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Analysis of using magneto-hydro-dynamic pump for the platinum recovery from spent auto catalytic converters

A. Fornalczyk [b], R. Przyłucki [a,*], M. Saternus [b], S. Golak [a]
[a] Managements and Informatics Department, Faculty of Materials Engineering and Metallurgy, Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice Poland
[b] Metallurgy Department, Faculty of Materials Engineering and Metallurgy, Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding e-mail address: roman.przylucki@polsl.pl

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ABSTRACT

Purpose: Applying the catalytic converters allow to eliminate the compounds harmful to the environment. Typical catalytic converter is built from the metallic or ceramic carrier with porous structure covered with the PGM metals especially platinum, palladium and rhodium. The content of these metals is on average about 2 grams. Catalytic converters have limited life time, and then they are scrapped. The necessity of waste disposal and very high prices of PGM metals are the reason why recovery of PGM metals from used auto catalytic converters has become more and more profitable.

Design/methodology/approach: This work presents method of PGM metals recovery from auto catalytic converters by means of solving them in the liquid metal. Liquid metal is put in motion using magneto-hydro-dynamic pump, and then the PGM metals are eluted from channels of the used auto catalytic converters.

Findings: All over the world the used auto catalytic converters are preceded by the use of pyrometallurgical, hydrometallurgical or mixed methods. Each method has some disadvantages. Pyrometallurgical methods need to use units which assure the necessary temperature. This is as expensive as energy consuming. Applying hydrometallurgical methods involve danger of creating many waste solutions which are harmful to the natural environment.

Practical implications: The way PGM metals are recovered from used auto catalytic converters by their dissolution in the liquid rotating metal allows to increase concentration of PGM metals in the solution by means of applying the same metal collector to flush other catalytic collectors. Motion of the metal essentially shorten the time of PGM metals elution from catalytic converters; whereas the flow of liquid metal in closed cycle limits the unfavorable influence of the process on the environment.

Originality/value: Method presented in this article is an innovative method and has never been applied. Additionally it is protected by a patent.

Keywords: Magneto-hydro-dynamic pump; PGM metals; Auto catalytic converters

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The increase of natural environmental pollution and the ecological requirements set by the governments of particular countries forced the car producers to construct engines which would be more friendly to the environment. One of the ways to obtain compounds harmless to the environment instead of exhaust gases is applying catalytic converters. Their main task is to limit the emission of dangerous substances such as: nitride oxide (NOx), hydrocarbons (CH) and carbon monoxide (CO). Typical auto catalytic converter is built mainly from metallic or ceramic carrier with porous structure covered with the PGM metals (see Figure 1). The most often used are: platinum, palladium and rhodium. Catalytic carrier is wrapped by the fibrous material (to prevent displacement) and closed in a shell made from stainless steel plate. The PGM layer is put on the ceramic carrier (Al_2O_3 with the addition of other oxides e.g. CeO_2), which has the honeycomb structure that means dense net of square holes. Such construction increases the active surface, therefore the contact zone of catalytic substances (Pt, Pd, Rd) with the exhaust gases, which flow through the channels. Applying catalytic converters initiates oxidation reaction of carbon monoxides and hydrocarbons as well as causes the reduction of nitric oxides. As a result, compounds neutral to the environment, such as carbon dioxide, water and nitrogen are obtained at the outlet of catalytic converters.

a)

b)

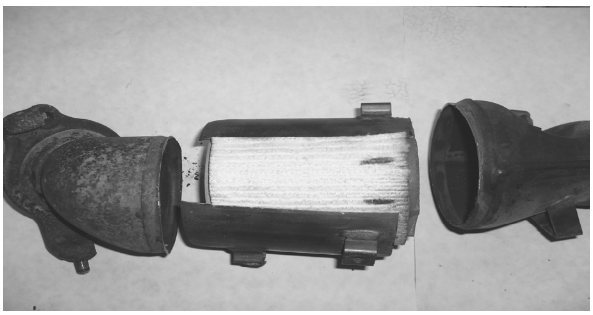

Fig. 1. a) Scheme of auto catalytic converter operation and b) real view (stainless steel shell, fibrous material and catalytic carrier)

The content of PGM metals in the catalytic converter carriers depends on their construction, use (average about 2 grams of PGM metals) and also manufacturer. Catalytic converters should be periodically regenerated, and after some time exchanged. So, more and more catalytic converters (coming from exchanged or immobilized car) go to scrapyards. The necessity of their disposal as well as the high prices of PGM metals makes recovery of such metals profitable. Recycling of catalytic converters also allows to limit the amount of deposited waste, consumption of natural resources and energy. Additionally, the level of pollutants emitted to the atmosphere during the recycling process is much lower than from primary process (obtaining PGM metals from ores).

