PRODUCTION OF SYNTHETIC NATURAL GAS FROM BIOMASS – PROCESS INTEGRATED DRYING

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Abstract. *Opportunities for process integrated feedstock drying in connection with the production of synthetic natural gas (SNG) from wet biomass via indirect gasification are investigated in this study. Drying is a very energy-intensive process step – corresponding to about 10% of the dry fuel lower heating value for woody biomass. Process integrated drying offers opportunities for reducing the external energy supply necessary for drying, thereby improving the overall process efficiency. Simulation models for three drying technology options – air, steam and flue gas drying – have been developed using the flowsheeting software tool ASPEN Plus. The influence of basic operation parameters on the performance of the different drying configurations is investigated using sensitivity analysis. Based on a proposed SNG production process that is built as an extension of a fluidized bed boiler for a combined heat and power plant, the potential for heat integrated drying is assessed using pinch analysis in combination with the developed drying models. The biomass – 100* MW_{th} *input for both combustion and gasification, respectively - needs to be dried from 50 to 10 weight-% moisture content prior to combustion/gasification. It is shown that it is not possible to cover all feedstock drying needs for the process by internal heat recovery. Steam drying offers the highest potential for heat integration with the proposed SNG process, making it possible to cover 47.7 % of the necessary total dry fuel supply to both combustion and gasification. However, not all process heat used in the steam dryer can be recovered, increasing the external heat need to the SNG process at a lower temperature level. Nevertheless, substantial savings are possible making use of integrated drying within the SNG production process compared to stand-alone drying.*

Keywords: *synthetic natural gas, process integration, biomass, gasification, drying*

NOMENCLATURE

Abbreviations

CFB	circulating fluidized bed
CHP	combined heat and power
DME	dimethyl ether
FT	Fischer-Tropsch
GCC	Grand Composite Curve
GHG	greenhouse gas
LHV	lower heating value
MC	moisture content (kg H_2O/kg total mass)
RR	recycle ratio
SNG	synthetic natural gas

Symbols

m	mass
P	electric energy (work)
q_{dry}	specific heat consumption for drying
Q	heat
u	wet content (kg H_2O/kg dry mass)
U	overall heat transfer coefficient
w_{dry}	specific work consumption for drying
Δh_{vap}	heat of vaporization
ε	thermal drying efficiency
φ	relative humidity
η_{is}	isentropic efficiency
η_{mech}	mechanical efficiency

Indices

a	air
dew	dew point
dry	drying
evap	evaporated
FG	flue gases
in	at inlet conditions
m	moist material
out	at outlet conditions
rec	recovered
sat	saturation
sh	superheated
source	heat source
sup	supplied

1. INTRODUCTION

The production of second-generation biofuels has been identified as a key technology roadmap towards a sustainable future energy supply by the International Energy Agency (IEA, 2008). Biofuels produced from lignocellulosic feedstock can be an important factor for the reduction of greenhouse gas (GHG) emissions. The production and use of biofuels for transportation – an application option currently discussed intensively – has been studied from a life cycle perspective by (Edwards et al., 2007; Pettersson and Harvey, 2008), among others. The resulting overall impact of biofuels on global warming mitigation determined by such studies depends significantly on assumptions made at both the process level as well as at a broader system level. A general consensus though is the importance of designing biofuel production processes with focus on efficient use of biomass, aiming not only at a maximum biofuel yield, but also taking into account other products and services such as heat and electricity, in order to achieve a high overall efficiency and positive GHG emissions reduction balances. This is often referred to as the biorefinery concept. In the framework of this concept the biomass feedstock drying step is of importance since it is a very energy-intensive process step that has a strong influence on the overall process performance. To dry for example biomass feedstock with a lower heating value (LHV) of 20 MJ/kg$_{\text{dry mass}}$ from 50 % to 10 % moisture content (MC), about 1.95 MJ/kg$_{\text{fuel,10\% MC}}$ are necessary (based on the energy of vaporization at 25ºC), corresponding to nearly 10 % of the dry mass LHV. A sound integration of the feedstock drying with the rest of the process is therefore also a key step in achieving a well-designed biofuel production process.

The range of second generation biofuels currently under development includes methanol, Fischer–Tropsch (FT) diesel, hydrogen, dimethyl ether (DME), and synthetic natural gas (SNG), sometimes also referred to as biomethane or substitute natural gas. The attraction of SNG as biofuel replacing fossil fuels resides in the fact that it can be directly used to replace fossil natural gas, and thereby can be readily used in a large number of applications and can make use of an existing distribution infrastructure. Due to the ease of mixing with other gaseous fuels, SNG can be seen as a potentially positive vector for other renewable energy sources such as biogas from fermentation and – on a longer term – hydrogen from renewable sources.

For SNG production in particular, several process schemes have been proposed (Mozaffarian and Zwart, 2003; Zwart *et al*., 2006; Tunå, 2008; Gassner and Marechal, 2009). Drying has not been considered in a number of these studies (Mozaffarian and Zwart, 2003; Zwart *et al*., 2006), the biomass feed being assumed to be at a MC of 15 %. Gassner and Marechal (2009) considered both air drying and steam drying within a thermo-economic optimization approach for the design of a SNG production process. Only air drying was analyzed in more detail: the influence of operational parameters (inlet air temperature and outlet wood humidity) on the overall process performance was assessed. For different optimization objectives the inlet air temperature was always close to the upper bound of the defined range (160 – 240 ºC) while the outlet wood humidity varied strongly depending on the optimization objective. However, no comprehensive discussion of the operation parameters of different drying techniques and the potential for integrating the drying process with the SNG production process has been done in any of the publications listed above.

