Fixed Bed Gasification of Steam Treated Food Waste (FW) and Municipal Solid Waste (MSW)

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Abstract

Gasification of biomass is becoming popular for production of energy to meet the challenges of time. The rapid depletion of fossil fuel reserve, environmental regulation, cost effective technologies allowing the use of low-grade natural resource for potential gains have led to use the waste material as a resource. The potential of energy recovery using Food waste (FW) and Municipal Solid Waste (MSW), has been established in this study. Recently Hybrid Gasification Ltd has developed a novel multi-stage fixed bed gasifier to treat difficult biomass residues with variable feed characteristics i.e. particle size, ash levels etc. These materials were tested using this 10 kg/h pilot scale gasification system for production of synthesis gas. The gasification system comprised of a fixed bed gasifier followed by a 2 in 1 cyclone scrubber for gas clean up. The part of produced synthesis gas once clean was successfully combusted in a 2 kW gas engine for power production. Both wastes received were steam treated at ~160 ^{o}C and 6 barg using a rotary autoclave followed by solid separation leaving wet fibrous biomass. This was then dried and briquetted before feeding to the gasifier. The fuel characteristics of both waste materials were determined by conducting proximate, ultimate and X-Ray fluorescent analysis. The gasification study demonstrated that the FW offers sustainable potential for energy recovery. This is due to its high CV and low ash content. MSW on the other hand had very high ash contents, leading to ineffective gasification. This material when soaked in waste cooking oil resulted in sustainable ignition. The chromatographic analysis of the gasified products indicated significant content of methane, carbon monoxide and hydrogen.

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1. Introduction

This report provides the test data obtained using gasification technology developed by Hybrid Gasification Ltd (HGL) UK. The pilot scale gasification system designed by HGL, is currently installed in Chemical Engineering Department University of Engineering and Technology (UET) Lahore, Pakistan. The article reports information on the test work carried out on feed preparation and characterization, pilot plant gasifier operation and its performance evaluation.

This includes: Drying, Pelletizing, Pellet drop test, Absolute and bulk density, Stove test, Proximate analysis and Ultimate analyses, X-ray Fluorescent spectroscopy analyses, Synthesis gas analyses and Gasifier operation with and without gas engine.

2. Environmental Drivers:

Life has become more challenging with ever increasing demand of energy without affecting the environment. Abiding by the environmental regulations is our collective responsibility. Burning of fossil fuels in vehicles, power plants, ships and boilers etc. is causing global environmental problems e.g. Global Warming, Ozone depletion, Photochemical smog, Acid rain and Local air pollution. As the world population is increasing, consumption of fossil fuels is increasing progressively. As the world is becoming more and more civilized, more and more waste is being produced. These problems are being enhanced manifold as the people’s way of living is improving and developing countries are becoming developed.

It is believed that fossil fuels shall exhaust in the near future. Also there is an immense legal pressure to find sustainable ways for producing energy. Dumping of solid waste is a major problem in developed countries in particular and in the rest of the world in general. In Europe, referring to European Union data, an average 62.6% of the total waste is land filled, 21.9% is incinerated, 4.5% is composted and 11.0% is recycled. In 2001 it was reported that total municipal solid waste (MSW) production is about 32 million tonnes per year in the UK. Some 85% of this MSW is generated in England by 85% of the UK population. Most of the solid waste is currently land filled. But this is not a viable option for the future because of unavailability of land and also it is not environmentally safe.

UK is facing one of the greatest challenges in waste management that is set to change the face of the waste industry in a relatively short period of time to implement the European Landfill Directive. England and Wales (Department of the Environment, Transport and the Regions, 2000), Scotland (SEPA, 1999) and Northern Ireland (Department of the Environment, 2000) published their waste strategies to cope with the Landfill Directive. It is anticipated that potentially 30.3 million tonnes of Biodegradable Municipal Waste (BMW) will have to be diverted from landfill by 2020. Also there is a need to find alternate energy sources, which can replace fossil fuels and at the same time can help get rid of waste in a clean way.

