Gasification Characteristics of Auto Shredder Residue

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Summary: Given the large volume of used tyre waste generated each year it is imperative that suitable re-use and disposal techniques are developed for dealing with this problem; presently these include rethreading, reprocessing for use as safe playground and sports surfaces, use as noise reduction barriers and utilisation as a fuel source. This paper reports on pilot scale studies designed to investigate the suitability of automotive waste for energy recovery via gasification. The study was carried out into auto shredder residue, which is a mixture of three distinct waste streams: tyres, rubber/plastic and general automotive waste. The tests included proximate, ultimate and elemental analysis, TGA, as well as calorific value determinations. In addition, the waste was tested in a desktop gasifier, and analysis was carried out to determine the presence and type of combustible gases. It was concluded that tyre waste and rubber/plastic waste are quite suitable fuels for gasification.

Introduction

The waste tyres in the world are estimated to be $5*10^6$ tonnes per year while in UK it is estimated as 0.44 Mt. [1]. Environmental legislation is beginning to impact the ways in which this waste stream can be stored and disposed off: for example in the EU, the Landfill Directive now prohibits the disposal of whole and shredded tyres to landfill, and many of the US states introduced regulations to deal with this problem. Successful re-use strategies developed so far have included rethreading, reprocessing for use as safe playground and sports surfaces, use as noise reduction barriers and utilisation as a fuel source. Scrap tyres possess a high volatile matter and low ash content and their energy content is higher than that of coal or biomass [2] . Thermo physical and combustion properties of the tyre char are in good agreement with those of coal dust [1]. Scrap tyres have been used as a fuel in cement kilns in the recent years. It is estimated that around 22% of used tyres in UK are shredded and energy is recovered.

The chemical composition of tyres is varied but typically it has 50% rubber, 25% fillers, 10% steel, 1% sulphur, 1% zinc oxide, processing oil, plasticizers and vulcanization accelerators [3]. The presence of heavy metals and chlorine due to PVC has also been reported [4].

Pyrolysis of scraped tyres is a valid solution and has reported in some studies [5-7]. In this paper we report an investigation carried out to study the suitability of automotive waste for recovery of energy through gasification. Auto Shredder Residue (ASR) which is mainly a mixture of three distinct waste streams: tyres, rubber/plastic and general automotive waste have been used.

Gasification Technology

Gasification technology is well developed and has been used extensively for power generation tasks throughout the world. Gasification is a process of conversion of solid carbonaceous material into a combustible mixture of gases in reducing environment through pyrolysis [8] . The gasification process offers higher energy recovery than combustion and incineration. The gases generated mainly comprise of carbon monoxide and hydrogen, though other byproducts are also produced. There are a variety of different gasifier configurations available depending upon the conditions and objective of the process; these include updraft, downdraft and fluidized bed reactors [9-12] . Downdraft gasifiers are preferred if producing a clean gas is the requirement. It is usual for some cleaning and conditioning of the generated gases prior to being fed into the power generation system.

Results and Discussions

Proximate Analysis

Proximate analysis of the three types of wastes were conducted and compared with typical data for wood. The results are shown in Fig. 1 and indicate that the tyre waste stream (A) has the lowest average ash content and highest average volatile matter content of the three wastes. General waste (C) on the other hand has highest average ash content.

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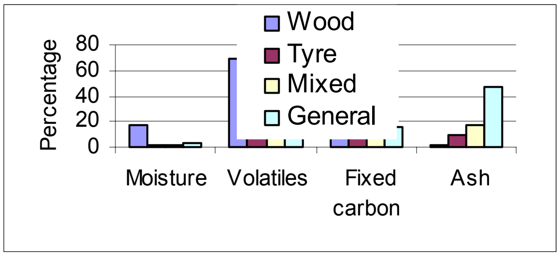


Fig. 1: Comparison of proximate analysis of auto shredder waste streams with wood.

Ultimate Analysis

The ultimate analysis results for the three different waste streams are presented in Fig. 2.

