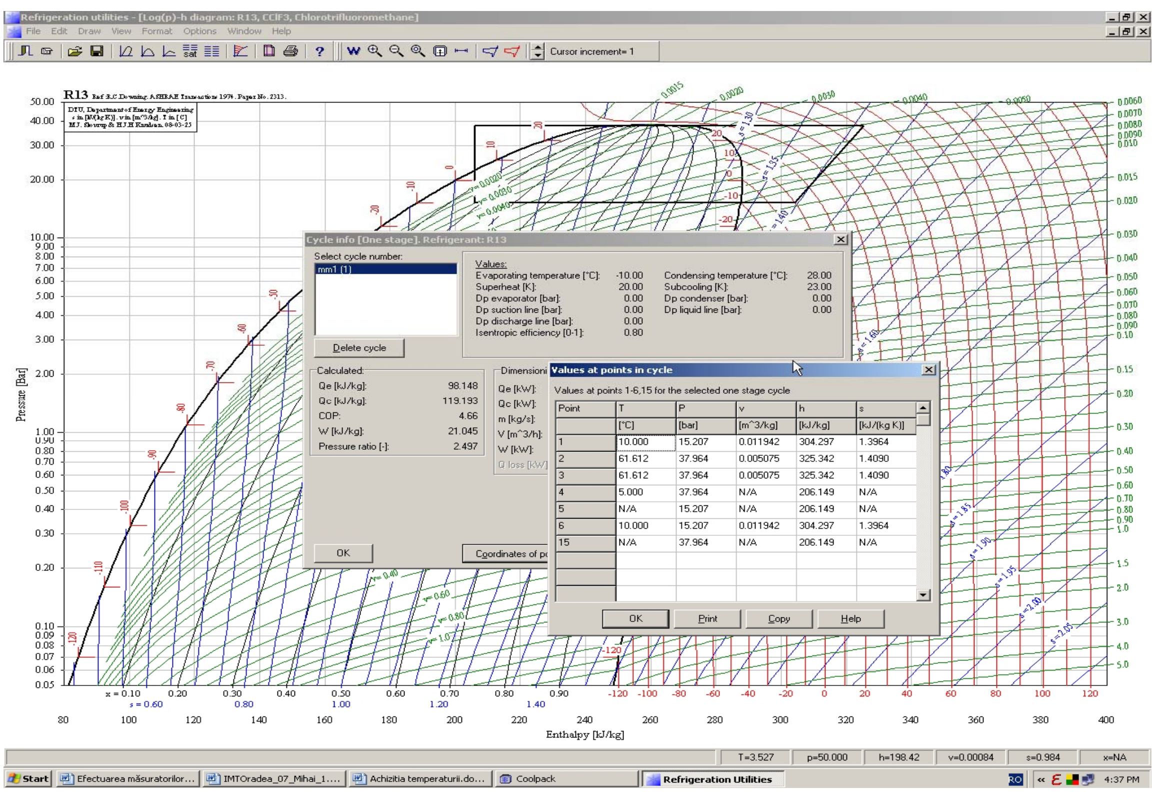


Fig.2. The thermodynamic cycle of a refrigerating system obtained using CoolPack

For calculation with the CoolPack software it is necessary to introduce data input (figure 3): the temperature of vaporization and condensation, the type of agent of refrigeration, refrigerating power, flow rate.

