CHAPTER IV

RESULTS AND DISCUSSION

The results of the experiments were conducted on the major advantage of the oyster mushroom gasification system. In the following section, the experiments will be presented accompanied by brief comments about the results.

1. Preliminary of Oyster Mushroom Substrate Waste Moisture Experiment

The moisture content of fresh oyster mushroom substrate waste is normally very high (40-60% wb). This causes untreated waste to have a low heating value. These properties can be improved by preheating the waste. This waste can be pre-store and dried in natural sun dry, which the necessary pretreatment equipment may not be used. Also local farmers themselves can carry out this pretreatment. The results are discussed below.

Figure 23 shows the variation of (%) moisture content (% wb, % db) against time of natural sun dry. In this experiment, 50 clusters of fresh oyster mushroom substrate waste are used for the example. It can be observed that the (%) moisture contents reduce with increase time of natural sun dry in clear sky. It can be observed that good agreements exist the (%) moisture content about 13.43 % wb (15.52 % db) at time of natural sun dry 4 days is the critical point and after 4 days (wet basis) dried nearly constant. For the fuel specification for downdraft gasifier as given by Kjellstrom [15], the moisture content should be below 20 to 30 % wb. In this experiment, it can be reasonably started to uses the oyster mushroom substrates waste, natural sun dry 4 days as biomass fuel for downdraft gasifier. As well as the lower percentage of moisture content were conducted to the more advantage for downdraft gasifier.

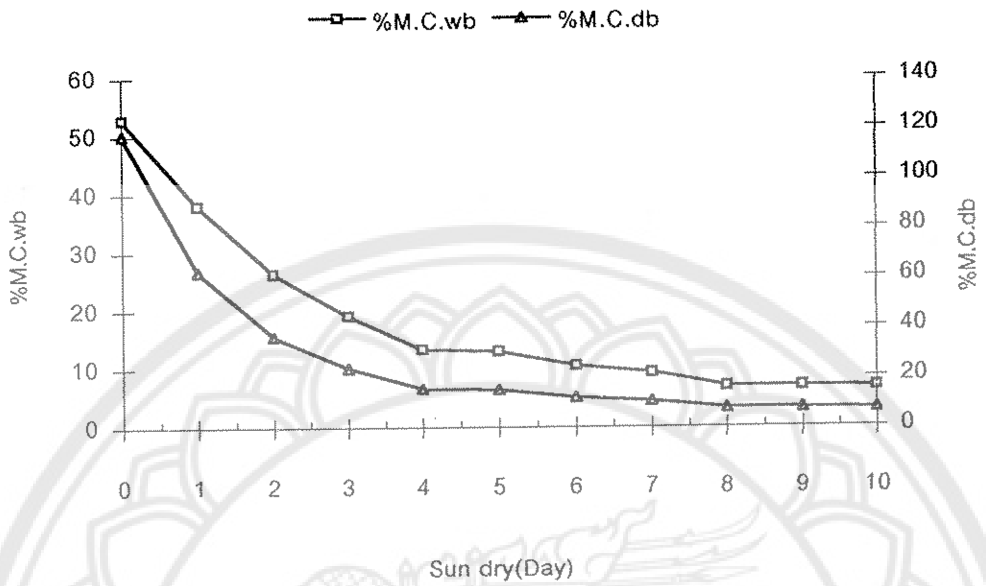

Figure 23 The Variation of (%) Moisture Content Against Time of Natural Sun dry

2. The Variable Airflow Rate Experiments Results

The experiments of a producer gas production at difference airflow rate, the three difference airflow rates are set at $3x10^{-3}$, $5x10^{-3}$ and $7x10^{-3}$ m^3/s of testing time 300 min for each flow rate. 35 kg of oyster mushroom substrate wastes are used as feedstock. The gasifier temperature is recorded every 20 min. A producer gas composition is analyzed by gasifier simulation program [22].

2.1. Airflow rate at $3.0x10^{-3}$ m^3/s

After testing, 15.51 kg of fuel is remained. The consumption rate is 3.89 kg/hr. The maximum combustion zone temperatures and reduction zone temperature are 912.2 °C and 749.8 °C, respectively.

A Producer gas compositions that analysis by gasifier simulation program, CO, CH_4 and H_2 are 18.01 %, 0.26 % and 0.04 %, respectively. Figure 24 shows the relationships between time with gasifier temperature at airflow rate $3.0x10^{-3}$ m^3/s. From the results obtained, it is observed that the combustion temperature conducted to the reduction temperature that the reduction temperature was varied proportionally with combustion temperature.

