International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2017; 5(4): 1875-1879

Received: 03-05-2017
Accepted: 04-06-2017

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Characterization, evaluation and optimization of a renewable energy based cold storage unit using biomass gasification, solar thermal energy and waste to heat energy technologies

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Abstract
This paper mainly deals with Characterization, evaluation and optimization of a cold storage using Biomass gasification and solar thermal technology with engine exhaust (waste energy) as complimentary input. Besides providing cold storage to farmers through waste heat generated through engine exhaust and solar thermal technology, electricity was also generated through biomass gasification. Farmers economy can be only developed through management of post-harvest losses and cold storage is most important for preservation of perishable items as well as agricultural/horticultural products besides dairy products and allied sectors. This hybrid system is installed at National Institute of Solar Energy, Ministry of New and Renewable Energy (MNRE). A downdraft gasifier (capacity 70 kg/hr.) has been installed to generate Producer gas which operates 50 kwe gas engine–generator generate electricity, and the exhaust of the Gas-engine is recovered with Heat Recovery system (HRU), And utilized for Cooling in cold storage plant by the method of Vapour Absorption Machine (VAM)..

Keywords: Characterization, evaluation, optimization, renewable energy, biomass gasification

1. Introduction

Inadequacy of energy supply adversely affects vital and essential requirements of any society. In India, while urban centres can be connected to central power grid, it is the rural areas that are facing the energy challenge. A large number of people in our villages do not have access to energy. Apart from supply shortage in remote locations, difficult terrain and forested area of several villages makes it difficult to connect them to the main power grid. It appears, therefore that these barriers can only be overcome by decentralized renewable energy for electrifying such villages that will also help in their economic and social development. To meet the rising demand of energy for overall development of the country simultaneously, it is also laying great emphasis on developing renewable energy as a sustainable solution. More than 40% of the population has little or no commercial energy access for their living and livelihoods. [1] Others with access often have to cope with poor and erratic availability. Not only is this a basic human need for quality of life but it constraints generation of productive activities and incomes and employment in rural areas which has itself become a critical factor in India's future development process. Further, the little supply that comes in such areas is from the use of kerosene for lighting and diesel for powering irrigation pumps and small enterprises. Almost all the agricultural and horticulture produce is concentrated in these rural areas and these areas in itself feed other non-agricultural based areas (rural areas). India’s horticultural production was about 283 million tonnes in the year 2015-16 [2] Because of the country's lack of adequate cold storage facilities and refrigerated transport, the value of fruits, vegetables and grains wastage in India at INR 440 billion annually. [3] Fruits and vegetables account for the largest portion of that wastage. Eighteen per cent of India’s fruit and vegetable production valued at INR 133 billion is wasted annually [4]. Horticulture provides 6.5% of the country’s GDP, 14% of employment and accounts for more than 11% of Indian exports with only 9% crop acreage. [5] While India’s agricultural production base is quite strong, wastage of agricultural produce is massive. It is estimated that, due to a lack of proper storage and transit facilities, about 22% of agricultural produce, especially fruit and vegetables, is spoiled. The wastage in fruit and vegetables is estimated to be worth about Rs.330 billion. [6] India, therefore, has tremendous growth potential with respect to rural-based food processing.

These technology solutions, range from multi-commodity cold storage facilities to controlled atmosphere storage to advanced ripening chambers that can reduce operating costs, protect and improve food quality, and be more energy efficient. The cold storage facilities for India‟s agricultural produce are short by more than 10 million tons. Additionally the energy expenses account for 28% of costs in cold storages. [7] A report commissioned by the Planning Commission of India to study the reasons for post-harvest losses in UP and Bihar points to lack of reliable power supply in these states. It also underlines that the larger cold storages located in city centers have been built primarily to store potatoes. Moreover, the greater the distance between the rural producer and the markets, the greater is the risk of post-harvest deterioration. Hence there is a need for small cold storages near the agricultural fields itself. This will reduce the transportation cost and as a result more farmers will be encouraged to use this facility. But the fact remains that a majority of India's villages are unelectrified and most of the electrified villages receive very little power supply during off-peak hours.

