DESIGN AND INVESTIGATION OF ADSORPTION REFRIGERATIONUNIT

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المُستخلص:

هذه الورقة تتعامل مع مشكلة تطوير وتصميم وحدة تبريد امتزازي تعمل بزوج موائع تشغيل ماء –زيوليت لتوليد البرودة والسخونة معاً باستخدام مصدر طاقة حرارية دافعة وذلك بإشعال الغاز الطبيعي في النظام. الوحدة تتكون من عمود الامتزاز مملوء بالزيوليت، المبخر، المكثف، ومبادلات حرارية، ومروحة هواء ، وغرفة احتراق. نظام الإمتزاز موصل مع وحدة تكييف الهواء. هذا النظام قادر علي العمل كمضخة حرارية.

في هذا العمل، القياسات التي تم القيام بها لوصف تغييرات درجة الحرارة في الوحدة، معدلات سريان الماء في دورتي التبريد والتسخين، أيضاً تم وصف التغيير في طاقات التسخين، والتبريد ، والموقد.

أظهرت النتائج المعملية أنه من الممكن إمداد البرودة والحرارة باستمرار حيث ارتفع معامل أداء الوحدة إلي ما فوق 1.4من الطاقة الحرارية الخارجة ليقترب 2.5 kW.

ABSTRACT

This work deals with design of an adsorption refrigeration plant, working with zeolite-water pair for combined production of cold and heat using a source of driving thermal energy by burning natural gas into the system. The plant is consists of absorber bed filled with zeolite, the evaporator, the condenser, heat exchangers, the ventilator and the fire chamber. The adsorption system was connected to the air conditioning unit. The plant is capable to work as a heat pump.

In this work, measurements were made to describe the change of temperatures in plant, the rate of flow of water in heating and cooling cycles, also to describe the change in heating, cooling and burner powers.

The experimental results show that it is possible to supply cold and heat continuously. The coefficient of performance of the plant is raised above 1.4, the heating output power is raised near 2.5 kW.

Keywords:Adsorption refrigeration, Zeolite, Heat pump.

INTRODUCTION:

The expanding population, Severe ecological reasons (ozone layer depletion due to CFC's, global warming due to HFC's and CO_2 emissions), as well as economical reasons (cut of the electricity demand due to air conditioning in summer, energy deregulation and subsequent expansion of cogeneration), make heat-driven alternatives to vapor compression machines more and more attractive, provided they are environmentally friendly and energetically efficient. Also, the crisis of energy and increase in oil prices led to increased interest in heat pumps and energy storage, as well as technology using primary sources. Great effort is spent on their development and usage as a consequence of primary energy saving. The idea of an adsorption heat pump is particularly interesting in the possibility of combine heating and cooling with gas in primary energy use. In practice, adsorption heat pumps barely used for their low performance number. Therefore, the expert's interest in recent years has focused on the combination utilizing primary heat and adsorption unit. In this work it is shown that the combination of heating device with the adsorption heat pump can raise the overall efficiency of heating, while maintaining costs. High potential of flue gases waste heat at cogeneration, solar energy and electrical energy can be used as energy sources[1].

This work describes the possibility of using mineral zeolite to increase the efficiency of energy usage for heating and cooling by means of equipment with the possibility of using more efficient conversion of primary energy in heating, during which time is usage also the cooling generated during processes in plant.

OBJECTIVES:

In this work, the main objectives is to:

- Investigate or to explore possibilities for increasing energy effectiveness of adsorption plant for simultaneous heat and cold.
- Verify experimentally the function of the prototype of adsorption equipment with continuous source of heat and cold.

METHODOLOGY:

1.1 Theoretical adsorption cycle:

The main components of an adsorption refrigeration machine are the zeolite storage reservoir with integrated heat exchanger, the condenser, the evaporator and three valves as shown below in figure (1). The field of isosters in figure (2) is takes place for the theoretical adsorption cycle between values of saturation of zeolite between x = 5 to 21 %. From the actual diagram of zeolite Y, it possible to take all important parameters those are necessary to describe the sorption system of zeolite-water[2].