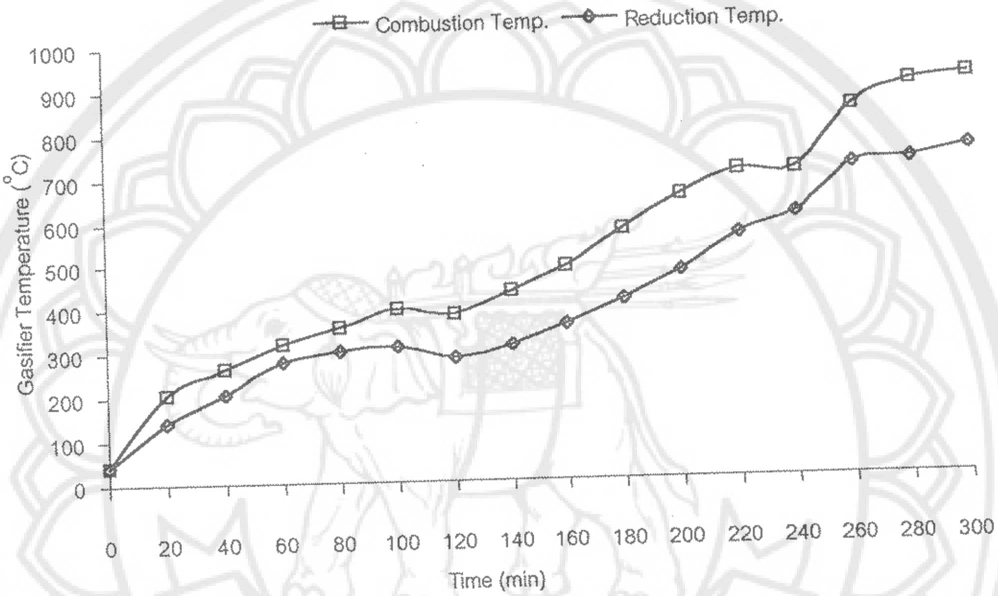

Figure 24 Relationships between Time Vs Gasifier Temperature at Airflow rate $3.0x10^{-3}$ m^3/s

2.2. **Airflow rate at $5.0x10^{-3}$ m^3/s**

After testing, 9.95 kg of fuel is remained. The consumption rate is 5.01 kg/hr. The maximum combustion zone and reduction zone temperatures are 954.7 °C and 759.4 °C, respectively. A Producer gas compositions that analysis by gasifier simulation program, CO, CH_4 and H_2 are 23.04 %, 0.28 % and 0.05 %, respectively. From the results obtained, it is observed that the combustion temperature conducted to the reduction temperature. The reduction temperature was varied proportionally with combustion temperature. Figure 25 shows the relationships between time with gasifier temperature at airflow rate 5.0x10^{-3} m^3/s.

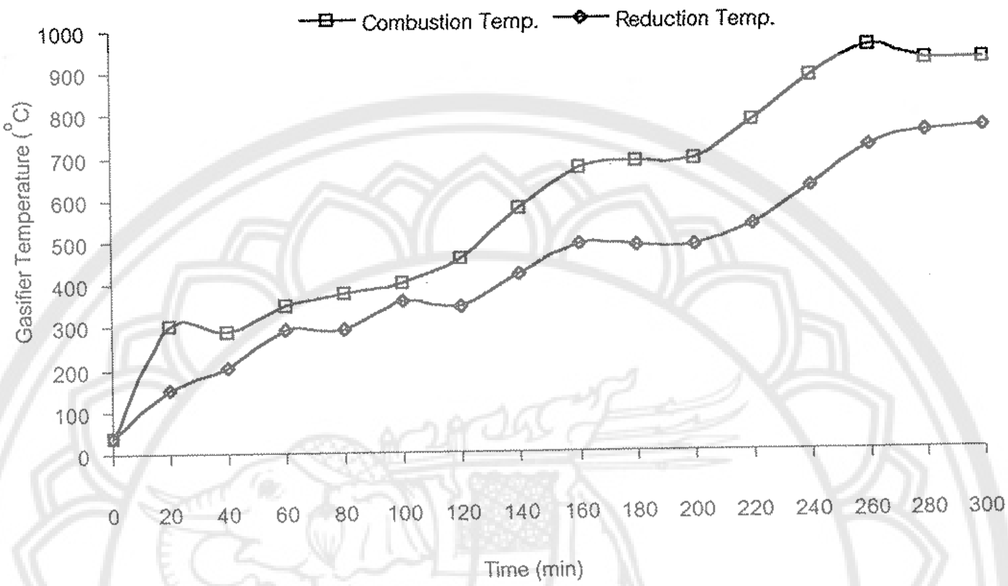

Figure 25 Relationships between Time Vs Gasifier Temperature at Airflow rate 5.0x10^{-3} m^3/s

2.3. Airflow rate at 7.0x10^{-3} m^3/s

After testing, 2.75 kg of fuel is remained. The consumption rate is 6.45 kg/hr. The maximum combustion zone and reduction zone temperatures are 977.1 °C and 798.5 °C, respectively. A Producer gas compositions that analysis by gasifier simulation program, CO, CH_4 and H_2 are 25.12 %, 0.30 % and 0.06 %, respectively.

Figure 26 shows the relationships between time with gasifier temperature at airflow rate 7.0x10^{-3} m^3/s. From the results obtained, it is observed that the combustion temperature conducted to the reduction temperature that the reduction temperature was varied proportionally with combustion temperature. The time at 100 min the combustion temperature dropped because the fuel flows not continuously. When an auger screw fuel flow control is operated the combustion temperature risen up.