3. System Descriptions

The Solar-biomass hybrid model for power generation and cold storage consists of six major components:

1. Biomass gasifier (capacity: 50 kWe)
2. Gas-engine Generator (capacity: 50 kWe)
3. Waste heat recovery Unit
4. Solar Scheffler dic (4 scheffler dishes of 16 sq.m. area each)
5. VAM (15 kW)
6. Cold Storage Chamber (20 tonnes capacity)

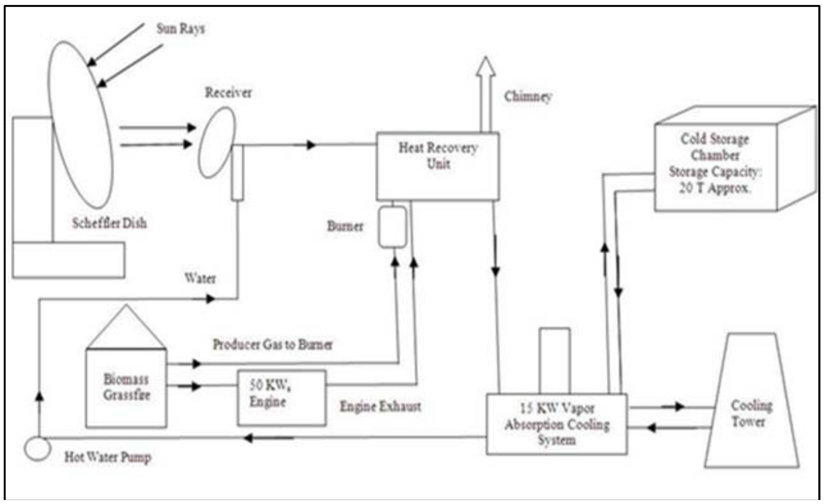


Fig 1: Line diagram of Cold Storage working on biomass gasification, waste energy exhaust & Solar thermal heat.

The selection of Updraft or Downdraft Gasifier would mainly depend upon the available fuel and the requirements of the application. Downdraft wood Gasifier requires wood chips, biomass briquettes or wood like agro-residues (such as stems, stalks). If fuel flexibility is required and need for fuel switching (say from biomass to coal or from one biomass to another) is anticipated, the updraft gasifier would be. For gasification of coal, updraft gasifier is suitable. Downdraft gasifier cannot accept coal. For direct heating applications, such as firing in kiln, furnaces, boilers, etc updraft gasifier would make a better choice. However, if the contaminants in fuel gas are likely to affect the end-product quality, the choice of downdraft gasifier makes better sense. There are situations where effect on end product quality is critical, but fuel flexibility is also an important consideration. In such situations suitable, updraft gasifier with gas scrubbing arrangement maybe selected. In the present experimental setup, downdraft gasifier was used and mainly wood chips, stalks were used as fuel source.

The biomass is fed in a downdraft gasifier and due to the process of gasification; the producer gas is produced inside the gasifier. This producer gas is fed to the engine- generator (at temp 350C-400C) unit which is a producer gas based engine. The conversion of electricity/ power generation takes place inside the engine-generator unit (50 kWe/hr.) and is fed to the smart grid for end use of consumers. The engine exhaust which would have been waste in normal gasification process is used to run VAM by using it in heat recovery system (HRU). Thus the utilization of waste energy takes place inside the heat recovery system and is an efficient example of energy management. In case of peak load, the energy exhaust is sufficient to run the VAM, however in case the peak load isn't obtained from the engine or the engine is idle, a provision of auxiliary firing from burner has been made to direct firing. The third provision of running VAM is through hot water cycle by using Solar Scheffler disc units for solar thermal generation. In case of non- sunny days, the VAM will operate on engine exhaust and/ or auxiliary firing and in case engine exhaust isn't available, the system will run on auxiliary firing only. Thus the system is designed in such a way that the cold storage can run for 24 hours (if needed) on solar, auxiliary firing and engine exhaust. It can also run on the combination of either of the two or on the combination of all the three as per load requirement.

