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ASSESSMENT ON THE HARNESSING OF THE ENERGY FROM THE BACK PRESSURE CHAMBER OF PALM OIL MILL

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Abstract

Malaysia being the second largest palm oil producer produced bio mass as a by-product. Essentially the bio mass is used as energy resource in the palm industry to cater for power requirements through co-generation process. However part of the unused steam is let out to the atmosphere through the back pressure chamber. Most of the mills are in the position to generate more power and supply electricity to nearby residential areas. In some or in most of the cases the low pressure steam is let to atmosphere as the power produced is normally more than sufficient for use in the palm oil mill. The assessment on the feasibility of recovering the let out steam through a small turbine generator set is presented in this paper. Also the choice on the optimal valve size used in the expansion of the turbine is found to influence the power production. The estimation on the available energy through this is about 35% of the main plant used energy for the optimal valve sizing of 3 inch. A numerical design analysis on the back pressure chamber energy is developed and the computations on the energy are presented.

Keywords: Renewable power, Back pressure chamber, Cogeneration, Palm oil mill.

1. Introduction

Malaysia with 429 palm oil mills around the country is the second largest palm oil producer next to Indonesia producing an abundant amount of bio-mass from the mill through empty fruit bunch, mesocarp fibre, shell and palm oil effluent resource [1]. This source extracted from the palm oil mill is also a potential renewable energy.

Currently most of the palm oil mill sustains their power requirement through the cogeneration process [2-3]. Energy gain through recovery during the energy

Nomenclatures

H_d	Enthalpy of discharge from back pressure chamber (kj/kg)
H_s	Enthalpy of steam (inlet) (kj/kg)
H_{st}	Specific enthalpy of steam at outlet (kj/kg)
H_{stBPV}	Specific enthalpy of steam from back pressure chamber (kj/kg)
H_t	Enthalpy of steam (outlet)(kj/kg)
H_{tBPV}	Enthalpy of steam from back pressure chamber (outlet) (kj/kg)
H_w	Enthalpy of water (kj/kg)
k	Energy conversion factor
L	Coupling factor
m_{sec}	Mass flow rate of steam at the back pressure chamber
r	Radius of the turbine blade (m)
T	Steam release duration from back pressure chamber (minutes)
P_e	Net electrical power (watts)
P_{eq}	Intermittent duty power rating for the chosen duty factor (watts)
$p_{(max)}$	Maximum pressure at the back pressure chamber (bar)
P_{mech}	Available mechanical power (hp)
$p_{(min)}$	Minimum pressure at the back pressure chamber (bar)
S_{BPV}	Secondary unused rate of energy (kj/kg/min)
t_c	Total cycle period (minutes)
t_{op}	Operating period (typically 15 minutes in this case)
v_f	Fuel flow rate (kg/h)
v_s	Steam flow rate (kg/h)
v_{sec}	Velocity of steam at the back pressure chamber (m/s)
v_1	Velocity of Steam flow rate at the intlet of turbine (kg/h)
v_2	Velocity of Steam flow rate at the outlet of turbine (kg/h)
V_1	Velocity at the input of turbine (m/s)
V_1	Velocity at the output of turbine (m/s)

Greek Symbols

η_B	Boiler efficiency (%)
ω	Angular velocity of the turbine (rad/s)
ε	Duty factor

Abbreviations

BPC	Back Pressure Chamber
GCV	Gross Calorific Value
SREPP	Small Renewable Energy Power Programme

transformation process (thermo-chemical and thermo-electrical) is critical towards its impact on sustainability. Through the wise use of energy recovered during the process, the palm oil mills strive to become self-sufficient in its operation. Recovery of energy is a feasibility solution to look for that support the non-critical and smaller domestic load around the mill. This is motivated highly due to the fluctuating changes in the climate in recent times, the rise of the electricity demand and the decrease in the fossil fuels making every possible recovery of energy.

The major challenge in trapping this energy is the minimal time (usually short time duty operation) availability of the pressure from the valve that might not be able to produce sufficient power generation capability through an auxiliary unit. However if this energy in thermal form (high pressure) energy be recovered and it improve the sustainability of the plant.

