Analysis of the influence of basic parameters of the magnetic separator EcMS-500 for non-ferrous metals on the separation force intensity

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Eddy-current magnetic separator EcMS-500 for non-ferrous metals is primarily designed to separate aluminium cans from other waste, but it can separate other non-ferrous metals such as brass and copper. During operation, the magnetic roller of separator creates eddy current field. These currents interact with metallic waste and generate attractive forces and interact with non-ferrous metals (aluminium, brass, copper) generating repulsive forces. Consequently, due to the effects of eddy currents, aluminium cans and other waste of non-ferrous metals are separated by ejecting from the magnetic separator belt, while passing over the roller. The paper presents the different types of solutions of magnetic separators. A special review is given to the design of the magnetic separator EcMS-500. The influences of the magnetic roller speed (revolutions per minute) and the conveyor belt speed on the ejection distance of cans are analysed. Also, the effect of cans shape on the separation forces intensity is considered. For defined diameter of the belt guide roller, the analysis has identified the optimum revolutions per minute that provides sufficient force of separation for non-ferrous metals with minimal force that burdens the connection of the magnet and the rotor.

Keywords: Eddy-current separator, Recycling, Metallic waste, Aluminium cans

1. INTRODUCTION

Application of eddy-current separators began in the early nineties. Increasing concerns about the preservation of the environment and the adoption of various directives on waste disposal increase the development of eddy-current separators. So, there are many manufacturers in almost all countries in the world today. At the same time, there has been published many papers about this subject. Nijhof G.H., [1] described one of the first principle of the separation of recycled aluminium and the significance of this separation. The paper describes the working principle of used equipment in the recycling process as well as the whole system of recycling. Rem P.C. et al., [2] are among the first who described the operation of the magnetic field on the particles separation. They showed the effects of particle size, shape and conductivity on the particle trajectory. Simulation results were compared with experimental data in order to optimize the design of the separator as well as its working parameters. Zhang S. et al., [3] investigated the influence of installation of two-drum eddy-current separators. The simulation results showed high compliance with the experimental results and it was the most significant for processing of small particles. ECSIM software was used for the simulation. Zhang S. et al., [4] explored the justification of applying of eddy-current separators. It is shown that the use of this separator can provide a high percentage of separation of aluminium waste.

Kohnlechner R. et al., [5] showed a new type of separator that takes the influence of variable magnetic forces and translation of particles. Lungu M., [6] presented the operation of a new type of separator which separates metallic particles in two stages: firstly, the high conducting particles are separated on the upper part of the drum, and then the remaining low conducting particles are separated at the lower part of the magnetic drum. Lungu M. and Schlett Z., [7] gave the solution for a new vertical drum eddy-current separator for separation of small particles with the size of 2-8 mm. Permanent magnets are placed vertically. Comparative analysis has proved that it was successfully applied and the costs of the equipment is lower than that of the horizontal drum eddy-current separator.

Cui J. and Forssberg E., [8] gave an overview of the significance of mechanical recycling of electronic waste as a review of the directives for governing in this area. The paper by Fengjie Y. et al., [9] showed that forces in the particles of waste and the separation effect directly affect the flying distance of separated waste. In the paper, simulation of the process is carried out by the finite element analysis of the magnetic roller based on COMSOL software, and the flying distance was got by the joint simulation of COMSOL software and MATLAB software. Ruan J. et al., [10] considered the eddy-current separator parameters that should be set to increase the separation effect of small crushed particles of aluminium waste. The critical speed of separation and the detachment angles of crushed aluminium particles are defined.

The paper by Li J. et al., [11] shown an innovative method for separation of printed circuit board from unsorted waste. A model trajectories of particles was performed by computer simulation and optimal speed of feeding belt and rotating speeds of magnetic roller are determined. Fenercioglu A. and Barutcu H., [12] analysed the force for aluminium waste separation using by FEM, taking into consideration drum speed, air gap between the material and the magnet pole, dimensions and conductivity of the material and magnet height. The same authors Fenercioglu A. and Barutcu H., [13] analysed the separation of crushed aluminium and copper cables. Analysis was performed using by FEM. Optimal conveyor feeding belt and rotating speeds of the magnetic drum are defined.