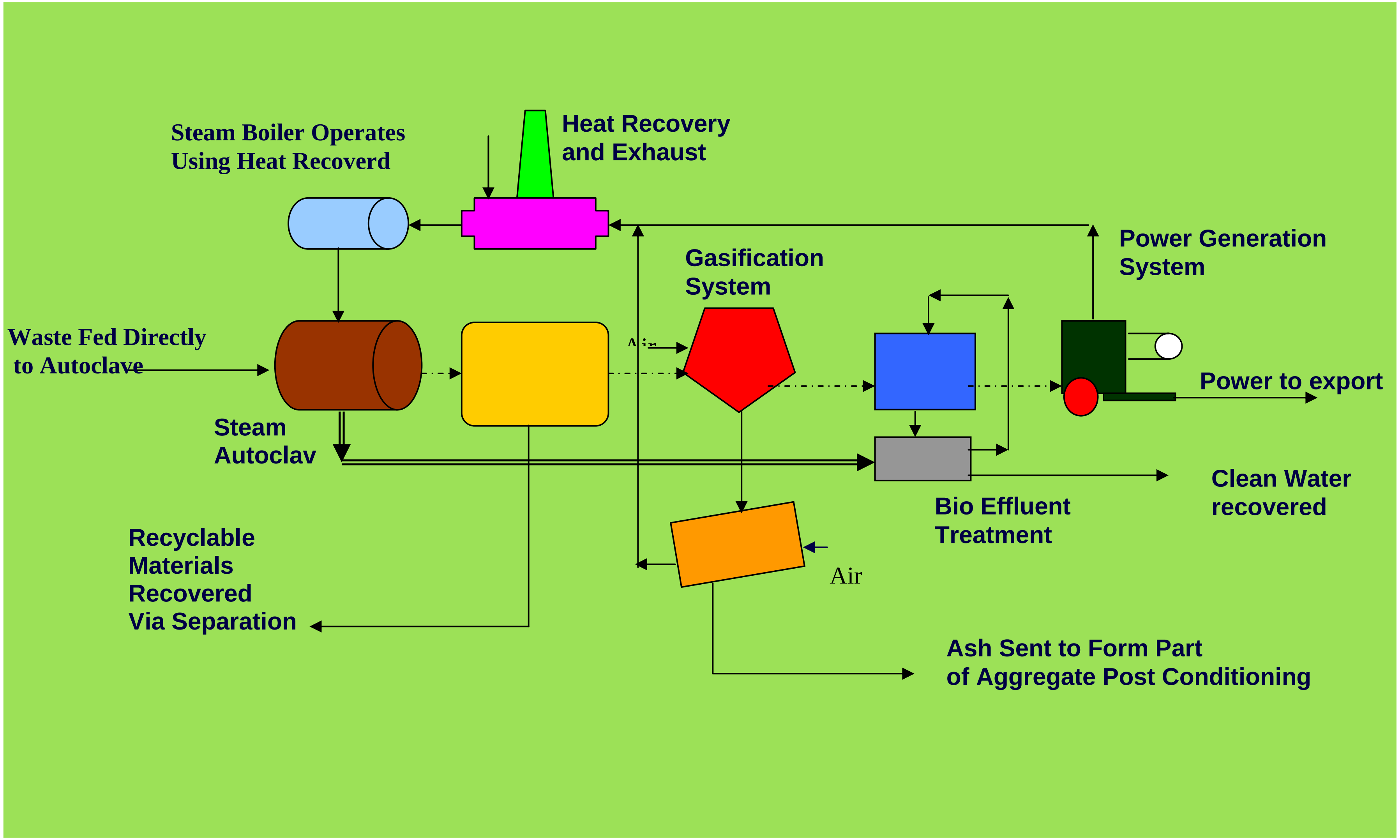
Renewable energy production and sustainable energy utilisation is necessary to push the international energy sector towards a high degree of sustainability. Biomass has less Nitrogen and Sulphur so NOx and SOx emissions will be less. Also biomass is a CO_2 neutral source of energy. Currently gasification of solid waste (biomass) for energy production is Best Available Technique (BAT). This not only produces energy but also gets rid of the waste. It competes with combustion in that it produces lesser pollutants e.g. Dioxins, Furans etc. that are toxic. It also provides safe disposal option for solid wastes and reduces environmental problems by getting rid of methane production, which is a Greenhouse gas produced from landfill. So it is the time to wake up and look for sustainable world if life is to be continued on this planet.

Being long been used for coal and wood, gasification was little tested for wastes such as Municipal Solid Waste, Sawdust, Horse Manure, Sugar Cane Bagasse, Rice Husk etc. So it was realised that there is a current need to test these materials for energy production using this versatile technology.

In order to maximise the recovery of valuable materials, one of the potential options is to employ a medium pressure steam treatment process generally known as steam autoclaving. In the past steam treatment has been used successfully for the sanitization of clinical waste. This form of waste attracts this method of treatment being commercially viable due to the relatively high gate fees. The current upward trend in disposal costs for MSW means that steam autoclaving processes are becoming increasingly economically viable.

In recent years direct EfW (energy from waste) has lost the support from the public and a shift in perception has been seen towards alternative energy recovery options such as gasification. As yet no commercial gasification plant has been built in the UK. However a number of semi commercial scale facilities to treat MSW and sewage sludge were installed during 2000-2005. These small pilot facilities have proved useful in terms of breaking the first barrier to help enhance the process understanding and are thus a move towards creating a positive image for alternative thermal treatment options (Malik, 2008).

