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Centrifugal dewatering performance in plastic films recycling

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ABSTRACT

Dewatering of plastic films is a highly energy-consuming recycling operation that largely affects the quality of the recycled product. Despite the importance of good drying, this operation has not been studied at laboratory or pilot plant scale. In this work, the mechanical dewatering of blown film grade high density polyethylene has been assessed by using a laboratory centrifuge. It is suggested that a plastic cake is formed under the centrifugal forces similar to the sludge cake after the filtration process. The water is retained within the plastic cake due to three phenomena: free water within the cake pores and voids, water maintained by capillarity (superficial and pendular) and water trapped due to the tortuosity of the plastic mass. The total moisture is a sum of an equilibrium moisture and a transient moisture. The equilibrium moisture depends on the centrifugal force (G) but it is independent of time. Conversely, the transient moisture is reliant on both the G-force and the centrifugation time. The experimental results showed that an optimum side length exists. The moisture content is minimized when the flake side lies between 1 and 2 cm. Finally, it has been found that the moisture content is a function of the plastic surface. Hence, the specific moisture content (the mass of water per total plastic surface) should be calculated to compare films with uneven thickness or made of different materials. In sum, the outcomes of this study may be fundamental for the further and more extensive research into the plastic films dewatering processes.

1. Introduction

The plastic waste generation has become a global issue since plastic products applications have extended to a large number of industrial sectors. Moreover, a large number of plastics are single-use products. Their low production costs and the lack of awareness among the population about the negative environmental impacts make them easily discarded materials. About 27.1 million tonnes of post-consumer plastic waste were collected in Europe in 2016. A 31.1% has been recycled and a 41.6% has been managed by energy recovery methods. However, a 27.3% has been still disposed of in landfills where the plastics accumulate for hundreds of years (PlasticsEurope, 2018). Flexible plastic materials or films are becoming increasingly popular. The economic savings due to the reduction in raw material consumption and several environmental benefits, for instance, reduced consumption of non-renewable resources are the main reasons. As a result, flexible plastics are used in a large number of sectors although packaging and agriculture are the most important. The packaging sector constitutes the 39.9% of the total plastic demand and films are mainly used for food packaging. (PlasticsEurope, 2018). A recent study indicates that films represent more than 50% of plastic household waste in several European countries (Mepex Consult, 2017). Moreover, there is an increasing trend towards the replacement of rigid products by flexible materials. Regarding agriculture, around 615,000 tonnes of agricultural plastic waste is generated in Europe every year. Almost 90% is composed of flexible materials (Bos et al., 2008). However, plastics films have a grave disadvantage which is their low recycling rates.

According to the EU Waste Framework Directive (2008/98/EC), recycling is the preferable waste treatment option ahead of the recovery and disposal. Several authors have studied the plastic solid waste (PSW) treatment technologies (Al-Salem et al., 2009, Hopewell et al., 2009). Recycling technologies are usually grouped into mechanical and chemical recycling. According to some authors who have studied the life cycle assessment (LCA) of different plastic waste management options, mechanical recycling ensures the biggest environmental benefits. Although, it depends strongly on the virgin material substitution ratio, i.e., the reduced amount of feedstock coming from non-renewable resources (Lazarevic et al., 2010). This rate decreases with the loss of recycled product quality as a result of the material degradation.

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Since the global consumption of plastic films is on the increase (Pira, 2017), it is necessary to ensure a sustainable development of this sector. For this purpose, efficient recycling technologies are required. The current recycling processes have been developed for the treatment of rigid plastics. However, the films behave differently and hence some technical issues appear during certain recycling operations. As a consequence, degradation and loss of mechanical and thermal properties occur.

It is important to study the behaviour of plastics films in order to optimize the recycling systems and increase the recycling rates. Mechanical recycling consists of several operations such as shredding, washing, drying, and re-granulation. The washing stage is important because the waste contains dirtiness and contamination that affects the quality of the recycled material. An effective drying process is needed afterwards because the excess of water during extrusion increases the chance for defects to occur and also pushes up energy costs (Tietz Roda, 2017). But in practice, the efficiency of drying technologies used for films treatment does not always reach the required level. To solve this problem, the recycling companies use successive centrifugation steps or add one thermal drying process at the end to remove the remaining moisture. In both cases, the recyclers must bear high operational costs since drying is considered as one of the most expensive operations (de Lima et al., 2016). For this reason, the study of plastic films and the optimization of drying systems are of great interest to the recycling companies.

