

MAGNETIC FLUID EQUIPMENT FOR SORTING OF SECONDARY POLYOLEFINS FROM WASTE

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Abstract

The paper presents the researches made on the FP7 project „Magnetic Sorting and Ultrasound Sensor Technologies for Production of High Purity Secondary Polyolefins from Waste” in order to develop a magnetic fluid equipment for sorting of polypropylene (PP) and polyethylene (PE) from polymers mixed waste streams. Because both PP and PE float in water, it is difficult to separate one from the other. The paper presents the principles of inverse magnetic density separation process and the results obtained in developing of lab scale equipment for high grade separation of polyolefins from different kinds of polymers mixtures in a single step. The evolution of the equipment design is also described, based on the simulation of polyolefins dynamic flow inside magnetic fluid in the magnetic field. The researches made on lab scale equipment show fruitful results that encourage the researches for the next step. The consortium of projects is still working on scaling up this equipment for industrial application, which will be installed in Romania in 2013.

Keywords: magnetic density separation, polyolefin, recycling, solid waste

1. Introduction

Plastic materials are one of the most used materials in the world. Still, as a consequence of global crisis, the global plastics production fell back from 245 million tons in 2008 to 230 million tons for 2009 (Plastics Europe, 2010), from 2009 to 2010 the global production of plastics increased

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by 15 million tons (6%) to 265 million tons (Plastics Europe, 2011). After Asia (43.5%), Europe (27 EU+N/CH) is the second largest producer (21.5%) with 57 million tons (Plastics Europe, 2011).

Demand from European converters increased by 4.5% from 2009 to 46.4 million tons in 2010. After usage, in 2010 there were 24.7 million tons of plastic waste left, but only 14.3 million tons were recovered (57.9%) by recycling (24.1%) and energy recovery (33.8%) (Plastics Europe, 2011; Achilias et al., 2008). The growth of plastics recycling is only almost 0.5% per year over the last 5 years, even after reusing, the recycling is the best solution in the plastic waste management (Butler et al., 2011). In 2010, 10.4 million tons (42.1%) of plastic waste was still landfilled (Plastics Europe, 2011). Of the European plastics demand, the polyolefins represent 48% (17% PE-LD, PE-LLD, 12% PE-HD, 19% PP) (Plastics Europe, 2011). Even new domains are proposed daily, packaging, building & construction and automotive industry represent the largest end use market segments for polyolefins.

It is necessary to mention that commercial applications used in polymers separation are usually restricted to particles size of 6.4 to 10 mm and throughput tonnage is limited due to rates of separation for the other techniques (Gent et al., 2009).

Because both PP and PE float in water, it is difficult to separate one from the other. Using floating in water technique, the polyolefins can be separated from the heavy plastics present in the plastics streams, but another technology is necessary to separate PP from PE. Because it is compulsory to have different densities of the fluid, floating in alcohol could be used, but the process must be repeated in many steps, using different concentrations (Shent et al., 1999). This technology is very expensive, dangerous and has limited separation flexibility.

Bezati et al. (2010) define one of the possibilities of plastic separation technologies based on X-ray fluorescence spectroscopy. The sorting process is very expensive and the efficiency is limited. In general, it is difficult to obtain high purity for separation of materials very close in density (Al-Salem et al., 2009).

Another separation technology is based on fluidization. Carvalho et al. (2009) develop this technology in tap water. The same technology was tested by Yoshida et al. (2010) in a gas-solid fluidized bed separator with silica sand. The float-sink of the plastics was affected, as the authors noted, by the air velocity for fluidization, the float-sink time and the feed amount of plastics. The possible causes of the effects were discussed by the authors, focusing on the apparent density of fluidized bed, the fluidization intensity, the size segregation of fluidized particle, the shape of the plastics and the interaction between the plastics during the float-sink process.

Gent et al. (2009) present the plastic separation using cyclone separation. As the lowest cost recycling process, density separation methods are presently used in virtually all the automated industrial plastics recycling processes as a cleaning and/or pre-concentration and/or preparation

phase for subsequent processing methods, or in some instances, to produce a marketable product, is the conclusion of the authors.

