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Authors(s)	Wolff, Deidre, Walsh, Eilín, McDonnell, Kevin
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Practical Experience with Woody Biomass in a Down-Draft Gasifier

Deidre Wolff¹, Eilín Walsh^{1,*} and Kevin P. McDonnell²

¹*School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland*

²*Crop Science, School of Agriculture, Food Science and Veterinary Medicine, University College Dublin, Belfield, Dublin 4, Ireland*

Abstract: Gasification is the cleanest method of obtaining energy from fossil fuels, but with increasing awareness of depleting fossil fuel reserves attention has shifted towards renewable sources of energy. Any carbonaceous material can be gasified to generate high-value end-products from otherwise potentially low-value materials. Gasification can also generate energy from purpose-grown bioenergy crops, and Ireland has an ideal climate to produce woody biomass for energy generation. This update outlines some preliminary results from an investigation into the most suitable woody feedstock for small-scale localised gasification to produce a synthetic gas suitable for use in internal combustion engines. Argentinean- and German-standard wood pellets and Irish-grown willow chips were gasified in a down-draft gasifier. Operation of the gasifier led to the observation that the willow chips bridged within the feedstock hopper which prevented completion of gasification. Implementing a stirring bar in the feedstock hopper prevented bridging and gasification was then successful. Collection of the gas produced during gasification of willow chip was unsuccessful, however gas composition analysis indicates pellets which meet the German-standard are more suitable than Argentinean-standard pellets for use in a down-draft gasifier; work is underway to determine the composition of willow-derived synthetic gas to determine the most suitable feedstock for decentralised gasification by rural communities in Ireland as part of smart farming systems.

Keywords: Gasification, wood chip, wood pellets, willow (*Salix* sp.), renewable energy.

INTRODUCTION

Significant attention has been paid in recent years to the environmental implications of the fuels that we as a global population use in our daily lives. It is no secret that combustion of fossil fuels releases gases with detrimental greenhouse effects. Finding a renewable and environmental alternative has become an area of substantial research in an effort to prevent further environmental degradation. Gasification, the thermo-chemical process of converting carbonaceous material into a combustible gas through partial oxidation [1], is the cleanest method of obtaining energy from a fuel [2]. Gasification operates in conditions of limited oxygen and generates a number of high-value products which can be used to generate electricity or can be processed further to produce chemicals, fertilisers, and hydrogen [1]. Gasification is more efficient than combustion and as such extracts more energy: an average waste-to-energy plant can convert one ton of municipal solid waste (MSW) into 550 kWh of electricity through incineration compared to the 1,000 kWh that can be produced by gasification of an equivalent amount of MSW. Gasification can therefore be used to convert otherwise low-value materials such as MSW into high-value products [2].

Gasification can be used to extract energy and value from by-products and waste streams from the commercial, industrial, agricultural, and domestic sectors. From an environmental point of view, gasification has a number of advantages: the gas produced during gasification is cleaned before it is used which reduces the content of sulphur and nitrogen oxides in the gas and therefore reduces their emission upon combustion of the gas; the formation of furans and dioxins, associated with the excess oxygen conditions of incineration, is avoided as the material is not combusted [1]; recycling is enhanced by gasification as metals and glass must be segregated from the feedstock prior to gasification, increasing the availability of these materials for recycling; and as gasification can be used to convert any carbonaceous material to high-value products, methane emissions from waste decomposing in landfills can be avoided, as can the risk to surface- and ground-waters from landfill leachate [3]. Given that the EU Landfill Directive has placed strict limits on how much waste, particularly organic waste, can be consigned to landfills, gasification holds great potential as a means of both generating renewable electricity and treating otherwise low-value waste materials [4].

As outlined earlier, gasification is a more energetically efficient process than combustion and can be used to generate heat and electricity. Plant biomass is inherently carbonaceous due to the lignin, cellulose, and hemicellulose contents and when used as a fuel

*Address correspondence to this author at the School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland; Tel: +353 1 716 7458; Fax +353 1 716 7415; E-mail: eilin.walsh@ucd.ie

does not contribute additional carbon dioxide to the atmosphere [5]. Gasification of biomass is a clean technology that uses renewable crop material and is suitable for localised use, for example by rural communities [1] to whom the crop material would be conveniently located. The specific crop material used in gasification is determined by the available resources in the catchment area: woody biomass can be recovered material such as forestry thinnings and wood-processing waste or can be purpose-grown energy crops [5]. Ireland has the most suitable climate in Northern Europe for the cultivation of energy crops, and the primary crops grown for energy purposes are willow and *Miscanthus* [6]. In 2007 the Irish government introduced the first in a series of grant aid schemes to encourage farmers to sow willow and *Miscanthus* for energy purposes. Most recent figures (December 2011) indicate that cultivation of bioenergy crops in Ireland stands at approximately 3000 ha [7]. Assuming a conservative dry matter yield of 10 t/ha from these energy crops 30,000 t of crop material could therefore be available for use as a feedstock for gasification.

