Preliminary Economical Examinations for a New Multistage Biofuel Drying System Integrated in Industrial CHP-power Plant

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ABSTRACT

The drying of biofuels should be as effluent-free and energy-efficient as possible to ensure safe and economical operation. This paper presents a new multistage drying system (MSDS), which provides significant benefits compared to conventional single dryer systems. Most promising, this new application is installed in integrated pulp and paper mills. The MSDS, simultaneously using secondary process energy, and back-pressure extraction steams as the drying energy, enables a smaller volume flow of drying air than single dryer systems. Depending on the structure of the system, up to even 100 % of the drying air can be utilized as combustion air. The use of MSDS also enables an increase in power boiler capacity, which enhances the production of power and heat in combined heat and power (CHP) plants. For example, if the solid capacity increase of a biofuel boiler is 10 %, the plant would produce about 2.4 % more net heat and 16.4 % more net power at the generator's terminals, minus the power demand of the boiler - MSDS process. Additionally, the improvement in CHP can be attained with decreased emissions of unburned organic compounds and CO from combustion as a result of the improved quality of the biofuels. When compared to direct steam drying, the MSDS also better minimizes or even eliminates the formation of condensate from the drying operation.

Introduction

The multistage structure of wet biofuel drying system was described earlier in an article ”A New Multistage Drying System”. MSDS has a promising application chance in drying wet wood before combustion in power boiler of integrated pulp and paper mills. This article describes calculated potentials of MSDS installation to increase CHP output quantities. A principal scheme for multistage drying system-steam boiler -integration is shown in Figure 1. MSDS may have one secondary energy heated predrying stage (S) of wet biofuel. From secondary energy heated drying stage is drying air outpurge into atmosphere through secondary energy reuptake heat exchanger, which preheats atmospheric air flow together with back pressure steam before air feed into first steam heated drying stage (1H). The outpurge of drying air out secondary energy heated drying stage is possible, because organic emissions from wood drying under temperatures 100 ^oC have no meaning. The utilization of secondary energy flows for drying decreases the demand of back pressure and extracted steams from steam turbine for wood drying.

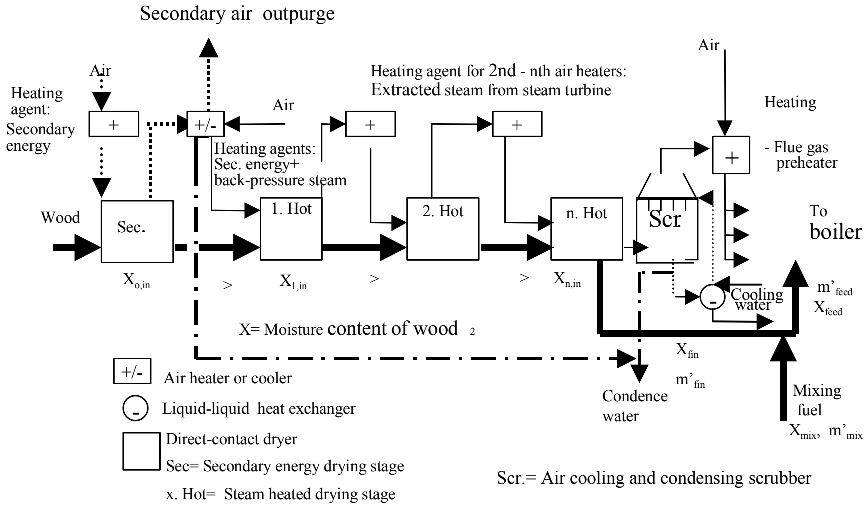

Figure 1. Principal scheme: The multistage drying system (MSDS). *)

