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ECOLOGICAL SAFETY OF NATURAL REFRIGERANTS IN DOMESTIC REFRIGERATING EQUIPMENT. ILLUSIONS AND REALITY

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ABSTRACT

This paper reveals that it is insufficient from the point of view of ecological safety to base the ecological evaluation of the perspectives of applying the new refrigerants upon the value of cooling capacity or coefficient of performance. Within the framework of solving the problem of reducing the greenhouse gases escape it is recommended to utilize the method of ecology-energetical analysis when choosing the refrigerants and comparing different types of the refrigerating equipment. For this purpose, it is suggested further developing the methods of the TEWI (Total Equivalent Warming Impact) analysis, in which it is taken into account the additional emission of carbon dioxide connected with the energy consumption of manufacturing the refrigerating equipment and its operation. The TEWI structure is analyzed taking into consideration all the energy consumption connected with the production of cold. It is proved that the energy consumption connected with manufacturing the domestic refrigerator contributes considerably to the TEWI value. For evaluating the perspectives of the new refrigerants utilization and the ecological examination of various devices of the refrigerating equipment, it is recommended to use the specific reduced Tewi values.

INTRODUCTION

The progress of sciences, which has shaped the modern civilization, affects the ecological situation on the Earth greatly. Barbaric exploitation of natural energy resources and unlimited contamination of the atmosphere with the harmful substances make the humanity solve the Global ecological problems. The consequences of some anthropogenic influence on the biosphere are noticeable now. For instance, increasing concentration of chlorine containing substances in the stratosphere has lead to the considerable depletion of the ozone layer. The growth of the carbon dioxide, methane, nitric oxides concentration in the atmosphere contributes to the Global Warming Impact considerably.

These complicated Global ecological problems can be solved only on the basis of the effective international collaboration. Signing the Montreal Protocol by many countries and the decrees about the restriction on throwing the greenhouse gases lately adopted at the conference in Kyoto (Japan), are the positive examples of such collaboration. Above-mentioned documents determine at considerable extent the main tendencies in the technological development of refrigeration engineering.

Total value of energy, consumed by the refrigerating plants in highly-developed countries is considerable. For instance, Italy takes 5% of Total energy consumption [1] only for storing foods. Taking into account the condition systems and industrial refrigerating systems the volume of consumed energy may reach 20% of Total electric energy production [2]. That's why, at present it has become absolutely obvious that the utilization of energetically efficient working fluids in the refrigerating equipment is one of the means, favoring to keeping the Earth climate. Just for these reasons some industrial countries are adopting the new standards on refrigerating equipment, stipulating for reduction of the annual energy consumption level. It is obvious that the documents adopted at the conference in Kyoto, will initiate the acceptance of international programs on the energy resources keeping.

Ecology-Energetical Analysis Of Refrigerating Equipment Efficiency

Today it is getting obvious, that the traditional evaluation of the perspectives of utilizing some type of refrigerating equipment according to such characteristics as cooling capacity, coefficient of performance, energy efficiency class is insufficient from the ecological point of view. That is why it is necessary to take the IIR

(International Institute of Refrigeration) recommendations as to the opportunity of applying the new TEWI criteria as up-to-date [3, 4]. Methodology proposed in early 90-ties by the AFEAS (Alternative Flyorocarbon Environmental Acceptability Study) members recommends to calculate the TEWI on the formula [5]:

$$TEWI_N = GWP \cdot L \cdot N + GWP \cdot m \cdot (1-\alpha) + GWP_{fa} \cdot M + \beta \cdot E \cdot N \quad (1)$$

where $TEWI_N$ - TEWI value for the time of system operating; GWP and GWP_{fa} - Global Warming Potentials of the refrigerant and foaming agent; L - refrigerant leakage, kg/year; N - system operating time; m - refrigerant charge in the unit of product, kg; α -utilized refrigerant fraction; β - CO_2 emission per kW·h, (CO_2)kg/kW·h; E - energy consumption for the equipment exploitation, kW·h per year.

Suggested methods of $TEWI_N$ calculation may be hardly taken as sufficient when solving the problem of ecologically based choice of alternative refrigerants. Indeed, the formula (1) omits energy expense on the refrigerating equipment working-out, producing separate details and junctions of the refrigerator, providing for the fire safety and etc., i.e. not all the energy expense is taken into account within the framework of realization of the so called "additional loop" (ISO-9001-87).

