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Thermodynamics Analysis of Rice Husk Fired Furnace

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Key words: Energy, efficiency, energy losses, drying temperature, moisture reduction, specific rice husk consumptions

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Abstract: The main objective of this research is to make thermodynamics analysis of rice husk fired furnace used in solar-rice husk hybrid steam power plant with moisture reduction of rice husk in Rice Husk Dryer at different temperature before feeding to the furnace. Rice husk is dried by passing flue gas to Rice Husk Dryer in counter flow direction. Feeding with dry rice husk at different temperature was found to increase plant fuel efficiency, to increase in furnace efficiency and to decrease in specific rice husk consumption. The result showed that specific fuel consumption was reduced from 1.761-0.974 kg kWh^{-1} at 110°C for 50 bar operating pressure on reduction of moisture from 0-100%. Furnace efficiency was found to increase from 52-94.05% at 110°C temperature on moisture removal from 0-100%. Plant fuel efficiency was found to increase from 16.23-29.32% at 50 bar on removing moisture content from 0-100% for drying temperature of 110°C. The efficiency of furnace increased with moisture removal before feeding to furnace was validated with actual rice husk fired furnaces. The difference of results of this research with actual furnaces for efficiency increment with moisture reduction of rice husk were found to be 0.04 and 0.09% only on 25% removal of moisture content.

INTRODUCTION

Energy demand is increasing rapidly all over the world. It is assumed that the supplies of major fossil fuel resources such as coal and oil will be depleted in about three decades. Alternately, the biomass, renewable source of energy from plants and animals can substitute the fossil fuel at lower environment impact. The biomass can be used to generate both heat and electricity to increase the economic development without increasing significant greenhouse effects to atmosphere[1]. Rice husk is the one of the major renewable resource for the agricultural based countries. One ton of rice paddy can produce 220 kg of rice husk[2]. The caloric value of rice husks lies between 13-19 MJ kg^{-1}; the average is closer to the higher heating value of 18 MJ kg^{-1}[3] and 12600 kJ kg^{-1}[4]. The rice husk fired furnace are mostly used most of the countries to generate steam in boiler for various purposes.

Rice husk fired furnace has become popular for steam power plant in combination with solar collector. Thus, rice husk fired furnace may play major role in improving the plant efficiency, plant fuel efficiency, etc. if the furnace efficiency is increased. Lee and Jou[5] had pointed that decreased in excess air supplied to the furnace by 1%, increases the furnace efficiency by 0.6%. About 10% reduction in excess air increases boiler efficiency by 0.5%. About 20°C reduction in flue gas temperature increases the boiler efficiency by 1%[6]. Munir *et al*.[6] has mentioned that the major losses were due to incomplete combustion, moisture in the fuel and dry flue gas loss. Singh *et al*.[7] has mentioned that the rice husk furnace efficiency obtained was 80% where 110% excess air was supplied to the furnace. Yadav *et al*.[4] has mentioned that the efficiency of furnace can be improved by supplying dry rice husk to the furnace by implementing Rice husk Dryer (RHD) in between Condensate Pre Heater (CPH) and Air Pre Heater (APH).

Yadav *et al*.[4] has only considered the moisture reduction and not the temperature at which the moisture is removed. In this research, the heat saved due to the temperature at which moisture is removed is taken into account. If the various temperature at which moisture is removed in RHD is taken into account, the furnace efficiency can be improved. The main propose of this research to find out the furnace efficiency, specific rice husk (fuel) consumption and fuel efficiency for certain output of steam power plant on the basis of moisture reduction of rice husk at different temperature in RHD and validation of furnace efficiency with actual rice husk fired furnace.

MATERIALS AND METHODS

The Rice Husk Dryer (RHD) implementation by Yadav *et al*.[4] is shown in Fig. 1. Between the Condensate Pre Heater (CPH) and Air Pre Heater (APH) that is between points 24 and 25, the RHD is implemented. Figure 2 shows the proposed rice husk dryer by Yadav *et al*.[4], in which point 24 is feeding rice husk to RHD and point 25 is the outlet from the RHD after drying the rice husk. The point 19 indicates the inlet of flue gas to RHD coming from Condensate Pre Heater (CPH) and point 24 is the exit of flue gas from RHD or inlet to Air Pre Heater (APH) of steam power plant.

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%[4]. The performance of rice husk furnace is evaluated for 60, 50, 40 and 30 bar boiler pressures and for 110°C, 100°C, 90°C, 80°C and 70°C drying temperatures in RHD. The average moisture content of rice husk is taken as 15.1% which was found during laboratory test at Asian Thai Food Pvt. Ltd., Sonapur, Sunsari, Nepal. The testing were carried out for 115°C temperature. The followings are the formulae developed for the performance analysis of the rice husk furnace. The proximate and ultimate analysis of rice husk is shown in Table 1[8].

Table 1: Proximate and ultimate analysis of rice husk

Proximate analysis		Ultimate analysis	
Property (%)	Wt. (%)	Property (%)	Wt. (%)
Moisture	6.1	Carbon	36.40
Ash	20.6	Hydrogen	4.84
Volatile matter	58.4	Oxygen	25.11
Fixed carbon	14.9	Nitrogen	0.44
Calorific value (kJ kg^{-1})	3420.0	Sulfur	0.17

On the basis of this ultimate analysis, the minimum air required for combustion of rice husk in the furnace is calculated using the formula[9]:

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

The air required for rice husk combustion for 15.1% moisture content of rice husk was calculated using the formula[8]:

$$\begin{aligned}&(CH1.6178O0.7389N0.0139)\ \text{Rice husk}+\\&1.9249(O_2+3.76\ N_2)\ \text{air}+(0.151\ H_2O)\ \text{moisture}=\\&(CO_2+0.9599\ H_2O+0.86650\ O_2+7.2376\ N_2)\\&\text{product gas}\end{aligned} \quad (2)$$

The air required for combust of dry rice husk was calculated using the formula[4]:

$$(CH_{1.6178}O_{0.7389}N_{0.0139})_{\text{Rice husk}}+1.035\ (O_2+3.76= CO_2+0.8089\ H_2O+3.8916\ N_2 \quad (3)$$

