



Effect of Furnace Temperature on the Distribution of Tar during Gasification of Miscanthus

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Biomass has been extensively recognised as a clean and sustainable energy source with the highest probability to substitute fossil fuel in the energy market. Its utilisation for energy generation is of particular interest to the world at large because of its potential to reduce global carbon dioxide emission. Concerning these considerations, gasification technology comes to the forefront of biomass conversion to various forms of energy for some reasons. Primarily, gasification offers a high flexibility in utilising different kinds of biomass feedstock to produce a combustible gas, making it more active process than pyrolysis and direct combustion. However, the major challenge associated with thermal gasification of biomass is tars and particulates formation. These compounds compromise the state of syngas, potentially harming end use systems especially those delicate to the quality of gas. In this research, tar sampling and analysis was performed based on a modified standard tar protocol followed by gas chromatography-flame ionisation detector (GC-FID) so as to quantify tar concentration in syngas produced from gasification of Miscanthus. Experiments was carried out at various furnace temperature in the range 350-650°C, with temperature enhancement, the abundance of phenolic compounds increases.

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ABBREVIATIONS

GC-FID : Gas Chromatography-Flame Ionisation Detector

1. INTRODUCTION

The global energy demand increases daily causing energy crisis as a result of the continued intensification of energy demand, Over-reliance on fossil fuels and a steep rise in global population [1] which further increases the costs of energy. Concerning the depletion of fossil fuels, global warming, energy dependence, environmental pollution and the ever-increasing global demand for more efficient energy generation [2], an alternative sustainable energy source needs to be widely explored.

Much of the global carbon dioxide emissions originate from the burning of fossil fuels which accounted for 85% of the total world energy supply in 2010 [1]. The ever-increasing greenhouse gases emission significantly affect the biosphere, leading to global warming, mitigation demand that anthropogenic greenhouse gas emissions be steadily decreased [3].

The way to mitigate global climate change is by deploying energy technologies that utilise alternative energy sources which do not release or releases a little amount of carbon dioxide into the atmosphere [3].

Biomass energy conversion is considered to be carbon neutral process and for this reason, it is getting increased attention as the most potential renewable energy source [4]. Its attraction as a source of renewable energy is that the quantities of carbon dioxide emissions resulting from the use of biomass derived fuels are compensated for by the quantities of carbon dioxide that were recently absorbed by plants during growth [2-3]. Therefore, the net increase in global carbon dioxide levels is zero.

For biomass energy utilisation, gasification is the feasible alternative to the other energy conversion technologies since it can upgrade biomass feedstock with lower energy value to synthetic gas with a higher energy value, which can be utilised in gas turbines and gas engines to produce energy [5-6]. Gasification can accommodate feedstocks with a broad range of

physical properties [3]. However, the major challenge associated with thermal gasification of biomass is tar and particulates formation. This compound compromises the condition of the produced gas making it difficult for its direct utilisation in downstream processes [7-8]. Tar formation is the limiting factor to the commercialisation of gasification technology [9]. If it is reduced from the syngas, gasification end use will be enhanced [10].

2. METHODOLOGY

2.1 Sample Collection

Collection of samples of organic contaminants present in syngas produced from gasification of miscanthus was carried out using a modified set-up of the standard tar and particle sampling method accredited and approved by European Committee for standardisation [11]. The modified set-up includes an electric furnace (MTF, Carbolite, UK), a row of three conical flasks, a vacuum pump (Masterflex, Cole Parmer, United States) and a flowmeter as illustrated in Fig. 3. Module one comprises of a furnace to stimulate the desired condition for slow pyrolysis by heating a steel pipe connected to the gas line. One end of the still pipe was sealed, and another end left open, the sealed used to place a biomass sample in the furnace while the opposite end will be left open to allow gasification products to exit to the sample line. Tar collection took place in module two, where the product gas was conducted to a system of three conical flasks connected in series. The first conical flask was left empty for moisture collection from the gas and partial condensation of tar; the second conical flask was filled with isopropanol to absorb the tar. The third conical flask was filled with cotton wool for product gas dehumidification and capture of tar aerosol. The first conical flask was kept at room temperature while the second and third conical flask were kept at low temperature by a mixture of ice, water, and common salt to allow condensation of water and tar from the product gas as well as preventing evaporation of isopropanol. Module three comprises of a vacuum pump, set at pressure 50 mL per min to maintain slow pyrolysis conditions and to avoid combustion of feedstock within the pipe by extracting the gas, a flowmeter, set at 25 m/s to avoid tar decomposition within the pipe. This modified set-up was developed based on the guidelines established by [11-13].