At the present moment the palm oil mill producers is reluctant to trap this energy as through their existing co-generation they produce power more than what is required for their own mill usages. The use of high power generator for operating for short time duration such as the dual magnetic circuit generator [4-6] the efficiency of the plant is increased within the limited operating time. This enhances the energy recovery that is usually wasted into the environment that support the non-critical load through the battery management system.

The control of the pressure from the Back Pressure Chamber (BPC) through the variation in the valve sizing increases the time availability for the pressurized steam making the duty cycle range be expanded. Integrating the above two strategy aids in the production of energy. This paper presents the assessment on the power generation from such a typical back pressure chamber of a typical palm oil mill.

2. Efficiency Computations of the Proposed Auxiliary Power Generation Systems

2.1. Palm oil energy systems

Figure 1 shows the growth of palm oil production in Malaysia [1]. The rapid growth in the production is an indication on the increase in the unused steam let out to atmosphere. Figure 2 shows the typical thermo-chemical process where biomass is directly burnt in the presence of air to convert chemical energy stored in biomass as heat [1]. The typical final steam produced is saturated steam with pressure and temperature at less than 21 bar and 210^0C respectively.

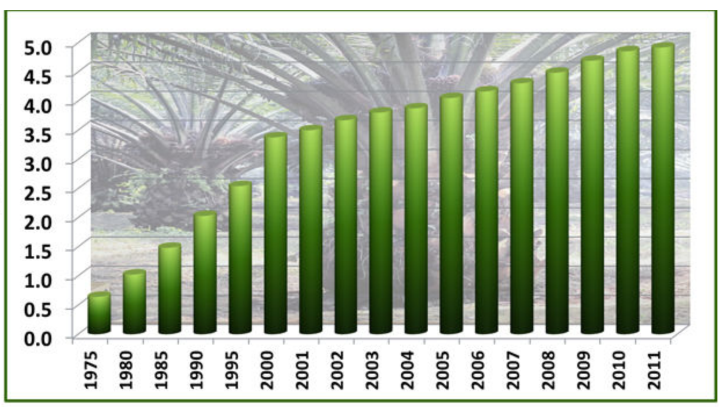

Fig. 1. Palm oil production growth in Malaysia [1].

The high pressure steam from the boiler enters the BPC at 17-20 bar and expands through the turbine blades for the energy conversion. After the energy conversion the low pressure steam that leaves the steam turbine at about 3 bar is stored in the BPC. The accumulated steam is then discharged to the atmosphere when the pressure is more than 3.5 bar. This steam is usually used for allied processes in the palm oil mill industry. Figure 3 shows the various efficiency of the system in available and also the proposed energy trapping from the BPC (shown in coloured box).

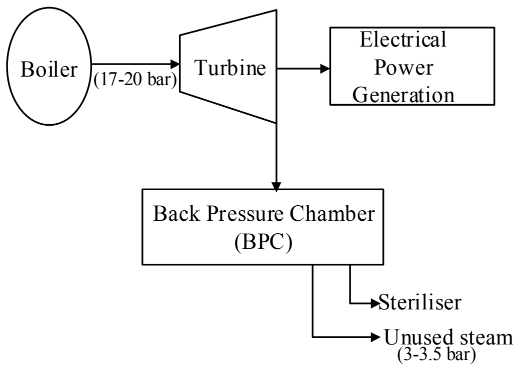

Fig. 2. Typical palm oil mill.

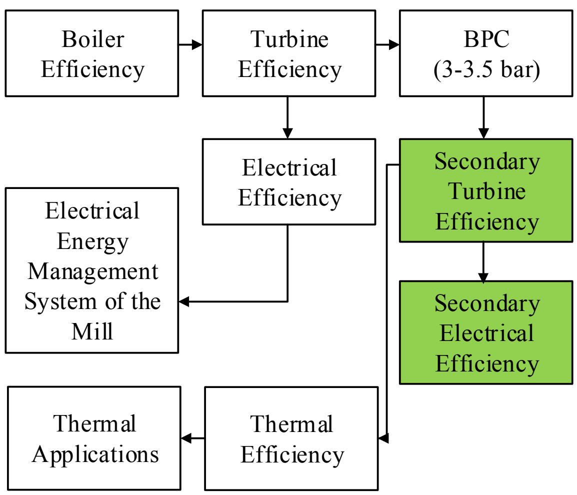

Fig. 3. Efficiency computations schematic.

