Environmental and Climate Technologies
2020, vol. 24, no. 2, pp. 221–230
https://doi.org/10.2478/rtuect-2020-0068
https://content.sciendo.com

Energy Efficiency Improvement in Thawing

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***Abstract* – The thawing process within fish processing is one of the most essential steps in manufacturing. Various processes of thawing can be used where efficiency varies between companies depending on such characteristics as energy consumption, the price of resources, etc. The main aim of the research is to increase the efficiency of thawing processes. Firstly, to analyse various thawing methods and to find the most efficient one by using multi-criteria decision making analysis method. Secondly, analysing data of thawing of existing company to find opportunities for improvements, including the change of existing technology. Results showed that the most suitable method for thawing is the air blast method. Case study showed that current thawing technology is outdated, thus suggested improvement would be to replace the current boiler house with a cogeneration plant. A sensitivity analysis for the cogeneration plant has been performed.**

***Keywords* – Boiler house; cogeneration plant; fish; food processing; manufacturing; MULTIMOORA; thawing**

1. INTRODUCTION

Within fish product manufacturing, many resources are used to maintain the quality of the food. Thawing, washing, and freezing are some of the preparation steps needed before resources are produced in an actual product [1]. As these processes use energy, energy efficiency has become even more topical in the industrial and district heating sectors [2]. Unnecessary use of energy could lead to negative impact on environment due to the released greenhouse gasses. To avoid this problem, it is suggested to invest in modern technologies, replacing non-renewable and fossil fuels with renewable energy sources [3].

Thawing as a process is necessary, because fish is previously frozen due long-term preservation and storage possibilities, another benefit of frozen product is that it can be distributed all over the word, as well as seasonal fluctuations can be reduced, assuring seafood supply all year [4]. This proves that fish thawing cannot be avoided in the fish processing. Knowing that thawing covers a large part in the total energy consumption in the company, thus finding the best thawing method suitable for the company's needs is essential. This allows to increase the efficiency of thawing, secure quality of the fish, and to make the most economically feasible choice.

Among other things, the thawing process plays a special role because this usually takes place before the preparation of the food and maintains the food's high quality. Thawing refers to the process of change from a frozen to unfrozen state, also to lose stiffness, numbness, or permeability

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by being warmed. Thawing at ambient temperatures is slow compared to using water, hot air, radiation, or other methods, it can also cause a rapid growth of microorganisms on the surface layers of the thawed product and hinder reabsorption of thawed water if done incorrectly. This could create the unsightly and often nutritionally wasteful drip loss [5].

Fish thawing methods vary, the most widely known and used methods for fish thawing are air (both still and forced), water, heated air, high pressure, impingement, vacuum, microwave, radiofrequency, and ultrasound. Each method has its own characteristics, showing how much energy, resources (such as water) are being used, and how much wastewater and CO_2 emissions are created as a result of each method during thawing. Additionally, methods such as high pressure, impingement, vacuum, microwave, radiofrequency and ultrasound are assumed to be innovative methods in the field of thawing. Currently, from all the innovative methods, microwave technology is being used the most already in large manufacturing companies [6].

The use of best available techniques (BAT) [7] will provide a more environmentally way to do every process considering this point of view. The main environmental benefits of the BAT application for fish and other types of seafood include reducing the generation of waste in every process, not only thawing, also scaling, skinning, eviscerating and filleting, etc., and less consumption of water for those methods that include thawing. Water is required in many thawing methods and therefore the wastewater typically contains dissolved organic matter and salts. Water amount normally used for fish thawing varies from 9.8 to 32 m^3 per ton of fish, considering an average of the different methods existing for this purpose and depending on the type of fish [8].

Thawing of frozen food is an essential step before any subsequent processing or cooking it might go through. It is known that the quality of frozen food is greatly associated with the thawing process it endures. Improper thawing methods have led to changes of chemical and physical properties of frozen food such as drip loss, enzymatic reaction, lipid and protein oxidation, and inhomogeneity. Traditional thawing methods, including air thawing and water immersion thawing, take a long time and are inclined to produce the previously mentioned quality deficiencies. Some novel technologies talk about how these limitations can be overcome by applying methods like microwave thawing, high-pressure thawing, and ultrasound-assisted thawing. Although microwave thawing has been successfully applied in practise, the main issue relies in the lack of consistency with heat transformation and proper temperature control. High-pressure thawing has limitations in practical applications as well due to its high costs as one of the newest technologies developing. Ultrasound-assisted thawing has the advantages of uniformity and saving time, mainly because of the rapid fading of ultrasonic waves near the freezing and thawing limits, and the conversion of sound energy to heat energy, leading to improved heat transfer [9], [10].

