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Oil–Water Separation Technology for Postharvest and Food Processing: Improving Productivity and Environmental Quality

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Oil-containing wastewater is generated during postharvest processing of crops and during food processing, and the oil reduces the efficiency of wastewater treatment processes and decreases water quality. In Japan, the water quality standard for facilities above a certain scale is set by the Water Pollution Control Law at <30 mg of n-hexane extracts per liter. There are many technologies for separating oil and water, including centrifugation, floatation, flocculation, and absorption. The recovered oil can be used as fuel and as a feedstock in the manufacture of tires, and especially the oil recovered under proper sanitary conditions can be used for cooking. Separation of the oil can also help to reduce the scale of wastewater treatment facilities, leading to a reduction in construction costs. In addition, separation improves wastewater quality and allows for the recycling of water, which is used in large quantities for food processing. In this separation engineering study, Value Function and Separative Work Unit were used to evaluate the economics of introducing oil–water separation technology to a food processing factory. The results, which revealed the economic performance equivalent to the degree to which the separation technology improved the wastewater treatment process, can be used to aid in decision-making regarding the feasibility of introducing oil–water separation technology in food processing facilities.

Key words: economic evaluation, oil–water separation, separation engineering, separative work unit, wastewater treatment

Introduction

Organic wastewater containing huge amounts of animal and vegetable oils is discharged from food-related facilities such as food processing factories, ramen shops, and school cafeterias, as well as from energy-related facilities such as palm oil factories. For example, at the Naoetsu-Yushi Co. Ltd. in Japan, the boiling of chickens generates wastewater that contains animal oils (Figs. 1 and 2), and this oil-containing wastewater decreases the separation ability of the factory's wastewater treatment facilities. At ramen shops and school cafeterias, washing the oil off of dishes and cooking equipment requires a large amount of dishwashing detergent, which decreases water quality. Oil clogs drains and generates offensive odors. To prevent these problems, additional staff members must be hired to clean the facilities. Wastewater generated at biomass refineries, such as palm oil factories, also contains considerable amounts of vegetable oil and is disposed of as industrial waste (Fig. 3). Recovery of palm oil from wastewater would not only increase profits but also reduce the amount of wastewater requiring treatment.

Oil–water separation technology is widely used to recover oil from wastewater generated during post-

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Fig. 1. Boil tank at the Naoetsu-Yushi Co. Ltd..

Fig. 2. Oil-containing wastewater generated at the Naoetsu-Yushi Co. Ltd..

Fig. 3. Oil-containing wastewater generated at a palm oil factory in Thailand.

harvest processing of crops and during food processing. There are many technologies for separating oil and water, including centrifugation, floatation, flocculation, and absorption. Recovering oil from wastewater prevents plumbing blockages and increases the processing ability of wastewater treatment facilities (Tsukii *et al*., 2008; Sato, 2009; Asakawa *et al*., 2010; Noguchi *et al*., 2012). Moreover, under proper sanitary conditions, the oil recovered during food processing can be used as food, and oil-free wastewater can be used as a water resource; that is, introducing oil–water separation technology offers an opportunity to generate a profit from effluent that would otherwise be wasted. In addition, the improved efficiency of a factory's wastewater treatment facilities can be expected to result in substantial cost reductions.

Although oil–water separation technology has the potential to improve water quality and productivity, it is not widely used in wastewater treatment systems. Objective evaluation has not been sufficient to encourage its adoption; therefore, economic evaluation based on a separation engineering analysis is required. In this study, the economic value produced by introducing oil–water separation technology at the Naoetsu-Yushi Co. Ltd. was calculated using Value Function (VF) and Separative Work Unit (SWU), and the cost recovery period for oil–water separation technology was determined and compared to the expected lifetime of the wastewater treatment system at the factory. The results of this study can be expected to facilitate decision-making regarding whether or not to introduce oil–water separation technology at some factories generating the oil-containing wastewater, not only the factory.