Performance Evaluation

During Day Time

When the amount of solar radiation is good i.e. during day time the biomass gasifier is not operational. The heat is obtained through Scheffler Dishes. Each scheffler dishes has a receiver where heat is concentrated and is absorbed by water which is inside the pipe at certain pressure connected with receiver. The heated water then passes through heat recovery unit gaining more heat and is feed to Vapour Absorption Machine which provides cooling to cold storage. Actually the water transfer its heat to Generator of Vapour Absorption Machine and water after losing heat is circulated back to solar field to gain heat.

During night time

When there is no radiation / solar energy then Biomass Gasifier is operational. The producer gas obtained from Gasifier is fed in internal combustion engine and we obtain 50 kW of mechanical energy, which is further coupled with generator to produce electricity also the exhaust gas coming out from internal combustion engine is passed through Heat Recovery unit with the help of pipe and the exhaust are losses it heat and, atmosphere through chimney thus from Heat Recovery unit the water gains heat and is feed to Vapour Absorption Machine and cooling is obtained.

During Low Radiation

At times there are conditions when there is neither high radiation nor low radiation so at such circumstances Biomass Gasifier and Scheffler Dish both are used. The producer gas obtained from Gasifier is fed to internal combustion engine where energy is obtained and the exhaust gas coming out from internal combustion engine is passed through Heat Recovery unit with the help of pipe. Some amount of producer gas is also directly fed to heat Recovery unit where the producer gas is burned to release heat and also the exhaust gases losses heat and the waste gases which don't have more energy is passed out. On the other hand heated water from Scheffler Dishes is also passed through Heat Recovery unit and its energy increases which is passed to Vapour Absorption Machine.

Thermodynamic Analysis

First law of thermodynamics is used to analyze the performance evaluation of hybrid cold storage using solar & exhaust heat of biomass gasifier. The energy equation is mainly defined for the major components of the hybrid cold storage using solar & exhaust heat of biomass gasifier. The energy, analysis has been investigated by several authors [8, 11]. The following energy balance equation of major components of cooling system are expressed as:

The useful heat gain (Q) is defined as

$$Q_1 = Q_{solar} \times \eta_{E,Scheffeler} \tag{1}$$

Where Q_{solar} is the solar energy falling on Scheffeler field may be expressed as

$$Q_{solar} = A_{ap} \times DNI \tag{2}$$

The energy efficiency $(\eta_{E,Scheffeler})$ of the Scheffeler field is expressed as

$$\eta_{E,Scheffeler} = (\eta_{opt} \times COS\theta) - a_1 \frac{(T_m - T_o)}{DNI} - a_2 \left[\frac{(T_m - T_o)^2}{DNI} \right] \tag{3}$$

Where η_{opt} is optical efficiency of the scheffeler technology, a_1 is the first order coefficient of the collector efficiency $(W/m^2\text{-}^0C)$, a_2 is the second order coefficient of the collector efficiency $(W/m^2\text{-}^0C^2)$, T_m is the mean temperature of the fluid is defined as

$$T_m = \frac{T_{15} + T_{16}}{2} \tag{4}$$

The mass flow rate of fluid (m_{fluid}) is calculated as

$$m_{fluid} = \frac{\eta_{E,Scheffeler} \times A_{ap} \times DNI}{\Delta T \times C_p} \tag{5}$$

Where, C_p is the specific heat of heat transfer fluid, ΔT is the temperature difference of heat transfer fluid across the Scheffeler field is expresses as

$$\Delta T = (T_{15} - T_{16}) \tag{6}$$

Generator: $$Q_g = m_4 \cdot h_4 + m_7 \cdot h_7 - m_3 \cdot h_3 \tag{7}$$

Condenser $$Q_C = m_7 \cdot h_7 - m_8 \cdot h_8 \tag{8}$$:

Evaporator: $$Q_e = m_9 \cdot h_9 - m_{10} \cdot h_{10} \tag{9}$$

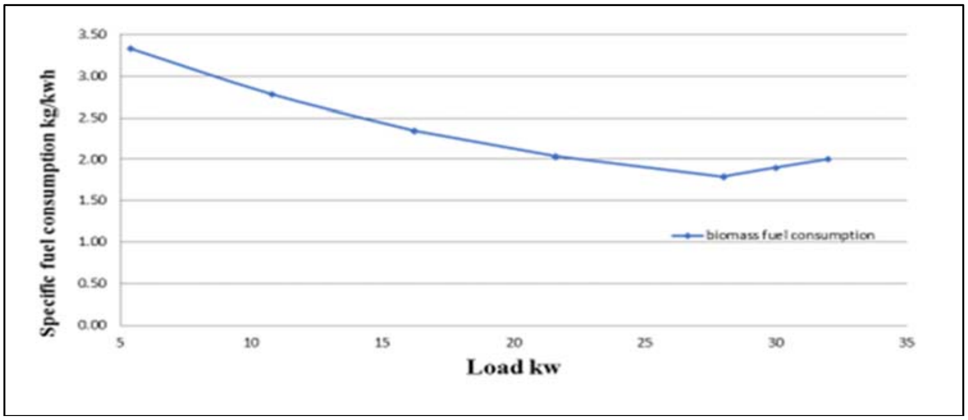
Pump-1: $$W_{p-1} = m_3 \cdot h_3 - m_2 \cdot h_2 \tag{10}$$

HE-2: $$Q_{HE-3} = m_2 \cdot h_2 + m_4 \cdot h_4 - m_3 \cdot h_3 - m_5 \cdot h_5 \tag{11}$$

The coefficient of performance of the ammonia based cooling system is expressed as

$$COP = \frac{Q_e}{(Q_g + W_{P-1})} \tag{12}$$

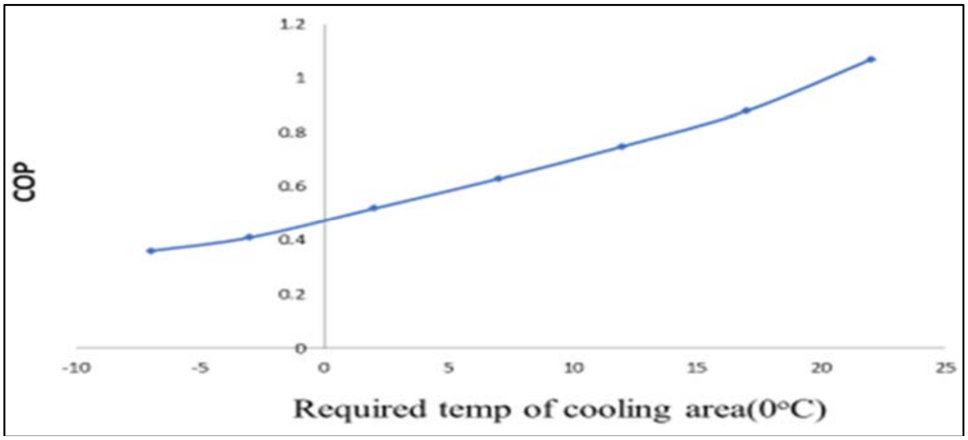
4. Results and Discussion
4.1 Specific fuel Consumption vs. load



Graph 1: Specific Fuel VS Load

The graph 4.1 showed relationship between specific biomass fuel consumption with optimal load. The curve showed the biomass fuel consumption is minimum in optimal load. But Specific fuel consumption increases at under load and over load conditions.