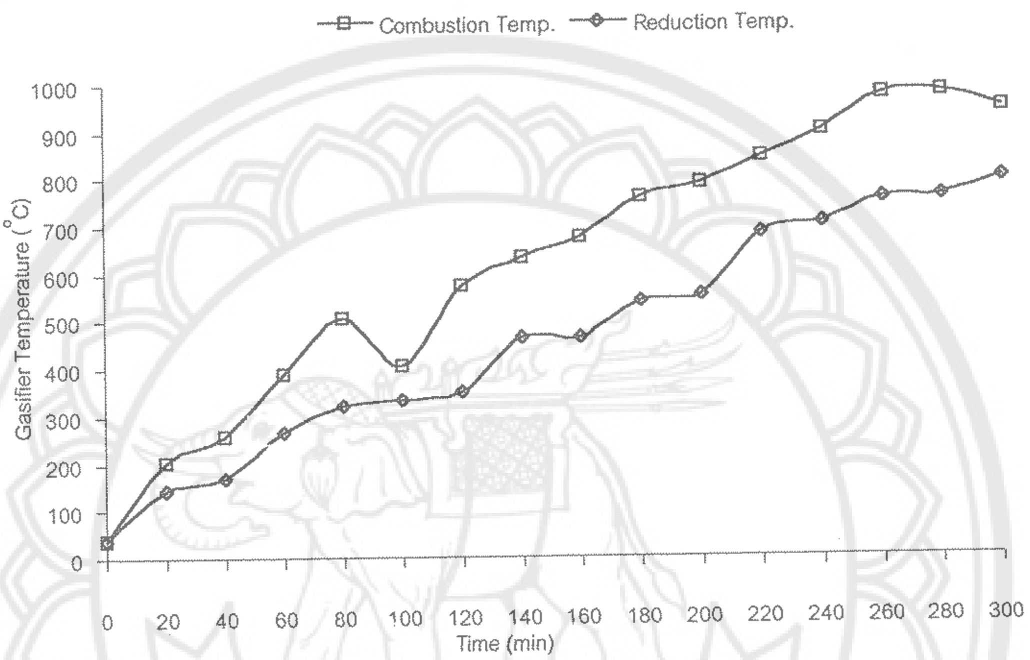

Figure 26 Relationships between Time Vs Gasifier Temperature at Airflow rate $7.0x10^{-3}$ m^3/s

Table 3 Details Combustible Gas Total heating value of gas and Different Airflow rate

Airflow Rate (m^3/s)*	Fuel Consumption Rate (kg/hr)	Combustion Temp (°C)	Reduction Temp (°C)	Combustible Gas (%)			Total Heating value of gas (MJ/Nm^3)
				CO	CH_4	H_2	
$3.0x10^{-3}$	3.89	901.5	749.8	18.01	0.26	0.04	3.76
$5.0x10^{-3}$	5.01	920.4	779.2	23.04	0.28	0.05	3.81
$7.0x10^{-3}$	6.45	977.1	798.5	25.12	0.30	0.06	4.34

*At 30 °C 1 atm

Table 3 is shown the details of the fuel consumption rate, the combustion temperature, the reduction temperature, the compositions of combustible gas and the total heating value of gas. The compositions of combustible gas and the heating value of gas are analyzed by gasifier simulation program [23]. The important combustible gas, CO, CH_4 and H_2 are corresponding to airflow rate, the increasing airflow rate, the important combustible gas are increased. The most important combustible gas of gasifier is CO. It is found that the highest CO is generated at $7.0x10^{-3}$ m^3/s, then $5.0x10^{-3}$ m^3/s and $3.0x10^{-3}$ m^3/s, respectively. The total heating value of gas is responding to airflow rate, the increasing airflow rate, the high total heating value of gas is increased. The fuel consumption rate is determined, it can be found that the variable of fuel consumption rate is corresponding to airflow rate, the increasing airflow rate, the fuel consumption rate is increased. Comparison between the three difference airflow rates, the highest fuel consumption rate is generated at $7.0x10^{-3}$ m^3/s, then $5.0x10^{-3}$ m^3/s and $3.0x10^{-3}$ m^3/s, respectively. In this thesis the fuel saving is conducted to gasifier advantage designing. Based on the above results, at $7.0x10^{-3}$ m^3/s airflow rate, a higher fuel consumption rate and CO yield, while $3.0x10^{-3}$ m^3/s airflow rate quite lower combustion temperature and CO yields. Hence, in this thesis, at $5.0x10^{-3}$ m^3/s airflow rate will be used for downdraft gasifier to run the oyster mushroom products processes.

3. Sterilization and Pasteurization experiments Results

According to the experiment procedure, the experiments are divided into 2 parts, part 1 to study a producer gas utilization for oyster mushroom agar media sterilization and part 2 to study a producer gas utilization for oyster mushroom substrate pasteurization.

3.1. Agar Media Sterilization Experiments

The experiments of agar media sterilization, the agar media are contained in autoclave. The autoclave is heat by downdraft gasifier at the conditions, 15 lb/in^2 (1.03×10^5 N/m^2) pressure, and 121 °C at least 30 min. The downdraft gasifier temperature, combustion zone temperature, reduction zone temperature, autoclave temperature and autoclave pressure are recorded every 20 min for data collection and analysis.

