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An Assessment of "Pyrolysis" as a Resource Recovery Option for Automobile Shredder Residue*

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ABSTRACT

Pyrolysis, the chemical cracking of organic materials such as polymeric materials represents an innovative technology to recover resources contained in automobile shredder residues (ASR). In this study the technical capabilities, economic viability and environmental impact of pyrolysis as applied to ASR has been investigated. Based upon data provided by pyrolysis equipment suppliers, the pyrolysis of ASR appears to be a viable option to deal with the growing quantities of this material currently being produced. However, the selection of the most appropriate pyrolysis technology is dependant upon local needs and requirements.

INTRODUCTION

The recycling of old discarded automobiles by shredding operations in North America results in the recovery of approximately 10 million tonnes of iron and steel each year [1]. This recycling of scrap metal in steel production results in a:

- 86% reduction in air pollutants
- 76% reduction in water pollutants
- 74% reduction in energy consumption
- 40% reduction in water usage
- 97% reduction in mining wastes

Yet, at the same time, this recycling process also generates close to 3 million tonnes of solid waste known as Automobile Shredder Residue (ASR), the majority of which is sent to landfills. Because of concerns regarding this solid waste, the automobile industry and their suppliers are working to produce the next generation of automobile which will be easier to disassemble and thereby facilitate the recyclability of the non-metallic components as well as those made of metal [2,3]. However, these newly designed automobiles will not be reaching the shredding operations for more than a decade. Conse-

quently, there is an urgent need now to deal with the growing quantities of ASR currently being produced.

One resource recovery option, which has received serious consideration for ASR is pyrolysis. Because ASR contains a large number of different plastic components, many contaminated with a large variety of both organic and inorganic materials, the thermal recovery of the hydrocarbons in these mixed plastics, represents an appealing recycling approach. During the last decade significant progress has been made in pyrolysis technology such that today there are several large scale pilot and demonstration units that are capable of processing plastic waste to produce chemical feedstock and fuel [4,5].

In this paper several key features of pyrolysis will be examined, especially as they relate to the recovery of resources from ASR. The examination will principally focus on technical capabilities, environmental impacts and economic viability.

THE PYROLYSIS PROCESS

Pyrolysis is the thermal degradation of organic materials in the absence of oxygen. The thermal degradation process causes complex organic molecules such as polymers to undergo chain scission processes to produce fuel gases, oils and a solid residue which contains carbon along with appreciable quantities of mineral matter. This simplistic concept of ASR pyrolysis is presented in Figure 1.

Depending upon the pyrolysis process being considered the yield of the pyrolysis products: gas; liquid and solid can vary greatly. For example in the case of a carbonisation processes, low pyrolysis processing temperatures are employed (e.g. about 350°C) to maximize the yield of the carbeneous char. Meanwhile in the case of a gasification process relatively high yields of the pyrolysis gas are the major objective, which are usually achieved by the use of high pyrolysis temperatures (700-800°C). The

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gases are then principally used on site as an energy source.

Figure 1. Schematic of the pyrolysis of ASR

Other pyrolysis techniques such as screw kilns and fast pyrolysis processes are designed to maximize the yield of the pyrolysis liquid, which can then be transported for use as a fuel or petrochemical feedstock. In all these processes the temperature and/or reaction time are carefully selected to maximize the yield of the desirable pyrolysis products.

FEED CHARACTERIZATION AND PREPARATION – Because ASR is a very heterogeneous material whose composition can vary depending upon the type of shredder and operating conditions it is always essential to have the ASR feed material fully characterized before thermal processing in order to ensure optimum processing. The National Research Council of Canada have conducted several characterization studies on a variety of ASR samples from several sources and some of these findings are presented in Table 1. This data gives some of the typical characteristics of ASR, but more importantly it also provides some data on the elemental composition of the material. This information is critical if secondary metal recovery processes are to be applied to the solid residues after pyrolysis. The data also identifies elements of concern regarding environmental emissions and potentially toxic materials.

Because of the relatively high inorganic content of ASR, several proponents of pyrolysis recommend a beneficiation process prior to thermal treatment. This pre-processing not only provides a higher organic rich fraction for pyrolysis, but also improves the energetics of the process. This arises because less inert, inorganic material has to be heated to the pyrolysis temperature. The pyrolysis of a heterogeneous waste such as ASR may also require some feedstock preparation, in order to ensure

that the process can accommodate the material. This is especially important when dealing with fluidized bed systems where bulky materials could cause technical problems. Consequently, depending upon the process, some size reduction of the feed may be necessary for the efficient operation of the pyrolysis process.