A STRAP process is proposed as shown in Figure 1.


Steam Boiler Operates
Using Heat Recoverd
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Clean Water
recovered
Bio Effluent
Treatment
Recyclable
Materials
Recovered
Via Separation
Air
Ash Sent to Form Part
of Aggregate Post Conditioning

3. Aims and objectives:

The primary objective of this test work is to demonstrate the suitability of HGL's novel gasification system to successfully gasify fiber obtained post steam autoclave treatment of MSW and FW. This study evaluates the gasifier operation using two waste streams (consisting MSW and FW). Both wastes are steam treated and plastics and metal removed prior to dispatch for gasification tests. The test work is divided into two main categories of:

a) Fuel characterization tests

These include, visual inspection, drying and pelletizing, proximate and ultimate analyses, XRF, pellet drop test, density evaluation, and stove test. These tests were performed at various sites as listed below:
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(i) Heat Transfer Lab UET, Lahore	Stove test, Visual inspection, Drying, Pelletizing, Drop test, Absolute Density, Bulk density.
(ii) Fuels Lab UET, Lahore	Proximate analysis
(iii) Newcastle University, UK (Advanced Materials and Analysis Unit)	Ultimate analysis
(iv) NETREC, Northumbria University, UK.	XRF analysis

b) Gasifier operation

At UET a gasification research facility has been developed jointly with HGL UK. These include a state of the art 100kg/h downdraft gasifier and a 10kg/h pilot gasifier as shown in Fugures 2-3 respectively. The pilot scale gasifier as shown in Figure-3 was employed to study the gasification of both MSW and FW.

