Solution Proposal for Utilization of the Waste Heat in Refrigeration Systems

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***Abstract* – The possibility for utilization of waste heat from processes in the food industry is presented in this paper. The need for reuse of waste heat comes from the fact that energy consumption in industrial companies is uneconomical and that environmental pollution has increased. Therefore, one of the method of reuse of waste heat that is applicable in industrial processes is presented in the paper. Potential primary energy savings is presented by implementing the waste heat recovery in the food factory. The paper presents a simplified solution proposal for installation of heat exchangers with the aim of utilizing the waste heat of the refrigerant. The results showed that by the implementation of simple heat recovery significant annual fuel energy savings can be achieved as well as fuel cost savings.**

***Keywords* – Waste heat, heat recovery, energy efficiency, food industry.**

1. Introduction

World energy consumption is increasing rapidly, while available resources remain limited.

For the last 40 years, global primary energy consumption has been growing constantly, and it is largely due to industry contributions. Primary energy consumption in the world has grown by an average of 1,6% per year in the last 10 years [1]. In industry sector it is required a huge amount of invested energy, which leads to problems in both primary energy consumption and CO_2 emissions. During industrial operations, a large part of the invested energy is dissipated as waste heat into the environment in various forms. Considering the huge amount of waste heat, the environmental and economic benefits obtained from the waste heat recovery would be significant [2].

The EU has focused on improving energy efficiency and increasing the use of renewable energy sources with the aim of reducing greenhouse gas emissions. However, despite increased investment in research and development of renewable energy sources and clean technologies, it is estimated that energy consumption in Europe for many years will be based on a large share of fossil fuels, which are dominant air pollutants and greenhouse gas emitters.

The constant growth of the price of energy and the increase of its share in the price of a unit product, demands greater reconsideration of the possibilities and evaluation of the approaches by which it is possible to make better use of primary energy in order to achieve the operating parameters of the plant [3], [4], [5]. In that sense, the utilization of waste heat energy as a source of useful energy has been investigated for a range of different industrial sectors [6], [7].

Panayiotou et al. investigated the opportunities for utilizing of waste heat and made estimation of the waste heat potential in EU industry presenting results by country and industry sector. The obtained results indicated that the large amount of waste heat is contained in the food, which means that there is a great potential in the food industry for the utilization of waste heat [6].

Huang et al. made an overview of waste heat recovery in order to highlight the current potential waste heat sources in the industry as well as possible technologies that can be used for waste heat recovery in industry [5].

Masud et al. investigated possibility of utilizing the heat of exhaust flue gases from diesel engine. After

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conducted experiments it was concluded that implementation of such a solution in different food processes can lead to a CO_2 emission reduction [7].

There are different ways of using energy in industry, and therefore the possibilities of increasing efficiency and achieving savings [8], [9], [10]. Within this paper, the possibility of using waste energy from thermal processes in the bakery industry is considered. The paper presents one of the possibilities of utilizing waste heat, i.e., improving energy efficiency by recovering waste heat from superheated refrigerant gas in refrigeration chambers. It has been shown that, by applying heat recovery, it is possible to use part of the waste heat that otherwise would be discharged from the system and thus achieve significant fuel energy savings and fuel cost savings.

2. Waste Heat Potential in the Food Industry

Globally, the food sector and agriculture together are responsible for about 30% of final energy consumption in the industry sector, with the share of the food sector exceeding 70% [11].

The food industry consumes a significant amount of energy for performing various thermal and/or cooling processes during which a significant part of energy is irretrievably lost in the form of waste heat. According to [12], [13], the most of the energy in the food sector is used for conversion into heat energy, about 59%, which is mostly obtained from fossil fuels. About 16% and 12% of electricity are consumed for cooling processes and various motor drives, respectively, Figure 1 [12], [13]. According to [14], as much as 30% of heat flows are lost at the end of the process in the form of waste heat. The most heat energy is used for baking, drying, pasteurization, cooking and heating, while electricity is mostly used for cooling processes 31% and for electric motor drive 25%, Figure 2.

Theoretically, any amount of heat that can be recovered from an industrial refrigeration system as result have an improvement in the system efficiency, but, in practice, the amount of heat recovered has to be large enough to justify investment in the main equipment [15], [16], [17].