To keep up with the continuing growth of quick freezing in the fishing industry, it has been necessary to develop industrial methods for reversing the freezing process in a proper way, that is thawing the fish for further processing, for cooking or for sale as wet fish, based on the needs. A fast thaw enables to meet market demands quickly as it will be in the shortest possible time. Different methods have evolved for thawing frozen fish in the many ways that are currently handled commercially, including large blocks of whole sea frozen fish, blocks of fillets or portions for catering use, even whole fish or other meats such as beef or pork. Methods of thawing on a small scale have been designed to assist in the preparation of frozen whole fish, fillets, and fish portions for immediate cooking, accordingly to the requirements of the market [11].

Thawing is a process used not only in the fish product processing, but also to thaw various types of food products, for example, meat, vegetables, etc. Therefore, even though the current research done is based on thawing in fish product manufacturing field, the method and assessment could be done for any other industry where thawing of resource is necessary. The thawing of food products is used in industries all over the world, therefore the results obtained from the comparison of thawing methods can be used in wider range.

The problems occurring in thawing are that process is inefficient, as well as resources are being used unnecessary, leading to high consumption of resources and energy, thus it needs to be sure that thawing is done efficiently. Within this research paper, two options on how to improve thawing process is viewed. Firstly, various thawing methods are being analysed to conduct which method would be more efficient considering various criteria. Secondly, analysis of the thawing process in the existing company is evaluated in order to find improvements on how increase the efficiency in the company. The aim of the research is to increase the efficiency of thawing processes in the existing company that could also be applicable for other industries where thawing process is required.

2. METHODOLOGY

Methodology consists of two parts that evaluate efficiency of the thawing process. First part analyses thawing process in the existing fish processing company, considering the thawing method and parameters related to it. The second part analysis the efficiency of various thawing methods, thus enable to compare them and to find the most efficient one.

2.1. Overall Description of Analysed Company

An operating fish processing company is being analysed, and the necessary data and the analysis has been assessed. More specifically, the thawing process of the company was analysed to find improvements in the specific process. Fig. 1 shows the general inflows and outflows of the thawing process.

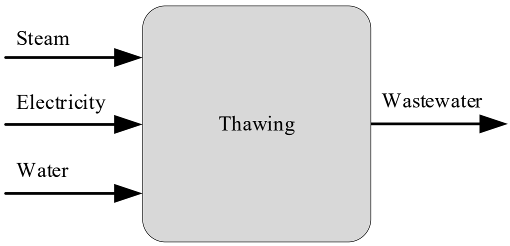

Fig. 1. Thawing process flow chart.

Blocks of fish arrive at the company with a weight from 10 to 15 kilograms each. These blocks are then stored in optimal conditions before thawing starts. The process starts with sorting approximately 9 blocks in metal racks. After filling 8 racks (for a total weight of around 1 ton), all of them are put manually inside a chamber for the thawing to begin, and the method the company currently uses is thawing with heated air.

The company has two boilers to perform the thawing process, each one with a capacity of 3.6 MW (around 6.5 tons/hr) and 1.4 tons/hr flow steam. The boilers use wood chips as fuel and have an efficiency of 59.5 %. The temperature of the steam inside the boiler is between 293 °C and 308 °C before going into the thawing chamber. After steam is expelled from boiler, it is combined with air at 20 °C to cool down and then enters the thawing chamber at temperature of 120 °C and a pressure of 2 atm. Inside the chamber, sprinklers provide water that is combined with the steam to make the process possible under the correct conditions. With the help of ventilators, steam with water flows throughout the chamber to achieve a temperature of 18 °C. The amount of water used in the sprinklers is unknown. This part of the process lasts 3–5 hours, depending on the type of fish and the quantity that is been thawed. The water used in the process, as well as the water that will come from the fish when the thawing is complete, goes to the wastewater treatment plant of the company, and is discharged into the ocean.

Regarding the thawing with heated air, although effective, this process demands high energy consumption and may cause a rapid growth of microorganisms on the surface layers of the thawed product and hinder reabsorption of thawed water, which creates unsightly and often nutritionally wasteful drip loss. When warm humid air is used to thaw blocks of frozen white fish, it can cause problems in maintaining the quality of the finished product because the fish at the edge of the frozen block thaw before the ones in the middle of the block. Thawing time can be reduced by separating the fish, either by hand or mechanically, but this is possible only after the blocks have been thawed, or tempered, for about 2 hours [12]. Heat can be recovered from the cooling equipment and compressors, but this involves the use of heat-exchangers and storage tanks for warm water, so it would be more of a long-term proposal. Recovered heat can be used for thawing deep frozen fish.