In this paper we report the results obtained in the FP7 project „Magnetic Sorting and Ultrasound Sensor Technologies for Production of High Purity Secondary Polyolefins from Waste” in order to develop a magnetic fluid equipment for sorting PP and PE from polymers mixed waste streams. This project uses the emerging technology called Magnetic Density Separation (MDS) (Bakker et al., 2007, 2009) to separate a complex mixture into many different materials in a single step, using one and the same liquid. The goal of this project is to develop cost-effective and clean technology based on MDS and ultrasound process control to recover high-purity polyolefins from complex plastic wastes (Rem et al., 2009; Di Maio et al., 2010). The project consortium is composed of six universities and research centers and six companies, all of them under management of Technical University of Delft, The Netherlands.

2. Experimental

The tests were performed using three kinds of polyolefin streams: Romanian and Dutch household waste, French demolition waste and Austrian automobile shredder residues. The properties of Romanian household waste were presented by Baltes et al. (2009) and Patachia et al. (2011). The properties of the demolition waste were presented by Serranti and Bonifazi (2010). The properties of car shredder light fraction were presented by Vajna et al. (2010).

In ordinary floating, at equilibrium, the particle density is equal to the liquid density (Archimedes principle). In MDS, the ferrofluid is attracted both by the Earth and by magnets and its weight varies with distance to magnet (Fig. 1). The Archimedes principle applied for ferrofluid is: the particle is at equilibrium if it has the same weight as the volume of replaced ferrofluid (Hu et al., 2010).

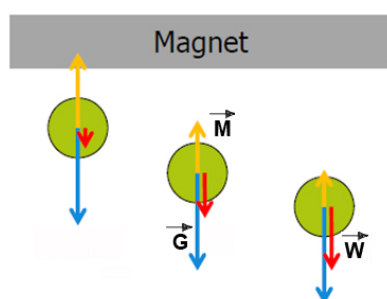


Fig. 1. Particle of magnetic fluid loaded by: M = magnetic force (variable), G = gravity (constant), and $W = G - M$, weight

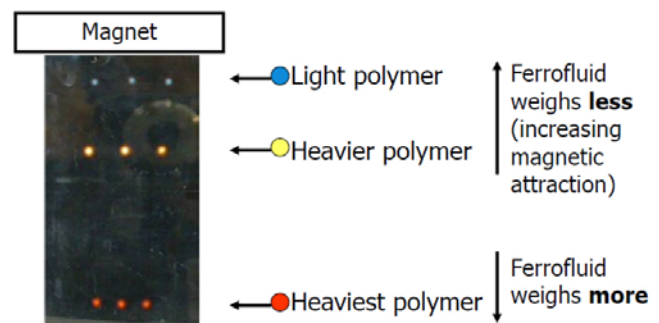


Fig. 2. Floating of different plastic particles in ferrofluid (Bakker et al., 2010a)

Based on these properties of the ferrofluid, the floating in ferrofluid is a feasible method for plastic particles separation (Fig. 2). Considering the density separation between PP and PE as 915 kg/m^3 (Di Maio et al., 2011), it is possible to apply the MDS to polyolefins separation (Fig. 3).

