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Short communication

Improving the power-to-heat ratio in CHP plants by means of a biofuel multistage drying system ☆

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Abstract

In biofuel drying in industrial power plants, a new multistage drying system (MSDS) can now be applied before combustion. By reducing the drying air mass flow, MSDS makes it possible to use a proportion of the combustion air in drying, and to lead that moist drying air into the combustion stages of the power plant boiler. MSDS increases the power-to-heat ratio and capacity of the power plant compared to power plants without drying systems. Previous increases came from biofuel homogenization and increased energy efficiency. Biofuel homogenization also reduces unburned organic emissions as a result of more complete combustion. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Multistage biofuel drying system; Power-to-heat ratio; CHP; Integrated pulp and paper mill; Decreasing emissions

1. Introduction

A scheme illustrating the integration principle of the steam boiler–multistage drying system is shown in Fig. 1.

Wet biofuel is pre-heated and pre-dried in the first drying stage with air, which is heated up with process secondary energy. The exhaust air from the first drying stage can be vented to atmosphere because the organic emissions from wood drying under temperatures of 100 °C are not significant [4]. The pre-dried biofuel is led into the second drying stage in which the feed temperature of

☆ Calculations are applied to wood (i.e. wood-based biomass) drying.

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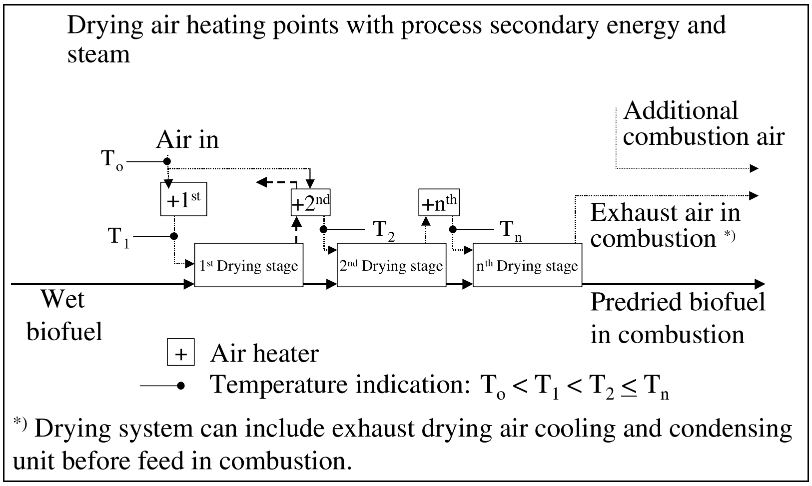

Fig. 1. Biofuel multistage drying system in a CHP plant [1–3].

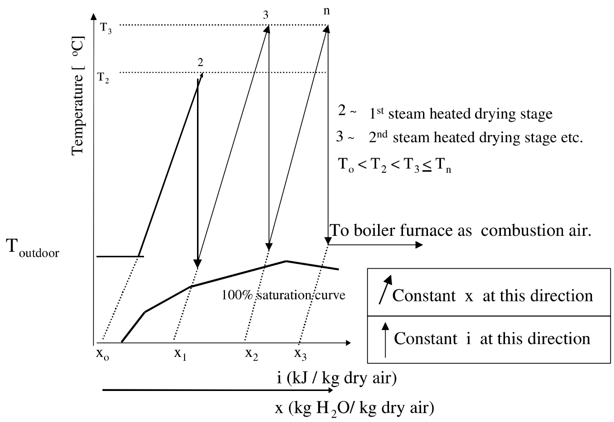

Fig. 2. Drying air moisture content increase in steam heated parts of MSDS shown in standard Mollier i, x-diagram as Salin–Soininen perspective transformation.

atmospheric drying air depends on backpressure steam temperature. The drying air temperatures in the third to nth drying stages depend on the temperature of the extraction steam. The MSDS may have a condensing scrubber that decreases the water content of exhaust drying air before feeding it, together with combustion air, into the power plant boiler. The progress of moisture increase of drying air in steam heated drying stages of MSDS is shown in the Mollier diagram in Fig. 2.

The power-to-heat ratio r of a CHP plant is determined as the ratio of output power to heat in the steam system for the usage of integrated pulp and paper mill after decreasing the internal power and heat consumption of the main process equipment [5]. Different heat losses to the atmosphere are not taken into account in the calculated results. Additional process values are given in the text.

