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Research Article

Thermodynamics Analysis of Solar-Rice Husk Hybrid Power Plant

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Abstract: The main objective of this study is to make thermodynamics analysis of different components of solar rice husk hybrid power plant with its modification of structure by implementing a Rice Husk Dryer between the Condensate Pre-heater and Air Pre Heater in order to feed dry rice husk to furnace and performance evaluation of power plant with respect to reduction of moisture content of rice husk using MATLAB, R2016a. The flue gas is passed to the Rice Husk Dryer, where the heat of flue gas is used to dry the rice husk before feeding to the furnace. Solar energy is limited to a 50% share in the daytime. In this research solar parabolic collector and Rice, husk feed is arranged in a parallel to produce steam. Feeding with dry rice husk in the furnace was found to reduce the heat loss due to heating moisture present in rice husk up to furnace temperature and also heat loss due to excess air supplied to the furnace for evaporating and superheating the moisture present in the rice husk. The increase in furnace efficiency, fuel efficiency, thermal efficiency and plant efficiency, reduction in specific rice husk consumption, reduction in excess air supply and decrease in rice husk consumption, etc. with respect to reduction in the moisture content of rice husk for the power plant are evaluated. The result showed that with the reduction of moisture from 10% to 90%, the power plant efficiency is to be increased by 6.97% to 64.86% for boiler pressure of 50 bar.

Keywords: Efficiency, energy, energy losses, moisture reduction, rice husk, solar energy

INTRODUCTION

The solar-rice husk hybrid power plant uses both solar heat and heat from rice husk to produce steam to run the turbine, which works on Rankine cycle. In day time heat is harnessed using parabolic solar collector and rice husk (biomass) feedstock is burnt as a supplementary to achieve a constant base load. In night, the plant is run at full load with only rice husk fuel. The hybridization power from solar and rice husk biomass in agricultural based countries would be a sustainable energy resource for the nations. Srinivas and Reddy (2011) had designed a hybrid power plant in which plant was considered to run half to full load (Srinivas and Reddy, 2014), where wet rice husk was fed to the furnace. Servert and Miguel (2011) also had discussed the technology for solar biomass hybrid system in which solar and biomass are arranged in parallel for energy generation with wet biomass directly fed to furnace (Servert and Miguel, 2011). Singh *et al.* (1980) designed and tested a cyclonic rice husk furnace in which 100 kg of paddy with 35% moisture was dried to 14% moisture (Singh *et al.*, 1980). Efficiency of furnace were different for different rate of rice husk feeding and air flow rates. The maximum efficiency was 80% with rice husk feed rate of 20 kg/h and air flow rate of 168 m^3/h. Munir et al. has mentioned that the major losses were due to incomplete combustion, moisture in the fuel and dry flue gas loss (Anjum *et al.*, 2014). About 10% reduction in excess air increases boiler efficiency by 0.5%. About 20°C reduction in flue gas temperature, the boiler efficiency was increased by 1% (Anjum *et al.*, 2014). It was also noted that the boiler efficiency was increased by 1% by decreasing the temperature difference of flue gas by 22°C. Lee and Jou (2011) had pointed that decreased in excess air supplied to the furnace by 1% increases the furnace efficiency by 0.6% (Lee and Jou, 2011). Controlling excess air within the required range will lead to decrease in the flue gas losses. Every 1% reduction in the excess air supplied to the furnace results in approx. 0.6% increase in the boiler overall efficiency (Anish, 2017). Thus, drying the moisture of rice husk before feeding to the furnace by implementing a Rice Husk Dryer between Condensate Pre Heater and Air Pre Heater can reduce the heat losses due to extra heat required to evaporate and superheat the moisture present in rice husk to furnace temperature and also the heat loss due to excess air supplied for burning the rice husk. This may be the gap for the research. In Concentrating Solar Power (CSP)

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plants, electricity is generated by heating a fluid (Synthetic oil) to high temperatures (typically over 375°C using solar radiation that has been concentrated using mirrors or lenses). The hot fluid is used to produce superheated stem (370-375°C, 90-100 bar) depending on the characteristics of the Rankine cycle that drives a Rankine cycle steam turbine connected to an electricity generator (Montes *et al*., 2009). The main objective of this study is to make thermodynamics (Thermal energy) analysis of different components of solar-rice husk hybrid power plant with its modification by implementing a Rice Husk Dryer (RHD) between the Condensate Pre heater (CPH) and Air Pre Heater (APH), in which rice husk is dried in Rice Husk Dryer (RHD) before feeding to furnace and performance (increase in furnace efficiency, fuel efficiency, thermal efficiency and plant efficiency, decrease in specific fuel consumption, excess air reduction and decrease in rice husk consumption) evaluation of power plant's analysis using MATLAB, R2016a with respect to percentage reduction in moisture present in the rice husk before feeding to the furnace.