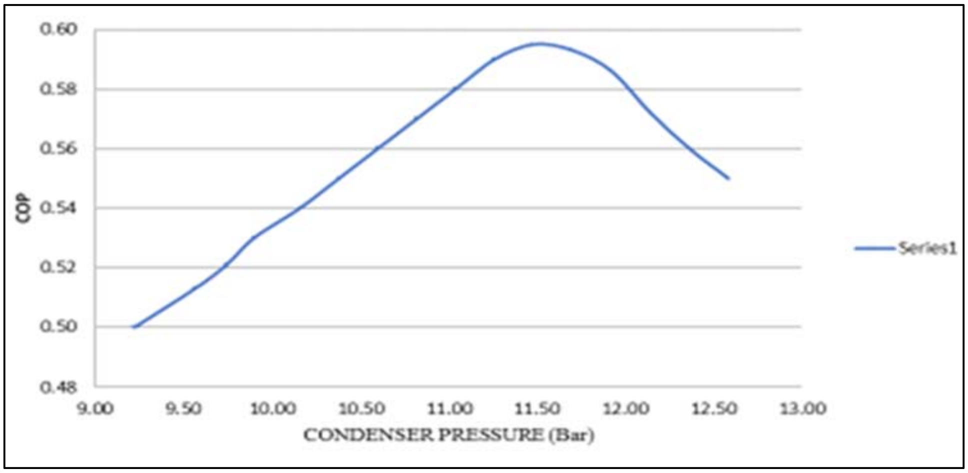
4.2 Variation of COP with Required cooling area temp



Graph 2: of COP vs. Required cooling area temp.

As Temperature required for cooling area decreases, Coefficient of Performance of the system decreases. This is due to increase in the Evaporator load to maintain low temperature of evaporator.

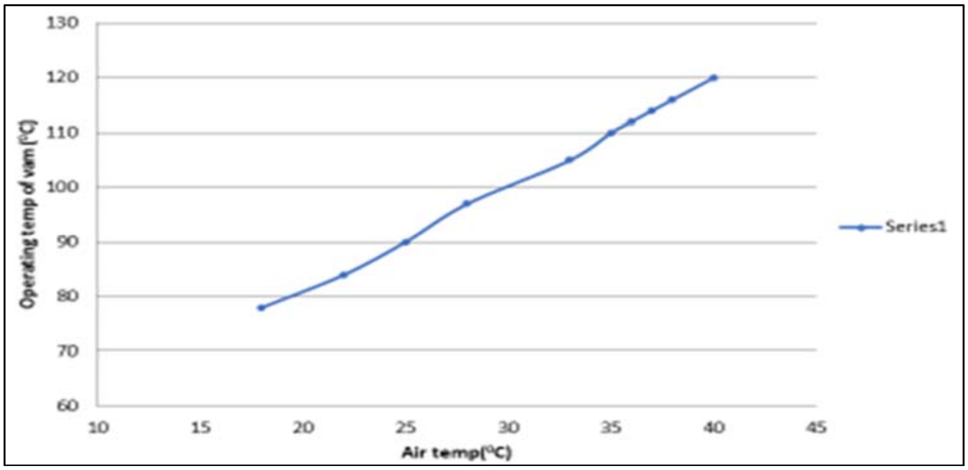
4.3 Effect of COP with Condenser pressure (bar)



Graph 3

Experiment shows the result of varying the condenser pressure. As system pressure goes up or down beyond optimum pressure of 11.48 bar, the COP decreases. This happens because refrigeration effect produced by ammonia decreases

4.4 Operating temp of VAM with varying ambient temp



Graph 4:- Operating temp vs. ambient temp

As ambient temperature increases,operating temperature of VAM also increases temperature of available water circulating in heat exchanger.Hence outlet temperature of ammonia coming out of condenser will be relatively higher i.e. Ammonia vapour will not convert in to liquid form,which will require extra load on generator hence required operating temp of generator gets increased.

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