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2. DESCRIPTION OF THE SEPARATOR EcMS-500

Eddy-current separator is an important component in the recycling chain. This machine is used for separation of non-ferrous metals, preferably aluminium, brass and copper, from unsorted or partially-sorted waste.

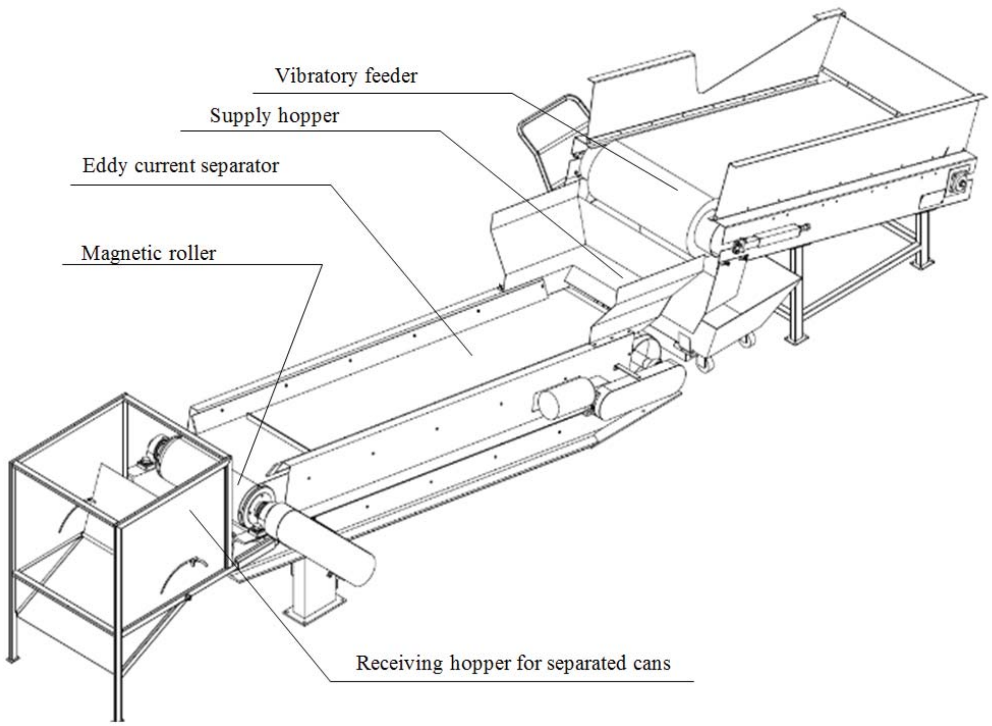

Figure 1: Position of eddy-current separator in the recycling process

In the recycling chain, bigger pieces are usually separated first (cardboard packaging, PET, etc.), then the metallic waste (separator of ferrous metallic waste) and finally, eddy-current separator that separates non-ferrous metals: aluminium, copper and brass of other non-metal waste. Vibrating feeder is often placed in front of eddy-current separator, distracting complete waste over conveyor belt to allow easier separation of non-ferrous metals (Figure 1).

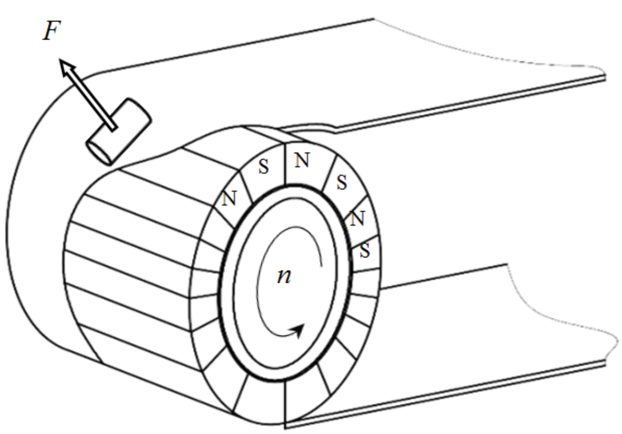

Figure 2: Sketch of magnetic roller and conveyor belt

The main segments of eddy-current separator at place of separation of waste are: conveyor belt, separator's magnetic roller shaft, magnetic and non-magnetic roller, supply hopper, electro-motor for magnetic roller shaft and conveyor belt drive.

Magnetic roller is a key component of eddy-current separator that is formed by alternately positioned permanent magnets in the S-N-S direction (Figure 2).