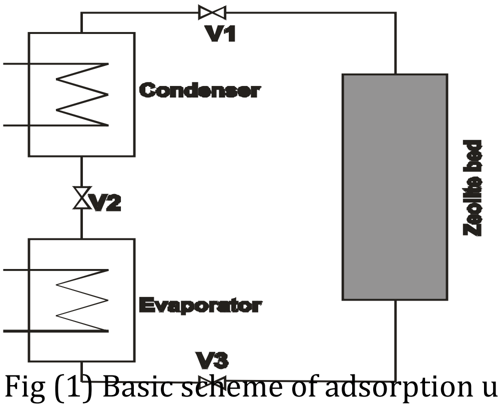


Fig (1) Basic scheme of adsorption unit

Conditions of system balance are specified from the following quantities:

- State of saturation of zeolite with water vapour (concentration "*x*").
- Partial pressure of water (*p*).
- Zeolite temperature (*T*).

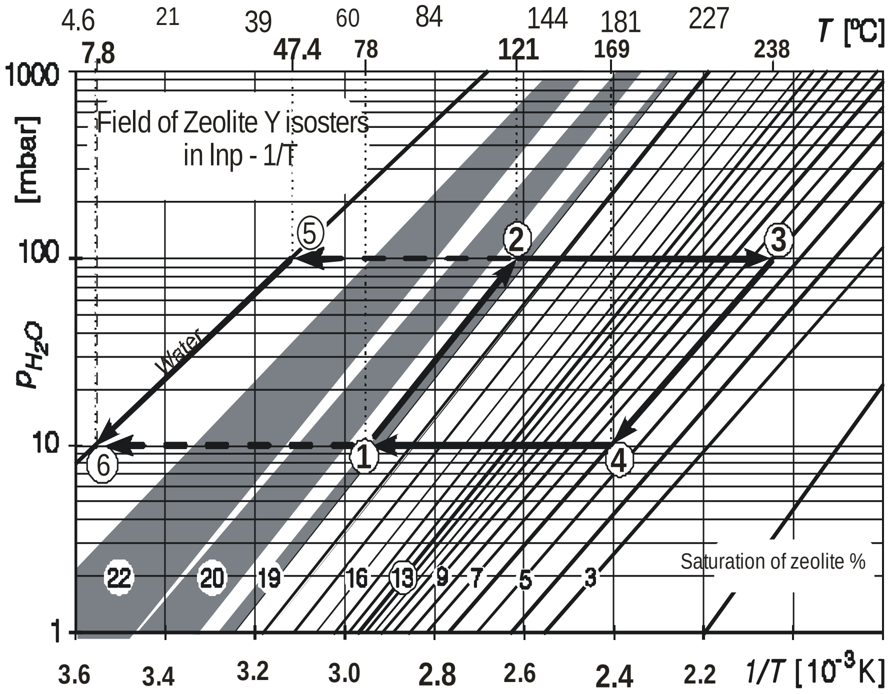


Fig (2) Field of zeolite Y isosters in Clapeyron diagram (lnp – 1/T)

The simplified calculations of energy flows for adsorption cycle with 1 kg of zeolite- Y are used values taken from the following table[3].

Table (1) Substance and process data.

