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Some Ecological and Economic Aspects of the Use of Sorption Heat Facilities in Russia

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Abstract

Ecological and economic aspects of the use of sorption heat facilities (refrigerators and thermal pumps) under the conditions existing in Russia are considered, along with their competitiveness in comparison with traditional systems. It is shown that sorption refrigerators are preferable in comparison with compression ones if waste heat (or solar energy) is used. If regeneration is carried out by burning natural gas, sorption devices can be more ecologically pure only in exclusive cases, so, in order to decrease emissions of greenhouse gases, is it reasonable to develop compression devices with high coefficient of performance ($COP \geq 4$). Sorption heat pumps with the coefficient of amplification $COA > 1$ are ecologically safer and economically more efficient that gas heaters. In the case of $COA_{abs} = 1.7$, consumption of natural gas decreases by 41 %; for $COA_{abs} = 1.5$ – by 33 %, which means substantial practical interest. Analysis may be useful either for the determination of the promising character of various sorption devices followed by elaboration of the corresponding technical policy or for choosing the economic parameters affecting the competitiveness of technologies, including those for separate regions of Russia.

INTRODUCTION

At present, the world community not only discusses but also realizes the measures aimed at stabilization and decrease in the emission of the so-called greenhouse gases (GG) that can cause substantial changes of the Earth's climate. These measures involve control of GG emission, establishment of emission taxes and pollution quotas. It is important to stress that the choice of measures determines not only ecological and economic consequences but also can stimulate the development and application of a technology. Thus, essential restrictions have already been introduced to achieve radical decrease in the emission of Freon compounds, which results in actual motivation for rejection of the use of Freon compounds in cooling systems. On the one hand, this stimulates the development of compressor refrigerating devices (CRD) which utilize natural working bodies. On the other hand, a niche opens for the application of sorption refrigerating devices (SRD) which can play an important part in decreasing the emission of GG. Potentially, SRD can replace Freon refrigerators that contribute into GG emission, both due to the direct emission of Freon compounds and due to the consumption of electricity, the production of which is accompanied by essential CO_2 emission. Enormous potential also is characteristic of sorption heat pumps (SHP) which are able to provide substantial economy of fuel and to decrease GG emission by tens per cent. A comparative analysis of compression and absorption heat pumps was carried out by the authors of [1]; however, they did not consider ecological aspects.

In the present work, ecological and economic aspects of the use of sorption heat devices (SRD and SHP) in comparison with the traditional systems of heating and cooling are considered.

ANALYSIS AND RESULTS

Cooling systems

At present, the only measure controlling GG emissions for the cooling systems is restriction with respect to Freon compounds. Energy consumption, which is directly connected with CO_2 emission, is not regulated. This stimulates the development of any cooling systems except those involving Freon, independently of their contribution into the emissions of other GG. In particular, this promotes the development of sorption systems which involve neither Freon nor electric energy but may use the heat of natural gas burning at the stage of regeneration. It is evident that a decrease in Freon emission does not mean automatic decrease in GG emission.

Following the methodology described in [2], let us analyze the conditions which are necessary for the creation of SRD ecologically purer than CRD in Russia. The analysis is based on the simplified approach and involves such generalized parameters as total (annual) energy consumption, mean efficiency of a device, average price of energy, *etc*.

For refrigerator devices, two kinds of GG emission exist: direct emission due to Freon compounds, and indirect emission due to energy consumption. In order to measure total GG emission, one used the annual TEWI (Total Environmental Warming Impact) which can be determined as follows [2]:

$$E = M \cdot \mathrm{GWP} \cdot \tau + WA \qquad (1)$$

where M is the mass of the working liquid (refrigerant), kg; GWP is Global Warming Potential, kg CO_2/kg of the working liquid; τ is annual loss (leakage) of the workling liquid, mass concentration; W is annual energy consumption, kW h; A is the mass of CO_2 produced per 1 kW h of energy consumed by the device, kg CO_2/(kW h).