In this study the integration of feedstock drying with the production of SNG is investigated in more detail. Three different models for drying – air, steam and flue gas drying – are presented and the influence of basic operation parameters is investigated using sensitivity analysis. Using pinch technology, the integration potential of the drying configurations with a SNG process – proposed in former work - is evaluated based on the Grand Composite Curve (GCC). Pinch technology has been demonstrated previously to be a very useful tool for evaluation of process integrated drying by Andersson *et al*. (2006). The performance behaviour revealed in the sensitivity analysis of the drying models is used to determine the most favourable operating conditions. By applying the principles of pinch technology a sound integration of the drying technology from an exergetic viewpoint is ensured. For a given economic background scenario the results of this study can be used to investigate the profitability of different drying alternatives in their optimum configuration.

2. DRYING IN THE CONTEXT OF BIOMASS USE FOR ENERGY APPLICATIONS

In the context of biomass use for power generation both by combustion and gasification, several investigations on different drying technologies and the influence of the dry fuel water content on the overall process efficiency have been done (Amos, 1998; Brammer and Bridgwater, 1999 & 2002). Amos (1998) estimates that the thermal efficiency of biomass power generation systems increases between 5 and 15% when drying the biomass prior to combustion/gasification.

Energy efficient biomass drying for pellets production by integration with other processes has been studied – among others – by Wahlund *et al.* (2002) and Andersson *et al.* (2006). This configuration can be seen as a kind of biorefinery delivering several services and products. Wahlund *et al.* (2002) demonstrated the benefits of integrating a steam drying system for the production of wood fuel pellets with a biomass fired CHP plant considering the overall power production as well as global CO_2 emission balances. Andersson *et al.* (2006) evaluated three different drying alternatives – steam drying, flue gas drying and vacuum drying – for integration with a pulp mill using pinch technology. The results showed that by making use of the pulp mill's available excess heat, it is possible to reduce global CO_2 emissions by (31-36 kg/MWh$_{\text{pellets}}$) compared to stand-alone pellet production. Flue gas drying was identified as the most attractive drying option in that study.

3. PERFORMANCE INDICATORS FOR DRYING

In order to be able to compare and evaluate different drying technologies, a number of performance indicators specific to drying are defined. A commonly used indicator is the thermal efficiency of a dryer ε, representing the ratio between the heat theoretically necessary for the drying process and the heat actually supplied to the dryer. Definitions vary as the heat needed for the drying process is often considered to be the evaporation of the moisture only (Berghel and Renström, 2002; Gassner and Marechal, 2009) but sometimes takes into account the heating of the moisture to the saturation temperature as well (Williams-Gardner, 1971). In this study the former definition will be used:

$$\varepsilon=\frac{m_{\mathrm{H_2O},evap}\cdot\Delta h_{vap}}{Q_{sup}} \tag{1}$$

where $m_{\mathrm{H_2O},evap}$ denotes the moisture being removed from the wet material, Δh_{vap} the specific heat of vaporization and Q_{sup} the externally supplied drying heat. The specific heat of vaporization Δh_{vap} being temperature dependent, its value at 25ºC was retained for both air and flue gas drying systems and its value at the corresponding saturation temperature was retained in the case of steam dryers in order to calculate the thermal efficiency of the dryer.

Another performance indicator - giving a more explicit idea about the performance of a dryer system - is the specific heat consumption of drying per mass of moisture evaporated q_{dry}. It is defined according to

$$q_{dry}=\frac{Q_{sup}}{m_{\mathrm{H_2O},evap}} \tag{2}$$

When the drying operation is designed for heat recovery – of particular interest in the case of steam drying – a net specific heat consumption q_{dry} can be defined where the supplied heat Q_{sup} in Eq. (2) is reduced by the amount of heat energy recovered from the evaporated moisture. This substantially reduces the specific heat consumption figures accounting for the fact that steam drying is usually only considered as an option when a heat sink is available for recovering the latent heat from the evaporated moisture.

In the same way a specific work consumption w_{dry} for the drying process can be defined, accounting e.g. for the power consumption of fans in recycle streams:

$$w_{dry}=\frac{P_{sup}}{m_{\mathrm{H_2O},evap}} \tag{3}$$

where P_{sup} denotes the electric energy consumption of the drying process.

4. SNG PROCESS DESCRIPTION & DRYING ALTERNATIVES

4.1. SNG production process

The SNG production process considered in this work has been presented previously (Heyne *et al.*, 2008). It consists of an indirect gasification step followed by a gas treatment chain consisting of tar reforming, scrubbing for removal of alkali compounds and sulphur, a two-step amine-based absorption for CO_2 removal combined with two methanation steps and a final drying stage. A flowsheet indicating the important process steps is presented in Fig. 1.

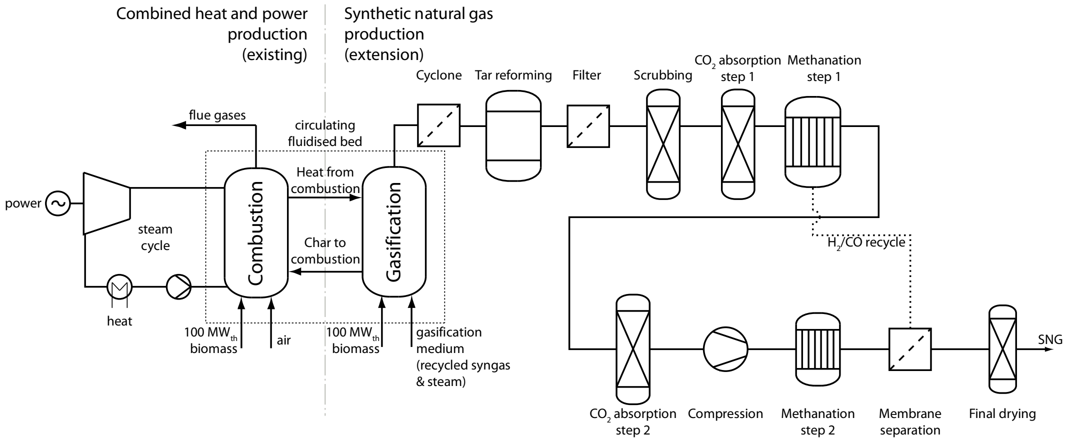

Figure 1. SNG production process flowsheet.