That is why the conclusion about the perspectives of this or that refrigerant or refrigerating equipment, obtained by means of thermodynamic analysis and by means of the formula (1) for domestic cooling appliances will be practically identical [6].

There are flammable substances R152a, R32, R142b, R290, R600, R717 and etc. among the alternative refrigerants offered by market. In some cases, even multicomponent refrigerants, containing these substances, and ensuring the high energy efficiency of the equipment are characterized with the high level of the flammability. In this situation the question about the influence of flammability, on the one hand, and the high energy efficiency of the refrigerating machine, on the other hand, on the cost of refrigerating plant is becoming principal. For instance, in the paper [7] it was marked that 5% reduction of the cost of the refrigerating system exploitation due to higher efficiency of the cycle in R290 did not compensate 30% increase in the expense on the firesafety means providing.

As it was shown by the studies carried out lately [8] the energy component in the cost price of the details and junctions of the domestic refrigerator is high enough to be taken into consideration when $TEWI_N$ calculating. So, the realization of the measures providing fire-explosion safety is not only technological problem, but has clearly expressed ecological aspect which is connected with both additional contamination of environment and the effect, the radiation activity carbon dioxide emitted during electricity production has on the atmosphere.

The necessity of working out quite a simple methodology of ecology-energetical analysis of the new generation refrigerating equipment has appeared due to some circumstances. Firstly, direct contribution of the halocarbons to the process of Global Warming is too considerable [9]. Secondly, considerable quantity of energy is spent in the process of the cold production. And, at last, development and realization of the national programs of energy resources saving will, for sure, follow the adopted in Kyoto decrees concerning the restriction of the greenhouse gase ejections into the atmosphere. For the first time in the mankind history the technological progress in the refrigeration engineering is realized under the ecological mottoes of saving the ozone layer and reduction ejecting the refrigerants having the high value of the GWP.

From the point of view of the mankind in general, the sum of energy expenses during the working out, production of the given refrigerating system and its whole-term exploitation may be adopted as a functional, reflecting a whole variety of factors determining the ecological properties of the system. It is easy to transfer the obtained sum of energy of consumption into the ecological criteria TEWI using the formula:

$$TEWI_N = GWP_R \cdot L \cdot N + GWP_R \cdot m \cdot (1-\alpha) + GWP_{fa} \cdot M + \beta \cdot E \cdot N + \sum_{i=1}^{n} \beta \cdot E_i , \quad (2)$$

where E_i - additional energy spending on manufacturing the i-th element of the refrigerating system and technical service of the refrigerating plant.

When calculating $TEWI_N$ it is necessary to take into account the possible energy consumption, connected with the construction of separate premises and installation of the equipment , providing ecological and toxicological safety when operating the refrigerating equipment. That is why it is reasonable to present the last term of the formula (2) as the sum of two terms:

$$\sum_{i=1}^{n} \beta \cdot E_i = \sum_{i=1}^{n} \beta \cdot E_i' + \sum_{i=1}^{n} \frac{M_i}{\alpha} \beta , \tag{3}$$

where E_i'- energy consumption, connected with manufacturing the refrigerating equipment; M_i - cost price of the premises, base, transportation, assembling, providing the fire safety measures, etc. α - tariff cost of electric power.

There is no need for special premises and specific conditions to ensure firesafety for domestic refrigerators. That is why the second item may not be considered when carrying out the analysis. Thus the first item of the formula (3) includes the energy consumption connected with manufacturing the refrigeration equipment, which is the indirect contribution into TEW_N. The second one is the indirect contribution in $TEWI_N$ of the energy consumption connected with the conditions of operating the refrigerating plant. Therefore, when carrying out the ecology-energetical analysis of refrigerating equipment of any kind, the $TEWI_N$ calculation should be performed by the formula:

$$TEWI_N = GWP_R \cdot L \cdot N + GWP_R \cdot m(1-\alpha) + GWP_{BA} \cdot M + \beta \cdot E \cdot N + \sum_{i=1}^{n} \beta \cdot E_i^! + \sum_{i=1}^{n} \frac{M_i}{\alpha} \beta . \tag{4}$$

The $TEWI_N$ criterion, calculated by the formula (4) take into account practically all the spectrum of energy consumption connected with the cold production. However, it has an absolute value and, thus, does not useful enough for the analysis and comparing the two different types of the refrigerating system, using refrigerant of some kind.