Materials and Methods

Food processing factory

The food processing factory, Naoetsu-Yushi Co. Ltd. produces boiled chickens from culled chickens, and the boiling process generates wastewater containing a large amount of organic oil, which causes wastewater treatment problems. In an attempt to solve these problems, oil–water separation technology was introduced into the wastewater treatment system of the factory. The technology operates on the basis of dif-

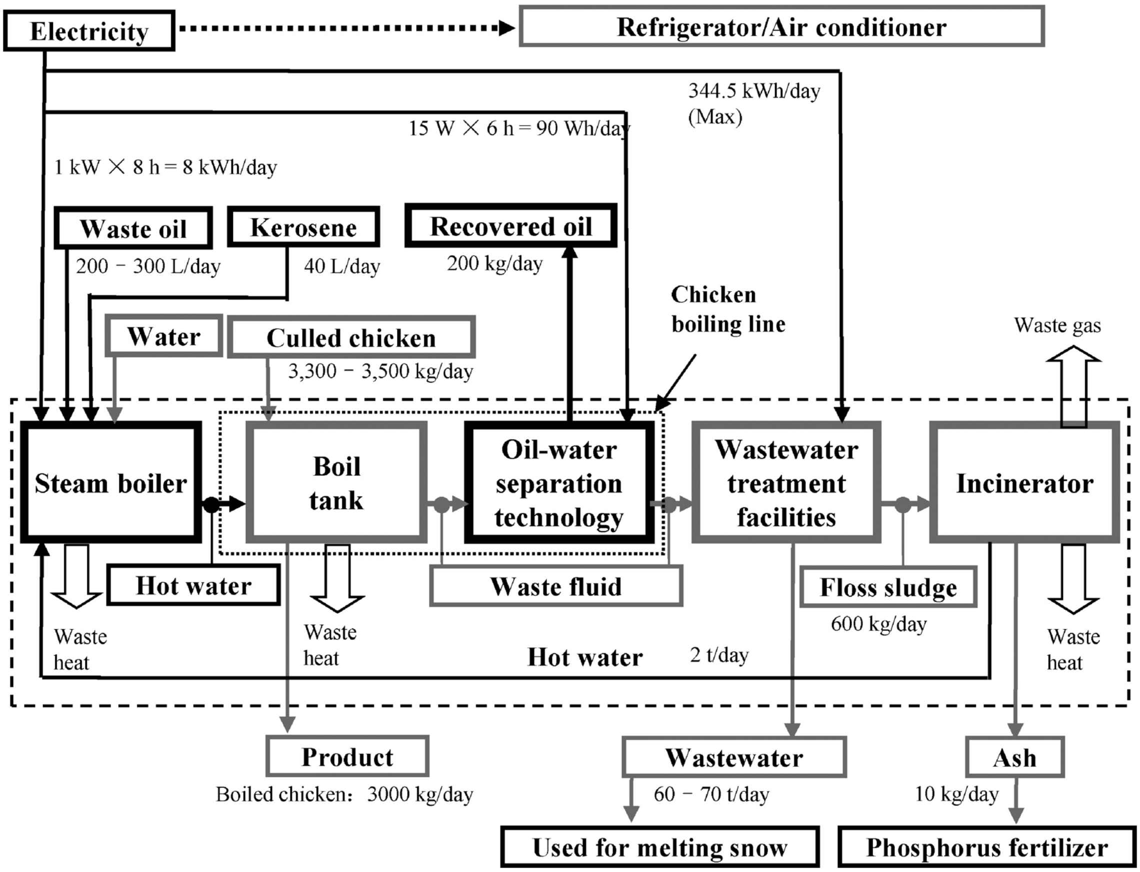

Fig. 4. Energy and material flow at the Naoetsu-Yushi Co. Ltd..

ferences between the specific gravities of water and oil and on the control of speed of wastewater flowing inside the technology; no chemical and biological treatments are involved. As a result, there are no changes in the water quality and no seasonal changes in the treatment volume, and controlling the treatment volume is easy. The energy and material flow of the factory is shown in Fig. 4. The oil recovered from the wastewater is used as fuel for the boiler, and the separated water is purified in the factory's wastewater treatment facility and used for melting snow.