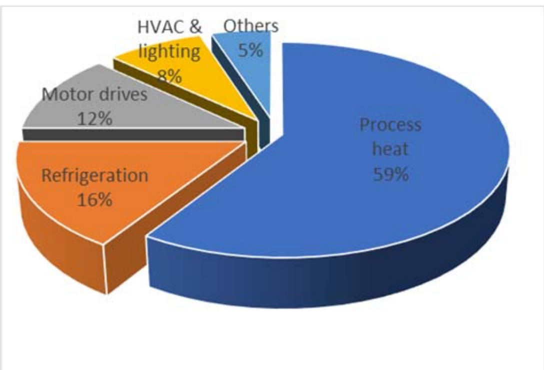

Figure 1. Typical energy consumption in the food industry [12], [13]

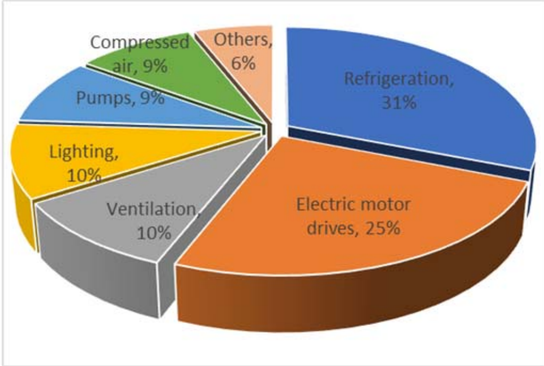

Figure 2. Electricity consumption in the food industry [12], [13]

The quality of the recovered waste heat which is determined by its temperature is an additional factor that can limit the possibility of heat recovery in an industrial refrigeration system. In food industrial processes the heat is usually used in low and medium temperature [12], [13], [15].

Finally, it is desirable to have the availability of waste heat sources that simultaneously matches the needs of users for waste heat. If there is a time mismatch between waste heat supply and user needs for waste heat it would be required a system for storing surplus waste heat energy [12], [15].

The possibilities for increasing the utilization of primary energy consumed during the operation of the refrigeration system are considered in this paper. In that sense, the possibilities of utilizing waste heat, i.e. energy that is usually discharged from the system, are considered.

3. Description of Production Process and Plant

The production of bread and pastries is the main activity in the bakery industry. The basic devices used in the processes of bread and pastry production are: wheat grinding mill, mixing machine, bread and pastry shaping machine, fermenter, ovens, storage refrigerators and boilers. Furnaces can be electric or those that use fossil fuels. Boilers, as the largest consumers of fuel, provide vapor that is used for heating or for production processes. Various heating and cooling processes of the food product take place in heat exchangers. Any air from the process, vapor and waste water streams above ambient temperature can be a source of energy.

The paper analyzes the possible savings for a bakery plant with the annual production of 4 tons of finished product. For the thermal needs of this plant, there is a 2 MW boiler in the boiler room that produces vapor, which is then used for heating space and for heating domestic hot water. The boiler uses two energy sources: natural gas and heating oil. About 20% of the total daily water consumption goes to replenish the boiler, 30% goes to the production process, while about 50% is used to maintain worker hygiene and equipment cleaning. For storage purposes, four cooling chambers have been installed. Potential places where waste heat could be used are the boiler, cooling chambers and sewage water from the hygiene and cleaning area.

This paper discusses in more detail the possibility of using the waste heat of superheated working fluid in refrigeration chambers.

4. Proposal for Waste Heat Recovery in Bakery Industry and Results

The ways of using energy in industry are different, and so are the possibilities of increasing efficiency and achieving savings. Within this paper, the possibility of heat recovery in industrial cooling systems is considered. Vapor compression refrigeration systems are designed to receive heat from the room and products, where it is undesirable, and transfer it to the environment at a higher energy level. By applying heat recovery, it is possible to use part of the waste heat that would normally be discarded from the system. There are several places in the refrigeration system where heat recovery can be performed, namely: condenser, superheated working gas at the outlet of the compressor, and compressor oil coolers [18]. If waste heat is needed to heat or preheat the water, the most efficient way is to use heat recovery from the refrigerant at the outlet of the compressor. This method of heat recovery is used for heating sanitary water or for heating water for washing and daily cleaning of rooms and appliances.

In analyzed food processing facility, there are 4 cooling chambers of installed power as follows: $Q_1 = 2$ kW, $Q_2 = 4$ kW, $Q_3 = 5{,}5$ kW and $Q_4 = 9$ kW. It is necessary to calculate the total heat energy released from the cooling chambers. The first step is to define how much heat can be obtained from the refrigerated space. In addition to the thermal energy that can be extracted from the refrigerated space, the total heat energy that can be obtained by recuperation, also, includes the heat as a consequence of the compression of the working medium in the compressor. So, the total heat energy that can be recovered is the sum of these two mentioned heat energies.

