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ENERGY AND ENVIRONMENTAL EFFICIENCY OF INDUSTRIAL REFRIGERATION INSTALLATIONS

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Abstract: Refrigeration installations are one of the biggest electricity consumers in the Food Industry companies. When choosing the refrigerant we have to consider its thermodynamic properties, as well as its impact on the environment. According to Regulation (EU) 517/2014 great part of the currently used refrigerants are going to be limited and put out of use. This article covers the factors that influence the energy efficiency of refrigeration installations. We compare two refrigerating installations – direct and indirect with refrigerant R134a. A comparison of two refrigeration installations, direct and indirect, with refrigerant R134a, has been made. The energy and environmental efficiency have been defined.
Keywords: Energy and environmental efficiency, refrigeration installations, global warming potential

INTRODUCTION

Refrigeration installations are one of the biggest electricity consumers in the Food Industry companies. This consumption may reach up to 85% of the total energy consumption, depending on the industry [5] (Figure1).

On the other hand, the energy consumption of the refrigerating installations is relatively stable as opposed to the processing units, due to the necessity of maintaining stable temperature regimes. That is why the profitability of the final product depends mainly on the energy efficiency of the refrigerating installations.

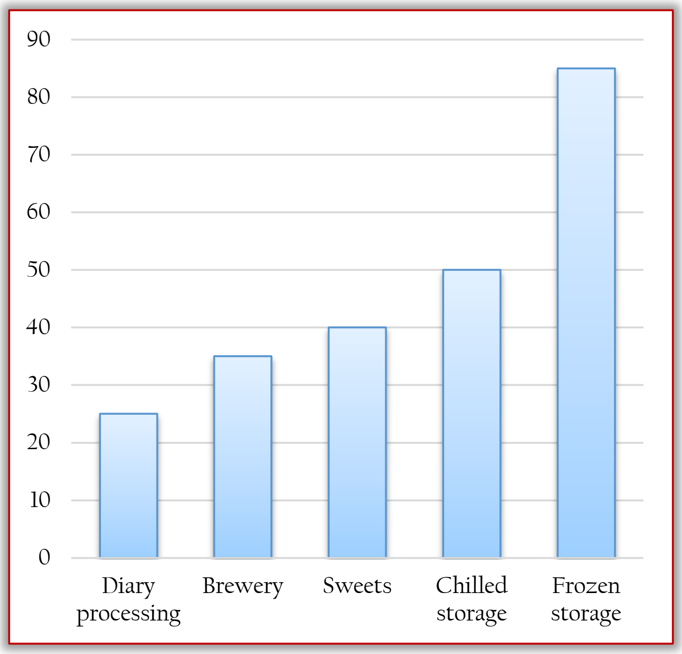

Figure1. Energy consumption during refrigeration processing

The main directions for increasing the energy efficiency of the refrigerating installations are related to:

- Choice of refrigerant.[1]
- Choice of refrigeration cycle – thermodynamic analysis.
- Choice of working parameters.
- Optimal thermal insulation of the refrigeration chambers and heat balances.
- Choice of refrigeration equipment.
- Utilization of waste heat.
- Exploitation.

CHOICE OF REFRIGERANT

When choosing the refrigerant we have to consider its thermodynamic properties, as well as its impact on the environment. According to Regulation (EU) 517/2014 great part of the currently used refrigerants are going to be limited and put out of use. For example, since January 1 2020 the use of fluorine–containing greenhouse gases with potential for global warming 2500 or more – R404A and R507 – for service or maintenance of refrigerating and air–conditioning equipment with charge quantity 40 tons of CO_2 equivalent or more.

Since the same date the selling of fresh refrigerants R404A and R507 will be banned. According to the Regulation the impact of the refrigerants is defined by ton(s) CO_2 equivalent. European countries, such as Norway, Spain, Poland, Denmark have adopted ecology tax for limitation of high potential global warming refrigerants. This tax is based on the global warming potential (Table 1)

Table 1. Prices in Norway in EU[7]

Refrigerant	Price tax excluded	Tax	End price
R32	46	27	73
R134a	25	58	83
R410a	28	82	110
R507	32	161	192

CHOICE OF REFRIGERATION CYCLE

When we have a refrigerant with high global warming potential GWP, one of the ways to reduce the quantity of the refrigerant is the transition from direct to indirect scheme of cooling by means of a cold carrier.

