PRODUCTION OF DRY WOOD CHIPS IN CONNECTION WITH A DISTRICT HEATING PLANT

by

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Moisture and its variation in wood chips make the control of burning in small scale heating appliances difficult resulting in emissions and loss of efficiency. If the quality of wood chips would be better, i. e. dried and sieved fuel with more uniform size distribution would be available, the burning could be much cleaner and efficiency higher. In addition, higher power output could be obtained and the investment costs of the burning appliances would be lower. The production of sieved and dried wood chip with good quality could be accomplished in connection with a district heating plant. Then the plant would make profit, in addition to the district heat, from the dried wood chips sold to the neighbouring buildings and enterprises separated from the district heating net using wood chips in energy production.

The peak power of a district heating plant is required only a short time during the coldest days of the winter. Then the excess capacity during the milder days can be used as heat source for drying of wood chips to be marketed. Then wood chips are sieved and the fuel with best quality is sold and the reject is used as fuel in the plant itself. In a larger district heating plant, quality of the fuel does not need to be so high

In this paper the effect of moisture on the fuel chain and on the boiler is discussed. Energy and mass balance calculations as a tool of system design is described and the characteristics of proposed dry chips production method is discussed.

Keywords: *biomass, bioenergy, biofuels, energy production, boilers, drying*

Introduction

The moisture content (MC) of wood based fuel has influences both on the fuel delivery chain and on boilers. The MC of fresh forest residue varies typically 55...60% (wet basis) and could exceed 60% during winter in Scandinavia in clear-cut storages, see fig. 1 (on the left, cases 5 and 6). On the other hand it may fall below 30% in favourable drying circumstances with transpiration drying method [1]. The large range of MC makes it difficult to control burning in the combustion chamber of the boiler. The small-scale boilers are typically designed for rather dry bio fuel. Therefore, the fuel collected from forests has often to be dried before burning. Drying of the residue in the clear-cut storages or landing storages needs in the Scandinavian climate at least one summer season and even then the result depends on the temperature and relative humidity of ambient air and precipitation, among other things. Further, the foliage and needle content decreases, which causes dry matter loss, see fig. 1 (on the right, cases 5 and 6). The other possibility is to dry chips or chunks *e. g.* in piles or bins. In this drying method, the loss of volatile hydrocarbons, respiration of living cells and the metabolic rate of microbes lead into dry matter loss, see fig. 1 (on the right, cases 1, 2, 3, and 4). This kind of dry matter loss is not yet well known for drying the forest residue in landings or clear-cut storages, but obviously it is smaller than for drying chips. Especially advantageous is the transpiration drying method in spring and summer, because it decreases rather rapidly the amount of water available for the living cells and organisms.

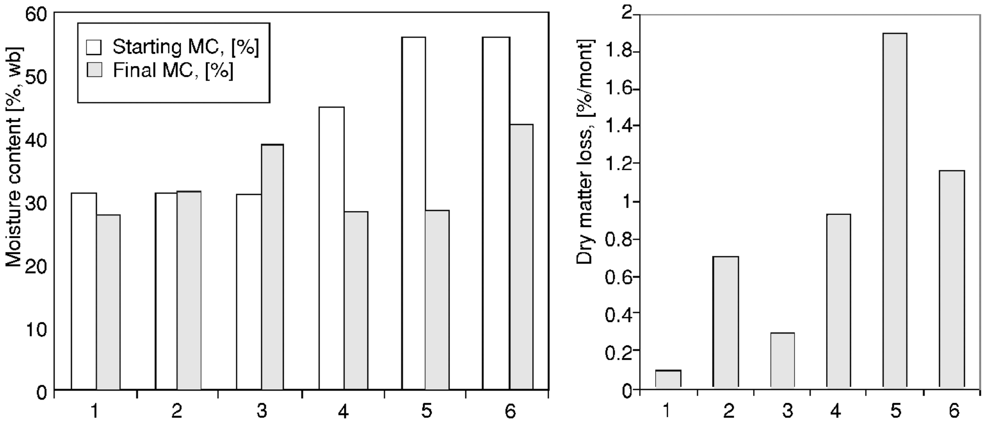

Figure 1. The initial and final MC and the dry matter loss (% per/month) of forest residue and chips in different long-term storages

The description of six experiments in fig. 1 is:

(1) Birch chip, uncovered large pile without under base plastic, storage time 14 months [2],
(2) Birch chip, uncovered large pile without under base plastic, storage time 14 months [2],
(3) Birch chip, uncovered large pile without under base plastic, storage time 14 months [2],
(4) Several species of chips, covered bin, storage time 4-7 months [3],
(5) Logging residue, clear-cut storage, storage time 12 months, dry matter loss only due to decrease of the needle content is taken into account [4], and
(6) Logging residue, landing storage, storage time 12 months, dry matter loss only due to decrease of the needle content is taken into account [4].