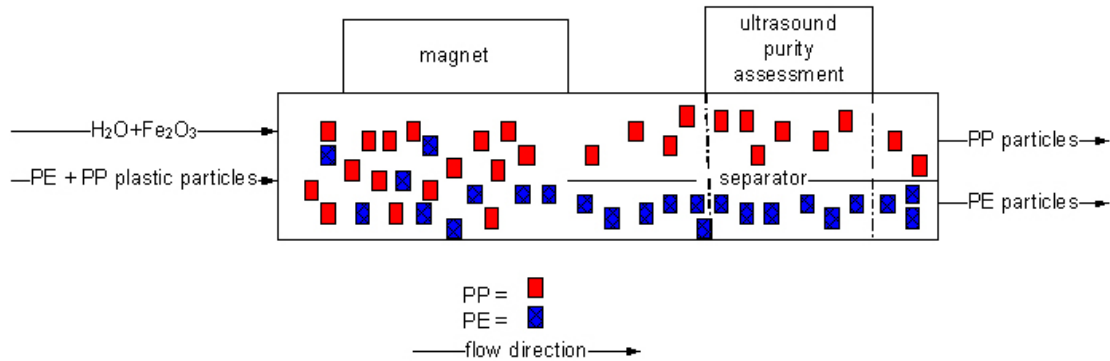


Fig. 3. MDS applied to polyolefins separation

The separation process flowchart is presented in Fig. 4. The floating in water fraction of the polymers waste is used as input in the process, collected from household solid waste, building & construction waste and automobile shredder residues. After granulation and flake thickness classification follows the cooking of the polymers, this means boiling in water with CaCO_3 and dewatering to remove all air bubbles from the surface, which can alter the floating process.

As output of the MDS separation there are three kinds of polyolefins: PP (density = $840\text{--}915 \text{ kg/m}^3$), PE I (density = $915\text{--}960 \text{ kg/m}^3$), PE II (density = $960\text{--}990 \text{ kg/m}^3$) and residues, collected in big bags after ferrofluid extraction. The residues were light particles ($\rho < 840 \text{ kg/m}^3$) and heavy things ($\rho > 1000 \text{ kg/m}^3$). These residues can be treated by incineration or pyrolysis, to extract energy and oils, or used as filling material in construction. After water treatment, this one can be reused in the MDS process, as well as the ferrofluid.

All the process is controlled using ultrasonic inspection with sensor array (Bakker et al., 2010b) and hyperspectral imaging to ensure the purity of the PP and PE (Bonifazi and Serranti, 2009, 2010, 2011; Serranti and Bonifazi, 2010; Serranti et al., 2011).