With such scheme the number of compulsory checks according to Regulation (EU) 517/2014 is reduced by half.

CHOICE OF WORKING PARAMETERS

The energy efficiency of the refrigeration installations mostly depends on the working parameter, which correspond to the normal working regime:

- evaporation temperature (t_0) – depends mainly on the process regime. Its reduction with 1K leads to average decrease of the cold–production Q_0 with 4% and the relative energy overconsumption increase with 3, 5%.
- condensation temperature ($t_к$) – depends on the type of the cooling environment and deviates in great limits during the seasons, as well as during the day and night. The increase of the tк with 1K leads to an average decrease of Q_0 with 2 % and the relative energy overconsumption increases with 3,5%.

OPTIMAL HEAT INSULATION OF REFRIGERATING CHAMBERS AND HEAT BALANCES

The insulation thickness increase is useful only if after making the heat balances, the heat flows from surrounding constructions are higher percentage from the total heat flows. In order to decrease the quantity of the refrigerant, Regulation (EU) 517/2014 makes transition to autonomous refrigerating installation. They have higher initial investments and installed cooling (electrical) power related to the central refrigeration installations.

The improvement of the technical equipment can lead to energy consumption reduction from 15 to 40%.

Example for such processes is the use of overheated steam after the compressor for heating of water in boilers, as well as use of heat condensation for heating at continuous cooling cycle.

EXPLOITATION

When evaluating the energy efficiency of a refrigeration installation we have to calculate the expenses for initial purchasing as well as the following exploitation expenses. The energy efficiency at exploitation depends on the following factors:

- organization of the exploitation;
- process discipline and personnel training;
- control and reporting of the refrigerating installation performance;
- high degree of automation;
- in time prevention and repair;
- rebuild and modernization of the refrigeration installations.

The main task of the exploitation is to secure safe and reliable work of the refrigerating units and machines, for maintaining the process regime in the cooling units at minimal cost of the produced artificial cold.

In order to make efficient the exploitation a thorough analysis of the separate elements of the refrigerating installation performance and their impact on the working regimes must be done.

Every refrigerating installation with a global heating potential over 5t equivalent of CO_2 must have a file. According to Regulation (EU) 2015/2067 every refrigeration technician must have a certified category for working with refrigeration installations, which is given after taking a theory and practice exam.

ANALYSIS OF THE REFRIGERATION INSTALLATION EFFICIENCY

We compare two refrigerating installations – direct and indirect with refrigerant R134a. The analysis is made by two way methodology, shown in (Campbell, 2006):

- Energy efficiency analysis;
- Environmental impact analysis.

Energy efficiency analysis

The energy efficiency of the refrigerating installations is valued by the total system coefficient of performance (COP_{total}), which is calculated by the following equation:

- For direct system with R134a

$$COP_{total} = \frac{Q_{0,Д}}{P_{k,Д} + P_{f,Д}}$$

- For indirect system with R134a

$$COP_{total} = \frac{Q_{0,Ин}}{P_{k,134A} + P_{f,134A} + P_p}$$

where:

» $Q_{0,Д}$ and $Q_{0,Ин}$ cool production of the evaporators, kW;
» $P_{k,Д}$ и $P_{k,134A}$– consumed power of the compressors in the direct and indirect system, kW;
» $P_{f,134A}$,$P_{f,Д}$ – consumed power by the fans of the condensers and air–cooling units, kW;
» P_p– consumed power of the pump, kW.

The results of the energy analysis are shown in Table 2.

Table 2. Analysis of the energy efficiency

№	Indicator	Unit	Direct	Indirect
I	AVERAGE TEMPERATURE REGIME		R134a	R134a
1.	Evaporation temperature – t_0	^0C	–7	–12
2.	Condensation temperature – t_k	^0C	50	50
3.	Cold production – R134a	kW	107	113,13
4.	Compressors power – $P_к$	kW	58,2	61,2
5.	Fans power – P_f	kW	6,03	10,2
6.	Pump power – P_p	kW	–	0,75
II	COMPARATIVE ANALYSIS			
1.	Total cold production– $\sum Q_0$	kW	107	113,13
2.	Total power – $\sum P$	kW	64,23	72,15
	COP_{total}		1,67	1,57

Conclusion: The energy efficiency of the direct refrigerating installation is higher than the indirect one:

$$COP_{total(direct)} = 1{,}67 > COP_{total\ (indirect)} = 1{,}57$$

Analysis of the ecological impact

The ecological impact on the environment is valued by the total equivalent warming impact – TEWI. The methodology of calculating the TEWI is developed by the International Institute of Refrigeration (IIR).

