1996

Universal Effective Cooling and Heating Systems on the Compressed Air

E. G. Zaulichnyi
Academy of Sciences of Belarus

A. P. Iakoushev
Academy of Sciences of Belarus

UNIVERSAL EFFECTIVE COOLING AND HEATING SYSTEMS ON THE COMPRESSED AIR

E.G. ZAULICHNYI, A.P. IAKOUSHEV

Institute of Power Engineering Problems

Academy of Sciences of Belarus

Sosny, Minsk, 220109, Belarus

ABSTRACT

Highly effective both as to dividing of the energy of the compressed air into hot and cold agents and as to the energy exchange of them with consumers as well as ecologically and technically safe cooling and heating systems with vortical gas-energy dividing tubes (VGEDT) have been developed. The systems have been tested for simultaneous using both as refrigerators and as heaters in the processes of galvanic plating of machines' details with zinc and chromium; for cold rooms and heating of rooms; for cooling of casings of electrical machines and electron units and processors. They are successfully used for simultaneous heating of chocolate glaze up to 60-70°C by a hot agent at the temperature of 80-95°C and effective cooling of these cottage cheeses after glazing with a cold agent at its temperature of 3-7°C. These systems are operating at the milk factory on the compressed air with the pressure of 0.57-0.73 MPa and generation of 12-15 kW cooling-down and 6-7 kW heating capacities. They completely replaced the water heating by a very expensive steam with the pressure of 0.3-0.6 MPa and the cooling of cottage cheeses with the help of an evaporator with brine at the temperature of (-15)°C, blowing over by two fans with flow rate capacity of 750 m^3/h each. The volume of cooling chamber for glazed cottage cheeses decreased here by a factor of 10, its mass decreased by a factor of 11, the economy of energy carriers such as vapour, cold and electric energy decreased by a factor of 2.5-3.

INTRODUCTION

The scientists confirm that the mankind is separated from a thermal death with one order of magnitudes. If we begin to use the energy of 10 times more than at present, then we inevitably die from "greenhouse effect". Emissions of carbon dioxide, sulphur dioxide and nitrogen oxides are all associated with energy production and each one has a detrimental effect on the environment. CO_2 is the main "greenhouse" gas responsible for global warning, SO_2 is the main cause of acid rain, and No_x contributes to both global warning and acid rain. Another catastrophe impending to the mankind is the destruction of the ozone layer. Scientists agree that emission of manmade chlorofluorocarbons, halons, carbon tetrachloride, methyl chloroform, methyl bromide and other substances are responsible for depletion of the ozone layer. Millions of ozone molecules are being destroyed every minute and this is increasing the amount of harmful ultraviolet radiation that reaches the Earth's surface. In order to stave off this catastrophe threatening to the mankind, i.e. "greenhouse effect" and destruction of the ozone layer, it is necessary to decrease cardinally but in some cases to stop the effluents of ecologically harmful combinations from the combustion of fuels, chemical and agrotechnical productions and technologies including the production of harmful halocarbon refrigerants to be discharged into the environment either.

Within 1973-1986 the growth of Gross Domestic Product (GDP) in the USA was 30% without increasing energy consumption. Just another picture can be observed in the republics of the USSR. The percent of the increase in GDP is directly proportional to the percent of the increase in energy consumption. Industrial enterprises recuperate only 35% of the energy discharged into the environment. Efficiency of the most part of technologies and equipment is shockingly low, there is no competent control for energy consumption [1]. The same situation is now at the post-Soviet Republics, including the Republic of Belarus. A sharp rise of prices for energy carriers imported into Belarus up to 25% and in some cases even up to 40% increased their share in a total cost of the products produced at the values of 2-5% in the developed countries. The development of energy and resources saving systems for co-generation of cold and heat becomes especially actual in Belarus which has no practically its own energy carriers.