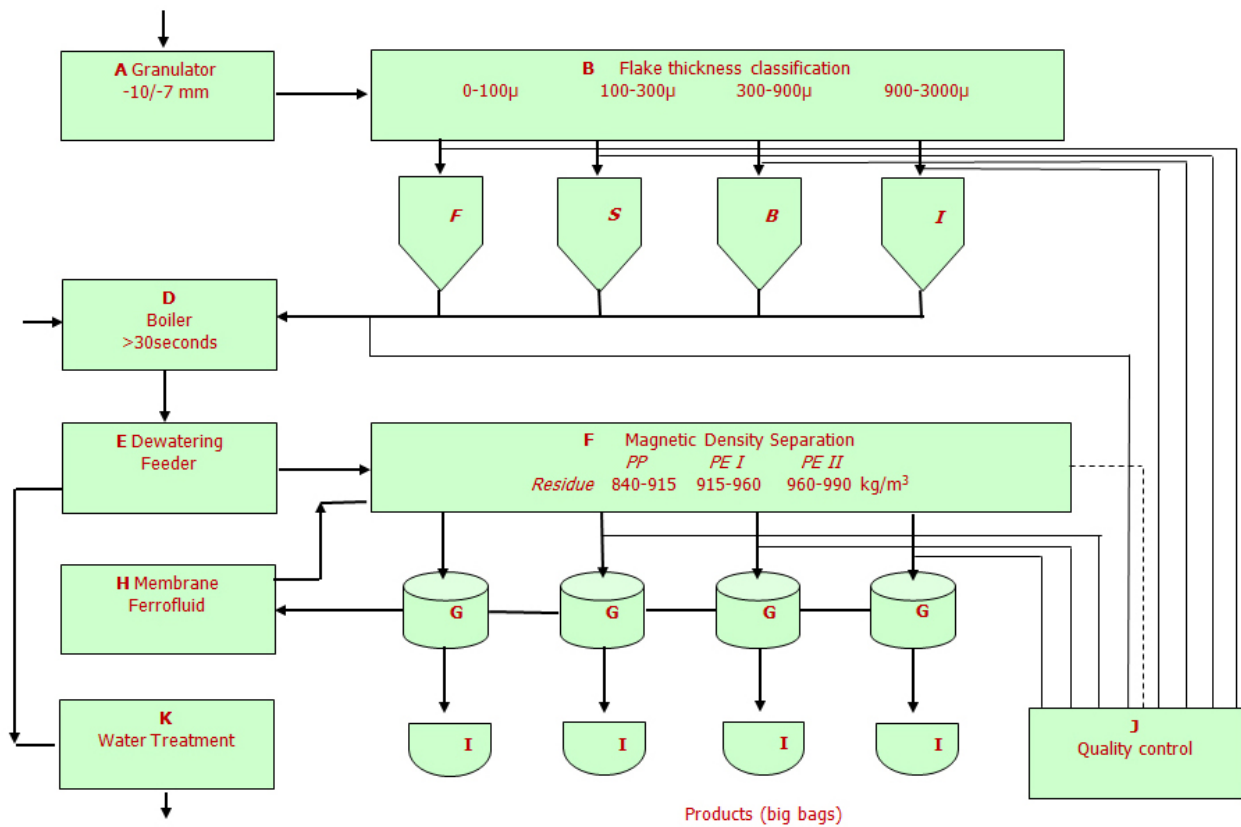


Fig. 4. Flowchart of the separation process based on MDS

Lab scale equipment was realized at Technical University of Delft (Fig. 5) based on the previous experience of the project team (Rem and Berkhout, 2007; Bakker et al., 2007, 2009). This equipment was designed for cooking, feeding, flow in MDS and process control experiments. In the back, the cooking unit, using electric heating, prepares the plastic flakes for feeding, reducing the air bubbles on the surface and decreasing the contact angle. On the back right side, the injection assembly feed the MDS with plastic flakes having an expansion box to drop the speed. On the right side the MDS realize the separation of the polyolefins in ferrofluid bath. Because this is the critical point of whole equipment, the experiments were focused on particle flow and MDS accuracy, in different working conditions. On the top of the MDS bath, the ultrasonic sensor array inspects the process. At the end of ferrofluid bath there are the separation channels, where the PP, PE flakes and residues are collected and removed by pumps. On the left side, the hyperspectral imaging equipment controls the accuracy of the process. The tests were performed on the MDS lab scale equipment.

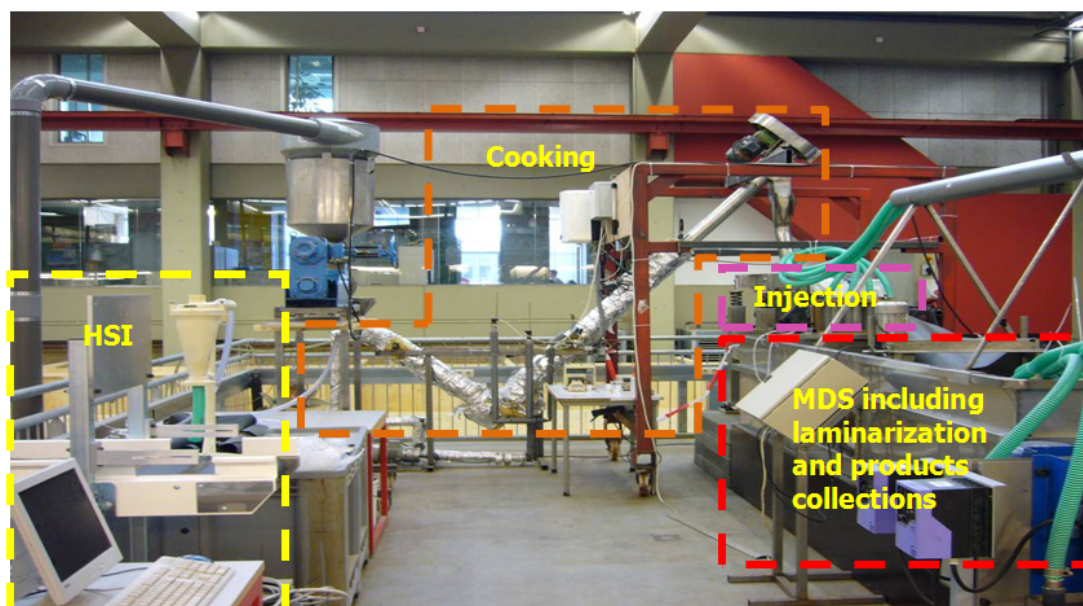


Fig. 5. Lab scale equipment for polyolefins separation based on MDS

3. Results and Discussion

Presence of the air bubbles on the surfaces decrease the density of the flakes (Fig. 6). The presence of 2mm^3 air on the flakes surface reduces the density of 200 mm^3 flake with 10kg/m^3 . For 0.5 mm thick flakes the effect is 4 times worse. The result is a strong inaccuracy of the separation, because PE ($910\text{-}920\text{ kg/m}^3$) are likely to mix with PP. For this reason, the removing of air bubbles must be done. There were two ways for wetting: in boiling water and in vacuum. To study the boiling influence on wettability, the contact angle (polymer-water-air) was measured. Boiling of polymer flakes decreases contact angle to below 90° (Fig. 7).