The air required for moist and dry rice husk for its combustion were found from Eq. 2 and 3, respectively and difference gave the excess air required due to the presence of moisture in the rice husk. The efficiency of furnace increased is given by Eq. 4[5]:

$$\eta_{\text{furance increased}}=0.6\times Air_{\text{excess\%}} \quad (4)$$

Thus, the efficiency of the furnace is given by Eq. 5:

$$\eta'_{\text{furance}}=\eta_{\text{furance}}+\eta_{\text{furance increased}} \quad (5)$$

Heat loss from per kg moisture, the modified equation of Yadav *et al*.[4]:

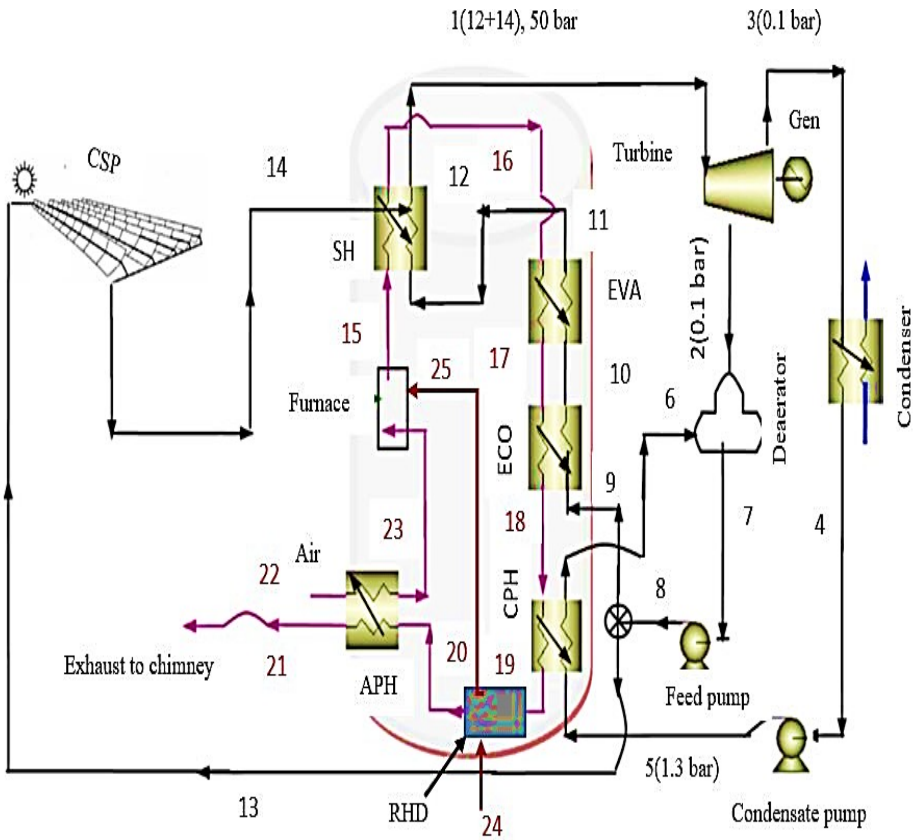

Fig. 1: Implementation of RHD in power plant between CPH and APH[4]

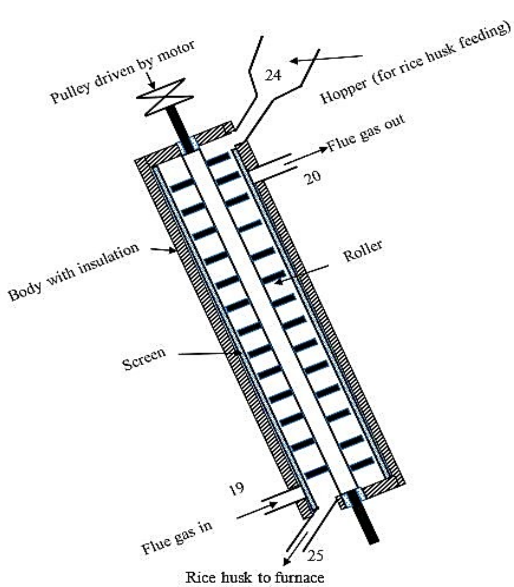

Fig. 2: Proposed RHD[4]

$$q_{moisture} = \{c_{pw} \times (t_{sat} - t_0) + L_v + c_{ps} \times (t_1 - t_{sat})\} - \{c_{pH}(t - t_0)\},\ kJ\ kg^{-1} \quad (6)$$

Total heat loss from moisture which is saved upon drying:

$$\dot{q}_{moisture} = q_{moisture} \times \dot{m}_{moisture},\ kW \quad (7)$$

Rate of rice husk reduction in consumption:

$$\dot{m}_{reduction} = \frac{\dot{q}_{moisture}}{CV\ of\ rice\ husk}, \frac{kg}{s} \quad (8)$$

Total mass of rice husk consumption:

$$\dot{m}_{total} = [(\dot{m}_{hN} \times 12) + (\dot{m}_{hD} \times 6)]/18\ kg\ sec^{-1} \quad (9)$$

$$\dot{m}_{hD} = \frac{\dot{Q}_{hD}}{12600}\ kg\ sec^{-1} \quad (10)$$

$$\dot{m}_{hN} = \frac{\dot{Q}_{hN}}{12600}\ kg\ sec^{-1} \quad (11)$$

$$\dot{Q}_{hN} = \frac{H_{bN}}{\eta'_{furance}}\ kW \quad (12)$$

$$\dot{Q}_{hD} = \frac{H_{bD}}{\eta'_{furance}}\ kW \quad (13)$$

$$H_{bD} = \frac{H_{D9-1}}{\eta_b}\ kW \quad (14)$$

$$H_{D9-1} = H_1 - \dot{m}_c \times h_{14}\ kW \quad (15)$$

$$H_{bN} = \frac{H_{9-1}}{\eta_b}\ kW \quad (16)$$

$$H_{N9-1} = H_1 - \dot{m}_1 \times h_8\ kW \quad (17)$$

$$\text{Fuel efficiency of plant, } \eta_{fuel} = \frac{\dot{W}_{net}}{\dot{m}_{total} \times \text{CV of rice husk}} \times 100\% \quad (18)$$

$$\text{Specific fuel consumption} = \frac{\dot{m}_{total} \times 3600}{\dot{W}_{net}}\ kg\ kWh^{-1} \quad (19)$$

RESULTS AND DISCUSSION

The furnace efficiency with reduction in moisture content of rice husk in RHD at different temperature were found and is shown in Fig. 3. According to Yadav *et al*.[4], the maximum furnace efficiency on 100% moisture removal of rice husk was 90.94%. But, as per this research the same efficiency was found to be 93.53, 93.66, 93.79, 93.92 and 94.05% on RHD temperature of 70°C, 80°C, 90°C, 100°C and 110°C, respectively (Fig. 3).