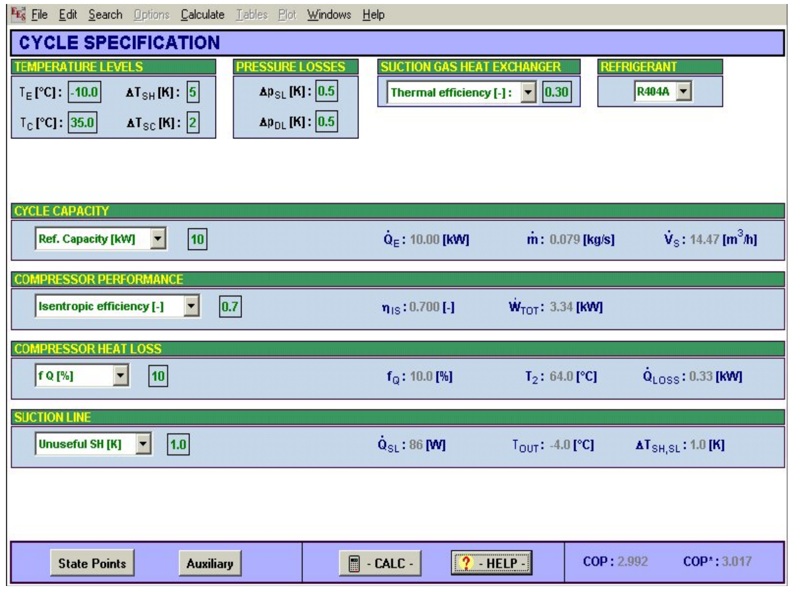


Fig.3. Window of CoolPack for input data

The thermodynamic cycle is represented using the software. An image obtained by the software for a one-stage cycle is in the figure 4.

