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Evaluation of A Micro-Scale Rice Straw Gasification Costs

Birolkayişoğlu[1]serkan TUĞ[2]İbrahim Savaş DALMIŞ[3]Türkan AKTAŞ[1]
Mehmet Recai DURGUT[1]Figen TAŞÇI DURGUT[1]
[1]*Namık Kemal University Agricultural Faculty Biosystems Engineering Dept./Turkey*
[2]*namık Kemal University Technical Vocational School/Turkey*
[3]*Namık Kemal University Engineering Faculty Mechanical Engineering Dept./Turkey*

Abstract: In this study, the economic analysis of gasification of rice straw was reviewed. Gasifier used in this research was developed by our department. Economic analysis for biofuel preparation and gasification processes were conducted separately. Biofuel preparation process consists of shredding and pelletizing. The unit cost of shredding and pelletizing of rice straw were found 0,079 $.kg^{-1} and 0,052 $.kg^{-1}, respectively. The total cost of preparing biofuel was 0,131 $.kg^{-1}. The cost of hourly biofuel consumption in gasification was 2.67 $.h^{-1}. The hourly cost of the gasification process was 3.57 $.h^{-1}. In the end of this research, the unit energy cost of syngas was found 0,146 $.kWh^{-1}.
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Keywords: Rice straw, gasification, pelletizing, syngas, biofuel, economic analysis

I. INTRODUCTION

Rice is one of the most important cereals consumed in the world after wheat. In recent years, rice production has increased in Turkey. The straws remaining on the surface of the field after the rice harvest is a problem for farmers. Silica content of rice straw is higher than other cereals. Therefore, it's difficult to break down the rice straws and very hard to decompose. Therefore, farmers are banned, although the rice straws remaining in the field are burned every year. This causes loss of energy and adverse environmental conditions.

Evaluation of rice straws with the proper techniques and different methods have made a significant contribution to the country's economy and also will help reduce the impact of adverse environmental conditions. The gasification process of rice straw is one of these methods. Gasification of rice straw will be able to gain $75x10^9$ MJ of energy in our country every year.

Biomass gasification is the most reliable and promising method nowadays to generate electricity, because this process provides sustainable & affordable alternative to fossil fuel based process plants at small and medium levels. From economic analysis it is concluded that biomass gasification technology is the most feasible technology if it is implemented in rural areas with an average population of 200 houses and in small industries [3].

The main conclusion is that the potential technical and economic benefits that industrially integrated biomass gasification systems can provide are important in the development towards a more sustainable motor fuel and green chemical production [1].

A research which was conducted by Guilherme and et al, aimed to evaluate the feasibility of a 100 kWe gasification system including an engine generator set, examining the major costs in using this technology and the sensitivity of different factors on the variation of the electricity cost. With a capital cost of 1,100.50 €.kW^{-1}, the levelized unit cost of electricity delivered (LUCE) found was 459,83 €.MWh^{-1}, which would make this technology uncompetitive even in places where the generation is done using diesel oil. The parameters that showed to have a greater impact on LUCE were, in decreasing order, the load factor, the gasifier capital cost, the electric conversion efficiency, the capacity utilization factor and the gasifier useful lifetime, but even with variations of 30% within the range considered no parameter alone would allow reducing the LUCE to a competitive level [2].

Feasibility of biomass gasification is very much dependent on the cost of the gasification facility and its operation. A cost analysis model was accordingly developed to analyze the unit cost of syngas production from micro-scale biomass gasification facilities. Costs considered included all capital and operating costs. The model was applied to evaluate a scenario for Mississippi in 2008. Results of the modeling indicated that operating cost was the major part of the syngas production cost, and the single-shift operating cost could be up to 83.64% of the total annual cost of syngas production at the 60 Nm^3.h^{-1} capacity level. Labor cost was the largest part of the operating cost and the total annual cost. The labor cost could be up to 73.60% of the total of annual operating cost and 61.56% of the total annual cost of syngas production [6].

In this research, the economic analysis of rice straw gasification was done. The aim of this research is to determine the unit energy cost of syngas and to compare it with LPG used residential and rural area.

II. METHOD

2.1. The machines which are used in the pellet production stages

Rice straw was provided from Thrace Region of Turkey for gasification. Collected rice straw prepared as biomass feedstock by shredding and pelletizing. The shredding machine used for the experiments has 15 kW of power and 100 $kg.h^{-1}$ capacity. Rice straw bales and shredding machine are shown in **Figure 1**.

Figure 1. Rice straw bales and shredding machine

Pelletizing machine has also 15 kW of power and 150 $kg.h^{-1}$capacity. This machine has vertical shaft and 6mm hole diameter. **Figure 2** shows the pelletizing machine used.