ALTERNATIVE SYSTEMS WITH VGEDT

The paper presents innovation multipurpose very compact cooling-and heating systems with VGEDT. The development of such systems is the result of the advanced theoretical and experimental studies in the fields of gas dynamics and heat-and mass exchange of complicated spiral-twisted reciprocal and separating turbulent flows with large pressure gradients across the channel of VGEDT and the following supply of cold and hot agents divided with the help of bubblers and (or) multispray distributors to the users [2-11]. Systems consist of two main elements. The first element is a simultaneous generator of cold and heat, so called vortical gas-energy dividing tube (VGEDT) (Fig. 1) where the known Ranque effect is realized [2, 3]. "Know-how" of the VGEDT developed by Prof. E.G. Zaulichnyi with the consumption of 2-3.3 m^3/min. at the pressure of 0.5-0.8 MPa with the efficiency of air energy dividing of 0.92-0.96 constitutes in determination of optimum relations among gas dynamic, thermal and geometric characteristics of flow and the tube, shapes of its construction elements, between dissipation and generation of energies in it. These relations in the developed construction of VGEDT allowed to intensify the known Ranque effect to the utmost and make the tube sufficiently more effective as to the depth of division of the energy of the compressed air by the temperature of agents into "cold" and "heat" in comparison with the greater part of the designs of the vortical tubes described in the literature [2, 4-8].