From first steam heated drying stage the drying air is flowing through series of consecutive drying air preheating points and drying stages into the power boiler as combustion air. The wet wood is led through series of drying stages into the power boiler furnace. The MSDS may have a condensing scrubber or corresponding to decrease water mass flow into the power boiler. The water condensing reduces the flue gas mass flow from combustion. The energy for drying is carried by indirect heating of drying air. The dryers can be heated indirectly by steam to compensate the energy lost by heating fuel into the adiabatic saturation temperature of incoming hot air and for heat losses into atmosphere. When drying stages and gas ducts are well insulated, heat losses into atmosphere can be neglected in calculations. The specific energy consumption Φ_{SEC} of an adiabatic drying system (n pcs drying stages) is as follows:

$$\Phi_{SEC} = \sum_{i=1}^{n} (\Delta\Phi + \Phi_{Ex})_i / (\Delta\dot{m}'_{H_2O}) \quad (1)$$

where $\Delta\Phi$ is power for heating drying air before drying stages, Φ_{Ex} power for compensating heat losses to keep drying action as adiabatic in respect to drying air and $\Delta\dot{m}'_{H_2O}$ is evaporated mass flow of moisture from fuel. The extra heating of drying stage Φ_{Ex} is given as:

$$\Phi_{Ex} = \dot{m}'_{ds} * c_{p,ds} * (t_{s,i} - t_{,i-1}) + \dot{m}'_{H_2O} * c_{p,H_2O} * (t_{s,i} - t_{i-1}) + \Phi_{im} \quad (2)$$

where $\dot{m}'$ is mass flow of solids or water of wet fuel in feed into the dryer, c_p is heat capacity of solid or water, t_s is the saturation temperature of hot drying air in dryer i, t_{i-1} is the outlet temperature of fuel from dryer i-1 or outdoors and Φ_{im} is the power needed for ice or snow warming and melting in winter in secondary drying stage or in the first hot dryer.

The MSDS connection to steam system in CHP-plant is shown in Figure 2.

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*) S+ (n-1) H means one secondary energy heated drying stage and n-1 pcs steam heated drying stages.

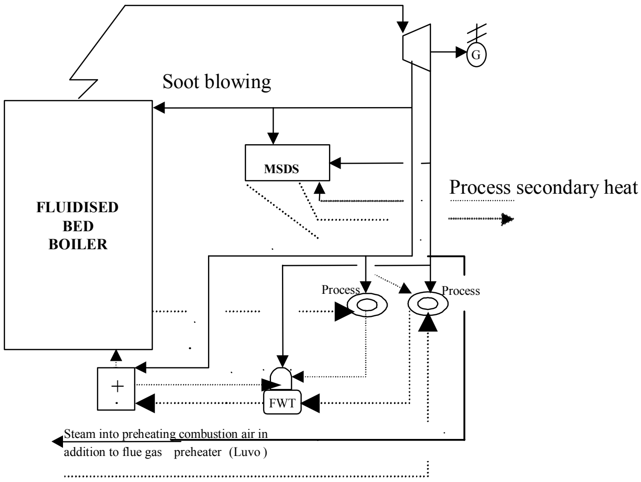

Figure 2. Multistage drying system (MSDS) connected to steam system in a CHP-plant. Note: + is feed water preheater, FWT means feed water tank , (.....) is condensate mass flow and (_____) is steam mass flow. Combustion air is preheated with flue gases (LUVO) and back pressure steam.

The multistage drying system can be connected to both single fuel type or multifuel types of power boilers. The plans are to dry only solid wood matter before feeding it into the furnace of the power boiler. It is argued that to stop wood drying at fiber saturation point FSP, which is the moisture content of wood (%), under which all remaining water in wood is increasingly tightly bounded the lower moisture content the drying is reached. The rough estimation for fiber saturation point of wood is 0.28 kg H_2O/ kg dry solid (0.22 kg H_2O/ kg wet wood). If the drying action is reached under FST-point of wood, the drying starts to consume energy for loosing the binded water. That energy consumption may be taken from increased mass flow of extracted steam from steam turbine. The result is, that the internal power consumption of boiler-multistage drying system -integrate increases and the output power of electricity decreases.

Heat losses into atmosphere

Heat losses depend on process values and equipment dimensions. For MSDS (S+2H) the highest heat losses into atmosphere are (at outdoor temperature 10 ^oC, 100 mm insulation) about 0.6 kW/m (insulated length, v_{air}= 15 m/s) for air ducts and 40 W/m^2 (area of dryer's mantel, at average temperature). The heat losses from air ducts decreases about 48 %, when insulation thickness is increased from 100 mm to 200 mm. The MSDS increases the boiler efficiency η_{Boil} (%, (steam effect / fuel effect)) in one specified process calculation from 92.6 % to 94.9 %.

CALCULATION

Process values for power boiler, steam circulation and MSDS are shown in Tables 1 and 2.