Table 1. Characteristics of Some ASR Samples

Study Reference	[6]	[7]	[8]
Bulk Density (kg/m ³)	404	438	340
Moisture (%)	6.0	2.6	7.8
Calorific Value (MJ/kg)	12.4	10.2	14.8
Ash Residues (%)	57.7	58.1	42
Elemental Analysis (%)			
C	ND	27.9	28.6
H	ND	4.0	4.1
N	ND	0.9	1.0
Cl	ND	0.5	1.8
S	ND	0.3	0.3
Si	ND	8.6	7.8
Metals (%)			
Fe	ND	17.7	12.4
Cu	1.11	0.62	1.13
Zn	0.92	0.94	1.19
Al	ND	1.39	1.45
Heavy Metals (%)			
Pb	0.28	0.24	0.40
Cd	0.007	0.005	0.004
Cr	0.042	0.023	0.030

PYROLYSIS PRODUCTS

Pyro Gas – The yield and characteristics of the gas produced from the pyrolysis of ASR is greatly dependent upon the process as well as the temperature and reaction residence time. However, based upon data from a recent survey of pyrolysis technologies the data presented in Table 2 give a reasonable approximation of the chemical composition of a typical pyrolysis gas [8]. These values are not inconsistent with others reported in the scientific literature [8-11]. While the heating value of the gas may be a little low compared to natural gas (35 MJm⁻³) it can be mixed with natural gas and used, either as a fuel for the pyrolysis reactor, or independently for other applications.

Table 2. Characteristics of a Typical ASR Pyro Gas [8]

Heating Value of Gas (MJ/m ³)	22
Chemical Composition (Vol. %)	
Hydrogen	28
Carbon Dioxide	23
Carbon Monoxide	20
Methane	13
C ₂ -C ₃ Hydrocarbons	10
C ₄ -up Hydrocarbons	3

The Pyrolysis Liquid – The yield of liquids produced by the pyrolysis of ASR is very much dependent upon the process employed and can vary greatly from one process to another. Clearly if a pyrolysis gasification process is

being considered, the technology has been selected to minimize liquid formation. However, several processes are designed to maximize the yield of pyrolysis liquid, and pyrolysis liquid yields as high as 30% have been reported [8]. However, depending upon the moisture content of the ASR feed, the pyrolysis liquid can contain measurable quantities of water from which the valuable oil fraction has to be separated.

In terms of the chemical composition of the pyrolysis oil, we have conducted a detailed chemical analysis of a pyrolysis oil fraction produced by a commercial screw kiln process. In this study we were able to separate a total of 269 chemical compounds and identify over 100 of these species using gas chromatography and mass spectrometry [11]. This analysis indicated that the pyrolysis oil was predominantly aromatic (66%) with many characteristics similar to a diesel fuel, although the distillation profile as measured by ASTM method D2887 showed clear differences. However, the measured heating value of 41 MJ/kg was significantly higher than that of No. 2 fuel oil (31 MJ/kg).

Table 3. Elemental Composition of a Typical ASR Pyro Oil

	Typical Value	Range
C (%)	83	76 - 86
H (%)	9.8	8.7 - 10.4
N (%)	1.7	0.1 - 2.5
O (%)	2.9	1.1 - 6.1
S (%)	0.53	0.27 - 0.81
Cl (%)	0.68	0.18 - 1.80

Elemental analysis of the pyrolysis oils obtained from the pyrolysis of ASR have been reported by several authors [8-11] and Table 3 provides some typical values, along with the ranges reported. From this table it can be seen that the oil contains measurable amounts of nitrogen, sulphur and chlorine. Typical nitrogen compounds include nitriles, isocyanates, amines and pyridine compounds. Meanwhile the principal sulphur compounds detected were aliphatic thiol compounds and substituted thiophenes. The presence of these compounds, not only give the oil an offensive odour, but also raises concerns regarding subsequent processing as a feedstock or a fuel

The Pyrolysis Residue. – While pyrolysis represents an excellent means of reducing the volume of ASR for subsequent disposal, because of its higher inorganic content, it does produce a significant quantity of solid residues. In terms of process economics it is therefore necessary to consider recovery of metals from this material

The elemental composition of the solid residue is dependent on the pyrolysis process and the extent of degradation. Table 4, however, provides some indication of the type of composition that can be expected. This data is taken from the average reported for several pyrolysis processes [8]. From this table it can be seen that the most abundant elements in the solid residue are silicon (Si)

and iron (Fe). The high values for these two elements are not surprising considering their concentration in the original feed. This concentrating of the inorganic materials in the solid residue does raise concerns regarding the heavy metals and their potential leachability. However, tests conducted in our laboratories on ASR pyrolysis residues suggest that the leachability of these heavy metals should not be of concern.

