Energy and Exergy Analysis of Fish Snack process

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ABSTRACT

Energy analysis of food processing has been a subject of several recent studies. To evaluate the energy efficiency of a process, energy analysis base on the first law of thermodynamics i.e., enthalpy (in case of thermal energy) used to be considered. But the first law of thermodynamics itself is not enough to display the truthful efficiency of energy. Then, the concept of exergy is introduced to the energy analysis. This paper was carried on the exergy analysis of the fish snack process. The EUD (Energy Utilization Diagram) was also applied as a tool to display the energy utilization scheme in each part of process system as well as the overall process graphically. The distributions of both the exergy loss and energy transformation were classified based on EUD. From the result of energy analysis, the possibility of improvement can be found out and the guidance was proposed as well as economic study.

***key words:** energy analysis, exergy analysis, Energy Utilization Diagram*

INTRODUCTION

Energy is very important in any kind of industry. There are two kinds of energy that mainly are used, i.e. thermal energy and electrical energy. In the past, to evaluate the energy efficiency of a process, energy analysis based on the first law of thermodynamics i.e., enthalpy (H) in the case of thermal energy, used to be considered. When we want to estimate both energy quantity and quality at the same time, the exergy concept will be included in the analysis of that process. Obviously an efficient system is the one in which energy losses are minimized. The second law of thermodynamics, or the entropy (S) increase law, is useful to indicate how much degradation of the quality of energy is associated with its usage. Exergy analysis is based on the separate quantification and accounting of usable energy called exergy (Ex) and unusable energy called irreversibility.

The term exergy is made up of two parts: ex come from Latin prefix for from or out, akin to Greek (ex) and ergon-Greek for work. In the past, the term "available energy" was used but now the term exergy was preferable in the energy society. The exergy analysis method will provide the true measure of effectiveness of energy uses through its application. It is a systematic approach of applying the first and second laws of thermodynamics to components and processes. However, the application of the second law of thermodynamics has been limited since lacking of information. The first law of thermodynamics, discussed in a later section, is widely used in engineering practice and it is the basis of the heat-balance method of analysis that was commonly used in energy-systems performance analysis. System involving heat or refrigeration uses the enthalpy of the working fluid in an energy balance to evaluate the system performance characteristics. Enthalpy is a function of the state of a substance and is defined as

$$H = I + PV \quad (1)$$

where I is the internal energy of the substance. A change in enthalpy is then

$$dH = dQ + Vdp \quad (2)$$

where dQ is the change in heat energy. Under a constant-pressure condition

$$dH = dQ = c_p dT \quad (3)$$

where c_p is the specific heat of the substance at constant pressure.

The second law of thermodynamics involves the reversibility and irreversibility of processes and is a very important aspect in the exergy method of energy-systems analysis. Ideal processes that are reversible do not occur in the real world, and the transfer of heat or the conversion of heat and work from one form to another always results in some work or heat loss. The fact that these losses occur in every energy process to some degree means that each time the working fluid in a system goes through a process, some of the initial available work in the working fluid is lost. Because of this loss, the working fluid cannot be returned to its initial state prior to the process without the aid of external work to account for the lost work. Under these conditions the process is irreversible. The irreversibility of a process is accounted for in the second law of thermodynamics and is indicated by an increase in entropy production that is not matched by equivalent production of work.

The exergy method is concerned with how well we use the available work that is generated from our energy resources. It answers the question of where, why, and how much of this available work is lost in our systems. This is the information required to design and operate more efficient systems from the energy conservation viewpoint. The application of the exergy method required the extensive use of entropy. This poses no problems since entropy is considered as a property similar to enthalpy and is listed in table for many materials. In those cases where tabular values of entropy are not available, entropy can be calculated from

$$dS = \frac{dH}{T} \tag{4}$$

Since dH = enthalpy, the entropy equivalence for any form of work or energy can be calculated.