Table 1. Process values for fluidized bed boiler (FBB) and steam system.

Steam process:		
The efficiency of high and low pressure parts of steam turbine:	88	%
The efficiency of generator:	98.5	%
Fluidized bed boiler:		
Excess air coefficient in combustion:	1.2	
Radiation losses into environment (assumed):	1.5	% (of fuel effect)
Preheated combustion air (CA) temperature before combustion:	136	^{o}C
Flue gas temperature from cooled furnace:	827	^{o}C
Outdoor air relative humidity at different temperature:	60 %	
Drying air humidity after scrubber:	7.3	vol-%, wet air
Drying air temperature before preheating:	40 $(t_{g,out})_n$	^{o}C
(Note: Temperature with after condensation (Without aftercondensation from the last drying stage number n))		
Feed water tank (FWT) and back-pressure (B-P) steam pressures:	3.4	bar(A)
Flue gas temperature from boiler unit:	181	^{o}C
Condensate temperature/pressure from processes:	80.2 ^{o}C / 1 bar(a)	
Preheated feed water temperature into boiler:	178	^{o}C
Flue gas temperature after CA-preheater:	120	^{o}C
Live steam / extraction steam pressures from turbine:	90 bar(A) / 9.5 bar(A)	
Live steam temperature:	525	^{o}C
Fuels: Wood: $\dot{m}'_o$ = 13 kg/s (tot) **Moisture:**	(Initial 57.5 %)	
Peat: $\dot{m}'_o$ = 9.5 kg/s (tot)	(48 % into furnace)	
Heat capacity of wet peat:	1.6	kJ/kgK (Constant)

Table 2. Initial data for MSDS.

Reference temperature for enthalpy balance:	0.01 ^{o}C (Equal with Table 1)
Heat capacity of dry wood solids:	(x+0.324)*4.184/(1+x) kJ/kg^{o}C
Note: Wood moisture x has the unit [kgH_2O/kg solid wood]	
Slip velocity in every dryers:	2 m/s
$(t_{g,out}-t_s)_i = 12\ ^{o}C$: Temperature differences between outlet air temperature from drying stage i and adiabatic saturation temperature of entering hot air. Set constant in every drying stages.	
Drying air temperature into secondary stage S:	70 ^{o}C
Drying air temperature into 1st / 2nd-nth stages (H) :	130 ^{o}C (1H) / 185 ^{o}C (2H-nH)

INTERNAL POWER CONSUMPTIONS OF MAIN PROCESS EQUIPMENT IN FBB-MSDS - INTEGRATE

Fluidized bed boiler (FBB) combusts wood and peat. Only wood is dried and peat is fed into furnace at 48 % moisture content. In one process case the internal power consumption (IPC) value for total integrate is 21.9 kW_e / MW steam effect of FBB, of which FBB's value is 18.5 kW_e/ MW steam effect of FBB and MSDS's (S+2H) value is 3.4 kW_e/ MW steam effect of FBB, when wood is dried from 57.5 % to 22 %. The distribution of IPC for main process equipment of total integrate is shown in Figure 3. For calculating fuel transport and feeding equipment: FBB has two separate main belt conveyors for wood and peat. MSDS has belt conveyors before and between dryers, screw feeder / dryer and belt conveyor from the last dryer to main belt conveyor of wood into FBB.