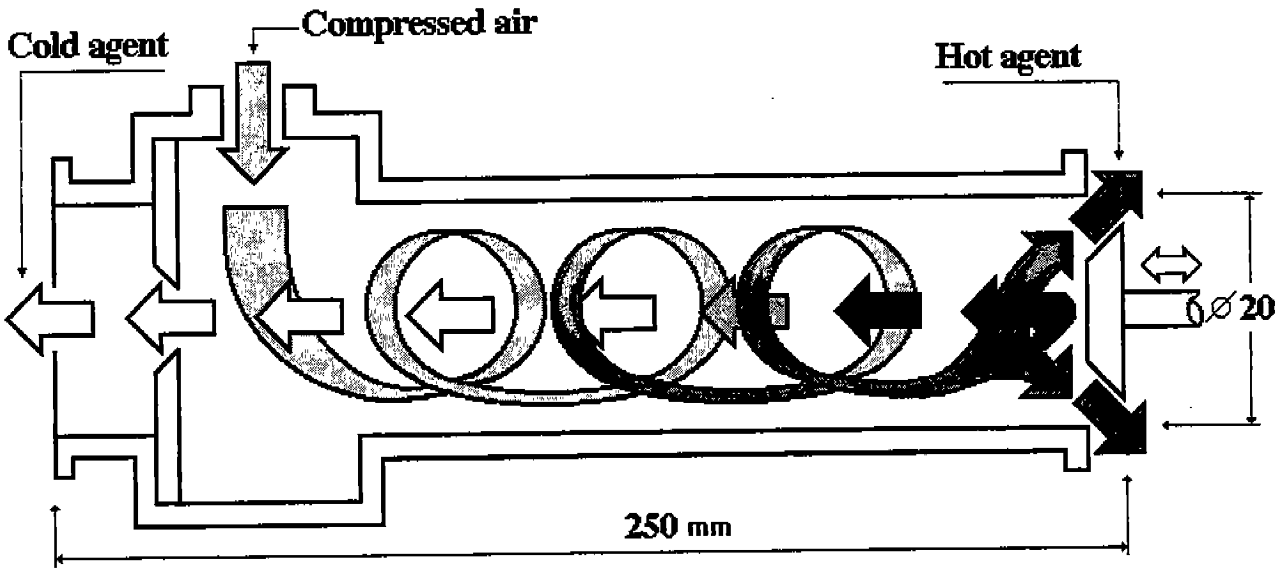

Fig. 1: Dividing of energy of the compressed air into cold and hot agents

The second important element of the system with VGEDT is special distributors of the agents of cold and heat divided into it as well as the supply of theirs to users. As a user it can be capacitance with the liquid (cooled or heated), heat exchanger (evaporator of heat pump, refrigerator) or apartment, chamber (for conditioning, cooling or heating). As elements of the system for the users are served special bubblers or multi-spray distributors of blowing over for both agents. Here, total values of energy of cold and heat increase by a factor of 1.5-3, removed from or supplied to users in systems in comparison with their values after dividing in VGEDT [9]. Multi-spray distributors are used for supplying of agents of the divided after VGEDT air into cooling chambers for processing of milk-and meat products or for storage of fruits and vegetables, for the purposes of heating of houses or conditioning, for cooling of casings of energy machines, electron units and computer processors. They also allow as bubblers to make intensively heat exchange between energy carrier and user and to distribute the supplied into the chamber agent uniformly along the volume of the chamber with the help of aggregate small sprays with the diameter of 2-4 mm. Multi-stage air screen or multi-spray air flow also intensify the energy exchange by a factor of 1.5-2 in comparison with blowing over by a fan of the evaporators [10-11].

CHARACTERISTICS OF VGEDT (EXPERIMENTAL DATA)

The developed VGEDT (Fig. 1) are the following ones: length - 0.25 m, diameter of a dividing tube - 0.02 m. This mass is about 2 kg. It in the different systems have passed n evaluation test successfully and are used for cold production aimed at cooling of liquids (electrolytes, water, oil) and products processing of meat-and milk industry, cooling of frames of energy machines and electronic units of processors and computers, storage of fruits and vegetables as well as for conditioning apartments, offices and chambers. Simultaneously they offer the function of heaters of different liquids (electrolytes, water) and air heaters for heating up of houses and apartments, for conditioning lodgments. In the developed VGEDT the intensively twisted compressed air brought up to the speed of sound is divided as to energy into cold and hot components with controlled correlation of flow ratio from 0.1 to 0.9 from the total air flow rate through VGEDT.. In the range of the pressure 0.5-0.72 MPa at temperature of 20-25°C and for the flow rate of 2-3 m^3/min. of the compressed air it generates 11-17 kW of cold with the temperature of cold portion of (-5+10)°C. In addition to refrigerant VGEDT generates simultaneously for the purposes of hot water supply, conditioning or heating of lodgments with heat energy of 2.9-8.5 kW and the temperature of the carrier of 70-120°C. With the relation of cold and hot components of 0.1 to the total consumption through VGEDT of the compressed air and at the pressure of its of 0.72 MPa their limiting temperatures have been measured: for the cold component - (-28)°C, and for the hot one - (+120)°C. Here, 0.9 of the cold air has been divided at the temperature of (+10)°C, what constitutes 17 kW as to cooling-down capacity.

The temperature difference between cold and hot components in VGEDT at the same pressure of the compressed air of 0.72 MPa depending on the ratios between themselves is fixed in the range of 58-110°C. Optimum maximum temperature difference is reached at the pressure ratio of the compressed air to cold agent equal to 8. With decreasing the pressure of the compressed air through VGEDT both the values of its cooling-down- and heating capacities and temperature difference between the agents of the divided air are decreased. In the developed VGEDT at the pressure of the compressed air of 0.72 MPa, 90% of cold air have cooling-down capacity of 17 kW at the temperature of 10°C. The maximum temperature difference between cold and hot agents is 110°C. And at the pressure of 0.59 MPa and other equal conditions cooling-down capacity decreases to 13.5 kW, and the maximum temperature difference - to 84°C and at the pressure of 0.5 MPa cooling-down capacity decreases to 10.1 and the maximum temperatures difference - to 60°C

TESTING THE SYSTEMS WITH VGEDT IN INDUSTRY

A similar system with such VGEDT at the pressure of the compressed air of 0.72 MPa was installed at German twisted and drawing machine about three years ago at a plant of chemical cotton processing in Mogilev. Within this period VGEDT with the help of a special distributor and cold air divided into it allowed to provide with operation free of damage of each from 72 rotating and heated to 230°C devices (galets) for thermal treatment of thread [12]. During the same period of time a vortical tube itself was not subjected to repair or maintenance. Without cooling by the system with VGEDT bearings and plastic rings with electronic sensors, which controlled the regime of thermal treatment were overheated to 100-120°C [6]. In 7-50 working days most of them were out of operation. Shut down of the machine, repair of galets are connected with large material and financial costs. Decreasing the temperature of bearings and rings by 30-50°C by the technique of forced cold air blowing into the vessel of the galet after VGEDT allowed to avoid these difficulties. VGEDT and the machine are operating free of damage up to now.