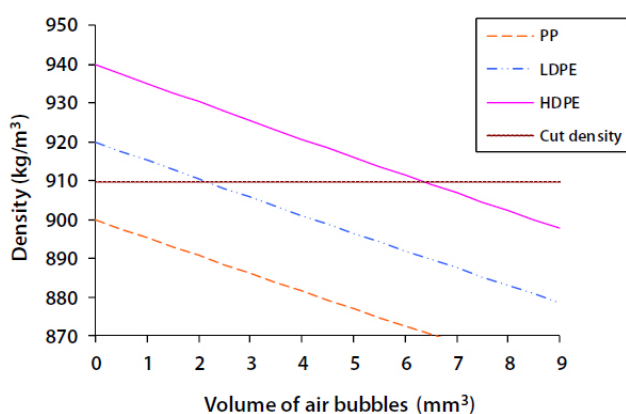


Fig. 6. Density of the polyolefins flakes vs. volume of air bubbles (Hu et al., 2010)

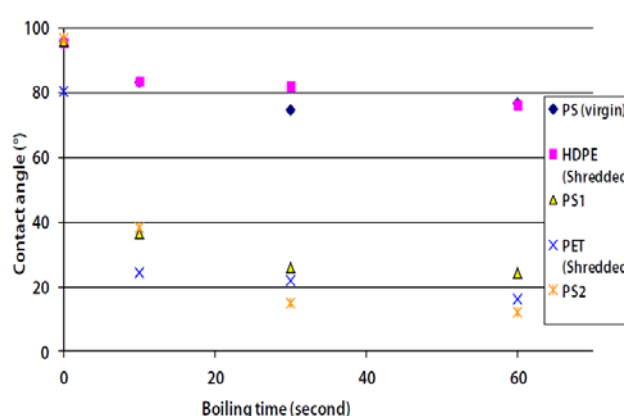


Fig. 7. Contact angle of polyolefins flakes depending on boiling time

To study the boiling time, mixtures of PE flakes and PP flakes were sink-floated in calibrated alcohol water liquids to get six samples of PP with densities within 5 kg/m^3 and another six samples of PE with densities within 5 kg/m^3 . Test samples 1 of PP and PE were not boiled. The other five test samples were boiled for 10 s, 30 s, 60 s, 120 s, and for a long time, respectively. One by one, the test samples of PP and PE are immersed in ferrofluid in the magnetic field and the floating position of the samples was recorded, and compared to the expected floating position for the density range of the polymer flakes. Fig. 8 presents the equilibrium position if polyolefin flakes in MDS function of boiling time. The polymer densities were in the interval indicated by dotted lines. The resulted safe boiling time was 60 seconds.

