End-of-life vehicles processing, towards a thermal treatment of auto shredder residue

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Abstract: All over the world, the management of End-of-life Vehicles (ELV) and Automobile Shredder Residue (ASR) is an increasing issue for the car industry. The setting up of several environmental directives, among others the notion of extended producer responsibility, encourage car manufacturers to find alternatives solutions to waste disposal. For 2017, China aims for the recyclability and energy recovery of 95% of total weight of used cars, and in order to reach this rate, the development of some ASR thermal processes could be envisaged. With this research, an overview of ELV management was given and the different solutions about ASR thermal treatment were presented. It is showed that in spite of its big heterogeneity, the high heating value of ASR makes pyrolysis and gasification very interesting, compared to incineration or disposal of in landfills.

Key words: end-of-life vehicles; automobile shredder residue; recycling; thermal treatment; gasification; pyrolysis

CLC Number: X734.2;TH16;TG1　　**Document Code**: A　　**Article ID**: 1001 - 4551(2011)04 - 0385 - 07

1　Introduction

Until 2008, the world car production had been increasing to reach more than 70 millions of vehicles, recently partly thanks to the emergence of new markets as it is seen in China or India. The diagram below shows the repartition of the car production in the United States, Europe, Japan and China. In the 1960s, most of production was in western countries, but in the next 30 years, it was seen that the emergence of Japan and its great car makers like Toyota, which is still the best world car company. Since 1990s, the production increases quickly in China where there are both a very big market and a cheap working force. In spite of the crisis that affected the world and particularly automobile industry, China car manufacturing performs well, it is now about 22% of the world production and it has recently overtaken Japan and the United States to become the first car manufacturing country (http://oica.net/category/production-statistics). From this perspective, China understood that it has to face with a real issue, the management of the growing number of End-of-Life Vehicles, and planned to conform itself with the European legislation[1].

1.1　Legislation

At the end of the twentieth century, some laws and agreements are voted in order to limit the effect of used cars on the environment, but legislation is not the same all around the world. The most important directive concerning ELVs is an European one, the directive of the 18th, September 2000 (2000/53/EC)[2] which aims the following goals:

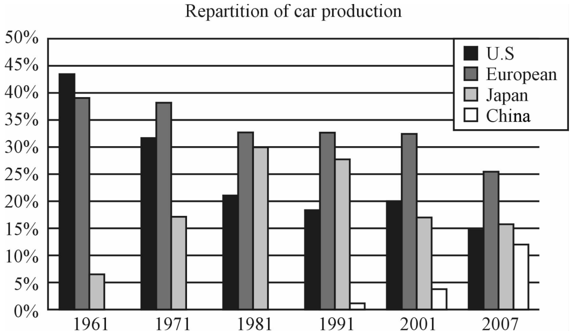

Figure 1　Evolution of the repartition of car production

(1) To harmonize all national measures about collecting and processing of ELVs in order to respect the environment.

(2) To give value to waste by promoting recovering and recycling.

Received Date: 2010 - 11 - 29

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(3) To implement preventive measures from the start of new vehicle design, for instance by reducing hazardous substances.

(4) Rates required by the directive for 2006:

- 80% of the total weigh of the car has to be reused or recycled.
- 85% has to be reused and promoted, 5% of which has to be energy promoted.

(5) Rates required by the directive for 2015:

- 85% of the total weigh of the car has to be reused and recycled.
- 95% has to be reused and promoted, 10% of which has to be energy promoted.

(6) For the new cars approved from 2005:

- 95% has to be reused and recycled, 10% of which has to be energy promoted.

This European directive shows the "polluter pays principle", which creates economic incentive for producer to take waste management into consideration at the design stage (in particular recycling)[3]. This directive gives responsibilities to car makers:

- They have to use more and more recycled materials in new vehicles.
- They have to give wreckers useful information for cleanup, disassembly and location of hazardous substances.
- They have to mark plastic pieces to recognize them easily.
- They have to publish their rates of reuse, recycling and promoting, of their cars.

In China, the goal is quite the same that in Europe, that means to bring the recycling rate of automotive products manufactured and sold in the country up to 95% by 2017[4]. Before these directives, recycling processes were only focused on the metallic part of the used car which is easy to recover, but now they are also had to deal with Automobile Shredder Residue. However, with the development of many kinds of plastics in the car industry, explained in the next paragraph, ASR has become a very complex mixture more difficult to be managed.

