5th EURASIA WASTE MANAGEMENT SYMPOSIUM
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# Development of Intensive Hot Syngas Clean-up System for Biomass Gasification

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***Abstract***

*Gasification is one of the most efficient ways to generate energy from biomass and carbon containing solid waste. Gasification of biomass produces syngas usually consisting of CO, $H_2$, $CH_4$, $CO_2$, $N_2$, $H_2O$ gases. However, besides these gases, syngas also includes pollutants such as particulates and tar. In order to utilize product syngas in an internal combustion engines and turbines, the final produced gas must be purified from these unwanted pollutants. In this study, an intensified and integrated syngas clean-up system, which consists of a sintered metal filter resistant to high temperatures to remove particulates and catalyst bed in order to remove tar, was designed and developed. Metal filters have diameters of 10µm and made of 316 L stainless steel properties. On the other hand, honeycomb-shaped nickel-based catalyst is used for tar cracking. This system was placed in the gas outlet of the fixed bed gasification reactor operated under hot gas conditions and at a fuel supply flow rate of 100 kg / h. The wood chip as biomass feedstock was chosen as the gasification raw material. The parameters that affects the cleaning of the produced syngas in the integrated syngas clean-up system and gas cleaning efficiency (particulates and tar concentration) were examined and the system was optimized accordingly. The average particulate matters amount of 0.2 $g/m_n^3$ and the average amount of tar 15 $g/m_n^3$ after intensive filter system. The results showed that the treated gas is not yet at a level that can be used in gas applications. Experiments still continue to better results.*

**Keywords:** Gasification, syngas, hot gas cleaning, catalytic filtration, renewable energy, biomass

## 1. INTRODUCTION

According to research in the field of renewable energy, biomass energy is known as the energy source that provides the biggest contribution to the global final energy demand by meeting about 13% of the total energy among renewable energy sources [1]. All types of waste, from biomass and forest residues to petrol coke, can be converted into valuable energy forms [2]. Biochemical and thermochemical conversion processes are methods to generate energy from biomass residues. Thermochemical conversion processes are combustion, liquefaction, pyrolysis and gasification. Direct combustion is the oldest and the most preferred method. However, considering the renewable, environmental and sociopolitical benefits, the use of technologies for the conversion of biomass into gas and liquid is increasing. Gasification process is more advantageous than other processes in terms of having multiple fuel production capacity as solid, liquid and gas and having high efficiency [3]. Gasification is the process of converting carbon-based feedstock into gas products with partial

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oxygen at high temperatures (> 700 ºC). Thermochemical conversion of feedstock at high temperatures produces syngas ($CO + H_2$) [4, 5]. Syngas must be purified from solid pollutants (dust), inorganic pollutants such as nitrogen compounds ($NH_3$ and HCN), sulfur compounds ($H_2S$), ash and metal compounds, and organic pollutants (tars) [6]. Syngas from gasification reactors damages engines and turbines unless it is purified from particles and tar. Therefore, gas cleaning efficiency determines the success of the gasification process [7]. This research, it is aimed to gasify the biomass in a fixed bed gasifier, to purify the pollutants in the syngas produced in a compact and integrated hot gas cleaning system and to produce the syngas in a quality that can be used in electricity generation.

## 2. MATERIALS AND METHODS

In this study, an integrated syngas clean-up process was developed to remove two main pollutants, particulate matter and tar in the syngas. The research is important in that it ensures the purification of two main pollutants in a single process and contributes to hot synthesis gas treatment studies.

### *2.1. Pilot Scale Gasification Reactor*

The schematic view of built in Gebze Technical University that the 150 kg/hour capacity pilot scale gasification reactor is given in Figure 2. This pilot scale reactor provides the necessary tests to be performed;

- to develop a concentrated cleaning technology,
- to optimize the operation and performance of the integrated hot gas filter system,
- to develop a cleaning strategy for synthesis gas produced using wood-based biofuels.