Knowing the heat losses from the boiler with air at 20 °C and the temperature needed for the thawing process, then it can be concluded that such high temperature is not needed. As the boiler at the company under research is very old, a more recent model of the same operational aspects could provide improvement, since current boiler performs at 59.5 % efficiency. Also, currently provided steam is in temperature between 293 °C and 308 °C, which is not required for normal thawing processes, an acceptable temperature would be around 120 °C. Changing the machine for a newer one with lower capacity (one that matches with the needs of the process) will ensure better performance.

Based on using cleaner production methodology, the combined heat and power (CHP) plant will be the object of analysis because of the need for electricity for the process to work properly. Since the company uses two boilers at a total capacity of 7.2 MW for the winter period, a CHP plant with the capacity of 7 MW will provide enough heat for the process. The cost of a plant of that magnitude is around 5.5 million €, including construction [12].

Due to the possibilities in Latvia and the costs, a financing entity will be needed. In this case, the bank can finance the project of changing the boilers for the CHP plant. Based on the bank terms for offer, an interest rate of 10 % an equity of 40 % with an interest of 12 % and an inflation of 2 % is used in the study [13]. Information about the company confirms that the same boiler has been used since they started operating which is around 70 years. With that information as a basis, and ensuring proper maintenance, we can assume to set the lifetime of the equipment at 70 years. According to the Food and Agriculture Organization of the United Nations, one tonne of fish thawed cost around EUR 6920.00 [14].

2.2. Sensitivity Analysis

A sensitivity analysis is a tool that is used to measure the effect on variations in estimated parameters on the investment decision criteria of a project, like the internal rate of return (IRR) and payback period or net present value (NPV) which is given in Eq. (1).

$$NPV = \sum_{t=1}^{n} \frac{R_t}{\left(1+i\right)^t}, \tag{1}$$

where

NPV	net present value;
R_t	net cash inflow-outflows during a single period t;
i	discount rate or return that could be earned in alternative investments;
t	number of timer periods.

For this scenario, the main parameters that will provide data for the sensitivity analysis are the relative changes of the NPV depending on:

- Investment;
- Price of raw materials;
- Price of product.

By running this analysis method, it can be identified which of the factors above have the greatest effect on the overall project and therefore which parameters require more attention. A perfect way to display the results and be able to interpret them is with a spider plot which will show the relative changes in the selected input parameter against the absolute changes in the decision criteria. At the end, the sensitivity analysis will answer questions tangled with the variation of the parameters.

2.3. MULTIMOORA

MULTIMOORA (Multi-Objective Optimization on the basis of Ratio Analysis) is one multi-criteria decision-making method that allows to evaluate various alternatives by considering indicators affecting them. Within the evaluation, the best alternative can be conducted. To obtain results from this method, three separate results needs to be calculated, after which the average value is obtained, showing the ranking of alternatives [15], [16].

The first step of the method is to prepare a decision making matrix, where all alternatives that need to be compared are listed. Indicators describing alternatives are acknowledged and a table with suitable values is filled [17].

The second step is called Ratio System. To calculate it, values of the decision-making matrix are taken to use Eq. (2).

$$x^*_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}, \tag{2}$$

where

x_{ij}	the response of alternative j to objective i;
x^*_{ij}	dimensionless number representing the normalized response of alternative j to objective i (in an interval [0;1]);

$i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$.

The third step of MULTIMOORA is to perform an optimization of obtained values from Eq. (2). For this case, the criteria are divided into two groups: beneficial (criteria that need to be maximized) and non-beneficial (criteria that need to be minimized). The sum of non-beneficial parameters is then subtracted from the sum of beneficial parameters as shown in Eq. (3).

$$y_j^* = \sum_{i=1}^{i=g} x_{ij}^* - \sum_{i=g+1}^{i=n} x_{ij}^* , \tag{3}$$

where

$i = 1, 2, ..., g$ – the objectives to be maximized;
$i = g + 1, g + 2, ..., n$ – the objectives to be minimized;
y_j^* – normalized assessment of alternative j with respect to all objectives.

The sum for each alternative is then calculated and an ordinal ranking in ascending order of the y_j^* shows the final preference of this method, achieving the final evaluation of the first method.