1.2 Materials, advantages and drawbacks of development of plastics

The automobile industry knows many external pressures, such as the rise of fuel costs, the globalization and competition with other constructors, but also the market demands, such as the comfort, the security, the aesthetic and the time of living. That results that cars have to be lighter and cheaper to be competitive, and that explains the great development of plastics[5].

Plastics have many advantages which explain why they are more and more used in automobile:

(1) Plastics are less heavy than metals, and in some cases their characteristics allow them to be used in the same manner as metals and ceramics. Their lightweight reduces fuel consumption, which is both economically and environmentally interesting.

(2) A greater design flexibility, there can be get more complex shapes by using plastics than metals. Their malleability during manufacture allows them to be cast, pressed or extruded.

(3) The costs, because plastic still are cheaper than steel or aluminum, and tooling costs are also less expensive than metal stamping or casting.

(4) There is not any corrosion with plastics, so there is not also any special treatment of materials which can be expensive.

(5) The reduction of the number of pieces which make assembly easier, so it can save time in the process.

(6) Plastics could be less noisy than metals, which is appreciated by users.

Even if plastics are used in most of cars, they would never replace steel for many components which are subjected to hard solicitations. That's why the proportion of plastics would stay in the next years between 10 and 20% of the total weigh of cars. Another drawback is the complexity of recycling, because with the increase of the number of materials (nowadays, a car includes around twenty types of plastics), it becomes more and more difficult to separate them in the ELV processing, it demands much time and so more money.

2 Steps of ELV Processing, from Collecting to Shredding, in Some European Countries

(1) Collecting

Users give for free their end-of-life car in their garage where the deregistration is provided. Harmful waste have to be sorted by service provider, ordinary pieces like bumpers or windscreens have to be removed, sorted and stored in specific container.

(2) Securing

All pyrotechnic elements which are found in air bags or safety belts have to be set off.

(3) Cleaning up

All polluting elements must be recovered: all fluids (brake fluid, oil, fuel, coolant, antifreeze, power steering fluid, windshield washer fluid) and the battery, which is composed of lead, a hazardous metal.

(4) Dismantling

Some pieces can be recovered in order to be remanufactured and reused in others vehicles (tires, steering columns, transmissions, engines fenders, radios, dynamotors, actuating motors, select plastic parts and components, glass, foams,...).

With the concept of Extended Producer Responsibilities, resulted from the 2000/53/EC directive, automobile constructors have to think about dismantling from the design stage, which means:

- Taking recyclability and homogeneity of materials into account.
- Making dismantling easier and faster.
- Using more recycled materials.

In several countries, an informatics system, IDIS (International Dismantling information System), has been set up to provide car dismantling companies with valuable information[6]. It is supervised and controlled by a consortium of automobile manufacturers of Europe, USA, Japan, Korea and Malaysia. In the last version (4.29), IDIS includes 726 models and it gives to dismantling companies some information to work more efficiently. For each element that must be removed before shredding, IDIS lists general information (materials, quantity, weight...), what tools and what method they have to use to dismantle it, how the piece is fixed, and so on. Some additional information can be given about safety, for example for pyrotechnic elements (air bag and seat belt), and some pictures make operation easier.

(5) Shredding

Shredder lines appeared in the 1960s in the United States to deal with the issue of car recycling[7]. The process is now well mastered: the hulk is grinding by hammers, and then pieces are usually sent to a two stage trommel, a screened cylinder used to separate materials functions of their size. Pieces are usually classified according to their size in two or three categories, undersize (< 10 mm), middling size (10 mm <... < 60 mm) and oversize (> 60 mm)[8]. For each size, the next step is usually sorting of a light and a heavy fraction thanks to air classification. The heavy fraction is mainly composed of ferrous and non ferrous metals, whereas the light one is mainly composed of plastics, fibers, dirt, glass particles, foam...

Ferrous metals (iron, steel) are easily recovered by using magnetic separators[9]. ELVs are very interesting, because with an average of 1 ton of used car, it can be recovered about 700 kg of ferrous metals. Non-ferrous metals (aluminum, copper, zinc...) are usually sorted by using eddy-current separators[10-11], and represent about 5% of the total weight.

3 Composition of ASR

When ferrous and non ferrous metals have been sorted, the result of that process can be called Automobile Shredder Residue (ASR) or auto fluff. ASR is a very complex and heterogeneous mixture including plastics, rubber, resins, textiles, but also small fragments of glass and unrecovered metals (iron, copper, zinc)[12-25].