Economic evaluation

In this study, an economic evaluation was conducted by using VF and SWU. This type of evaluation is widely used to analyze separation processes, particularly in the field of nuclear power engineering (Takeda, 1988; Fuchs and Peierls, 1997; Bernstein, 2009). In separation process, a feedstock is generally separated into products and wastes, and the separation ability of the process can be estimated from the difference between the value of the separated products and wastes and the value of the feedstock.

Recovered resource and evaluation conditions

The oil–water separation process evaluated in this study involved the separation of oil from oil-containing wastewater, for the purpose of using the recovered oil as a resource and reducing the load on the downstream wastewater treatment system. The recovered oil that contains minimum amounts of water and other contaminants has value as food not only fuel for the boiler, as long as sanitary conditions are maintained. As the amounts of water and other contaminants in the recovered oil increase, its value as fuel energy or food energy resource decreases. The separated water that contains no oil or other contaminants can be used as a source of non-potable water. The higher the proportion of oil and other contaminants in the separated water is, the less the gain in the value of the water

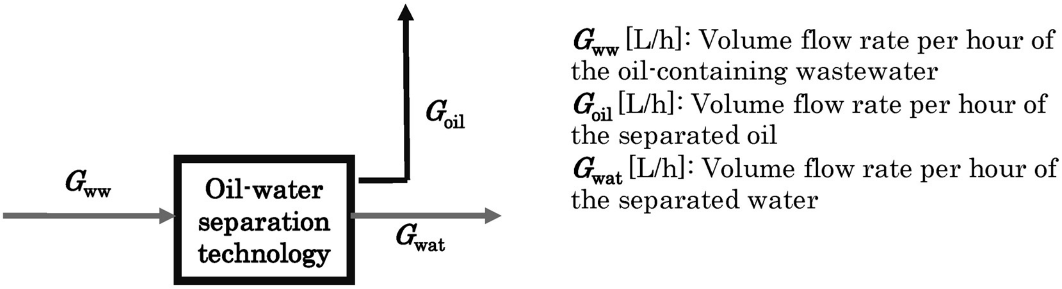

Fig. 5. Energy and material flow for the oil–water separation technology at the Naoetsu-Yushi Co. Ltd..

resulting from the increase in the work load required for water purification is. In contrast to separations that produce products and wastes from a feedstock, oil–water separation in this case produces two different products, oil and water, from the feedstock, oil-containing wastewater.

SWU for the separation was calculated on the basis of the previous studies using the material and energy flow of the food processing factory (Noguchi *et al*., 2011; Otsuka *et al*., 2013). On the assumption that contaminants other than oil could be removed easily, the wastewater was treated as containing only oil and water, and the separation of these resources was the focus of the calculation. The pressure and temperature were assumed to be the same before and after the separation.

G_{ww}, G_{wat}, and G_{oil} [L] are defined, respectively, as the volume (or mass) flow rates of the oil-containing wastewater of the separated water (which contains either no oil or less oil than the feedstock), and of the separated oil (which contains either no water or less water than the feedstock) (Fig. 5). SWU for oil–water separation, δU_s [JPY/h], was calculated using the following equation:

$$\delta U_S = G_{oil} V_S(X_{oil}) + G_{wat} V_S(X_{wat}) - G_{ww} V_S(X_{ww})$$

where $V_S(X)$ [JPY/L/h] is the value function that converts each concentration X to its economic value as resource; X_{ww} [-], X_{wat} [-], and X_{oil} [-] are, respectively, the mixing ratios (which correspond to the concentrations) of the oil in the oil-containing wastewater, the oil in the separated water, and the oil in the separated oil. V_s was determined from data presented at a hearing conducted at the food processing factory in March 2013 for the purpose of describing the current status of the factory.

In addition, the time required to recover the cost of introducing and maintaining the wastewater treatment system and the oil–water separation technology was determined from the calculated SWU.