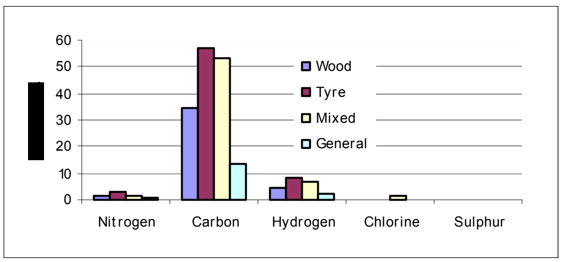


Fig. 2: Ultimate analysis results of auto shredder waste streams and wood.

Tyre waste has the highest carbon, hydrogen and nitrogen (CHN) content. The CHN content of general waste is low by comparison to both the other streams; this might be attributed to the high percentage of non-combustibles (ash) in this stream. All waste streams contain chlorine and sulphur, most of which will become part of producer gas in the form of HCl and H_2S. These gases can be scrubbed from the flow using aqueous systems dosed with caustic or suitable oxidising agents.

Using the ultimate analysis results, calorific values of the three waste streams were determined and compared with wood, as shown in Table-1. Dulong formula has been used to calculate the Gross Calorific Value (GCV) in MJ/kg. It can be seen that the calorific value for tyre and mixed wastes was higher than that of wood, suggesting a good energy recovery potential. The Calorific Value established in this study is significantly higher than that has been reported in some studies [6] but the Calorific Value for General Waste is very low.

Table-1: Calorific values [MJ/kg] for auto shredder waste and wood.

	Wood	Tyre	Mixed	General
Test 1	17.3	26.3	22.7	6.1
Test 2	16.8	20.1	23.8	5.9
Average	17.05	23.2	23.2	6

Elemental Analysis

Elemental analysis was carried out using a Spectro Xlab 2000 energy dispersive x-ray fluorescence spectrometer and the results are shown in Table-2. The ash fusion temperature, given in Table-3, calculated from elemental analysis for all the three wastes was estimated to be greater than 1350 °C. The slagging propensity is established to be low for tyre and mixed waste and medium for general waste, suggesting that tyre and mixed waste pose no threat of clinker formation during gasification, though there is that possibility for general waste. It is recommended to mix the pellets of general waste with tyre and mixed waste for better gasification characteristics.

Thermo-gravimetric Analysis (TGA)

TGA analyses were carried out for all the three wastes separately at two different temperatures. Results obtained from TGA are plotted in Fig. 3-8.

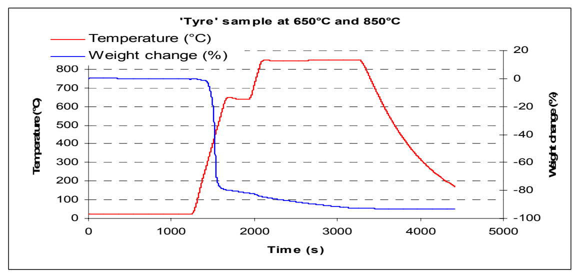


Fig. 3: Thermo-gravimetric analysis of tyre waste at 650 and 850 °C.

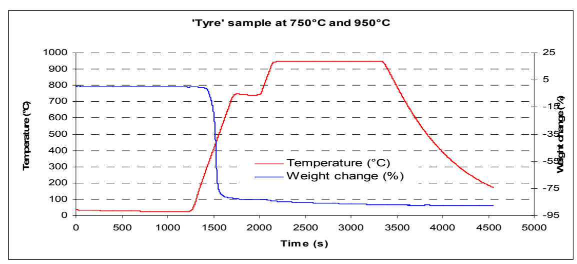


Fig. 4: Thermo-gravimetric analysis of tyre waste at 750 and 950 °C.

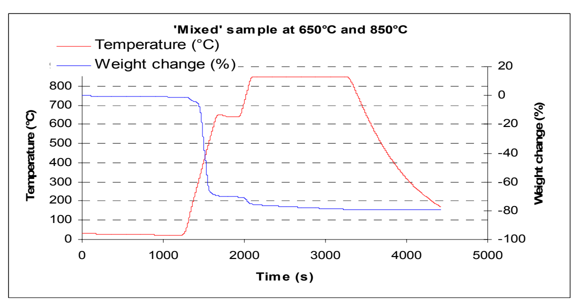


Fig. 5: Thermo-gravimetric analysis of mixed waste at 650 and 850 °C.