Magnetic roller, which is attached to the drive shaft, rotates at high speed. Non-magnetic roller, which is also connected to the drive shaft, rotates at considerably lower speed, in conjunction with the belt which is bended over it (Figure 3). Magnetic rotor is consisted from the shaft and permanent magnets, which are alternately positioned in the S-N-S pattern. Rotation of the magnetic roller creates an eddy magnetic field. When non-ferrous metal waste passes over the non-magnetic roller (cans, in this case), a magnetic field is created with an opposite polarity relative to the magnetic roller, which leads to the repulsive force in the non-ferrous metal. The intensity of the separation force is influenced by many parameters, including the speed of the magnetic roller, conveyor belt speed, the material characteristics (conductivity and density of the waste material are dominant). The higher conductivity and lower density of material creates higher force of separation. Size and shape of the material also affect to the intensity of the force of separation.

The materials being sorted are different in shape, size, density, etc., and it is difficult to issue conclusions about the intensity of the force without laboratory testing.

The direction of the force F_r acting on the metallic waste is shown in Figure 3. In the initial phase, the force of gravity is greater than the repulsive forces F_r, so the material stays in contact with the belt. When the value of the vertical projection of the force F_r exceeds the value of the force of gravity, waste separation occures. Non-magnetic material continues to move on the conveyor belt, passing over the roller and the centrifugal force acts on it. Receiving hopper has, in its middle part, a splitter that separates non-metallic waste and non-ferrous metals.