2.2. Analytical design approach

An analytical approach to the power availability from the back pressure chamber and its estimation in the electrical power is presented in this section.

The boiler efficiency (η_B) is given as in Eq. (1)

$$\eta_B = [v_s(H_s - H_w)/v_f\ GCV \quad (1)$$

The turbine efficiency (η_t) is given as in Eq. (2)

$$\eta_t = (H_s - H_t)/(H_s - H_{st}) \quad (2)$$

The secondary thermal efficiency (η_{th}) available is given as in Eq. (3)

$$\eta_{th} = v_s(H_d - H_t)/v_f GCV \quad (3)$$

The rotational speed of the turbine depends on the kinetic energy of the fluid flow rate that depends on the sizing of the valve. Therefore the rate of energy at the back pressure chamber available is given in Eq. (4)

$$S_{BPV} = \frac{(H_d - H_{tBPV})}{(H_d - H_{stBPV})} T * m_{sec} * v_{sec} \quad (4)$$

The work done mechanically is given by Eq. (5)

$$Workdone(P_W) = \omega r * S_{BPV} \quad (5)$$

Using the Eqs. (1) – (5) the available energy from the steam is computed and is taken as the available energy at the output of the turbine. The efficiency is used to compute the net power available from the model using the above formula. Therefore power available at the input of the generator is given as in Eq. (6)

$$P_{mech} = kP_W = \frac{v_2^2}{v_1^2} P_W \quad (6)$$

The conventional alternator is not suitable for the applications as the energy production require an appropriate generator that generates high power density for short period operations [4-5]. There are also few other design variations that can be used to enhance the efficiency for the same volume as that of the conventional structures [5]. The machine as seen in Fig. 4 is used for the estimation and is developed with an outer rotor structure and is optimised to produce short time high density power capability, which is highly suitable for this secondary energy recovery palm oil condition. The series of permanent magnet (PM) array to produce an electromagnetic force as voltage through the stator coils.

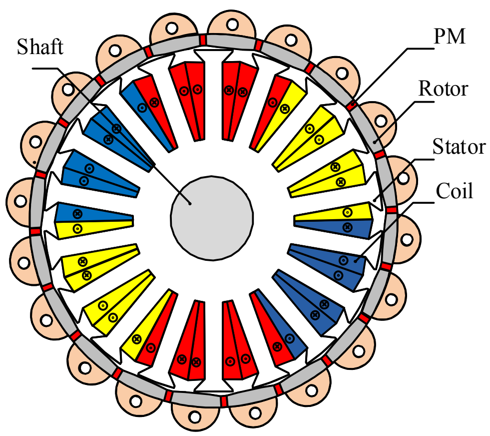

Fig. 4. Proposed generator.

The electrical power available at the secondary generator is given as in Eq. (7).

$$P_e = L * \frac{P_{mech}}{3600} * GCV \quad (7)$$

The energy that can be trapped is computed using the Eq. (8).

$$E_e = P_e * T \tag{8}$$

One of the key parameters in the mechanical power availability and the increase of the efficiency lie on the value sizing. The reduction in the sizing of the valve increases the kinetic energy of the system thereby the velocity at the output and thereby the available mechanical power. However the energy released is for short time duty [7], eventually helping to produce power ON and OFF. However if the size of the valve is increased the velocity of the pressure released from the BPV is reduced but the available time to rotate the turbine is reduced. Figure 5 shows the short time duty operation. In other words the idle period is reduced. Essentially the duty cycle is given as in Eq. (9).

$$\varepsilon = \frac{t_{op}}{t_{op}+t_c} \tag{9}$$

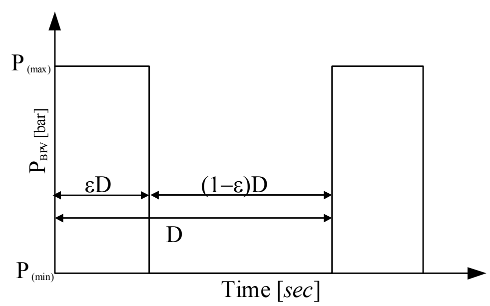

Fig. 5. Short duty operation of the auxiliary systems.