The next step is Reference Point Theory, where the maximal value from the normalized values are found by using Eq. (4).

$$\min_{(j)} \left\{ \max_{(i)} \left| r_i - x_{ij}^* \right| \right\} , \tag{4}$$

where r_i is the i^{th} co-ordinate of the maximal objective reference point.

To obtain the semi-results from the Reference Point Theory, the ordinary ranking by descending order is conducted.

The next step is calculated by using data in the decision-making matrix in order to achieve utility of the alternative. The name of this method is called Full-Multiplicative Form. Again, beneficial and non-beneficial criterion are considered. To perform this step, Eq. (5) is used.

$$U_j^{'} = \frac{\prod_{g=1}^{i} x_{gi}}{\prod_{k=i+1}^{n} x_{kj}} , \tag{5}$$

where

i – number of objectives to be maximized;
n–1 – number of objectives to be minimized;
U'_j – utility of alternative j with objectives to be maximized and objectives to be minimized.

Based on the sub-results calculated in Eq. (5), the ranking of alternatives is done in ascending order.

Now, three sub-results within MULTIMOORA method are obtained. The main step within the MULTIMOORA method is to calculate the average value considering the obtained sub-results. The best alternative will be the one with the lowest ranking.

3. RESULTS

The aim of every sustainable manufacturing process is to minimize created waste and the amount of resources being used in the production process. With a quality point of view, either increase production with same resources or minimize resources keeping actual production, it is suggested to replace the current boiler house with a CHP plant. This suggestion was made based on the fact that the current temperature used in the production process is too high and can be significantly reduced.

Table 1 shows the costs of such a thawing process, based on the annual consumption of the company as well as the characteristics of the CHP plant.

TABLE 1. COSTS OF THAWING PROCESS

Concept	Price, EUR
Frozen fish, ton	6920.00
Electricity	0.29
Water	483.20
Wood chips	415.57
Total per ton	7819.06
Total per kg	7.82

The revenue is the income generated from normal business operations and it includes the discounts and deductions for returned merchandise (if any), since the costs are subtracted later to calculate net income. Since revenue come from sales, a profit margin of 55.8 % considering the product costs EUR 7.82 and is sold at EUR 12.19. This, with the information on the flows of raw materials and finished goods, would mean that, with this product alone, the company is able to generate EUR 1 112 337.50 per year.

3.1. Calculation of NPV

Fig. 2 combines cleaner production point of view as well as socio-economic aspects of a change, providing a chart of relative changes depending on investment, price of raw materials, or product price.

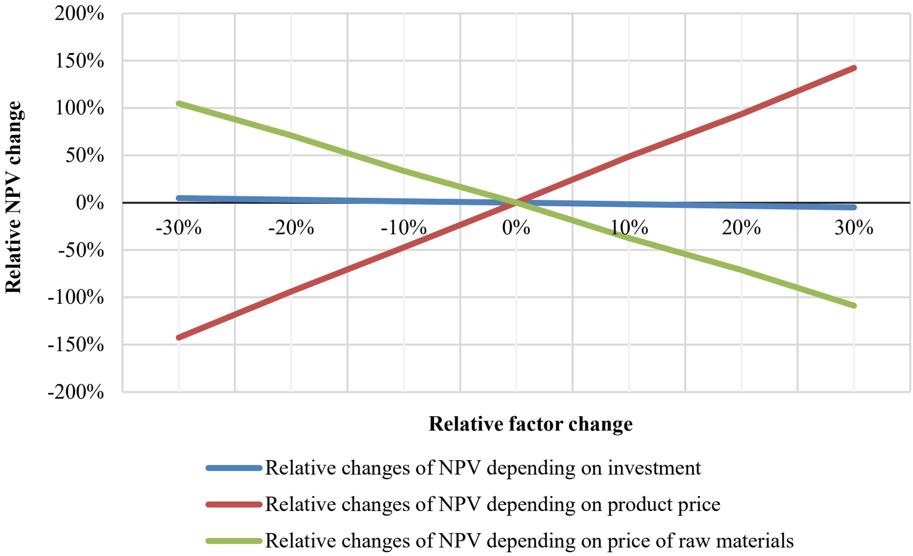

Fig. 2. Relative changes of company with CHP.

Results show that NPV is greatly affected by product price. The internal rate of return or discounted cash flow rate of return with this case and based on the provided information is 96 %, making this project a great investment since it will provide a high profit percentage after considering the net present value.

