TRIGENERATION IN DAIRY INDUSTRY: EXERGETIC AND ENVIRONMENTAL ASPECTS

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Abstract
Trigeneration cycles permit the combined production of power, heat and cold. Thus, it is possible to save fossil fuel and to reduce emissions of greenhouse gases, as compared to the separate production of these commodities. Having in view that dairy industry plays an important role inside food industry and admitting that dairy industry is a significant energy consumer, the implementation of trigeneration will be of great relevance. This paper present the exergetic aspect and the environmental one of a trigeneration technology analyzed in this study. The solution might be implemented in a dairy farm and is based on a gas engine with an absorption type cooling machine working with NH3 – H2O.
The exergetic analysis is based on first and second law of thermodynamics, and shows the thermodynamic imperfection of a process, including all quality losses of materials and energy that are omitted using the first law analysis. Using natural gas instead of a fossil fuel, will result CO2 emission reduction due to trigeneration. Also, the used refrigerant (NH3) has good thermodynamic properties and is an environmentally friendly one.

Keywords: diary industry, trigeneration, exergy, emission

1. INTRODUCTION

Kyoto Conference, held in 1997, was the event where industrialized countries decided to diminish the CO2 emissions for the mitigation of the global climate change. Intergovernmental Panel on Climate Change (IPCC) predicts that energy and industrial sectors based on fossil fuels are responsible for about half of anthropogenic CO2 emissions. A more efficient energy use and wide penetration of renewable fuels use instead of fossil fuels are ways to follow in order to reduce CO2 emissions.

A solid option in the frame of increasing the renewable share and the efficiency of energy production is trigeneration. This technology allows the production of three energy products: power, heat and cooling. Trigeneration can offer a better efficiency than producing the three energy products separately while diminishing the environmental impact. The main applications for trigeneration are local plants within shopping centers, office buildings and industrial processes. Trigeneration offers benefits not only to the building owners but to the society itself. Such a technology is able to pay for itself in less than 2 years, according to the specific local electric rates, costs of natural gas or other fuels used and the load profile of the building [1]. Other advantages are related to the increased power reliability, reduced power requirements on the electric grid, improvement of the environmental quality, diminished energy consumption, less dependence on oil coming from abroad.

Trigeneration plants may use natural gas, which replacing other fossil fuel led to the reducing in the emissions of the CO2. In the following table, the emission factors of greenhouse effect gases are presented for the main fuels, including natural gas. It is seen that the emission factors of C, CO and NOx of the fossil fuels are higher than those for natural gas.

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Emission factors (t/TJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>21.10</td>
</tr>
<tr>
<td>Diesel oil</td>
<td>21.81</td>
</tr>
<tr>
<td>Natural gas</td>
<td>15.30</td>
</tr>
<tr>
<td>Firewood</td>
<td>0.00</td>
</tr>
<tr>
<td>Coal</td>
<td>26.80</td>
</tr>
<tr>
<td>Sugar cane bagasse</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Using a green refrigerant like ammonia in the system, is assured the working with a zero Ozone Depletion Potential refrigerant, the main environmental problem in connection with refrigeration and air-conditioning, which led to the regulation of the Montreal Protocol.

2. ABOUT THE DAIRY INDUSTRY

Dairy industry involves processing raw milk into products such as consumer milk, butter, cheese, yogurt, condensed milk, milk powder and ice cream.

It uses processes like chilling, pasteurization and homogenization. Typical by-products include buttermilk, whey and their derivates. Dairy industry plays a vital role in most countries economy and in foreign trade, due to its size, growth and diverse products. The industry is dependent on energy for the processes required for food freshness and safety. Due to its important energy consumptions, dairy industry presents a high potential for trigeneration, specially in regions where natural gas reserves are significant.

In the traditional way, dairy industry is characterized by different demands, as seen in Figure 1.

This industry offers, as seen above, an important number of products. Produced electricity is used to operate pumps, stirring rods, beaters, mills, slicing machines, packing machines, heating systems, fans and compressors and many others. Produced steam is used to pasteurize, to sterilize, to heat water and air and for cleaning.

Its other functions refer to packing machines, industrial pots, etc. Produced chilled water is used in pasteurizing machines, cooling machines, production tanks, packing machines, cooling rooms and in the salt water in which cheese is submerged during manufacture. Produced cooling tower water is used in pasteurizing machines, production tanks, etc. It covers the cooling needs is activities that do not require chilled water. There is also the possibility to use cooling tower water in series with chilled water. Produced compressed air is used in pressing, cutting or packing activities. Produced potable water is used in the manufacture process of different products, preparation of ferments, cleaning, etc.

3. THE EXERGETIC ASPECT OF THE TRIGENERATION SYSTEM USE

For a dairy farm asking for electricity, heat and cold, is depicted the trigeneration technology given by the solution of internal combustion engine coupled with an absorption type cooling machine working with NH3 – H2O. The combined solution is given in Figure 2. The annual energy demands are noted by P (power), Q (heat) and C (cold).

