Abstract This study was performed to investigate the possibility of utilizing sewage sludge as a fuel. The drying characteristics of sewage sludge were examined by using vacuum evaporation and fry-drying technology in a batch-type rotary evaporator. In addition, the optimal drying conditions of sludge in the vacuum evaporator were investigated in terms of the vacuum pressure, temperature, and oil dosage ratio, etc. Experimental results showed that the moisture content in the sludge decreased with increases in oil/sewage sludge ratio and temperature. Dried sludge fuel (SDF) product could be obtained with on average less than 5% moisture content and a lower heating value of more than 4000 kcal/kg. Considering energy efficiency, we suggest that the optimal operating condition for drying sludge is −450 mmHg of vacuum, a temperature of 100°C, a drying time of 90 min, and a sludge/oil ratio of 1:1. The SDF product was shaped as granules and fluff-type particles. Evaluated from the perspective of the energy balance and economic considerations, this sludge drying system with vacuum fry drying could be used for effective sludge treatment and the production of SDF.

Key words Drying · Sewage sludge · Vacuum evaporation · Sludge-derived fuel (SDF) · Frying

Introduction

The amount of sludge produced in sewage treatment plants has increased as the number of treatment facilities and the quantity of sewage discharged has increased. The number of sewage treatment plants operating at the end of 2007 was 347 (capacity over 500 m³/day) and the quantity of sludge produced was 7518 ton/day. About 68.5% of the sludge was dumped in the ocean, 11% incinerated, and 18.5% recycled.1 The regulations on the ocean disposal of sewage sludge are likely to be strengthened, along with the implementation of the '96 Protocol of the London Convention preventing pollution caused by ocean disposal. According to the Korean Waste Management Act, ocean disposal of sewage sludge will be completely prohibited as of 2012 in Korea. Alternative treatments and measures are urgently required and an agenda for integrated treatment infrastructure should be established.

Along with the prohibition of ocean dumping and landfilling, disposal of sewage sludge has focused on the sludge-derived fuel (SDF) system, preferably accompanied by energy recovery.2–4 The fry-drying process was originally used in the food industry,5 but its application could now be expanded to include the drying of sewage sludge. This technology evaporates moisture in sludge after mixing it with oil such as bunker C oil, waste oil, or waste cooking oil. Fry drying is the immersion of sludge in oil at temperatures higher than the boiling point of water. The mixing of sludge and oil secures the liquidity of organic sludge to facilitate handling throughout the drying process. The contact of the sludge and oil induces a series of chemical and physical reactions that result in changes in color and texture, development of a crust, and high rates of heat and mass transfer.6,7

The fry-drying system has been studied mainly in terms of batch-type drying at comparatively high temperatures, but continuous-type drying and vacuum evaporation systems have been very little studied. The operating temperature could be maintained low due to the low boiling points resulting from the vacuum condition in the whole evaporation process. This technology could produce a comparatively high quality of fuel product that contains about 20% moisture content with high calorific value, while 1% moisture content and 5% oil content could be obtained in pilot test.

The aim of this study was to examine the drying characteristics of sewage sludge using vacuum evaporation and immersion frying technology. In addition, the optimal drying conditions of sludge with respect to the oil dosage ratio and temperature were investigated. Laboratory bench-scale experiments and pilot plant tests were conducted. A
pilot plant with a capacity of 30 ton/day was operated as a continuous-flow evaporator with an oil recycling system. However, this article describes only the experimental results of the laboratory batch-type tests carried out to investigate some fundamental parameters for the design and operation of the vacuum dryer.

Materials and methods

Experiments on sludge drying were carried out using a laboratory-scale apparatus operated as a batch-type evaporator consisting of a vacuum evaporator, rotary mixing system, and temperature controller. Figure 1 shows the schematic of the batch-type drying apparatus, which is a modified general rotary evaporator. This sludge drying apparatus could carry out vacuum evaporation and apply immersion frying technology, thus securing the plasticity of organic sludge by mixing it with oil such as refined petroleum oil and utilizing the differences in boiling points of oil and water. This drying process comprises three steps: mixing sludge and oil, evaporation, and oil recovery.

Oil in an oil bath was used as an frying, and the vacuum condition in the evaporator was maintained at from −450 to −600 mmHg during the tests. The experimental tests were carried out by immersing a boiling flask containing sewage sludge and oil into an oil bath maintained at a temperature between 90° and 120°C. The two types of oil used in this study were 100% cooking soybean oil and refined petroleum oil; these were purchased in a local supermarket and from the petroleum industry, respectively. The sewage sludge used in this experiment was a filtered sludge discharged from the anaerobic sludge digester of J sewage treatment plant in Seoul, Korea. The dehydrated sludge which had been filtered using a centrifugal dewatering filter had an average moisture content of more than 78%. The water content, oil content, fixed carbon, volatile matter, and ash content of the raw sludge and dried sludge were determined according to the standard methods (APHA, 1995). The heating value was determined using a bomb calorific analyzer (Leco AC-350, USA).

Results and discussion

Thermal characteristics of sewage sludge before and after drying

The proximate analysis results of raw sewage sludge used in this study are shown in Table 1. The moisture content of raw filtered-digested sludge was 78.8%. This moisture content seems to indicate quite good filterability. The analytical results of dried sludge obtained at a vacuum pressure of −450 mmHg and an operating temperature of 100°C in the vacuum rotary evaporator are also shown in Table 1. The mixing ratio of sludge and oil was 100:100 (w/v basis).

Even though the moisture content of raw sludge was 78.8% before drying, it could be decreased to 2.4% after drying. This value is considered to be very low compared with that achieved by conventional drying systems. The percentages of volatile matter and ash before drying were 12.4% and 1:1.5 on a w/v basis) to find the optimum sludge/oil mixing ratio.