MATERIALS AND METHODS

The modified power plant of Srinivas and Reddy (2014) is shown in Fig. 1. The power plant designed by Srinivas and Reddy (2014) consists of a boiler unit (Furnace, Super heater (SH), Evaporator (EVA), Economizer (ECO), Condensate Pre-Heater (CPA) and Air Pre-Heater (APH)), Turbine, Condenser, Condensate pump, Deaerator, Feed pump and Concentrated Solar Panel. In the modified power plant, a Rice Husk dryer (RHD) is implemented between CPH and APH. The flue gas coming from CPH is passed through the RHD, where the heat of flue gas is taken by the rice husk and is dried. The flue gas coming out of the RHD is then passed through the APH, where air takes heat from the flue gas and gets pre heated before entering into the furnace for combustion. The proposed rotary type RHD is shown in Fig. 2, in which rice husk is fed (to the point 24) and exit (from the point 25). The flue gas inlet to RDH is through point 19 and exit from RHD is point 20. The followings are the assumptions made for the modified hybrid power plant. The plant is assumed to run at full load in night where only rice husk is used as fuel. For day operation 50% of heat is assumed to be supplied from solar thermal and remaining from rice husk as supplementary.

The ultimate analysis of rice husk is taken as C: 36.74%, H: 5.51%, O: 42.55%, N: 0.28%, S: 0.55% and ash 14.37% (Ganesh and Srinivas, 2012). The temperature of steam at inlet to turbine is taken as 450°C. The performance of power plant is evaluated for different boiler pressures of 30 bar, 40 bar, 50 bar and 60 bar. The temperature of steam coming out of the solar collector is assumed as 350°C and is heated to 450°C in super heater. Super heater takes heat from boiler. The temperature of flue gas coming out of economizer is assumed as 300°C. The isentropic efficiencies of turbine and pump are assumed as 75%, mechanical efficiencies of turbine and pump as 96%, boiler efficiency as 90%, furnace efficiency as 52%, collector efficiency as 75% (Hirasawa *et al*., 2013), electrical generator efficiency as 98%, condenser efficiency as 86% (Elepano, 2000), efficiency of Rice Husk Dryer as 98%. The atmospheric pressure and temperature are taken as 1.01325 bar and 25°C