All over the world the used auto catalytic converters are treated using pyrometallurgical, hydrometallurgical or mixed methods. Many intermediate stages are applied to obtain pure metals in such technologies. The first step is to collect the used catalytic converters and dismantle them. Then the catalytic carriers are grinded and homogenized. The next stage is to solve them, separate and refine PGM metals. Refining of PGM metals allows to obtain metals of high purity but in the same time many dangerous chemical substances are produced. In addition the process is really energy consumptive. Calcinations, ion exchange, solvent extraction, hydrolysis, reduction and oxidation processes, precipitation [1,2] are the main processes used in refining of the PGM metals. Figure 2 shows the general scheme of PGM metals refining process.

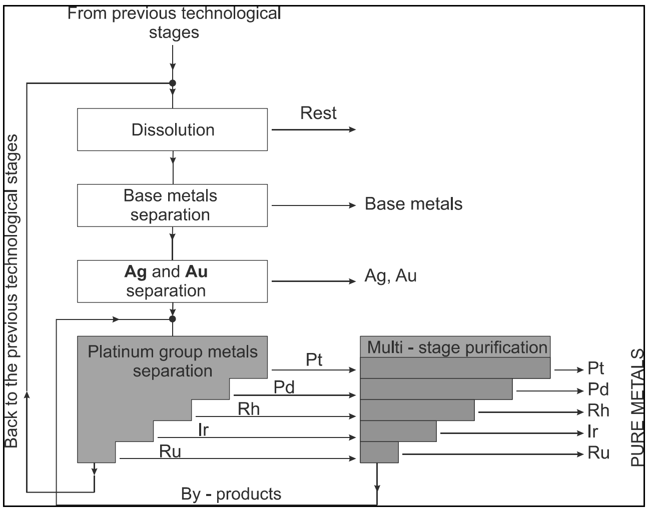

Fig. 2. Refining/purification of PGM metals [1,2,3]

When applying hydrometallurgical methods in catalytic converters treatment, PGM metals change into the form of chloric complexes (MCl_6^{2-}) as a result of their dissolving in aqueous solution of chlorides, chlorates, chlorine, hydrogen peroxide, bromates, nitrates and aqua regia. Solution obtained in such a way contains PGM metals, however their concentration is rather small. Therefore the next stage is to concentrate the solution and PGM metals extraction.

When applying pyrometallurgical methods for catalytic converters treatment, the grinded catalytic carrier is melted with the addition of other metal, the main aim of which is to be PGM metals collector (it is a liquid matrix). In this operation PGM metals go to alloy and then carriers are separated and scrapped. The obtained alloy containing PGM metals is used in this form or PGM metals are refined. Figure 3 presents the most commonly applied pyrometallurgical and hydrometallurgical methods of PGM metals recovery from used auto catalytic converters.

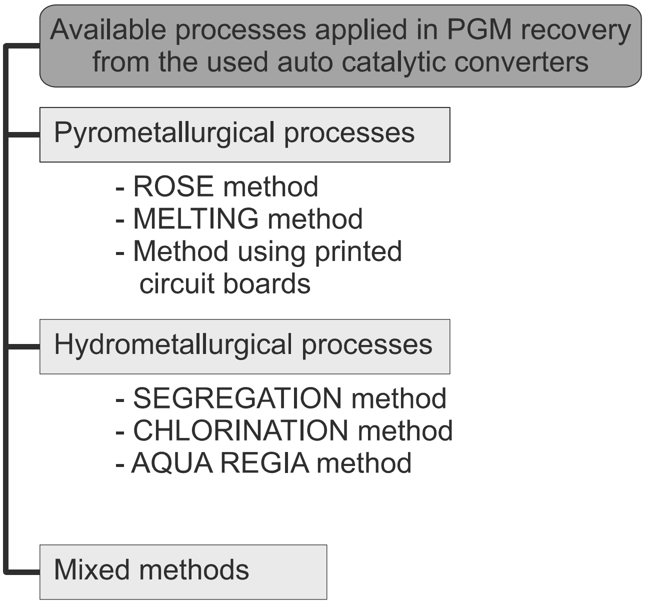

Fig. 3. Pyrometallurgical and hydrometallurgical methods applied for recovery PGM metals from used auto catalytic converters [4,5,6]