In the previous study (Heyne *et al.*, 2008) the SNG process was designed as an extension of an existing CHP plant based on circulating fluidized bed (CFB) boiler technology. The heat for gasifying the biomass is transferred via the circulating bed material from the combustion to the gasification side, and unburnt char is fed back to the combustion unit. As presented in the previous study and in (Thunman *et al.*, 2007) the extension of an existing power cycle with a gasification unit for biofuel production reduces the investment cost and risks for such an installation compared to a stand-alone plant, and offers good opportunities for heat integration at the same time. In this study, the size of the process was assumed to be 100 MW_{th} biomass energy input for both the CHP boiler and the gasification process.

With respect to feedstock drying, this process represents an interesting case given that several alternative process heat sources are available for drying purposes: the combustion unit releases flue gases that can be used for drying, high temperature excess heat recovered from the SNG process can be used as heat source for steam drying and low temperature heat can be applied as heat source in air drying.

Drying of biomass feedstock prior to the gasification step was not considered in previous work, i.e. the incoming biomass was assumed to be at a moisture content of 10 wt-%. As the average moisture content of woody biomass is usually around 50 wt-%, a drying step needs to be considered. In this paper, three different biomass drying models are presented and used to investigate the potential for integrated drying using excess heat from the SNG production process based on heat stream data. Both the SNG process and the three drying models presented were modelled using the commercial flowsheeting software package *ASPEN Plus* (AspenTech, 2006).

4.2 Air drying

The air drying model used within this study is based on work by Holmberg and Ahtila (2004,2005). Both single-stage drying with recycle and multi-stage drying were considered in their studies and were analyzed for energy and exergy performance as well as drying costs. The models for both systems include a recovery unit for increasing the efficiency. From an energetic point of view both systems perform similarly having a specific heat consumption of 2700-2900 kJ/kg H_2O evaporated. As the two systems differ little from a thermodynamic viewpoint and since the single-stage dryer setup constitutes the less complex and easier to control device, it was chosen for investigation in this study. Some adjustments to the model compared to the work of Holmberg and Ahtila (2005) were done, such as taking into account pressure drop and heat losses.

A flowsheet for the single-stage air drying unit is shown in Fig. 2. The incoming air is preheated in the heat recovery unit, mixed with the recycled drying air before being preheated by an external heat source. After leaving the dryer, part of the air is recycled whereas the other part is used in the heat recovery unit for preheating the incoming air. In contrast to Holmberg and Ahtila (2005), a pressure drop over the drying unit was assumed making the use of a fan for the recycle gas necessary. The heat loss Q_{loss} was defined as a fraction of the total heat needed for heating up biomass and moisture and evaporation of the water content that is to be removed from the biomass, denoted Q_{dry} in the figure. This definition of the losses applies for the other drying models as well.

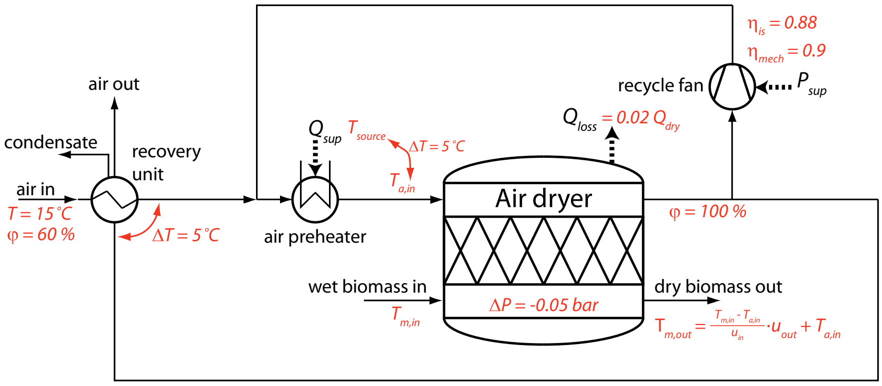

Figure 2. Flowsheet for single-stage air drying model with heat recovery showing the main modelling assumptions.

The air leaving the dryer was assumed to be at saturation, as in Holmberg and Ahtila (2005). To determine the outlet temperature of the dried material, the simplified estimation from Holmberg and Ahtila (2005) was adopted, assuming a linear temperature increase of the moist material with decreasing moisture content.

The main parameters influencing the performance of the air-drying system are the temperature of the external heat source used for drying and the recycle ratio. An increased recycle ratio will reduce the need for supply of external heat as shown by Holmberg and Ahtila (2005), but will at the same time increase the costs for recompressing the recycle stream as well as the investment cost for the dryer as a higher volume flow through the dryer will require larger equipment. To illustrate the influence of these two parameters a sensitivity analysis was performed, based on a biomass flow of 1 kg dry mass/s to be dried from 50% to 10% moisture content. This test case was also used for assessing the performance of the two other drying systems. Both the recycle ratio *RR* and the temperature level of the heat source were varied. The temperature range evaluated (70 to 130 ºC) represents the range of heating media generally available, namely hot water and low pressure steam.