The specific fuel (Rice Husk) consumption for 1 MW output of steam power plant was calculated and was found as shown in Fig. 4-8. The specific fuel (Rice Husk) as per Yadav *et al*.[4] was 0.967 kg kWh^{-1} on 100% removal of moisture content of rice husk at 60 bar operating temperature. But, in this research, the same was found to be reduced to 0.962, 0.961, 0.959, 0.958 and 0.957 kg kWh^{-1}, respectively at 70°C, 80°C, 90°C, 100°C and 110°C at 60 bar operating temperature.

The plant fuel efficiency obtained by Yadav *et al*.[4] for 60, 50, 40 and 30 bar pressures are shown in Fig. 9. In this research, when temperature of RHD was considered, the plant fuel efficiency was found to be increased. For 50 bar pressure, the fuel efficiency as per Yadav et al is 29.00% (Fig. 9). According to this research for same 50 bar pressure, the fuel efficiency found is 29.32, 29.29, 29.25, 29.21 and 29.17%, respectively for RHD temperature of 110°C, 100°C, 90°C, 80°C and 70°C (Fig. 10-14).

Pressure analysis of RHD: For the pressure analysis of RHD, the following dimensions are taken:

- Length of RHD, L = 1.5 m
- Diameter of cover of RHD, D = 37 cm
- Diameter of screw, d = 34.4 cm
- Gap between cover and screw = 37-34.4/2 = 2.6/2 = 1.3 cm

For screw:
- N = 26 rpm
- Velocity, v = π×d×N/60 = 0.5 m/s
- $A = \pi \times 0.344^2/4 = 0.0929$
- Power, W' = F×v
- Or, F = w'/v = 7/0.5 = 14 kN
- Force, $F_s = P \times A \Rightarrow P = F_s/A = 14/0.0929 = 150.7$ kPa

For rice husk:
- Density, ρ = 221 kg m^{-3}
- Area, $A = \pi \times 0.344^2/4 = 0.0929\ m^2$
- Volume of rice husk, $V = A \times L = 0.1349\ m^3$
- Force of rice husk, $F_h = \rho \times V \times g = 221 \times 0.1394 \times 9.81 = 0.302$ kN
- Pressure due to rice husk, $P_h = F_h/A = 0.302/0.0929 = 3.25$ kPa
- Force due to atmosphere, $F_0 = P_0 \times A = 101 \times 0.0929 = 9.3829$ kN
- Total pressure, $P_{total} = 150.7+3.25+101 = 254.95$ kPa
- Total force, $F_{total} = F_s+F_h+F_0 = 14+0.302+9.3829 = 9.7924$ kN

Pressure calculation for flue gas:
- Combustion chamber temperature
- $T_c = 850+273 = 1123$ K
- $T_{19} = 224.16+273 = 497.16$ K
- $T_{20} = 152.6+273 = 425.6$ K
- $P_c/T_c = P_{19}/T_{19} \Rightarrow 5000/1123 = P_{19} = 2213.5$ kPa

The pressure P_{19} is reduced to 1/8th time by throttling the flue gas and then led to the RHD using Bernoulli's equation:

$$\frac{P_{19}}{\rho g} + \frac{V_{19}^2}{2g} + Z_{19} = \frac{P_{20}}{\rho g} + \frac{V_{20}^2}{2g} + Z_{20}$$

Assuming, $Z_{19} = Z_{20}$:

$$P_{20} = \frac{1}{8} P_{19}$$

Then:

$$\frac{P_{19}}{T_{19}} = \frac{P_{20}}{T_{20}} \Rightarrow \frac{\frac{2213.5}{8}}{497.16} = \frac{P_{20}}{425.6} \Rightarrow P_{20} = 236.9\ kPa$$

Since, pressure at 20 point is <24 point, the flue gas does not pass up through rice husk feeder.

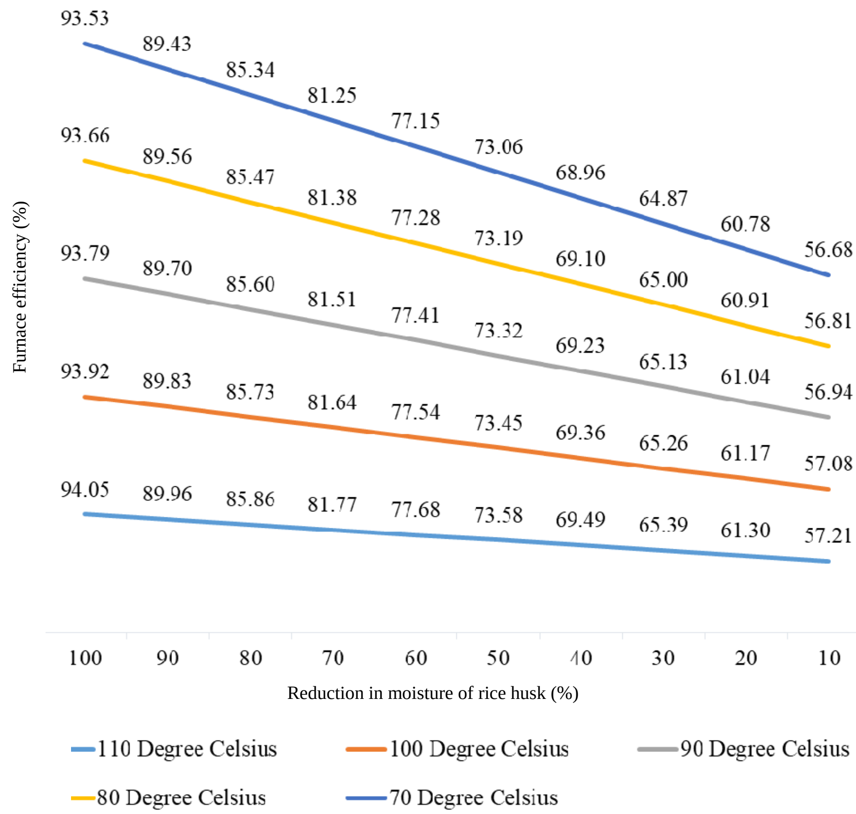

Fig. 3: Furnace efficiency vs. moisture reduction of rice husk at different RHD temperature