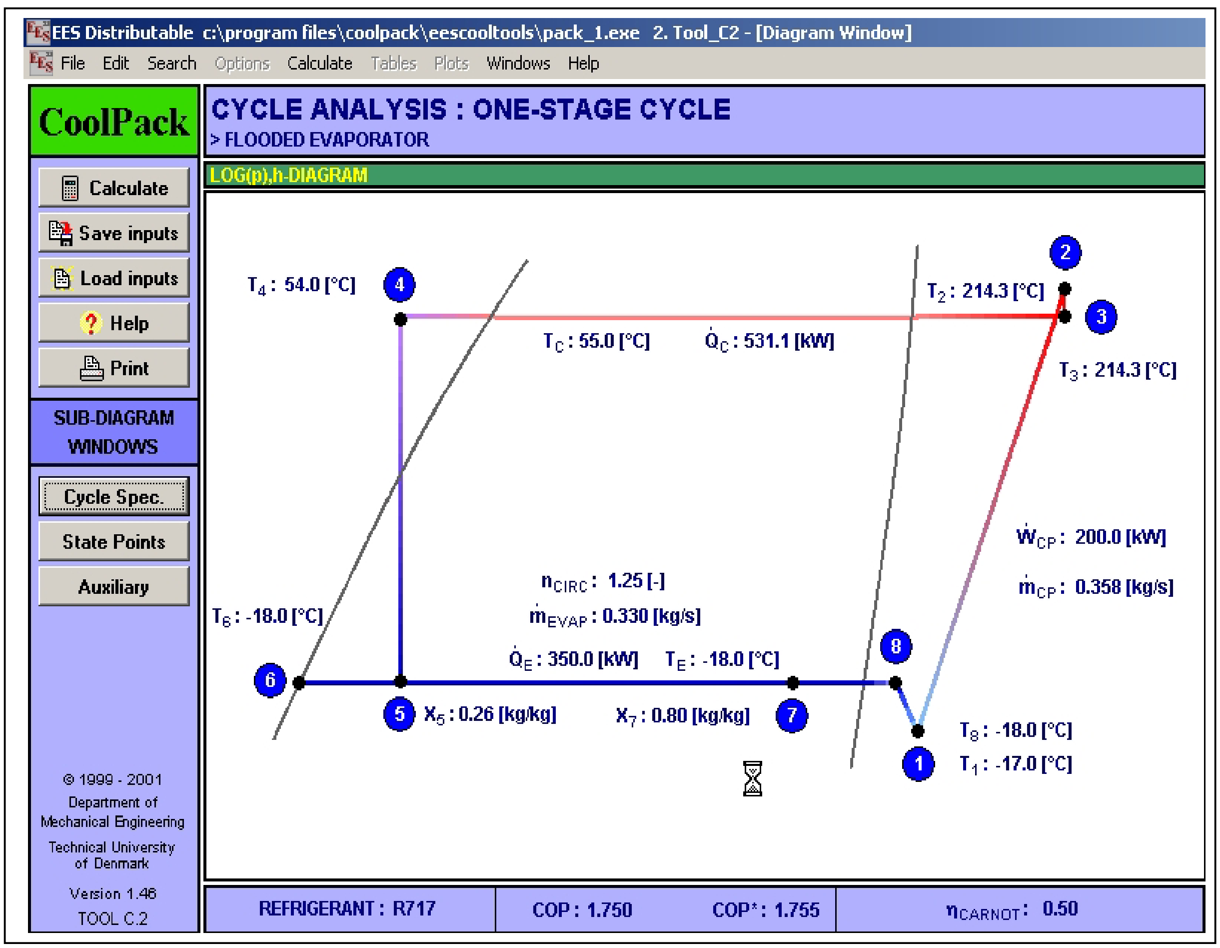


Fig.4. One –stage **vapor-compression refrigeration cycle**

The software holds account of the functional characteristics for the various component elements which belong to the installation.

Thus the software is conceived to take account of:

- ✓ **The process of super cooling of the condenser** - the ideal case corresponds to the state of saturated liquid while in the real case that it is slightly cooled (point 4 in the diagram). Window "TEMPERATURE LEVELS".
- ✓ **The process of vaporization** - the vapours at the end of the theoretical process are on the point of intersection of the saturated vapour line and the isotherm, but actually the vapours are slightly overheated (point 7 in the diagram). Window "TEMPERATURE LEVELS".
- ✓ **Over- heating inside the supply line** - the aspiration of the vapours in the compressor is carried out at a temperature lower than the ambient one. This pipe should in theory be insulated thermal but for installations with low power it is not necessary. It is possible to have a heat transfer with bad consequences on the parameters of efficiencies of installation (see items 7-8). One can modify three parameters: parasitic over-heating, the intrusion of heat and the temperature of exit. Window "SUCCTION LINE".
- ✓ **Losses of pressure at aspiration and discharge** - dependents on the process of friction in the event of flow of the refrigerating agent in contact with the walls or between the layers, with turbulence etc. WINDOW "PRESSURES LOSSES».
- ✓ **Heat exchanger** -if high power heat exchanger is used, one can consider that the totality of the heat yielded by the refrigerating liquid can be absorbed by the vapours.
  The real case comprises losses and then the output is: (7) where (T1-T10) represents the real difference in temperature and (T5-T10) the possible maximum value. If there is no exchanger then we must choose the option "No SGHX". It is obvious that such an exchanger has a positive contribution on the installation. Window "SUCTION GAS HEAT EXCHANGER
- ✓ **Real operation condition for the vapour compressor** - if in the ideal case the process of compression is isentropic in the real case there are losses due to: the heating of the vapour by the walls with the aspiration, the cooling of the vapour by the walls with discharging, the friction of the vapour inside the cylinder, piston and another elements.

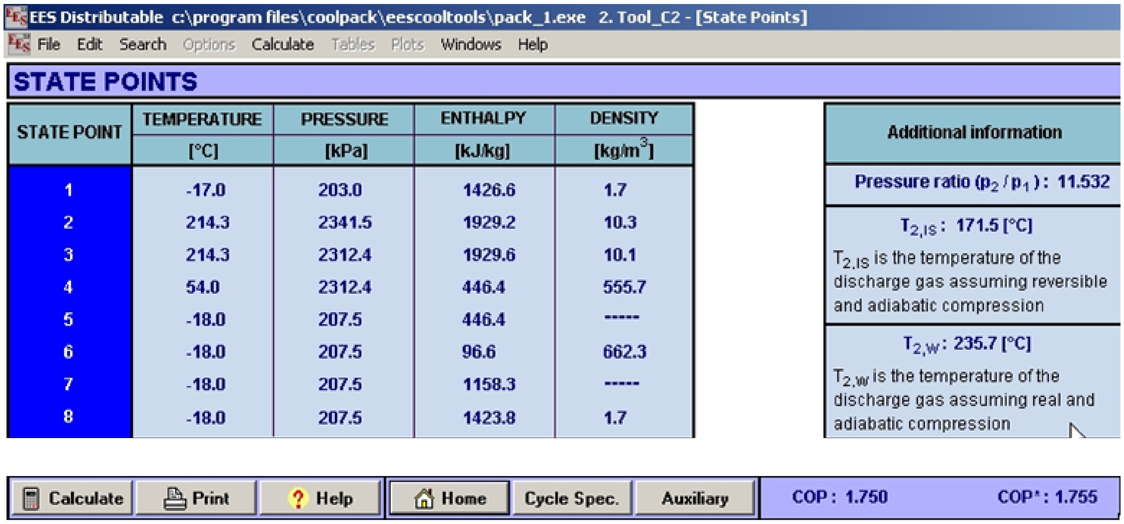
Taking these considerations into account one can define the isentropic efficiency η_{is} for compression with the relation:

$$\eta is = \frac{l_{iz}}{lr} = \frac{P_{iz}}{P_r} \qquad (8)$$

where (liz), (Piz) represent mechanical work (power) necessary to the process of compression and (Lr), (Pr) correspond to the real case.

Window "COMPRESSOR PERFORMANCE".

If the compressor is cooled one uses the window "COMPRESSOR HEAT LOSS".



EES Distributable c:\program files\coolpack\eescooltools\pack_1.exe 2. Tool_C2 - [State Points]

STATE POINTS

STATE POINT	TEMPERATURE [°C]	PRESSURE [kPa]	ENTHALPY [kJ/kg]	DENSITY [kg/m³]
1	-17.0	203.0	1426.6	1.7
2	214.3	2341.5	1929.2	10.3
3	214.3	2312.4	1929.6	10.1
4	54.0	2312.4	446.4	555.7
5	-18.0	207.5	446.4	-----
6	-18.0	207.5	96.6	662.3
7	-18.0	207.5	1158.3	-----
8	-18.0	207.5	1423.8	1.7

Additional information

Pressure ratio (p_2 / p_1): 11.532

$T_{2,IS}$: 171.5 [°C]

$T_{2,IS}$ is the temperature of the discharge gas assuming reversible and adiabatic compression

$T_{2,W}$: 235.7 [°C]

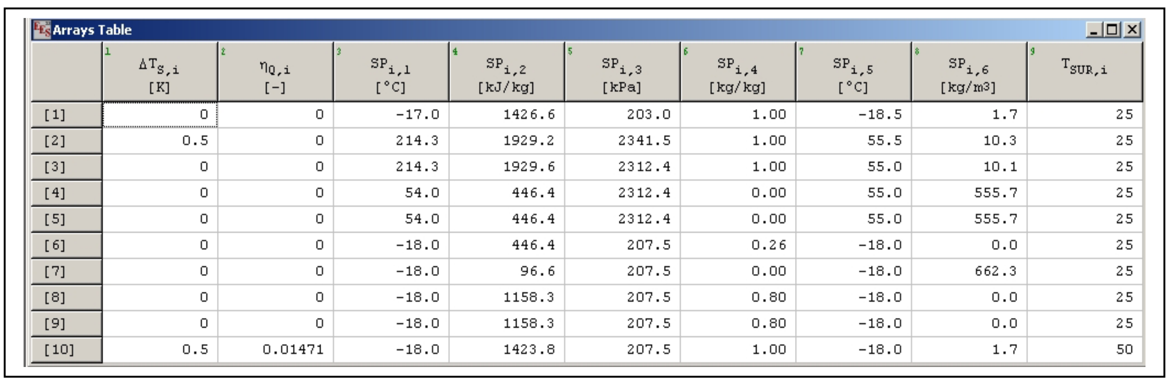
$T_{2,W}$ is the temperature of the discharge gas assuming real and adiabatic compression

Calculate | Print | Help | Home | Cycle Spec. | Auxiliary | COP: 1.750 | COP*: 1.755

Fig.5. Thermodynamic parameters of the cycle in specific points

In the window "STATE POINTS" of the software, one can calculate (see fig.5.) the values of the parameters in the characteristic points of the cycle.

Thus one can calculate various thermodynamic parameters of the cycle by calling upon window "CALCULATE" and on the screen are posted the results (figure 6).