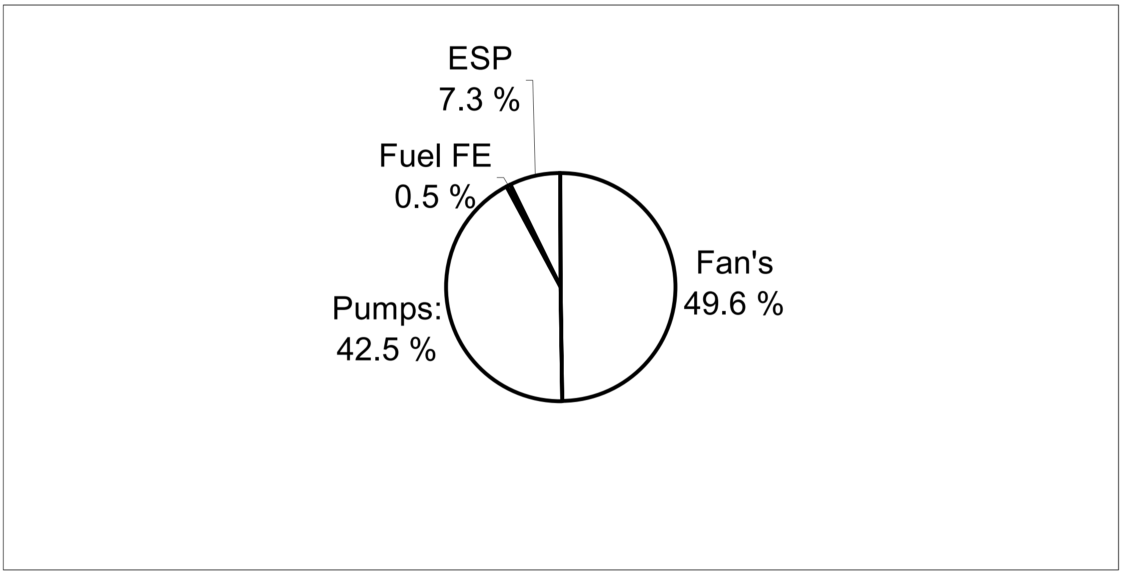

Figure 3. The distribution of internal power consumption for main process equipment in total integration (FBB and MSDS: S+2H). Fuel FE contains fuel transport and feed equipment (belt conveyors and screw feeders) and ESP is electrostatic precipitator with three separation chambers. The wood end moisture from MSDS in calculation is 22 % (0.28 kg H2O/kg solid wood) with drying sequence 57.5-55...22 %.

CALCULATED RESULTS *)

In Figure 4 is shown net power and net heat productions of FBB-MSDS -integration as function of end moisture of wood with initial moisture content 57.5 %. In Figure 4 is shown, that the net heat for integrated paper and pulp mill is decreasing because of the steam consumption in MSDS.

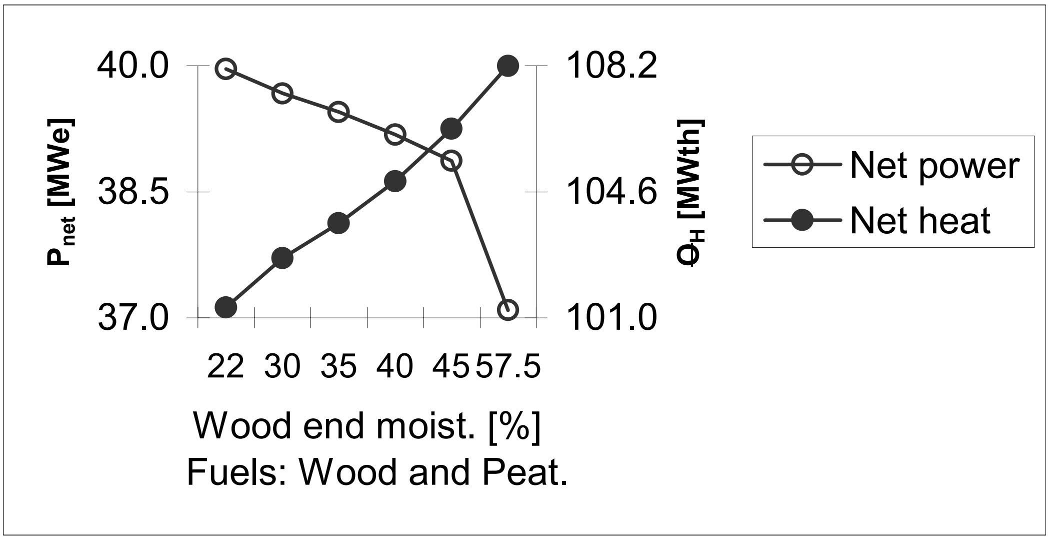

Figure 4. Net CHP-production values of power plant with MSDS: S+2H vs. wood end moisture. (Combustion occurs with equal solids amount as in boiler without MSDS). P_{net} is a net power output, $\varnothing_H$ is a net heat for integrated pulp and paper mill, wood drying sequence is 57.5-55 ... zz % and $(t_{g,out}-t_s)_i$= 12 °C. **)

*) Note! Heat losses into atmosphere are not taken in account for in all calculated results in figures 3 … 9.
**) Note! xx-yy...zz means: Wood moisture into MSDS – out secondary energy drying stage ... out MSDS.