The exergy analysis method is based on evaluating the work that is available at various points in a system. From an analysis of the available work throughout a system the quantity and location of lost work and useful work can be determined. This is the information required to make a complete exergy analysis of a system and to locate inefficient processes, equipment, or operating procedures. There are two approaches to evaluating the available work in a system, one for designing new systems and the other for evaluating existing systems. Available work is calculated on the basis of a final heat-sink reference that is generally taken as the surrounding environment. The available work at any given point in a system is

$$\text{Available work} = (H-H_o) - To(S-S_o)$$

For a given process the change in available work from point 1 to point 2 is

$$\text{Available work change} = (H_2-H_1) - To(S_2 - S_1)$$

If no useful work is done in the process, this change is a loss in available work. One parameter used in system selection is the plant efficiency, which is usually based on a heat-balance analysis. A true measure of the plant efficiency is based on the available-work principle:

$$\eta = \frac{useful\ work}{available\ work} = \frac{available\ -\ lost\ work}{available\ work}$$

EUD (Energy Utilization Diagram)

EUD (Energy Utilization Diagram) has been utilized as a graphic tool for analyzing the energy and exergy loss in a chemical process. It can simultaneously describe the results of the first and the second laws of thermodynamics on a single diagram. Because of its extension from a diagram between $(1-T_o/T)$ versus Q, Ishida and Ohno (1983), to a diagram between the energy level A and the energy transformation including physical or chemical processes.

When an energy transformation in a process system is examined, we can refer to statements of energy conservation, the first law of thermodynamics and the second law of thermodynamics as follows:

$$\Delta H_{ed} + \Delta H_{ea} = 0 \tag{5}$$
$$\Delta S_{ed} + \Delta S_{ea} \geq 0 \tag{6}$$

Every process must donate or accept energy at some certain energy level. The process which donates energy is called energy donor and the one accepts energy will be called energy acceptor where ΔH_{ed} and ΔS_{ed}, respectively, mean the change is enthalpy and entropy for an energy-donating process, while ΔH_{ea} and ΔS_{ea} mean those for an energy-accepting process. In equation (6), the total entropy change in the whole system must be greater than or equal to zero.

The entropy has a dimension of energy temperature. Thus, the exergy change Δex can be defined as follows:

$$\Delta Ex = \Delta H - T_0 \Delta S \tag{7}$$

where T_0 is the reference temperature and its set at 298.15 K (25°C) in this study.

As for summation of the exergy change, we can have

$$\Delta Ex_{ed} + \Delta Ex_{ea} = (\Delta H_{ed} + \Delta H_{ea}) - T_0(\Delta S_{ed} + \Delta S_{ea})$$
$$= -T_0(\Delta S_{ed} + \Delta S_{ea}) \geq 0 \tag{8}$$

Hence, $-(\Delta Ex_{ed} + \Delta Ex_{ea})$ is always positive and this amount is the exergy loss caused by the energy transformation.

Then,

$$\Sigma \Delta E_i = -\Delta E_{ed} - \Delta E_{ea}$$
$$= \Delta H_{ea}[-(\Delta E_{ed}/\Delta H_{ea}) - (\Delta E_{ea}/\Delta H_{ea})]$$
$$= \Delta H_{ea}[(\Delta E_{ed}/\Delta H_{ed}) - (\Delta E_{ea}/\Delta H_{ea})]$$
$$= \Delta H_{ea}(\Delta A_{ed} - \Delta A_{ea}) \geq 0 \tag{9}$$

where A is defined as

$$A = \frac{\Delta Ex}{\Delta H} = 1 - \frac{T_0}{(T)} \tag{10}$$

A is called the energy level. A is the height along the ordinate, i.e., the energy level of an energy donor must be greater than or at least equal to that of an energy acceptor. It is an intensive value and represents the energy quality. Since the energy change of the acceptor process ΔH_{ea} is positive, we can have