Name	Symbol	Unit	Value
Specific heat capacity of zeolite Y	c_{zeo}	$(J/kg.K)$	1008
Thermal conductivity of zeolite	λ_{zeo}	$(W/m.K)$	0.105
Zeolite density	ρ_{zeo}	(kg/m^3)	700
Desorption factor	f_{des}	$(-)$	1.35
Latent heat of vaporization at 10°C	l_{v10}	(kJ/kg)	2501
Latent heat of vaporization at 100°C	l_{v100}	(kJ/kg)	2257
Specific heat capacity of water	c_{H_2O}	$(J/kg.K)$	4176
Adsorption capacity at desorbed state	x_{dil}	(kg/kg)	0.05
Adsorption capacity at adsorbed state	x_{conc}	(kg/kg)	0.21
Adsorption capacity difference between adsorption phase and desorption phase	Δx	(kg/kg)	0.16

$\Delta x = x_{conc} - x_{dil}$

Processes of Adsorption heating device are take place in the vacuum range between 1000 - 10 000 Pa in phases outlined on the diagram in figure(2). The processes involved are as follows [4]:

Isosteric heating (1-2): Zeolite in the initial state ***1*** and has a temperature 78 °C, the partial pressure of water vapour 1000 Pa and concentration x =21%. By closing valves V_1 and V_2 the zeolite storage will be heated to the 121°C. Concentration during the state change to ***2*** will be constant, the pressure was changed from 1000 Pa in state ***1*** to 10 000 Pa in the state ***2*** on isoster x = 21%. The heat flow to the zeolite bed will be:

$$q_{12} = c_{12} * \Delta T_{12} = \left(c_{zeo} + c_{H_2O} * x_{conc}\right) * \Delta T_{12}$$

(1.1)

$$=(1008+4176*0.21)*(121-78)=81.05\ \text{kJ/kg}$$

Desorption phase (2-3): The valve V$_1$ is open and the temperature of zeolite will rise to the 238 °C. The concentration of zeolite decreases to 5% because water vapour (at pressure 10000 Pa) flows to the condenser and condenses in the state ***5***. The valve V$_1$ then closed again. Zeolite at the same time receives heat, which is needed on rising temperature of zeolite and water. In addition, it is still needed heat on releasing water from zeolite. That is along the path (***2–3***) and released exactly 16%. The calculation is carried out into two steps as follows:

$$q_{23(1)}=c_{23}*\ \Delta T_{23}=\left(c_{zeo}+\frac{\Delta x}{2}*\ c_{H_2O}+x_{dil}*\ c_{H_2O}\right)*\ \Delta T_{23}$$

(1.2)

$$=(1008+0.08*4176+0.05*4176)*(238-121)=181.45\ \text{kJ/kg}$$

$$q_{23(2)}=f_{des}*\ l_{v100}*\ \Delta x \qquad (1.3)$$

$$=1.35*\ 2257*(0.21-0.05)=487.51\ \text{kJ/kg}$$

Condensation phase (5-6): Water vapour flowing in the desorption pressure 10 000 Pa and a temperature between 121 to 238 °C into the condenser and at point ***5*** transferred condensation heat.

$$q_{cond}=-l_{v100}*\Delta x \qquad (1.4)$$

$$= -2257 * (0.21 - 0.05) = -361.12 \ \text{kJ}/\text{kg}$$

Cooling phase (3-4): The zeolite is cooled to a temperature of 169 °C along isoster***3-4*** and the release of condensate and by opening valve V_2 the pressure in the zeolite reservoir decreases again to 1000 Pa (from point ***5*** to point ***6*** on the curve of water vapour – pressure). The concentration of water in the zeolite remains constant at x =5%. In the process, heat removed to conform to the total heat capacity and temperatures difference.

$$q_{34} = c_{34} * \Delta T_{34} = (c_{zeo} + c_{H_2O} * x_{dil}) * \Delta T_{34} \tag{1.5}$$

$$= (1008 + 4176 * \ 0.05) * (169 - 238) = -83.96 \ \text{kJ/kg}$$

$$q_{56} = c_{H_2O} * \Delta T_{56} \tag{1.6}$$

$$= 4176 * (47.4 - 7.8) = 165.37 \ \text{kJ/kg}$$

Adsorption phase (4-1): When closing the valve V_2 and opening valve V_3. Zeolite reservoir adsorbs water vapour at constant pressure of 1000 Pa from the evaporator (point ***6***). During this process the heat is released, therefore it is necessary to cool the zeolite bed so that, it is temperature not to rise up over 80 °C, when adsorption is slowing down till it stops, which is undesirable. The heat of phase change, which is needed for evaporation, is supplied from ambient to the evaporator. The corresponding released heat quantities are:

$$q_{41_{(1)}} = c_{41} * \Delta T_{41} = \left(c_{zeo} + \frac{\Delta x}{2} * c_{H_2O} + x_{dil} * c_{H_2O} \right) * \Delta T_{41}$$

(1.7)

$$= (1008 + 0.08 * 4176 + 0.05 * 4176) * (78 - 169) = -141.13 \text{ kJ/kg}$$

$$q_{41_{(2)}} = -f_{des} * l_{v10} * \Delta x \qquad (1.8)$$

$$= -1.35 * 2501 * (0.21 - 0.05) = -540.22 \text{ kJ/kg}$$

The heat of evaporation of water from ambient is:

$$q_{evap} = l_{v10} * \Delta x \qquad (1.9)$$

$$= 2501 * (0.21 - 0.05) = 400.16 \text{ kJ/kg}$$

In the sorption cycle, occurs three theoretical useful heat flows at different levels of temperature:

- Condensation heat at desorption.
- Zeolite heat removed at adsorption.
- Heat flows across the evaporator in the adsorption.

Temperature range required for desorption lies between 150 - 300 °C. The higher the resulting desorption temperature, the lower the saturation value of the zeolite, and the higher the possibility in the following adsorption to receive water.

1.2 Calculation of the system’s energy effectiveness (theoretical coefficients of performance):

Coefficients of performance are calculated for the whole working cycle with 1 kg of zeolite [5].Coefficient of performance in cooling phase can be calculated as:

$$COP_{cooling} = \frac{q_{evap}}{q_{12} + q_{23}}$$

(1.10)

$$= \frac{400.16}{81.05 + 181.45 + 487.51} = 0.53$$

Coefficient of performance in heating phase:

$$COP_{heating} = \frac{q_{34} + q_{41} + q_{cond}}{q_{12} + q_{23}}$$

(1.11)

$$= \frac{83.96 + 141.13 + 540.22 + 361.12}{81.05 + 181.45 + 487.51} = 1.50$$

If we take into consideration the operation of adsorption system by utilization of both energy flows–heats from heat exchanger in zeolite bed and cold from evaporator, the total plant COP can be calculated as:

$$COP = \frac{q_{evap} + q_{34} + q_{41} + q_{cond} + q_{56}}{q_{12} + q_{23}}$$

(1.12)

$$= \frac{400.16 + 83.96 + 141.13 + 540.22 + 361.12 + 165.37}{81.05 + 181.45 + 487.51} = 2.26$$

The values of calculated COP are theoretical values, because the real system operation includes a lot of energy losses as heat losses, friction losses of energy flows, throttling losses and others.

Design of the adsorption system for combined cold and heat production:

The aim of adsorption system design was the possibility of continual operation at simultaneous cold and heat generation. Due to discontinual adsorption process, it is necessary to provide during the regeneration of zeolite bed necessary amount of cold for continuous operation. For this reason was designed evaporator with possibility of cold accumulation into ice providing of cold flow during desorption phase, as it is shown in Fig(3). In the time of zeolite desorption the evaporator is separated from adsorber bed by pressure valve and desorbed water vapour cannot flow to evaporator after condensing in condenser. After finishing of desorption the water condensate flows back into evaporator and new cycle will restore the ice store. By this way the discontinuity of the cooling process can be removed.