The net heat for mill can be maintained at reference level (boiler without wet wood drying) by increasing the solid amount in combustion. In Figure 5 is shown the required solid increase in combustion to maintain the net heat Φ_H for mill equal than earlier without MSDS, if the sec. drying stage efficiency is not high enough. The solid increase in combustion is necessary to compensate MSDS internal heat (as steam) consumption. If the secondary energy heated drying stage is effective enough, the solids amount in combustion can be reduced to maintain the net heat production. The specific energy consumption Φ_{SEC} of drying is decreasing as the outdoor temperature, the number of steam heated drying stages and wood moisture reduction increase: In specified drying operation with wood moisture reduction 57.5-55...22 % at outdoor temperature 10 ^oC, Φ_{SEC} of S+2H is 3746 kJ/H_2O and Φ_{SEC} of S+3H is 3631 kJ/kgH_2O. With wood end moisture 40 % in same specified drying operation Φ_{SEC} of S+2H is 4030 kJ/kgH_2O at 10 ^oC and 5279 kJ/kgH_2O at -10 ^oC outdoor temperatures. *)

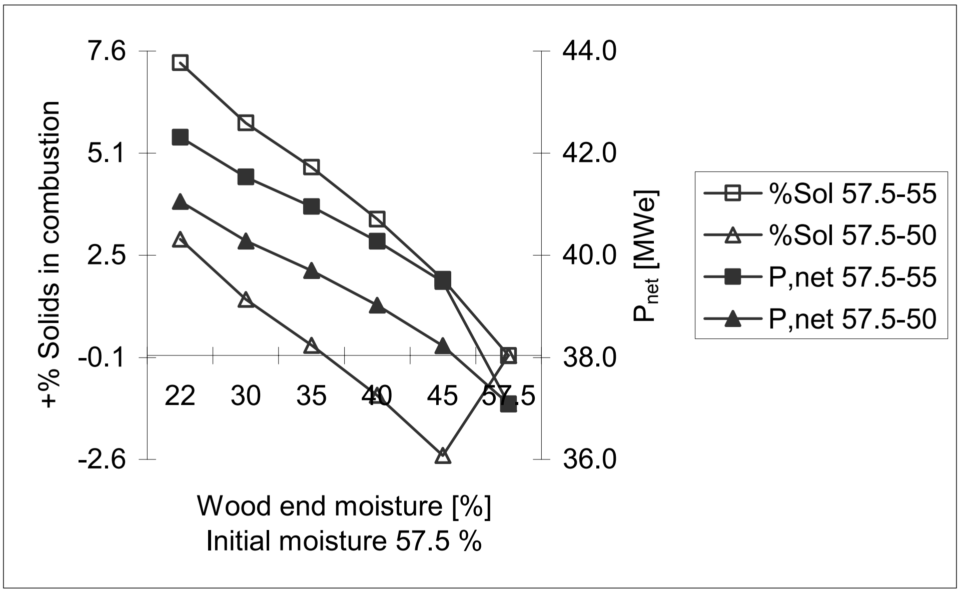

Figure 5. Solid increase (%Sol) in combustion to maintain initial net heat for integrated paper and pulp mill as a function of wood end moisture and secondary energy heated drying stage efficiency. Initial moisture wet wood (here 57.5 %) is mixed with dried wood mass flow before combustion. P_{net} is a net power production, $t_{outdoor}$ is 10 ^oC, $(t_{g,out}-t_s)_i$= 12 ^oC and MSDS: S+2H.

In Figure 6 are shown net heat and net power production output values with 10 % solids increase (mixing fuel is initial wet wood into dried wood mass flow) in combustion as a function of wood end moisture.