All bars shown in fig. 1 are arithmetical mean values of a numerous tests reported in sources. The storages 1, 2, and 3 were located in the cold climate of Lapland, which may explain the small amount of dry matter loss.

The effective heating value (LHV) expressed in the unit kWh/per total mass [kg] depends strongly on the MC. This expression is commonly used, but from the point of view of transportation costs the unit kWh/loose-m^3 may be more relevant. These two are compared in fig. 2 (on the left). It can be seen that the former decreases 51.1% but the latter only 14.5% if MC increases from 30 to 60%. Round trips with tractors or trucks are not needed essentially more with wet than with dry fuel. Dry matter loss also reduces the heating value. These two factors determine the heat content in a certain amount of fuel, see fig. 2 (on the right).

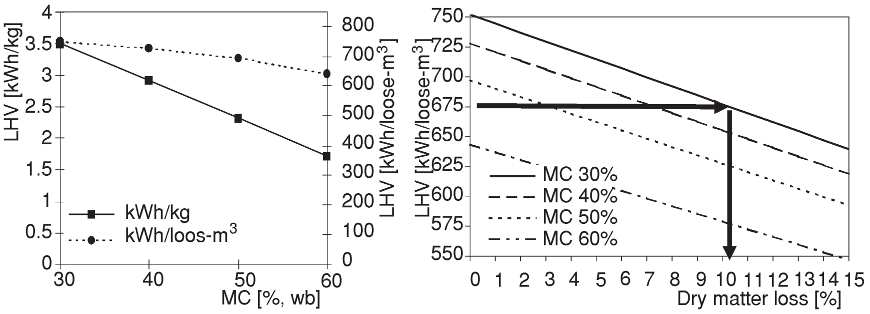

Figure 2. The effective heating value as function of MC (on the left) and as function of dry matter loss and MC as a parameter (on the right)

The density of the dry matter is assumed to be constant. The shrinkage during drying is insignificant above the fibre saturation point (MC app. 30%) [5]. Also the heating value of dry matter is considered constant, because the relative amounts of carbon and hydrogen do not notably change despite the dry matter loss [4].

If MC of fresh wood is 55% and it dries to final MC 30% during storage, the dry matter loss should be less than 10.2% to get any benefit in heat content, see fig. 2 (on the right). During one years storage time the dry matter loss should be less than 0.85%/month. Combining the information in figs. 1 and 2 we may conclude, that the long-term storage drying methods introduced earlier do not inevitably provide any gain in the heat content of fuel. However, they need more work, time and capital compared to a system, where fresh fuel is possible to transport to the heating plant, where it will be burned directly or dried artificially. This kind of long and expensive logistic fuel chain is necessary if the boiler plants are not able to use wet bio fuel or if any efficient drying method is not available. On the other hand, some amount of long-term storages is necessary in the case of crisis or other exceptional situations.

The shedding of foliage and needles is often good from the viewpoint of soil nutrition, concerning especially peat land forestry. There the nutrition decrease is a decisive factor for annual growth and it is possible to compensate by returning ash back into forest in the case of collecting fresh residue. More problematic is mineral land forestry, where the lack of nitrogen limits annual growth. In combustion the nitrogen is released into atmosphere and the benefit of returning ash decreases.

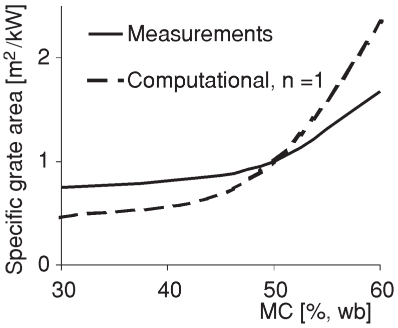

Figure 3. The specific area of the grate as function of the moisture content of fuel

