# Downdraft Gasification Trials of Recycled Textile

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## Background and Objective

The objective of this trial was to assess whether a reformulated waste textile material created by BWF Recycling Ltd, Harby Road, Langar, Nottinghamshire, NG13 9HY, could be satisfactorily used as a downdraft gasification feedstock.

Funding was provided by European Union Regional Development Fund Ingenuity and Innovation Vouchers, and arranged through the University of Nottingham Environmental Technology Centre.

Experimentation was undertaken between June and August of 2014, by Dr Andrew N. Rollinson, at laboratories in Energy Technologies Building, Innovation Park, Jubilee Campus, University of Nottingham.

## Method

### *Textile Material*

The textile was supplied in the shape of cylindrical “pucks” of approximately 8 cm diameter and 3 ≤ cm ≤ 7 length (Figure 1.a). The pucks were reportedly of mixed synthetic and natural fibre origin. The textile had been compacted but was unbonded so that the pucks split apart with relative ease (Figure 1.b), and produced airborne dust when handled.

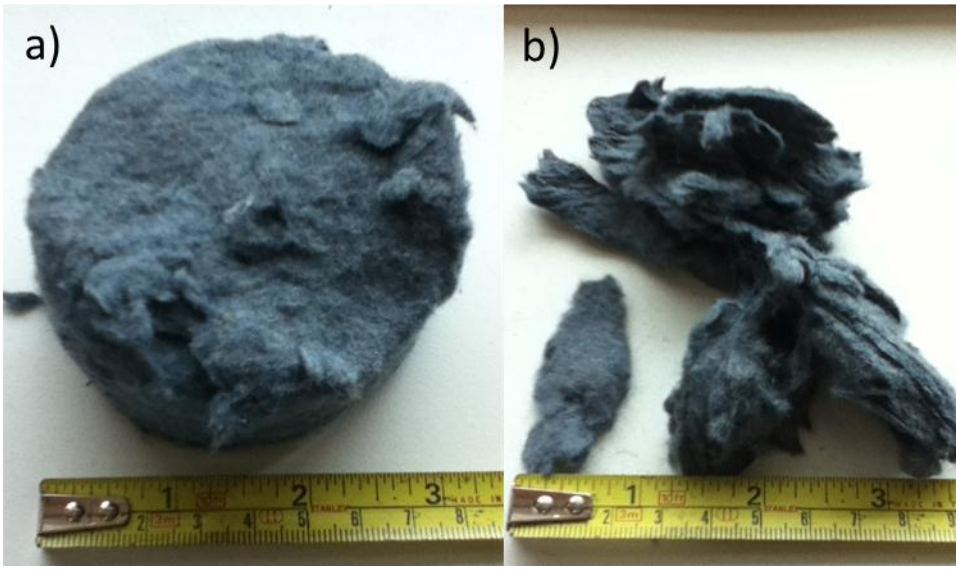


**Figure 1. Textile a) as supplied, and b) separated.**

### *Gasification*

A 10kW Power Pallet from GEK All Power Labs (Figure 2) was used for gasification experiments. The system is designed for small-scale off-grid electricity production from wood chips, and can tolerate up to 30% feedstock moisture. It comprises a conventional imbert-style downdraft reactor combined with proprietary controls and pre-heating process adaptations. Feedstock is loaded into the hopper and fed to the reactor by an automated 7 cm diameter auger. Specified feedstock size range for the system is 1.3 ≤ cm ≤ 3.8 cm, with < 10% fines tolerable.

Prior to entry into the reactor, feedstock passes through two heat exchangers. Firstly within the auger channel (the drying bucket) there is non-contact heat exchange with post-reactor gases; then secondly non-contact heat exchange with the engine exhaust gases in the “pyrocoil” region situated

directly above the gasification reactor. From the Pyrocoil onwards, feedstock falls through the reactor under gravity.

The system operates under slight negative pressure created during steady state operation via a three cylinder Kubota gas ignition engine*. Sub-stoichiometric airflow enters the combustion zone of the reactor (again via engine suction) sufficient only to provide heat for pyrolysis, drying, and reduction zones and to create autothermal operating conditions (no external heat input required). Reactor temperature is monitored by thermocouples and a range of pressure sensors which also control the auger feed and intelligent grate shaker. Post reactor particulates are captured by a cyclone, and a packed bed filter comprising woodchips and sieved fines collects any tar products prior to the engine intake valve.