$$\Delta A_{ed} \geq \Delta A_{ea} \qquad (11)$$

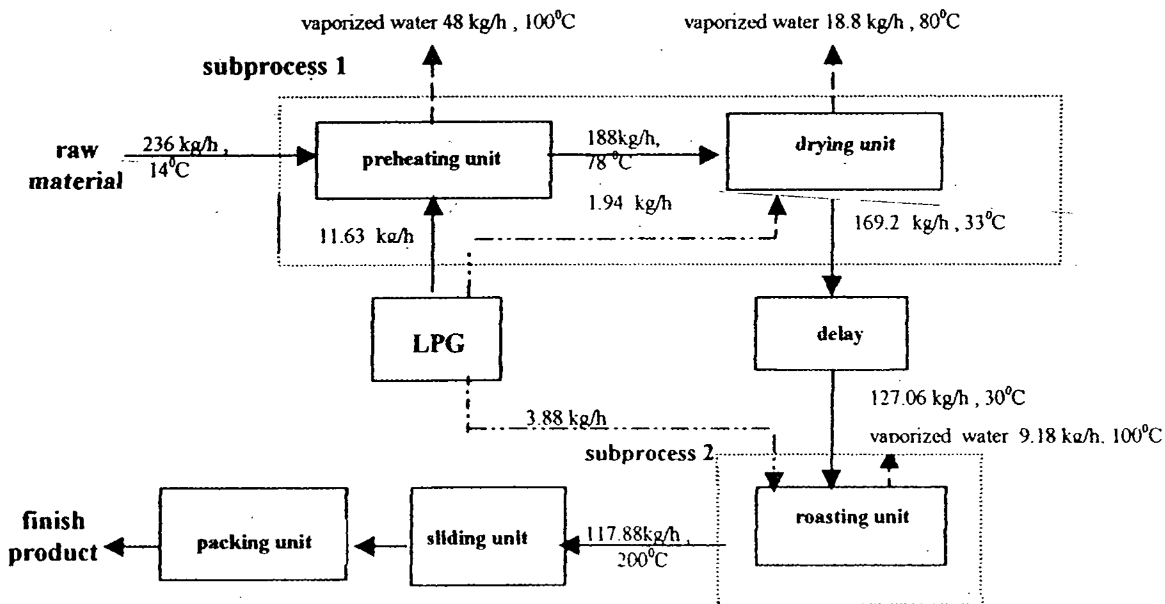
Equation (11) shows that the energy level of the energy donor must be greater than, or at least equal to, that of the energy acceptor.

The Energy Utilization Diagram (often abbreviated as EUD) is a diagram in which the energy levels, A_{ed} for the energy donating process and A_{ea} for the energy accepting process are plotted against the transformed energy ΔH_{ea}. The amount of exergy loss in the subsystem can be seen on the diagram as the area between the curves of A_{ea} and A_{ed}, where the difference $(A_{ed} - A_{ea})$ indicates the driving force for the energy transformation.

ENERGY AND EXERGY ANALYSIS OF FISH SNACK PROCESS

Figure 1 shows a simplified diagram of fish snack process. Raw material was low temperature fish paste. It was formed into sheet at the sheeting forming unit. I this unit did not have thermal energy. The fish shee moisture was removed in the preheating unit. It was fe 236 kg/h at 14°C and its output was 188 kg/h at 78°C The water 48 kg/h was vaporized at 100°C. The shee fish's specific heat was 3.433 kJ/kg°C. Then, the fisl sheet was sent to dry in drying unit. Temperature ir dryer was 80°C . The fish sheet had 33°C outsid dryer. The dry sheet was left. To produce the fisl snack product, the sheet was roasted in the roasting uni to have a sponge form of product. After delay, it ha 127.06 kg/h at 30°C and 117.88 kg/h at 200°C outsid roasting unit . It had vaporized water 9.18 kg/h a 100°C. After that, it was carried to the sliding unit t cut into small pieces and continued to the packing uni to be ready as finished products. The heat source o process was heat from the combustion of liqui petroleum gas (LPG). Low Heating Value of LPG wa 45,606 kJ/kg.

The fish snack process had two subprocesses. Ir this subprocess, there were the preheating unit and th drying unit.



Simplified diagram of fish snack process

RESULT OF ENERGY AND EXERGY ANALYSIS

In Table 1, for example, efficiency (eff_i) meaned enthalpy efficiency which is defined by enthalpy output divided by total enthalpy input and eff_e meaned exergy efficiency (effectiveness) defined in the same manner.

Preheating Unit

Table 1. Enthalpy analysis of preheating unit

enthalpy input	kJ/h	%	enthalpy output	kJ/h	%
1. fish	-8912.07	-1.7	1. fish	3.42×10^4	6.6
2. LPG	5.30×10^5	101.7	2. vaporized water	1.08×10^5	20.7
			3. loss	3.79×10^5	72.7
			- heat loss	2.32×10^4	6.1
			- other	3.56×10^5	93.9
ΣH	5.21×10^5	100.0	ΣH	5.21×10^5	100.0
			$eff_i = \frac{(1.42 \times 10^5)}{(5.21 \times 10^5)} \times 100$ = 27.26 %		

The preheating unit had its efficiency 27.26 % and its effectiveness 4.93 % as shown in Table 1 and 2, respectively. Heat loss means lost from equipment, whereas other means all lost of that unit.