The results are presented in Fig. 3. It can be clearly seen that the specific heat consumption decreases with increased recycle ratio. However, this effect is counterbalanced by the strongly increasing specific work consumption. The influence of the heat source temperature is more significant for a high recycle ratio as the recycled air flow increases more pronouncedly for the lower temperatures since the driving temperature difference between air and the biomass to be dried is lower. The thermal drying efficiency is not that different for different heat source temperature levels and low recycle ratios. At higher recycle ratio the difference is more pronounced and the efficiency even is larger than unity for low heat source temperature levels. This again has to be seen in the context that the work consumption – that is not considered in the definition of the thermal efficiency – increases exponentially. The thermal efficiency is therefore a partly misleading performance indicator and should always be analyzed with care.

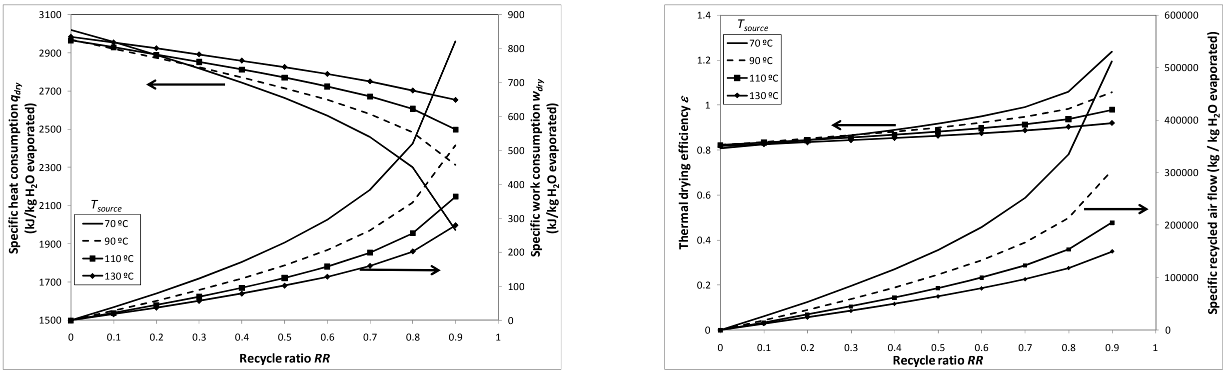

Figure 3. Influence of recycle ratio *RR* and temperature level of the heat source T_{source} on the performance of a single-stage air dryer. a) specific heat consumption and specific compression work; b) thermal drying efficiency and recycled air flow.

4.3 Steam drying

Steam drying is an interesting alternative for process integrated drying. Circulating steam at a given pressure is superheated by an external heat source (usually steam at a higher pressure). The superheated steam entering the dryer is used for heating up the moist material and evaporating the moisture. The evaporated moisture is separated from the circulating steam and condensed, delivering heat at a temperature level determined by the drying pressure. A large fraction of the heat used in the drying process can thereby be recovered. No dilution with air or flue gases occurs; therefore all of the latent heat in the moisture can be recovered. The setup of the steam dryer and the main modelling assumptions are shown in Fig. 4.

The model developed was validated using experimental data for steam drying of sawdust and willow wood chips by Berghel and Renström (2002). A minimum temperature approach difference was used in order to determine the flow of circulating steam in the dryer. For modelling purposes, the steam is assumed to be cooled down to a certain temperature above the saturation temperature (T_{sat} + ΔT_{min}) thereby heating the moist material up to the saturation temperature and evaporating the moisture, before being mixed with the evaporated moisture. Other authors have determined an adapted volumetric heat transfer coefficient for drying *U* for modelling drying applications, see for example Ståhl and Berghel (2008). Both approaches are a way of representing the relation between the heat transferred and the heat exchange area or - in the case of drying – dryer volume.

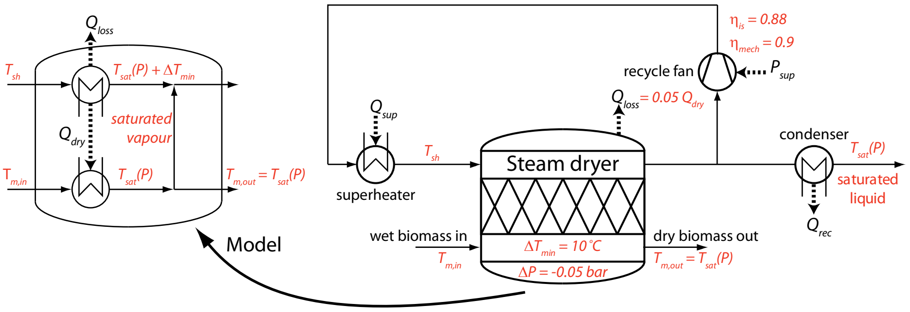

Figure 4. Steam dryer flowsheet showing the main modelling assumptions.

A lower assumed value for ΔT_{min} will result in larger equipment. Since there are problems in determining the heat transfer coefficient *U* in drying processes (Ståhl and Berghel, 2008) the ΔT_{min} approach is a simple way of determining thermodynamic performances of different steam dryer setups for screening. The higher heat losses (5 % instead of 2 % compared to the air drying system) are justified by the higher temperature level and reported problems with heat losses in particular at the entrance and exit of a pilot scale steam dryer (Berghel and Renström, 2002).