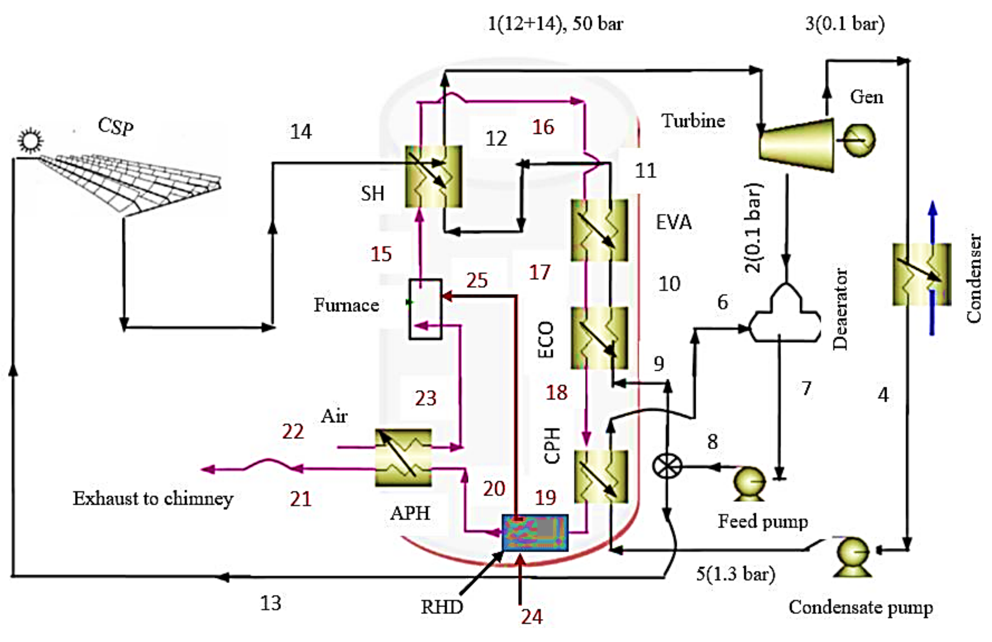

Fig. 1: Modified power plant

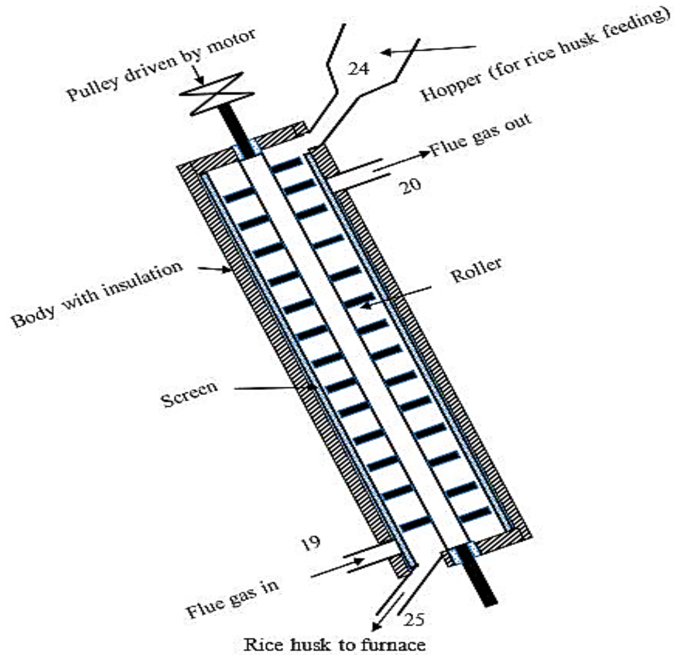

Fig. 2: Rice husk dryer

respectively. The moisture content in rice husk is taken as 15.1%. The followings are the formulae developed for the thermodynamics evaluation of the hybrid power plant.

For turbine:

Total power generation = W_{genout}, kW (1)

Power supplied to generator = $\dot{W}_{gen\ in} = \frac{W_{genout}}{\eta_{gen}}$, kW (2)

Power supplied to turbine shaft = $\dot{W}_s = \frac{\dot{W}_{gen\ in}}{\eta_s}$, kW (3)

Power inlet to turbine = $H_1 = \frac{\dot{W}_s}{\eta_t}$, kW (4)

Mass flow rate at inlet to turbine = $\dot{m}_1 = \frac{H_1}{h_1}$, kg/ (5)

At exit to turbine (for state 2′):
Entropy of saturated water = $s'f_2$, kJ/kg.K
Entropy of evaporation = s'_{fg2}, kJ/kg.K
Enthalpy of saturated water = h'_{f2}, kJ/kg
Enthalpy of evaporation = h'_{fg2}, kJ/kg
Dryness fraction at state 2′ = $x'_2 = \frac{s_1 - s'f_2}{s'_{fg2}}$

At actual exit state of turbine (state 2″)

The theoretical enthalpy at the exit to turbine at state $2' = h'_2 = h'_{f2} + x'_2 \times h'_{fg2}$, kJ/kg (6)

Theoretical work done by turbine = $w_{th} = h_1 - h'_2$, kJ/kg (7)

Actual work done by turbine = $w_{act} = \eta_t \times w_{th}$, kJ/kg (8)

Actual enthalpy at exit to turbine at state 2" = $h"_2 = h_1 - w_{act}$, kJ/kg (9)

Mass flow rate at inlet to turbine = $\dot{m}_1 = \frac{\dot{W}_s}{w_{act}}$, kg/s (10)

Dryness fraction at actual exit to turbine (state 2") = $x''_2 = \frac{h''_2 - h'_{f2}}{h'_{fg2}}$ (11)

Enthalpy at inlet to deaerator from turbine (state 2) = $h_2 = h'_{f2}$, kJ/kg (12)

Enthalpy at inlet to condenser (state 3) = $h_3 = h''_2 - h_2$, kJ/kg (13)

Mass of dry saturated vapor = $m_g = \dot{m}_1 \times x''_2 = \dot{m}_3$, kg/s (14)

Mass of water entering to deaerator (state 2) $\dot{m}_2 = \dot{m}_1 - \dot{m}_3$, kg/s (15)

For condenser:

Heat loss by steam during condensation = $q_{condenser} = h_3 - h_4$, kJ/kg (16)

Total heat gained by cooling water = $\dot{q}_{cooling\ water} = q_{condenser} \times \dot{m}_3$, kW (17)

Mass flow rate of cooling water $\dot{m}_{cooling\ water} = \frac{\dot{q}_{cooling\ water}/\eta_{condenser}}{c_{pw} \times (T_0 - T_i)}$, kg/s (18)

For condenser pump:

Condenser pump work $w_{cp} = v_{f4} \times (P_5 - P_4)$, kJ/kg (19)

$h_5 = w_{cp} + h_4$, kJ/kg (20)

Power supplied to condenser $\dot{W}_{cp} = (w_{cp} \times \dot{m}_3)/\eta_p$, kW (21)

For Condensate pre Heater (CPH):

Heat supplied to condensate water by CPH $q_{5-6} = c_{pw} \times (t_6 - t_5)$, kJ/kg (22)

$h_6 = h_5 + q_{5-6}$, kJ/kg (23)

For deaerator:

Temperature at the exit to deaerator $t_7 = \frac{\dot{m}_2 \times t_2 + \dot{m}_6 \times t_6}{\dot{m}_2 + \dot{m}_6}$, ^oC (24)

$\dot{m}_6 = \dot{m}_3$
$h_7 = \frac{h_6 \times \dot{m}_3 + h_2 \times \dot{m}_2}{\dot{m}_2 + \dot{m}_3}, \frac{kJ}{kg}$ (25)

For feed pump:

Feed pump work $w_{fp} = v_7 \times (p_8 - p_7)$, kJ/kg (26)

$\dot{W}_{fp} = w_{fp} \times \dot{m}_1$, kW (27)

$h_8 = h_7 + w_{fp}, \frac{kJ}{kg}$ (28)

For furnace: Proximate and ultimate analysis of rice husk is shown in Table 1 (Srinivas and Reddy, 2014). On the basis of above ultimate analysis, the minimum air required for combustion was found using following chemical equation.