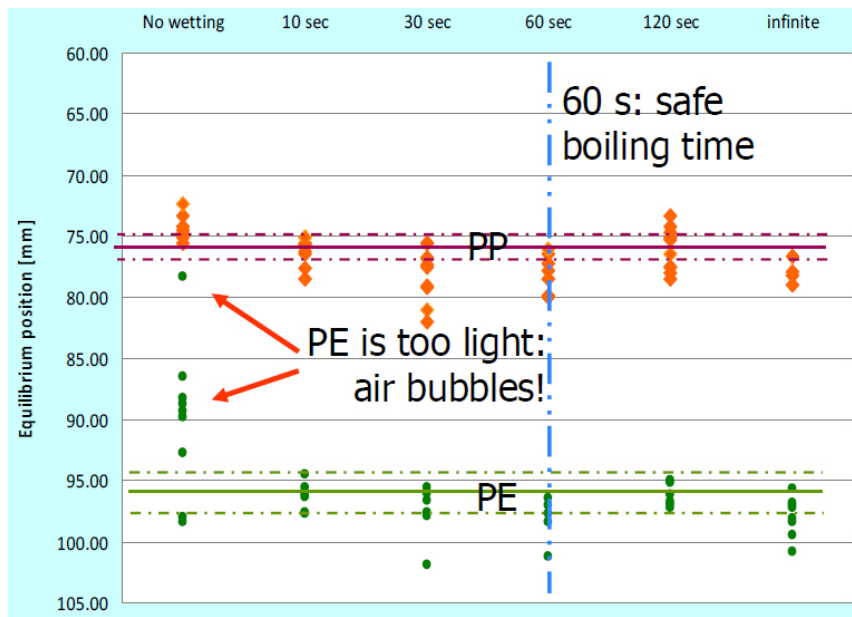


Fig. 8. Equilibrium position if polyolefin flakes in MDS depending on boiling time

Both boiling and wetting in vacuum remove all air bubbles from the surface of the flakes, and they work for all tested polymers. Wetting in vacuum is more expensive, needs to be done in batch, but can also remove air from polymer particles with an air pocket, e.g. tubes. It does not result in permanent wetting (not after air-contact). Boiling is cheap and results in “permanent” wetting (even after the flakes are brought again into the air atmosphere) because of the formation of a microscopic layer of CaCO_3 . However, it cannot remove air pockets efficiently. Boiled flakes need to be cooled before MDS. Shredded plastics wet better than virgin; sometimes shredding is sufficient to achieve wetting.

To study the feeding transport in the MDS channel and separation, the simulation of plastic particles flow in the ferrofluid was performed. This simulation was done at Barcelona Supercomputing Centre, using 512 CPUs from the 16384 CPUs of the supercomputer and Alya

code (Houzeaux et al., 2010). The 3D model of the feeding and MDS channel (Fig. 9) was simplified to a 2D model (Fig. 10) to reduce the computational costs.

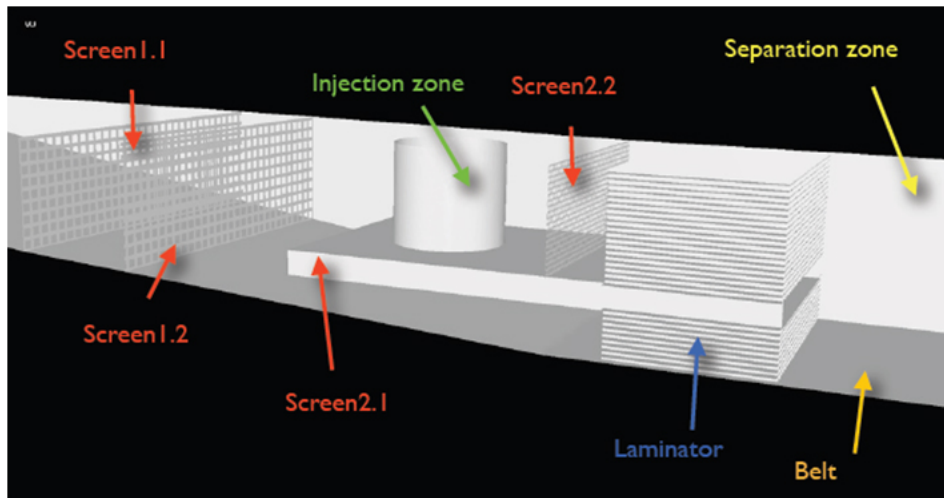


Fig. 9. 3D model of the feeding and MDS channel

The tests made on lab scale equipment reveal the dispersion of the polymers at collector, which decrease the efficiency of the separation process. The same problem was observed on the simulation (Fig. 10). Responsible for this turbulence is the injection cylinder.