*) Note! All moisture (water) in wood particle is assumed to be frozen in winter

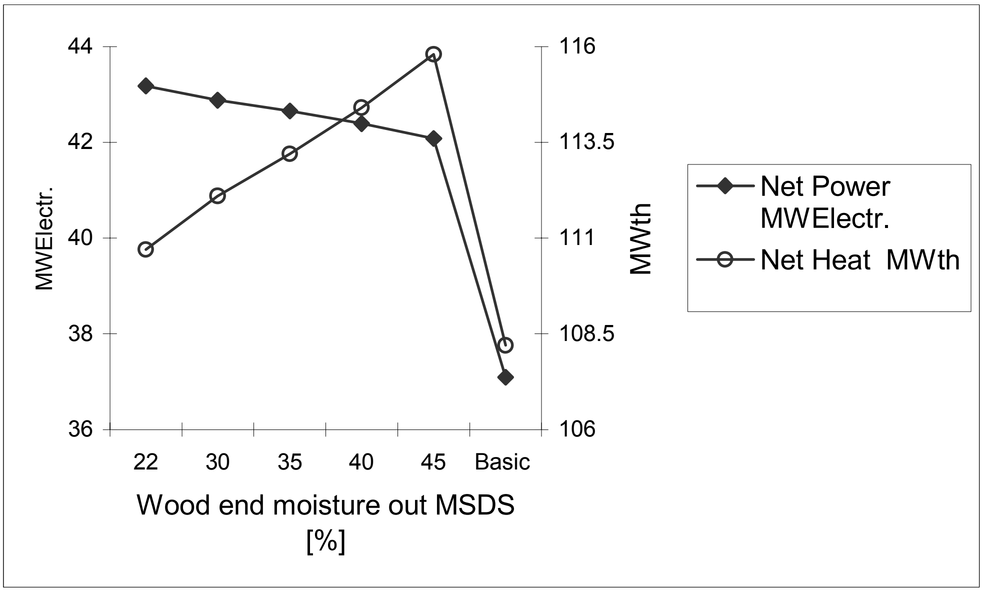

Figure 6. CHP-values of focused power plant (+10% solids in comb.) as function of wood end moisture. Basic means values for power boiler without wet wood drying system. MSDS: S+2H, $t_{outdoor}$= 10 °C and $(t_{g,out}-t_s)_i$= 12 °C. Fuels are wood and peat. Wood drying sequence is 57.5-55...22 %.

The net heat and net power productions are increased, because MSDS enables solids increase in combustion. The solids increase in combustion is possible, because wet wood drying outside power boiler furnace decreases the flue gas mass flow from combustion unit. In Figure 7 is shown the wet wood mass flow growth into boiler-msds –integration as a function of peat mass flow decrease to keep the net heat production for the integrated paper and pulp mill constant. The wood demand is smaller with mixing initial moisture wood into the dried wood than with drying all wood mass flow into the combustion, because all wood drying consumes more steam for drying.