As for the air dryer, a sensitivity analysis was performed based on the test case defined previously. The parameters varied for this system are the drying pressure, the superheating temperature T_{sh} of the recycled steam as well as the minimum approach temperature ΔT_{min} used. The results are shown in Figs. 5 and 6.

The specific heat consumption is the net value taking into account the recovered energy in the condenser as useful energy. This favours the performance of steam dryers; indeed this is one of the main reasons for choosing this type of equipment. A suitable heat sink where the condenser heat can be effectively used should be available to justify the installation of a steam dryer. In a combined heat and power plant in Skellefteå, Sweden, an installed steam dryer operates at 4 bar (Wahlund *et al.*, 2002) making heat recovery at high temperature possible. The steam produced is used in a condensing turbine for electricity production. Another commercially available steam dryer has an operation range of 0.2 to 8 bar (Exergy, 2008).

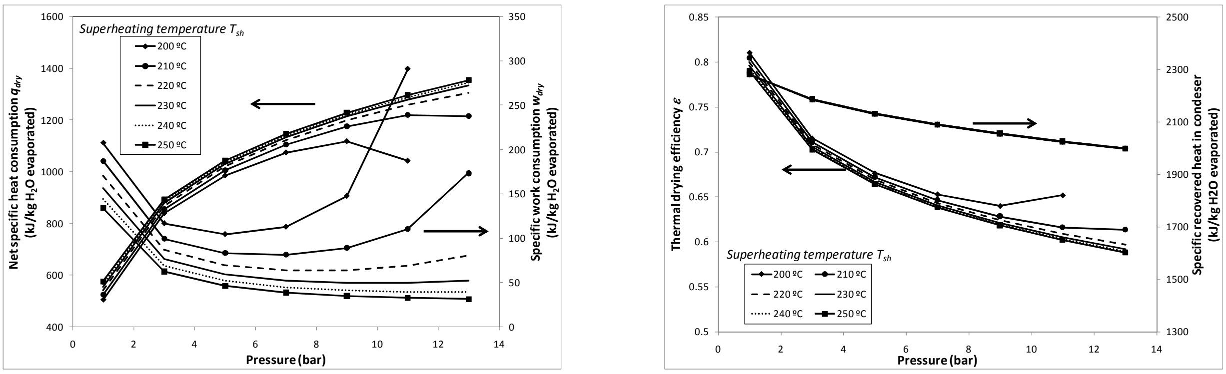

Figure 5. Influence of operating pressure and steam superheating temperature T_{sh} on the performance of a steam dryer. a) net specific heat consumption and specific compression work; b) thermal drying efficiency and heat recovery.

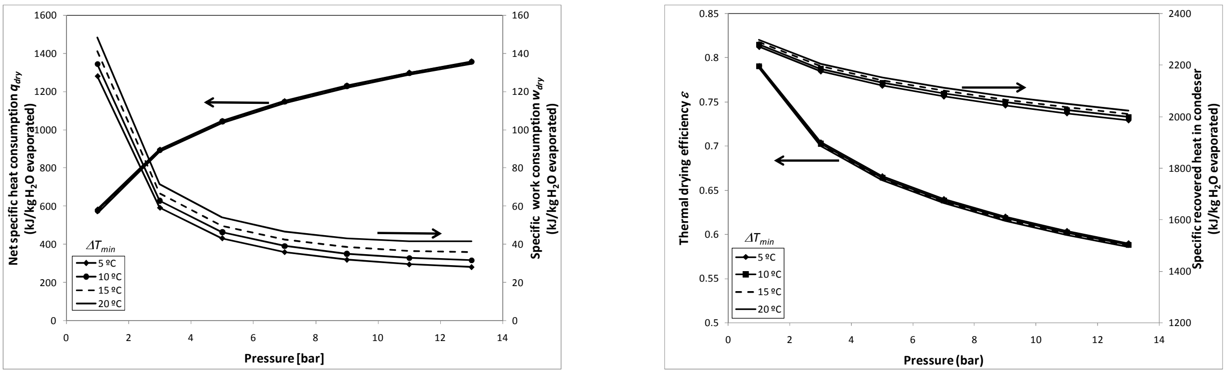

Figure 6. Influence of operating pressure and driving temperature force ΔT_{min} on the performance of a steam dryer. a) net specific heat consumption and specific compression work; b) thermal drying efficiency and heat recovery.

The figures clearly show the influence of the operating pressure on performance. The net specific heat consumption increases with pressure as more of the externally supplied energy is used to heat up the solid material with the remaining moisture and is therefore not recoverable. On the other hand, the specific work consumption decreases as the volume flow of circulating steam decreases with higher pressure. This is however not valid if the superheating temperature is only slightly above the saturation temperature of water at the operating pressure. Due to a small temperature change in the circulating steam, high volume flow rates are necessary to fulfil the drying task and the specific work increases substantially. These operating conditions should be avoided. A higher superheating temperature leads to a lower specific work but also leads to a lower thermal drying efficiency. The assumed ΔT_{min} has a very small influence on system performance. Both net specific heat and work are strongly dependent on the choice of pressure. Low pressure leads to a low specific heat need, but this of course also implies that the condensation heat is only available at a lower temperature level. When considering integrating of a steam dryer system with an existing background process, the choices of operating parameters are actually limited because the temperature levels of the heating stream are already set. The choice of pressure level then determines the temperature level of the condenser.