The gas engine is connected to a 10kW generator and provides power on-demand. The generator responds to meet varying external load which subsequently dictates engine fuel intake and hence increases or decreases the rate of air flow through the reactor.

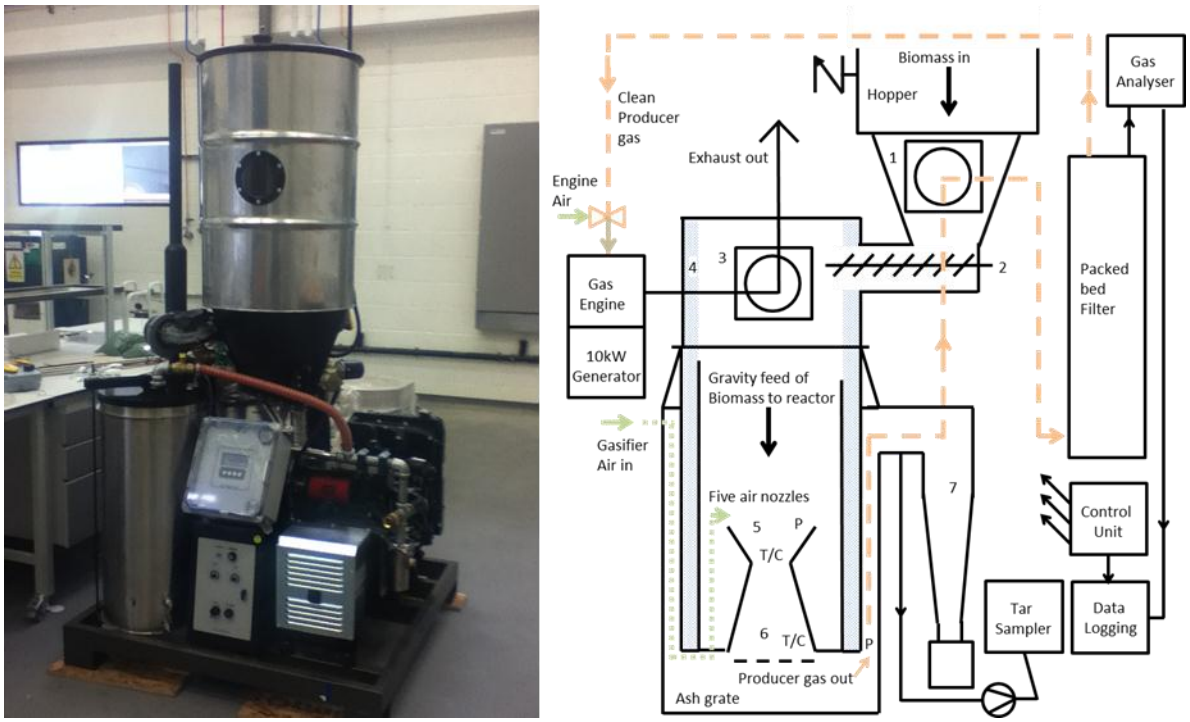


**Figure 2. Power Pallet gasifier and schematic. 1. Drying bucket, 2. Auger, 3. Pyrocoil, 4. Insulation, 5. Combustion zone, 6. Reduction zone, 7. Cyclone particle separator. T/C = thermocouple, and P = pressure sensors relay to Control Unit.**

* At start-up, electric fan blowers are used to generate suction and to divert dirty gases from the engine to a flare stack via a manually operated valve.

### *Physical Properties*

Bulk density was measured using a 1 Litre cylinder. Hygroscopicity was measured by immersing the sample in a quantity of water and observing the rate of water uptake. Calorific value was obtained using a formula determined by Sheng and Azevedo (2005)[†]. Lower heating value was obtained from the following formula:

LHV = HHV - (0.212)(H) – (0.0245)(Moisture) – (0.008)(O).

### *Proximate and Ultimate Analysis*

A TA instruments Q500 was used for thermogravimetric analyses. Samples were placed into a clean platinum pan (10 mm diameter x 2 mm depth), and loaded evenly up to the rim but not compacted down. Experimentation (at atmospheric pressure) was commenced using three high purity gases (100% $N_2$, air, and 100% $CO_2$) from Air Products. Data was logged every 0.6 seconds and saved on a personal computer. Repeat sets were taken and the mean value obtained.

For proximate analyses, the sample was heated from room temperature to 110°C under $N_2$ flow (of 120 ml per minute) at 10°C, then held for 10 minutes. Temperature was increased to 900°C at a rate of 20°C per minute, and then held for 15 minutes. The carrier gas was then switched to air at a flow rate of 120 ml per minute.

