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Energy utilization, carbon dioxide emission, and exergy loss in flavored yogurt production process

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ABSTRACT

This paper investigates the impact of food production processes on the environment in terms of energy and exergy utilization and carbon dioxide emission. There are three different energy utilization mechanisms in food production: Utilization of solar energy by plants to produce agricultural goods; feed consumption by herbivores to produce meat and milk; fossil fuel consumption by industrial processes to perform mixing, cooling, heating, etc. Production of strawberry-flavored yogurt, which involves these three mechanisms, is investigated here thermodynamically. Analysis starts with the cultivation of the ingredients and ends with the transfer of the final product to the market. The results show that 53% of the total exergy loss occurs during the milk production and 80% of the total work input is consumed during the plain yogurt making. The cumulative degree of perfection is 3.6% for the strawberry-flavored yogurt. This value can rise up to 4.6%, if renewable energy resources like hydropower and algal biodiesel are employed instead of fossil fuels. This paper points the direction for the development of new technology in food processing to decrease waste of energy and carbon dioxide accumulation in the atmosphere.

1. Introduction

Scarcity of energy resources and carbon dioxide concentration in the atmosphere are two major concerns of humanity. Since the beginning of the industrial revolution in 1850's, energy demand is rising, resources are diminishing and carbon dioxide concentration in the atmosphere is increasing. Consequences are publicly blamed for numerous environmental and climatic adverse observations. Increasing thermodynamic efficiency and decreasing CO_2 emission are essential. This paper illustrates the importance of a detailed thermodynamic analysis for a food production process. The strawberry-flavored yogurt production process is selected as an example, since it involves three important stages: agriculture, dairy farming, and industrial processes. Plants take energy from a renewable source, i.e. sun, and perform photosynthesis. The environmental cost for the agriculture is only due to the consumption of non-renewables, such as fertilizers, microelements and diesel consumed by farming machinery. Herbivores take energy from plant-based feed and use this energy for growth, locomotion, heat transfer, etc. In the case of calves, a small part of the intake energy is used for lactation, too. Industrial processes mainly consume fossil fuels; thus, the environmental cost of these operations is rather large. This paper shows the thermodynamical differences between the consumption of renewables and non-renewables by plants through photosynthesis, by calves to synthesize milk, and by industrial processes like mixing, refrigeration, transportation etc.

Energy utilization to produce several food products had been the subject of some studies in the past. However, the overall production process of flavored yogurt had never been a subject of such a study before. The exergy loss and carbon dioxide emission was not a part of previous studies either. This paper presents a unique approach, where the energy utilization, the carbon dioxide emission, and the exergy loss are calculated for a food product starting with the cultivation of the ingredients in the farm, and ending with the transfer of the final product to the market.

2. Methods

Fig. 1 shows the system chosen for the analysis. System boundaries involve milk production in the dairy farm, agriculture of strawberry and sugar beet, industrial processes to produce milk

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Nomenclature

b	Stream availability, kJ/kmol
CDP	Cumulative degree of perfection, –
CCO_2E	Cumulative carbon dioxide emission, kg/ton
CEnC	Cumulative energy consumption, MJ/ton
CExC	Cumulative exergy consumption, MJ/ton
h	Enthalpy, kJ/kmol
m	mass, kg
Q	Heat, kJ
s	Entropy, kJ/(kmol K)
T	Temperature, K
W	Work output from the system, kJ
x	Molar fraction
X	Exergy, kJ

Subscripts

0	Restricted dead state
i	Any species
in	Inlet
k	Index of heat sources
out	Outlet

Superscripts

th	Thermomechanical
ch	Chemical

powder, sugar, jam and flavored yogurt, and recycling and waste management. Hydrosphere, lithosphere, and atmosphere act as water and carbon reservoirs, and are included within the system boundaries. Nutrient rich water consumed during the production is fully recycled. Fertilizers, pesticides, and micronutrients consumed during the agriculture are non-renewable chemicals, and the environmental cost for these raw materials is accounted for. Electricity used in all processes is generated from fossil fuels. The energy or exergy consumed due to human labor is not accounted for, since it was practically impossible to collect representative data. Transportation of goods is also taken into account. Average transportation distances are determined by considering the geographical situation in Turkey. Product delivery trucks are considered to be making one-way trip only, since in practice they usually carry other products on the way back. If trucks return empty, than the distance is multiplied by two to determine the actual distance traveled.