The system with VGEDT described here with cooling-down capacity of 11-12 kW at the pressure of the compressed air of 0.53 MPa at the temperature of a cold agent of 10-12°C and heating capacity of 2-2.5 kW at the temperature of a hot agent of 65-73°C was used as a cooling system and a heating one simultaneously for three baths of cylinders' chrome-plating for the lifts of dump truck bodies at the plant in Minsk. Diameters of the chrome-plated cylinders are 80-120 mm, the length is about 500 mm. The total volume of the electrolyte in three baths constitutes 5.5 m^3. The system was made of one VGEDT, three bubblers for cooling of the electrolyte in the process of chrome-plating (keeping its temperature going at the level of 52-55°C) and two bubblers for preliminary heating of the electrolyte up to this temperature. The surface of heat-and mass exchange of each from 5 bubblers is 0.5 m^2. Before the introduction of the system with VGEDT a preliminary heating of the electrolyte was carried out with the help of steam through coil heat exchanger from the tube with the diameter of 40 mm which was placed on the bottom of the bath. A cooling water of 2.4 m^3/h is supplied through the same heat exchangers in the process of chrome-plating. At combined using steam and hot air after VGEDT through bubblers the time for a preliminary heating of the electrolyte from 10-20°C to 52-55°C decreases from 1 hour to 8-10 minutes. It is reduced the consumption of expensive steam by a factor of 6-7 due to intensification of heat-and mass exchange by bubbling in comparison with free convection from smooth tube-type heat exchanger to the bottom of the bath. The cold agent at complete exception of the cooling water allows the optimum temperature of electrolyte during the whole period of plating to be sustained. The cold agent at complete exception of the cooling water with the help of bubblers allows the optimum temperature of the process to be sustained during the whole period of plating. Using the system of three bubblers and one VGEDT with cooling-down capacity of about 12 kW pointed out above at the automobile plant electrolyte in 3 baths for chrome-plating of details more than 35 kW of heat was removed from it as a total. The evaporator of ammonia refrigerator with heat exchange surface of not less than 300

m^2 for these purposes was not possible to be placed in a total volume of these baths of 5.5 m^3. Summary surface of heat- and mass exchange of bubblers constituted only 1.5 m^2.

USING THE SYSTEM WITH VGEDT AT THE MILK FACTORY

At the milk plant in Minsk cooling and heating system with VGEDT with simultaneous generation of cold and heat has been installed in the line for production of glazed with chocolate cottage cheeses (Fig. 2, a), cooled in the cooler (1) with the help of the evaporator (2) with brine (4) at the temperature of (-15)-(-17)°C. A cold agent from VGEDT (Fig. 2, b) replaces brine cooling (2, 4). A hot agent in the vessel (15) for water heating replaces vapour (7). Hot water in the vessel (15) is necessary for chocolate glaze heating (16) up to the temperature of 60-70°C for covering cottage cheeses with chocolate casing (5). Cottage mass from a feed-control device (8) through moulding automatic control machine in the form of bars (5) with the mass of 50 g is glazed with a hot chocolate from the bath (16) by the pump (9) at the temperature of 60-70°C. The glazed cottage cheeses (5) are transferred by a netted conveyer (10) onto a belt conveyer (6) of the chamber of the cooler (1).