Table 4 Details of Oyster Mushroom Agar Media Sterilization Experiments

Experimental Number	Fuel Consumption Rate (kg/hr)	Combustion Temp (°C)	Reduction Temp (°C)	Time (min)	Sterilization Condition	
					Final Pressure (lb/in^2)	Final Temp (°C)
1	3.16	962.9	726.4	300	16	122.2
2	3.29	912.4	701.5	300	15.5	121.7
3	3.80	984.3	702.6	300	16	122.2

The oyster mushroom agar media sterilization is set at 3 times of experiments to investigate the parameters. The working time is set at 300 min/batch. The details of oyster mushroom agar media sterilization experiments are shown in Table 4. It can be found that the oyster mushroom agar media sterilization by using downdraft gasifier, the results are quite good in sterilization condition, which can operate sterilization. The final temperature of experiment No 1, No. 2 and No. 3, are 122.2, 121.7 and 122.2 °C, respectively. The final pressure of experiments No. 1, No. 2 and No. 3, are 16 lb/in^2, (1.10x10^5 N/m^2), 15.5 lb/in^2 (1.07x10^5 N/m^2) and 16 lb/in^2, (1.10x10^5 N/m^2), respectively. It can be found that the variable of fuel consumption rate is corresponding to airflow rate, the increasing airflow rate, the fuel consumption rate increased. For the experiment No. 2, compared to the experiments No.1 and No. 3, the combustion temperature No. 2 is the minimum but also can operate on the sterilization condition.

Figure 27 and 28 shows the relationships of combustion temperature, sterilization temperature and airflow rate with time of experiment No. 1. It can be found that at 531.7 °C of combustion temperature conducted to the sterilization temperature and sterilization pressure are 121.7°C and 15.5 lb/in^2 (1.07x10^5 N/m^2), respectively.

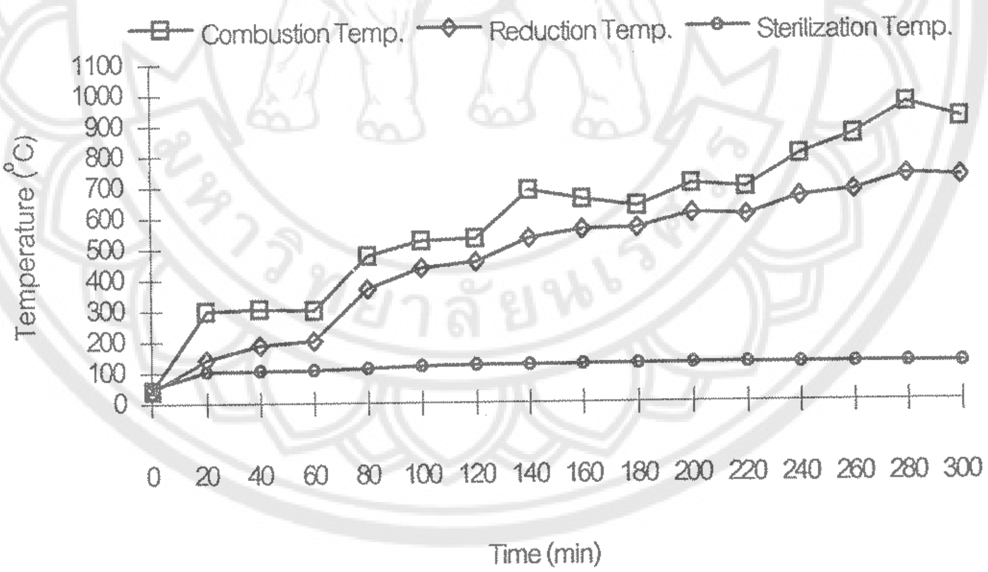

Figure 27 Relationships between Gasifier Temp and Sterilize Temp with Time of Sterilization Experiment 1

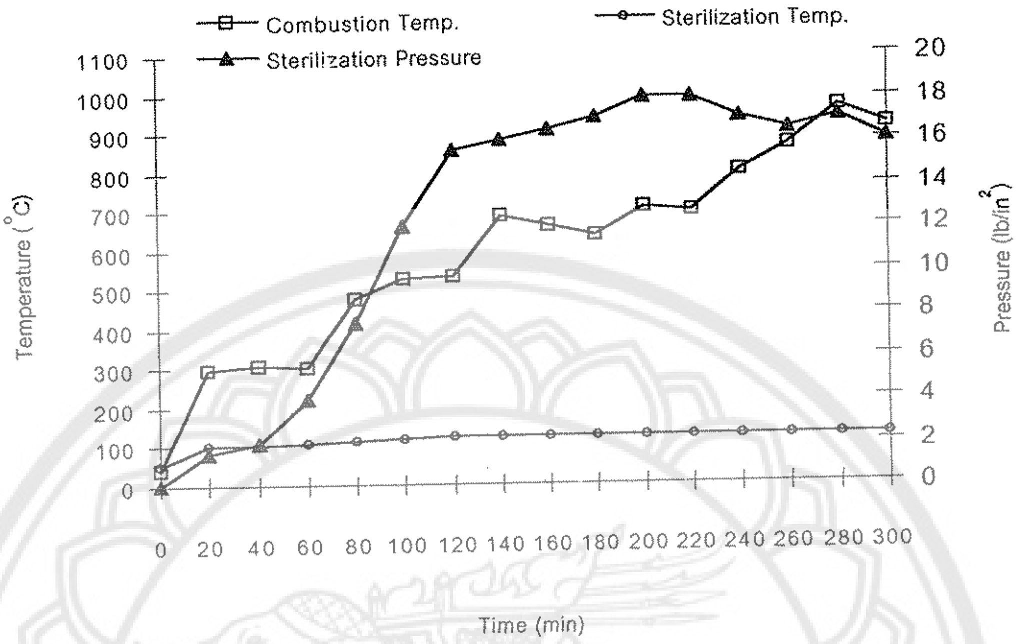

Figure 28 Relationships between Temp and Sterilize Pressure with Time of Sterilization Experiment 1