Let us now compare emissions for SRD (2) and CRD (3):

$$E_{\mathrm{abs}} = \frac{Q_0}{\mathrm{COP}_{\mathrm{abs}}\eta_{\mathrm{b}}} A_{\mathrm{abs}} \qquad (2)$$

$$E_{\mathrm{comp}} = \frac{Q_0}{\mathrm{COP}_{\mathrm{comp}}} A_{\mathrm{el}} + M \cdot \mathrm{GWP} \cdot \tau \qquad (3)$$

where Q_0 is average annual cooling load, kW h; COP is coefficient of performance; η_b is the efficiency of heat production in combustion chamber (for SRD with natural gas combustion); A_{abs} depends on the kind of input energy: $A_{abs} = A_{N.G.}$, that is, the amount of CO_2 produced per 1 kW h of heat obtained by natural gas combustion ($A_{abs} = 0$ when thermal waste is used). The cooling load Q_0 and the mass of working liquid M are proportional to the cooling power P_0: $Q_0 = HP_0$ and $M = mP_0$, where H is the yearly number of working hours recalculated to the total power, and m is the mass of working liquid required for producing 1 kW of cooling power, kg.

Let us consider two cases with natural gas and thermal waste (solar energy) used as energy source for regeneration.

Sorption type cooling devices using natural gas

Combining equations (2) and (3) gives an equation for a relative decrease in GG emission e obtained by using this kind of SRD:

$$\varepsilon = \frac{E_{\mathrm{comp}} - E_{\mathrm{abs}}}{E_{\mathrm{abs}}} \beta\eta_{\mathrm{b}} \frac{A_{\mathrm{el}}}{A_{\mathrm{N.G.}}} - 1 + \frac{m}{H}\frac{GWP\,\tau}{A_{\mathrm{N.G.}}} \mathrm{COP}_{\mathrm{abs}}\eta_{\mathrm{b}} \qquad (4)$$

where $\beta = \mathrm{COP}_{abs}/\mathrm{COP}_{comp}$. The negative value of e means that SRD with natural gas heating is ecologically cleaner than CRD. Direct emission of freons may be neglected, and eq. (4) is simplified to $\varepsilon \approx \beta\eta_b(A_{el}/A_{N.G.}) - 1$. Hence $\varepsilon > 1$ if

$$A_{el}/A_{N.G.} > 2/(\beta\eta_b) \qquad (5)$$

From eq. (4) it can be seen that e depends not only on the characteristics of the device (COP, GWP, τ, m), but also on the operating time H and on the electric power generation mode A_{el}.

Let us compare SRD based on the LiBr–H_2O working pair with regeneration via natural gas combustion ($A_{N.G.} = 0.2$ kg of CO_2/(kW h), $\eta_b = 0.85$) currently having the highest efficiency ($\mathrm{COP}_{abs} = 1.2$) with electric CRD. Analysis was performed with the assumption that $H = 1000$ h/yr and $A_{el} = 0.65$ kg of CO_2 (kW h) (this roughly corresponds to Russian standards). It appeared that even this effective SRD is ecologically cleaner ($\varepsilon > 0$) only if compared with moderately effective CRD (whose $COP_{comp} \leq 3$) using "dirty" freon R-404a (GWP = 3800). This means that the given SRD mostly deteriorates the ecological situation because of additional release of GG (primarily, CO_2) due to the relatively low COP of the SRD. The use of electric power generated at atomic or hydroelectric power stations ($A_{el} << 0.65$ kg of CO_2/(kW h) could make CRD even more ecologically advantageous. Thus to reduce GG release it is reasonable to develop effective CRD with high COP but not SRD, operating on natural gas.

A similar approach may be used to analyze the total annual expenses C for the production of cold (in roubles) for both technologies. For SRD based on natural gas

$$C_{abs} = \frac{Q_0}{COP_{abs}\eta_b} k_{N.G.} \tag{6}$$

while for CRD with electric drive

$$C_{comp} = \frac{Q_0}{COP_{comp}} k_{el} \tag{7}$$

where k_{el} and $k_{N.G.}$ are the costs of 1 kW h of electric energy and heat obtained by burning natural gas, respectively. Then, the annual savings are

$$S = C_{comp} - C_{abs} = \frac{Q_0}{COP_{comp}}\left(k_{el} - \frac{k_{N.G.}}{\beta\eta_b}\right) \tag{8}$$

The sorption devices will be more economical than the compression ones if $S > 0$, or

$$\frac{k_{el}}{k_{N.G.}} > \frac{1}{\beta\eta_b} \tag{9}$$

Assuming $\eta = 0.85$ and $\beta = 0.35$, the $k_{el}/k_{N.G.}$ ratio should be more than 3.36. According to the prices for June 2003 in Russia, this ratio is equal to 6.65, which makes SRD economically profitable. Even with more dynamic increase in the price of gas compared to the electric energy, this situation is likely to be conserved for rather long time, which stimulates more rapid development of SRD in Russia.