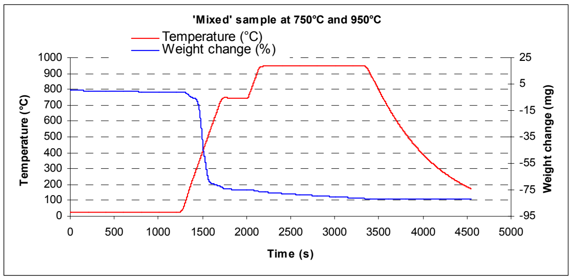


Fig. 6: Thermo-gravimetric analysis of mixed waste at 750 and 950 °C.

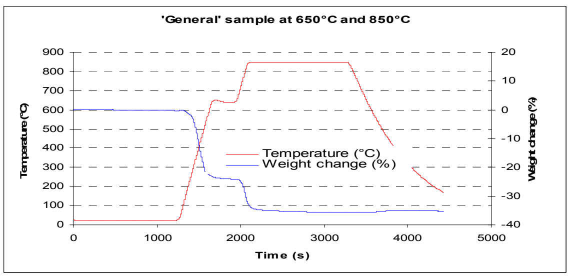


Fig. 7: Thermo-gravimetric analysis of general waste at 650 and 850 °C.

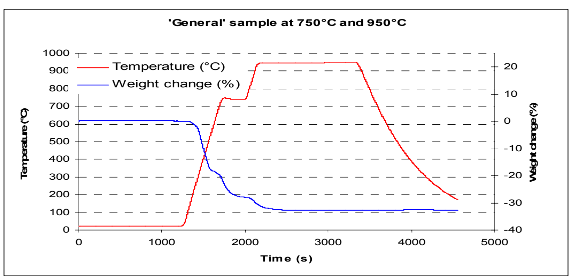


Fig. 8: Thermo-gravimetric analysis of mixed waste at 750 and 950 °C.

These graphs are plotted for percentage weight loss and temperature as a function of time. Proximate analysis shows that tyre waste contains 53.15% volatile matter. From Fig. 3 it can be seen that all the volatile matter is released after 258.3 sec (4.3 min) at 450 °C. Similar results are obtained form Fig. 4 which shows that all the volatile matter is released after 259 sec (4.31 min) at 454 °C.

For mixed waste, all the volatile matter (36.29%) is released after 233 sec (3.9 min) at 411 °C as can be seen from Fig. 5. Fig. 6 confirms the results by showing that the volatiles are released after 228 sec (3.8 min) at 401 °C.

For general waste all of the volatile matter is not released even after 35 minutes at 850 °C and 950 °C. This is probably because of high ash content of the waste which restricts the release of volatile matter.

Mixed waste released its volatile matter earlier and at lower temperature as compared to tyre waste. Residence time for complete pyrolysis of tyre waste is 4.3 minutes and for mixed waste is 3.8 to 3.9 minutes.

Table-2: Elemental Analysis.