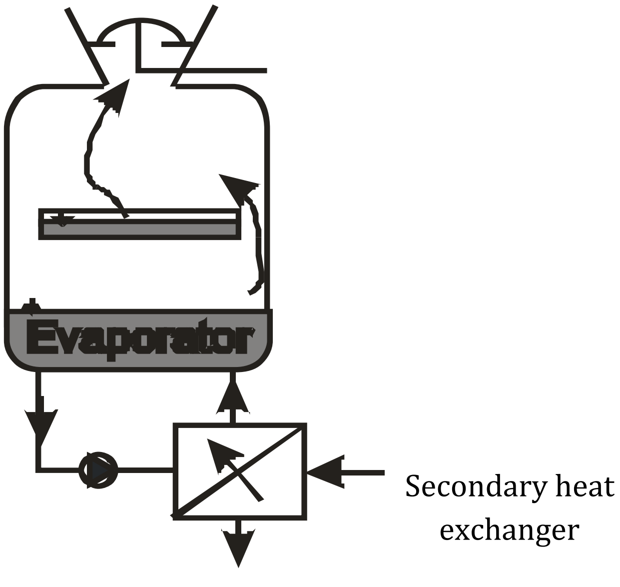
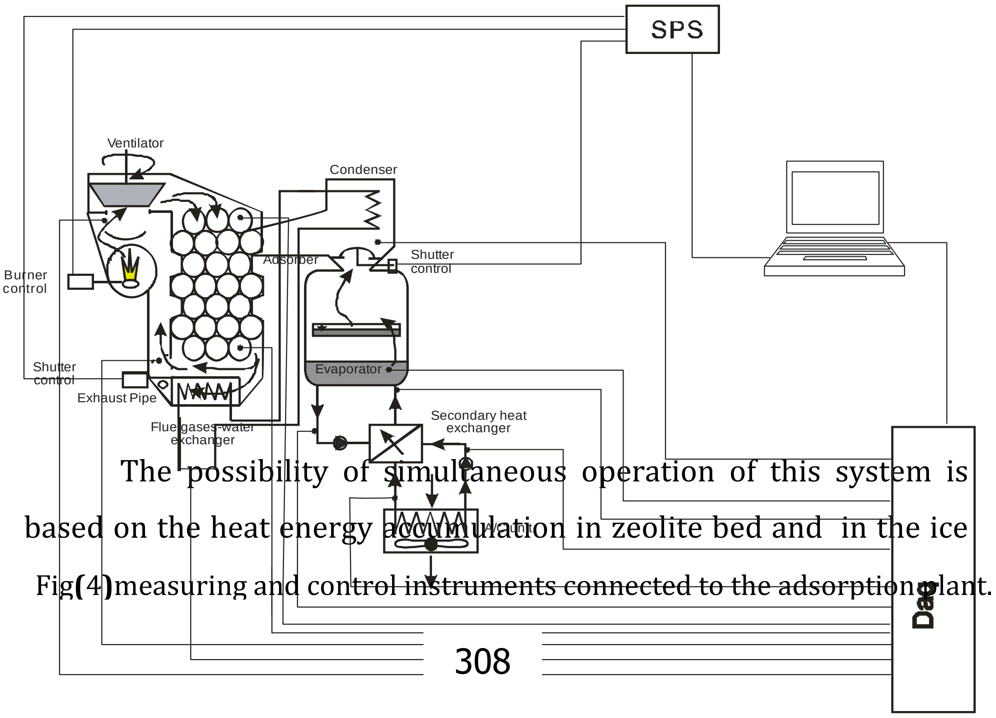


Fig (3) the evaporator and ice tank

The total arrangement of the proposed system for continuous operation at simultaneous cold and heat generation is shown on the Fig(3). The main two separated parts of the system are zeolite bed with combustion chamber and condenser with evaporator. High temperature combustion products flow by ventilator in the space of zeolite bed and then back in the mixed chamber, where they are mixed with fresh combustion products. Before the combustion products go to the exhaust they flow through cooler to heat water for heating circuit. The same cooler is used after finishing of desorption for cooling of zeolite to achieve of working temperature. It is necessary to use the flap valve for switching-over from the phase of desorption heating to adsorption cooling. It enables combustion products flow from the adsorber directly to mixing chamber and by ventilator back to absorber or from adsorber through combustion products – water heat exchanger by ventilator back to the adsorber for his cooling during adsorption.