Initially, the furnace was fixed at 350°C, with the closed end of the steel pipe enclosing a 4-grams of miscanthus positioned in the hottest (centre) region of the furnace. Fig. 1 illustrates the tar sample collection set-up.

A rubber stopper and vacuum grease was used to maintain an airtight arrangement. The experiment was ready to start as soon as the required furnace temperature stabilised and the sample ready at the end of the tube. A 30-min residence time was chosen to provide ample time for tar formation and absorption to occur. After reaching the residence time, the steel pipe was removed from the furnace by means of heat resistant gloves. The contents of the first and second conical flasks was mixed and poured into a glass bottle and kept in a freezer, below 5°C prior to analysis to reduce degradation of the sample solution. Once the first and the second conical flask contents were collected, the metal tube and rubber tubing were thoroughly cleaned using ethanol and rinsed with water to avoid impurities influencing subsequent runs. The entire method was repeated for furnace temperature 450°C, 550°C and 650°C without replication.

2.2 Sample Preparation and Analysis

The four collected samples, approximately 100 mL each in isopropanol were prepared and

analysed to identify the fingerprint of all chromatographable compounds present using gas chromatography-flame ionisation detector (GC-FID). The FID specifically responds to all hydrocarbon compounds which burns in Oxy Hydrogen flame [14-15]. The signals produced by the FID represent most of the typical tar components [14].

2.2.1 Sample preparation

1.5mL of each sample were transferred into a 2mL polypropylene eppendorf tube. 0.15g of sodium sulphate were added to each tube and the sample was initially vortexed for 1min at 2000rpm and centrifuged afterwards at 12500 rpm for 5min. 990 μL of the supernatant of each sample were transferred into a 2mL glass sample vial and 10 μL of a 1000ppm solution of 4- fluorophenol was added to each vial.

2.2.2 Sample analysis

A quality analysis of the sample was carried out by using an Agilent 7890B gas chromatograph through a capillary column type J&W DB-5-122-5032 of dimension 30m long, 250 μm diameter, and film thickness of 0.25 μ m. Table 1 illustrate the set parameters.