Figure 2- 100 kg/h gasification plant


Downdraft Gasifier
Wet Scrubber
Blower
Recycle Pump

Figure 3 Pilot scale HGL gasifier

A simplified PFD of the system is shown in Figure 4

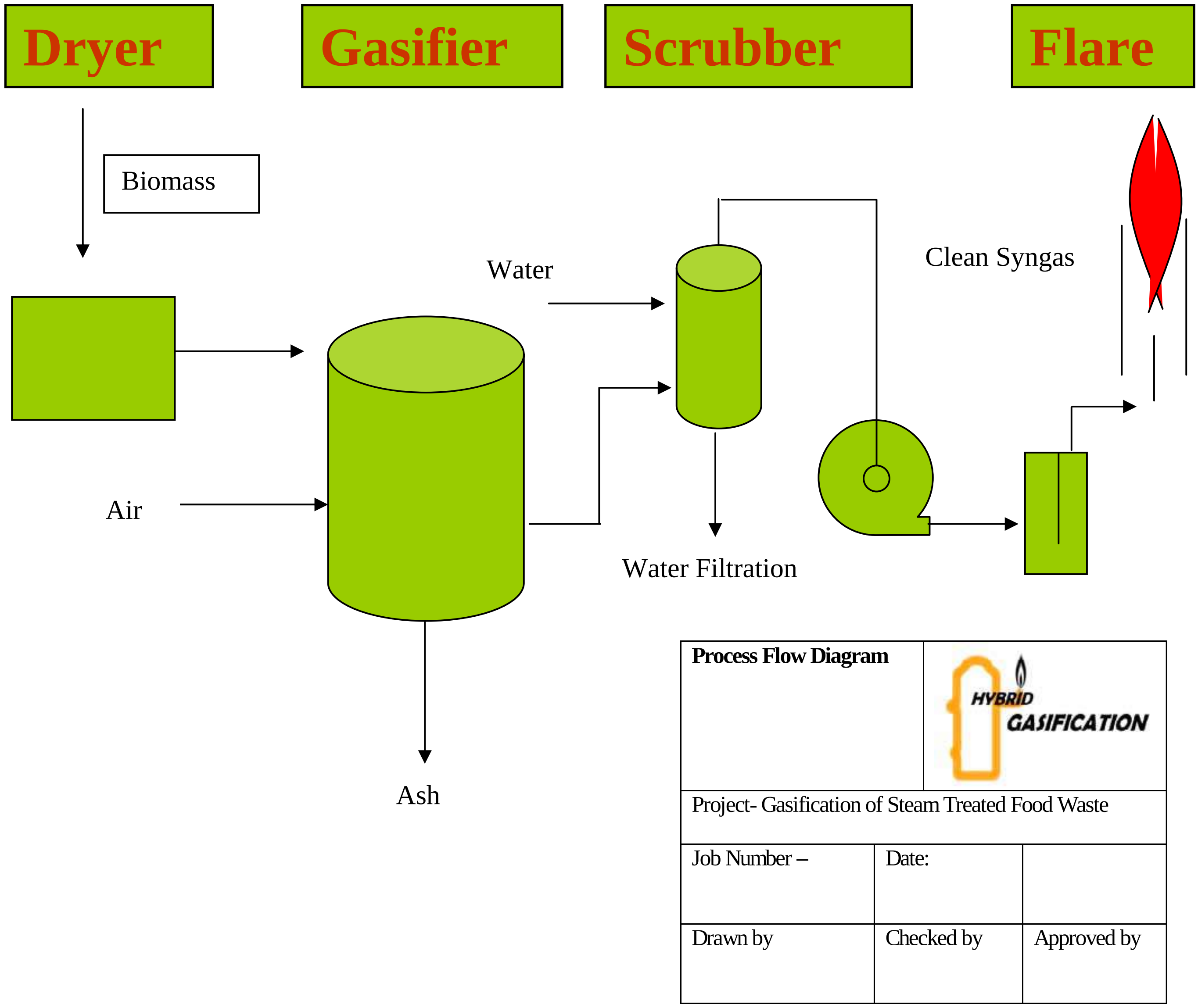


Figure –4 PFD of Gasification Plant

4. Gasification Systems

4.1 What is Gasification?
Gasification converts low quality low value wastes into useful product known as "Synthesis Gas". It is a thermo-chemical decomposition of lignocelluloses compounds with production of char, oil/tar and volatile compounds.

Gasification is arguably the most versatile of the conversion processes having applications in almost every sector of energy demand [Merrick, 1984]. It is the only technology that offers both, upstream (feedstock flexibility) and downstream (product flexibility) advantages. Because of its ability to use low-cost feed stocks, gasification is the technology of choice for many industrial applications [Stiegel and Maxwell, 2001]. Tchobanoglous differentiates between gasification and combustion by saying that:

"Gasification is a method to transfer the heating value of solid biomass into heating value of producer gas (CO, H_2 and H/Cs) and some sensible heat, while in combustion the heating value of the solids is completely transferred into sensible heat." [Tchobanoglous, 1993]

The gasification is a series of complex concurrent and consecutive chemical and thermal process, which is not well understood [Reed, and Das 1988]. Gasification is a two-step, endothermic (heat absorbing) process in which a solid fuel (biomass or coal) is thermo-chemically converted into a low- or medium-BTU gas.

Biomass gasification is the latest generation of biomass energy conversion processes, and is being used to improve the efficiency and to reduce the investment cost of biomass electricity generation through the use of gas turbine technology. Economic studies show that biomass gasification plants can be as commercial as conventional coal fired plants [Badin and Kirschner, 1998].

Performance of a fixed bed gasifier is determined by feed characteristics. The main biomass characteristics that affect the performance of the gasification system are moisture content, mineral and volatile matter, particle size and bulk density.

Various types of gasification processes are discussed in literature. Some of the major categories are:

(i) Downdraft Gasifier
(ii) Updraft Gasifier
(iii) Fluidized Gasifier

In recent past, Hybrid Gasification Ltd (HGL) UK has developed a gasifier, which have design features which offer:

- Unique grate design with no restriction to flow of fuel and ash therefore no bridging effect
- Uniform aerodynamics in gasification zone thus no hotspots

- Multiple Primary oxidant Inlets thus better carbon control
- Extended Ash zone and ash cooling using steam injection

4.2 HGL Process

HGL's pilot gasification system's key components include: a 10 kg/h novel gasifier, a two in one cyclone/ scrubber followed by spark free fan assembly followed by gas engine and power generator set. Other assembly comprise of: A feed hopper, Ash removal cone, water recirculation loop, various valves and monitoring gear.

The HGL's process is unique in converting biomass into synthesis gas. The exclusive design of the gasifier offers uniform airflow through the fuel bed when fuel is allowed to flow under gravity without any constriction. Hybrid gasification 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 biomass feed stocks. A simplified process flow diagram is shown in Figure 4.

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 as shown in Figure 5. 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.

Figure – 5 Flare Flame from HGL's Pilot Scale Gasifier

4.3 Description of Waste Material

Waste samples of MSW and FW, 25 kg each, are used to study feasibility of these wastes as a feed stock for HGL gasification system. Both wastes are steam treated (at 160 °C and 5bar) and inerts and/or plastics removed prior to gasification test work.

The MSW mainly consists of household black bag waste. On the other hand FW mainly consists of super market outdated products such as items of fruits, vegetables, oils, fats etc.

The detailed characterization tests of wastes would help in establishing operating parameters for HGL gasification system.

5. Test Description, Results and Discussion

Two waste materials, Municipal Solid Waste (MSW) and Food Waste (FW) are tested during these trials.