Element		Tyre waste	Mixed waste	General waste
Na	%	< 0.059	< 0.11	< 0.19
Mg	%	< 0.0098	< 0.017	< 0.036
Al	%	0.0081	0.0191	0.1142
Si	%	0.0813	0.2278	0.922
P	%	0.00233	0.0027	0.0235
S	ppm	374.1	1307	738
Cl	ppm	903	14820	2867
K	%	0.0626	0.1881	0.366
Ca	%	0.6045	3.149	5.998
Ti	%	0.057	0.712	0.6888
V	ppm	4.9	14.8	< 17
Cr	ppm	19.5	34.2	250.1
Mn	%	0.00999	0.01214	0.073
Fe	%	1.206	1.225	10.47
Co	ppm	21.2	< 17	< 63
Ni	ppm	28.9	42.5	222.4
Cu	ppm	171	760.7	1227
Zn	ppm	4563	10500	7788
Ga	ppm	2	< 3.8	< 9.1
Ge	ppm	< 1	< 1.9	< 3.2
As	ppm	7.8	< 7.5	58.5
Se	ppm	11.2	< 0.9	< 2.4
Br	ppm	31.9	17.7	99.4
Rb	ppm	0.9	9.3	26.5
Sr	ppm	63.2	131.3	389
Y	ppm	< 0.8	< 1.4	< 3.7
Zr	ppm	13.9	55.7	301.6
Nb	ppm	< 0.8	7	12
Mo	ppm	20.2	11.2	97.4
Ag	ppm	< 0.5	2	9
Cd	ppm	38.5	32.6	24.5
In	ppm	< 0.5	< 0.6	< 1.5
Sn	ppm	20.1	32.4	390.5
Sb	ppm	8.7	43.5	211.8
Te	ppm	3.5	< 0.6	< 1.2
I	ppm	< 1.9	< 2.4	< 5.6
Cs	ppm	< 0.1	< 0.1	< 0.1
Ba	ppm	1656	2083	8374
La	ppm	< 4.8	< 5.9	< 7.4
Ce	ppm	25.3	16.6	43.3
Pr	ppm	41.2	35.5	105
Nd	ppm	31.6	41	68
Sm	ppm	2.8	2.8	4.6
Hf	ppm	4.1	17.7	91
Ta	ppm	< 16	< 38	< 74
W	ppm	< 18	< 31	< 40
Pt	ppm	< 0.1	< 0.1	< 0.1
Hg	ppm	< 1.4	< 2.1	< 5
Ti	ppm	< 1.8	< 3.5	< 10
Pb	ppm	431.4	1411	5955
Bi	ppm	< 2.1	< 4.1	< 13
Th	ppm	6.2	< 3	< 8.3
U	ppm	< 1.6	< 2	< 3.7

Table-3: Ash fusion temperature and slagging propensity of the wastes.

	Tyre waste	Mixed waste	General waste
Ash fusion temperature	> 1350 °C	> 1350 °C	> 1350 °C
Slagging propensity	Low	Low	Medium

Also volatile release at lower temperature indicates that high reactivity char will be produced during pyrolysis stage therefore will enhance the produced gas quality. General waste can also be treated by mixing it with tyre and general wastes making it inert.

Stove Test

Stove test of general waste, tyres waste, mixed waste and wood waste were carried out to study the combustion characteristics inside the gasifier bed while being the intense heat during combustion process. The flame produced in the case of each waste stream is shown in Fig. 9 (a-c). The flame produced by wood is shown in Fig. 9 (d) for comparison purposes. It was observed that tyre and mixed waste pellets kept their shape during burning just like wood; however the pellets of general waste were found to disintegrate in the gasifier bed. Tyre and mixed waste streams demonstrated the highest burning rate as determined by the strength of the flame and the calorific value analysis; the shape of flame during burning remained similar to wood. In the case of general waste, the low burning rate can lead to ignition problems. Additionally for the general waste stream, the plastic components appeared to be melting and sticking to the gasifier surface.

Performance in Desktop Gasifier

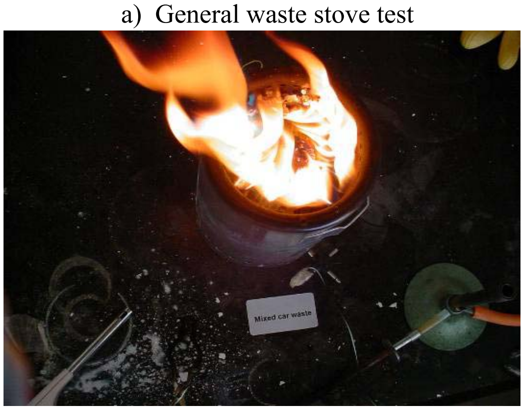
The waste was gasified in desk top gasifier. The gas analysis results for auto shredder waste streams and wood, taken at a sampling point just above the desk top gasifier bed are shown in Table-4, and also plotted in Fig. 10; the results are quite similar to wood. Hydrogen content in general waste gas is lowest. It may be observed that considerable variation in burning characteristics of the fuels under study. This is mainly due to variable composition of the gases produced.

Table-4: Gas analysis from gasifier bed.