Table 2. Exergy analysis of preheating unit

exergy input	kJ/h	%	exergy output	kJ/h	%
1. fish	341.40	0.06	1. fish	5.16×10^3	0.9
2. LPG	5.46×10^5	100.0	2. vaporized water	2.17×10^4	4.0
			3. loss	1.25×10^5	22.9
			- heat loss	6.85×10^3	5.5
			4. irreversibility	3.94×10^5	72.2
ΣEx	5.46×10^5	100.0	ΣEx	5.46×10^5	100.0
			$eff_e = \frac{(2.69 \times 10^4)}{(5.46 \times 10^5)} \times 100$ = 4.93 %		

Drying Unit

Table 3. Enthalpy analysis of drying unit

enthalpy input	kJ/h	%	enthalpy output	kJ/h	%
1. fish	3.42×10^4	28.0	1. fish	4.65×10^3	3.8
2. LPG	8.85×10^4	72.0	2. vaporized water	4.23×10^4	34.4
			3. loss	7.60×10^4	61.8
			- wall	5.43×10^3	7.1
			- other	7.06×10^4	92.9
ΣH	1.23×10^5	100.0	ΣH	1.23×10^5	100.0
			$eff_i = \frac{(4.70 \times 10^4)}{(1.23 \times 10^5)} \times 100$ = 38.21 %		

The dryer size was 2.33 m x 6.4 m x 4.50 m and coated with fiber glass 3 inch thickness insulation Then heat loss from dryer's wall was 7.1 %.

Table 4. Exergy analysis of drying unit

exergy input	kJ/h	%	exergy output	kJ/h	%
1. fish	5.16×10^3	5.4	1. fish	121.51	0.1
2. LPG	9.11×10^4	94.6	2. vaporized water	8.50×10^3	8.8
			3. loss	3.41×10^3	3.6
			- wall	309.16	9.1
			4. irreversibility	8.43×10^4	87.5
ΣEx	9.63×10^4	100.0	ΣEx	9.63×10^4	100.0
			$eff_e = \frac{(8.61 \times 10^3)}{(9.63 \times 10^4)} \times 100$ = 8.95 %		

Overall Of Subprocess 1

Table 5. Enthalpy analysis of overall of subprocess 1

enthalpy input	kJ/h	%	enthalpy output	kJ/h	%
1. fish	-8912.07	-1.5	1. fish	4.65×10^3	0.8
2. LPG	6.19×10^5	101.5	2. vaporized water	1.50×10^5	24.6
			3. loss	4.55×10^5	74.6
ΣH	6.10×10^5	100.0	ΣH	6.10×10^5	100.0
			$eff_i = \frac{(1.55 \times 10^5)}{(6.10 \times 10^5)} \times 100$ = 25.41 %		

For subprocess 1, which means preheating and drying unit had efficiency 25.41 % and effectiveness 4.74 % as shown in Table 5 and Table 6, respectively.

Table 6. Exergy analysis of overall of subprocess 1

exergy input	kJ/h	%	exergy output	kJ/h	%
1. fish	341.40	0.05	1. fish	121.51	0.0
2. LPG	6.37×10^5	100.0	2. vaporized water	3.01×10^4	4.7
			3. loss	9.67×10^4	15.2
			4. irreversibility	5.10×10^5	80.1
ΣEx	6.37×10^5	100.0	ΣEx	6.37×10^5	100.0
			$eff_e = \frac{(3.02 \times 10^4)}{(6.37 \times 10^5)} \times 100$ = 4.74 %		

Roasting Unit

In this unit, the fish sheet had a quite low moisture about 9.18 kg/h. From Table 7 and Table 8, its efficiency was 51.12% and its effectiveness was 16.70%

Table 7. Enthalpy analysis of roasting unit

enthalpy input	kJ/h	%	enthalpy output	kJ/h	%
1. fish	2.18×10^3	28.0	1. fish	7.08×10^4	39.6
2. LPG	1.77×10^5	72.0	2. vaporized water	2.07×10^4	11.6
			3. loss	8.75×10^4	48.8
			- heat loss	9.09×10^3	10.4
			- other	7.84×10^4	89.6
ΣH	1.79×10^5	100.0	ΣH	1.79×10^5	100.0
			$eff_i = \frac{(9.15 \times 10^4) \times 100}{(1.79 \times 10^5)} = 51.12\ \%$		