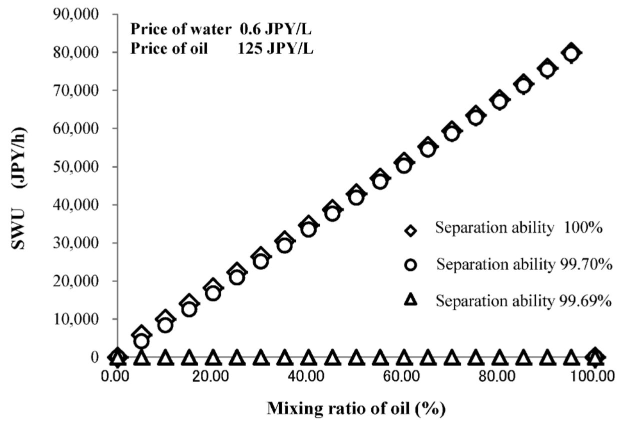

Fig. 6. Calculation of Separative Work Unit (SWU) for various mixing ratios of oil at the Naoetsu-Yushi Co. Ltd..

Results and Discussion

Using the VF based on the hearing conducted at the food processing factory, we calculated the effect of the mixing ratio of oil on the SWU as the separation ability of the oil–water separation technology which is equal to the purity of the recovered oil was decreased from 100% in increments of 0.01% (Fig. 6). At oil mixing ratios of 0% and 100%, the SWU was 0 JPY/h regardless of the separation ability because these ratios represent pure oil and pure water, for which no separation is required. At separation abilities of $<$99.70%, the SWU decreased sharply, almost to 0 JPY/h. This result indicates that a separation ability of at least 99.70% is necessary to produce value. This is because the oil as a valuable resource needs to be at least 99.70 % pure, as indicated by the hearing data; at a purity of

Table 1. Calculated cost recovery periods.

	Wastewater treatment system	Oil–water separation technology
Initial cost (JPY)	60 million	13 million
Operating cost (JPY/month)	307,205	1.35
Initial cost-recovery period (months)	58.1	12.6
Total cost-recovery period (months)	70.7	

<99.70%, it is treated as wastewater rather than as oil.

The difference between the output value (the benefit determined from the SWU calculation) and the input value (the amount invested in the wastewater treatment system and the oil–water separation technology) represents the value generated (or wasted) by introducing the separation technology into the factory. Using the SWU and the initial and operating cost of the facilities, the cost recovery period can be estimated.

The initial cost and operating costs of the wastewater treatment system and the oil–water separation technology of the food processing factory are listed in Table 1. The SWU calculation for the food processing factory (carried out for a separation ability of 99.70% and an oil mixing ratio of 10% for the oil-containing wastewater) gave a result of 1,340,464 JPY/month, under the assumption that the factory was operated for 160 hours per month. The surplus after the operating cost was subtracted was used as recovering the initial cost.

The calculated periods required for recovery of the initial cost of the oil–water separation technology and the wastewater treatment system are listed in Table 1. The lifetime of the oil–water separation technology was not considered in this study, and the lifetime of the wastewater treatment system was taken to be 30 years. The results obtained indicate that after recovery of the initial cost (which took 58.1 months), the surplus after the operating cost was subtracted was profit. Because the cost recovery period was shorter than the lifetime of the wastewater treatment system, introducing the oil–water separation technology in the food processing factory was revealed to be economically feasible.

Conclusions

For the food processing factory, the SWU was determined by means of calculations involving decreasing the separation ability of the oil–water separation technology from 100% in increments of 0.01%. On the basis of data from the hearing conducted at the food processing factory, a VF was determined and used to calculate the SWU; the separation ability of the oil–water separation technology necessary to produce value was determined to be at least 99.70%. The cost recovery period for introducing the oil–water separation technology in the food processing factory can be calculated from the SWU and can then be used to guide decision-making about whether to introduce the technology.

The results of the current study revealed the economic feasibility of the oil–water separation technology. The use of such technology in the treatment of wastewater generated during postharvest processing of crops and during food processing and the use of separated oil and water as resources can be expected to increase.

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