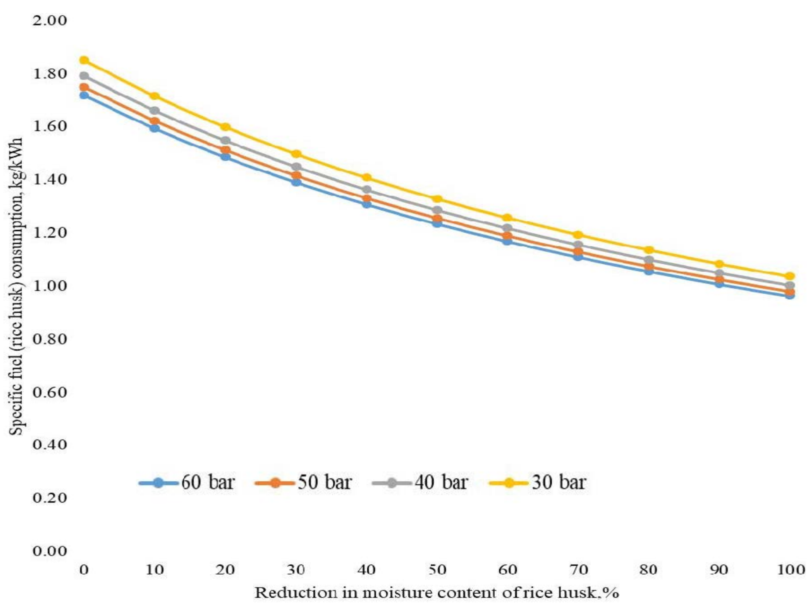

Fig. 4: Specific rice husk consumption vs. moisture reduction in rice husk[4]

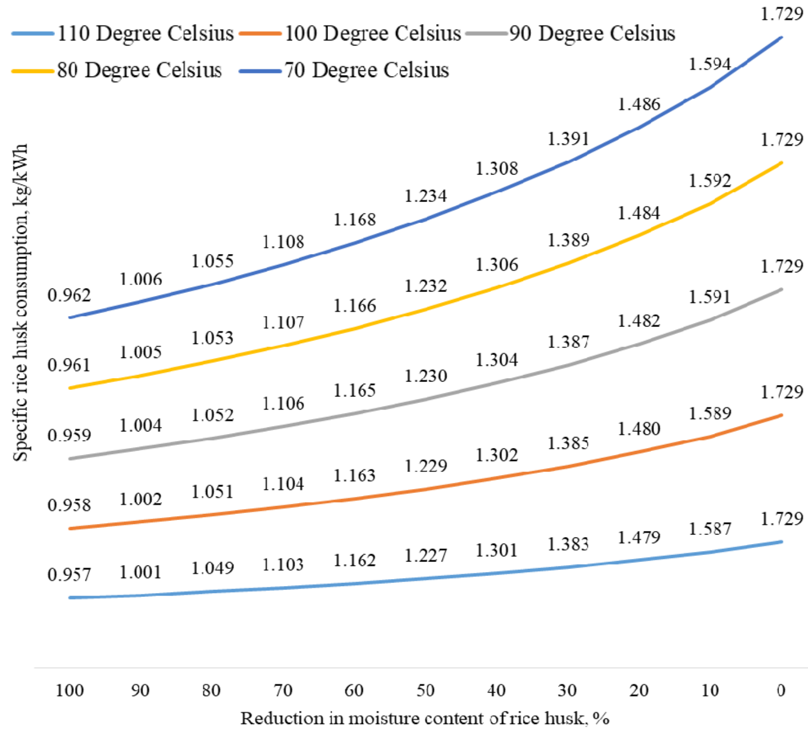

Fig. 5: Specific rice husk consumption vs. moisture reduction in rice husk for 60 bar

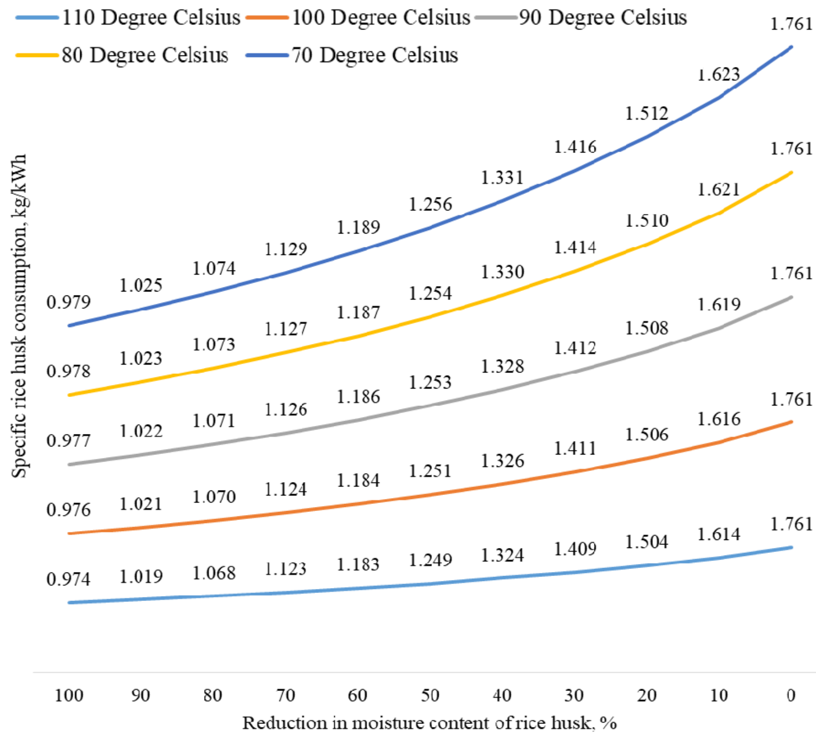

Fig. 6: Specific rice husk consumption vs. moisture reduction in rice husk for 50 bar