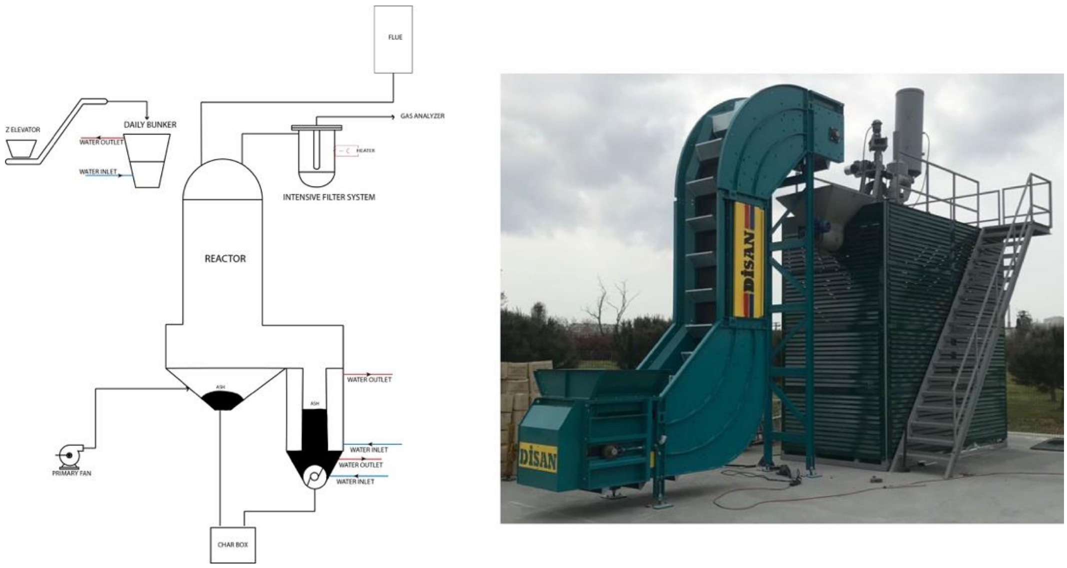


*Figure 1. Basic scheme and general view of pilot scale gasification reactor*

### *2.2. Integrated Filter System*

In the research, stainless steel filters were used to provide particulate removal. Nickel based catalyst was preferred for tar removal. The filter system and the catalyst beds are combined. Thus, a intensive and integrated gas cleaning system has been designed. This system was placed at the gas outlet and aimed to remove both particulate matter and tar.

The cleaning system is covered with insulating material to keep the temperature, then wrapped with a resistance to heat the gas. In the innermost part, a replaceable filter assembly was placed and nickel-based catalysts were filled in the filter. In addition, a thermocouple and a control panel are connected to the system to control the energy time and temperature level of the resistance.

A sintered metal filter with different pore sizes resistant to high temperatures was preferred for the removal of particulate matter. Metal filters have 10µm diameter and 316 L stainless steel properties. Honeycomb-shaped nickel-based catalyst is used as catalyst.

### *2.3. Gravimetric Particulate Matter and Tar Analysis*

The "Tar Protocol" [8] was followed to determine the concentrations of tar and particulate matter. The tar protocol includes a set of procedures for the measurement of organic gas contaminants and particles in generating gases from biomass gasifiers. The procedures are designed to cover different types of gasifiers (updraft or downdraft, fixed bed or fluidized bed gasifiers), different operating conditions (0-900 °C and 0.6-60 bar) and different concentration ranges (1 mg/$m_n^3$ to 300 g/$m_n^3$).

For determining the pollution load of the gasifier reactor firstly the Module 1, Module 2 and Module 3 all series were placed one after the other as shown in Figure 3. Then, by adding catalyst into the integrated filter system Module 1, Integrated Filter System, Module 2 and Module 3 were sequenced, and the experiments were repeated. In this way, the effect of steel filter and catalyst jointly on syngas cleaning was investigated. Rotameter and pump are placed at the end of the impenger bottles for the adjustment and control of the gas flow rate.