After shredding, the size of these fragments varies from 15 cm to less than 1 mm. Nowadays, researchers try to find solutions about the utilization of ASR which are usually disposed of in landfills. With the increase of tax fees for disposal, the lack of space, and of course the pressure of the new regulation which will come into force in 2015 in Europe, a great effort has been doing to confront this difficulty. Thanks to its high heating value, many researches are done about thermal processes, like pyrolysis or gasification, but in this case it is necessary to know well the composition of ASR, in order to optimize the process.

When reviewing scientific publications which deal with this subject, it is surprising about the differing values. In table 1, it is a summary of reported values of material composition of ASR. Many reasons explain this discrepancy:

(1) Of course, ASR composition depends on the feed. It depends on the type of vehicles (passenger cars, trucks, buses...), the age (for instance, as we have seen previously, there are more and more plastics than before, as well as electronics), the brand (all car makers do not necessary use the same materials).

(2) ASR composition depends on disassembling step: what have been recovered before shredding? One example is tires which are sometimes found in shredder residue composition, whereas actually the trend is to re-

cover them for recycling.

(3) ASR composition depends also on sorting processes which can more or less recover all metals.

(4) It depends on the good representativeness of the sample analyzed. In [19], they give some explanations about this real issue.

			Plastics(hard/soft)	Metals	Textile/fiber/fabric/sponge	Wood/paper/cardboard	Wire(ceramic and electric materials)	Rubber/elastomer/tyre	Foam	Fine materials	Glass	Others
References	Mirabile, Pistelli et al. 2002		41		10		3	21			16	9
	Boughton and Horvath 2006		24	5				15		20	8	28
	Kim, Joung et al. 2004	Small cars	20,59	1,58	36,37	1,63	4,22	8,06		2,74	16,8	8,01
		Large cars	23,55	0,78	47,07	0,95	5,14	5,85		1,92	8,77	5,99
	Hwang, Yokono et al. 2008		37	11	9		1	13	11	18		
	Galvagno, Fortuna et al. 2001		20		25			20		35		
	Isabel de Marco and Cabrero 2002		18,85		9,2	2,8	0,6	24,45	3,55	40,55		
	Pineau, Kanari et al. 2005		13	12	16,4	5,1	1,7	8,9	7,4	34	1,5	
	Zolezzi, Nicolella et al. 2004		20	6	5	10		38	4,5	1		15,5
	Das, Curlee et al. 1995		19,3	8,1	45,1	8,6	2,1	5,3	2,2	5,8	3,5	
	Ambrose, Hooper et al. 2002		33	3	7	3	5	18	15	13		3
	Sakal, Urano et al. 2000	Sample 1	21,2	5,6				11,6		61,6		
		Sample 2	16,4	21,8				10,2		51,6		
	Saxena, Rao et al. 1995		8,6	6,4	24,4	4,4		2,7		51,5	2	

Table 1 Composition of ASR (% of weight) in the literature

(5) The last difficulty to compare values is to deal with different classification of materials.

In the diagram of ASR composition (Figure 2), an average ASR composition in percentage of weight was given. For all reasons before-mentioned, it has to note that it is just an approximation, but it gives a good idea of what ASR is made up. According to [13], heating value of ASR is about 15 to 30 MJ/kg, that is as interesting as coal.

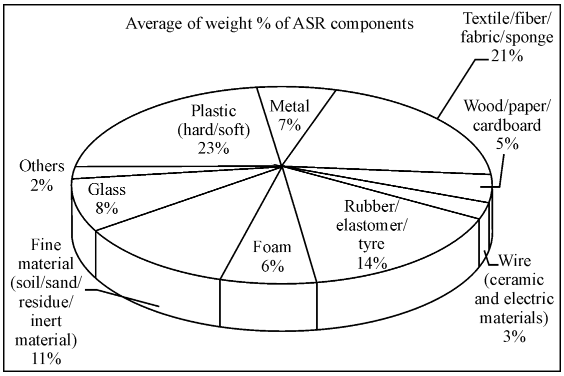

Figure 2 Diagram of ASR composition

Some other processes can be used to sort some of plastics in ASR, like heavy media separation or froth flotation, but they still are not really economically viable, that's why ASR is still disposed of in landfills or incinerated, which are the not the best solutions in relation with the environment. However, for some decades, research has also been done to use ASR as feedstock in thermal processes.