3.2. MULTIMOORA

Decision-making matrix for the thawing methods can be seen in Table 2. Four alternatives were considered based on the most popular methods used in food manufacturing: steam, microwave, water, and air blast. Indicators used for the evaluation were: energy consumption, cost of technology, water consumption, and CO_2 emitted. The total amount of assumed production was 5000 tCO_2 of the product in a year. Water consumption that is used in the technical processes to perform the main process for two alternatives – microwave and air blast – is zero. However, water consumption is an essential indicator, therefore the water data in the decision-making matrix are shown not as real data but as aligned values.

Data for the decision-making matrix (energy consumption, cost, and water) was obtained from the manufacturers of the thawing equipment. Data for created CO_2 emissions indicator was calculated based on the water and energy consumption.

TABLE 2. DECISION-MAKING MATRIX OF VARIOUS THAWING METHODS

	Energy consumption, kW	**Cost, EUR**	**Water, m^3**	**CO_2 emissions, t**
Steam	45 000.00	22 366.18	4.00	2 502.12
Microwave	375 000.00	31 312.65	1.00	20 812.50
Water	137 500.00	8 946.47	2.00	7 633.85
Air blast	42 285.71	13 419.71	1.00	2 346.86

Considering the calculations and obtained sub-results of the MULTIMOORA method, ranking from each sub-result method and the main result can be seen in Fig. 3.

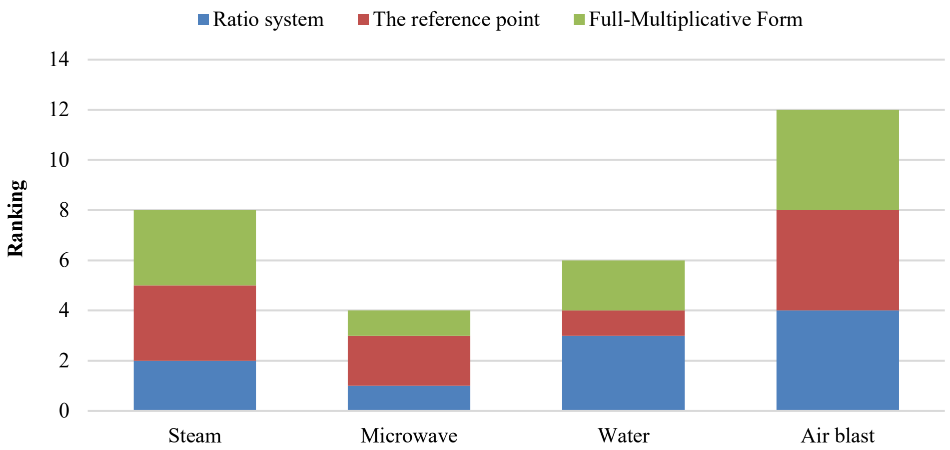

Fig. 3. Evaluation of MULTIMOORA ranking.

Fig. 3 shows the ranking values combined, meaning that thawing method with the highest number of achieved rank is the least efficient method. In this case, the most efficient method is air blast method that shows the best results in all three methods and MULTIMOORA altogether. Microwave thawing method is assumed to be the least efficient method as the overall number of ranking is the lowest. Obtained results show that air blast technology would be the best option in case when new thawing method are being implemented in the manufacturing process. Thawing method using steam also has high potential to be used for thawing processes. However, both water and microwave methods need to be clearly evaluated for each company before being introduced in the company. Additional evaluation of criteria would be suggested, performing analysis with the precise data of the particular company for better understanding of the results and the most suitable thawing method.

4. Discussion and Conclusions

Thawing could be a high energy demanding and resources (including water, electricity, etc.) consuming process, thus attention needs to be payed to performance of it. In this research paper, fish thawing process has been analysed.

MULTIMOORA method was used to evaluate various thawing methods (including steam, water, microwave, and air blast), assuming that production of the company would be 5000 t of fish per year. The thawing method that showed the best results was air blast method. Indicators considered for the method were energy and water consumption, the price of technology, and created CO_2 emissions. It can be concluded that air blast technology shows the highest efficiency compared to other analysed thawing methods. This knowledge can be used when manufacturing companies need to consider the change of existing thawing technology to new one. In this research paper, thawing of fish is considered, however thawing is used in other fields as well, for example, meat, vegetable, etc., thus results of this study is applicable for thawing for other food products.

In this research paper, the thawing process within an actual fish processing company in Latvia is analysed. It was concluded that a high amount of energy is used in the current production, therefore replacement of the current boiler with a cogeneration plant is made. In this way the total amount and temperature of steam can be provided in a sustainable way.

Acknowledgement

This research is funded by the Ministry of Economics of the Republic of Latvia, project EnergyPath, project No. VPP-EM-EE-2018/1-0006.

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