Comparison between experiments No.2 that shows in Figure 29, 30 and the experiments No.3 that shows in Figure 31, 32, at 514.3 °C and 556.7 °C of combustion temperature experiments No.2 and the No.3 conducted the sterilization temperature and sterilization pressure are 121.7 °C, 15.5 lb/in^2 (1.07x10^5 N/m^2) and 122.2 °C, 16 lb/in^2 (1.10x10^5 N/m^2), respectively. It can be found that the time that can be operated sterilization condition (121 °C, 15 lb/in^2 (1.03x10^5 N/m^2)) of experiments No.1, No. 2 and No. 3 are 120, 100 and 120 min, respectively.

The sterilization pressure of experiments No.1, No.2 and No.3 are controlled by autoclave valve release, the results that show in Figure 28, 30 and 32 quite constant.

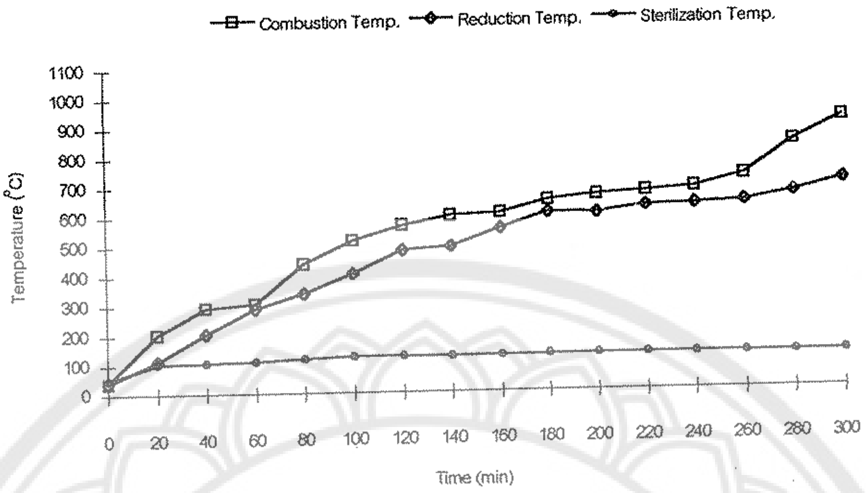

Figure 29 Relationships between Gasifier Temp and Sterilize Temp with Time of Sterilization Experiment 1

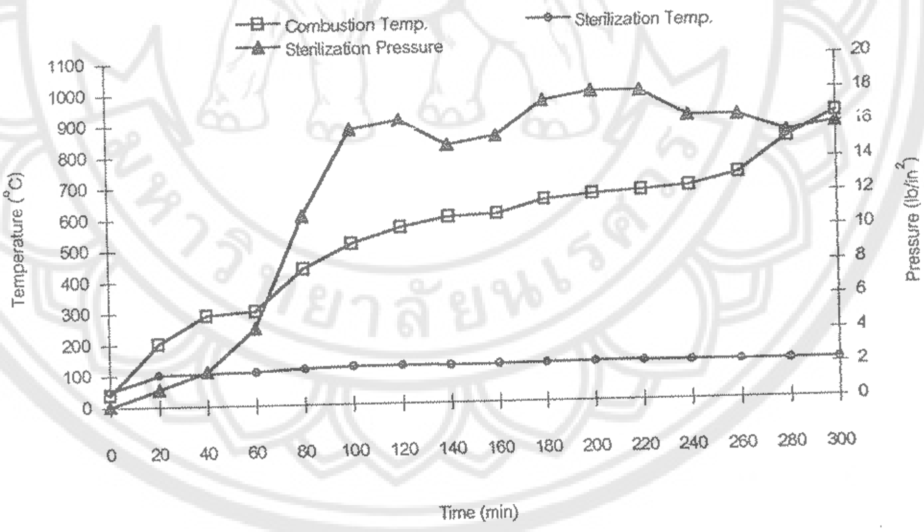

Figure 30 Relationships between Temp and Sterilize Pressure with Time of Sterilization Experiment 2

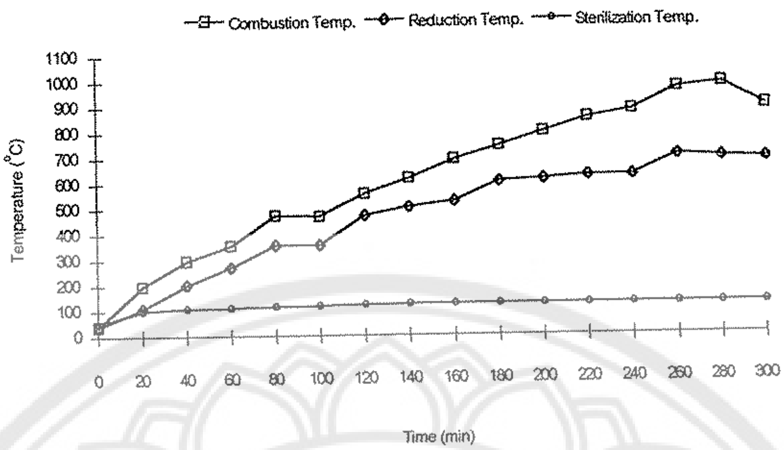

Figure 31 Relationships between Gasifier Temp and Sterilize Temp with Time of Sterilization Experiment 3