The reduced $\overline{TEWI}$ value may be considered as the criterion of the degree of the ecological purity for comparing the domestic refrigerating apparatuses:

$$\overline{TEWI} = TEWI_N / TEWI_E , \tag{5}$$

where $TEWI_E$ - indirect contribution in the $TEWI_N$ of the energy expenses for domestic refrigerator exploitation, in which one uses some refrigerant ought to be compared (for instance, R600a).

When carrying out the analysis of the economical efficiency of the refrigerating machines the specific reduced expenses – i.e. the ones, related to the cold produced during a year [10], are applied too widely. The analogous approach may be also spread on the $TEWI_N$ function, from the formula (4). In this case, when comparing the ecological qualities of the domestic refrigerating apparatuses of different capacities and constructions, working at any temperature regimes, using different refrigerants, it is possible to consider the ratio of the $TEWI_N$, value and the quantity of cold worked out per (definite period of time τ) as an integral criteria:

$$Tewi = TEWI_N / (Q_0 \cdot \beta \cdot \tau) . \tag{6}$$

where Q_0 - cool capacity, kW.

It should be underlined that the Tewi coefficient may be used as an integral criterion of optimization (the goal function) in the tasks of choosing the composition of polycomponent working fluid of the refrigerating plant. Varying the components concentration of the mixture and solving the task of minimizing the Tewi function it is possible to choose the optimal, from the point of view of ecology, composition of the working fluid. The methods of vector optimization may be recommended as the mathematical apparatus for solving the given task. The efficiency of applying these methods is demonstrated in the paper [11].

For solving the tasks of refrigerating system optimization, various criteria of optimization (the goal function) are used. Coefficient of performance (energy optimization) reduced undimensioned expenses or cost function [7] (economical optimization), or any reduced vector criteria [11] may be used as the goal function. However, unlike the Tewi these criteria do not reflect the antropogenic influence on the Earth climate, which the refrigerating equipment caused.

Quite opposite the Tewi criterion combines optimally the ecological aspects, economical factors and the energy consumption. There is a certain Tewi advantage over the economical factor criteria purely [7,10]. The last ones depend greatly on the economical factors characteristic for this or that state, and to a small extent on the technological peculiarities of the equipment. In this aspect it may be declared that kW·h is the most reliable currency than any national one, as it depends neither on the taxes legislation nor on inflation.

Taking into account the above-mentioned principles, let us carry out the evaluation of the effect the additional energy consumption have on the $TEWI_N$ structure and value. For this purpose let us consider two scenarios turning the joint-stock company in the Ukraine · to the production of domestic refrigerators, in which the refrigerant R134a is used as the first variant, and R600a - as the second one.

The economical indices of the joint-stock company per 1997 were used as the base information for the calculation. Components of the energy consumption required for production of the refrigerator type 1 are shown in Table 1.

Table 1.

Energy consumption of the raw materials, details, manufacturing the refrigerator type 1

No	Components	Mass, kg	Energy consumption		% of Total energy consumption
			per 1 kg, MJ/kg	MJ	
1	Metal including the compressor (1)	43.540	60	2612.4	31.44
2	Polystyrene	12.700	140	1778.0	21.40
3	Foam polyurethane	6.590	224	1476.2	17.77
4	Evaporator materials. aluminum (sheet, pipe)	3.320	300	996.0	12.00
5	Copper pipes, including capillary pipe	0.39	135	52.6	0.63
6	Refrigeration oil	0.34	80	14.4	0.17
7	Foaming agent	0.53	80	42.4	0.51
8	Refrigerant	0.18	90	30.6	0.37
9	Energy consumption of manufacturing (2)			586.3	7.06
10	Other complements (3)	5.21	138	719	8.65
	TOTAL			8307.9	100

(1) Mass of compressor XKB6.65-1 is practically equal to the mass of FR13K (103H6946), manufactured for R600a.

(2) When calculating energy consumption the equivalent of 4 cents per 1 kW·h was taken.

(3) The average norm of energy consumption of the refrigerator type 1 when manufacturing was taken.

The Table 1 shows, that the main contribution to the energy consumption, connected with the refrigerator manufacturing, is made by the constructing materials. The refrigerant's contribution is extremely small (less than 1%).