The temperature of the combustion chamber decreases, if the moisture of fuel increases, because energy is needed to evaporate the water. Further, to dry the fuel a higher rate of primary air is needed, which cools down the chamber. The temperature drop has disadvantages concerning thermal performance and emissions of the boiler. The propagation of the ignition front in grate firing boilers has been modelled and measured by several authors [6-8]. The propagation rate and therefore the needed grate area depends among other things on the MC of fuel, see fig. 3. According to measurements for wood chips and peat the needed grate area increases by approximately 120% when the moisture content of fuel increases from 30 to 60% [7]. The theoretical need of combustion area on a grate is also presented in fig. 3. It has been derived from the maximum propagation rate with the excess air ratio 1 [8]. The drying stage is excluded in the theoretical curve. If it had been included the curve would be even steeper.

The gas-phase CO oxidation rate during combustion depends on the temperature and CO, O_2, and H_2O concentrations in the combustion chamber [9]. The computational temperature in upper part of combustion chamber of the grate-fired warm water boiler is shown in fig. 4. It can be seen, that if the CO is not totally oxidized in the lower part of the combustion chamber because of the insufficient mixing or delay time, the oxidation time increases strongly in the upper part combustion chamber if the moisture content of the fuel exceeds 50%.

The initial volumetric concentration of CO in the calculations is 0.5% and final 0.005%. Completely mixed flow in the upper part of combustion chamber is assumed. The oxidation time is calculated with the method described in [9]. The mean temperatures in the lower and upper parts of the combustion chamber are calculated with the method described in [10]. If the mean temperature is lower than 800 °C the oxidation time begins to increase rapidly and if the temperature is lower than 740 °C the oxidation time exceeds the delay time in the upper part of combustion chamber of the considered boiler.

The grate area is large because of long drying stage and low rate of propagation of ignition front. The heat transfer surface area must be larger because of the lower temperature in the combustion chamber. The combustion chamber has to be more spacious to get sufficient delay time for oxidation. As a conclusion, this kind of boiler is more com-

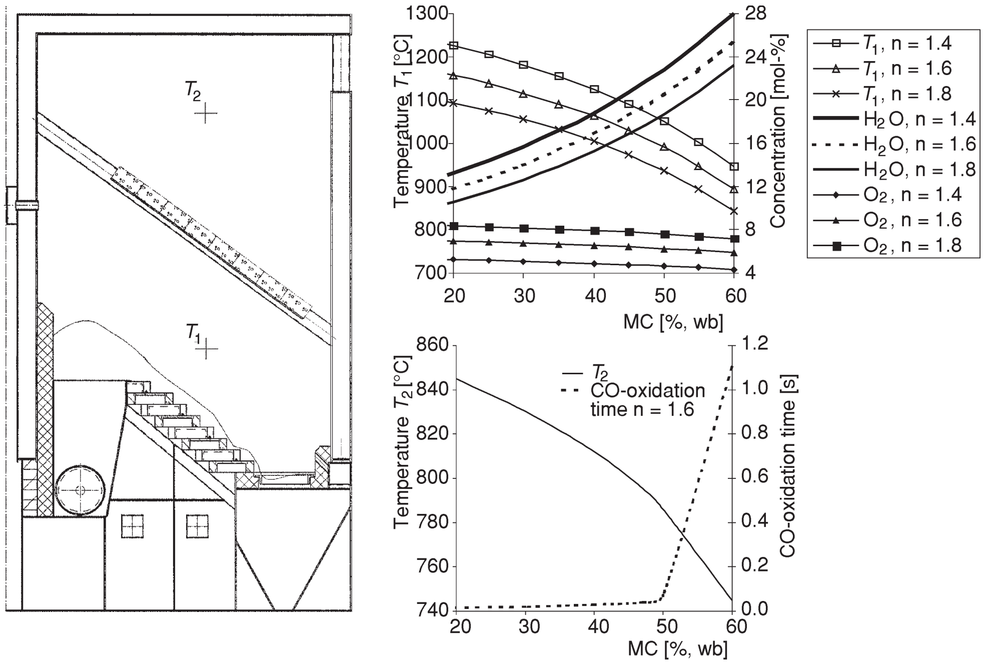

Figure 4. The construction of the grate firing boiler, 99% oxidation time of CO and parameters affecting it

plicate and expensive than a boiler for dry fuels. However, a greater risk of pollutant emissions remains in grate-type boilers designed for wet bio fuels than for dry bio fuels. With higher primary air flow rate also the NO_x emissions tend to increase [11].