There are many methods (see Fig. 3) used to recover PGM metals from used auto catalytic converters, however almost all of them have some disadvantages. Pyrometallurgical methods require applying special units in which the appropriate temperature can be reached. This can be a problem, mainly if the temperature is about 2000°C (PGM metals have high temperature of melting). Furnaces which can ensure the required working conditions are very expensive as well as energy-consuming. In case when the alloy containing metal collector and PGM metals is obtained, it is necessary to find application for such alloy or to treat this alloy by hydrometallurgical processes to obtain pure PGM metals. On the other hand, applying hydrometallurgical methods may cause danger of creating liquid waste, which is very harmful to the natural environment (grinded catalytic converter carriers are dissolved in the acid or lye). These methods also need special treatment and exercise care because cyanides, concentrated acids and chlorine are used.

Both types of PGM metals recovery methods are complex, multistage, in which the appropriate catalytic converter carrier grinding and primary homogenizing is needed (the initial content of platinum is about 0.2%). Then many essential operations are applied and at the end a method, which allows to separate the obtained platinum or other PGM metals from the solution or alloy and refine it/them to the desirable level.

During the recovery process of PGM metals from used auto catalytic converters there it is necessary to analyze the primary content of the PGM metals in catalytic converters. There are two reasons: first one was mentioned before - catalytic converters are made by different manufacturers so the amount of PGM metals in them can be varied, second - sometimes the catalytic carriers are poisoned or overworked and then the level of platinum and PGM metals in them is below 0.2% (it is really difficult to distinguish such catalytic carriers judging by their look from the ones with higher level of PGM metals).

2. Description of work methodology

This work presents the method of PGM metals recovery from used auto catalytic converters basing on the dissolving them in liquid metal. In this method the metal collector is used, the main aim of which is to capture platinum. In case of PGM metals recovery from used auto catalytic converters the main problem is the efficiency of PGM metals elution from catalytic carriers. Single flushing of the catalytic carrier with liquid metal allows to recover only part of metals. Additionally, if the level of PGM metals is low in single catalytic carrier, the process seems to be unprofitable. Much better results can be obtained if the multiple flushing is used. However, this is troublesome taking into account the necessity of keeping the appropriate temperature and applying the protective atmosphere (to prevent metal oxidation). The best solution in this case could be applying the continuous flushing with liquid metal and placing catalytic converters carriers in this flux.

Setting the liquid metal in motion mechanically is very difficult because of the high temperature of metal and its aggressiveness. It would be better to use Lorenz force created in the liquid metal as a result of work of the rotating electromagnetic field. Taking into account the low content of PGM metals in the single catalytic carrier it is justifiable to flush them simultaneously from many catalytic converter carriers in the same process by means of the same flux of liquid metal flowing in the closed cycle.

Applying magneto-hydro-dynamic pump to PGM metals recovery from used auto catalytic converters is based on the fact, that liquid metal (see Figure 4) is placed in the ring-shaped channel, round which heating inductor coiled around the core is located. The main aim of the inductor is to generate the vortex field with the axis compatible with the ring axis. Rotating electromagnetic field creates rotary currents in the liquid metal, which influence electromagnetic field of the heating inductor, generating Lorenz force. This force causes the rotary motion of the metal. Placing catalytic converter carriers in such generated flux of liquid metal allows to flush platinum, palladium and rhodium from carriers capillaries. The constant motion of metal essentially influences the process of flushing intensification. Applying the same metal to flush many catalytic converters makes the PGM metals go to the solution of liquid metal, so the concentration of these metals is higher and higher reaching the level ensuring profitability of the extraction process of PGM metals from metal collector. Using closed cycle of liquid metal limits unfavorable influence of the process on the environment.

Lack of movable parts in the system is the basic advantages of applying magneto-hydro-dynamic pump of such construction.