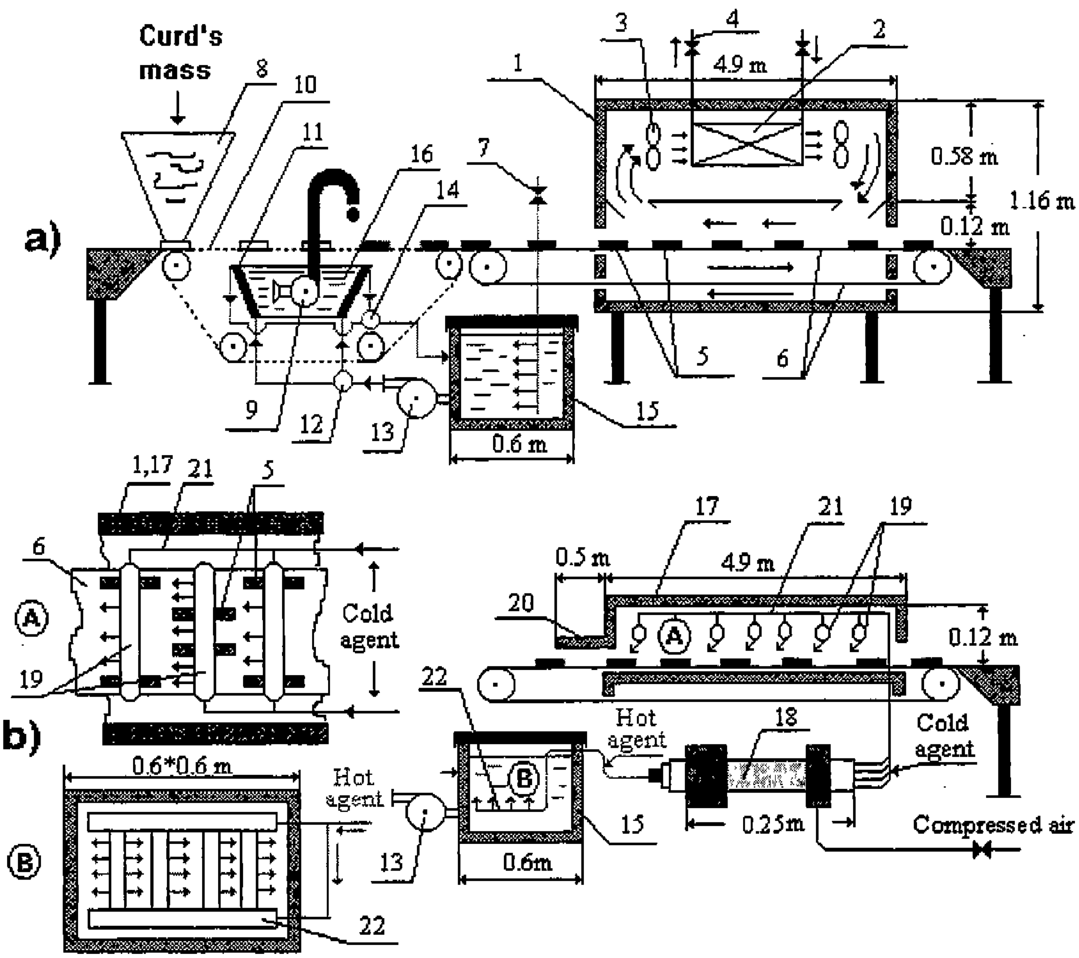

Fig. 2 Replacemant of cooling by brine of the glazed chocolate cottage cheeses and heating up of chocolate glaze by steam - a) for the systems with VGEDT with simultaneous generation of cold and heat-b)

