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A numerical study on the behavior of coastal waste particles in a wind-power sorting system for renewable fuel production

Jonghyuk Yoon [a], Do-Yong Kim [b], Daegi Kim [a,*]

[a] Bio Resource Team, Plant Engineering Division, Institute for Advanced Engineering, 175-28, 51 Goan-ro, Beagam-myeon, Cheoin-gu, Yongin-si, Gyeonggi-do 17180, Republic of Korea
[b] Department of Environmental Engineering, Mokpo National University, 61 dorim-ri, 1666 Yeongsan-ro, Cheonggye-myeon, Muan-gun, Jeonnam 58554, Republic of Korea

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ABSTRACT

In this study, a Computational Fluid Dynamics (CFD) to analyze the coastal waste particles in a wind-power sorting system is applied to produce renewable fuel using commercial CFD package (ANSYS-CFX code). The numerical methodology results predicted various coastal waste shredded inside the sorting machine. Furthermore, to identify the effect of working conditions on separation characteristics, a parametric study is performed. These study findings will offer appropriate a wind-power sorting conditions according to the purpose of using coastal waste. Under basic conditions, the characteristics of coastal waste particle behavior and the sorting of waste particles were analyzed, and the behavioral changes of diverse particles were identified by changing the airflow rate to improve the sorting performance. As a result, an appropriate airflow rate, $Q_{air} = 85\ m^3/min$, at which the change in the airflow rate can simultaneously meet the conditions for both the recovery of the combustibles and the removal of the incombustibles, was selected with the selection efficiency rate was 92%, and the combustibles content was 99%. Based on the results of the analysis, the particle characteristics of sorting were identified to reduce and recycle the coastal waste.

1. Introduction

Marine debris has been classified into the coastal, sink, and floating types consisting of some kind of manufactured or synthesized solid waste material (Iñiguez et al., 2016; Thushari et al., 2017). Anthropogenic marine wastes are associated with diverse human activities and come from a wide variety of sources both onshore and offshore (Derraik, 2002; Islam and Tanaka, 2004). Marine waste has become a serious global problem of late in the marine environment, such as in the biology of marine animals and the economic activity in the marine area (e.g., fishery and the fishing industry) (Derraik, 2002; Possatto et al., 2011 Thiel et al., 2013)

In 2006, the United Nations (UN) General Assembly reported that the marine litter has rapidly increased worldwide. The UN sub-organizations United Nations Environment Programme (UNEP)/Regional Seas, Food and Agriculture Organization (FAO), and Ocean Conservancy (OC), and the world's non-governmental organizations (NGO) have been collecting information and preparing world reports related to marine waste (Ariza et al., 2008a, 2008b). Furthermore, South Korea is bounded by the sea on three sides, and has a large coast, with the size of its exclusive economic zone 4.5 times the national land area (Jeong et al., 2005; Kim, 2010). Due to the large-scale fishing activities in the coastal waters, the expansion of industrial sites due to economic development, and the increase in leisure activities caused by the improvement of the people's living standards, the amount of ocean wastes (e.g., marine floating wastes, submerged wastes on the ocean floor, shellfish, and deposited contaminants, is increasing, leading to serious marine pollution (Ariza et al., 2008a, 2008b; Li et al., 2016; Possatto et al., 2011). The coastal environmental quality of the beach areas is important for tourism and for living sites. Both coastal and marine wastes have negative ecological and socio-economic effects on the fishery, shipping, and recreational activities; they also diminish the aesthetic beauty of the coastal amenities. To sum up, coastal waste can affect the aesthetic appeal of beaches and can reduce their recreational value and tourism quality (Ariza et al., 2008a, 2008b; Iñiguez et al., 2016; Thiel et al., 2013).

According to the statistical data of the Marine Litter Integrated Information System approximately 78,000 tons of marine waste were collected in South Korea in 2016 (Marine Litter Information System, 2018). Of these, 53% were coastal wastes, 34.1% underwater deposited wastes, 6.6% floating wastes, and 6.3% disaster wastes. Marine wastes contain long-term decay-resistant materials

* Corresponding author.
E-mail addresses: daegi.kim81@iae.re.kr, daegi.kim81@gmail.com (D. Kim).