Table 4. Elemental Composition of a Typical ASR Pyrolysis Residue

Si (%)	17.5
Fe (%)	18.5
Al (%)	4.8
Cu (%)	1.9
Zn (%)	1.5
Pb (%)	0.26
Cd (%)	0.0022
Cr (%)	0.073
Cl (%)	0.96
S (%)	0.39

However, prior to disposal, metal recovery options represent revenue generating potential that cannot be overlooked. It has also been suggested that the material can be blended with other materials for use in a cement kiln [10]. Vitrification to produce ceramic materials is also an option [8].

ENVIRONMENT EMISSIONS FROM THE PYROLYSIS OF ASR

When considering pyrolysis as a recovery option for ASR it is essential that all environmental impacts are considered to ensure that both ecological and human health considerations are fully addressed.

While pyrolysis has been championed as an environmentally clean technology there is limited data in the scientific literature to support many of the environmental claims. This information is essential because ASR contains chlorine, sulphur and nitrogen as well as whole range of heavy metals, whose fate during processing must be accounted for.

Analysis of data supplied by several companies with pyrolysis experience with ASR [8], however, suggests that environmental emissions to the air and water can be minimized and controlled within current environmentally regulated limits. However, when the pyrolysis products of ASR are used as a fuel, it is essential to ensure that appropriate emission control devices such as scrubbers and bag house filter systems, are employed to ensure harmful environmental emissions are controlled.

THE ECONOMICS OF ASR PYROLYSIS

The economics of many pyrolysis processes are clearly dependent upon the operating capacity, product yields and the sale of marketable products. In a recent survey of pyrolysis processes that have been applied to ASR,

the size of the processing equipment ranged from 1 tonne/hour to 21 tonne/hour, with capital costs ranging from less than \$1M US to \$40 M [8]. However, a typical shredding operation in North America would essentially require a 2 tonne/hour plant to process the ASR produced on site and cost about \$8M [1]. Using information contained in the NRC Pyrolysis report [8] it is possible to generate economic data for a "typical" ASR process. A simplification of this data is presented in Table 5 and presents some of the economic considerations that need to be evaluated in an economic analysis of pyrolysis as a resource recovery option.

Table 5. Economics Case Studies (all cost based on \$ per tonne of treated ASR)

	CASE #1	CASE #2	CASE #3
EXPENSES			
Capital Repayment Cost	69.44	69.44	69.44
Total Operational Costs	36.47	36.47	36.47
Waste Disposal at \$501/t	5.0	25.0	30.00
Total Costs	111.91	130.91	135.91
REVENUES			
Sale of Gas	63.58	63.58	63.58
Sale of Liquid	15.49	15.49	15.49
Solid as Fuel	4.00	0	0
Metal Recovery	12.50	12.50	0
Gate Fee to break even	16.00	40.00	57.00
Total Revenues	111.58	131.58	136.08

In table 5 three cases are considered. In case 1 the assumption is made that there is a market for all the solid residue produced (i.e. aggregate at \$10/t and metals at \$125/t). With this type of recovery a tipping fee of only \$16/tonne is required for the pyrolysis process to break even. In Case 2, the assumption has been made that only the recovered metals have value while the majority of the solid residues has no economic value and needs to be disposed of. In this case it is necessary to charge a tipping fee of \$40/tonne to achieve a break even point. In Case 3, no revenue has been assigned to any of the solid residue. In this case a tipping fee of \$57/tonne is now required for economic neutrality.

It should be noted that whilst the data presented in Table 5 represents an over simplification of the economics it is based upon economic data supplied by a variety of companies who have experience in the pyrolysis of ASR. Based upon this data, it would appear that it should be possible to process ASR by pyrolysis and make a profit providing the operators can receive a tipping fee in the \$20-\$40/tonne range.

CONCLUSION

Based upon available information, the pyrolysis of ASR appears to be a viable resource recovery option for dealing with the growing quantities of this material being generated. The size and type of pyrolysis process selected for a particular operation should, however, depend upon the needs and requirements of the operator. However, prior to the final selection of a particular pyrolysis process, it is essential to establish that:

- the economics are based upon a sound analysis of current costs and markets
- full environment emission data is provided to substantiate the impact assessment
- markets exist for all saleable products.

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