Figure 2. Pelletizing machine

A downdraft fixed bed gasifier was designed and fabricated to perform the gasification process for rice straw pellets. This prototype biomass gasification system was developed by Biosystem Engineering Department.

Experimental set up includes gasifier reactor, cyclone, gas cooling unit and condensation tank, vacuum pump and its service water tank, flare unit, measurement and control components, gas chromatography device and its components[4]. The gasification system is given with **Figure 3**.

Gasifier reactor is throathless type and reactor diameter is 350mm. The capacity of reactor is 25 kg of biomass. System has fixed bed reactor with upper air inlet.

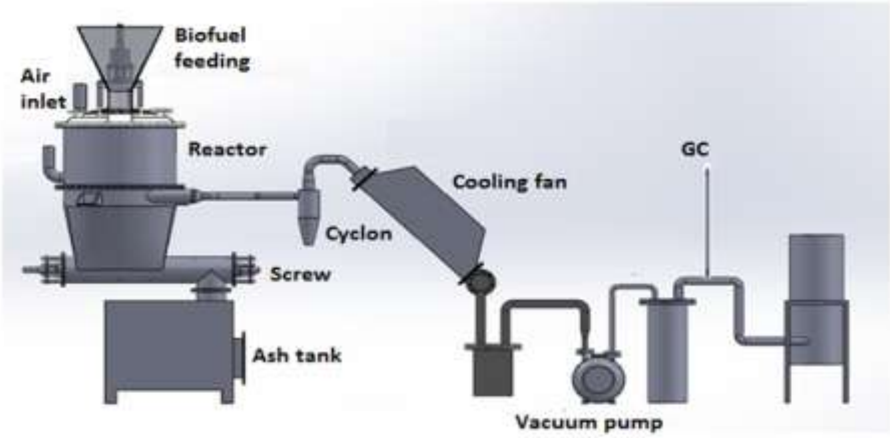

Figure 3. The schematic view of gasification system

The system components which were efficient on energy consumption are the stirrer motor, cooling fan's motor, ash removal screw's motor and vacuum pump. These components are shown in **Figure 4**.

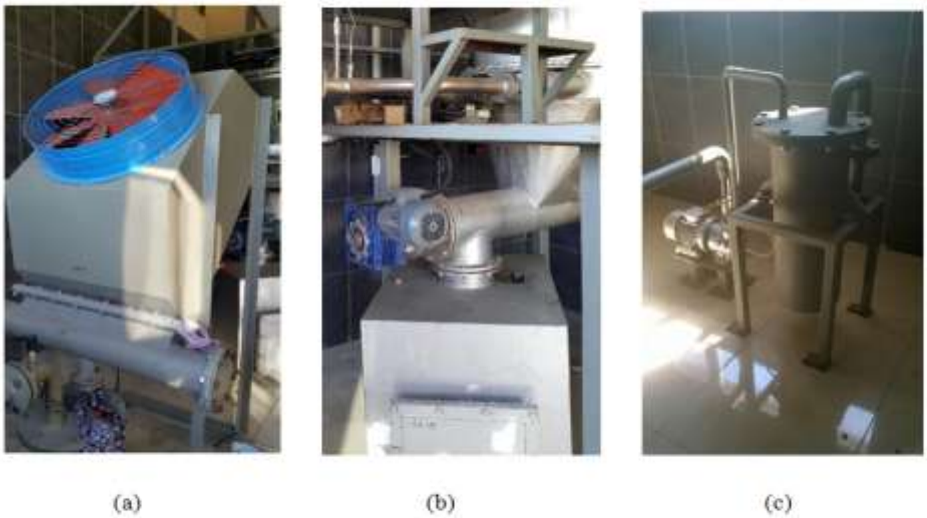

Figure 4. The electric consumption elements on gasification system: (a) cooling fan's motor, (b) ash removal screw's motor, (c) vacuum pump.

The characteristics of electric motors used in the system are given in Table 1.

Table 1. The characteristics of electric motors used in the system

Unit	Power
Vacuum Pump	1.50 KW
Cooling fan	0.55 KW
Ash removal screw	0.55 KW

2.2. The characteristics of rice straw pellets
The characteristics of rice straw pellets are given in Table 2.

Table 2.The characteristics of rice straw pellets

Mean diameter	6.2	mm
Mean length	53.6	mm
Bulk density	562.3	kgm^{-3}
Unit density	1226.4	kgm^{-3}
Lower Heating Value	12.77	$MJkg^{-1}$
Higher Heating Value	13.84	$MJkg^{-1}$

2.3. Syngas analysis and determination low heating value

The syngas sample with the help of a pipe from the maingas output line were taken and analyzed with Agilant 7890A GC model gas chromatography. After determination of flammable gases contents of syngas with GC, the lower heating value of syngas was calculated by using the following equation[5];

$$LHV_g = 10{,}8 \cdot H_2\% + 12{,}63 \cdot CO\% + 35{,}8 \cdot CH_4\% \quad (1)$$

Where; LHV_g ($MJ.Nm^{-3}$) is thelowerheatingvalue of syngas, thecoefficients in front of flammablegasesarethelowerheatingvalue of them.