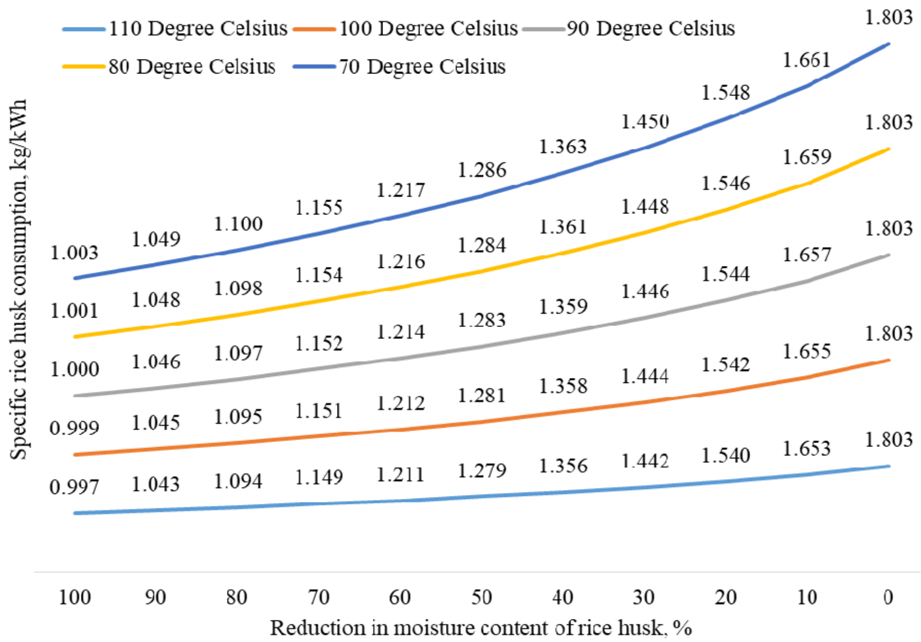

Fig. 7: Specific rice husk consumption vs. moisture reduction in rice husk

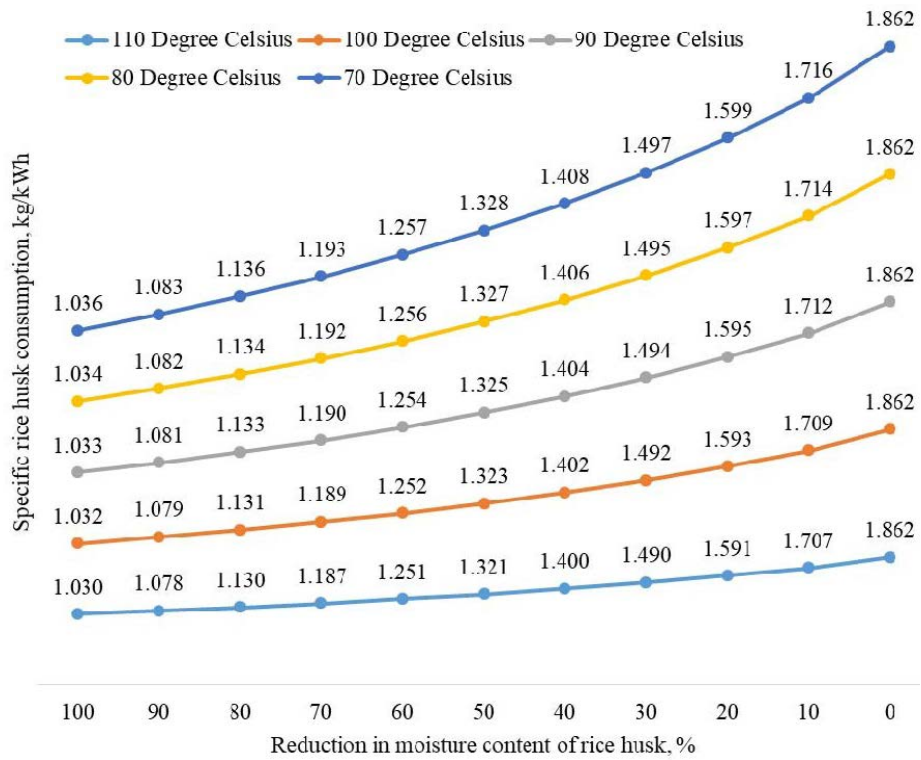

Fig. 8: Specific rice husk consumption vs. moisture reduction in rice husk

Validation of the research: The research was validated with the rice husk fired furnace of Asian Thai Food (P) Ltd. and Pashupati Khadhya Tel Udhyog Pvt. Ltd., Sonapur, Sunsari, Nepal.