Ultimate analyses for elemental C, H, N, and (by balance) O composition, was undertaken using a CE Instruments Flash EA1112 analyser. Samples and standards (2,5-(bis[5-(tet-butyl-2-benzo-oxazol-2-yl)thiophene) were weighed ($8.3 \leq mg \leq 10$) into tin capsules then ignited at 900°C using oxygen over a copper oxide catalyst. Product gas was passed over electrolytic copper to remove $O_2$ and magnesium perchlorate to remove $H_2O$ en route to a GC column and Infra-Red detector. Helium was used as carrier gas.

## Results and Discussion

### *Gasification Trials*

With downdraft gasification, the fuel needs to be robust and retain its form inside the reactor to maintain adequate heat and gas transfer. If it swells due to do moisture absorbance or melts due to heat, then this can inhibit gas circulation inside the reactor. There are also fuel feeding issues such as an ability of the fuel to flow rather than clog within the hopper and auger feeder.

As a preliminary experiment, I ran the reactor with only a small quantity of mixed woodchip and textile, (enough for one and a half hours, so about 10 cm deep inside the hopper) to assess how the textile would stand up to the moderate temperatures attained within the feeding system (the drying bucket and pyrocoil entry), and to test whether it would absorb moisture as the reactor cooled following shutdown. The textile pucks were not durable or dense enough to be fed 100% into the gasifier and they were also too large to fit through the gasifier auger as supplied. To overcome this, in addition to blending with a majority of wood chip, I spilt each puck into quarters.

[†] Sheng, C., Azevedo, J.L.T. Estimating the higher heating value of biomass fuels from basic analysis data. *Biomass Bioenergy*, 2005, 28, 499-507.

Due to the synthetic fibre content of the trialled feedstock, I suspected that there may be some melting prior to the reactor. This was not the case. The preliminary trial was successful in that there was no melting of textile in the auger channel or the pyrocoil, and the textiles also remained very dry. The textile samples had very low moisture content (see Figure 5) in comparison to woodchip (ca. 15%), which is beneficial for feedstock moisture generates condensed water in the hopper region after shutdown.

I then ran a series of gasification tests using a full hopper (sufficient for ca. 8 hours of operation at 4 kW) filled with a 50:50 mix of textile and P45 standard wood chip (see Figure 3). There were immediate problems due to the fuel in the hopper "bridging". The bridging was caused by textile frictional binding within the hopper rather than it flowing downwards, and consequently the auger was unable to feed through any fuel. By agitating the hopper contents with a broom handle the blockages could be freed, but it was only temporary, and within a minute the problem recurred. I repeatedly tried to resolve this issue over a number of days, incrementally reducing the column height (therefore vertical pressure) on the fuel inside the hopper until it was only 1/10$^{th}$ full, and reducing the ratio of textile to wood chip down to ca. 30:70. Despite this, the problem could not be resolved and I could not get the fuel to feed. I did not want to go beyond a 30:70 mixture as partly this would have undermined the usefulness of any success achieved in the trials.

**Figure 3. Textile fibre mixed with P45 woodchip in Power Pallet hopper.**

During these attempts at gasification, I was able to free the auger and pull some textile and wood chip through into the pyrocoil and reactor, such that a quantity of textile was now in the main high temperature zones of the reactor. This however created additional problems with gas transfer. It became increasing difficult and eventually impossible to ignite the reactor. Figure 4 shows the emptied reactor looking down at the air nozzles and the throat section. The reactor is ignited by inserting a propane torch into a port that outlets just above the air nozzles. The photograph in Figure 4 was taken after stripping the reactor to try and resolve the ignition problem. Pieces of textile are visible on the reactor sides. Not shown in this Figure is an accumulation of textile dust extracted from the ash grate. Despite only ever episodically feeding the 50:50 textile:wood chip through the

auger, a large quantity of textile dust had also accumulated inside the reactor which could either be the direct cause of, or have exacerbated, the gas transfer/ignition problems. Previous successful attempts with wood chip gasification have identified that even with relatively low concentrations of fines (ca. 10%) gas transfer within the reactor can be inhibited and that a full clean out is required.

Due to these occurrences, the trials were aborted. Despite these failures, it is my opinion that gasification of the textile may be feasible with some modification and/or using different systems. A discussion of this, along with further results of ex-situ analysis on the textile samples that affect gasification potential is given in the subsequent sections.