In the cooler (1) the glazed cottage cheeses are cooled by air which is circulating along the circuit over the conveyer (6) with cottage cheeses (5) and the cooled evaporator (2) with brine blown over by fans (3). The surface of heat exchange of the evaporator is 25 m^2. For non-frosting surfaces of the evaporator the temperature of air blown over cottage cheeses before their outlet of cottage chamber is 3-5°C. To the outlet of cottage cheeses into the cooler after their glazing with a hot chocolate the temperature of air increases up to 10-12°C. 3-4 hours after continuous work of the line the evaporator is covered with rime with the thickness of 3-5 mm what decreases the rate of heat transfer by 50-60%. The temperature of air blown over cottage cheeses immediately increases after the evaporator up to 7-10°C. To the beginning of inlet of cottage cheeses into the chamber of cooler it reaches 12-15°C. Here, glaze on the cottage cheeses after their passing through the cooler remains soft. Rigidity of chocolate casing of cottage cheeses becomes insufficient. Casing automatic control machine begins to crumple cottage cheeses. They are necessary to be returned for a repeated formation and glazing. The line is necessary to be stopped for the evaporator to be defrosted. All these factors increase the cost price of the product. The designed value of its heating in the evaporator is 4°C, maximum cooling-down capacity is approximately 11 kW. 3-4 hours after continuous work of the line and frost-bitten of the evaporator this value decreases up to 4.5-5 kW. The installed capacity of electromotors of two fans (3) is 1.5 kW.

Vapour (7) under the pressure of 0.3-0.5 MPa through the bubblers heats the water in the vessel (15) - Fig. 2, a. The capacity of the vessel is 150 l. Water heated in the vessel at the temperature of 72-85°C with the help of the pump (13) through the collector (12) is transferred into the jackets (11) for chocolate glaze being heated up in the bath (16). Recycled water from the jackets (11) through the collector (14) is returned to the vessel (15). Cooling and heating system with VGEDT (Fig. 2, b) and their supply for cooling cottage cheeses with the help of the tubes-distributors (21) (fragment A) and water heating in the vessel (15) with the help of bubbler (fragment B) completely substitutes the energy carriers: brine, steam and electric energy used before on the line of cottage cheeses glazing. Here, the former volume of the cooler's chamber (17) decreased almost by a factor of 10. The mass of the cooler (1) decreased by a factor of 11. There was no necessity to use the evaporator (2) and fans (3). There was no problem of defrosting the evaporator as well as the removal of 150-200 liters of water after 3-4 hours of the line's operation. A cold agent after VGEDT (18) at the temperature of 5-9°C in the chamber decreased by a factor of 10 (17) with the help of 16 distributors (19) is blowing over cottage cheeses intensively (5) by a number of sprays with the velocity of 4-5 m/s coming in the opposite direction of the conveyer (6) - (fragment A, Fig. 2, b). A hot agent after VGEDT at the temperature of 85-95°C is supplied through the bubbler (22) the vessel (15) for water preheating (fragment B, Fig. 2, b) and its preheating up to the temperature of 60-70°C.

EXPERIMENTAL CHARACTERISTICS OF THE SYSTEMS

The system with VGEDT installed on the line of glazed cottage cheeses is operating at the plant in the range of pressures of the compressed air 0.57-073 MPa at the temperature of 20-25°C. The results of the experimental measurements of temperatures of cold and hot agents divided in VGEDT depending on the ratio of consumptions μ of a cold agent to the compressed air through VGEDT as well as to the temperature of the compressed air are presented in Fig. 3. The curves 1-5 are computer approximation of the experimental points: 1, 2 - temperatures of a hot agent at pressures of 0.7 and 0.6 MPa, correspondingly; 3 - the compressed air for both values of pressures; 4, 5 - for temperatures of a cold agent. As it is seen the temperature of a cold agent at small values of μ=0-0.4 laminates depending on the pressure of the compressed air (Fig. 3). At greater pressures in VGEDT the more deep dividing of the energy of the compressed air on the temperature. At μ>0.4 the influence of the pressure on the temperature of the agent is not practically observed. The same occurs for the temperatures of a hot agent. At small consumptions of a hot agent [(1-μ)- little] the temperature of a hot agent decreases with decreasing the pressure of the compressed air. At the temperature of the cold agent of 5-9°C necessary for cooling of cottage cheeses and its consumption $\mu\cong0.8$ the temperature of the hot agent changes from 76 to 95°C at the pressure of the compressed air of ≈0.7 MPa. With increasing the pressure up to 0.6 MPa its temperature will be ≈76-78°C. Thus, as to their values, the temperatures of both a cold agent and a hot one correspond to the temperatures necessary for cooling of cottage cheeses and preheating of chocolate glaze even at the pressure of the compressed air of more than 0.57 MPa. All experimental data of temperatures have been obtained with the help of platinum resistance thermometers.