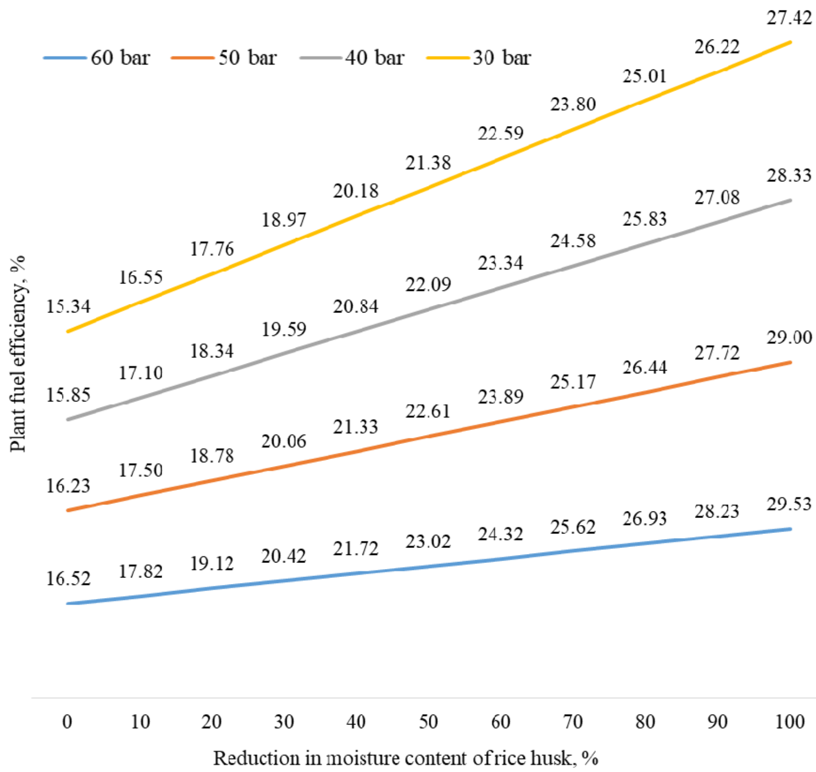

Fig. 9: Plant fuel efficiency vs. moisture reduction[4]