In order make a continuous operation of the generator a continuous rotations through the mechanical turbine is required. This can be achieved if we are able to expand the steam uniformly through the entire duration of time (in other words reduce the idle time to be minimal. Figure 6 shows the extended operation for continuous power rating.

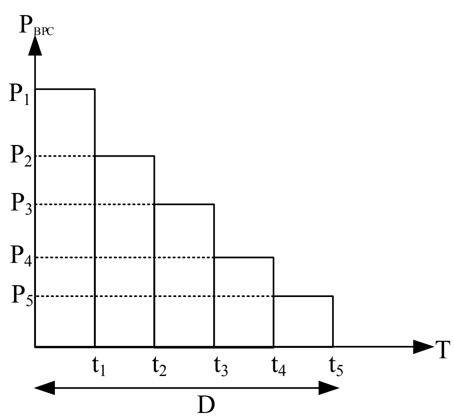

Fig. 6. Extended operations for continuous operations.

The equivalent power is computed through the equivalent load power analysis [7] given as in Eqs. (10) - (11).

$$P_{equivalent(id)} = \sqrt{\frac{{P_1}^2 t_1 + {P_1}^2 t_2 + {P_1}^2 t_3 + {P_1}^2 t_4 + {P_1}^2 t_5}{(t_1 + t_2 + t_3 + t_4 + t_5)}} \quad (10)$$

$$P_e = P_{equivalent(id)} \sqrt{\varepsilon} \quad (11)$$

where

$P_{equivalent(id)}$: Intermittent duty power rating for a duty factor of ε

P_e: The net electrical power is given as

3. Assessment on the Energy

3.1. Steam energy computations

The amount of the enthalpy from the back pressure chamber is the available amount of heat available at any particular instant of pressure release. Hence it is a variable and is depend on the pressure at the valve and the range of available enthalpy from the BPC is shown in Figure 7. For various values on the BPC pressure the available enthalpy is computed and based on the equations from the preceding section the efficiency is computed.

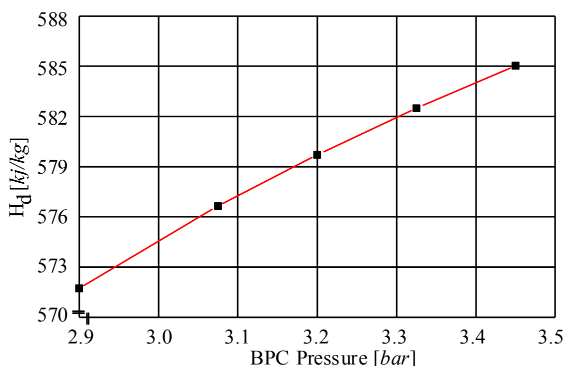

Fig. 7. Available enthalpy based on the output from the BPC.

For the typical analysis on the operating load conditions the BPC is operating for 15 minutes and is ideal for the next 45 minutes and once again the process repeats. Equation (7) gives us the operation conditions that determine the load curve that help to choose the generator to be used for this application.

It can be inferred that this makes the turbine to do mechanical rotations for a short time period and rest of the period idle until the pressure builds up to the set level. If the size of the valve is increased such an instance the expansion duration in the turbine is increased with the decrease in the velocity. That means the production of voltage is compromised as the rotation of the machine (speed of revolution) is reduced.

Figure 8 shows the estimation of the mechanical power available for energy conversion, derived based on the available enthalpy of steam using the proposed generator.

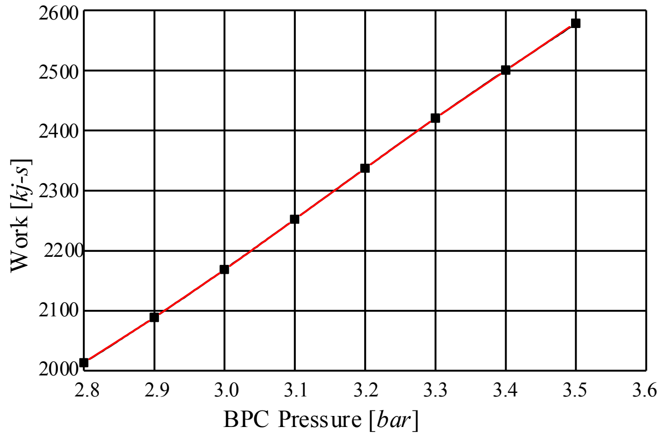

Fig. 8. Estimation of the mechanical power available for energy conversion.