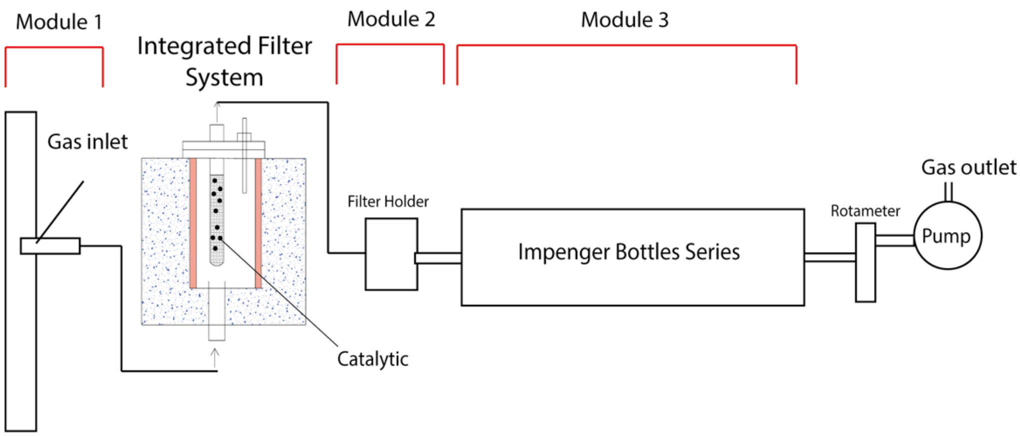


*Figure 3. Schematic view of the integrated filter system and experiment set*

## 3. RESULT AND DISCUSSION

Syngas was purified in the integrated filter system and analyzed. The samples were taken in accordance with the Tar Protocol and the particulate matter and tar amounts in the syngas produced were determined.

### *3.1. Online Gas Analysis*

Percentage of $O_2$, $CO_2$, CO, $H_2$, $CH_4$, $N_2$ gas ratios and gas temperature were measured with the Online Syngas Analyzer. Gas analysis results are given in Table 1.

*Table 1. Gas analysis results*

| $T_{gaz}$ °C | $O_2$ (%) | $CO_2$ (%) | CO (%) | $H_2$ (%) | $CH_4$ (%) | $N_2$ (%) |
|---|---|---|---|---|---|---|
| 179.6 | 0.58 | 11.23 | 20.23 | 7.94 | 3.53 | 56.49 |

### *3.2. Gravimetric Particulate Matter and Tar Analysis Results*

The reactor was operated with a feed rate of 100 kg / hour. A fiber filter was placed in the filter holder shown in Module 2, and then the filter was extracted with isopropanol by Soxhlet extraction in the laboratory. Thus, particulate matter and tar were separated and the amount of particulate matter in the gas was calculated. Soxhlet extraction set is given in Figure 4.

*Figure 4. Soxhlet extraction set*

100 ml sample was taken from the total tar sample in isopropanol from the impinger bottles, connecting pipes and Soxhlet extraction and placed in a rotary evaporator. The amount of tar was calculated by separating isopropanol and tar from each other. The rotary evaporator set is given in Figure 5.

*Figure 5. Rotary evaporator set*

Particulate matter and tar concentrations in the syngas are given in Table 2.

*Table 2. Concentration of particulate matter and tar results in syngas*

| **Gas flow, L/min** | **Sampling time, min** | **Gas temperature at the inlet, ºC** | **Gas temperature at the outlet, ºC** | **Particulate mater concentration, (g/$m_n^3$)** | **Tar concentration, (g/$m_n^3$)** |
|---|---|---|---|---|---|
| 15 | 30 | 350 | 35 | 0,204 | 14,95 |

## 4. CONCLUSION

In this research, determined the amount of tar and particulate matter in the syngas is higher than the optimum levels in gas applications. For this reason, studies continue until better results are obtained.

## ACKNOWLEDGMENT

This work was funded with the contribution of TUBITAK. The authors are grateful to the Kastamonu Entegre Ağaç Sanayi ve Ticaret Anonim Şirketi group for providing the raw material and gas analyzer, the DISAN group for the feedstock feeding conveyor system and Gebze Technical University for their laboratory studies.

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