Fig(4)measuring and control instruments connected to the adsorption plant.

The possibility of simultaneous operation of this system is based on the heat energy accumulation in zeolite bed and in the ice store in the evaporator. It enables cooling process also during desorption, and heating process also during adsorption when the burner does not work and the heat is gained from adsorber bed.

EVALUATION OF THE EXPERIMENTAL INVESTIGATION:

The investigation were done on the pilot plant which have been manufactured on the base of natural gas as primary energy source by using of Y-zeolite with the gas burner output of 15 kW. The values of outputs in following figures are average values from the whole cycle times.

In Fig(5) are shown the values of system heat and refrigerating output and the burner output in dependence on the value of cycle time. Heat and burner output decreases with the increase of cycle time due the fact, that the time of gas burning remains during the various cycles constant. The refrigerating output is for various cycle times approximately constant, because the adsorption process is stronger at the cycle beginning and the adsorption intensity decreases during adsorption cycle only temperately.

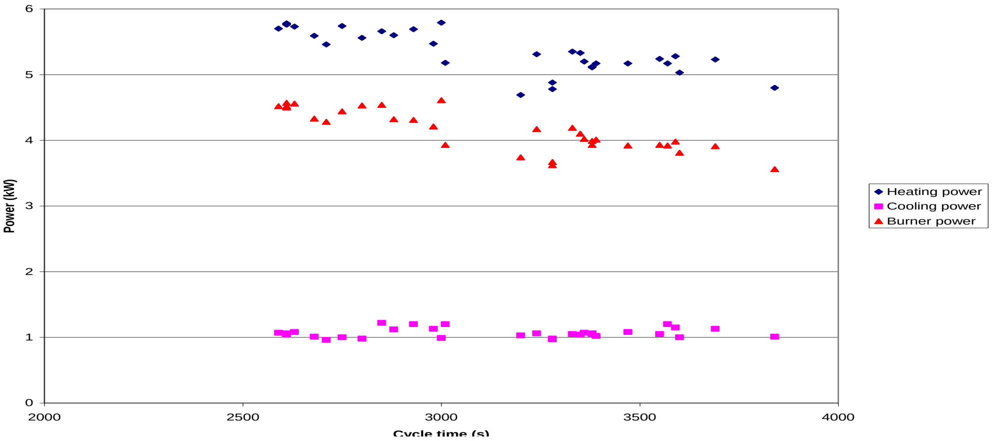
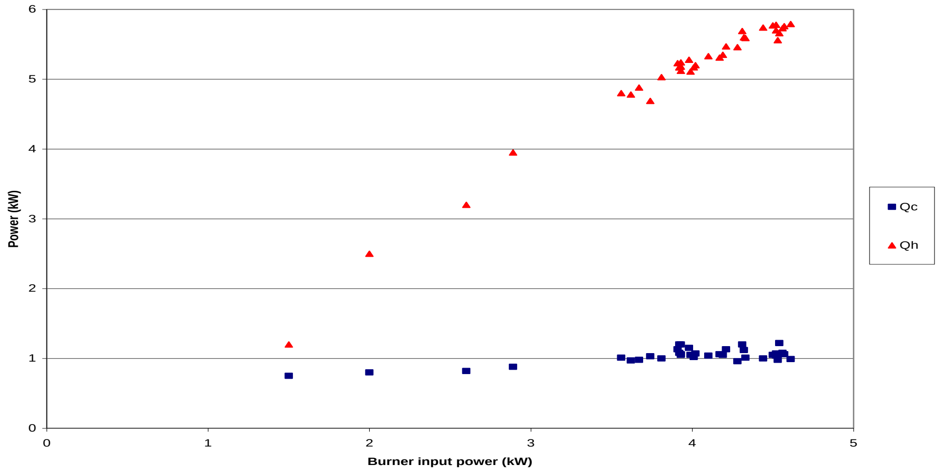


Fig (5) Dependency of plant power's on the cycle time.