The thermal energy obtained due to the compression of the working medium in the compressors according to the recommendations [19] is 17% of the total capacity of refrigeration devices:

$$Q_K = 0{,}17 \cdot (Q_1 + Q_2 + Q_3 + Q_4) \qquad (1)$$

$$Q_K = 3{,}485\ kW$$

The amount of available energy for recovery also depends on the load of the cooling devices. On average, refrigeration units operate at 70 - 80% of capacity. Taking into account some mean value, 75%, it is possible to calculate the heat energy available for recuperation, i.e. the heat energy that is discharged from the cooled space [19]:

$$Q_{pr} = 0{,}75 \cdot (Q_1 + Q_2 + Q_3 + Q_4) \qquad (2)$$

$$Q_{pr} = 15{,}375\ kW$$

The total available heat for recovery can now be obtained:

$$Q_{tot} = Q_K + Q_{pr} = 18{,}86\ kW \qquad (3)$$

The total available thermal energy is 18,86 kW. However, the amount of this thermal energy, which can be converted to useful in the form of hot water, is limited.

The proposed solution for installing a heat exchanger for heat recovery from cooling chambers is shown in Figure 3.

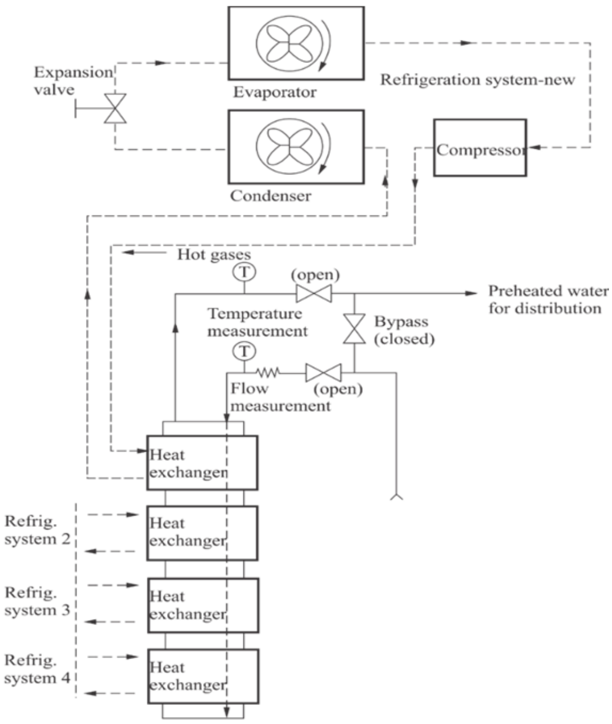

Figure 3. Proposal of solution for installation of heat exchanger for heat recovery from cooling chambers in the production space [18]

In such a recovery device, the pipe through which the working medium passes and which exits the compressor is connected to the heat exchanger unit. The return pipe from the heat exchanger further goes to the condensing unit. In this case, the refrigerant vapor exiting from the compressor, passes through the heat exchanger and then goes to the condenser. A by-pass valve is also installed due to the possibility of shutting off the water flow to the heat exchanger if recuperation is not required. It is also suggested to install a device for measuring temperature and flow.

Heat is transferred from the warmer fluid to the colder in the heat exchanger. In this way, the water in the heat exchanger is heated by the refrigerant vapor. Average heat exchangers have an efficiency of about 60 - 80% [19]. Taking some mean value, a heat exchanger efficiency of 70% is adopted. This efficiency of the heat exchanger is used for determining the actual heat transferred to the water, at a known amount of available heat energy for recovery.

Thus, the total heat transferred to the water can be calculated:

$$Q_w = Q_{tot} \cdot 0{,}7 = 13{,}202\ kW \quad (4)$$

For a baking plant, with an average annual production of 4 tons of finished product, the average daily water consumption is Wd = 30 m^3/working day. Since this plant operates all 365 days a year, it is obtained that the annual water consumption is about 11000 m^3. Half of the total water consumption is used for maintaining hygiene and cleaning equipment, at average temperature 40 - 50°C, which would mean that the average water consumption for these needs is W_{dh}=15 m^3 per working day, and the total annual consumption is 5475 m^3.

The average daily water consumption, converted into kilograms per hour is 625 kg/h. Now it is possible to calculate how much heat energy per kilogram is needed to heat 625 kg/h of water:

$$q = \frac{Q_w}{m_w} = \frac{13{,}202 \cdot 3600}{625} = 76{,}0435\ \frac{kJ}{kg} \quad (5)$$

Based on the previously calculated parameters, a temperature can be obtained, at which it is possible to heat cold tap water in the heat exchanger. It is adopted an average tap water temperature of 13ºC as a reference temperature:

$$q = c_p\left(t_{waste} - t_{reference}\right) \Rightarrow \quad (6)$$

$$t_{waste} = t_{reference} + \frac{q}{c_p} = 31{,}2°C.$$

The obtained temperature of 31,2 ºC represents the value of the temperature to which it is possible to heat the water in the heat exchanger. Thus, the preheated water is further distributed to all taps in changing rooms and toilets, and to the production area to the place for maintaining hygiene and cleaning equipment, where it is mixed with hot water from the boiler with a maximum temperature of 80ºC as needed.