Theoretical air required for combustion is calculated (Domkundwar and Kothandraman, 2009) by the equation:

$$\frac{1}{100}\left[\frac{8}{3}C + 8\left(H - \frac{O}{8}\right) + S\right] \times \frac{100}{23} = \frac{1}{23}\left[\frac{8}{3}C + 8\left(H - \frac{O}{8}\right) + S\right] \quad (29)$$

The moisture content of rice husk was tested in the laboratory of Asian Thai Food at Biratnagar, Nepal.

Table 1: Proximate and ultimate analysis of rice husk

Proximate analysis		Ultimate analysis	
Property	Wt %	Property	Wt %
Moisture (%)	6.1	Carbon (%)	36.4
Ash (%)	20.6	Hydrogen (%)	4.84
Volatile matter (%)	58.4	Oxygen (%)	25.11
Fixed carbon (%)	14.9	Nitrogen (%)	0.44
Calorific value, kJ/kg	3420	Sulfur (%)	0.17

The moisture present in rice husk was found 15.1% and on that basis of that moisture content, the air required for the combustion of rice husk in the furnace was found using the chemical combustion equation as below:

$(CH_{1.6178}O_{0.7389}N_{0.0139})_{Rice\ husk} + 1.9249(O_2 + 3.76\ N_2)_{air} + (0.151\ H_2O)_{moisture} = (CO_2 + 0.9599\ H_2O + 0.86650\ O_2 + 7.2376\ N_2)$ product gas (Srinivas and Reddy, 2014) (30)

For dry rice husk: For dry rice husk the air required for the combustion was found using the chemical equation as shown below:

$(CH_{1.6178}O_{0.7389}N_{0.0139})_{Rice\ husk} + 1.035\ (O_2 + 3.76N_2) = CO_2 + 0.8089\ H_2O + 3.8916\ N_2$ (31)

Air required for per kg of wet rice husk and air required for per kg of dry rice husk were calculated and from that excess air required per kg of wet rice husk compared to dry rice husk was calculated.
The efficiency of furnace increased is given by:

$\eta_{furnace\ increased} = 0.6 \times Air_{excess\ \%}$ (32)

$\eta'_{furnace} = \eta_{furnace} + \eta_{furnace\ increased}$ (33)

Heat loss from per kg moisture $q_{moisture} = c_{pw} \times (t_{sat} - t_0) + L_v + c_{ps} \times (t_1 - t_{sat})$, kJ/kg
$\dot{m}_{moisture}$ = mass of moisture per second (34)

Total heat loss from moisture $\dot{q}_{moisture} = q_{moisture} \times \dot{m}_{moisture}$, kW (35)

Reduction of rice husk consumption $\dot{m}_{reduction} = \frac{\dot{q}_{moisture}}{CV\ of\ rice\ husk}, \frac{kg}{s}$ (36)

Total rice husk consumption:
Considering the biomass input only (for night operation):

Heat taken by water from boiler, $H_{9-1} = H_1 - \dot{m}_1 \times h_8$, kW (37)

Heat supplied to boiler, $H_{bN} = \frac{H_{9-1}}{\eta_b}$, kW (38)

Heat supplied by furnace to boiler = Heat of rice husk = $\dot{Q}_{hN} = \frac{H_{bN}}{\eta'_{furnace}}$, kW (39)

Mass consumption of rice husk, $\dot{m}_{hN} = \frac{\dot{Q}_{hN}}{12600}$, kg/s (40)

Total rice husk consumption: For hybrid system (both biomass and solar)-day operation:

Heat shared by solar, $H_{wc} = \frac{H_1}{2}$, kW (41)

Heat required to superheat the steam coming out from solar collector:

$$h_{sup} = c_{ps} \times (t_1 - t_{14}) \text{ , kJ/kg} \quad (42)$$

Rate of mass through solar collector, $\dot{m}_c = \frac{H_{wc}}{h_{14}}$, kg/s (43)

Heat supplied to solar collector, $\dot{Q}_c = [\dot{m}_c \times (h_{14} - h_{13})]/\eta_c$, kW (44)

Heat taken by water from boiler, $H_{D9-1} = H_1 - \dot{m}_c \times h_{14}$, kW (45)