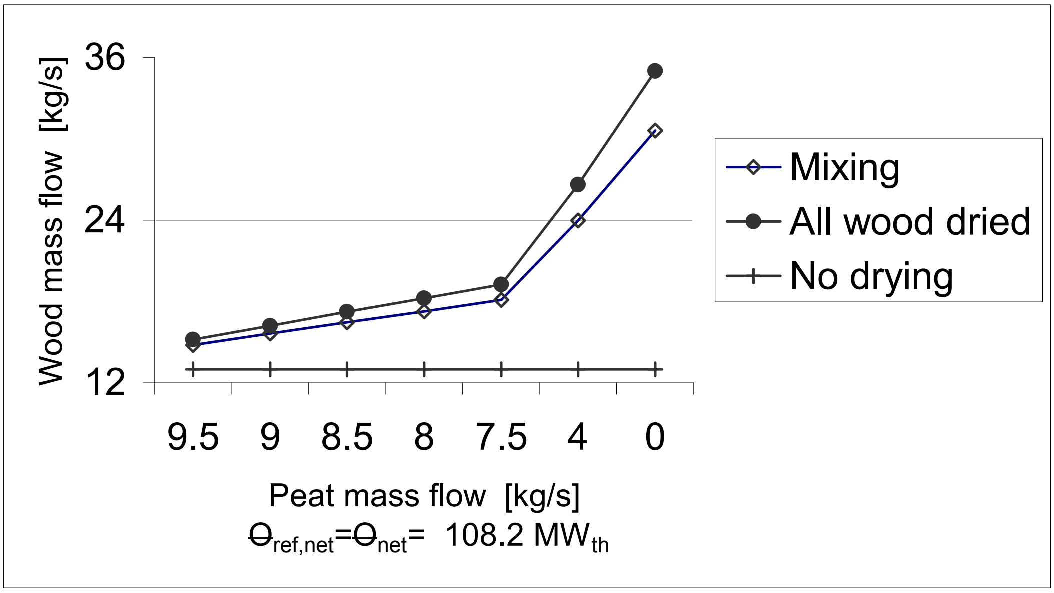

Figure 7. Increase of wood mass flow versus decrease of peat mass flow to keep net heat for integrated pulp and paper mill constant. Operation methods: All wet wood mass flow is dried or initial moisture wet wood is mixed with dried wood mass flow before combustion. MSDS: S+2H, wood drying sequence is 57.5-55...22 %, $t_{opendoor}$ is 10 °C and $(t_{g,out}-t_s)_i$= 12 °C.

In Figure 8 is shown the savings in fuel costs of purchased peat against the decrease in peat mass flow into combustion, when peat is compensated with initial moisture wet wood.

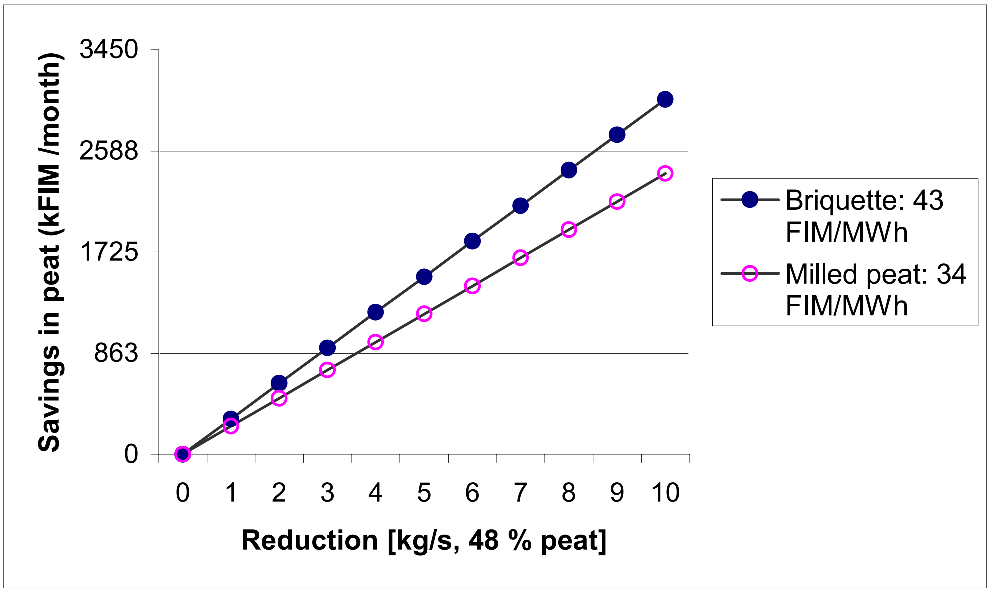

Figure 8. Monetary savings (kFIM) in peat costs / month in wintertime as a function of peat mass flow reduction into combustion, when peat is replaced with initial moisture wet wood from increased production in focused integrated pulp and paper mill.

In Figure 9 is shown sensitivity of FBB-MSDS -integration against the feed temperatures of drying air into steam heated drying stages, when the moisture decreases of wet fuel are equal in MSDS (S+2H). It can be read from Figure 9 that the net CHP values have no reasonable differences between feed temperatures 130 ^{o}C and 185 ^{o}C of drying air into 2nd hot drying stage in MSDS (S+2H). But there is one difference: the mass flow of drying air. The decrease of drying airflow causes savings in investment costs, because of smaller sizing of process equipment.