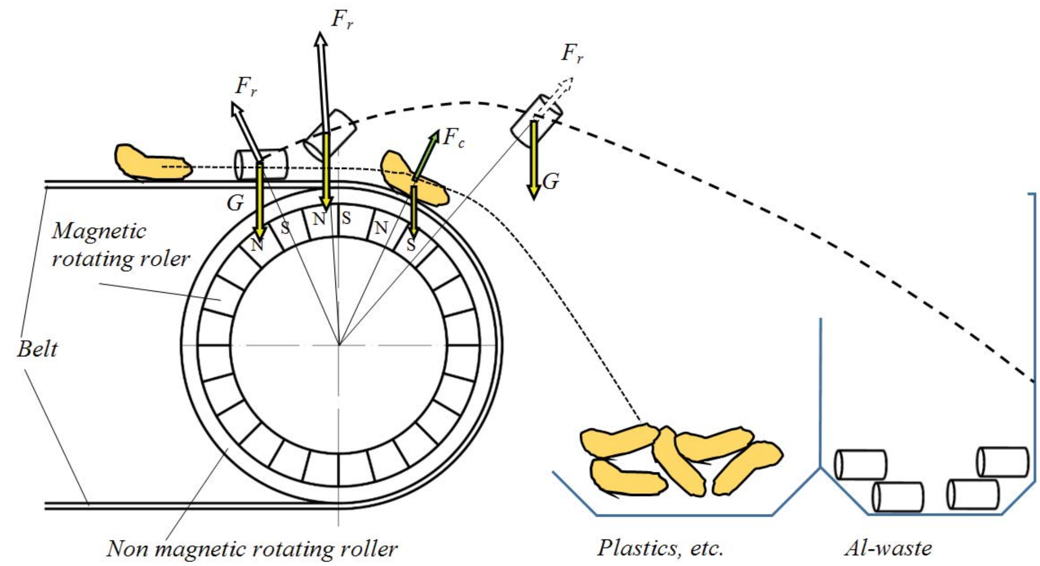

Figure 3: The principle of separation of aluminium cans

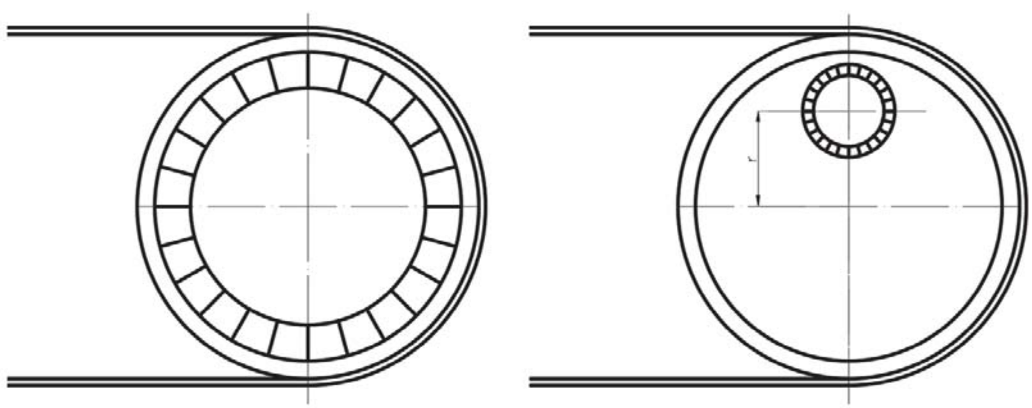

Figure 4: Basic functioning principle of eddy-current separator

As shown in Figure 3, the material is ejected and its movement represents the projectile motion, and the initial speed is important for the ejection distance of the object.

The characteristics which are significant for the separation of non-ferrous metals are the shape and the size of the pieces, density and conductivity of pieces, and also humidity of the metal pieces, adhesion, a fibrous properties of the material, etc. Besides this, the separation process may be affected by design parameters of eddy-current separator such as belt speed, rotor speed, way of delivery of unsorted waste, rotor design which directly determines the magnetic flux and magnetic frequency, type of magnet, etc.

According to the solution of the magnetic roller, there are two major type of eddy-current separator: with a centrically mounted axes of non-magnetic and magnetic rotor (Figure 4a) and with an eccentrically mounted axes of non-magnetic and magnetic rotor (Figure 4b).

Eccentrically mounted rotor is technically complicated to perform and produce. In this separator, magnetic field bandwidth is smaller, so that the non-ferrous metal is in a shorter time period exposed to the effects of magnetic force. Separator EcMS-500 is constructed in a way where the axis of the magnetic and non-magnetic rotor are mounted centrally. This concept was chosen because it does not require installation of any electronic equipment, it is easy for maintenance and does not require a clean and dry working conditions. Also, the selection of the solution type is affected by the fact that it is known that cans are the dominant type of non-metal waste.

3. TESTING OF SEPARATOR EcMS-500

In order to define the basic performance of the magnetic separator EcMS-500, depending on the user requirements, it is not always necessary to measure the force on magnetic roller. Since the primary function of the separator EcMS-500 is separation of cans from the unsorted waste, it is assumed that it is enough to measure the horizontal distance where the cans fall into the receiving hopper, having in mind that the paper [11] shows that the horizontal distance is directly dependent on the size of the magnetic force.

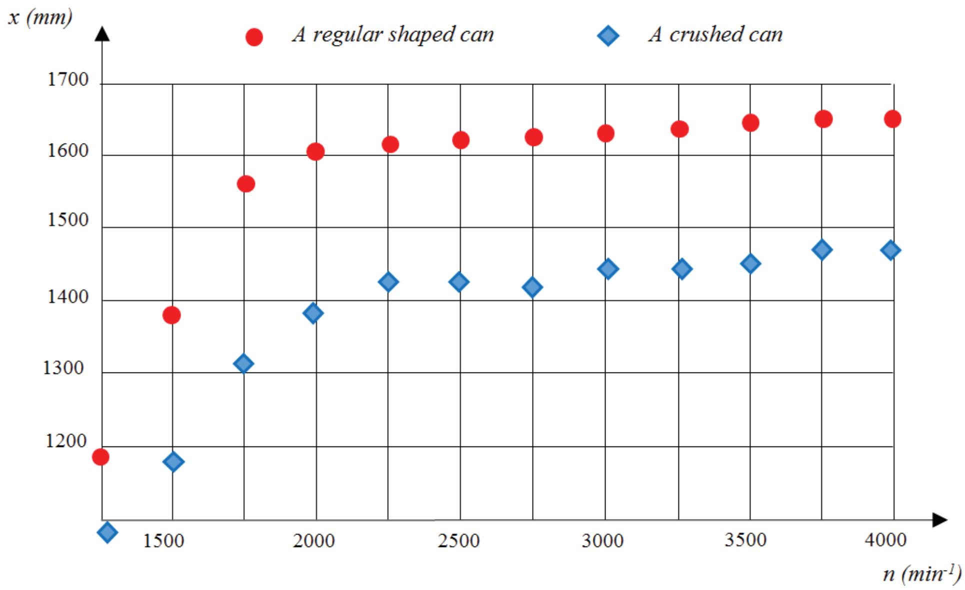

Figure 5: The effect of changes of number of revolution of magnetic head to the length x