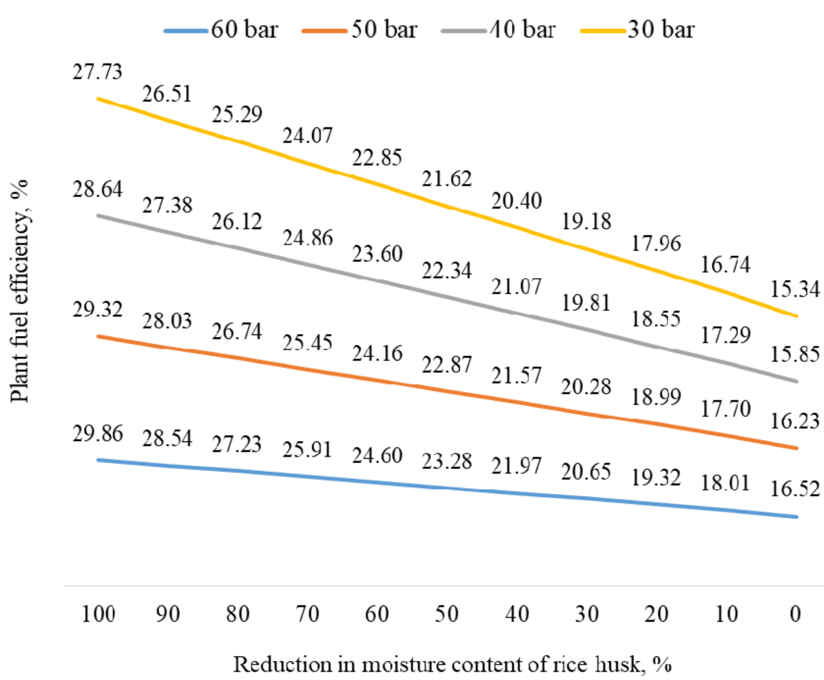

Fig. 10: Plant fuel efficiency vs. moisture reduction for 110°C RHD temperature

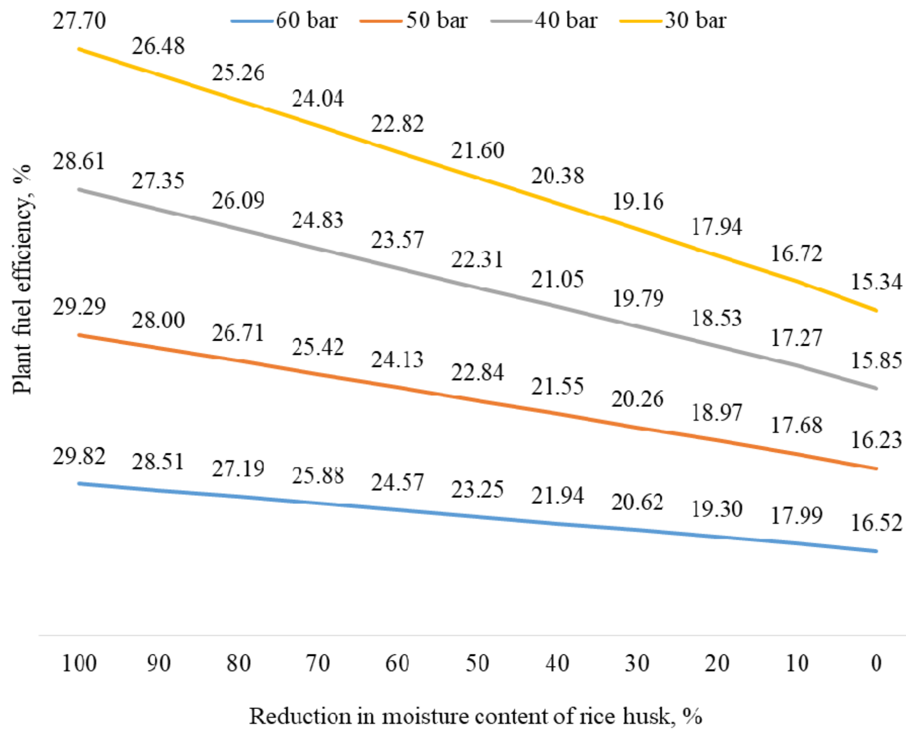

Fig. 11: Plant fuel efficiency vs. moisture reduction for 100°C RHD temperature

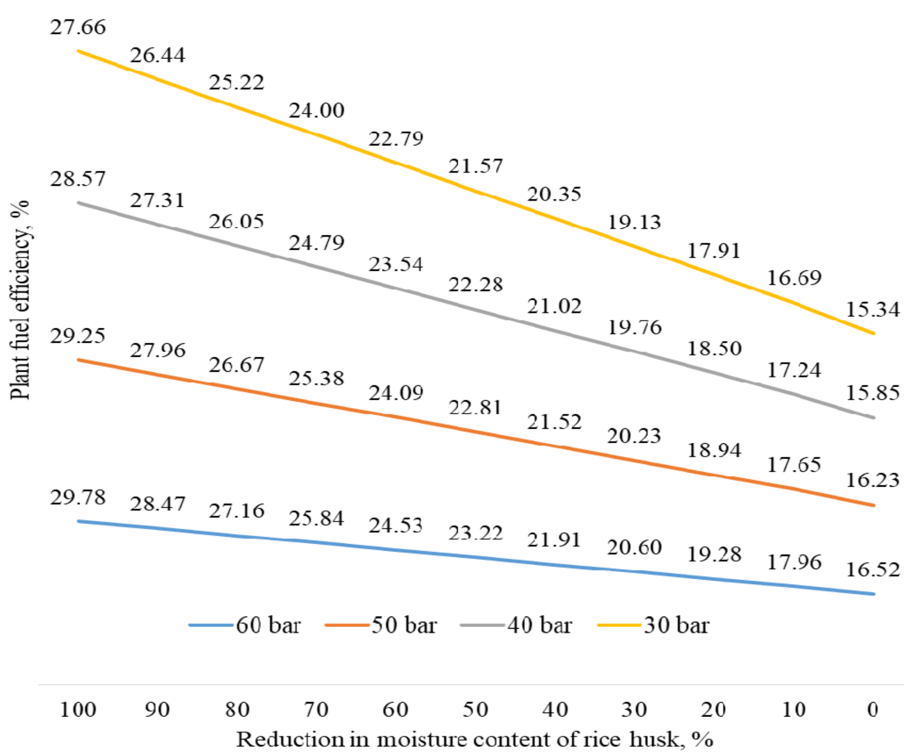

Fig. 12: Plant fuel efficiency vs. moisture reduction for 90°C RHD temperature

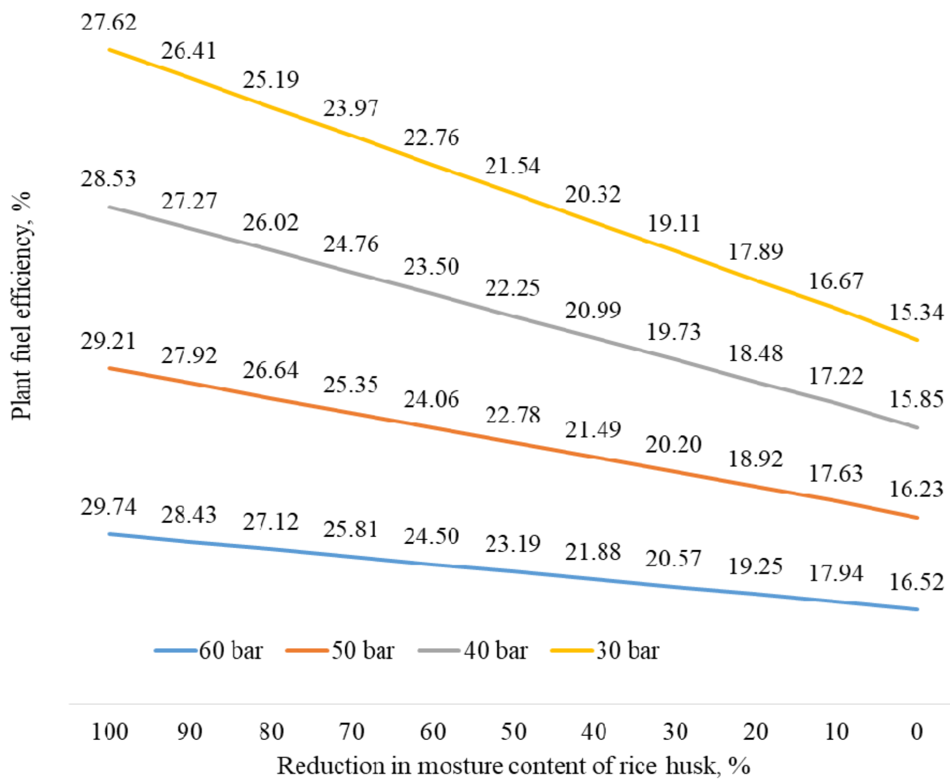

Fig. 13: Plant fuel efficiency vs. moisture reduction for 80°C RHD temperature

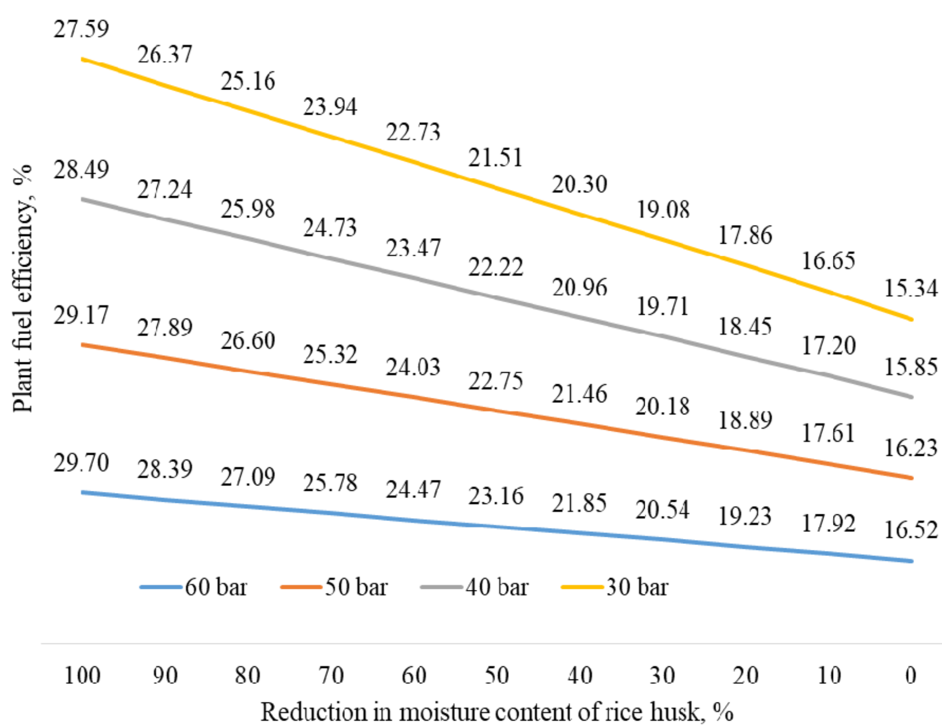

Fig. 14: Plant fuel efficiency vs. moisture reduction for 70°C RHD temperature

Fig. 15: Rice husk fired furnace of Asian Thai Food, Sonapur, Sunsari, Nepal

For Asian Thai Food (P) Ltd.: The research was validated with the rice husk furnace of Asian Thai Food (P) Ltd. shown in Fig. 15. The efficiency of Asian Thai Food furnace was found with 15 and 20% moisture content of rice husk.