Using industry-derived wood waste as a feedstock for gasification has a distinct advantage over fresh biomass: wood wastes are often dried as part of the original processing and so do not require further drying prior to gasification, which requires a moisture content of between 10 and 20% for optimal thermal efficiency [1]. In the case of energy crops, however, it is necessary to reduce the moisture content of the fresh biomass by either passive or active drying prior to gasification. Particle size of the feedstock should also be adjusted for optimal environmental efficiency as smaller-sized particles tend to contain less alkalis and nitrogen [4] which contaminate the gas stream and so must be removed. Feedstocks are generally reduced to 20-80 mm particle size [4]. Particle size reduction of wood-based feedstocks is achieved by either chipping or pelleting the material; which method is used depends on the composition of the wood material [8]. Wood pellets are usually made from unprocessed, dry, waste wood which can be either hardwood or softwood in nature. Softwoods are more suitable for pellet production than hardwoods due to the higher lignin content which acts as a binding agent; hardwoods such as willow require the addition of a binding agent [9]. Pellets have lower moisture content and higher energy density than chips as a result of their processing. Wood chip preparation is more economical than pelleting as the required level of processing is lower and can be carried out on a small-scale, localised basis. The higher moisture content associated with wood chip

must be considered, however, to prevent degradation of the feedstock during storage [10].

The most appropriate gasifier configuration is determined by the intended final use of the produced synthetic gas, i.e. whether the gas is to be used in internal combustion engines, to generate heat and electricity, or processed further into high-value products such as chemicals or fertilisers. The primary distinction between gasifier designs relates to the position of the active bed. Fixed bed gasifiers are the most traditional design [4], are best suited to small- or medium-scale applications, and are relatively easy to operate [1]. Fixed bed gasifiers are further classified as up-draft or down-draft based on the direction of flow of air/oxygen within the gasifier. In most designs the material to be gasified is introduced at the top of the reactor; in up-draft gasifiers the air/oxygen is introduced counter-currently while in down-draft gasifiers the air/oxygen is introduced co-currently with the feedstock [11]. Up-draft gasifiers have good overall process efficiency as the configuration facilitates heat recovery from the synthetic gas as it passes through the incoming feedstock. The biomass feed also filters the upward-flowing gas which produces a gas with low particulate content [11], however the tar content of the gas is high as pyrolysis vapours produced higher in the gasifier are swept upwards with the synthetic gas [1].

Down-draft gasifiers produce synthetic gas with a low tar content as the tar is destroyed by thermal cracking as it passes through the hot reaction zone at the bottom of the reactor [1]. A low tar content is important when the objective of gasification is to produce a synthetic gas for use in internal combustion engines [12]: McKendry [4] described down-draft fixed bed gasifiers as being the most suitable configuration for the production of synthetic gas for use in internal combustion engines due to the inherent low tar content. There is no counter-flowing feedstock in down-draft gasifiers and so the gas leaving down-draft gasifiers is in the range 900 - 1000°C and has a high particle content [4]; overall process efficiency is low. Fluidised bed gasifiers achieve lower tar production than up-draft fixed bed gasifiers but higher tar production than down-draft fixed bed gasifiers [1]. Fluidised bed gasifiers can be directed to medium- and large-scale operations, and the feedstock enters at the top, middle, or bottom of the bed according to the design specifications. Fluidised bed gasifiers can be operated at high pressures which is important when the synthetic gas must be compressed, for example for subsequent use in a gas turbine [4].

Northern Europe has a climate well-suited to the production of short rotation coppice which can be efficiently gasified to produce a synthetic gas for heat and electricity generation or the production of chemicals and other high-value products. The nature of short rotation coppice lends itself to localised production and could be optimised for small-scale gasification to provide energy for rural communities. This report outlines preliminary results of an investigation into the most suitable feedstock for small-scale localised gasification using a down-draft gasifier in Ireland for the generation of a synthetic gas which could be used in internal combustion engines.