Heat supplied to boiler, $H_{bD} = \frac{H_{D9-1}}{\eta_b}$, kW (46)

Heat supplied by furnace to boiler = Heat of rice husk = $\dot{Q}_{hD} = \frac{H_{bD}}{\eta'_{furnace}}$, kW (47)

Mass consumption of rice husk, $\dot{m}_{hD} = \frac{\dot{Q}_{hD}}{12600}$, kg/s (48)

Total rice husk consumption, $\dot{m}_{total}(Day\ and\ night) = [(\dot{m}_{hN} \times 12) + (\dot{m}_{hD} \times 6)]/18$, kg/s (49)

Net- work output for plant:

Power consumption by condensate pump, $\dot{W}_{cp} = \dot{m}_3 \times v_4 \times (P_5 - P_4)$, kW (50)

Power consumption by feed pump, $\dot{W}_{fp} = \dot{m}_1 \times v_7 \times (P_8 - P_7), kW$ (51)

Power consumption by rice husk dryer motor, $W_{hd} = 7\ kW$ (52)

Actual work of plant, $w_{actual} = h_1 - h''_2$, kJ/kg (53)

Actual shaft work of plant, $\dot{W}_s = \dot{m}_1 \times w_{actual}$, kW (54)

Net -work of plant, $\dot{W}_{net} = \dot{W}_s - \left(\dot{W}_{cp} + \dot{W}_{fp} + \dot{W}_{hd}\right)$, kW (55)

Fuel efficiency of plant:

Fuel efficiency of plant,

$$\eta_{fuel} = \frac{\dot{W}_{net}}{\dot{m}_{total} \times \text{CV of rice husk}} \times 100\ \% \quad (56)$$

Increase in fuel efficiency of plant =

$$\frac{\text{(fuel efficiency of plant on drying rice husk} - \text{fuel efficiency of plant when rice husk is not dried)}}{\text{fuel efficiency of plant when rice husk is not dried}} \times 100\ \% \quad (57)$$

Reduction in rice husk consumption:

$$\frac{\text{(rice husk consumption when rice husk not dried} - \text{rice husk consumption when rice husk dried)}}{\text{rice husk consumption when rice husk not dried}} \times 100\ \% \quad (58)$$

Specific fuel consumption = $\frac{\dot{m}_{total} \times 3600}{\dot{W}_{net}}\ kg/kWh$ (59)

Efficiency of plant:

$$\eta_{plant} = \frac{\dot{W}_{net}}{\frac{(\dot{Q}_c \times 6) + (\dot{m}_{hN} \times 12 \times 12600) + (\dot{m}_{hD} \times 6 \times 12600)}{24}} \times 100\ \% \quad (60)$$

Thermal efficiency of plant:

$\dot{q}_c = \dot{Q}_c \times \eta_c$, kW

$\dot{q}_{N\ rice\ husk} = \{\dot{m}_5 \times (h_6 - h_5) + \dot{m}_1 \times (h_1 - h_9)\}$, kW

$\dot{q}_{D\ rice\ husk} = \{\dot{m}_5 \times (h_6 - h_5) + \dot{m}_9 \times (h_1 - h_9) + \dot{m}_{13} \times h_{sup}\}$, kW

$$\eta_{th} = \frac{\dot{W}_{net}}{(\dot{q}_c \times 6 + \dot{q}_{N\ rice\ husk} \times 12 + \dot{q}_{D\ rice\ husk} \times 6)/24} \times 100\ \% \quad (61)$$

RESULTS AND DISCUSSION

With generator power output of 1 MW, the followings results were found.

On modification by implementing RHD in which rice husk is dried before feeding it to furnace, the efficiency of boiler furnace is found to be increased with decrease in moisture content of rice husk, Fig. 3. This is due to the fact that heat is lost in the furnace to evaporate and superheat the moisture present in the rice husk, which is carried by the flue gas. The maximum furnace efficiency was found to be increased by 40.94% compared to Srinivas and Reddy (2014).

The fuel efficiency of the hybrid power plant is found to be increased with the reduction in moisture content of the rice husk in RHD before feeding to the furnace, Fig. 4. It is to be seen that fuel efficiency is increased as working pressure is increased from 30 bar to 40, 50 and 60 bars. The fuel efficiency with decrease