The potential end-users of forest chips in small scale in Finland (*e. g.* farmers and greenhouse, piggery or poultry farm owners) consider the large range in moisture content and particle size as the biggest problem in using forest chips [12]. These variations cause operational problems especially in small-scale boilers. One quarter of Finnish farmers, who are not using wooden fuels, are interested to invest in bio fuel boilers, if homogenous fuel would be available at a reasonable price [12].

The Ministry of Trade and Industry has set an expansion goal of 300% for the use of forest chips from the year 2002 to the year 2010 [13]. At most reasonable price forest residue is available from clear-cut final felling. This fraction is widely used in power plants and in large-scale district heating boilers. The new challenging situation requires, however, harvesting also a large amount of whole tree and stem based chips from thinnings. These fractions are more expensive and, therefore, suite better for local small scale heating purposes. Improving the quality of this fraction assists in achieving new users for wood based fuels.

In Finland the duration of coldest outdoor air temperature is typically short. Due to this feature of weather conditions the biomass boilers for space heating have reserve thermal capacity most of the year. In this paper a method is proposed, where this excess heating effect is used in drying chips for the fuel market. Also sieving of wood chips is proposed to achieve high quality fuel to be marketed. The lower grade residue is then used as fuel in the district heating plant itself. Also modelling of the energy economy of this kind quality chips producing boiler plant is described. The calculations concentrate on grate-fired boilers. In Finland Satakunta Polytechnic has developed methods for energy co-operatives [14]. The described local activity may be suitable additional commercial operation for energy co-operatives.

Modelling of the heating load

The duration curve of outdoor temperature is shown in fig. 5 (on the left). The U-value of the mantle of the building and the air flow rate of ventilation and infiltration are assumed to be constant. An average value for the heat load of producing warm tap water is used. The heat demand of the building (or the district heating network) is then calculated with eq. (1) and the energy amount with eq. (2):

$$\phi = (G + \dot{C})\Delta T(t) + \phi_{dw} \tag{1}$$

$$Q = \int_0^{t_a} \phi(t)\mathrm{d}t \tag{2}$$

where

ϕ – heat power demand of a building [kW],
G – SUA = conductance of the mantle [kWK^{-1}],
$\dot{C}$ – heat capacity flow of the ventilation and infiltration [kWK^{-1}],
ϕ_{dw} – heat power demand for producing warm tap water [kW],
Q – yearly heat energy demand for the building [kWh], and
t_a – time of the heating period = 8760 h.

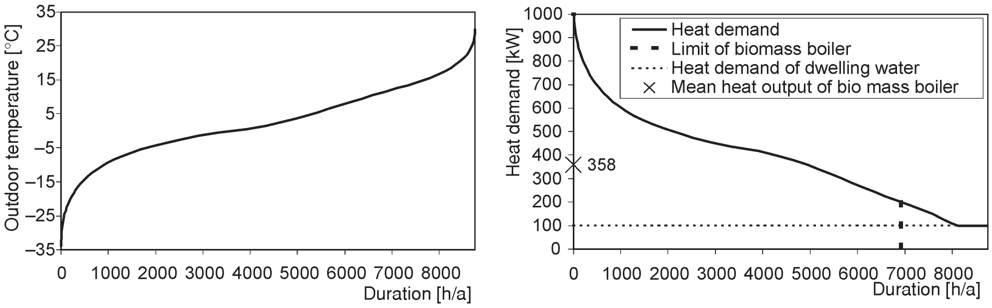

Figure 5. The duration curve of outdoor air temperature in Southern Finland (on the left) and of the heat demand (on the right)

As a result, the duration curve of the heat demand and thereby energy needed from the biomass boiler are shown in fig. 5 (on the right).

The biomass boiler is assumed to produce all the heat during the whole heating season. The minimum heat load of the bio mass boiler is assumed to be 20% of the peak load 1000 kW. The heat demand of producing warm tap water is assumed to be 10% of the peak load. During summer there is 1838 hour period, when the heat demand is below the minimum heat load of the boiler. During this period, for instance, a boiler using light oil is needed (or a smaller biomass boiler). This period includes also the assumed maintenance shutdown of 14 days of the biomass boiler. The energy produced during the operation time of 6922 h of biomass boiler represents 91.5% of the total energy of 3264 MWh and its mean heat output is 358 kW. The availability of the biomass boiler is assumed to be 99% of operation hours.