4.4 Flue gas drying

Flue gas drying is a common way of making use of the low temperature energy in flue gases from a combustion process. Rotary dryers using flue gases are the most dominant equipment type used in biofuel drying processes (Wimmerstedt, 1999). In pellet production plants that are not connected to a power plant, a dedicated burner is used for providing hot gases used for drying. The exhaust gas temperature in this case may vary between 400 to 800 ºC (Ståhl and Berghel, 2008), depending on the excess air in the boiler. When considering a biofuel process based on indirect gasification the combustion section will be used for production of steam and electricity and exhaust gases only are available after the economizer. The temperature level is then around 160 ºC.

The model developed for flue gas drying is set up according to the flowsheet presented in Fig. 7, also showing the basic modelling assumptions. Flue gases enter the dryer, are partly recycled and a condenser unit is optionally installed, recovering heat at a low temperature level – e.g. to heat up return water from a district heating system. The losses were estimated to be 3% of the total heat need for drying due to a higher temperature level compared to the air dryer (2% losses).

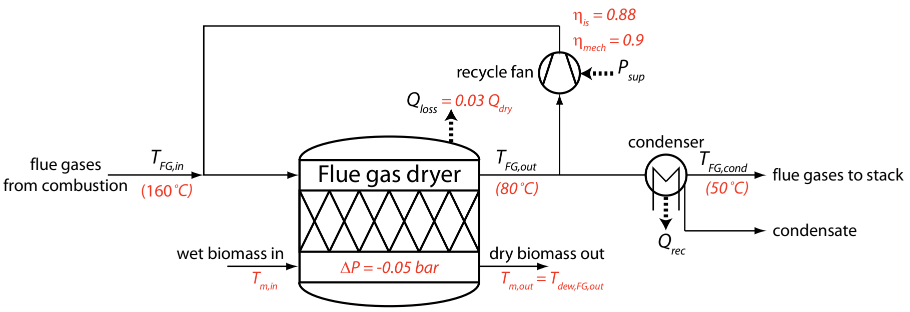

Figure 7. Flue gas dryer flowsheet showing the main modelling assumptions.

A sensitivity analysis was performed for the same test case as for the two other dryers, analyzing the main parameters of the model. The only variable that can directly be changed within the flue gas drying process is the recycle ratio *RR*, but since changes in the inlet and outlet temperatures could occur when performing a process integration study, the influence of these two parameters was also investigated.

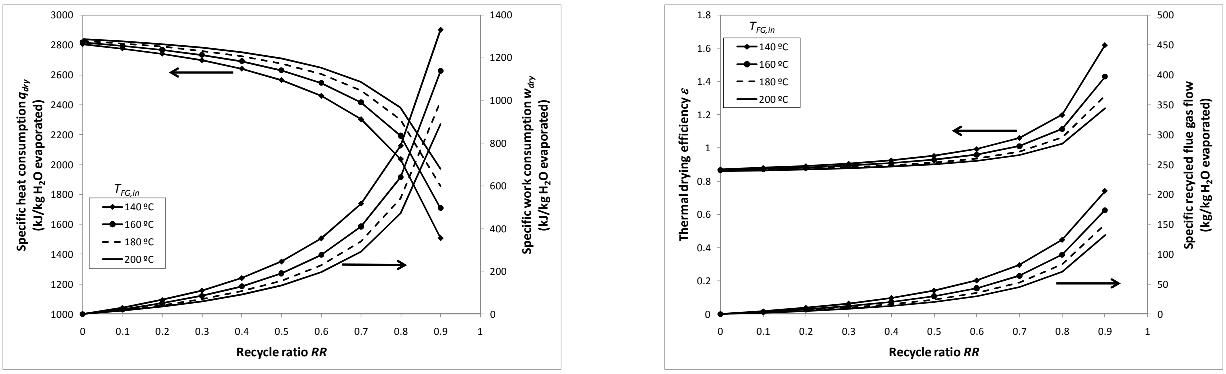

Figure 8. Influence of the recycle ratio *RR* and the flue gas inlet temperature $T_{FG,in}$ on the performance of a flue gas dryer. a) Specific heat and work consumption; b) thermal efficiency and recycled flue gas flow.

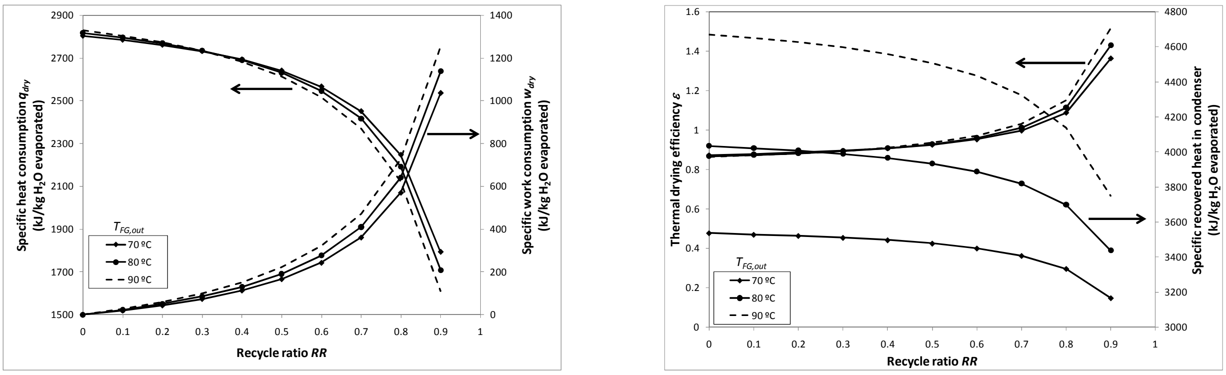

Figure 9. Influence of the recycle ratio *RR* and the flue gas outlet temperature $T_{FG,out}$ on the performance of a flue gas dryer. a) specific heat and work consumption; b) thermal drying efficiency and recoverable heat in the condenser.