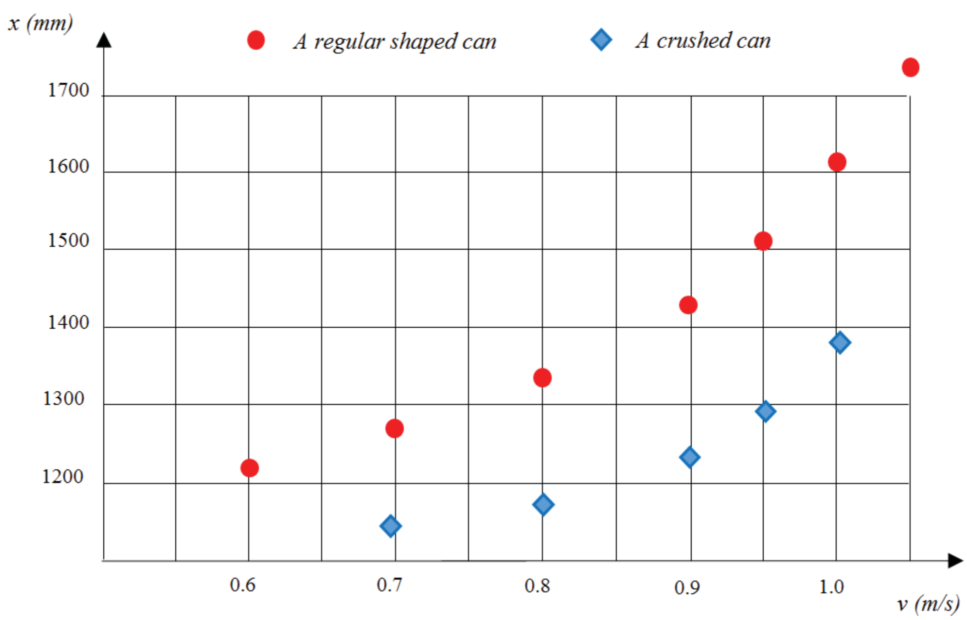

Figure 6: The effect of changes of belt speed to the length x

Measurements were performed on existing solution design of EcMS-500 separator.

The ejection distance of cans depends on various parameters, but in this paper an influence of the number of revolution of the magnetic roller (Figure 5) and the effect of changing of the belt speed of the belt conveyor (Figure 6) are analysed. In both cases, during the examination, there were used two types of cans: cans of regular shape, i.e. those that are not crushed and totally crushed cans that have a minimum volume of form.

The main technical characteristics of the conveyor are: the height of the upper edge of the roller from the floor is 880 mm, the angle of the conveyor of the magnetic separator to the horizontal is 10°, and the width of the conveyor is 500 mm. While varying the number of revolution of the magnetic roller, the conveyor belt speed was $v = 1$ m/s. While varying the speed of the conveyor belt, the speed of the magnetic roller was $n = 2000$ min^{-1}.

It should be noted that the measurement was carried out so that the conveyor contained only aluminium cans without other waste. In this way, the obtained values of the horizontal distance where the cans fall is certainly greater than in the exploitation conditions. However, this does not reduce the significance of the results obtained, because the investigated parameters are the speed of rotation of the magnetic rotor and the speed of the conveyor belt. The test results showed that with increase of the number of revolution per minute (Figure 5) over 2000 min^{-1}, the increase of the distance where the cans fall is very small. This applies to both types of cans, while the distance is shorter in case of totally crushed cans. Influence of the speed of the conveyor belt can be seen in Figure 6. When the belt speed increases above 1 m/s, the distance (x) is growing rapidly. The results shown in Figure 5 and Figure 6 were obtained by averaging the values of large number of repetitions. Also, for retesting with the changed parameters, the same set of cans was used and with the same order of placing on the conveyor belt. Changing the speed of the magnetic and non-magnetic roller was performed via frequency converters.Design of the magnetic separator EcMS-500 is shown in Figure 7.

a)

b)

Figure 7: Layout of solution for the magnetic separator EcMS-500

4. CONCLUSION

This paper presented the basic technical characteristics of eddy-current separator EcMS-500, where the axis of the magnetic and non-magnetic rotor are mounted centrally.