Arrays Table

	$\Delta T_{S,i}$ [K]	$\eta_{Q,i}$ [-]	$SP_{i,1}$ [°C]	$SP_{i,2}$ [kJ/kg]	$SP_{i,3}$ [kPa]	$SP_{i,4}$ [kg/kg]	$SP_{i,5}$ [°C]	$SP_{i,6}$ [kg/m3]	$T_{SUR,i}$
[1]	0	0	-17.0	1426.6	203.0	1.00	-18.5	1.7	25
[2]	0.5	0	214.3	1929.2	2341.5	1.00	55.5	10.3	25
[3]	0	0	214.3	1929.6	2312.4	1.00	55.0	10.1	25
[4]	0	0	54.0	446.4	2312.4	0.00	55.0	555.7	25
[5]	0	0	54.0	446.4	2312.4	0.00	55.0	555.7	25
[6]	0	0	-18.0	446.4	207.5	0.26	-18.0	0.0	25
[7]	0	0	-18.0	96.6	207.5	0.00	-18.0	662.3	25
[8]	0	0	-18.0	1158.3	207.5	0.80	-18.0	0.0	25
[9]	0	0	-18.0	1158.3	207.5	0.80	-18.0	0.0	25
[10]	0.5	0.01471	-18.0	1423.8	207.5	1.00	-18.0	1.7	50

Fig.6. Thermodynamic parameters of the cooling cycle

3. RESULTS OBTAINED BY EXPERIMENTAL DETERMINATIONS

The system of data acquisition carried out in our laboratory makes it possible to determine the temperature in points which correspond to the theoretical cycle. Thus, on the cooling installation eight sensors of temperature are placed. The results collected using the data acquisition device LabJack U12 is subjected to a conversion data by the LabView software. In this case, the system of measurement can gather data which correspond to the several heating - cooling successive stages. It is possible to modify the operation of the installation with the system of adjustment per thermostat. In figure 7 is presented the data acquisition characteristic at the field of the temperature for the cooling cycle with mechanical compression, with only one stage of compression and in figure 8 with two periods.

