Application of Biomass Gasification System as a Sustainable Energy Technology to Improve Efficiency and Reduce Smoke Emission from Sterilization of Mushroom Growing Substrates

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Abstract: - Mushroom growing substrate is generally derived from waste biomass or agricultural residues. Spent substrate is high energy content by-product from mushroom cultivation where it can potentially replace fuelwood for hot steam generation. However, direct burning of spent substrate is troublesome due to low efficiency and excessive smoke emission. Alternative energy conversion of the by-product should be used instead. In this work, recycling of spent substrates through gasification to provide heat for sterilization of substrate bags has been investigated. From the results obtained, spent substrate was successfully used as fuel in a gasifier. Satisfactory operation was obtained. Gasification of spent mushroom growing substrate could provide required thermal input, with clean fuel to the local mushroom farm. Thermal efficiency of about 20% was achieved, compared to less than 5% from existing furnace. Preliminary economic analysis showed that the farm can save around $300 a month, with simple payback period to positive cash flow of less than 12 months.

Key Words: - Bioenergy system, Efficiency improvement, Mushroom cultivation, Producer gas, Recycle, Renewable energy, Waste management

1 Introduction

Mushroom growing is increasingly becoming popular in Thailand as a means to generate income, improve quality of life for rural people and promote sustainable development in local communities. Examples of commercially cultivated mushrooms in Thailand are shown in Table 1. Mushrooms are typically grown in wooden logs, compost beds, or biomass substrate bags. Some mushrooms such as oyster, abalone, yanagi and shiitake mushrooms are normally grown in substrate bags.

Table 1: Commercial mushrooms in Thailand [1]

Common name (latin name)	Market price ($/kg) *
Oyster mushroom (*Pleurotus ostreatus*)	0.99-1.31
Abalone mushroom (*Pleurotus cystidiosus*)	2.30-2.63
Shiitake (*Lentinula edodes*)	5.25-5.91
Yanagi (*Agrocybe cylindracea*)	8.21-9.85
Parasol mushroom (*Macrolepiota gracilenta*)	13.0-16.5
King oyster mushroom (*Pleurotus eryngii*)	6.57-8.21
Straw mushroom (*Volvariella volvacea*)	2.96-3.94
Button mushroom (*Agaricus bisporus*)	2.63-3.94
Silver ear (*Tremella fuciformis*)	9.85-11.5
Wood ear (*Auricularia auricula*)	0.99-1.64
Reishi (*Ganoderma lucidum*)	33.0-50.0

* ($1.00 = 30.45 Thai Baht, exchange rate on March 2011)

For mushrooms cultivated in bags (Fig. 1), equipments including mixer, bagging machine, compacting machine, steam generator, and sterilizing autoclave are required. Common bag preparation method involves (i) mixing of sawdust, rice bran and gypsum with water content in the range of 60-65%; (2) filling and compacting the mixtures in the plastic bags; (3) sterilizing the substrate bags with hot steam at 90-100^{o}C for 3-4 h in a closed autoclave; (4) cooling down and ready to inoculate with mushroom spawn.

Thermal energy is provided from wood burning. This process is energy-intensive, consuming large amount of wood, but spent substrates are available in abundance. At present, they are discarded. Some is burnt as a means for waste management. The burning of these by-products has serious socio-environmental impacts including emissions of greenhouse gases, smoke, and tars, leading to complaints from neighbors. There were attempts to substitute wood by spent substrates. However, direct firing of spent substrates in furnaces, semi open pits, and other open burning application is rather poor. Combustion efficiency is low with high smoke emission, and process control is limited. Alternative utilization method is therefore needed [2-5].

Gasification offers optional conversion technology for the biomass residues available that has high thermal efficiency and environmental acceptability. Utilization of farm processing wastes into energy increases the value of agricultural output and reduces the operational cost. The technology is relatively economical for use in small scale enterprises and in rural areas. Many types of biomass gasifiers have been developed and installed for agricultural residues [6-9]. Generation of gaseous fuels from solid materials makes gasification very appealing. Gasification is a thermochemical processing of a solid into a fuel gas known as producer gas. Reactions involved include pyrolysis, oxidation and reduction, which produce combustible gases like CO, H_2 and HCs.

In this work, spent substrates from bag-type mushroom cultivation have been utilized as a source of sustainable energy via gasification. A simple downdraft fixed bed gasifier system was developed. It was installed and operated at a local mushroom farm, with the aims to reduce operating cost of current sterilization practice by utilizing by-products, and to demonstrate a cost effective and practical producer gas burner to provide process heat with appropriate gasification technology. Experimental data obtained from the operation were presented. Analysis of its energy use and operating cost was conducted, and compared with existing system from conventional practice.