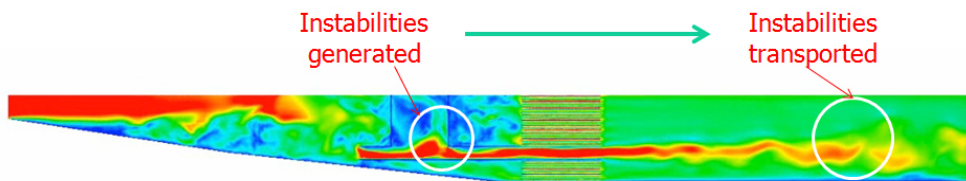
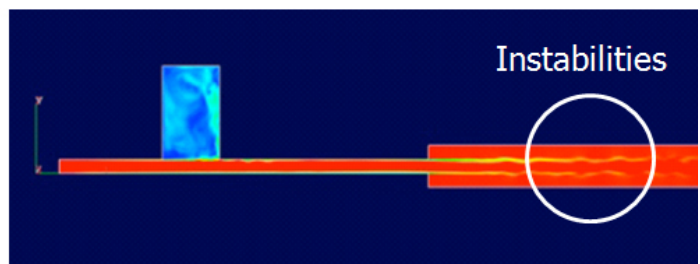
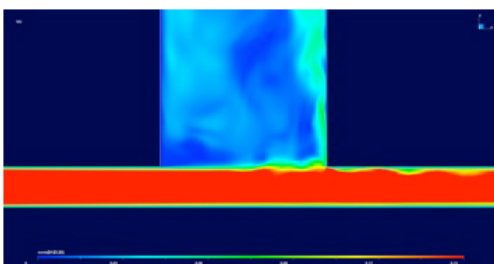


Fig. 10. Instabilities in the first version of 2D model

Simulations with different dimension and shapes of the feeding channel were performed. The intermediary results and final design are presented in Fig. 11. In the first version, the instabilities are still present, due to large perpendicular feeding channel (Fig. 11.a). Reducing the size of the feeding channel decreases the vertical oscillations of the particles, but the turbulence is still too high (Fig. 11.b). Having an inclined narrow feeding channel, there are no macro instabilities (Fig. 11.c). The final design of the entrance in the MDS channel includes also a laminator, which tries to make the flow laminar in the shortest distance as possible.