METHOD AND MATERIALS

Feedstocks

Within Northern Europe, Ireland has the most suitable climate to produce woody biomass [13]. *Miscanthus* and SRC willow are the primary bioenergy crops grown in Ireland and are used in both pellet and chip form for energy generation (chipped usage dominates). In this research willow, an indigenous bioenergy crop, was investigated as a potential feedstock for a down-draft gasifier used for decentralised synthetic gas production in Ireland. The willow was chipped as it was considered this form would be more applicable to rural communities as the level of processing and associated economic input are lower than pelleting. The chip was not uniform in size and consisted of a mixture of chip and bark material. Pellets were also investigated as a potential feedstock for localised gasification. Two samples of pellets were gasified: the first sample was an Argentinean-standard made from pine and the second sample was a German-standard made from pine/spruce.

Prior to gasifying any of the feedstocks each was analysed for moisture and ash content as well as calorific value. Moisture content was determined according to CEN/TS 14774-2:2004 [14] by weighing, drying in a convection oven at 105 °C, and reweighing. Ash content was determined according to CEN/TS 14775:2004 [15] by weighing, placing in a furnace until ashed, and reweighing. The calorific value of each feedstock was determined using a Parr 6400 Calorimeter¹.

Gasifier Unit

The gasifier used in this investigation was a GEK Imbert down-draft gasifier² which consists of a hopper for feedstock storage, a reactor where the gasification process occurs, a cyclone, and a charcoal filter through which the synthetic gas passes en route to a flare (Figure 1). The rate of biomass flow is controlled by gravity and is fed into the reactor by means of a feed-in auger. The rate of gas flow is controlled by an air compressor which controls the pressure over the gasifier: increasing the flow of air increases the pressure over the reactor and thus increases the flow of gas through the gasifier.



Figure 1: GEK Imbert down-draft gasifier.

To monitor the performance of the gasifier using each feedstock examined a number of process parameters were recorded including: reactor temperature throughout the gasification process; the length of time required for ignition (temperature of 60 - 100°C to be reached); the length of time required for gas ignition; and the composition of the produced gas. Gas samples were analysed by gas chromatography using a Varian 450-GC CO/CO₂ Analyser³ for CO₂, O₂, CO, CH₄, N₂, and H₂ concentration.

¹Parr Instrument Company, Illinois, USA.

²Gasifier Experimenters Kit, California, USA.

³Agilent Technologies, California, USA.

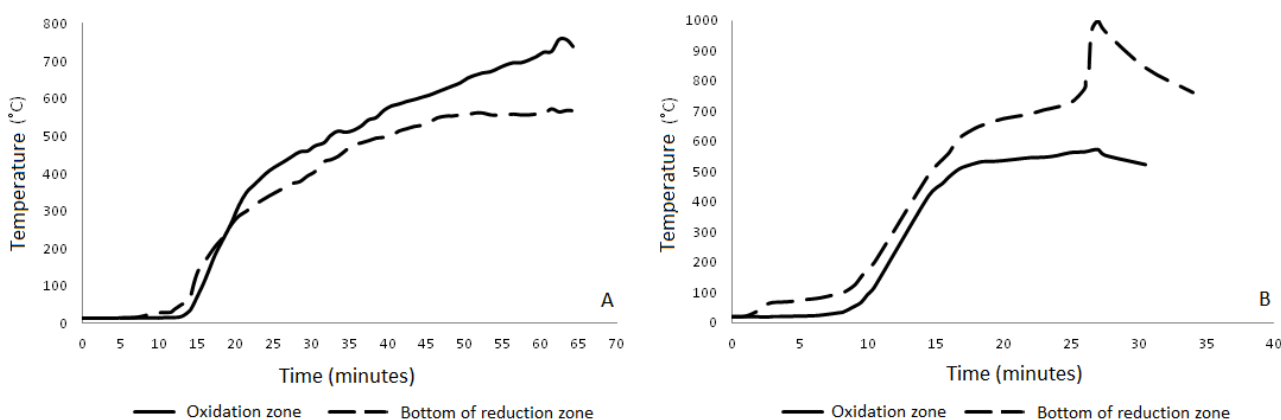


Figure 2: Temperature profiles of **A:** Willow chip (without stirrer) and **B:** Willow chip (with stirrer).