In practice, grate-fired biomass boilers are usually dimensioned for base load. Their share of the peak load is often approximately 40-60%, because their investment costs are high compared *e. g.* to light-oil boilers and their share of the total produced energy does not notably increase, even if their share of peak load increases. On the contrary, it may even decrease, see fig. 6. The minimum heat load (% of the peak load) and the shape of the duration curve have a notable influence on the energy share of the biomass boiler.

The warranty clause of minimum load for the biomass boiler is often in Finland approximately 20%. As a practical limit for high quality performance 30% of peak load is reported in Sweden [15]. Purely from the point of view of maximum energy production, the optimal share of peak load is then 60-70%.

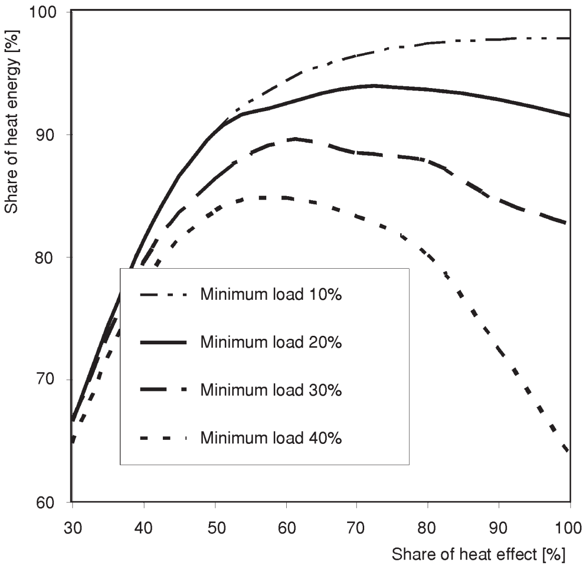

Figure 6. The share of biomass boiler of produced energy as a function of the share of heat effect, minimum heat load as a parameter

Modelling of drying

The dryer in this method is planned to operate with warm air, which is blown through a deep bed of chips. Air is heated in a recuperative heat exchanger by hot water from the boiler. The energy needed for drying depends on the initial and final MC of the chips, the outdoor air temperature and humidity and temperature of the hot drying air. Wood is hygroscopic material, which can bind water vapour from the surrounding atmosphere [16, 17]. It is not useful to dry it below the equilibrium MC of the dimensioning outdoor temperature. On the other hand, to maintain a good quality and to prevent the loss of volatile hydrocarbons, the respiration of living cells and the metabolic rate of microbes, a maximum MC of 25% is proposed [18]. In this study, a final MC of 20% was chosen as a basis for calculations. It should be safe for long-term storage and also it is clearly higher than the equilibrium MC. The influence of other parameters on the heat demand is shown in the fig. 7.

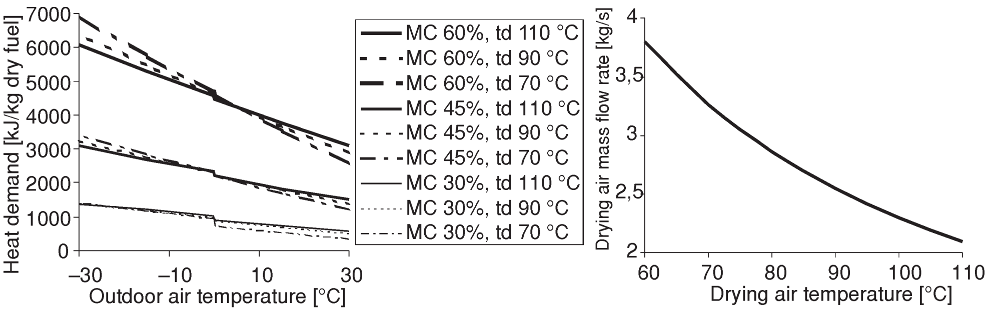

Figure 7. The influence of outdoor air temperature, initial moisture content and drying air temperature (td) on the specific heat demand of drying (on the left), and the drying air mass flow rate as function of drying air temperature (on the right)

The heat demand composes of the evaporation heat, the heating of ice, water and wood and the melting of ice. The sorption heat is not notable, because the final MC is near of the fibre saturation point of wood [19]. This and heat losses of the drying silo are excluded in calculations. The outdoor air temperature is 0 °C and the starting MC is 45%, when calculating the drying air mass flow rate.