Dependence of the horizontal length of the trajectory of the ejected cans on the number of revolutions of the magnetic roller is defined. It was noticed that the increase of the number of revolutions per minute of the magnetic roller over 2000 min^{-1} leads to slight increase in the horizontal length of the trajectory. Since the horizontal length of the trajectory directly depends on the magnetic force, it is concluded that higher speed of the magnetic roller (more than 2000 min^{-1}) leads to slight increase of the magnetic force. This conclusion is important for the construction of eddy-current separators, because the increase of the number of revolutions per minute increases the centrifugal force of the magnets, which burdens their connection with the shaft of the magnetic roller.

Dependence of the horizontal length of the trajectory of the ejected cans to the conveyor belt speed is defined. It was observed that as the belt speed increases significantly, the intensity of separation force increases rapidly. This especially refers to the belt speed above 1 m/s. Increasing the speed also dictates the layout and content of the machine in the sorting line.

For both cases, it is shown that the shape and condition of cans affect the intensity of separation force. Nevertheless, the existing solution of the magnetic roller induces a separation force with sufficiently high intensity for any form of cans.

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REFERENCES

[1] G.H. Nijhof, “Aluminium separation out of household waste using the Eddy Current technique and re-use of the metal fraction”, Resources, Conservation and Recycling, Vol.10, pp. 161-169, (1994)

[2] P.C. Rem, P.A. Leest and A.J. Akker, “A model for eddy current separation”, International Journal Mineral Processing, Vol. 49, pp. 193-200, (1997)

[3] S. Zhang, C.P. Rem and E. Forssberg, “Particle trajectory simulation of two-drum eddy current separators”, Resources, Conservation and Recycling, Vol. 26, pp. 71–90, (1999)

[4] S. Zhang, E. Forssberg, B. Arvidson and W. Moss, “Aluminum recovery from electronic scrap by High-Force eddy-current separators”, Resources, Conservation and Recycling, Vol. 23, pp. 225–241, (1998)

[5] R. Kohnlechner, Z. Schlett, M. Lungu and C. Caizer, “New wet Eddy-current separator”, Resources, Conservation and Recycling, Vol. 37, pp. 55-60, (2002)

[6] M. Lungu, “Separation of small nonferrous particles using a two successive steps eddy-current separator with permanent magnets”, International Journal Mineral Processing, Vol. 93, pp. 172–178, (2009)

[7] M. Lungu and Z. Schlett, “Vertical drum eddy-current separator with permanent magnets”, International Journal Mineral Processing, Vol. 63, pp. 207–216, (2001)

[8] J. Cui and E. Forssberg, “Mechanical recycling of waste electric and electronic equipment: a review”, Journal of Hazardous Materials, Vol. B99, pp. 243–263, (2003)

[9] Y. Fengjie, C. Weifang and Z. Dehao, “The research of simulation on eddy current separation process based on MATLAB and COMSOL”, Procedia CIRP, Vol. 56, pp. 520–523, (2016)

[10] J. Ruan, L. Dong, J. Zheng, T. Zhang, M. Huang and Z. Xu, “Key factors of eddy current separation for recovering aluminum from crushed e-waste”, Waste Management, Vol. 60, pp. 84–90, (2017)

[11] J. Li, Y. Jiang and Z. Xu, “Eddy current separation technology for recycling printed circuit boards from crushed cell phones”, Journal of Cleaner Production, Vol. 141, pp. 1316-1323, (2017)

[12] A. Fenercioglu and H. Barutcu, “Finite Element Analysis of Separation Force on Non-ferrous Metals Induced by Eddy Current Separator”, PIERS Proceedings, Prague, Czech Republic, 6-9 July 2015, pp. 434-438, (2015)

[13] A. Fenercioglu and H. Barutcu, “Separation of Granule Non-Ferrous Metals in Shredded Cable Waste with Eddy Current Separator”, Proceedings of the World Congress on Mechanical, Chemical and Material Engineering–MCM 2015, Barcelona (Spain), 20-21 July 2015, Paper No. 250, pp. 250-1 – 250-5, (2015)