RESULTS AND DISCUSSION

It should be noted that while investigating the optimum feedstock for localised gasification of woody biomass to produce synthetic gas for use in internal combustion engines, a design flaw became apparent when willow chip was investigated: it was observed that bridging occurred in the feedstock hopper during the initial stages of gasification which prevented completion of the gasification process. To overcome this flaw a stirring bar attached to a motor was fitted within the hopper that intermittently rotated to agitate the feedstock. The effect of the stirring bar is evident in the temperature profiles of gasification before and after the implementation of the bar (Figure 2): a higher temperature was reached earlier in the process following installation of the stirring bar. This indicates the stirring bar had successfully prevented bridging of the feedstock and the gasifier had received a continuous supply of feedstock.

Table 1 outlines the characteristics of each of the feedstocks investigated for the production of synthetic gas for use in internal combustion engines. The willow chip had a higher moisture content than either of the pellets, which was expected. The calorific value of the two pellet samples was quite similar while the calorific

value of the willow chip was approximately 7.5% lower than the standard pellets (Table 1) and the 18.6 MJ/kg reported by McKendry [4] as the lower heating value of wood. The process parameters measured indicate that the longest ignition time was recorded for willow chip, considered to be due to the higher moisture content. The shortest gas ignition time was recorded for the Argentinean-standard pellets (data not shown). This reflects the shortest time from the beginning of the gasification process until the production of a combustible synthetic gas.

Samples of produced gas were collected during each test of each feedstock. Unfortunately the gas collected during the willow chip investigation proved to have the same composition as air, indicating unsuccessful sample collection. Comparing the composition of the gas produced from the gasification of the two standard pellets (Table 2), it is clear that the highest methane content was recorded for the German-standard pellets, a value which is higher than values reported by other authors (e.g. Erlich and Fransson [16]; McKendry [4]; Klass [17]). At 2.8%, the methane content of the Argentinean-standard pellets is closer to the reported values. The gas produced from the gasification of the Argentinean-standard pellets had a

Table 1: Moisture Content, Ash Content, and Calorific Value of Each Feedstock Investigated

Feedstock	Willow chip	Argentinean pellet	German pellet
Biomass flow rate (kg/h)	7.2	10.06	6.57
Tar production	12.31	4.29	n/a
Moisture content (dry basis) (%)	12.9	8.4	7.7
Moisture content (wet basis) (%)	11.4	7.8	7.1
Ash content (%)	0.90±0.03	0.10±0.02	0.21±0.09
Calorific value (MJ/kg)	17.28±0.02	18.78±0.06	18.66±0.06

Table 2: Comparison of Recorded Compositions of Produced Gas with Published Values

Constituent gas	Argentinean pellet	German pellet	Erlich and Fransson [16]	McKendry [4]	Klass [17]
% H ₂	20.6	19.4	11.9 ± 1.1	15-20	17.0
% CO ₂	12.9	17.6	9.9 ± 1.0	10-15	9.0
% N ₂	39.7	42.6	50.4 ± 1.7	40-50	45.0
% CH ₄	2.8	4.4	2.6 ± 0.2	3-5	1.0
% CO	22.9	15.9	25.7 ± 1.7	10-15	18.0

higher content of both CO₂ and H₂ than the gas produced from the German-standard pellets (Table 2).

Based on this compositional difference it is suggested that pellets which meet the German-standard are a more suitable feedstock for the production of gas for use in internal combustion engines. Furthermore, although pellet durability was not quantified during this investigation, it was observed visually that the Argentinean-standard pellets turned into a layer of fine dust which hardened along the internal surfaces of the gasifier, a phenomenon not observed with the German-standard pellets. This also indicates that the German-standard pellets are more suitable than the Argentinean-standard pellets for the production of synthetic gas in a down-draft gasifier.

CONCLUSIONS AND FURTHER WORK

The implementation of a stirring rod within the feedstock hopper proved successful in preventing bridging of willow chip within the gasifier. It is therefore recommended that a similar modification be made to down-draft gasifiers to ensure optimum process efficiency when using chipped woody biomass as a feedstock.

The composition of the gas produced from the two pellets samples indicates that the German-standard pellets are more suitable for the production of synthetic gas for use in internal combustion engines, which is the focus of this investigation. No conclusions can be drawn, however, on the composition of the synthetic gas produced from the gasification of willow chips as gas collection was unsuccessful. Further work is currently underway on the use of willow chip as a feedstock in this modified down-draft gasifier and on the durability and tar production associated with all feedstocks investigated in order to determine the most suitable feedstock for synthetic gas production in rural communities for use in internal combustion engines.

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