The influence of drying air temperature on the heat demand is not strong, even if the needed drying air mass flow rate reduces strongly with increasing drying air temperature.

The needed drying air mass flow rate is calculated according to a simplified calculation model, which is reported earlier in [20]. To be precise, the water transportation and evaporation inside single particles should be considered [19, 21]. However, because the bed is deep and the final MC is relatively high, the accuracy of the simplified model is assumed reasonable for the energy and mass balance calculations. For dimensioning the dryer a more accurate method should be considered. The total pressure drop of the heat exchanger, ducts, dampers and the drying bed is assumed to be 1000 Pa for calculating the fan power and energy. The thickness of the bed is assumed to be 0.5 m. Measurement results of the pressure drop of the bed are reported in [19]. The total efficiency of fan and electric motor is assumed 0.7.

Energy and mass balance calculations

The principal schema of the boiler plant with a dryer is shown in the fig. 8. The dryer is connected in parallel with the district-heating network. The fuel of the boiler is a mixture of wet unsieved chips and the dry reject fraction from the sieve.

By combining the models for heat load and drying it is possible to calculate the amount of dried chips available for market. It depends on the share of the effect of the biomass boiler and on the dimensioning of the dryer, see fig. 9.

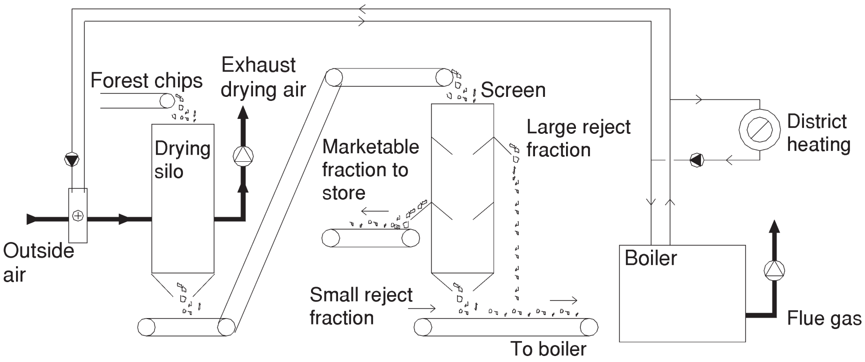

Figure 8. Principal schema of the dryer and sieve in a boiler plant

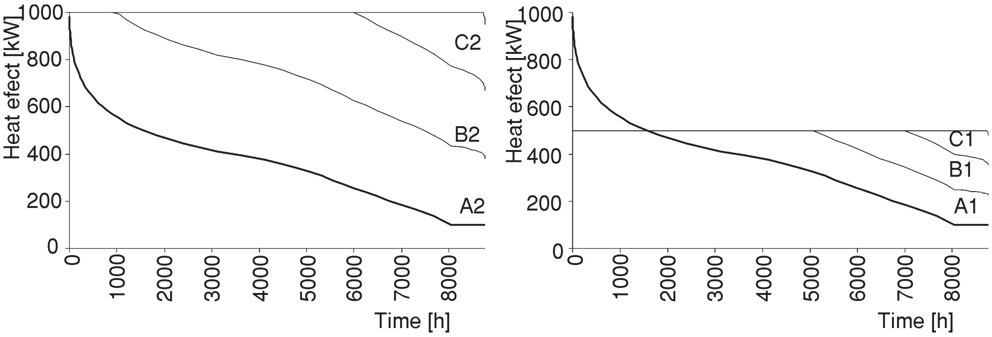

Figure 9. The heat demand of the district heating network and the dryer depending on the dimensioning of the dryer. The boiler is dimensioned for the peak load of the network (on the left), or for half of it (on the right)

More detailed information about the mass flow rates and main components of the system are shown in tab. 1.