4 Thermal Processes

There are different kinds of thermochemical processes, like combustion (incineration), pyrolysis, gasification, hydrolysis, liquefaction or hydrogenation[26]. In this research, it only deals with the first third ones, because the last three ones only require a more homogeneous feedstock, that is not the case with ASR.

4.1 Incineration

In the combustion process, the atmosphere is rich in oxygen, so flying materials burn. Products of this exothermic reaction are inerts (ashes) and noncombustible hot gases. The calorific energy can for instance be recovered for the production of pressure steam[27].

The incineration process has some environmental impacts, because of the production of bottom and fly ashes which contain heavy metals (As, Cr, Cd, Pb and Cu)[28]. The bottom ash (85% of total incineration ash) could be reused as raw material for road construction, but fly ash has to be treated to remove or stabilize heavy metals before using it as construction materials. Two solutions are usually used for the treatment: acid washing and solidification[28].

The cost of incineration depends of the composition of ASR. The chlorine included in ASR is very corrosive for the reactor, so it causes problem of maintenance. The PCB (polychlorinated biphenyls) that can be found in ASR requires also a high temperature of process, which increases the cost of construction and the cost of treatment.

Drawbacks of incineration are the following:

(1) Have to use a large amount of air to burn wastes.

(2) Have to deal with dangerous emissions of nitrogen oxide, sulphur oxide, carbon.

(3) Have not much energy recovery (only 40%).

(4) Even if it is economically viable, it is still an expensive process.

Actually, incineration has a bad reputation with people, due to the impact on the environment and the poor yield. That's why pyrolysis and gasification processes are encouraged to be developed.

4.2 Pyrolysis

Pyrolysis process is a thermo chemical decomposition of ASR thanks to an endothermic reaction in a reducing atmosphere (oxygen is removed in the reactor, replaced with nitrogen)[27]. The heat needed for the reaction can be indirectly brought, with an external source, or directly brought, by burning a piece of the internal charge. It appears that pyrolysis is more environmentally friendly than incineration with less carbon emissions, and also with a higher energy recovery (70% versus 40%).

The main products of pyrolysis process are char (solid), tar and oil (liquid) and syngas (gaseous). The percentage of these products depends on operating conditions of thermal treatment: the initial composition of ASR, the temperature and pressure into the reactor, the residence time and the type of catalyst agent used[17].

Actually there are different kinds of pyrolysis processes[29-31]:

(1) Conventional or fast pyrolysis, playing on residence time.

(2) Vacuum pyrolysis, which decreases the boiling point and avoid secondary chemical reactions.

(3) Screw kiln or rotary kiln pyrolysis.

Nowadays, in most of companies that manage ASR, pyrolysis process is generally followed by gasification.

4.3 Gasification

Contrary to pyrolysis process, the atmosphere in the gasifier is not starved in oxygen. So others chemical reactions are made which lead to different products[32-33], mainly a mixture of gases called syngas (CO, H_2, CO_2, CH4).

Gasification reactors currently available for commercial use can be grouped into the three main categories[34]:

(1) Moving-bed (or fixed-bed) gasifiers

The feedstock is loaded from the top of the reactor while the air is introduced from the bottom (counter-current) or at the sides (co-current). ASR goes through the different zones of the reactor (drying, pyrolysis, reduction) to be finally converted into gas. The highest temperature of the reactor is greater than 1200 ℃

(2) Fluidized-bed gasifiers

There are not different reaction zones. They have an isothermal bed operating at temperatures usually around 700 ~ 900 ℃, lower than maximum fixed bed gasifiers temperatures. There are two kind of fluidized bed gasifiers which are bubbling fluidized bed gasifier (velocity of the air between 2 and 3 m/s) and circulating fluidized bed gasifier (between 5 and 10 m/s).

(3) Indirect gasifiers

In this technology, the heat is provided by the combustion of a part of gases or chars produced by the gasification.

A comparison of these technologies is done in[35], where it is learned that a low tar content is necessary for a better energy recovery.

5 Semi or Fully Commercial Plants

5.1 Incineration

Nowadays, some large scale plants have been created for the treatment of ASR. Even if the loss of energy is high, incineration reduces the volume of waste and so it still is an alternative of landfills. For instance, since 2005 the Oppama plant of Nissan processes 5,500 tons of ASR per year. ASR is converted into steam which is used in painting operation in the facility. ASR can also be burnt with MSW (Municipal Solid Waste): according to[17], 10% of ASR incinerated with MSW don't show any variations compared to only MSW combustion.