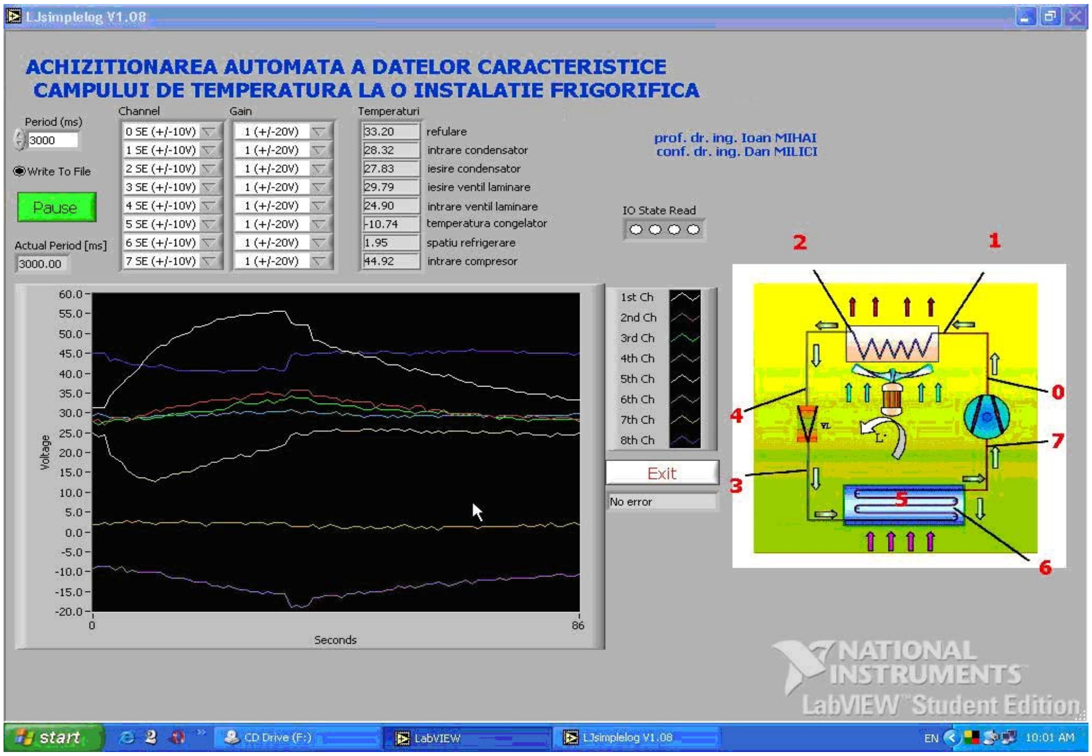


Fig.7. Experimental data, one period

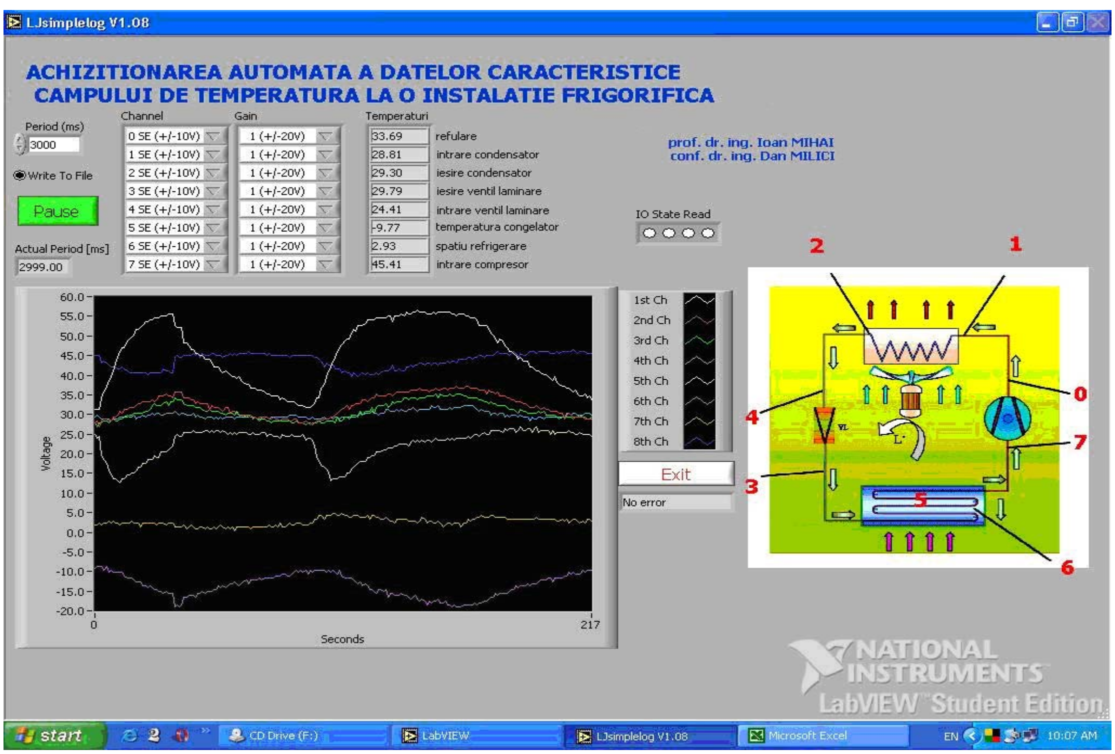


Fig.8. Experimental data, two periods

4. CONCLUSIONS

In this article we presented two possibilities of determining the temperature in certain points which characterize the operation of a cooling cycle. The first case considers the calculation carried out using software for the thermodynamic cycle according to the physical characteristics of the refrigerating agent.

One obtains by calculation eight points for each entry (input) and output of the apparatuses which compose the installation. It is possible to determine for each point the enthalpy, the entropy and the effectiveness.

To check if there is an agreement between the theoretical data and the phenomena obtained in experiments, we conceived a system of data acquisitions. If the results are compared one can observe that there is a notable agreement between the two categories of results. The errors are not important and then the methods make it possible to determine the field of temperature in any place.

REFERENCES

[1] **A. BEJAN, A.D. KRAUS**, Heat transfer handbook, John Wiley & Sons Inc. Hoboken, New Jersey, 2003.

[2] **LABJACK CORPORATION** - LabJack U12 User's Guide Revision 1.09 12/22/2004 www.labjack.com.

[3] **I. MIHAI, A. LUPOAIE**, Achiziționarea automată a datelor caracteristice câmpului de temperatură la o instalație frigorifică, Suceava, 2006.