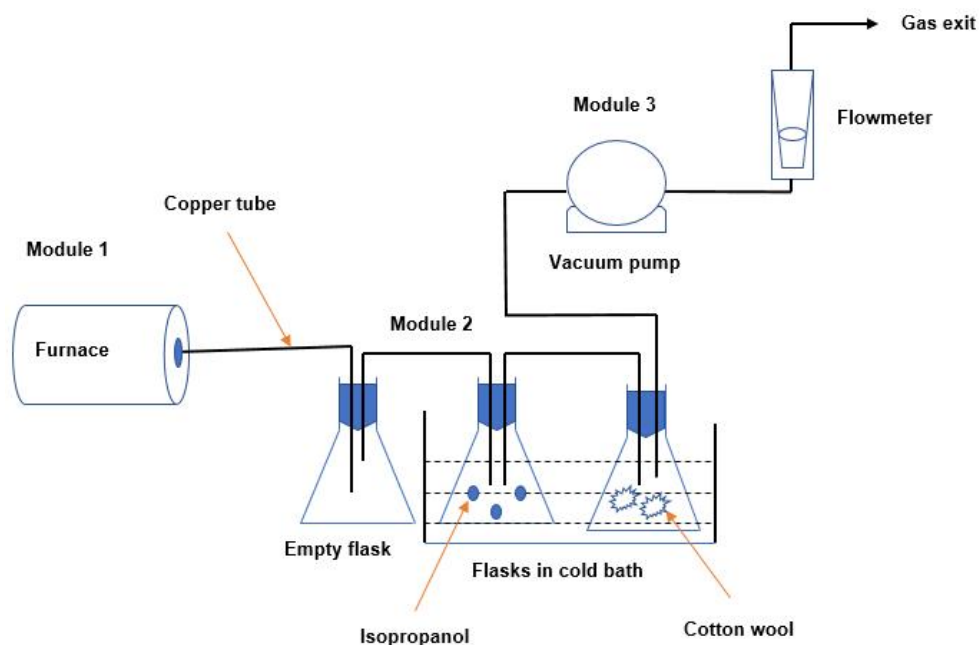


Fig. 1. A sketch of modified tar sampling collection system

Table 1. Operating conditions for tar analysis

Parameters	Specification
Inlet parameters:	
Inlet temperature	250 °C
Injection mode	Split
Split ratio	10:1
Septum purge	3mL/min
Injection volume	1mL
Oven parameters:	
Temperature changes	Programmed as follow: 55°C for 3 min then 12 °C/min to 300 °C (no hold).
Detector parameters:	
Carrier gas	Hydrogen gas heated at 350 °C.
Carrier gas flow rate	40 mL/min
Air flow	450 mL/min
Nitrogen gas makeup flow	50 mL/min

3. RESULTS AND DISCUSSION

Table 2 demonstrates an increase in compounds abundance with increasing furnace temperature from 350°C to 650°C. The same trend was observed by Fagbemi, Khezami & Capart [16]. By varying the temperature from 400°C to 900°C, they observed an increase in tar yield with increase in temperature until 600°C beyond which the tar yield decreases. Pyrolysis of biomass can start as low as 200 °C and substantially completes by 650 °C [17-19]. In this temperature range, lignocellulosic biomass (the cellulose, hemicellulose, and lignin in biomass) produce mixed oxygenated, primary organic condensable molecules, which are also called primary tars [18-19]. As the reactor temperature increases, secondary reactions take place in the gas phase, converting oxygenated tar compounds to light aromatic hydrocarbons and subsequently forming larger polycyclic aromatics hydrocarbons in tertiary processes [16]. This accounts for the increase in the tar yield with increase in furnace temperature. In this range of temperature, phenol is one of the major tar

compounds [9, 17-18] and for this reason standardisation was done to identify phenol.

For the purpose of identifying the correlation between the individual components at furnace temperature 350°C and 650°C, a mirror chromatogram was generated as illustrated in Fig. 2.

Fig. 3 demonstrates an increase in compounds peak ratios with increase in temperature from 350°C to 650°C. It was also observed that the abundance of phenol increases. The increase in phenolic compounds with temperature enhancement can be explained by the transition from lignocellulosic biomass products to phenolic products during slow pyrolysis process [18-20]. In a similar experiment for temperature ranging from 400°C to 800°C, Carrick [21] observed an increase in the abundance of phenolic compounds with an increase in furnace temperature. This result is also consistent with that found by Milne & Evans [19]; Fiamegos et al. [22]; Moersch et al. [23].

Table 2. GC-FID peak area for tar compounds present in samples collected at furnace temperature 350°C to 650°C

Peak	Retention time	Peak area			
		350 °C	450 °C	550 °C	650 °C
Peak 1	1.93	53.54	121.29	126.74	267.67
Peak 2	3.92	77.62	93.33	109.97	208.61
Peak 3	4.53	13.87	16.34	18.58	47.48
Peak 4	5.47	7.09	28.39	31.31	84.44
Peak 5	5.96	14.83	22.80	30.56	59.68
Phenol	6.45	8.07	9.46	10.42	24.91
Peak 7	8.06	13.30	48.17	54.30	130.56
Peak 8	9.72	17.87	59.78	78.57	211.54
Peak 9	10.91	9.39	33.55	55.52	152.61
Peak 10	11.31	3.47	10.32	11.62	32.67