3.2. Mechanical energy computations

Figure 9 shows the mechanical energy derived based on the estimation of the enthalpy of steam available for the energy conversion.

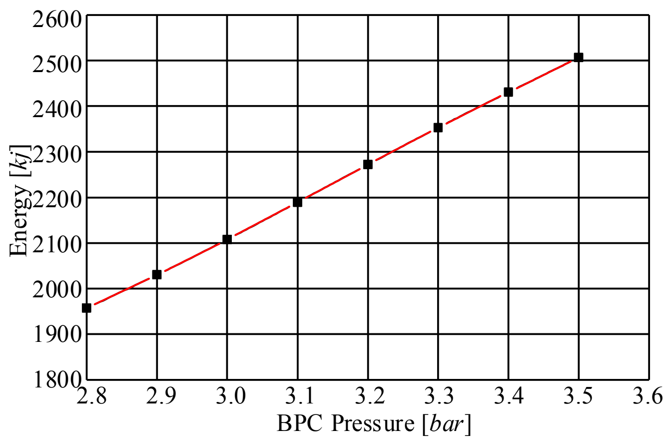

Fig. 9. Estimation of the mechanical power from the secondary unit.

Figure 10 shows the efficiency computations based on the mechanical output. As seen between the pressure bar of 3.5 bar to 3.3 bar the energy conversion is estimated to run in the short time duty ratio condition typically 15 minutes. The above graph represents when a 3" valve is used. However when sizing of the valve is changed the duration of the steam available to the secondary turbine is prolonged thereby the power production, but with lesser value. This is presented in the subsequent section of analysis. Between 3.3 bar to 3.2 bar the generator is required to recover. In other words between the 3.5 bar to 3.3 bar the generator is operated and between 3.3 bar to 3.2 it is allowed to free run and after this the BPC valve is closed so that the pressure once again built from 3.2 bar to 3.5 bar and once again the generator is operated. A monitoring system on the pressure at the inlet and the outlet in real time is required for the continuous operation of the generation system.

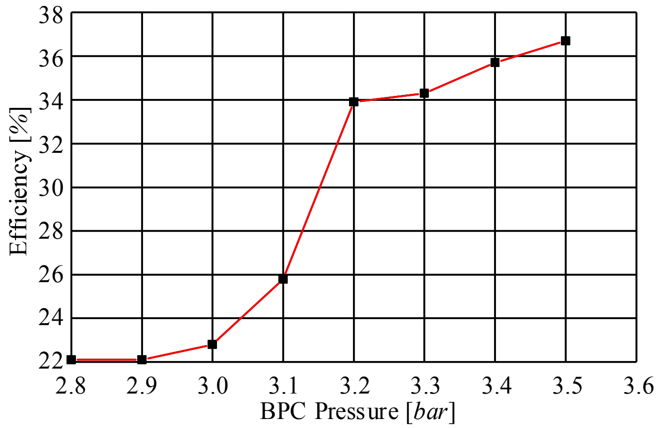

Fig. 10. Efficiency range for the pressure drop.

3.3. Valve size analysis

The valve size is a function of the pressure released from the BPV. A smaller size of the valve relates to the increase in the velocity of the steam and the pressure drop inside the BPV chamber is faster. This introduces a short time operating condition of the proposed auxiliary system. In other case if the expansion time of the steam in the turbine of the proposed auxiliary system is increased with reduced velocity through a bigger valve the available energy for rotation of the turbine is increased and thereby the power produced is increased.

In other words the relation of the valve ratio is to decrease the idle time (which is 45 minutes for the palm oil mill in the current scenario) and thereby the expansion is continued for better power produced through the proposed architecture. The double stator generator proposed in this design eventually help to produce higher power than that of the conventional electrical generator.