The exergy analysis overcomes the limitations of the first law of thermodynamics. The exergy concept is based on the first and second laws of thermodynamics.
Exergy is the maximum useful work which can be obtained from an energy carrier, imagining that this energy carrier is conducted until the environment conditions through a reversible process.

Its application indicates clearly the locations of energy degradation in a process and allows one to quantify the loss of efficiency due to the loss of the quality of the energy, thus indicating where the process can be improved and, therefore, what areas should receive technical attention.

Figure 3 depicts the exergetic flows for a trigeneration plant. The consumed exergy was written as \( E_x \) and useful exergy as \( E_u \).

The exergy balance leads to the calculation of the irreversibility (also known as exergy destruction or exergy loss).

\[
\begin{align*}
\sum E_{\Delta}^{p,q,c} &= E_x^p + Q + C \\
E_x &= P - \Delta P^Q - P_c, \quad E_u^Q \\
E_u &= \sum E_{\Delta}^{p,q,c} \\
E_c &= E_x^p + \sum E_{\Delta}^{p,q,c}
\end{align*}
\]

(1)

Exergy losses consists of exergy flowing to the surroundings, whereas exergy destruction indicates the loss of exergy inside the process boundaries due to irreversibility [2].

The exergy balance is:

\[
E_x^p + Q + C = P - \Delta P^Q - P_c + E_u^Q + E_u + \sum E_{\Delta}^{p,q,c}
\]

The exergetic losses caused by irreversibilities are symbolized by \( E_{\Delta}^{p,q,c} \) and \( P_c \) is the power consumed by the refrigeration plant. The term \( \Delta P^Q \) is the power diminished due to cogeneration (combined production of heat and power).

4. THE ENVIRONMENTAL ASPECT OF THE TRIGENERATION SYSTEM USE

As mentioned before, trigeneration represents an option when we speak about reducing CO\(_2\) emissions. For a natural gas, used instead of a fossil fuel, with the composition: methane 90\%, ethane 6\%, nitrogen 3\%, carbon dioxide 1\%, and considering a complete burning, the methane is completely transformed in CO\(_2\). The CO\(_2\) emissions (\( e_{CO_2} \)) for 1 MWh of this type of natural gas is 0.198 t CO\(_2\).

In calculation, CO\(_2\) emissions reduction will be determined by the multiplication of fuel savings with the specific carbon dioxide production of 1 MWh of natural gas [3]. CO\(_2\) emission in the case of trigeneration is:

\[
e_{CO_2}^T = e_{CO_2}^{boiler} \cdot F_{boiler} + e_{CO_2}^{eng} \cdot F_{eng} + e_{CO_2}^{el} \cdot (E_h - E_s) \tag{3}
\]

In the above equation \( F \) means annual fuel consumption, \( E_h \) is electricity bought to the grid and \( E_s \) is electricity sold to the grid, if the engine produces more electricity then the needs are.

The annual CO\(_2\) emission reduction due to the trigeneration is:

\[
\Delta e_{CO_2} = e_{CO_2}^S - e_{CO_2}^T \tag{4}
\]

Where \( e_{CO_2}^S \) denotes the CO\(_2\) emissions in the case of separate production:

\[
e_{CO_2}^S = e_{CO_2}^{boiler} \cdot F_{boiler} + e_{CO_2}^{el} \cdot E_h \tag{5}
\]
The advantage of the absorption type cooling machine working with NH₃ – H₂O is given by ammonia as the refrigerant. Its presents good thermodynamic properties and of heat transfer. Is widely available and inexpensive [4].

The air-conditioning and refrigeration industry has been facing a major transition in the last decades, inforced by the environmental concern related with the impacts of refrigerant emissions. The first global environmental issue revealed was depletion of stratospheric ozone. Are shown old-generation refrigerant as the important contributors to the depletion of the stratospheric ozone layer. Except the care for the ozone depletion, the global warming concern, with need of greenhouse gas emissions reductions, is also on the agenda of specialists. Refrigeration contributes to global warming both by the release of refrigerants and by the emission of carbon dioxide and other greenhouse gases is powering the equipment.

In this context, ammonia has again become a serious contender for use in refrigeration. It is natural, halogen free substance, with no ozone depletion potential (ODP=0) no global warming effect (GWP=0).

The major disadvantages are that it is toxic (MAK 50 ppm) and flammable in certain concentrations.

5. CONCLUSIONS

The paper revealed the high potential for trigeneration of the dairy industry, due to its various utilities and great variety of products and processes.

The implementation of this solution in a dairy farm will allow the production of power, heat and cold needed in its activity.

The benefits bought by this technology are also environmental, being possible to estimate the annual CO₂ emission reduction obtained due to trigeneration.

6. REFERENCES