The character of changing $TEWI_N$ with possible using of flammable refrigerants in the domestic refrigerator was regarded within the framework of four variants:

A. $TEWI_N$ calculation without taking into account the firesafety measures when R600a is used.
B. $TEWI_N$ calculation taking into account firesafety measures. The cost price and, consequently, the energy consumption, connected with manufacturing the refrigerator with R600a, were increased at 30% [7]. In the author's opinion, the real energy consumption will be much more the above mentioned one.
C. $TEWI_N$ calculation with twicely thickening the isolation in the refrigerator type 1 where the refrigerant R134a used). Joint-stock Company used R141b as the foaming agent.
D. The calculation of the $TEWI_N$ presumes the isolation thickening in the two refrigerators compared.

Without taking into account the refrigerant utilization the $TEWI_N$ calculation was performed by the formulas (1) and (4). When the $TEWI_N$ calculating the GWP value was taken for 100 years' interval: $GWP_{R134a}=1200$, $GWP_{R141b}=630$, $GWP_{R600a}=0$, $\beta=0.7$ kg CO_2/kW·h. The refrigerator's operating time was taken as 7 years, accordingly to EuroStandards. The main characteristics of the two refrigerants compared are in Table 2, Table 3 and Fig. 3 show the $TEWI_N$ structure.

Table 2.

Main characteristics of two compared refrigerators

Calculation variant	Refrigerant	Twenty-four-hours' energy consumption	Energy consumption for the operating time	Energy consumption of the refrigerator manufacture	Total energy consumption
		kW·h	kW·h	kW·h	kW·h
A	R134a	2.27	5799.8	2307.8	8107.6
	R600a	2.11 (1)	5391.0	2307.8	7698.8
B	R134a	2.27	5799.8	2307.8	8107.6
	R600a	2.11	5391.0	3000.1 (2)	8391.1
C	R134a	1.135 (3)	2899.8 (3)	2717.8	5617.6
	R600a	2.11	5391.0	3000.1	8391.1
D	R134a	1.135	2899.8	2717.8	5617.6
	R600a	1.065	2721.0	3410.1	6331.1

(1) Taking into account the higher energy efficiency of the R600a [12].
(2) Taking into account the 30% increase of energy consumption of manufacturing the refrigerator. This figure is less than the one which could be obtained at 30% increase of the refrigerator cost price.
(3) Taking into account the reduction of energy consumption for twenty-four-hours owing to thickening the isolation.

Table 3.

$TEWI_N$ structure for the domestic refrigerator type 1

Variant	Refrigerant	Direct contribution into $TEWI_N$				Indirect contribution into $TEWI_N$				$TEWI_N$	$TEWI_N$ (AFEAS)	Tewi
		refrigerant		isolation		energy consumption of manufacture		energy consumption of operation				
		abs	%	abs	%	abs	%	abs	%			
A	R134a	216	3.47	333.9	5.36	1615.5	25.95	4059.9	65.22	6225.3	4609.9	3.268
	R600a	0	0	333.9	5.83	1615.5	28.23	3773.7	65.94	5723.1	4107.6	3.005
B	R134a	216	3.47	333.9	5.36	1615.5	25.95	4059.9	65.22	6225.3	4809.8	3.268
	R600a	0	0	333.9	5.38	2100.0	33.83	3773.7	60.79	6207.6	4107.6	3.259
C	R134a	216	4.48	667.8	13.86	1902.4	39.51	2029.9	42.15	4816.1	2913.7	2.529
	R600a	0	0	333.9	5.38	2100.0	33.83	3773.7	60.79	6207.6	4107.6	3.259
D	R134a	216	4.48	667.8	13.86	1902.4	39.51	2029.7	42.15	4816.1	2913.5	2.529
	R600a	0	0	667.8	13.47	2387.1	48.13	1904.7	38.40	4959.6	2572.5	2.604

The given Table 3 show that when $TEWI_N$ is calculated on the formula recommended by AFEAS (1), then ecological expediency of using R600a in domestic refrigerators is obvious. However, the $TEWI_N$ calculation in which the energy consumption of manufacturing the refrigerator is taken into account, reveals the perspectives of the R134a using. And from Table 3 proves, that the ecological expediency of turning the domestic refrigerating appliances to the refrigerant R600a is no more, than illusion.