Table 1. The volume flow rate of chips, mass flow rate drying air and basic information of drying air fan and drying silo

Case	Wet chips		Dried chips	Drying air	Fan		Druing silo
	Incoming [m^3/a]	Own use [m^3/a]	To market [m^3/a]	Mass flow rate [kg/s]	Power [kW]	Energy [MWh/a]	Face area [m^2]
A1	8758	5877	2880	3.4	3.3	15.5	6.6
B1	12296	6453	5843	6.8	6.6	19.7	13.2
C1	12829	6534	6296	10.2	9.9	17.4	19.9
A2	25433	9497	15936	4.0	4.3	35.8	8.5
B2	41988	12443	29545	8.0	8.5	53.9	17.0
C2	46022	13082	32940	12.1	12.8	51.1	25.5
A2*	30367	10681	19686	7.7	7.4	59.1	14.9
B2*	43108	12873	30235	15.3	14.9	72.5	29.8
C2*	44388	13067	31321	23.0	22.3	62.5	44.6

* Drying air temperature 70 °C

MC of incoming fresh forest chips is assumed to be 50%, drying air temperature 100 ºC besides the cases marked with asterisk and the duration curve of outdoor air temperature is accordant to climate of Southern Finland, see fig. 5. For clarity, in calculating results for chips amounts are expressed in units of loose-m^3. The density of dry material is assumed to be 150 kg/loose-m^3. The chips shrink when dried below the fibre saturation point and the relative shrinking in this case is approximately 3%. This is omitted in calculations. The amount of reject depends on the raw material and on the quality of the chipping machine. It has to be deducted from the amount of dried chips to market. On the other hand, this reject reduces the incoming mass flow of wet chips, because the boiler uses this residue fraction itself.

From the data in tab. 1 useful interdependencies in system design can be seen. Firstly, the amount of chips to market increases with increasing drying air mass flow rate, but not linearly as is the case with fan power and dryer face area. The growth of amount of marketable chips is from 65 and 85% when increasing the capacity of dryer 100% (*i. e.* from one third to two thirds of full capacity), in other words from case A1 to B1 and from A2 to B2, respectively. With equal increase in capacity from B1 to C1 and from B2 to C2 the growth is only 9.6 and 11.4%, respectively. On the other hand, the share of marketable chips compared to the incoming amount of chips increases with increasing drying capacity. This is because with greater drying capacity the use of drying energy is emphasized during warm season. The same feature concerns drying air fan. Even if the size of drying air fan increases linearly with the increasing capacity of dryer, the need of fan energy does not. This is because the fan operates the longer time with a partial load the greater is the capacity of dryer. It is possible to optimise the capacity of the dryer taking into account investment costs. Secondly, drying enables also an increasing share of biomass boiler of the peak load. The problem of minimum load can be avoided by using energy for drying at summertime, see fig. 5. This is profitable, because the specific heat demand is relatively low at warm season, see fig. 7. This also replaces oil with cheaper biomass in the case of oil fired secondary boiler. Therefore, the size of the biomass boiler can be included in the optimisation. Thirdly, modelling gives possibilities to study the effects of changing operational parameters. Contrary to expectations, decreasing the drying air temperature from 100 to 70 °C increases the amount of marketable chips. For instance, in the case of one third of full capacity (from A2 to A2*) the increase is 23.5%. From the point of view of dimensioning the components there is an optimum for the drying air temperature, too. The drying time and the subsequent size of the dryer decrease but the size of the heat exchanger increases with increasing drying air temperature.

Conclusions

Building-up a boiler plant with dryer and sieve offers possibilities for extra incomes *e. g.* farmers and other members of energy co-operatives. In the proposed method one large boiler for low quality fuel produces high quality fuel for many small-scale boilers. The load of the boiler is more even than in the traditional district heating use, see fig. 8. Therefore, controlling of the combustion enhances and problems of minimum load use are avoidable. The method has also indirect advantages. It brings savings in investments, because the boilers of end-users can be designed small and simple due to the high quality of fuel. The higher the temperature of combustion chamber and combustion gases are the smaller the heat transfer surface needed in the boiler is, see fig. 4. The homogenous fuel enhances possibilities for accurate control of combustion, which improves the efficiency and reduces pollutant combustion emissions of these small boilers.

On the other hand, the product is new in Finnish fuel market and, thus, the supply chain has to be created. Even if benefits from the point of view public economy exist, the private economical break-even point depends strongly on the price of dried and sieved chips. The price will take place between pellets and untreated forest chips. Investment costs of the boiler plant are higher than those of the traditional plant due to the dryer and sieve. Logistics of delivering fuel to market affects the size of the store. If the demand profile of the fuel is similar with the heat demand profile of customers, the maximum store volume is needed at autumn in the beginning of heating season. From spring to autumn the production is larger than the consumption. Size of the store is essential from the point of view of investment costs and modelling is needed for dimensioning it. Long-term storage in forest is not necessary with this method and the fuel chain from forest to district heating plant shortens and simplifies.

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