2.4. Economic analysis of the pellet production

The economic analysis of the gasification process was conducted in two groups without investment costs. The first of these is the cost of preparing the biomass, the second is the cost of operating of the gasification plant[4].

Fuel consumption rate (FCR) and gas production rate (GFR) of gasifier system were adjusted by the automation system 20.4 $kg.h^{-1}$ and 35.1 $Nm^3.h^{-1}$, respectively.

2.4.1. Calculation of the cost of preparing the biomass

The cost of shredding operation of rice straw

The cost of hourly energy that is consumed in the process shredding of rice straw was calculated by using the following equation;

$$CS = PSxUEP \quad (2)$$

Where; *CS* ($\$.h^{-1}$) is the hourly energy cost of shredding; *PS* (KW) is the power of shredding machine, *UEP* ($\$.KWh^{-1}$) is the unit price of electrical energy.

The labor costs of shredding of rice straw was calculated by using the following equation;

$$LCS = nxHOC \quad (3)$$

Where; *LCS* ($\$.h^{-1}$) is labor costs of shredding, *n* is number of workers, *HOC* ($\$.h^{-1}$-person) is the hourly operating cost of a worker.

Two persons worked in shredding operation and the hourly operating cost of a worker was 3.42 $\$.h^{-1}$.

The total cost of shredding operation of rice straw is;

$$TCS = CS + LC \quad (4)$$

Where; *TCS* ($\$.h^{-1}$) is the total hourly cost of shredding operation.

The shredding cost of unit biomass was calculated by using the following equation;

$$SCUB = \frac{TCS}{CPS} \quad (5)$$

Where; *SCUB* ($\$.kg^{-1}$) is the shredding cost of unit biomass, *CPS* ($kg.h^{-1}$) is the capacity of the shredding machine.

The cost of pelletizing

The hourly cost of pelletizing process was calculated by using the following equation;

$$CPL = PPLxUEP \quad (6)$$

Where; *CPL* ($\$.h^{-1}$) the energy cost of pelletizing; *PPL* (KW) is the power of the pelletizing machine, *UEP* ($\$.KWh^{-1}$) is the unit price of electrical energy.

The labor costs of pelletizing of rice straw were calculated by using the following equation;

$$LCP = nxHOC \quad (7)$$

Where; *LCP* ($\$.h^{-1}$) is labor costs of pelletizing operation, *n* is number of workers, *HOC* ($\$.h^{-1}$-person) is the hourly operating cost of a worker.

Two persons also worked in pelletizing operation and the hourly operating cost of a worker was 3.42 $\$.h^{-1}$.

The total pelletizing cost was calculated by using the following equation;

$$TCP = CPL + LCP \quad (8)$$

Where; *TCP* ($\$.h^{-1}$) is the total hourly cost of pelletizing operation.

The pelletizing cost of unit biomass was calculated by using the following equation;

$$PCUP = \frac{TCP}{CPP} \quad (9)$$

Where; *PCUB* ($\$.kg^{-1}$) is the pelletizing cost of unit biomass, *CPP* ($kg.h^{-1}$) is the capacity of the pelletizing machine.

The cost of preparing of the unit biofuel was calculated by using the following equation;

$$CPUB = SCUP + PCUP \quad (10)$$

Where; *CPUB* ($\$.kg^{-1}$) is the unit mass cost of preparing of biofuel.

The cost of hourly biofuel consumption in gasification was calculated by using following equation;

$$COBC = FCRxCPUB \quad (11)$$

Where; *COBC* ($\$.h^{-1}$) is the cost of hourly biofuel consumption in gasification and *FCR* ($kg.h^{-1}$) is the fuel consumption rate of the biomass gasification unit.

2.4.2. Calculation of operating costs of gasifier

Operating costs of gasifier was calculated by determining the energy consumption of electric motors used in the system.

The electric motor which runs the ash removal screw works 20% of total operating time. In the calculations for this situation have been taken into consideration.

The energy cost of vacuum pump's electric motor;

$$ECVP = PVPxUEP \quad (12)$$

The energy cost of cooling fan's electric motor;

$$ECCF = PVCxUEP \quad (13)$$

The energy cost of the electric motor of ash removal screw;

$$ECRS = PRSxUEPxk \quad (14)$$

Where; *k* is the rate of ash removal screw and total operating time.