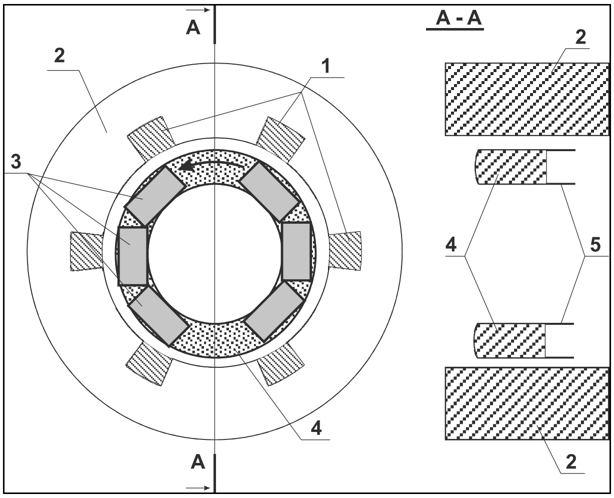

Fig. 4. Method of PGM metals recovery from used auto catalytic converters applying electromagnetic field: 1 - winding; 2 - magnetic core; 3 - catalytic converter carriers; 4 - liquid metal; 5 - channel

Inductive pumps are divided into three basic types taking into consideration the kind of electromagnetic field generated by the inductor:

- with pulsating field,
- with rotating field,
- with running field.

In this case the pump using rotating or running field can be only applied. Typical problems, which should be solved in case of magneto-hydro-dynamic units, are the following:

- problem connected with starting the unit - for the pump to start working, its channel has to be fulfilled with the liquid metal to 2/3 of its volume,
- during work of the unit, temperature above the temperature of metal melting should be constantly kept,
- when the work of the unit is almost finishing the metal should be removed from the pump channel.

To design such units some primary assumptions have to be made especially determining the kind of metal, required difference in pressure, needed liquid flux [9,10]. The next stage is to choose the type of unit and its parameters. This requires the analysis of complex problems connected with calculations of electromagnetic field and flow area. In some cases it is also necessary to analyze the temperature field.

Elaborations concerning issues of designing magneto-hydro-dynamic pumps can be divided into four groups [9]:

- works, which only include the analysis of electromagnetic field,
- works, which contain solution of magneto-hydro-dynamic problem solving separately equations concerning electromagnetic field and hydrodynamics,
- works, in which after solving divided equations for electromagnetic field and flow area there is correction of solution by the iterative return to the electromagnetic field analysis,
- works, which contain solution of conjugated electromagnetic and flow fields.

The additional problem is the fact, that there are only few programs that can be used for the analysis of electromagnetic field taking into consideration the density of induced current as an effect of metal motion in magnetic field [11].

The modelling process could be made as 2D or 3D depending on the required calculation precision or the geometrical system of the pump. In case of axial symmetry units, 2D model seems to be sufficient. The starting point in such case becomes the analysis of electromagnetic field basing on the equation (1) [11-13].

$$\nabla\times\left(\frac{1}{\mu}\nabla\times\boldsymbol{A}\right)+\mathrm{j}\omega\sigma\boldsymbol{A}=\boldsymbol{J}_{\mathrm{s}} \tag{1}$$

where:
A - magnetic vector potential;
μ - magnetic permeability;
ω - angular frequency;
σ - conductivity;
J_s - surface density of forced current.

Variable electromagnetic field induces current J (2) in the pump channel, which interacts with magnetic induction B (3) generating electromagnetic force f (4) and (5).

$$\boldsymbol{J}=\mathrm{j}\omega\sigma\boldsymbol{A} \tag{2}$$

$$\boldsymbol{B}=\nabla\times\boldsymbol{A} \tag{3}$$

$$\boldsymbol{f}_{\mathrm{m}}=\frac{1}{2}\mathrm{Re}\left(\underline{\boldsymbol{J}}\times\underline{\boldsymbol{B}}^{*}\right) \tag{4}$$

$$\begin{aligned} f_x &= -\frac{1}{2}\left(\mathrm{Re}(J)\mathrm{Re}(B_y)+\mathrm{Im}(J)\mathrm{Im}(B_y)\right)\\ f_y &= \frac{1}{2}\left(\mathrm{Re}(J)\mathrm{Re}(B_x)+\mathrm{Im}(J)\mathrm{Im}(B_x)\right) \end{aligned} \tag{5}$$

where:
J - surface density of current;
B - magnetic induction;
f_m - average value for the period of volume density of magneto-dynamic forces.