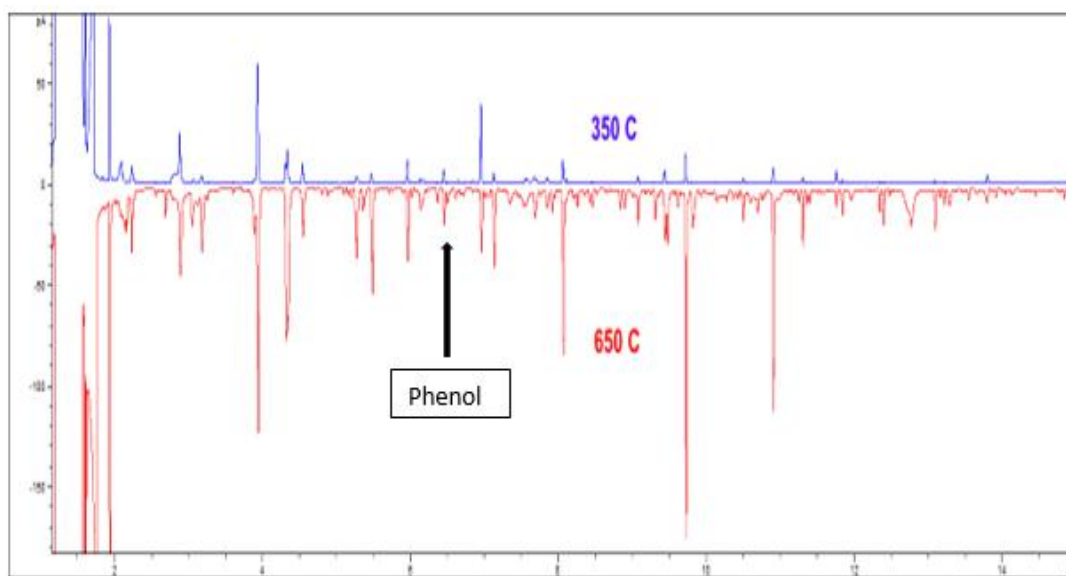


Fig. 2. A GC-FID mirror gas chromatogram representing fingerprints of compounds present at furnace temperature 350°C and 650°C

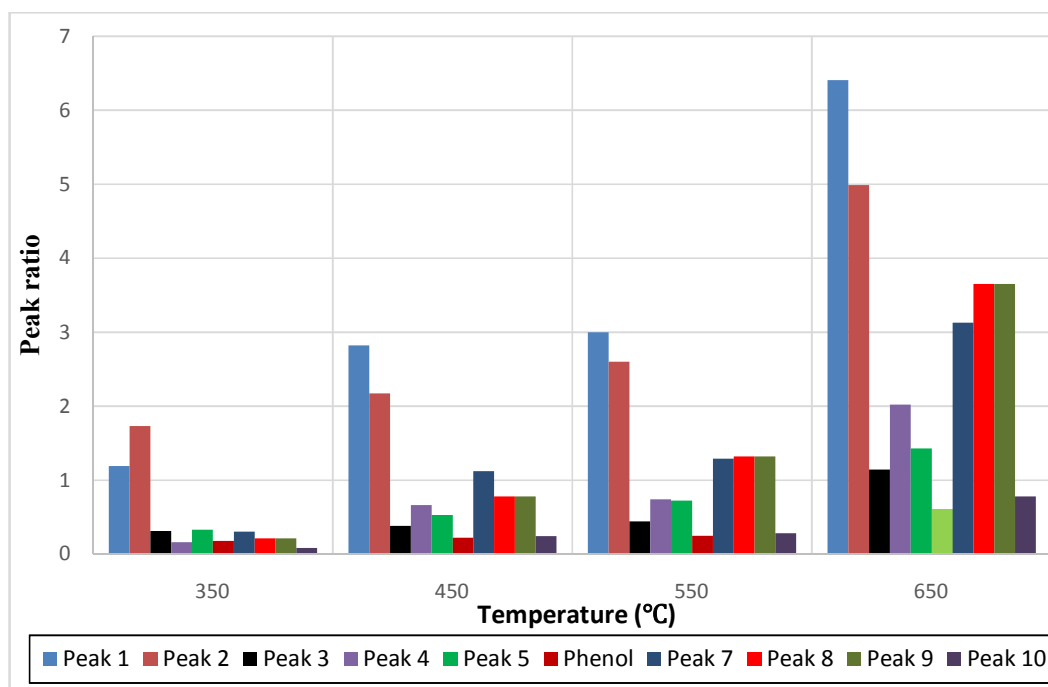


Fig. 3. Effects of temperature on the abundance of compounds produced by GC-FID analysis

4. CONCLUSION

This study was conducted to investigate the behaviour of tar with an increase in temperature from 350°C to 650°C. Tar sampling and collection was done using a modified tar protocol.

Tar analysis was done using a GC-FID. Standardisation was done to identify phenol which is a major tar component in pyrolysis. The result showed an increase in the abundance of condensable hydrocarbons with an increase in temperature.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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