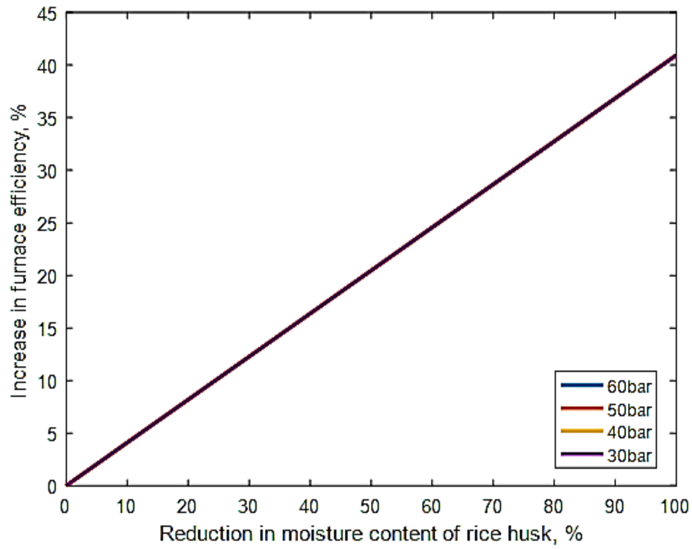

Fig. 3: Furnace efficiency Vs. Reduction in moisture content

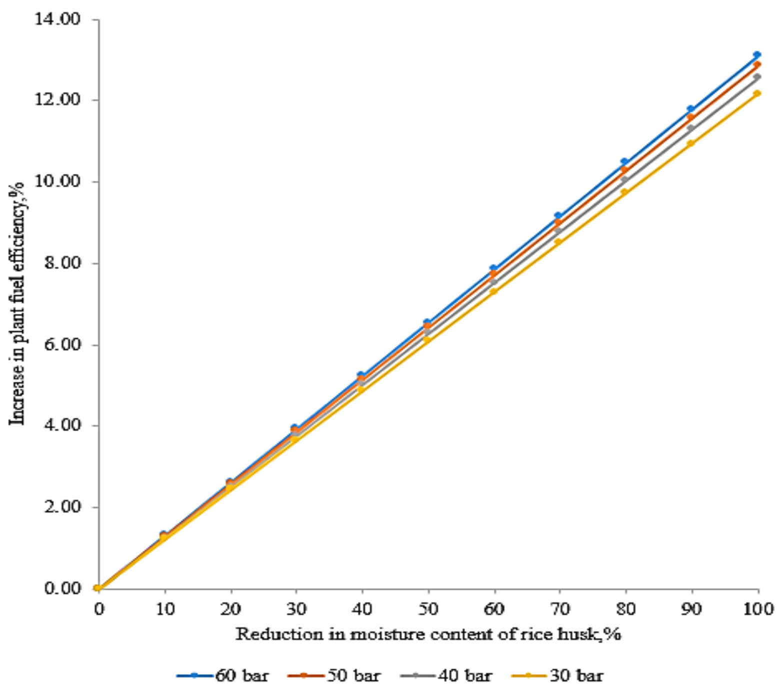

Fig. 4: Increase in fuel efficiency with decrease in moisture content

in moisture content was found to be increased maximum by 12.16%, 12.56%, 12.85% and 13.09% for 30 bar, 40 bar, 50 bar and 60 bar respectively compared to Srinivas and Reddy (2014).

The air supplied to the boiler furnace is found to be decreased on the reduction of moisture content of rice husk, Fig. 5. This is due to the fact that excess air is required to evaporate the moisture present in the rice husk. According to Srinivas and Reddy (2014), excess air required is 80% for combustion of rice husk but this can be reduced by 68.32% for combustion of rice husk on removal of moisture content, which is analyzed through this research.

The plant efficiency is found to be increased as the moisture present in the rice husk is removed before feeding to the boiler furnace, Fig. 6. For 50 bar operating pressure, the plant efficiency with 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%, respectively removal of moisture present in the rice husk was found to be increased by 6.97, 13.83, 20.58, 27.21, 33.74, 40.16, 46.49, 52.71, 58.83 and 64.86%, respectively compared to Srinivas and Reddy (2014). The increment of plant