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such as waste fishing nets, waste ropes, Styrofoam buoys, and various plastics. (Marine Litter Information System, 2018). The most common method of disposal of marine wastes is landfill or incineration after collection. Due to the limited landfill capacity caused by the increasing wastes, the environmental pollution caused by the qualitative waste diversification, and the social avoidance of waste treatment facilities, however, the waste disposal methods using landfill or incineration have many limitations (Iñiguez et al., 2016; Islam and Tanaka, 2004; Thiel et al., 2013). Furthermore, appropriate institutional maintenance and technical improvements are continuously required (Aydın et al., 2016; Derraik, 2002. Eco-friendly waste treatment and the use of waste energy have attracted much attention of late. The technology for producing solid refuse fuel (SRF) from selected combustible wastes is a representative example (Borrelle et al., 2017; Iñiguez et al., 2017). As marine wastes contain a large proportion of combustible wastes such as waste fishing gear and wood, it is necessary to apply the SRF production technology thereto. As shown by their composition, coastal wastes have a high calorific value (approximately 4,500–6,000 kcal/kg), and can thus be applied to the high-efficiency energy industry (Pietrelli et al., 2017; Unal et al., 2017). To produce high-quality SRF in the forming process, it is important to effectively sort out combustible materials like plastic, and wood as well as incombustible materials like sand, shells and etc. due to space constraints. To come up with an effective counterplan, the rapid evolution of numerical methodologies for computational fluid dynamics (CFD) analysis made it possible to predict the behavior of coastal waste particles inside various sorting machines. Previous studies mainly considered the particle behavior inside cyclone separator, and environmental conditions on the sample characteristics for recycling construction waste (Balestrin et al., 2017; Chu et al., 2017; Corrêa et al., 2004; Fitzpatrick et al., 2015; Lee et al., 2013; Safikhani and Mehrabian, 2017; Yang et al., 2013; Yuan et al., 2015). Even though there is currently much interest in various methods of selecting waste, there has been limited research on a compact wind-power sorting system as well as on a numerical analysis. As for the sorting principle, shredded coastal wastes were selected through the following overall stages: pre-sorting, main sorting, and classification. In the pre-sorting stage, different kinds of shredded coastal waste start to roll down the inclined plate, and then they become partially pre-separated. In the main sorting stage, the shredded coastal wastes dropped from the inclined plate receive momentum force from an air blower. (Gundupalli et al., 2017; Iñiguez et al., 2016; Zheng et al., 2018).

In this research, CFD simulation on the fluid flow and coastal waste behavior inside a wind-power sorting system was performed using the Lagrangian particle tracking method. In addition, the effects of various flow rates of the air blower on the coastal waste behavior were numerically evaluated to present a conceptual design for the wind-power sorting system. The numerical methodology for determining the behaviors of various coastal wastes was introduced to predict the amount of shredded coastal waste inside the sorting machine. In addition, to identify the effects of the working conditions on the separation characteristics, a parametric study was also performed.

2. Numerical analysis method

2.1. Schematic design of the sorting system

In this study, numerical analysis for a coastal waste treatment facility was carried out using the CFD methodology to propose guidelines for the conceptual design of the facility, as shown in Fig. 1. The SRF from coastal waste which mainly consists of combustible materials (such as plastics, wood chips and etc.) is able to have a high calorific value. Through the wind-power sorting, the coastal wastes are separated between two different kinds of material as combustibles and incombustibles. The decision regarding the sorting method to use for recovering the target material depends on the density and shape properties of the coastal wastes. Fig. 1 shows a schematic of the sorting system that was used, which consisted of waste slots, an inclined plate, an air blower, and two conveyors rotating in opposite directions. As the low-density materials are highly affected by momentum force, numerous combustible materials are placed on the conveyor #1 whereas most of the high-density incombustible materials are placed on conveyor #2. Eventually, the materials on the conveyor system rotating clockwise (conveyor #1) are recovered and the materials on conveyor #2 are rejected in the classification process.

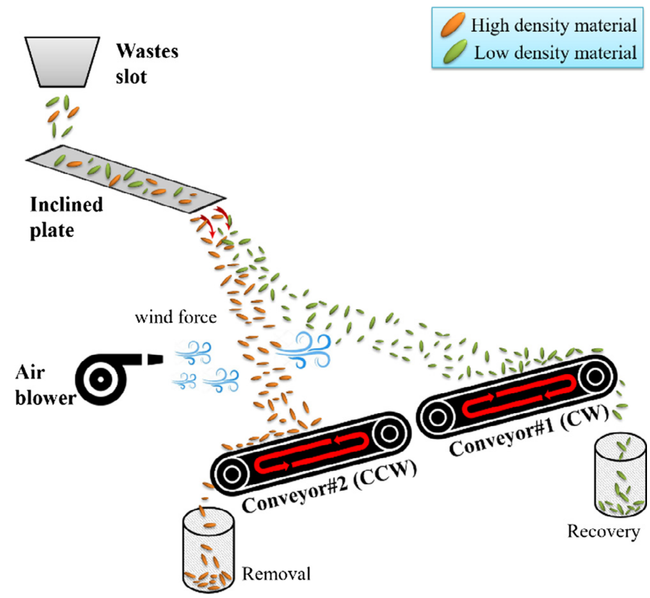

Fig. 1. Schematic of the sorting system of coastal wastes.

3. Governing equations

To predict the fluid flow and behavior of the shredded coastal waste inside the sorting system, three-dimensional (3-D) Reynolds-averaged Navier-Stokes (RANS) analysis based on the Euler-Lagrangian method was performed using the commercial CFD program of ANSYS CFX 18.0 (ANSYS Inc.).

For the continuum phase of air, the governing equations for mass and momentum conservation with the standard k-ε turbulence model, Eq. (1)–(2) were used, as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_j) = 0 \quad (1)$$

$$\frac{\partial \rho U_i}{\partial t} + \frac{\partial}{\partial t}(\rho U_i U_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i}(\tau_{ij} - \rho\, \overline{u_i u_j}) + \rho g \quad (2)$$

where U is the velocity vector, t is the time, ρ is the density, p is the pressure, g is the acceleration of gravity, τ is the stress tensor and $\overline{u_i u_j}$ is the Reynolds stress tensor.

As air-flow is dominant over particle behavior, only the one-way coupling method for momentum transfer was considered. Once the air-flow field was determined, the trajectories of the shredded coastal wastes could be predicted. The shredded coastal wastes were treated as spherical particles, based on the equivalent diameter principle. The motion of discrete particles was calculated