2. Calculated results [1]

2.1. Optimal number of drying stages in a multistage drying system

Compared to a CHP plant without an MSDS installation, biomass pre-drying in MSDS enhances power production, but drying consumes heat. If the amount of solids in combustion is not increased, the net heat in the steam system to be used for pulp and paper integration decreases [2,3]. MSDS is regarded as an open system if it contains drying stages from which exhaust drying air is partially outpurged into the atmosphere. A CHP plant with an open MSDS installation gives greater CHP production than a CHP plant with a closed MSDS structure. Process secondary energy utilization in drying can be transferred directly to the fuel effect growth of the combustor, which accomplishes simultaneous power and heat production increases in the CHP plant without increasing the capacity of the combustor to burn solids [2,3]. A high degree of wood drying increases power production. High heat production rates come from secondary process energy utilization in drying and minor biofuel pre-drying. The closed MSDS structure, consisting of two steam heated drying stages, is enough for wet wood drying before combustion, because, from the point of view of process control and operation, that kind of MSDS structure will be easier to operate than an MSDS structure that includes more drying stages. A closed MSDS structure with two drying stages is enough to take all exhaust drying air from MSDS into the focused wood and peat combusting CHP plant boiler, together with the total combustion air feed. Increasing the number of drying stages increases the heat for use by the integrated pulp and paper mill, but may decrease power production because of the increasing internal power consumption of the process equipment.

2.2. Changes in CHP production with auxiliary process equipment installations in the open multistage drying system, which includes three drying stages

2.2.1. Addition of secondary energy recovery heat exchanger to focused open MSDS structure

Secondary energy recovery is accomplished by the indirect heating of feed drying air into the second drying stage with exhaust drying air from the first drying stage, as shown in Fig. 1. In Fig. 3, the influence of secondary energy recovery on the net output values of CHP plant is shown as a function of wood end moisture from drying.

Secondary energy recovery has no special effect on net power production (see Fig. 3), but it has an effect on the net value of heat that may be used in integrated pulp and paper mills. An air–air heat exchanger increases drying air fan power. Secondary energy recovery decreases the use of extraction and backpressure steams in drying, which increases the net heat useful for integrated pulp and paper mills.

[1] The notation $57.5\text{-}55 \cdots x$[wt% H_2O_{tot}], which is referred in all calculations, means the following wood drying sequence: moisture in first drying stage, moisture in second drying stage to moisture out of MSDS. First drying stage drying efficiency is constant in all calculation points. Outdoor temperature and relative humidity, RH, in all calculations are 10 °C and 60%.

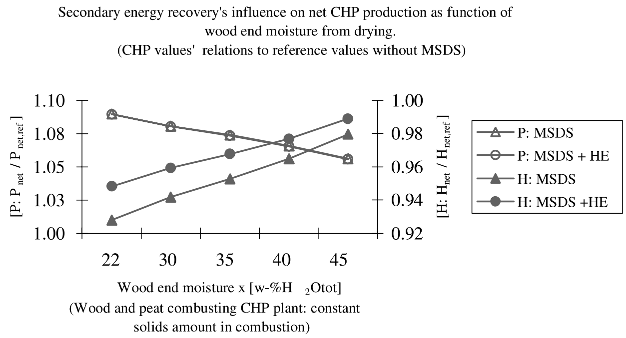

Fig. 3. Influence of a secondary energy heat recovery exchanger on CHP capacity as a function of wood pre-drying. (HE = heat exchanger, P = power, H = heat). Wood sphere diameter = 10 mm and drying air velocities in all drying stages are 2 m/s.

2.2.2. Addition of condensing scrubber to focused open MSDS structure

In Fig. 4, the influences on flue gas mass flows from the combustion of the secondary energy drying stage exhaust drying air outpurge, and of the exhaust drying air condensing scrubber of the last drying stage are shown as wood end moisture functions.

In Fig. 4, the first decrease in flue gas mass flow from combustion compared to flue gas mass flow from the CHP plant without MSDS and with closed MSDS installation results from drying air partial outpurge. The second decrease results from the influence of the condensing scrubber on the humidity of combustion air. In the modernization of CHP plants, the partial outpurge of water and the condensing scrubber enable a solid increase in combustion and the maintenance of flue gas mass flow from combustion relatively equally when compared to the CHP plant without MSDS installation.