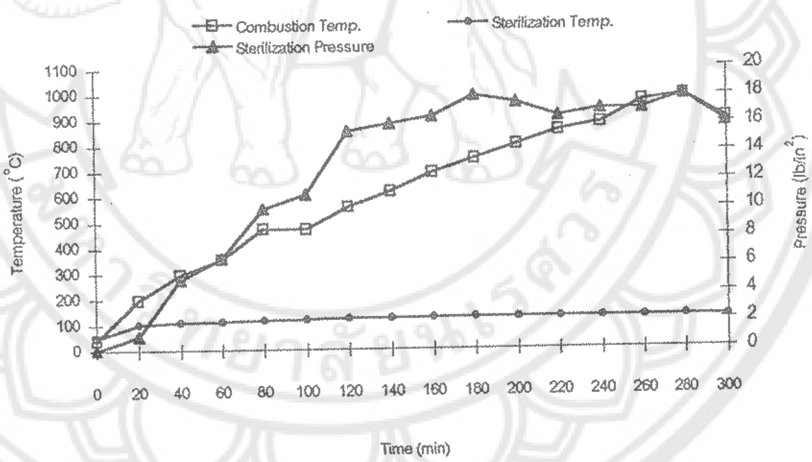

Figure 32 Relationships between Temp and Sterilize Pressure with Time of Sterilization Experiment 3

3.2. Oyster Mushroom Substrate Pasteurization Experiments

The experiments of the oyster mushroom substrate pasteurization, the oyster mushroom substrates are contained into the pasteurization tank with 20 liter of clean water. The downdraft gasifier is stared to heat the oyster mushroom substrate in the pasteurization tank on the condition that the temperature of water in the pasteurization tank is 100 ° C at least 120 min. The temperature in combustion, reduction, drying zone and pasteurization temperature are recorded every 20 min for data collection and analysis.

Table 5 Details of Oyster Mushroom Substrate Pasteurization Experiments

Experimental Number	Fuel Consumption Rate (kg/hr)	Combustion Temp (°C)	Reduction Temp (°C)	Time (min)	Pasteurization Temp (°C)
1	3.42	902.4	702.3	300	100
2	3.64	938.6	711.6	300	100
3	3.75	987.6	809.4	300	100

The oyster mushroom substrate pasteurization is set at 3 times of experiments to investigate the parameters. The testing time is set at 300 min/batch. The details of oyster mushroom substrate pasteurization experiments are shown in Table 5. It can be found that the oyster mushroom substrate pasteurization by using downdraft gasifier, the results are quite good, which can be operated pasteurization condition (100 °C, at least 120 min). The final temperature of experiments No 1, No. 2 and No. 3, are same results, 100 °C. The fuel consumption rate is determined, it can be found that the variable of rate airflow rate is corresponding to fuel consumption rate, the increasing airflow rate, the fuel consumption rate increased. For the experiment No. 1, compared to the experiment No. 2 and No. 3, the combustion temperature No. 1 is the minimum but also can operated on the pasteurization condition. Figure 33, 34 and 35 show the relationships of combustion temperature, pasteurize temperature and airflow rate with time of experiments No. 1, No.2 and No. 3. It can be found that at the combustion temperature of experiments No. 1, No.2 and No. 3 are 902.4, 938.6 and 987.6 °C, respectively. It can be found that the time that can be operated pasteurize condition of experiments No.1, No. 2 and No. 3 are 100, 120 and 100 min, respectively.

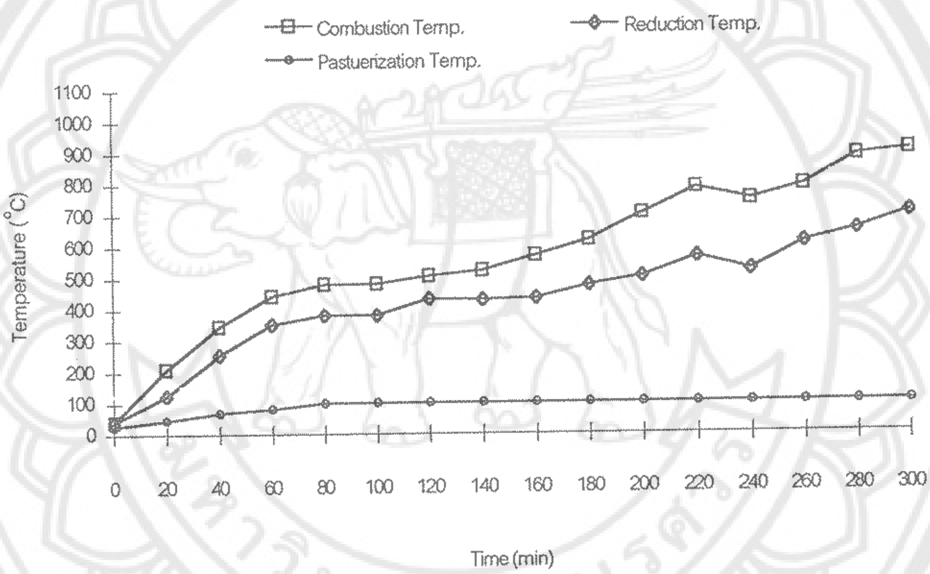

Figure 33 Relationships between Gasifier Temp and Pasteurize Temp with Time of Pasteurization Experiment 1