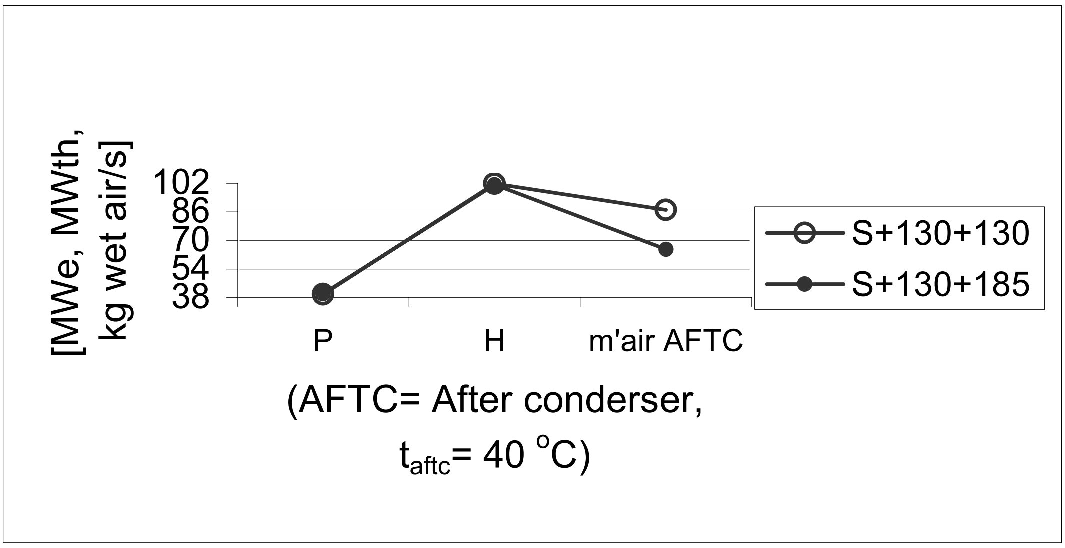

Figure 9. Sensitivity of CHP net output values versus Inlet temperatures of drying air into steam heated drying stages of MSDS: S+2H in focused power plant. Drying air temperature after the condensing scrubber is 40 ^{o}C (100% saturated with water). P is power and H is heat. Fuels are wood and peat. Wood drying sequence is 57.5-55...22 % and open-door temperature is 10 ^{o}C in both calculated results.

DISCUSSION

This study includes only net power and net heat production values. The estimations don't include investment costs, operation costs and the possibility that service life of steam boiler (i. e. increased solids burning capacity) is getting longer as a result of wet fuel multistage drying system (MSDS) connection into power plant. The order of magnitude of multistage drying system investment costs are estimated to be 30… 40 % of totally new power boiler's investment costs. It has to be taken into account that wet fuel predrying before boiler furnace possibilities decrease of flue gas mass flow from combustion. The smaller flue gas mass flow gives chances to decrease the power boiler dimensions. These dimension reduction can be reach totally in new power plant investments. The gross-income from net power production will increase about 7.8 % (constant solids in combustion) or about 16.4 % (10% solids increase in combustion as wood). With an effective secondary energy drying stage or by increasing of power boiler's solids burning capacity, the power and heat productions of CHP-plant are simultaneously increased with MSDS installation. With power price of 200 FIM/MWh (≈ USD 30 / MWh) with specified process values the yearly increase in power monetary output values (8000h /year) are about 0.7 million USD (constant solids in combustion) or about 1.43 millions USD (10% solids increase in combustion). The peat can be replaced with increased wood mass flow into combustion. This leads to reduction in peat cost of supplying. It's possible to reach savings of around USD 100.000 per month in peat purchased cost in wintertime in focused pulp mill CHP-plant with fuel effect 182 MW.

CONCLUSION

Multistage drying system gives good chances to dry big portion of wet fuel before combustion and feed the humid drying airflow along staged combustion airflow into the combustion unit. Multistage drying system gives also excellent chances to utilize secondary energy flows in drying. The secondary energy utilization improves energy efficiency of integrated pulp and paper mill. Improved combined heat and power (CHP) production and savings in fuel expenses achieve relatively short payback time for MSDS investment.

NOTATION

cp	Heat capacity	kJ/kg K
H	Steam heated drying stage	
$\dot{m}'$	Mass flow	kg/s
Φ	Heat flow or specific energy consumption	J/s or kJ/kgH_2O
P	Power	J/s (electricity)
S	Secondary energy heated drying stage	
t	Temperature	K
x	Moisture	w-%H_2O_{tot} or kgH_2O/kg dry solid

Note! [w-%H_2O_{tot}] has an abbreviation [%] in text.

Substripts

ds	Dry wood solids	net	Net value
Ex	Extra	s	Adiabatic saturation
i /n	i^{th} or n^{th} drying stage in MSDS	SEC	Specific energy consumption
im	Ice heating into 0 ^{o}C and melting		

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