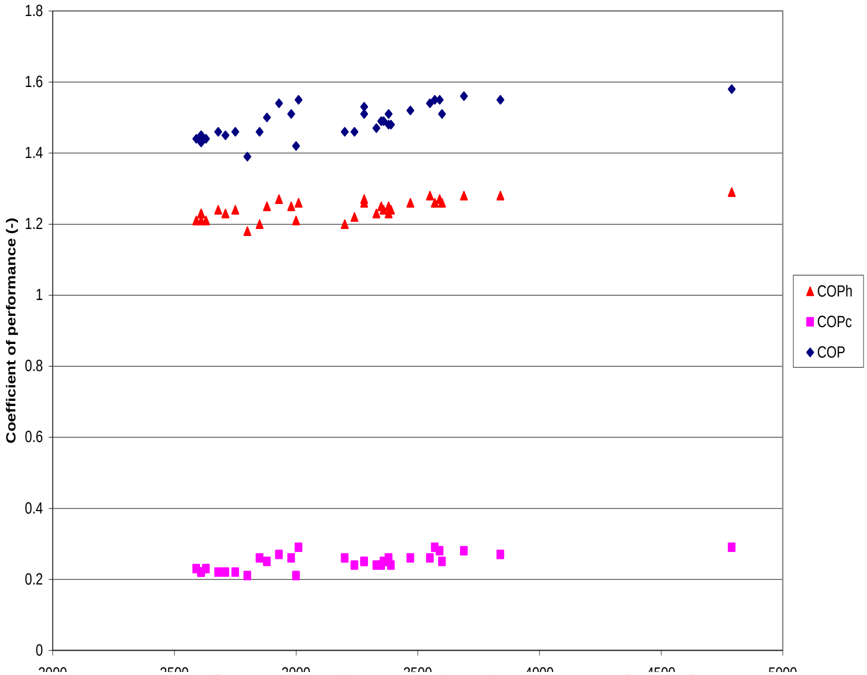
The dependence of system heat and refrigerating outputs on the burner output is shown in the Figure 6. At the cycle beginning the burner output is spent to the heat of the material matter (till about 1,1 kW of burner output). The temperate increasing of refrigerating output with the burner output can be seen till about burner output 3 kW, then refrigerating output rises in minimal values or remains approximately constant because the first phase of desorption heat needs the lower amount of energy then second, which is important for increasing of zeolite free capacity and consequently also refrigerating output increasing.



Burner output power(kW)

Fig (6) Dependency of the plant power to the burner output power.

The dependence of coefficient of performance on the cycle time is shown in Figure 7. The values of COP with cycle times rise and reach maximum values for total plant COP of about 1.6.



Fig(7) Dependence of coefficients of performance on the cycle time

CONCLUSIONS

The principles of adsorption refrigerating cycle operation were used for development and design of energy system for combined heat and cold generation on the base of adsorption refrigerating plant utilized the natural gas as primary source of energy. The problem of discontinual processes in the adsorption refrigerating cycle was solved by heat accumulation in the zeolite bed and cold accumulation to the ice in the evaporator. Developed system works in continuous operation in simultaneous cold and heat generation, then it realizes simultaneous function of refrigerating and heat pump system.

Measurements on the realized prototype of this system show the possible utilization for water heating to about 55^0C and for water cooling to about 0^0C at sufficiently higher effectiveness in comparison with cold or heat generation in separate production in conventional adsorption refrigerating or heat pump systems. Proposed energy system is suitable for heating purposes with surface heating systems and for air-conditioning in industry or residential buildings.

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