5.1 Analysis of Materials Used for Gasification

5.1.1 Municipal Solid Waste

MSW is generally defined as ‘‘household waste plus other waste of a similar composition collected by (or on behalf of) the local authority’’ [Official Journal, 1999]. In practice, this means that if the waste generated by a particular commercial business is collected along with household waste the material is classed as MSW [Burnley, 2001].

Municipal solid waste generally consists of household waste, some commercial waste and waste taken to civic amenity sites. It may also contain street sweepings and some trade waste if it is under the control of Local Authorities in terms of collection and disposal [European Union, 1999]. The MSW is mainly composed of paper, plastic, metal, fabric, residue of kitchen, rind, wood, coal-ash, brick, etc. [Li Xiaodong., et al, 2001]. Typical composition of MSW is given in Table 1 [Burnley et al., 1999].

Table 1: Typical MSW composition

Type	**%**
Paper and card	32
Putrescible materials	21
Textiles	2
Fines (<5mm)	7
Miscellaneous combustibles	8
Miscellaneous non-combustibles	2
Ferrous metals	6
Non-ferrous metals	2
Glass	9
Dense plastics	6
Film plastics	5

Post steam Autoclave process removes both metal and plastics as a high value recyclables.

5.1.2 Food Waste

The food waste under consideration here belongs to supermarket out dated waste which may consist of packaged food including vegetables, meat and dairy products. The typical contents are listed in Table 2.

Table 2 Typical FW composition

Organics:	Transportation Packaging	Product packaging	Others
Meat Fish Cheese Bakery goods Grains Coffee grounds Packaged perishables Vegetable oil	Card-board-boxes Waxed cardboard boxes Wire-bound wooden crates; other types of wooden crates Wooden pellets Plastic shrink wrap Plastic stretch wrap	HDPE milk jugs HDPE buckets Glass bottles Tin cans Gable top poly-coated paper cartons Food service cups, plates and utensils Poly-lined bags Foil pre-measured coffee packets	Office and mixed waste paper Newspaper Paper towels Water Used multi-material display stands

The composition of the above may have seasonal variation. Typical analyses of main components are given in Table 3.

Table 3: Typical FW analysis

Description	**Vegetable food waste**	**Meat scraps**	**Fats**
Moisture (%)	78.29	38.74	0
Volatiles (%)	17.1	56.34	97.64
Fixed carbon (%)	3.55	1.81	2.36
Ash (%)	1.06	3.11	0
Carbon (%)	49.06	59.59	73.14
Hydrogen (%)	6.62	9.47	11.54
Oxygen (%)	37.55	24.65	14.82
Nitrogen (%)	1.68	1.02	0.43
Sulphur (%)	0.2	0.19	0.07
CV (MJ/kg) (daf)	20.23	30.49	38.3

5.2 Preparation and Testing of Waste Materials

Following steps are taken to characterise and prepare the wastes for fixed bed gasification:

- Visual Inspection
- Drying
- Pelletizing
- Drop Test
- Absolute & Bulk Densities
- Proximate Analysis
- Ultimate Analysis
- XFR Analysis
- Ash Softening Temperature Estimation
- Stove Test

5. 2.1 Visual inspection

Both wastes are received in plastic containers. Visual inspection has shown that both MSW and FW contained pieces of glass and plastics and felt quiet wet. FW looked very oily and gave smell indicating the presence of cheese.

5.2.2 Drying:

Both materials are dried in a laboratory tray drier to achieve moisture content below 15%. Batches of 5 kg each are loaded into a tray drier and took 3 – 4 hours for each batch. Temperature of the drier is maintained at 110 °C.

5.2.3 Pelletizing:

Dried MSW and FW are pelletized using a manually operated hydraulic press pelletizer with operating pressure in the range of 100 and 200 psi. It produces one pellet of 2.5*5.3*5.3 cm^3 size in one operation. The pellets piles are shown in Figure 6a,b. It is observed that pellets made at 100 psi are of lower strength than those made at 200 psi.

Figure 6a: MSW pellets **Figure 6b: FW pellets**

5.2.4 Drop Test: ASTM D440-86

MSW particularly required high pressure to maintain its shape. This is probably due to its high ash content, which probably hinders cohesion. A drop test was conducted to check the suitability of the pellets for gasification.

Drop tests of the pellets prepared at two different pressures are carried out for two different heights to determine their strength with reference to being dropped from feeding hopper. The results are given in Table 4.