The main factor, 30% reducing the Total Equivalent of Global Warming – $TEWI_N$ is the reduction of thermal streams into the refrigeration compartment and sharp-freeze compartment owing to using the effective thermal isolation. Two firms raised the energy efficiency class till "B" and "C" just at the expense of thickening the thermal isolation. Thickness of the isolating layer of the refrigerators manufactured by these firms reaches for $7 \cdot 10^{-2}$ m in the refrigerating compartment and $1 \cdot 10^{-1}$ m in the sharp-freeze compartment. Domestic refrigerating appliances, manufactured by the Joint-stock Company have twice lessened thickness of isolation.

The second significant factor influencing the TEWI value is the compressor's energy efficiency (up to 10-18% [13]) which should be adopted to the working fluid used. The optimal choice of energy efficient refrigerant is only the third significant factor, influencing the TEWI value - 3-7%. That is why the excessive importance which is attached to the choice of the refrigerant is unjustified from the ecological point of view.

The transference to the natural flammable refrigerants without taking into account the above-mentioned factors cannot provide by itself the TEWI reduction in the hermetic refrigeration system.

CONCLUSION

In this paper the author didn't aim to advertise the advantages of this or that refrigerant. The facts, given in the paper show that it is the multicriterial task and it requires taking into account the different, some times discrepant factors. It is expedient to take these factors into account having them in the energy units which are conveniently transferred into the ecological factor $TEWI_N$ with following transformation into the specific reduced value Tewi. The $TEWI_N$ calculation with taking into account the energy consumption of manufacturing the domestic refrigerating appliances may change the conception of the ecological expediency of the turning-on to the flammable refrigerants, having low GWP value.

REFERENCES

1. Mattarolo L. Valutazione delle perdite di exerdia negli impianti frigoriferi // J.C. Freddo. - V.37. - No 1.- P. 3-9.
2. Revelle P., Revelle Ch. Our environmental / Book 3. Energetical problem of mankind. -Moscow: Mir Published, 1995. - 291 p. (in Russian).
3. CFCs, refrigeration and HCFCs 9th informatory Note: Int. Inst. of Refrig.-Paris (France). - 1993.
4. Lucas L. A new challenge: from the ozone layer to the greenhouse effect // Proc. International Cong. "Energy efficiency in refrigeration and Global Warming Impact-Gent (Belgium).-1993.-P.31-43.
5. Fisher S.K., Fairchild P.P., Hughes P.S. Global Warming implications of replacing CFC // ASHRAE J. - April 1992. - P. 14-19.
6. Zhelezny V.P., Zhidkov V.V. Ecological and energetical aspects introduction alternative refrigerants in a refrigerating engineering - Donetsk: Donbass, 1996 -144 p. (in Russian).
7. Douglas I.D., Braun J.E., Groll E.A., Tree D.R. Trade-off Between Flammability and Performance of Hydrocarbon // Proc.19th Int. Cong. of Refrig.- Hague (Netherlands). - 1995. -V. 4. - P. 155-162.
8. Zhidkov V.V. Ecological and energetical analysis of domestic refrigerating appliances working with alternative refrigerant (experiment and methods calculation) / Diss. on searching the Ph.D (in Russian).
9. Intergoverment Panel on Climate Change (IPCC), Climate Change: The IPCC Scientific Assessment, World Meteorological Organization / United National Environment Program, Cambridge Univ. Press, 1990.
10. Bikov A.V., Kalnin I.M. Cruseh A.S. Refrigerating machines and heat pump (Growing of efficiency) -Moscow: Agropromisdat Publishing, 1988. -287p. (in Russian).
11. Mazur V.A., Clodic D., Shamray A.A. Optimal Refrigerant Selection. Multicriteria Approach // Int. Conf. - CFCs The Day After. Proceedings p. 57-65, Padova 21-23 Sept. 1994.
12. Kalnin I.M., Smislov V.I. Ways of solving the problems of conversation domestic refrigerating equipment to ozone-safe refrigerants // Kholodilaya technika. -1995. -No1. -P.3-7 (in Russian).
13. Krasnovsky I.N., Muravia E.S., Onistchenko V.P. Elaboration of Compressor Working on R134a // Proc. Int. Compressor Engineering Conf. at Purdue, Purdue Univ. USA. - Purdue Univ.. - 1996. - P. 247-250.