When calculating the TEWI for a defined refrigerating system, we consider the potential of the greenhouse effect from the emissions of the used refrigerant, as well as the indirect potential from the carbon dioxide emissions, caused by the electricity production, consumed during the refrigeration installation exploitation. TEWI is calculated by the following equation:

$$TEWI = (GWP \times L \times N) + (GWP \times M \times (1 - \alpha R) + (N \times P \times \beta)$$

where:

» GWP is the global warming potential of the refrigerant; for CO2 = 1,00, for R134a – GWP = 1430;

» L – losses from refrigerant omissions for 1 year, kg;

» N – exploitation lifetime of the refrigeration installation; N = 10 years

» M – system refrigerant mass, kg;

  - in direct refrigeration installation: M R134a = 96 kg;
  - in indirect: M R134a= 46,4 kg (the quantities in the units and pipelines are calculated);

» αR – coefficient of regeneration of the refrigerant, after the exploitation lifetime; αR = 0,75;

» P– consumed energy of the installation for an year, kWh;

» β – coefficient of the CO_2 emissions during production and transportation of energy. β= 0,35.

The yearly losses from omissions are calculated as follows:

$$L = S.M$$

where:

» S – total yearly losses during exploitation, prevention and repairs. During investigating of refrigerating installation it is stated that: S=(7÷27)%.

We accept: for direct S = 20 % and indirect S = 7 %.

Analyzing the equation for calculating the TEWI we can conclude that not always the direct impact of the refrigerant over the global warming is defining. The energy efficiency f the system also has a significant impact.

On the other hand, the equation does not count the ecological impact from the destruction of the refrigerants after the exploitation lifetime (yet there are no true data for the potential when destroying the refrigerants).

When defying the yearly energy consumption we accept:

- installation working time: τp = 21h;
- number of working days during the year – 365.

The calculation of the ecological impact over the environment is shown in Table 3.

Table 3 .Ecological impact analysis

№	Index	Unit	Direct	Indirect
I.	OUTPUT DATA		R134a	R134a
1.	Mass of the refrigerant – M	kg	96	46,4
2.	Year omissions – L	kg	19,2	3,25
3.	Total consumed power	kW	64,23	72,15
4.	Yearly consumed power – P	kWh	492323	553030
II.	ECOLOGICAL IMPACT:			
1.	From omissions	–	274560	46475
2.	From refrigerant regeneration after the exploit. lifetime	–	102960	49764
3.	Indirect impact from energy consumption	–	1723131	1935605
*	TEWI – from refrigerant		377460	96239
*	$TEWI_{total}$	–	2100591	2031844

CONCLUSIONS

- The ecological impact of the refrigerant in indirect refrigeration installation is 3.9 times lower.
- The total ecological impact of the indirect refrigeration installation decreases by 3.3%.
- The yearly energy consumption in the indirect refrigeration installation is increased by 11%.
- According to Regulation (EU) 517/2014 the checkups number for the direct with 137t equivalent of CO_2 is two and for the indirect installation with 66,4t equivalent of CO_2 is one.

Main directions for reduction of the ecological impact:

- to use one–component refrigerants or azeotropic ones;
- for reducing the omission the pipeline connections must be soldered;
- in refrigerating installations with high volume branched system pipelines – to use indirect or cascade systems with R744(CO_2) in the lower cascade.
- In industrial refrigeration installations – use of natural refrigerants such as R717 (ammonia) and cascade machines – R717/R744 (CO_2).
- Exploitation discipline – well trained personnel, who can perform the requirements for ecology safety.

Refrigeration is always on, which is why it consumes up to 50% of the energy in a typical Food Industry equipments. Investing in energy-efficient equipment and controls can lower utility bills and keep food fresher longer.

Due to the complex nature of refrigeration, and the current trends towards natural refrigerant options, the refrigerating installations continually invest in engineering and technical training to ensure that provide the customers with expertise that is second to none.

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