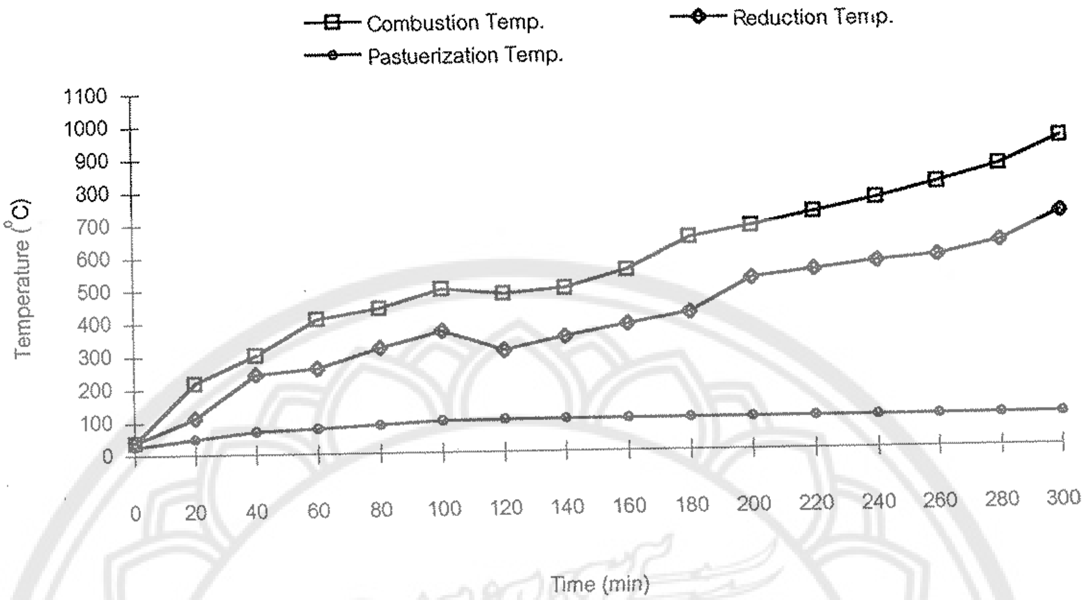

Figure 34 Relationships between Gasifier Temp and Pasteurize Temp with Time of Pasteurization Experiment 2

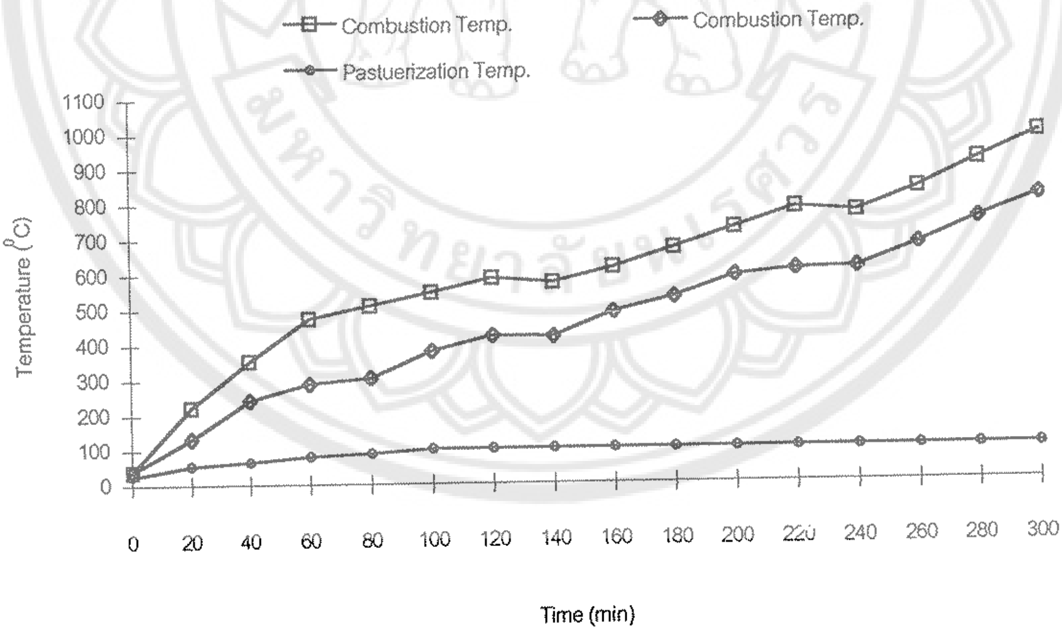

Figure 35 Relationships between Gasifier Temp and Pasteurize Temp with Time of Pasteurization Experiment 3

4. Financial Analysis

The methods for estimating the calculating the simple payback of the oyster mushroom substrate waste gasification system are shown as following.

4.1. Method and Results

In order to perform the calculation, the following data are required and the necessary assumptions are made.