Data about the agriculture of strawberries and sugar beet, dairy farming and transportation are obtained from the literature. Information regarding energy utilization and processing rates of the equipment are obtained from the manufacturer web sites.

Mass, energy and exergy balance is performed for each operation. Exergy (availability) is defined as the maximum work that a system can produce, without violating the laws of thermodynamics, if it is brought to thermal, mechanical, and chemical equilibrium with its surroundings via reversible processes. The governing equations for this steady-flow system are:

Mass balance:

$$\sum (m)_{in} - \sum (m)_{out} = 0 \tag{1}$$

Energy balance:

$$\sum (mh)_{out} - \sum (mh)_{in} = Q - W \tag{2}$$

Exergy balance:

$$\sum (mb)_{in} - \sum (mb)_{out} - \sum_k Q_k \left(1 - \frac{T_0}{T_k}\right) - W = X_{loss} \tag{3}$$

Where k is the number of heat sources and b is the flow availability of a stream. The exergy content of a stream depends on its thermomechanical state (pressure, temperature, composition) and

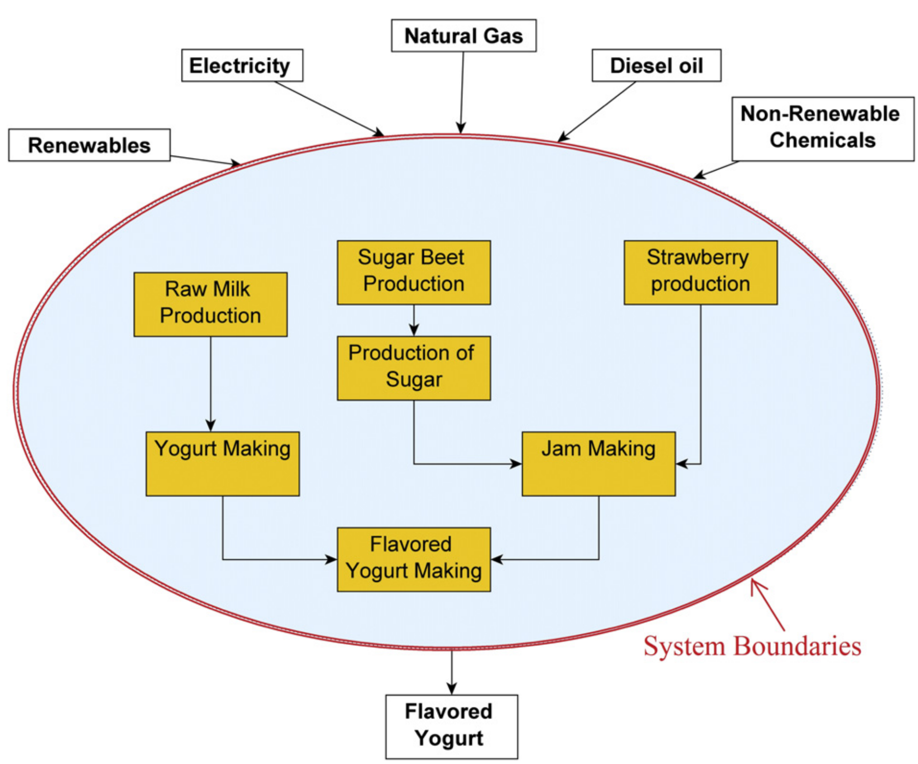

Fig. 1. Overall system.