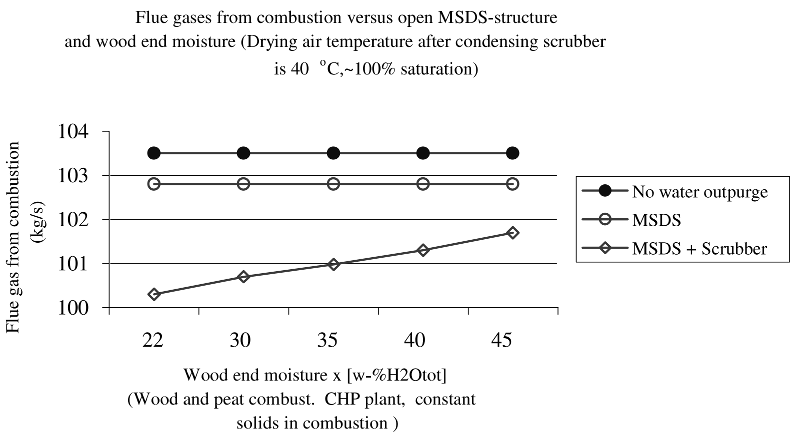

Fig. 4. Influences of partial drying air outpurge and condensing scrubber on flue gas mass flow from combustion as a function of wood end moisture. The excess air factor for combustion is 1.2 in all calculations.

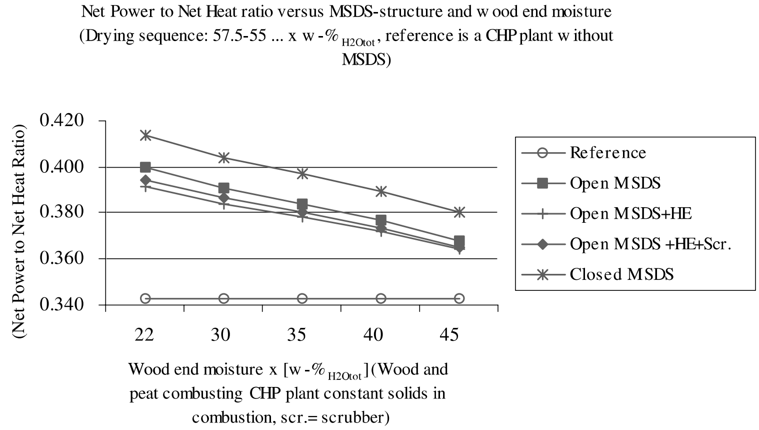

Fig. 5. Influences of combinations of multistage drying system on CHP plant power-to-heat ratio as a function of wood end moisture.

2.3. Summary of net power-to-net heat ratios with different MSDS combinations

Fig. 5 shows summary of the influences of different MSDS-structures on power-to-heat ratios as a function of wood end moisture in focused CHP plant. The more the wood is pre-dried in MSDS, the higher is the power-to-heat ratio growth of CHP plant when compared to the reference plant without MSDS.

3. Internal heat recovery in different multistage drying systems in focused CHP plant

In Table 1, heat recovery rates are shown as a function of drying stage number in MSDS. In Table 2, the corresponding condensate water mass flows and temperatures from the drying operations shown in Table 1 are shown. Heat recovered in the scrubber water cooling system is not included in the calculated power-to-heat ratios, because the cooling water outlet temperature from the scrubber water cooler is lower than lowest condensate temperature in the steam system.

Table 1
Heat recovery rates in different open MSDS structures in a CHP plant

Drying stages' number	Heat from first drying stage exhaust air (MW_{heat}): A	Heat from scrubber water circulation (MW_{heat}): B	(B) of total drying heat consumption in MSDS (%)
3	1.75	7.60	34.40[a]
4	1.08	9.90	46.00[a]
5	0.77	10.80	51.00[a]

Condensates are excluded. Wood drying sequence is 57.5-55 ··· 22 wt% H_2O and equal process parameters.
Heat recovered to: drying air in second drying stage (A). Heat recovered to: cooling water system (B).
[a] Heat losses are not taken into account.

Table 2
Condensate mass flows and temperatures from open MSDSs as shown in Table 1

Drying stages' number	Scrubber condens. mass flow (kg H_2O/s)	Scrubb. condensate temp. (°C)	Sec. energy recovery HE condensate mass flow (kg H_2O/s)	Sec. energy recovery HE condensate temp. (°C)
3	2.50	37.50	0.30	19.60
4	3.50	44.30	0.06	21.80
5	4.00	50.20	0	0

4. Conclusion

The power-to-heat ratio of the CHP plant boiler–MSDS integration depends on available process secondary energy flows, biofuel drying rate and existing process equipment. The possibilities to increase the solids burning capacity of the combustor benefit both power and heat production. An increase in power production only is enough when the process heat demand of integrated pulp and paper mill decreases due to the closing of pulp and paper making processes. Biofuel homogenization in MSDS stabilizes the combustion and improves the operability of the combustor.

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