Table 8. Exergy analysis of roasting unit

exergy input	kJ/h	%	exergy output	kJ/h	%
1. fish	35.96	0.0	1. fish	2.62×10^4	14.4
2. LPG	1.82×10^5	100.0	2. vaporized water	4.16×10^3	2.3
			3. loss	2.58×10^4	14.2
			- heat loss	3.00×10^3	11.6
			4. irreversibility	1.26×10^5	69.1
ΣEx	1.82×10^5	100.0	ΣEx	1.82×10^5	100.0
			$eff_e = \frac{(3.04 \times 10^4) \times 100}{(1.82 \times 10^5)} = 16.70\ \%$		

EUD OF FISH SNACK PROCESS

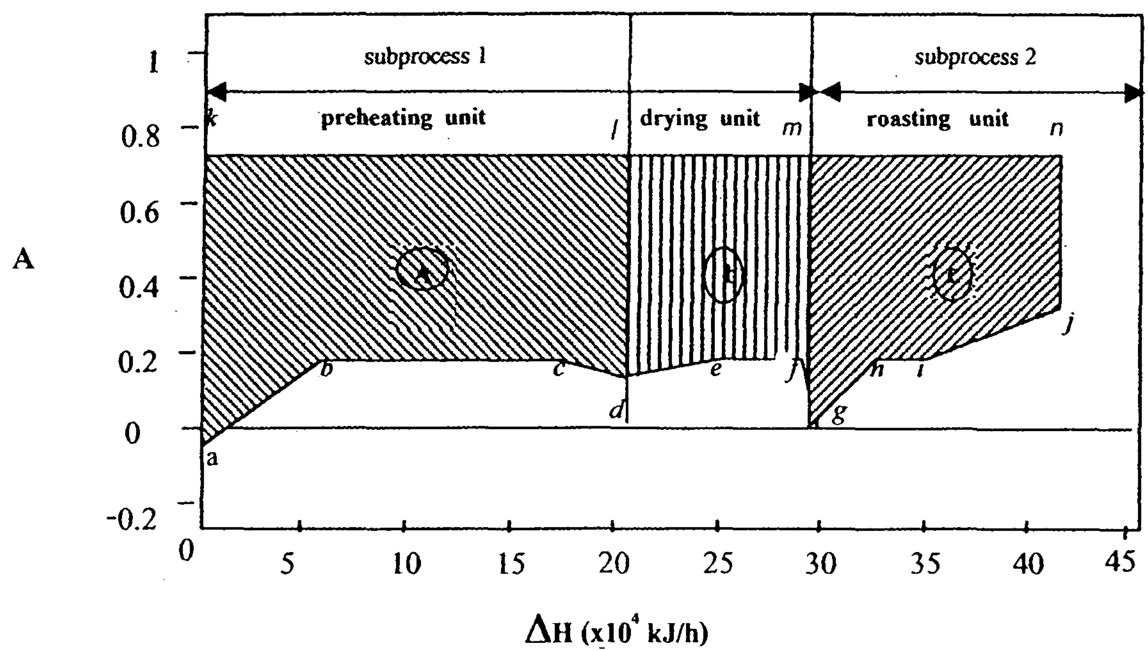


Fig 2. EUD of fish snack process

Figure 2 showed EUD of overall fish snack process. The exergy loss of preheating unit shown as area (A) was more than that of drying unit (B) and roasting unit (C). At preheating unit, energy donor process represents by line *kl* was heat combustion of LPG around 1100°C. While the energy accepting processes were heating process of fish sheet from 14°C to 100°C, represented by line *ab*, vaporizing moisture at 100^0C represented by *bc* and changing temperature of sheet from 100^0C to 78^0C represented by *cd*.

At the drying unit and roasting unit, the energy donating process, *lm* and *mn*, were similar to the preheating unit. The energy accepting processes were *de*, *ef* and *fg* lines. For roasting unit, they were *gh*, *hi*, and *ij* lines.

CONCLUSION

This paper was carried on the exergy analysis of the fish snack process . From the analysis, the fish snack process had two subprocesses. Subprocess 1 had the overall efficiency 25.41 % and its effectiveness 4.74 % . In this subprocess, there were the preheating unit and the drying unit . Their efficiencies were 27.26 % and 38.21 % and their effectivenesses were 4.93 % and 8.95 %, respectively. Subprocess 2, there was only roasting unit. It had efficiency 51.12 % and effectiveness 16.70 %. For the possibility of improvement at preheating unit , the zinc plate was proposed to install as a heat loss protection. The plate could save LPG about 864 kg per year per line. By recovering heat form hot air of the roasting unit could save LPG about 1,440 kg per year per line.

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