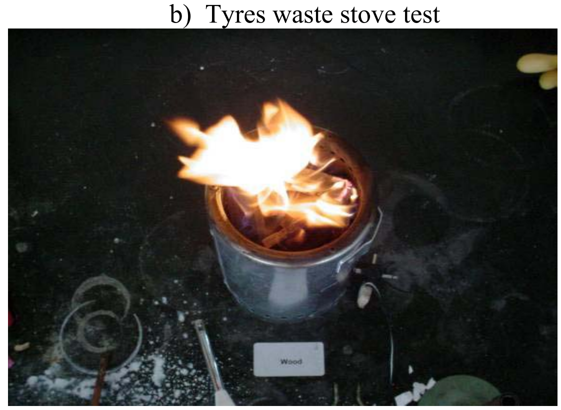
		Wood	Tyre waste	Mixed waste	General waste
Hydrogen, %	**Test 1**	**0.25**	**3.57**	**2.34**	**0.25**
	Test 2	**0.25**	**4.41**	**3.2**	**1**
	Average	**0.25**	**3.99**	**2.77**	**0.6**
Hydrogen cyanide, ppm	**Test 1**	**10**	**20**	**74.6**	**----**
	Test 2	**1**	**33.3**	**22.47**	**----**
	Average	**5.5**	**26.67**	**48.5**	**----**
Carbon dioxide, %	**Test 1**	**20**	**10**	**12.05**	**9**
	Test 2	**18**	**8**	**11**	**9.2**
	Average	**19**	**9**	**11.5**	**9.1**
Carbon monoxide, ppm	**Test 1**	**8000**	**6111.1**	**7142.9**	**3850**
	Test 2	**5000**	**6750**	**8823.5**	**1765**
	Average	**6500**	**6430.6**	**7983.2**	**2807.5**

a) General waste stove test

b) Tyres waste stove test



c) Mixed waste stove test



d) Wood stove test

Fig. 9: Stove test results.

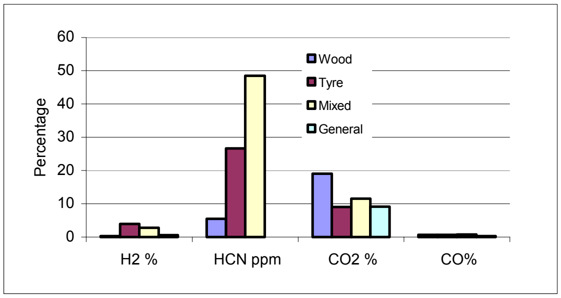


Fig. 10: Comparison of gas analysis results for auto shredder waste and wood.

Experimental

The experimental stages of the investigation were as follows:

Visual Inspection

The auto shredder residue consisted of three different streams, which were given the following names for identification purposes:

Tyre waste (A) consisting of larger pieces of tyre cuttings, thermo-plastics, plastics and small pieces of wood.

Mixed waste (B) consisting of rubber, plastics, thermoplastics and small pieces of wood.

General waste (C) containing pieces of cloth contaminated with lube oil, foam, small pieces of glass and metal.

Collection of Representative Sample

Representative samples of each of the three waste streams were obtained and were cut into very small pieces using a scalpel. Hard pieces of plastics and wood were filed to reduce size. All the materials were then mixed and screened through a 16 mesh sieve and representative samples were taken through quartering. In the case of general waste, cloth pieces were finely cut and mixed with the waste. The waste material was passed through a 16 mesh sieve and representative sample was collected as above.

Palletizing

Cylindrical pellets were prepared using a Graseby laboratory scale hydraulic press at a pressure of 12 tonnes/in^2. Fig. 11 shows the pellets prepared; typical dimensions were 32mm diameter and 15mm thickness, with a weight in the range 8 – 10 g.

iv. Proximate analysis
v. Ultimate analysis
vi. Elemental analysis
vii. Thermo-gravimetric analysis
viii. Stove test
ix. Desk top gasifier studies.

Fig. 11: Pallets of Waste.