Figure 11 shows the estimated mechanical power output to the valve sizing ratio. The valve ratio is the ratio of the maximum available valve size (V_{max}) to the minimum available valve size (V_{min}).This valve sizing ratio is the function of the pressure reduction in the BPC from 3.5 bar to 3 bar.

3.4. Estimation on the electrical energy

Figure 12 shows the electro-magnetic power produced by the proposed generator. As seen the operation of the generator between 300 rpm to 900 rpm produced about 350W of electrical power output for the operating voltage of 60V to 120V, which can be used to power small lighting loads. The electromagnetic power developed depends on the magneto motive force (mmf) produced inside the generator for various rotational speed is presented in Figure 12. The three phase generated voltage (Phase A, Phase B and Phase C) at various rotational speed is shown in Figure 13. It is seen that the average voltage in all the phases is same concluding the stable power production from the auxiliary unit of generator.

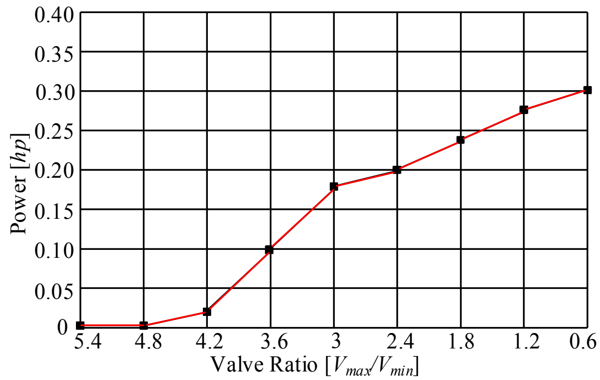

Fig. 11. Estimation of the mechanical power output to valve sizing.

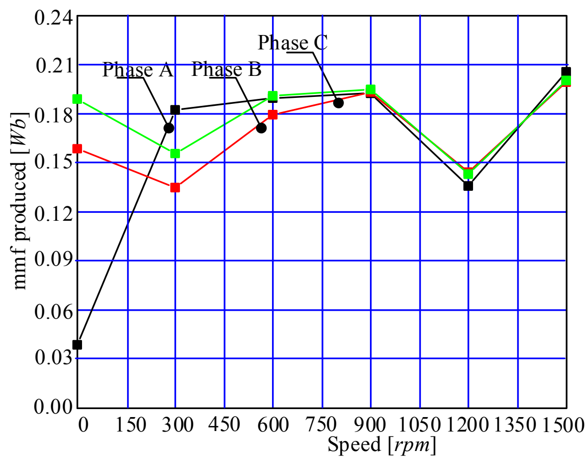

Fig. 12. Estimation of the electro-magnetic power output to the valve sizing ratio.

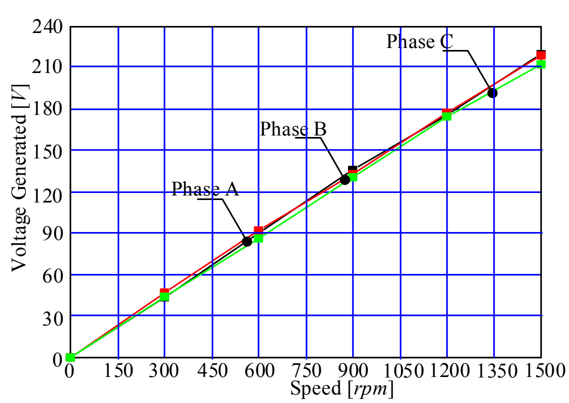

Fig. 13. Three phase voltage generation through auxiliary unit.

4. Conclusions

Plant biomass based cogeneration plants of the palm oil mills are capable of producing enough power to the milling process. However the let off steam energy which is generally short time periodic value can be tapped with the use of generators that operate at peak values for short duration. The assessment on the feasibility of recovering such the let out steam through a small turbine generator set is presented in this paper. The unused steam from the outlet of the back pressure chamber through the choice on the appropriate short time duty generator is investigated. The valve sizing which is critical factor in the energy conversion process is also tested for the optimal case. In the analysis it is found an electrical power of 350W can be generated at 60-120V level for the optimised valve sizing of 3 inch. The energy that is generated can be used to power small non critical and domestic lighting loads.

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