2 Methodology

The farm is in Khon Kaen, Thailand. This small enterprise does not only produce mushrooms, it also supplies ready-to-fruit substrate bags to neighboring farms and people. Its hot steam is generated from a water tank heated by a locally made furnace, consuming about 9000 kg of fuelwood a month. This costs around $300 a month ($1.00 = 30.45 Thai baht, exchange rate on March 2011). Cost of fuelwood tends to increase as supply is becoming difficult. Fuel switching is welcome in order to prevent deforestation problem. Furthermore, the farm is situated near residential area where smoke and emissions may be offensive, especially during cold seasons.

Utilization of spent substrates as replacement fuel via gasification was undertaken in this work. Existing wood fired furnace was modified to accommodate a gasifier and a gas burner. Limited runs were done to evaluate the system performance.

Fig. 1: Typical mushroom growing in substrate bags

2.1 Spent substrate as fuel

A substrate for growing mushrooms was mainly made of compacted sawdust, weighing about 1 kg. After 5-6 months used in cultivation, a spent substrate would be about 0.4 kg on average. Its heating value was about 18 MJ/kg. The shape and size of these substrates can be easily reduced to a uniform block of about 50 mm on each size. Density appeared to be sufficient (above 200 kg/m^3) to be used as a suitable feedstock for gasification.

2.2 Gasification system

A single-stage, downdraft, throat-type, fixed-bed gasifier was designed and built (schematically shown in Fig. 2). The gasifier components included an insulated cylindrical reactor, a rotatable grate, and an ash pit. Loading of fuel feedstock was done from the top, piling on the grate. The reactor wall was made of firebrick and covered with a steel sheet. Air was induced through circumferential holes by a fan downstream. The gasifier core was designed such that a cross section area was reduced downstream of the air inlets to form a throat or constriction. The reactor volume was designed to require recharging once every two hours when working at rated capacity. The grate area of 0.10 m^2 was designed from specific gasification rate of 250 kg/h/m^2 and the fuel feed rate of 25 kg/h. Ash formed was removed from the gasifier by the rotatable grate and fell into a water sealed, ash pit. The volume of the ash pit was sufficiently large to allow long hour operation without ash removal.

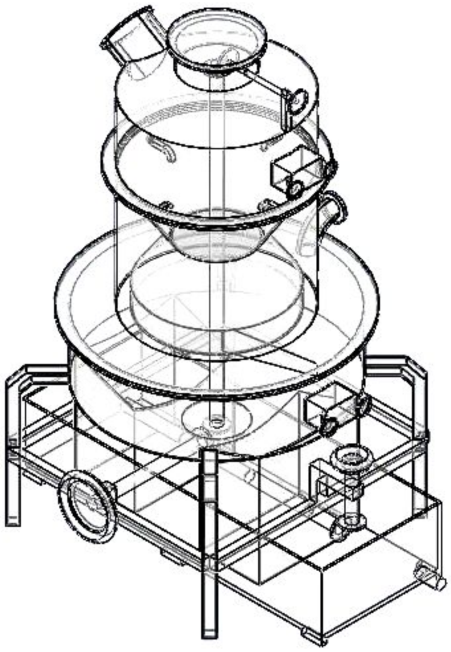

Fig. 2: Schematic drawing of the gasifier

Fig. 3: Configuration of the gasifier system used

The gasification system consists of the gasifier, an induced draft fan, a cyclone and a gas burner. Fig. 3 shows the system setup. Bottom of the main reactor was tightly sealed by water. The gas burner was positioned beneath the existing water tank.

2.3 Test procedure and data analysis

Initially, a small amount of burning charcoal was used to establish a fire on the grate inside the gasification reactor. The induced draft fan was started, drawing air in to sustain combustion. Immediately afterwards, spent substrates were loaded and the cover was closed. Air was regulated by valves in such a way that combustible producer gas was generated. This would take about 20-30 min for a stable flame at the gas burner to be established. Producer gas was utilized to provide hot steam to the sterilizing autoclave.