The gasification system's key components include: a 10 kg/h novel gasifier, a two in one cyclone/ scrubber followed by spark free fan assembly. Other assembly comprise of: A feed hopper, Ash removal cone, water recirculation loop, various valves and monitoring gear. The exclusive design of the gasifier offers uniform airflow through the fuel bed when fuel is allowed to flow under gravity without any constriction. The gasifier design has accommodated all the features required for a perfect gasification unit to treat difficult residues with variable ash and composition. This makes it suitable for a wide variety of solid feed stocks. The gasification process can be divided into three main zones

(i) Fuel feeding zone – Top one third
(ii) Fuel gasification zone – Middle one third
(iii) Ash discharge zone – Bottom one third

Feed is loaded in the gasifier from the top feeding hopper – situated in zone 1 through a manually operated slide valve. Blower is started and air supply controlled by a regulator valve provided at the inlet of the blower. Water flow rate to the gas scrubber is set at the desired level.

The fuel is ignited through an ignition port provided on the side of the gasifier using a Bunsen burner situated in zone 2. Initially zone 2 is filled with a small amount of charcoal to start the process. Synthesis gas generated in the gasifier is drawn through wet scrubber. Inside the scrubber, gas comes into contact with water, which gives quenching effect and also removes tar and particulates trapped in the gas. Fresh water is supplied to the scrubber and after cleaning the gas drains to re-circulation tank. After leaving the scrubber, gas is passed through an orifice plate where its flow rate is measured using a water manometer. The gas then passes through the three-way regulator valve (used to control the gas flow depending upon the fuel characteristics) to a flare where it is combusted. Once the steady state condition is achieved part of the gas is diverted to gas engine for power generation. In zone 3 the gasifier is filled with sand which is then removed slowly to help flow of ash under the gravity force.

Conclusions

Tyre waste has highest CV thus indicate good potential for energy recovery.

High ash fusion temperature for tyre and mixed wastes shows low slagging propensity therefore can be considered suitable for fixed and moving bed gasifiers.

Gasification of all wastes generated typical composition of producer gas but due to limited data no correlation can be drawn with respective elemental anaysis.

Tyre waste and mixed waste were found to be ideal gasification fuels and can be used with little pre-treatment (drying, pelletising etc) except shredding to a suitable size. In the case of general waste, the combustion and composition problems can be overcome by inclusion with the mixed tyre or mixed waste to obtain good burning rate and to avoid air blockage.

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References

1. K. Holikova, L. Jelemensky, J. Annus, J. Markos, *Petroleum and Coal*, 47, 10 (2005).
2. C. Berrueco, E. Esperanza, F.J. Mastral, J. Ceamanos, and P. García-Bacaicoa, *Journal of Analytical and Applied Pyrolysis*, 74, 245(2005).
3. S. Seidelt, M. Muller-Hagedorn, H. Bockhorn, *Journal of Analytical and Applied Pyrolysis*, 75, 11(2005).
4. P. D. Filippis, F. Pochetti, C. Borgainni, and M. Paolucci, *Waste Management and Research*, 21, 459 (2003) .
5. C. Roy, A. Chaala, and H. J. Darmstadt, *Journal of Applied Pyrolysis*, 51, 201 (1999).
6. I. M. Rodriguez, M. F. Laresgoiti and M. A. Cabrero, *Fuel Processing Technology*, 72, 9 (2001) .
7. S. Ucar, S. Karagoz, A. R. Ozkan and J. Yanik, *Fuel*, 84, 1884 (2005).
8. A.V. Bridgwater, *Pyrolysis and Gasification of Biomass and Waste*, CPL Press, UK, 2003.
9. T. B. Reed, B. Levie and M. S. Graboski, *Fundamentals, Development & Scaleup of the Air-Oxygen Stratified Downdraft Gasifier*, The Biomass Energy Foundation Press, UK, 1994.
10. K. Ahmed, *Biomass in Renewable Energy Technologies*, World Bank Technical Paper, p. 240 (1994).
11. T. B. Reed, Agua Das, *Handbook of Biomass Downdraft Gasifier Engine Systems*, The Biomass Energy Foundation Inc. Golden Co., UK, 1988.
12. T. B. Reed, G. Siddhartha, *A Survey of Biomass Gasification 2001*, The Biomass Energy Foundation Inc. Golden Co., UK, 2002.