Table 4: Drop Test Results

	Drop height, 2 ft	**Drop height , 3ft**
100 psi MSW	Pellet broke into small pieces	-
FW	Pellet broke but observed relatively stronger than MSW	Pellet broken into small pieces
200 psi MSW	Pellet maintained the shape	pellet maintained its shape, only small part broken form the corner
FW	Pellet maintained the shape	Pellet maintained the shape

Size of the fuel in the gasifier bed dictates its gasification kinetics. It is important that pellets maintain their integrity inside the gasifier when dropped from the feed hopper. If the pellets disintegrate inside the bed it may cause to pore blockages this will lead to poor air distribution and channeling which ultimately direct to hot spots and bridging, a highly undesirable situation in the operation of a gasifier.

5.2.5 Absolute and Bulk Densities   ASTM D3289-03, E1109-86

Absolute and bulk densities of the materials are measured. A three litre cylinder is employed to estimate the bulk density. For absolute density measurement, a pellet size and mass is obtained and is given in Table 5. Absolute and bulk densities for wood chips are included for comparison.

Table 5: Absolute and Bulk Densities of the Materials

	Absolute density (kg/m^3)	Bulk density (kg/m^3)
MSW*	816	452
FW*	822	535
Wood chips	836	250

*MSW/FW briquetted at 200psi.

The results indicate that FW is found to be slightly denser than MSW.

5.2.6 Proximate Analysis   ASTM D3172-73

Five representative samples were prepared for both MSW and FW. The averages of all five results are tabulated below in Table 6. A typical analysis for wood is also given for comparison.

Table 6: Proximate Analysis Results

	As received*			Dry basis*			Dry ash free basis*		
	MSW	FW	Wood	MSW	FW	Wood	MSW	FW	Wood
Moisture (%)	50.9	29.3	16.66	-	-	-	-	-	-
Volatile matter (%)	18.8	51.1	68.33	38.2	72.4	82	71	77.8	83.67
Fixed carbon (%)	7.6	14.6	13.33	15.5	20.7	16	29	22.2	16.33
Ash (%)	22.7	4.9	1.66	46.3	6.9	2	-	-	-

*Average of five tests

The results show that the moisture level for as delivered MSW is much higher than FW therefore would require more heat energy for drying to desired levels of ~15% as required by fixed bed gasifiers.

Looking at levels of volatile matter both MSW and FW are found to be reasonably reactive therefore good gasification performance is expected in terms of cold gas efficiency. However, ash content of the MSW is eight times higher than FW that suggests much larger ash zone. Higher ash content of MSW pose no operational threat as HGL gasifier has unique design which is meant to cope with high and variable ash levels and offers no flow restrictions through gasification zone.

5.2.7 Ultimate Analysis: ASTM D3176-84

Two representative samples are prepared for both MSW and FW as required by the method. The average of the two test results are given in Tables 7 along with typical analysis of wood and anthracite for comparison. The calorific values are estimated using Du Long formula.

Table 7: Ultimate Analysis of MSW and FW Including Wood and Anthracite

	MSW	FW*	Wood	Anthracite
Carbon (%)	36.35	56.65	43.43	88.9
Hydrogen (%)	4.96	8.76	6.08	3.4
Oxygen (%)	10.13	23.54	46.29	2.3
Nitrogen (%)	1.43	3.95	0.67	1.55
Sulfur (%)	0.83	0.19	0.43	0.81
Ash	46.3	6.9	3.11	3.04
CV (MJ/kg)	9.35	26.33	15.15	34.37

All at dry basis; *Average of two tests

As expected, FW has much higher CV therefore offers better energy recovery potential. However, Nitrogen levels are found to be ~3 times higher than MSW indicating higher NH_3 formation during gasification which may require additional mitigating stage as part of emission control system. Ash levels in MSW are found to be almost 50% range that can be reduced by adding an inerts removing stage prior to drying.

5.2.8 X-Ray Fluorescence Spectrometry (XRF) Analyses:

Energy dispersive polarized X-Ray fluorescence spectrometry is used to determine metal contents of waste heavy metals and other trace elements present in the material. These elemental analyses are required to determine the ash softening temperature.

Representative samples for both of the materials are prepared and XRF analyses are carried out. Levels of toxic heavy metals are given in the Table 8.

Table 8: Heavy metals in MSW and FW

Elements	Concentration in FW (μg/g)*	Concentration in MSW (μg//g)*
Mercury	< 2	2.3
Cadmium	< 0.7	1.2
Arsenic	< 1	< 1
Chromium	< 15	< 15
Titanium	344.1	2874
Lead	15.4	755.7

*Values with less than (<) sign are out side the measurement range of the apparatus

The data shows much higher level for the presence of Lead in MSW than FW. The Lead, which is evaporated during gasification, can be contained during gas clean up stage however majority of the Lead remains in the ash.