Again, the relationship between decreasing heat consumption and increasing work consumption – as for the air dryer – when increasing the recycle ratio can be observed in Figs. 8a and 9a. The thermal drying efficiency increases above unity due to the increasing contribution of the recycle fan work to the drying process that is not taken into account in the thermal efficiency. This is also illustrated by the increasing flow of recycled flue gases in Fig. 8b. The amount of flue gases entering and leaving the dryer per kg moisture evaporated decreases with increasing recycle ratio, at the same time decreasing the opportunities for heat recovery in the flue gas condenser (Fig. 9b). The potential heat recovery is of course also strongly influenced by the dryer outlet temperature (for a fixed outlet temperature after the condenser of 50 ºC). It is interesting to note that changes for all investigated indicators are relatively small up to a recycle ratio of 0.5. The influence of temperature changes at both the inlet and outlet on the dryer performance is more pronounced at higher recycle ratios.

5. HEAT INTEGRATION STUDY

Using pinch analysis, the potential of the three drying alternatives was assessed for integrated feedstock drying for the SNG production process described in a previous paper (Heyne *et al.*, 2008). The GCC of the process streams related to processing of the product gas from gasification to obtain grid-quality SNG is illustrated in Fig. 10. The SNG process considered is a base case scenario. However, as shown by Heyne *et al.* (2008), changes in different sub-process stages significantly affect the amounts of excess process heat and internally recoverable heat for a given biomass feedstock feed-rate and will thereby also change the premises for integration of drying. This of course implies a design of the drying process already during early design considerations for the SNG process in order to be able to adapt the two processes to each other for maximum heat recovery. The case study presented however highlights the basic considerations when designing a drying process. The relationships revealed in the sensitivity analysis between supplied heat and work as well as volume flow (indicating equipment size) can be used to determine the most favourable economic configuration based on market price conditions for the SNG process under consideration.

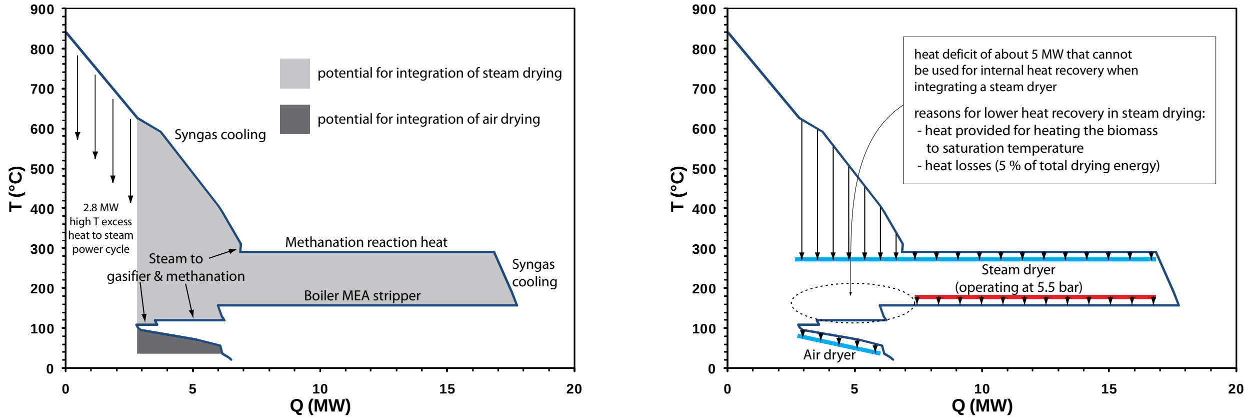

Figure 10. Grand Composite Curve (GCC) of the proposed SNG production process. a) visualizing the integration potential for both steam drying and air drying; b) illustration of the test case.

Table 1. Opportunities for integrating the drying process with the SNG production process.

Basic conditions

Initial moisture content biomass(1) (% of total mass)	50	Thermal input(1) (MW)	100
Moisture content dried biomass(1) (% of total mass)	10	Effective LHV (dried biomass) (kJ/kg)	17.35
kg H_2O evaporated per kg dried biomass(1)	0.8	Biomass feed (dried biomass) (2) (kg/s)	11.54

Dryer performances with integration

	Air dryer	Steam dryer	Flue gas dryer
Heat for drying from SNG process (kW)	3300	14000	4451(3)
Heat source/superheating/flue gas temperature (ºC)	80(4)	275	160 → 80
Heat recovered (kW)	-	9350	6791(5)
Temperature level of heat recovery (ºC)	-	155	80 → 50
Recycle ratio (-)	0.6	-	0.6
Specific heat consumption (kJ/kg H_2O evaporated)	2613	3328 (1209(6))	2546
Specific work consumption (kJ/kg H_2O evaporated)	243	29	277
Possible dry fuel delivery (kg/s)	1.58	5.51	2.18
Fraction of total necessary dry fuel supply (%)	13.7	47.7	18.9
SNG process cold gas efficieny – no drying(7)	0.594	0.594	0.594
SNG process cold gas efficiency – external drying(8)	0.520	0.520	0.520
SNG process cold gas efficiency – integrated drying	0.538	0.587	0.545

(1) : for combustion and gasification unit, respectively

(2) : overall supply to gasification and combustion unit

(3) : based on flue gas flow from the combustion unit (air-excess ratio of 1.2 for combusting the dry biomass input into the combustion unit and the non-gasified char that is returned from the gasifier to the combustion chamber)