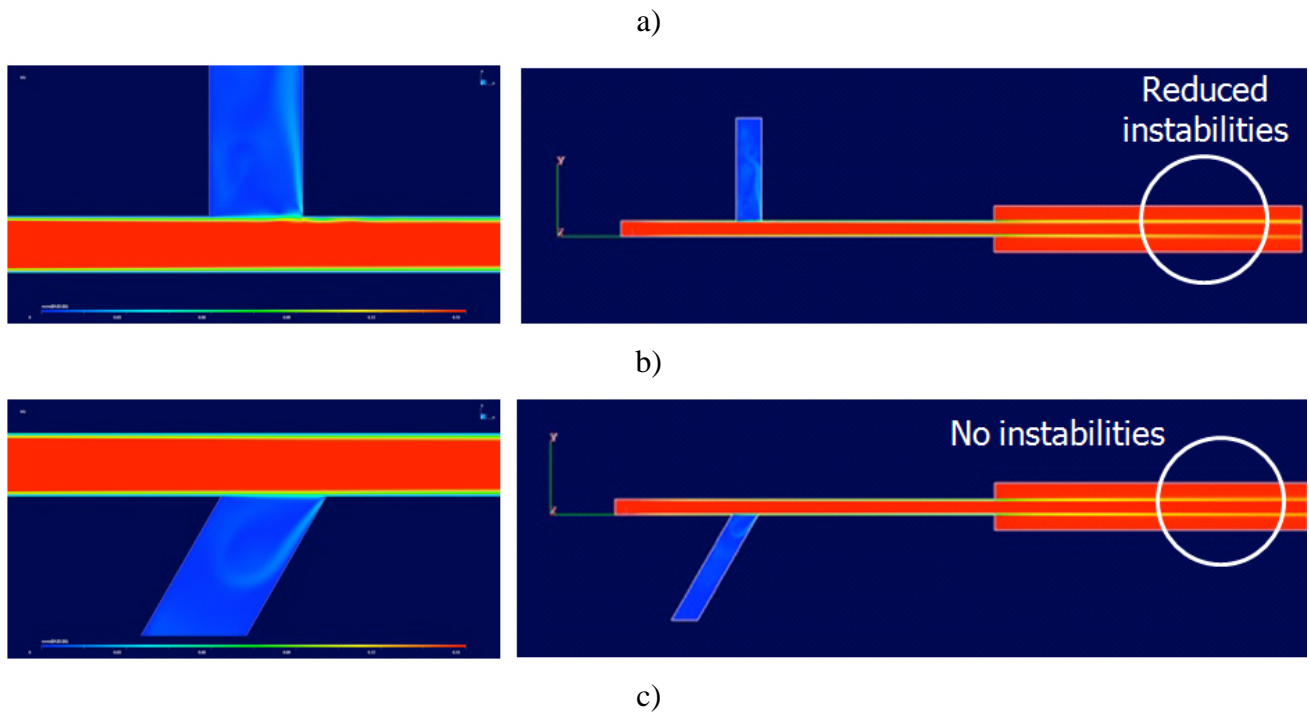


Fig. 11. Flow simulation steps and improvements of the 2D model

Micro turbulences are needed at the beginning of the MDS channel because help to release the particles if they are happen to stick on each other and reduce big scale turbulences in the channel. These micro turbulences should decay fast and reduce to an acceptable scale before reaching the splitters at the end of the separation channel.

Fig. 12 presents the displacement of flakes in the channel turbulence flow (vertical velocity, $V_y=0.01\text{m/s}$, period=2s) function of particle diameter and density. The displacement decreases with increasing of diameter and decreasing of density.

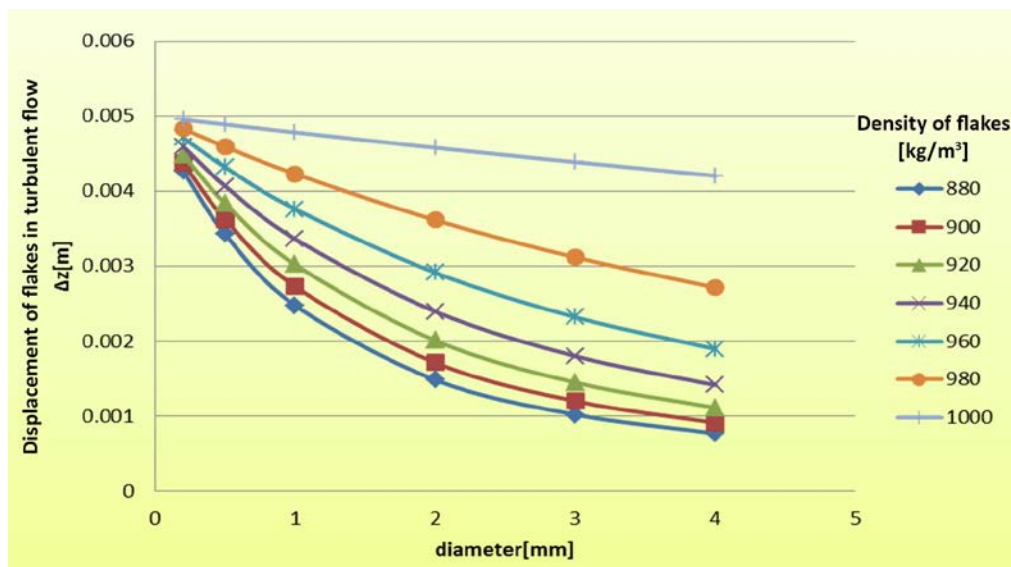


Fig. 12. Displacement of flakes in the MDS channel turbulence

4. Conclusions

The MDS method is adequate for separation of high quality secondary polyolefins from different plastic waste streams. Before the MDS process the polymer waste particles must be prepared by boiling 60 seconds in water with CaCO_3 and dewatering, to remove air bubbles from the surface and to decrease the contact angle below 90° .

Using the CFD was determined the shape and dimension of the feeding channel. With an inclined narrow feeding channel, there are no macro instabilities. There were obtained only micro turbulences, which help the separation process.

The researches made on lab scale equipment show fruitful results that encourage us for the next step, the pilot plant MDS equipment, now under developing. All the results of this research were applied in the scaling of lab equipment to the pilot plant. After the tests on the pilot plant, the solutions will be ready to be implemented in the commercial version of the MDS equipment.

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