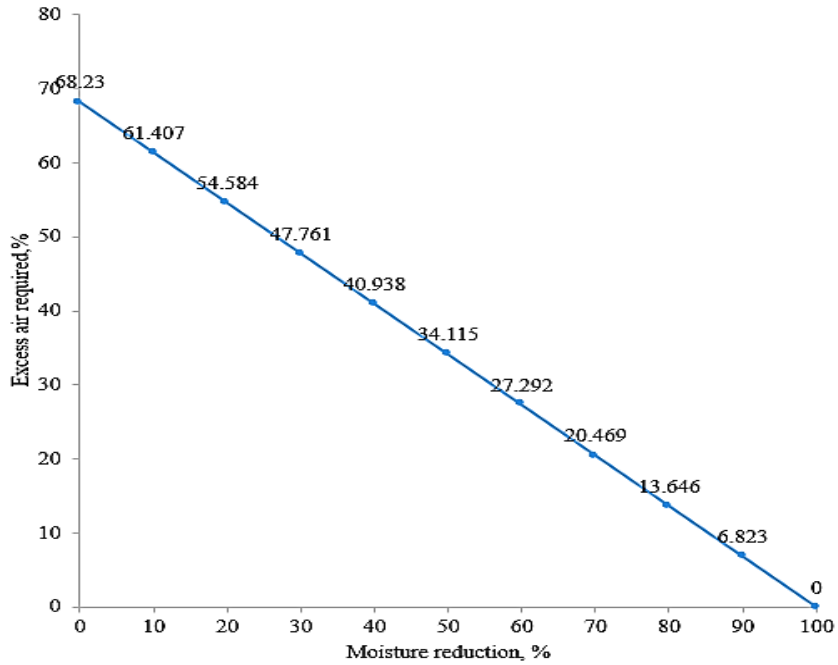

Fig. 5: Moisture reduction Vs Excess air required

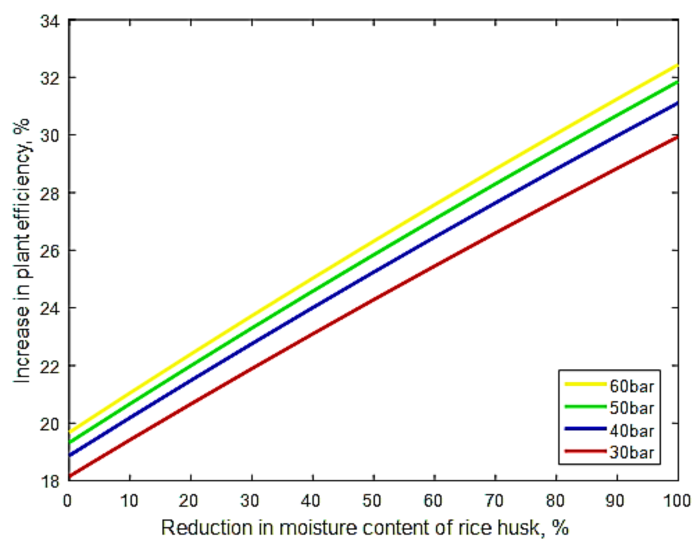

Fig. 6: Increase in plant efficiency with moisture reduction

efficiency was found to lower for 30 and 40 bar operating pressures and higher for 60 bar operating pressure compared to 50 bar operating pressure.

The specific rice husk consumption is found to be decreased as moisture present in the rice husk is removed before feeding to the boiler furnace, Fig. 7. It is also to be noted that specific rice husk consumption is decreased as the operating pressure is increased. For 50 bar operating pressure on removing moisture content of rice husk by 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%, respectively the specific rice husk consumption were found to be 1.75, 1.62, 1.51, 1.42, 1.33, 1.26, 1.19, 1.13, 1.07, 1.02 and 0.98 kg/kWh, respectively. Figure 8 shows the decrease in rice husk consumption with the reduction in moisture content in the rice husk before feeding to the boiler furnace. For 50 bar operating pressure on reduction of moisture content of rice husk by 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%, respectively the rice husk consumption were found to be 0.51, 0.48, 0.44, 0.42, 0.39, 0.37, 0.35, 0.33, 0.31, 0.30 and 0.29 kg/s, respectively. It was found that rice husk fuel consumption was decreased as operating pressure was increased.