The labor cost of gasifier;

$$LCG = nxHOC \quad (15)$$

The one employee during the operation of the gasification unit is sufficient.

The hourly cost of the gasification process is calculated with the following equation;

$$HCGP = ECVP + ECCF + ECRS + LCG \quad (16)$$

The total hourly cost of the preparing biofuel and operating gasifier was given below;

$$TC = COBC + HCGP \quad (17)$$

The cost of unit volume of syngas was calculated with the following equation;

$$CUG = \frac{TC}{GFR} \quad (18)$$

Where; *GFR* ($Nm^3\ h^{-1}$) is the gas production rate of the gasifier. GFR was almost 35.1 $Nm^3.h^{-1}$.

The unit energy cost of syngas was calculated with the following equation;

$$CEG = \frac{3{,}6\ xCUG}{LHV_g} \quad (19)$$

Where; *CEG* ($\$.KWh^{-1}$) is the unit energy cost of syngas, LHV_g ($MJ.Nm^{-3}$) is lower heating value of syngas.

III. RESULTS

3.1. The lower heating value of syngas

In the end of syngas analysis with GC, the lower heating value of syngas was calculated as average 4.43 $MJ.Nm^{-3}$.

3.2. The cost of preparing of the biomass

The costs of preparing of the biomass were given in Table 3. Total cost of preparing of the unit biofuel (CPUB) and the cost of hourly biofuel consumption in gasification process (COBC) were 0.131 $\$.kg^{-1}$ and 2.67 $\$.h^{-1}$, respectively.

Table 3. The cost of preparing of the biomass

Shredding	
Hourly Energy Cost (CS)	1.01$\$.h^{-1}$
Hourly Labor Cost (LCS)	6.84 $\$.h^{-1}$
Total (TCS)	7.85 $\$.h^{-1}$
Cost of unit biomass (SCUB)	0.079 $\$.kg^{-1}$
Pelletizing	
Hourly Energy Cost (CPL)	1.01 $\$.h^{-1}$
Hourly Labor Cost (LCP)	6.84 $\$.h^{-1}$
Total (TCP)	7.85 $\$.h^{-1}$
Cost of unit biomass (PCUB)	0.052 $\$.kg^{-1}$
Total cost of preparing of the unit biofuel (CPUB)	
0.131 $\$.kg^{-1}$	
The cost of hourly biofuel consumption in gasification process (COBC)	
2.67 $\$.h^{-1}$	

3.3. The Operating costs of gasifier

The operating costs of the gasifier were given separately for each unit in Table 4. The hourly cost of the gasification process (HCGP) was calculated 3.57 $\$.h^{-1}$.

Table 4. Operating costs of gasifier

The energy cost of vacuum pump's electric motor (ECVP)	0.10 $\$.h^{-1}$
The energy cost of cooling fan's electric motor (ECCF)	0.04 $\$.h^{-1}$
The energy cost of the electric motor of ash removal screw (ECRS)	0.01 $\$.h^{-1}$
The labor cost of gasifier (LCG)	3.42 $\$.h^{-1}$
The hourly cost of the gasification process (HCGP)	3.57 $\$.h^{-1}$

Using the above values, the total hourly cost of the preparing biofuel of operating gasifier (TC) and the cost of unit volume of syngas (CUG) was calculated 6.24 $\$.h^{-1}$ and 0.18 $\$.Nm^{-3}$, respectively.

The unit energy cost of syngas (CEG) was calculated as0.146 $\$.KWh^{-1}$.

IV. DISCUSSION

The cost per unit energy of syngas was found 0,146 $\$.kWh^{-1}$ in economic analysis of gasification process. The most important part of biomass preparation costs comprise the cost of labor. In our research, this value is almost 87%. Previous studies also were reported to be high labor costs in the gasification process [6]. In our micro-scale gasifier, there are 2 workers in the process of preparing biomass. In case of biomass preparation units combined and equipped with automation, the labor costs per unit mass will be significantly reduced.

The LPG cost used in residential and rural area in our country is average 0,164 $\$.kWh^{-1}$.This shows that after paying off the investment costs of the gasification system, obtained syngas can easily compete with LPG.

V. CONCLUSION

The capacity of gasification unit used in this research is micro-scale, since the energy cost of syngas has been a bit high. For commercial purposes to be established in large enterprises, this cost will be reduced. Evaluation of rice straw as a source of energy, will provide a major contribution to the country's economy.Also, adverse environmental conditions that arise by the burning of the rice stalks on the field will be prevented. Therefore, the establishment of gasification plants with the largest capacity in the region should be encouraged.

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