Limited test runs were performed for water boiling test to evaluate the thermal performance of the system [10]. Measurements were taken by monitoring fuel consumption rate and amount of water used on an hourly basis. The gas flow rate was measured with a volume meter. The cool, dry, clean gas was sampled using gas bags and analyzed on a Shimadzu Model GC-8A gas chromatograph for measuring volumetric concentration of H_2, O_2, N_2, CH_4, CO, CO_2. Standard gas mixtures were used for quantitative calibration. Gas temperature at the gasifier exit and flame temperature were measured every 10 minutes. The following parameters are calculated;

Specific gasification rate:

$$SGR = \frac{fuel\ mass\ \ flow\ rate}{reactor\ cross\ section\ area} \tag{1}$$

Gas production rate:

$$GPR = \frac{producer\ gas\ \ flow\ rate}{reactor\ cross\ section\ area} \tag{2}$$

Gasification efficiency:

$$\eta_{gas} = \frac{producer\ gas\ energy\ content}{fuel\ energy\ content} \tag{3}$$

Overall thermal efficiency:

$$\eta_{th} = \frac{heat\ to\ steam}{fuel\ energy\ input} \tag{4}$$

3 Results and Discussion

Operation and performance of the gasification system are presented first. Then, socio-economic consideration is described.

3.1 System operation and performance

Operators with technical experience were trained to run the system by a team of engineers and technicians. The gasifier was able to start within 15 min and attain steady state operation from cold start in about 30-60 min. The gasification system appeared to operate well and run smoothly without any sign of deterioration or excessive emissions. No tar problem and no visible smoke were observed. Fuel flow obstruction due to bridging, throat or channel formation did not occur. As a precaution, poking at regular interval was undertaken. The gasification system was also found to generate steam faster than the existing solid fueled furnace.

Several test runs on the system were carried out. Producer gas could be ignited successfully in which bright orange flame was established. Gas production rate was found to be about 480 $m^3/h/m^2$. Composition of the producer gas was shown in Table 2. The gaseous fuel's lower heating value was estimated to be 3.73 MJ/m^3. This was in the low end of the documented average gas heating value of producer gas from downdraft gasifier systems [11]. Gasification efficiency was calculated to be 39.5%. About 10-15% of the feed input remained as solid residues, constituting ash. Visual inspection of ash revealed a small fraction of charcoal left. It was normally disposed of with the water seal. No clinkering or agglomeration was encountered.

From steam generated and fuel consumption rates, system thermal efficiency was approximated to be around 20%. Better insulation and better design of steam generator may be implemented to further improve thermal efficiency of the system.

Up to the time of reporting, the system has been in use for over 9 months. Results were consistent throughout the experimental campaign. The operators were satisfied with the installation of the gasifier system in place of existing furnace.

3.2 Economic and social considerations

The economic performance was determined as a simple period to positive cash flow. This involves considering the initial investment and additional operating costs, and the wood fuel cost savings. Positive cash flow is reached when the investment and cumulative operating costs equal to the cumulating fuel cost savings. It should be noted that no discount rate is considered here. The overall installation cost included costs for an induced draft fan, gas burner, refractory and structural materials, piping, insulation, painting, engineering design and construction expenses. The additional operating cost was from maintenance cost and miscellaneous operating materials associated with the gasifier system that would not be present in the wood-fired furnace. The gasifier system required an investment of about $3,400 and an additional operating cost of about $10 a month. Since spent substrates were used to replace all of the fuelwood, saving in fuel cost of approximately $300 a month was obtained. This gave rise to a simple period to positive cash flow of less than 12 months.

Table 2: Composition of producer gas

Component	% v/v
CO	11.55
CO_2	10.27
H_2	9.62
CH_4	3.36
O_2	2.62

Substitution of fuelwood with spent substrates from mushroom cultivation generated less waste. Gasification process and ongoing reactions occur in a closed system. Combustion of producer gas was cleaner than burning of solid fuels. As a result, smoke emission was far less than from previously existing system, hence no more complaints from neighbors are reported. Cleaner workplace environment was realized. There was also skill development among the farm employees who trained to operate the system. The farm can become a demonstration site for mushroom farmers to come and learn from their experience.

4 Conclusion

Potential use of spent substrates as replacement fuel for wood was considered in this study. It was found that they were excellent feedstock for gasification. They have high energy content, similar to fuelwood. The downdraft throat-type gasifier was found to perform satisfactorily with spent substrates in hot steam generation application. Producer gas generated was utilized to fuel a burner at required thermal output rating for sterilization of mushroom growing substrates. Thermal efficiency was significantly improved. No problem during operation was observed. Spent substrates from mushroom cultivation appeared to have potential as a biofuel candidate.

The operators and owner were satisfied with the system. Economic analysis results showed that the gasifier system operation was viable. Simple period to positive cash flow was estimated to be less than a year. Plan is ongoing to implement similar modification to other farms in the region.

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