It is seen, that with increasing the pressure of the compressed air through VGEDT from 0.6 to 0.7 MPa , both heating capacity (curves 1, 2) and cooling-down capacity (curves 3, 4) of the agents divided in it increase. The range of measurement of cooling-down capacity here for cooling cheeses at the temperatures of 5-9°C is indicated in 12-15.3 kW. One can see, that these values even for minimum values of the pressure of the compressed air 0.57 MPa are better than maximum values at brine cooling of cheeses. With due account of such important factors as that cooling-down capacity of the system with VGEDT does not depend on the duration of its operation (there is no frosting of heat exchange surface of multi-spray distributors), as well as the intensity of heat exchange with the help of 16-stage screen is more effective than with blowing over by fans at brine cooling, the system with VGEDT is turned to be more preferable for cooling cheeses. Heating capacity of a hot agent for chocolate glaze heating constitutes here 5.5-7 kW. This is more than enough for replacement of very expensive heating of water by vapour.

By the measured values of temperatures, pressures and consumptions for three constituent components of air in VGEDT have been determined experimental values of cooling-down and heating capacities for cooling and heating systems. The results of these measurements are presented in Fig. 4. Points designate the data of experimental measurements, curves 1-4 - the results of linear computer approximation of corresponding experimental data.

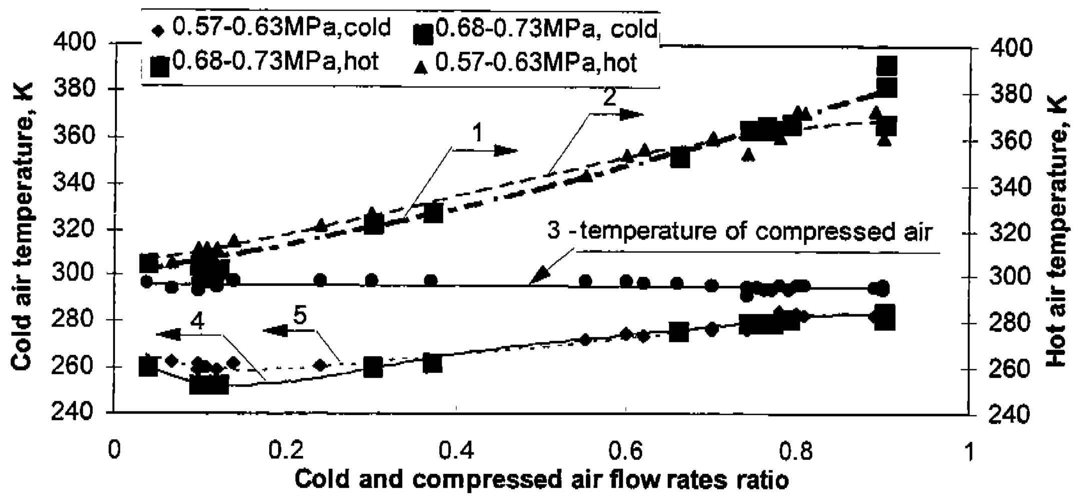

Fig. 3. Cold and hot air temperature as a function of cold and compressed air flow rates ratio