For 15% moisture present in rice husk:

- For 15% moisture
- Steam production = 6 ton h^{-1} = 6×1000/3600 = 1.67 kg sec^{-1}
- Enthalpy of water at 1 bar, 25°C = 417.51 kJ kg^{-1}
- Enthalpy of superheated steam at 15 bar 200°C = 2796.1 kJ kg^{-1}
- Enthalpy required to produce steam at 15 bar, 200°C = 2796.1-417.51 = 2378.59 kJ kg^{-1}
- Energy required to produce steam = 1.76×2378.59 = 3964.32 kW
- Energy supplied to boiler by furnace = 3964.32/0.9 = 4404.80 kW
- Mass of rice husk consumed = 2150 kg h^{-1} = 0.60 kg sec^{-1}
- Energy from rice husk to furnace = 0.60×12600 = 7525 kW
- Efficiency of furnace = 4404.80/7525 = 58.54%

For moisture content of 20%:

- Mass of rice husk consumed = 2600 kg h^{-1} = 0.72 kg sec^{-1}
- Energy from rice husk to furnace = 0.72×12600 = 9100 kW
- Efficiency of furnace = 4404.80/9100 = 48.40%
- Increase in furnace efficiency on 25% removal of moisture content = 58.54-48.40 = 10.14%
- As per research result the increment of furnace efficiency on 25% moisture removal of rice husk = 10.23%

Fig. 16: Furnace of Pashupati Khadhya Tel Udhyog, Sonapur, Sunsari, Nepal

- Difference of research result and actual plant result = 10.23-10.14 = 0.09%
- This validates the research result in which variation of research with actual plant is only by 0.09% when moisture content is reduced by 25%

For Pashupati Khadhya Tel Udhyog: Similarly, the furnace efficiency of Pashupati Khadhya Tel Udhyog (p) Ltd. was found for 15 and 20% moisture content of rice husk. The furnace is shown in Fig. 16.

For 15% moisture content of rice husk:

- Steam production = 6 ton h^{-1} = 6×1000/3600 = 1.67 kg sec^{-1}
- Enthalpy of water at 1 bar, 25°C = 417.51 kJ kg^{-1}
- Enthalpy of superheated steam at 15 bar 250°C = 2914.08 kJ kg^{-1}
- Enthalpy required to produce steam at 15 bar, 250°C = 2914.08 -417.51 = 2496.57 kJ kg^{-1}
- Energy required to produce steam = 1.67×2496.57 4160.95 kW
- Energy supplied to boiler by furnace = 4160.95/0.9 = 4623.28 kW
- Mass of rice husk consumed = 2200 kg h^{-1} = 0.61 kg sec^{-1}
- Energy from rice husk to furnace = 0.61×12600 = 7700 kW
- Efficiency of furnace = 4623.28/7700 = 60.04%

For moisture content of 20%:

- Mass of rice husk consumed = 2650 kg h^{-1} = 0.74 kg sec^{-1}
- Energy from rice husk to furnace = 0.74×12600 = 9275 kW

- Efficiency of furnace = 4623.28/9275 = 49.85%
- Increase in furnace efficiency on 25% removal of moisture content = 60.04-49.85 = 10.19%
- As per research result the increment of furnace efficiency on 25% moisture removal of rice husk = 10.23%
- Difference of research result and actual plant result = 10.23-10.19 = 0.04%
- This validates the research result in which variation of research with actual plant is only by 0.04% when moisture content is reduced by 25%

CONCLUSION

On considering the drying temperature during moisture reduction in RHD, the furnace efficiency and plant fuel efficiency were found to be increased and specific rice husk consumption was found to be decreased by significant amount.

NOMENCLATURES

$\eta_{furance}$ = Efficiency of furnace assumed (%)
$\eta_{furance\ increase}$ = Efficiency of furnace increased due reduction in excess air (%)
$\eta'_{furance}$ = Final efficiency of furnace after reduction in moisture content of rice husk (%)
$q_{moisture}$ = Heat loss per kg of moisture in flue gas (kJ kg^{-1})
c_{pw} = Specific heat capacity of water (kJ kg^{-1})
t_{sat} = Saturation temperature of water (°C)
t_0 = Atmospheric temperature (°C)
t_1 = Temperature of steam (°C)
c_{pH} = Specific heat capacity of rice husk, (kJ kg^{-1} K)
t = RHD temperature at which rice husk is dried (°C)
$q'_{moisture}$ = Total heat loss saved due to moisture reduction in flue gas (kW)
$m'_{moisture}$ = Total mass of moisture removed upon drying (kg sec^{-1})
$m'_{reduction}$ = Rate of reduction in rice husk consumption (kg sec^{-1})
m'_{total} = Total rice husk consumption (day+Night) (kg sec^{-1})
m'_{hD} = Total rice husk consumption in day (kg sec^{-1})
m'_{hN} = Total rice husk consumption in night (kg sec^{-1})
Q'_{hN} = Heat supplied by furnace to boiler in night (kW)
Q'_{hD} = Heat supplied by furnace to boiler in day (kW)
H_{bD} = Heat of boiler in day (kW)
H_{D9-1} = Heat taken by water from boiler in day, kW
H_{bN} = Heat of boiler in night (kW)
H_{N9-1} = Heat taken by water from boiler in night (kW)
W'_{net} = Net output of plant (kW)

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