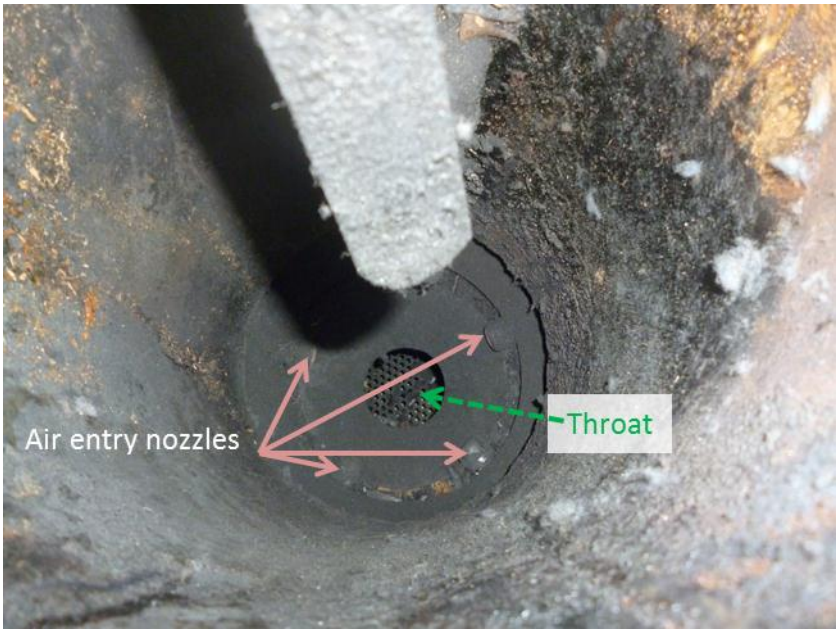


**Figure 4. View inside 10 kW Power Pallet reactor chamber after failed attempts at gasification using blended feedstock of textile and wood chip.**

## *Material Properties and Observations on Future Gasification Possibilities*

In theory, anything containing carbon can be gasified. The process involves heating a carbon-based fuel without oxygen such that volatile gases with high calorific value are released. Wood generally comprises ca. 70% volatiles up to temperatures of 500°C. With slow heating the process is optimised for gas production with a relatively high content of CO and $H_2$ in the "producer gas". In downdraft gasification, as used in this trial, producer gas is increased by the design configuration of the reactor creating a reduction zone as a final stage (post air inlets). This zone utilises residual charcoal - that is created in-situ as a normal by-product of pyrolysis - for further CO and $H_2$ production from the following endothermic reactions (R1 and R2). Thus in downdraft gasification systems, when assessing whether a fuel is "good", consideration is given to the amount of gas released, but, of perhaps greater importance is the quantity of fixed carbon and the ratio of fixed to volatiles, since this determines how much charcoal will be left over to form sufficient depth of reduction zone.

$C + CO_2 \rightarrow 2CO$ ΔH = +172 KJ/mol R1

$C + H_2O \rightarrow CO + H_2$ ΔH = +131 KJ/mol R2

The fixed carbon content of the textile fibre pucks was relatively poor (Table 1). Common values for wood chip are between 12 – 20 %. Therefore in downdraft gasification applications, blending the textile with woodchips would be essential in order to create sufficient charcoal to reduce the volatile gases.

**Table 1. Proximate and ultimate analyses of textile samples, along with calorific values. Standard deviation values shown in row below.**

| Ultimate analysis (% daf) | | | | Proximate analysis (% dry basis) | | | HHV | LHV |
|---|---|---|---|---|---|---|---|---|
| N | C | H | O | Volatiles | Fixed carbon | ash | (MJ/kg) | (MJ/kg) |
| 0.02 | 43.81 | 5.97 | 50.20 | 89.67 | 4.66 | 4.19 | 20.92 | 19.22 |

Durability of feedstock is a major consideration for downdraft gasification. Though the textile pucks were robust enough to pass through the feeding system, their physical properties such as propensity to dissociate, to form dust, and their "stickiness" inside the hopper were the reason for failure of the trials. If the textiles could be treated in some way to make them more durable and resistant to dust formation or breakage, then this would certainly improve their potential as downdraft gasification fuel. The ideal size would also have to be reduced if the Power Pallet were to be the system of choice.

There are however different types of gasifier, that would perhaps be more suitable to accepting this textile as a fuel. For example fluidised and/or circulating bed gasifiers accept feedstock in shredded form and blow the material through the high temperature reaction zone. This would likely remove the problems experienced here with textile durability, dust formation, and clogging in hopper and reactor. It may also be possible to gasify 100% textile without the need for blending with wood chips.