After determining the volume density of forces, they should be treated as an initial condition in hydrodynamics calculations, which are done basing on Navier-Stokes equation (6) complemented by the equation of stream continuity (7) [14,15].

$$\rho\left[\frac{\partial\boldsymbol{v}}{\partial t}+\boldsymbol{v}\cdot\mathrm{grad}\boldsymbol{v}\right]=-\mathrm{grad}\ p+\rho\cdot\boldsymbol{g}+\frac{\eta_{\mathrm{d}}}{\rho}\cdot\Delta\boldsymbol{v}+\boldsymbol{f}_{\mathrm{m}} \tag{6}$$

$$\mathrm{div}\ \rho\mathbf{v}=0 \tag{7}$$

where:
ρ - density;
p - pressure;
g - gravitational acceleration,
η_d - dynamic viscosity coefficient.

Solution of Navier-Stokes equation allows to estimate if the assumed hydrodynamic parameters are reached.

In metallurgy of steel and nonferrous metals numerical calculations are often applied to reflect the processing conditions [16-18].

For the analysis of electromagnetic field numerical program Flux or another appropriate module from Ansys program will be used. HD module from Ansys program (Fluent) will be applied for the analysis of flow field.

Time consumption of numerical simulation of such process is very high. It can be also mentioned that geometrical digitization of the model for electrodynamic calculations and flow field is different. In case of electromagnetic field analysis the determining factor of net dense is the frequency of electromagnetic field and resulting from it depth of the field penetration in particular calculation areas.

For the flow area the fluid velocity in particular fragments of calculating areas becomes essential. Calculation models also vary taking into account the time step of the calculations. Therefore, the analysis of electromagnetic field is suggested to be done as a symbolic description, not time description. It allows to limit number of calculations of electromagnetic field. However, there is necessary to transfer the volume density of electrodynamic forces in the form of average values after period. As there is no compatibility of digitalization nets, a interpolation has to be applied. The data exchange between electromagnetic and hydrodynamic calculations will be based on the rectangle net with the density twice higher than the density of nets for electromagnetic and hydrodynamic simulations. Rectangle net containing distribution of forces has to be transformed into net of node used in hydrodynamic calculations. So, the bilinear interpolation will be applied [8]. Figure 5 shows the suggested scheme of numerical calculations. At the first stage of the research loose coupling between analysis of electromagnetic field and flow area is suggested as the one to be used.

3. Conclusions

Environmental protection, limitation of waste, using valuable and secondary materials are the requirements of our times. Recovery of such valuable materials like precious metals especially platinum, palladium and rhodium used in production of auto catalytic converters is particularly interesting. This results from the profitability of the process. The main cause of it is the high price of precious metals. Life time of auto catalytic converters is limited. Processing of two tons of used auto catalytic converters allows to avoid outputting 150 tons of ore and consecutive stages of treatment in order to obtain pure metal. Nothing but the comparison of such values: 2 tons of used catalytic converters and 150 tons of ore, gives more economical solution, not to mention ecology.

In presented solution we offered the rationalization of the recovery process of PGM metals by their elution from used auto catalytic converters. Applying the same metal collector allows to increase platinum concentration in the solution. Using, for the elution, the liquid metal which is in motion by means of electromagnetic field guarantees the comprehensiveness of the unit construction and allows to apply the protective atmosphere during the process.

The offered calculation methods allow to determine the basic exploitive parameters of the unit and as a result the stage of modelling research could be partially eliminated.

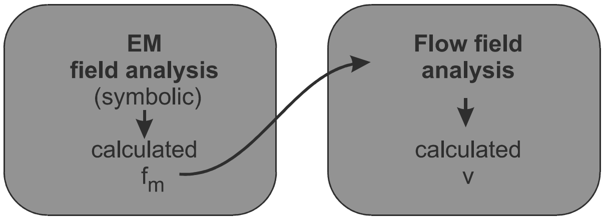

Fig. 5. Conjugation of calculating modules for the analysis of electromagnetic field and flow area

Acknowledgements

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