The required moisture content of the dry material depends on the extrusion profile of the material and extruder characteristics such as venting and degassing efficiency. The average number varies between 1 and 12% (EREMA, n.d.). Thermal drying is usually placed after mechanical drying due to its high costs. Therefore, the centrifuge function is to remove the largest amount of water and, thus, reduce the energy required for thermal drying. The use of centrifuges can be found in several patented recycling processes. Some machinery manufacturers assure that a correctly designed centrifuge should be able to remove all the water from the plastic materials (Tietz Roda, 2017). The thermal step would not be necessary then.

A lack of research into plastic flexible materials drying or dewatering methods has been identified. Many recycling companies agree that the development of new technologies has been carried out based on the observations made by the industry. Nonetheless, other research fields exist where the drying has been extensively studied. This is the case of the wastewater treatment sludge. The dewatering of the sludge is usually accomplished by centrifugal forces or by pressing. The commonly used equipment is centrifuge (decanter), vibrating screen, rotary press, filter press, belt filter press, and rotary vacuum filter. The selection and design of the dewatering equipment depend mainly on the characteristics of the material to be treated. For instance, the cake compressibility and the fine particle size are the most important features of the sludge (Wakeman, 2007). The dewatering efficiency can be improved by the use of specific chemicals (e.g., surfactants) which reduce the liquid surface tension (Svarovsky, 2001).

In this field, different equations are used to describe the drainage or dewatering of wet cake which is formed during filtration. The moisture content is usually expressed by the saturation value (S). The saturation is the volume fraction of the wetting liquid within the pores and voids of the cake. The material is considered fully saturated (S = 1) when all the pores and voids are filled with the liquid. During the centrifugation, the saturation decreases up to an equilibrium point (S_∞) that is reached after a large amount of time. The total saturation is a sum (Eq. (1)) of the equilibrium saturation and the transient saturation ($S_T(t)$), which is a function of time (Eq. (2)).

$$S_{total} = S_\infty + S_T(t) \quad (1)$$

$$S_T(t) = (1 - S_c)(1 - S_p - S_z)S_t(t) \quad (2)$$

The moisture content at the equilibrium cannot be totally removed with increasing centrifugation time but it depends on the centrifugation force (G). Different types of trapped liquid exist within the cake: free liquid in the cake pores ($S_t(t)$), pendular liquid in the particle contact points (S_z), liquid retained by capillary forces (S_c), and bound liquid in the particle pores (S_p) (Eq. (3)).

$$S_\infty = S_c + (1 - S_c)(S_p + S_z) \quad (3)$$

The drainage of the free liquid is a function of the centrifugation time raised to n (Eq. (4)). The exponent n is equal to 0.5 when the particle surface is smooth and to 0.25 for rough surfaces. It also depends on the hydraulic diameter (d_h) of the particle that is given by Eq. (5).

$$S_t(t) = \left(\frac{4}{3}\right)\left(\frac{1}{t_d^n}\right) \quad (4)$$

$$d_h = 0.667\frac{\varepsilon d}{(1-\varepsilon)} \quad or \quad d_h = 7.2\frac{(1-\varepsilon)K^{1/2}}{\varepsilon^{3/2}} \quad (5)$$

where ε is the cake porosity, d is the diameter of the particle and K is the cake permeability.

The saturation due to capillary rise is affected by the G-force, some properties of the wetting liquid (density, interfacial tension and contact angle) and some characteristics of the cake (height, porosity, and permeability).

$$S_c = \frac{4}{B_0} \quad (6)$$

$$B_0 = \frac{\rho G H d_h}{\sigma \cos\theta} \quad (7)$$

The pendular saturation is reliant on the value of the capillary number N_c. The G-force, the hydraulic diameter and some properties of the liquid are needed to calculate this number.

$$\begin{cases} S_z = 0.075 & N_c \le 5 \quad (a) \\ S_z = \frac{5}{(40+6N_c)} & 5 \le N_c \le 10 \quad (b) \\ S_z = \frac{0.5}{N_c} & N_c \ge 10 \quad (c) \end{cases} \quad (8)$$

$$N_c = \frac{\rho G d_h^2}{\sigma \cos\theta} \quad (9)$$

Finally, the bound liquid depends on the particle characteristics.

The aim of this work is to study the dewatering of thin HDPE films by centrifugation at laboratory scale. The approach of water-waste sludge dewatering is used to explain plastic films drying processes. It is suggested that three types of trapped water coexist within the plastic cake: free water, water retained by capillarity and water trapped due to the tortuosity of the plastic mass. The influence of centrifugation time, centrifugal force, plastic mass, flake size and film thickness has been evaluated. Finally, the dewatering of a few additional plastic materials, e.g. low density polyethylene (LDPE), polyethylene terephthalate (PET), and embossed low density polyethylene, have been assessed. The outcomes of this study could be used to establish the fundaments for further research and understanding of the flexible plastics drying.