5.2.9 Ash Softening Temperature

Ash softening temperature determines the behavior of ash in the bed and therefore dictates the performance of gasifier. Fuels having low ash softening temperature tend to cause sintering and slagging and thus can lead to bed flow problems. For an uninterruptible operation of a gasification system ash softening temperature of the fuel should ideally be higher than the highest temperature inside the gasifier (maximum design operating temperature – 1200 °C).

The XRF analyses for metal contents are used to estimate the ash softening temperature as:

FW – 1357 ^{o}C
MSW – 1297 ^{o}C

Considering the above results both wastes will have very low clinkering propensity.

5.2.10 Stove Test:

Stove tests of both FW and MSW pellets were carried out to study the combustion characteristics inside the gasifier bed while being exposed to intense heat during combustion process. The pictures of tests are shown in Figure 7 a,b.

It is found that MSW is very difficult to ignite. This is due to its high ash content, which acts as heat sink. This can either be overcome by removing the inerts from MSW or by adding organic waste to enhance its CV as discussed previously.

Pellets behavior is monitored throughout the test and it is found that pellets of both of the wastes maintained their shape and did not disintegrate during the combustion process.

Figure 7a: FW stove test

Figure 7b: Oil soaked MSW stove test

5.3 Gasifier Operation Using MSW and FW Briquettes

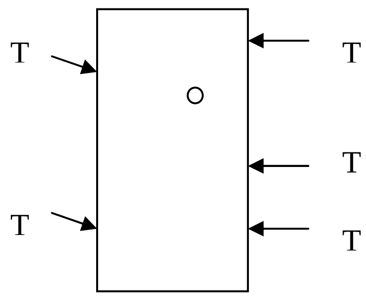
The pilot scale gasifier is operated using both MSW and FW as described in section 4.2. Since the briquettes made are oversized than required by the test gasifier therefore these are divided into four quarters using hacksaw prior to feeding the gasifier. Other operating parameters are listed in Table 9.

Table 9 Operating Parameters

Property /Stream no.	1 Fuel	2 Air	3 Fuel Gas	4 Inert ash*	5 Clean Fuel gas	6 Water to drain	7 Power & Heat	8 Water Make up	9 Flue Gas
Flow kg/h	8	19.2	20	ND	20	ND*	ND	ND	ND
Temp C	Amb	Amb	450	Amb	40	ND		Amb	~400
Press mbar	Amb	50	55	Amb	55	ND		Amb	Amb

*Quantity varies from waste to waste

PICO is employed to record temperature history at various levels inside the gasifier as indicated in the sketch below. Since temperature probes inside the gasifier are positioned to avoid any hindrance to fuel flow therefore do not reflect the true thermal regimes inside various zones. These are only used as an operating and control tool. Typical temperature logs of the operation are presented in Figure 8a, b below.