The supplied textile is highly hygroscopic: 12.44g absorbed 100 ml of water in 2 minutes, probably due to the synthetic fibres and high electrostaticity. But, this did not appear to be problematic. The bulk density of the textile was 124 ± 7 g/L, about half that of wood chip. Though successful feeding was never achieved, the differences in using a blended feedstock with woodchips would likely lead to gravity separation inside the hopper after a few hours of operation, with wood chip tending to the bottom and textile rising to the top. This would then have subsequent detrimental effects on reactor performance.

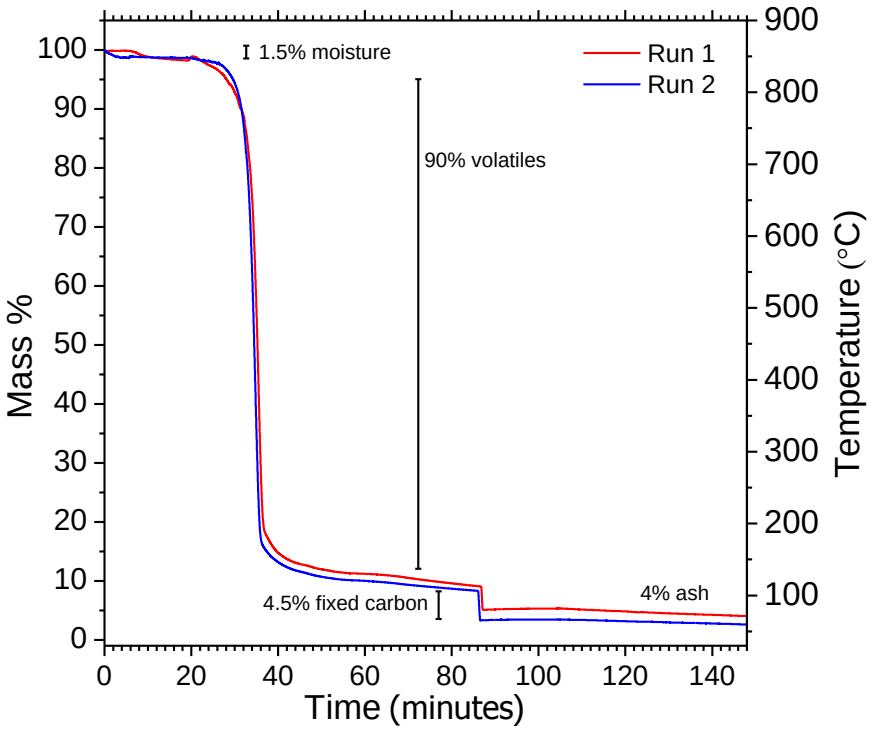


**Figure 5. Results of Thermogravimetric analysis for the textile sample.**

## Conclusions

The textile material supplied by BWF Recycling Ltd, proved to be unsuitable for energy production via downdraft gasification in the 10 kW Power Pallet. The reasons were:

1. Its resistance to flow inside the hopper which resulted in constant fuel bridging. This consequently stopped the material from successfully falling into the auger channel and therefore prevented fuel feeding.

2. Its propensity to dissociate and form dust. This led to clogging of the reactor bed such that gas flow was inhibited and ultimately that the reactor could not be ignited.

For the above reasons, steady state operation could not be achieved. There were further aspects of the textile in its as-supplied form which were identified as being detrimental to its use as a downdraft gasifier fuel, but could not adequately be tested. Namely:

3. It had a very low fixed to volatile carbon ratio. Blending with wood chips in appreciable amounts would be required in order to create sufficient char for adequate reduction reactions and therefore to give decent producer gas purity.
4. The textile had low bulk density and was highly hygroscopic. This may impose greater labour and care with storage and handling.

There were however some positive attributes of the textile that make its utility as a gasification fuel potentially feasible:

5. Its calorific value was comparable to some woody biomass fuels.
6. It passed through the milder temperature regions of the auger and drying systems without melting.

In summary: Aside from the low fixed carbon content, the negative aspects of this material as a downdraft gasifier fuel are related to handling and durability. It may not be too costly or difficult to pre-treat the material and upgrade its form such that it is less prone to disintegration and dust formation. In its present form, the textile material would seem better suited to alternative types of gasifier such as those operating on the fluidised or circulating bed principle.