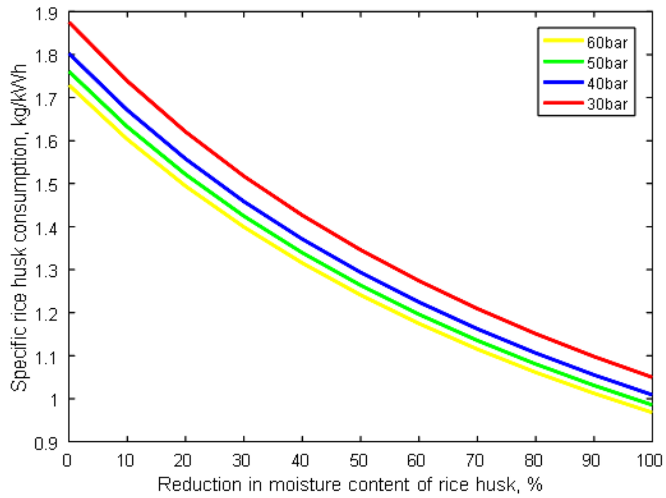

Fig. 7: Specific fuel consumption with moisture reduction in rice husk

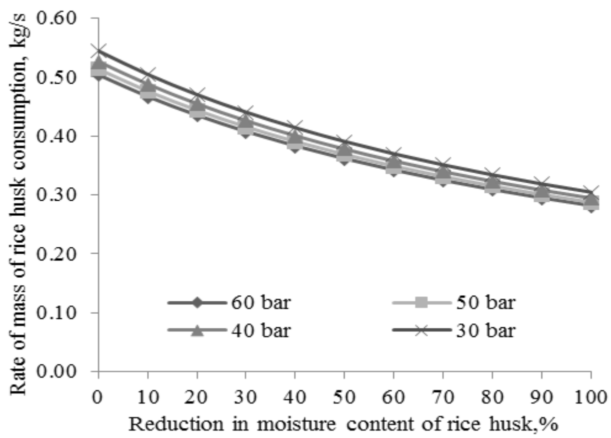

Fig. 8: Decrease in rice husk consumption with decrease in moisture content

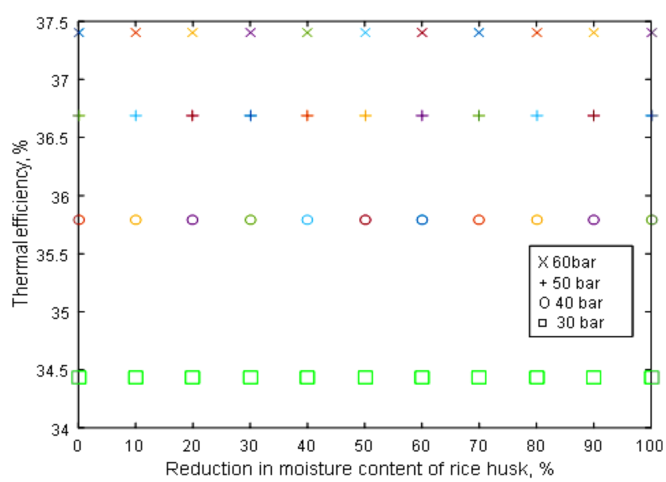

Fig. 9: Thermal efficiency of plant Vs. Operating pressure

The thermal efficiency of plant was found to be increased as operating pressures were increased as compared to Srinivas and Reddy (2014). The thermal efficiencies for 30 bar, 40 bar, 50 bar and 60 bar operating pressures were found to be 34.82, 36.02, 36.92 and 37.64%, respectively, Fig. 9.

CONCLUSION

The existing hybrid plant, on modification with implementing of rice husk dryer between CPH and APH, the heat of the flue gas can be used to dry the rice husk which is hitherto lost in the atmosphere through chimney. The modification is found to increase the overall plant efficiency, reduce in rice husk consumption, increase in fuel efficiency, reduction in specific rice husk consumption, decrease in excess air supply for combustion and increase in furnace efficiency by significant amount.

RECOMMENDATION FOR FURTHER RESEARCH

In the condensation process in the condenser about 61% of total heat is carried out by the cooling water. Such heat can be either used to dry the rice husk or can be used to heat the air supplied for combustion with proper modification in the plant. A proper design for RDH.

ACKNOWLEDGMENT

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Nomenclatures:

CSP	: Concentrated Solar Panel
SH	: Super Heater
EVA	: Evaporator
ECO	: Economizer
CPH	: Condensate Pre Heater
APH	: Air Pre Heater
RDH	: Rice Husk Dryer
$\dot{W}_{genout}$	: Power generated from generator
$\dot{W}_{gen\ in}$	: Power supplied to generator
η_{gen}	: Efficiency of generator
$\dot{W}_{s}$	: Power supplied to turbine shaft
η_{s}	: Turbine shaft efficiency
$\eta_{turbine}$	: Turbine efficiency
w_{th}	: Theoretical work of turbine
w_{act}	: Actual work of turbine
$q_{condenser}$	: Heat loss by steam in condenser
$\dot{q}_{cooling\ water}$	: Total heat gain by cooling water
$\eta_{condenser}$	: Solar collector efficiency
$\dot{m}_{cooling\ water}$	: Rate of mass flow of cooling water
c_{pw}	: Specific heat capacity of water
w_{cp}	: Condenser pump work
$\dot{W}_{cp}$	: Power consumed by condenser pump
w_{fp}	: Feed pump work
$\dot{W}_{cp}$	: Power consumed by feed pump
$\eta_{furnace\ increased}$	: Increase in furnace efficiency
$Air_{excess\ \%}$	: Percentage increase in excess air
$q_{moisture}$	: Heat loss per kg moisture
$\dot{q}_{moisture}$	: Total heat loss from moisture
$\dot{m}_{reduction}$	: Reduction in rice husk consumption
H_{9-1}	: Heat taken by water from boiler
$\dot{q}_{rice\ husk}$	: Heat from rice husk
H_b	: Heat supplied to boiler
$\dot{Q}_h$	: Heat supplied by furnace
$\dot{m}_h$	: Mass consumption of rice husk
$\eta'_{furnace}$	: Efficiency of furnace after drying rice husk
H_{wc}	: Heat shared by solar collector
h_{sup}	: Enthalpy gained by steam from solar collector in SH
$\dot{Q}_c$	: Heat gained by solar collector
$\dot{m}_{total}$	: Total rice husk consumption
η_{fuel}	: Fuel efficiency of plant
η_{th}	: Thermal efficiency of plant
η_{plant}	: Efficiency of plant
$\dot{q}_{rice\ husk}$	: Heat of rice husk

Suffix:

N	: For night
D	: For day.

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