Comparing equations (5) and (10) for $k_{el}/k_{N.G.} > 1/\beta\eta_b > A_{el}/A_{N.G.}$ we conclude that sorption devices are economically sound though they give higher GG emissions than compression devices; this situation occurs in Russia with the price pattern of today. For the price politics of the state to take into account equally the economic and ecological constituents, it is necessary to maintain the ratios $k_{el}/k_{N.G.} = A_{el}/A_{N.G.}$.

Sorption refrigerating devices with regeneration from heat emission or from solar energy

Such a device is always ecologically safe, since it does not emit GG. Then, a decrease in CO_2 emission will be precisely equal to the emission for the case of CRD; annual saving is calculated using eq. (8) with $k_{N.G.} = 0$. For a more detailed analysis, it is necessary to take into account the energy consumed for the creation of SRD itself.

In the practical aspect, in order to realize this kind of SRD, it is necessary to decrease regeneration temperature to T_r = 80–130 °C, which will allow using low-temperature heat emission of industry, as well as solar heat obtained with the help of cheap flat receivers. It should be noted that the new composite sorbents of water described in [3–5], the so-called selective water sorbents, or SWS, allow achieving COP ≈ 0.6 for T_p = 80–85 °C [6, 7].

Thus it may be concluded that for feeding from natural gas SRD may be ecologically more pure than CRD only in exclusive cases, while for the use of waste heat or solar energy they are always ecologically more sound.

Heating systems (sorption thermal pumps)

Let us compare CO_2 emission for STP (10) and gas heater (GH) (11):

$$E_{abs} = \frac{Q_h}{COA_{abs}\eta_b} A_{N.G.} \tag{10}$$

$$E_{burn} = \frac{Q_h}{\eta_b} A_{N.G.} \tag{11}$$

where Q_h is annual heat evolution, COA_{abs} is the coefficient of amplification of SHP (COP of heating). Assuming the source of primary energy to be the same, we may write down a decrease in emission:

$$\varepsilon = \frac{E_{burn} - E_{abs}}{E_{burn}} = 1 - \frac{1}{COA_{abs}} \quad (12)$$

If COA > 1, we always obtain a decrease in emission. This decrease can be very important because it allows one to decrease the consumption of natural gas by 41 % for COA_{abs} = 1.7 and by 33 % for COA_{abs} = 1.5. Let us remind once more that a more detailed analysis requires taking into account CO_2 emission when manufacturing a device.

The main problem of sorption technology is the necessity to use an external heat source for the evaporator. However, under the conditions existing in Russia, the situation seems rather favourable, because geothermal water with a temperature of 30 °C or higher can be used for these purposes over vast territories (in particular, in West Siberia).

Calculating the cost of energy consumed by SHP (13) and GH (14) we obtain:

$$C_{abs} = \frac{Q_h}{COA_{abs}\eta_b} k_{N.G.} \quad (13)$$

$$C_{burn} = \frac{Q_h}{\eta_b} k_{N.G.} \quad (14)$$

The portion of cost saving is

$$\gamma = \frac{C_{burn} - C_{abs}}{C_{burn}} = 1 - \frac{1}{COA_{abs}} = \varepsilon \quad (15)$$

So, for COA > 1 the sorption heat pumps are ecologically more sound and economically more profitable than gas heaters. The situation in Russia could even more improve if the quotas for GG emission saving were introduced. This would allow one at first to increase the price of SHP in order to make it more competitive in comparison with GH, and to direct these funds to the organization of a large production of cheap SHP.

As these sorption devices, one may use absorption systems based on LiBr–H_2O pair with COA_{abs} = 1.7 (41 % energy saving) or adsorption heat pumps based on zeolite – water pair with two adsorbers, which may theoretically give COA_{abs} ~ 1.7 for regeneration temperature below 130 °C [3, 5]. Such a solution allows us, on the one hand, to use low-potential heat for regeneration (waste heat, solar energy), on the other hand, to use water instead of oil as a heat carrier.

CONCLUSIONS

The analysis carried out in this work may be useful for estimating the promising character of the use of sorption heat devices for cooling and heating, elaboration of effective technical policy and choice of economic parameters affecting the competitiveness of technologies, including those within the separate regions of Russia. The proposed solutions will allow us to decrease the amount of consumed fuel and energy consumption of the income, which falls within the course of the Energy Strategy accepted by the Government of RF for the period up to 2020. This will allow additional increase in the actual gross domestic product and mass consumption.

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