5.2 Feedstock for blast furnace

In [13, 36], it is learned that it could be interesting to use the fluff as an auxiliary fuel in a blast furnace. The blast furnace is an old technology which use iron ore and coke as raw materials to make pig iron, an intermediate material used in the production of steel and cast iron. For some decades, research has been done to improve both environmental and economic aspects, with the utilization of other raw materials, like ferrous waste or shredder residue. The fluff can be introduced in the raceway, the area just before the heart of the reactor, where temperature is very high (nearly 2 000 ℃), the atmosphere rich in oxygen and the residence time very short (less than 2 s). These conditions are ideal for ASR treatment, and pollutants, like heavy metals, are totally dissolved in the hot metal or in the slag. In order to have a more efficient yield, it is necessary to mix ASR with the pulverized coke.

5.3 Cement manufacturing

Using ASR in cement manufacturing, as a substitute or as a complement of coal and mineral ores, has two main advantages for the environment: first, it reduces the volume of ASR disposed of in landfills, moreover it saves an important part of raw material, there are less mining, transporting and preparing operations of coal and mineral ores. Finally it could reduce emissions[37]. Another good point of the utilization of ASR as fuel in cement furnaces, is that ashes are absorbed in the clinker.

The most important drawback is the high heterogeneity of ASR composition, which has of course an impact on the cement quality.

5.4 Pyrolysis/Gasification

The following technologies are one of few processes that could be classified as semi or fully operational[38]:

(1) The Ebara plant in Japan, with the TwinRec technology[39], is one of the best example of success. It is mainly composed of a rotary fluidized bed gasifier under pressure and a cyclonic combustion chamber for the vitrification of fines ashes. The syngas obtained can be used in many other processes. In the last decade, various plants use this technology to treat ASR[39].

(2) The PKA process (owns by Toshiba), the Pyromelt process (Lurgi Ensorgung) and the TWR process (Siemens) are done in two steps: a pyrolysis following by gasification. Fuel gases that we get as a result of gasification are reused to heat the rotary kiln of pyrolysis step. Residues of ferrous and non ferrous metals in ASR can finally be sorted and steam can be used in other processes.

(3) The Schwarze process (SVZ, Global Energy) is one of the oldest concepts of gasification. Products of this process are steam and syngas, mainly composed of carbon monoxide CO and hydrogen H_2. This syngas can after be used in chemical process to make methanol, ammonia or formic acid[40].

6 What about China?

6.1 Research in remanufacturing

Actually there is not any thermal treatment plant of ASR in China. Now research are mostly focus on remanufacturing of some parts of cars[41]. It is obvious that dismantling and remanufacturing activities can be economically viable thanks to the cheap Chinese labor force, but many improvements could again be done. For instance, marking parts of cars to know materials faster, the limitation of kinds of plastics or a dismantling manual to train workers. For remanufacturing, it has to make progress about non destructive controls, to be sure that all pieces resent in market are safe and efficient.

6.2 Towards new strategies in China

Remanufactured parts of cars come from used cars which were made about 10 years, 15 years before, or even more. They are intended to replace used pieces in another car, with same characteristics than a new one. Parts of cars which are removed for remanufacturing are engine, transmission or steering gear; this is the core of the vehicle, mainly composed of metals. However, metals represent about 75% of car, so in order to recycle or to energy recover 95% of weight of ELVs in 2017, there is no choice to manage ASR, which represents about 25% of weight.

Two strategies could be followed:

(1) Developing technologies to sort different kinds of plastics which composed ASR, to recycle them separately.

(2) Developing thermal processes, to use ASR as feedstock or to recover syngas or energy.

Due to the high heterogeneity of ASR, the first strategy is technically feasible: heavy media separation, froth flotation or optic sorting processes can remove some of plastics from ASR, like PVC, which leads to hazardous substances with heat such as chlorine. Nowadays, these technologies are hardly economically viable but are the subject of many research[42-43]. The great advantage of the second strategy is precisely that it does not sort any materials from this complex mixture before using it as feedstock.

7 Conclusion

The use of pyrolysis and gasification technologies is not fully commercial in many countries. Even if these thermal processes were created a long time ago, they are hardly suitable with ASR as feedstock because of its high heterogeneity. However, mechanical separation of ELVs is possible, but not economically viable, that's why thermal treatment is a very interesting alternative in order to reach 95% of weight of ELVs in recycling/recovering, in 2015 for European countries, and 2017 for China.

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