(4) : assuming hot water production using the hot streams available in a temperature range of 60-100 ºC as indicated in Fig. 10

(5) : in case there is a heat sink available for using this heat (e.g. district heating network)

(6) : net specific heat neat accounting for the heat recovery

(7) : as determined by (Heyne *et al.*, 2008)

(8) : external flue gas drying making extra fuel necessary – 3100 kJ_{Fuel}/kg H_20 evaporated (Wimmerstedt, 1999)

As indicated, a lot of heat at high temperature level is released during syngas cooling and the methanation process. The excess heat at highest temperature that cannot be recovered internally within the gas processing is assumed to be used to increase the steam production of the power cycle with which the gasification process is integrated. The high temperature heat could be used for running a steam dryer, the condensation of the evaporated moisture being used for steam production and running the boiler of the stripper in the amine based CO_2 separation process (*Boiler MEA stripper* in Fig. 10). Part of the heat can be recovered at a lower temperature when condensing the vapour in the CO_2 stream at the top of the stripper. This lower temperature heat could be used in an air dryer as illustrated in Fig. 10 by the dark grey area. The flue gas drying cannot be illustrated in the GCC presented which only includes the product gas treatment process. It is assumed that flue gases from the combustion cycle are available at 160 ºC. As the thermal input to the combustion cycle is equal to the gasification process biomass input the amount of flue gases can be estimated. Using these assumptions the capacity for each drying process using process heat has been assessed, the results being shown in Tab. 1. The parameters for the drying systems are partly set by the temperature levels of the SNG process in this case (e.g. methanation temperature level serving as heat source for the steam dryer). Other parameters such as the recycle ratio for both the air and flue gas dryer are variable and can be adjusted – making use of the sensitivity analysis presented – based on economic considerations. As mentioned before, the recycle ratio mainly affects the ratio between electricity and thermal heat supply. If large amounts of excess heat are available, the recycle ratio should be chosen low in order to keep electricity costs low. In this case study, the excess heat is not sufficient to cover the whole drying need and a high recycle ratio is desirable to reduce the specific heat need for drying. In order to avoid an excessive increase of the specific work consumption however, the recycle ratio was limited to a value of 0.6. A more in-depth assessment of these parameters would be necessary for given economic data, of course.

5. DISCUSSION

The results shown in Tab. 1 clearly indicate that none of the three drying alternatives is capable of providing the drying capacities for both the gasification and combustion cycle (11.54 kg dried biomass/s) from process integrated drying in the case studied.

The steam dryer provides the highest capacity with 5.51 kg/s but it has to be kept in mind that not all the heat used by the dryer can be recovered as indicated in Fig. 10b. There is a deficit of heat of about 5 MW (or 2.5% of the overall thermal heat input) that has to be supplied externally to cover the processes' heat demand. Compared to the fraction of dry feedstock provided by steam drying (47.7%), this is a rather low figure. Additional drying is necessary even if all three alternatives were integrated into the process, which is an unlikely option. Substantial savings can be made though when integrating the drying process with the SNG production process compared to stand-alone drying of the biomass.

In the case of flue gas drying, a large amount of heat is assumed to be recovered in the condenser for use in a district heating network. It would be possible to increase the drying capacity of the dryer by lowering its outlet temperature. The lower limit for this temperature though is the dew point temperature and a decrease in dryer outlet temperature is also associated with a lower heat recovery potential in the condenser reducing the heat supply to e.g a district heating network. The amount of dried fuel supplied by flue gas drying of course depends on the size of the combustion unit the SNG process is integrated with.

Similarly, the air dryer capacity is a direct function of the amount of excess heat available at low temperature level. The cold gas efficiency for SNG production drops substantially from 59.4% to 52.0% when including the drying step as an external process. The integration of the drying process can to some extent counterbalance the drop in efficiency, with steam drying offering the highest potential. These efficiency numbers have however to be interpreted with caution since the heat deficit for the steam dryer has not been considered, nor are the detailed interactions with the steam power cycle represented. The final choice of drying technology applied in such a process will be based on a number of parameters such as: limits for inlet and outlet temperatures, pressure levels, market prices for heat, electricity and biofuel, possibilities to deliver low temperature heat to a district heating network and not least emission regulations. Drying of biomass is associated with release of organic substances (mainly terpenes), the extent mainly being dependent on the drying temperature. This will cause effluent streams – either gaseous or aqueous - needing treatment, and might reduce the heating value of the biomass. All these parameters need to be assessed for the specific type of process and plant location. The drying alternative should be assessed during the planning of the process if possible, rather than being designed posterior for a fixed process scheme as done in this study, as changes can then be done to the process in order to favour an optimum integration of drying.

6. CONCLUSIONS

Models for three different biomass drying alternatives – air, steam and flue gas drying – have been presented and the dependence of their performance on the basic operational parameters assessed with the help of sensitivity analysis. Steam drying was shown to be an effective technology for process integrated drying within the production of SNG as a high level of heat recovery is possible from the evaporated moisture. Based on a given case of SNG production via indirect gasification, the opportunities for process integrated drying have been illustrated for all three technologies. Steam drying can contribute to the largest extent to the supply of dry biomass accounting for 47.7 weight-% of the necessary overall feed to the process. By flue gas and air drying, an additional 18.9 and 13.7 weight-% can be supplied, respectively. This is not sufficient to cover the whole drying demand but represents a large potential for savings compared to stand alone drying. The choice of drying technology for a SNG production process will be the result of economic considerations as well as process sub-step choices and operation parameters, the latter ones strongly influencing the heat integration opportunities for drying.

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