Indicative Thermocouple Configuration

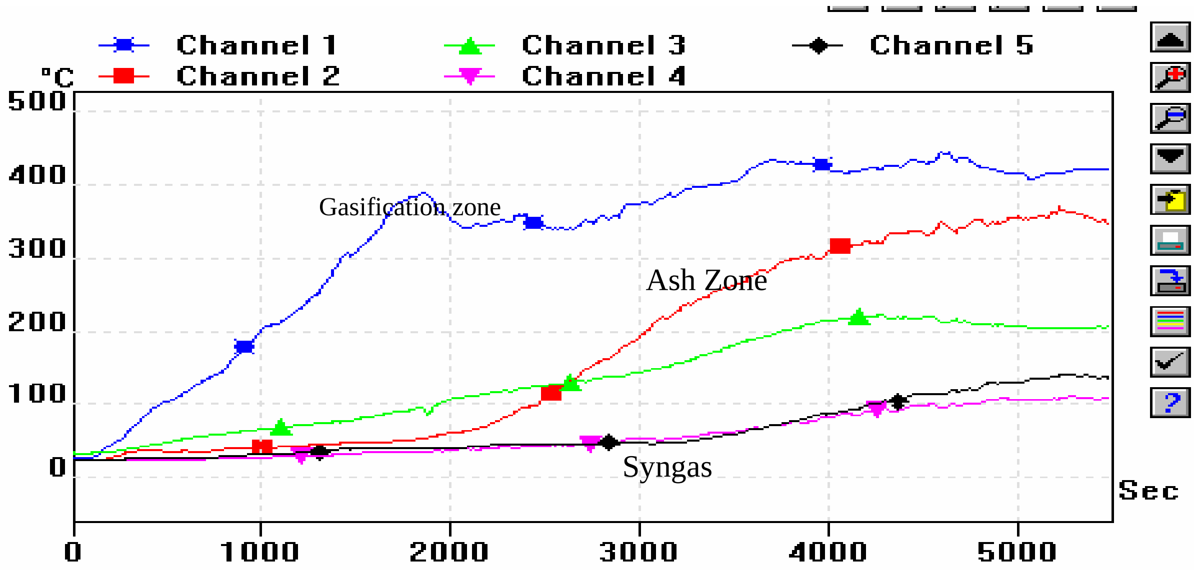


Figure 8b Typical Temperature Log

These temperature profiles are normally used to observe the gasifier performance at various operating regimes and then used to optimize the plant operation. For example it has been observed that once gasification zone temperature reaches 350-400 ^oC sustained gasification would start therefore it is the time to close the ignition port. The temperature of synthesis gas gradually increases but when passed through the scrubber it remains in 50- 75 ^oC range suitable for gas engine operation. In the case of FW the temperature recording are found generally higher when compared with MSW.

5.4 Gas Analysis

Once gasifier achieves steady state operating condition gas samples are taken using expandable balloons. In order to avoid any hydrogen leakage ideally gas should have been analyzed immediately but it was not possible due to non-availability of gas chromatograph adjacent to gasifier. However getting to the nearest testing facility caused a 3-4 hours of time delay. Nevertheless the gas analyses obtained are given in Table 10. The results show relatively low levels of H_2 indicating its escape. This is confirmed when compared with data predicted by HGL's empirical model.

Table 10: Gas Analyses

	FW		MSW	
	Average*	Model	Average$	Model
Ar (%)	2.21	-	2.07	-
N_2 (%)	67.01	56.6	67.34	72.7
CH_4 (%)	2.56	3.27	1.54	2.24
C_2H_2 (%)	ND	1.12	ND	1.63
C_2H_4 (%)	ND	3.2	ND	2.2
CO (%)	11.29	12.1	14.89	4.49
CO_2 (%)	10.13	7.5	8.4	8.95
O_2 (%)	1.67	-	1.2	-
H_2 (%)	5.13	13.9	4.58	6.21
CV (MJ/m3)	3.1	7.61	3.1	4.31

*Average of three results
$Average of two results

The ultimate analyses of MSW indicate it to be of relatively low CV to sustain gasification. Therefore MSW is soaked in cooking oil to bring its CV close to wood. Three kg of MSW is soaked in two litre of cooking oil. This is then gasified successfully to produce combustible gas with an estimated CV of 4.31 MJ/Kg .

The overall cold gas efficiency is estimated to be ~62.3. No tar/oil was monitored for this test. For every kg of MSW/Oil mix 18.5 m^3 of synthesis gas is estimated.

In contrast to MSW, FW is found to be very easily gasifiable material. The steady state gasification operation is achieved within 3 – 4 minutes of ignition. The system is run for several hours of the day continuously without interruption. A consistent flame is observed throughout the operation as can be seen in the picture given in Figure 2.1.

It is estimated that 19.2 m^3/h of syngas with CV of 7.61 MJ/m^3 is produced and fuel consumption rate is estimated ~8 kg/h. The cold gas efficiency is estimated to be 69.3%.

5.5 Production of Electricity from Syn Gas.

In order to demonstrate the potential of Syngas to be used for electricity production, a petrol generator of Honda make with $160cm^3$ cylinder and 2.2 KW is employed. The part of syngas is diverted to run 2.2 kWe Honda petrol Genset while remainder of the syngas is flared. The gas engine generated electricity in a sustainable manner until the supply of gas exhausted. Figure 9 demonstrates this activity.

Figure 9 Synthesis Gas Operating the Engine

6. Conclusions and Recommendations

A R&D facility is developed and being used for various MSc and PhD studies

STRAP concept is expected to be a successful way forward – further work is continuing

A novel gasifier to treat difficult solid residue is developed and patent application is in progress.

Development of commercial scale STRAP facility is currently being pursued in UK

Following conclusions can be drawn from this trial work.

Both MSW and FW are gasifiable materials therefore would not only offer the waste disposal in a clean manner but also serve as a resource for green energy.

Moisture content of both FW and MSW is found to be higher than the prerequisite range of 15-20% suitable for good gasification therefore requires drying prior to gasification.

FW having low ash with high CV offers a good potential for energy recovery. Cold gas efficiency of 69.3% are estimated however higher efficiency can be achieved when gasifier is designed FW specific.

On the other hand MSW is found to have relatively low CV and high ash contents. It is proposed that further removal of inerts during separation stage would help improve CV and decrease in ash levels. Alternatively a high organic waste stream can be introduced to compensate for minimum CV requirements. For these trials however spent cooking oil was used to co-gasify MSW allowing smooth gasifier operation.

Ash fusion temperature of both FW and MSW is estimated to be considerably higher than the average operating temperature of the gasifier.

Both FW and MSW pellets maintain their shape during drop test when prepared using pressures more than 200 psig.

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