The total annual amount of energy that can be obtained by recuperation can be calculated based on the total annual water consumption of 5475 m^3 or 5475000 kg as following:

$$Q_{rek} = \frac{m_w \cdot c_p\left(t_{waste} - t_{reference}\right)}{3600} \Rightarrow \quad (7)$$

$$Q_{rek} = 115865\ \frac{kWh}{year}$$

The total annual amount of energy that would be achieved by recuperation, can be obtained by multiplying the total heat, which is transferred to water according to expression (4), with the number of operating hours of refrigeration equipment:

$$Q_{rek} = Q_w \cdot \tau = 115649{,}5\frac{kWh}{year} \quad (8)$$

In this case, it will be adopted that the total annual amount of thermal energy that could be obtained by heat recovery from refrigeration units is 115 MWh/year.

Based on the assumption of the share of natural gas and heating oil in the total annual fuel consumption for boiler operation, 80 and 20% respectively, it is possible to calculate the fuel and cost savings on an annual basis.

An overview of annual fuel savings and annual cost savings for these two energy sources used for boiler operation in baking plant is given in Table 1.

Table 1. Annual fuel and cost savings resulting as utilizing waste heat

Energy source	Energy source cost	Bottom thermal power	Annual fuel saving	Annual fuel cost saving (EUR)
Natural gas, m^3	0,51 EUR/m^3	33,3 MJ/m^3	9945,95	5072,43
Heating oil, l	0,79 EUR/l	42 MJ/l	1971,43	1557,43

Based on the total annual fuel cost savings and data on the total annual production of 4000 kg in analyzed
baking plant, it can be obtained saving per kilogram of finished product as follows:

$$\frac{Cost\ saving}{finished\ product\ in\ kg} = \frac{6629{,}86}{4000} \quad (9)$$

$$\frac{Cost\ saving}{finished\ product\ in\ kg} = 1{,}65\ \frac{EUR}{kg}$$

Utilization of waste heat can, also, contribute to CO_2 emissions reduction. The CO_2 emission reduction potential, showed in Table 2, was calculated based on the specific CO_2 emission factors for natural gas and heating oil given in [20].

Table 2. CO_2 emission reduction potential

Energy source	Coefficient of CO_2 emission (kg/MWh)	CO_2 emission reduction (kg/a)
Natural gas, m^3	220,2	20258,4
Heating oil, l	310,3	7136,9

The data in Table 2 show that total CO_2 saving potential by waste heat utilization is 27,4 t CO_2/annual.

Total value of the investment is estimated at 5250 EUR. Total investment includes also auxiliary equipment, valves, sensors, temperature and flow meters, and refrigerant and water pipelines and represents the approximate price.

Since savings of 6629,86 EUR per year are expected, the simple payback period can be calculated as follows:

$$PB = \frac{investment}{cost\ saving} = \frac{5250,00}{6629,86} \quad (10)$$

$$PB \approx 9,5\ months$$

Economic calculations showed that the payback period in this case is minor than one year and it is about 10 months. Based on the relatively short payback time it can be concluded that this way of utilizing waste heat, ie. installation of heat exchangers for utilization of waste heat from cooling chambers in the bakery is justified.

5. Conclusion

There are many examples of irrational use of energy in the world. Large amounts of energy generated as by-products in various processes are released into the environment on a daily basis. In order to use this waste energy and convert into useful energy, it is necessary to take appropriate energy efficiency measures. By increasing efficiency, not only more economical production is achieved, but also the reduction of environmental pollution, which favors the efforts that are being made in the world to protect and preserve the environment.

The paper presents a potential energy saving measure in a bakery plant, namely the installation of a heat exchanger in a system with cooling chambers, with the aim of utilizing the waste heat of superheated gas of the working medium. Total annual amount of thermal energy that could be obtained by heat recovery via heat exchangers from refrigeration units is estimated at 115 MWh annual.

It was, also, estimated that implementation of heat recovery in the refrigeration system can produce annual fuel cost savings of 6629,86 EUR per year for analyzed bakery plant. Since the average annual production is 4000 kg of finished product, this would mean savings of 1.65 EUR per kilogram of finished product. It is assumed that the preheated water in the heat exchanger is further distributed to all taps in changing rooms and toilets and to the production area to the place for maintaining hygiene and cleaning equipment where it is mixed with hot water from the boiler as needed.

By reducing fuel consumption, CO_2 emissions are also reduced. It was obtained that total CO_2 saving potential by waste heat utilization is 27,4 tons of CO_2 per year. The payback period is also calculated based on the total value of the investment and annual cost savings. Based on the obtained relatively short payback time it can be concluded that this way of utilizing waste heat is justifid.

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