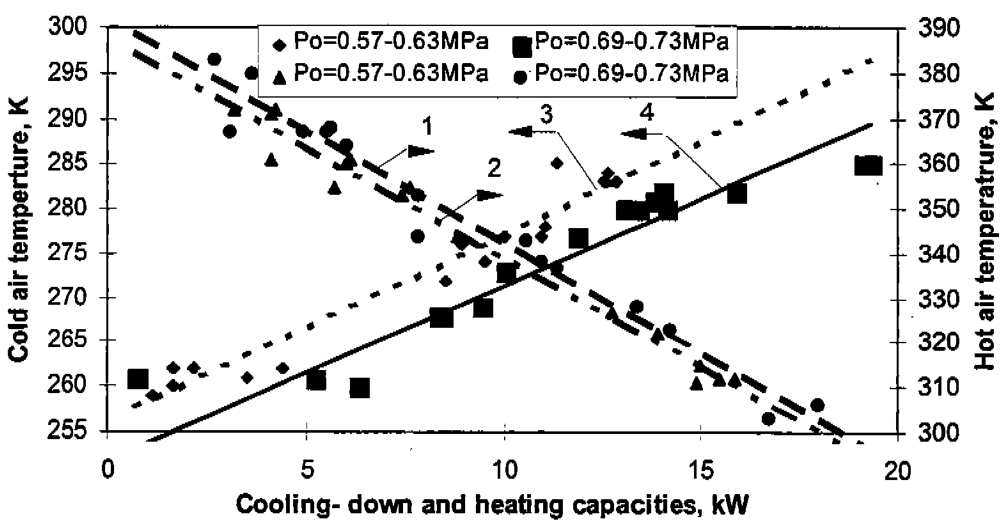

Fig. 4: Cooling-down and heating capacities versus cold and heat agents temperatures

CONCLUSION

At various using universal cooling-and heating systems with VGEDT, they have shown a good performance as ecologically and technologically safe non-inertia systems. The absence of frictionable and rotating details in the systems makes them be long-term and reliable in operation without frequent maintenance and repair to be done. At simultaneous generation of cold and heat by the systems there is no necessity in using expensive energy-and metal-intensive evaporators, fans, condensers and heaters for defrosting of evaporators of traditional ammonia and refrigerating machines as well as heaters, refrigerators and conditioners for heating liquids and gases. In many applications where local-distributed supply of cold and(or) heat to users is necessary the systems with VGEDT are non-alternative.

REFERENCES

1. Martynenko, V.L. Ganzha. Approach to the development and realization of energy saving program in BSSR. Coll. "Energy saving in BSSR economy". Minsk, 1989.
2. Merkulov. Vortical effect and its application in techniques. M., Mash., 1969.
3. Ranque. USA patent No 1952281, applied for Dec. 6, 1932, issued March 27, 1934.
4. Zaulichnyi. Friction, heat exchange and carry-over of the material in turbulent boundary layer of high enthalpy compressed gas. Coll.: HMT, Minsk, Vol. 1(1972).
5. Sivych, E.G. Zaulichnyi. Investigation of the turbulent boundary layers on a permeable rough surface with heat transfer. Proc. 6th Int. Heat Transfer Conf., Toronto, Canada, Vol. 2(1978).
6. Zaulichnyi, B.M. Melamed, A.D. Rychkov. Numerical investigation of two-phase polydisperse flows in axisymmetric Laval nozzles. 3-Multi Phase Flow and Heat Transfer Symp. - Workshop, Miami Beach, USA, Part B. Elsevier Sci. Publ. Amsterdam, 1984.
7. Zheltovodov, E.G. Zaulichnyi, V.M. Trofimov. Development of models for heat exchange in the conditions of supersonic separation of turbulent flows. J. Ap.Math.and Tech. Ph., 4(1990).
8. Chalatov. Theory and practice of twisted flows. Kiev, Naukova Dumka, 1980.
9. Kutateladze. Heat Transfer and Hydraulic Resistance. M., Energoizdat, 1990.
10. Volchkov, E.G. Zaulichnyi, S.S. Kutateladze. Blocking cooling at the supply of foreign gas into the turbulent boundary layer. J. Ap. Math. and Tech. Ph., 2(1967).
11. Volchkov. Near-wall gas screens. Novosibirsk, Nauka, 1983.
12. Zaulichnyi, A.P. Iakoushev. Development of effective vortical gas-energy distributing air tubes (VGEDT) and their application as a generator of cold and heat. Int. Conf. May 10-13, 1994, Hannover, Germany. IIR, France, Paris, 1994-1.