Assumptions:

1. The economic life of the system	10	years
2. The rate of interest for economic life of the system	10	%
3. The escalation rate	4	%
4. The capital cost of the system (overall)	50,000	Baht
5. The annual operating and maintenance cost	5 %	of capital cost
6. The cost of electricity (at 2004-04-20) for blower of downdraft gasifier	2.47	Baht/kWh

(1 batch (1 pasteurize batch and 2 sterilize batch) used electricity 3.5 kWh)

7. No savage value
8. Negligible labor cost (carried out by family member)

Primary condition:

1. The capital cost of the gasifier system (overall)	50,000	Baht
2. The annual operating and maintenance cost	2,500	Baht
3. The cost of electricity for blower of downdraft gasifier (300 batch/year)	2,594	Baht
4. The cost of LPG (at 2004-04-20)	14.80	Baht/kg
5. The cost of LPG used for 600 sterilizes batch/year (Sterilization LPG used = 0.9 kg/ sterilize batch)	7,992	Baht/year

6. The cost of LPG used for 300 pasteurizes batch/year
(Pasteurization LPG used = 2.1 kg/ pasteurize batch) 9,324 Baht/year

4.2. The equation for calculating payback period

The future amount is calculated from the equation (15).

$$F_n = \frac{(1+i)^n - 1}{i} \qquad (15)$$

When

F_n = Future amount

i = interest rate

n = number of year

For the present value is calculated from equation (16).

$$PW = CI + \sum_{i=1}^{n}[F_n/(1+i)^n] \qquad (16)$$

When

PW = Present value

CI = Present amount

F_n = Future amount

i = interest rate

n = number of year

The present values of economic analysis cost of the oyster mushroom substrate waste gasification are shown in Table 6.

Table 6. The economic analysis of the oyster mushroom substrate waste gasification

(Escalation rate = 4 %) UNIT:Baht

Year	System cost	O&M cost	Electricity cost for blower	Total	Present value
0	50,000	-	-	50,000	50,000
1	-	2,500	2,594	5,094	4,631
2	-	2,600	2,698	5,298	4,378
3	-	2,704	2,806	5,510	4,139
4	-	2,812	2,918	5,730	3,914
5	-	2,925	3,035	5,959	3,700
6	-	3,042	3,156	6,198	3,498
7	-	3,163	3,282	6,446	3,308
8	-	3,290	3,414	6,703	3,127
9	-	3,421	3,550	6,971	2,957
10	-	3,558	3,692	7,250	2,795

Total Value 86,448

4.3. The simple payback period

The energy saving cost for oyster mushroom agar media sterilization and substrate pasteurization by using gasifier substrate waste system instead LPG system. When LPG 1 kg = 14.80 Baht (at 2004-04-20)

For sterilization 600 sterilize batch/year = 600 × 13.32

= 7,992 Baht/year

(1 sterilize batch using LPG 0.9 kg/batch, saving 13.32 Baht)

For pasteurization 300 pasteurize batch/year = 300 × 31.08

= 9,324 Baht/year

(1 pasteurize batch using LPG 2.1 kg/batch saving 31.08 Baht)

Total energy saving cost = 7,992 + 9,324 = 17,316 Baht/year

The present values of energy saving cost of the oyster mushroom substrate waste gasification are shown in Table 7. (Escalation rate 4%)

Table 7 Present Values of Energy Saving Cost of Gasification System

Year	Energy saving (Baht)	Present value (Baht)
1	17,316	15,742
2	18,009	14,883
3	18,729	14,071
4	19,478	13,304
5	20,257	12,578
6	21,068	11,892
7	21,910	11,243
8	22,787	10,630
9	23,698	10,050
10	24,646	9,502
	Total Value	123,896

For the simple payback period based on an estimated operational life of ten years and the energy saving is concerned. The payback period of the oyster mushroom substrate waste gasification is calculated to be 5 years. The results are shown in Figure 36, this mean that the energy saving by the oyster mushroom substrate waste gasifier system that using substrate waste substitute LPG is considered reasonable when the present value cumulative energy saving cost equal the present value of cumulative system cost. The present value energy saving cost of ten year is 123,896 Baht.

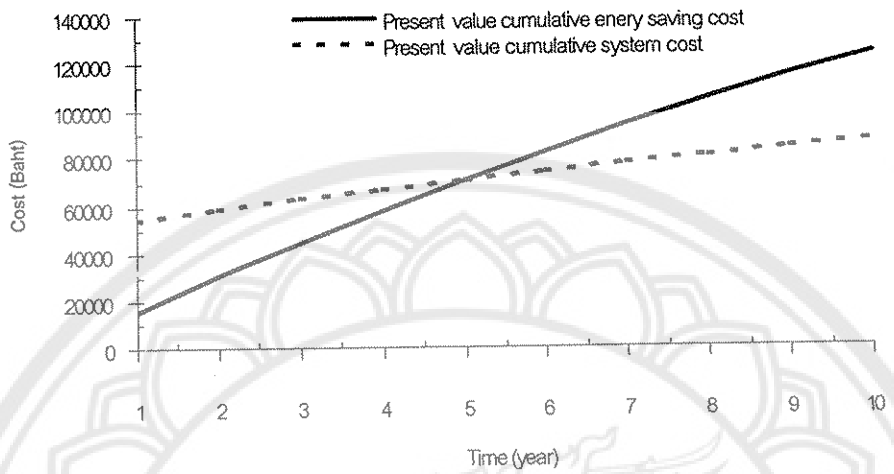

Figure 36 Evaluation of Payback Period in the Oyster Mushroom Substrate Waste Gasifier System