Project Report

Integration of the control strategies for a heat pump dryer

D2.3 SusOrgPlus project

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Abstract

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1 Introduction

SusOrgPlus is a multi- and trans-disciplinary project aiming at the development of systemic solutions for processing of organic food stuffs, simultaneously catering for resource efficiency, high product quality and utilisation pathways for under- utilised raw materials and the production of novel, value added products. Thus, it will help to increase consumer acceptance, the overall sustainability of the sector and the livelihoods of the producers. The Norwegian participation in SusOrgPlus will provide the organic sector with (a) smart processing technologies (b) value-added products (natural additives and colourants) and (c) increased process efficiency, reduction of specific resource demands and phasing out of fossil through use of renewable energy sources (RES).

Organic food processing is characterised by empirical approaches resulting in high specific raw material and energy demands as well as product deterioration, thus, impacting on overall sustainability and product quality. SusOrgPlus will address these issues for the processing and production of value-added products of selected plant and animal origin products. The concept of heat pump drying by using natural refrigerants will be demonstrated for an industrial drier. The drying process will be event controlled so that the drying conditions can be improved with respect to product quality and energy efficiency. The SusOrgPlus concept will allow to phase in renewable energy sources in organic food preservation, recover drying energy and reduces the amount of primary energy consumption by up 75%. SusOrgPlus will focus on the development of a market ready drier concept which can be implemented by small or medium sized producers and stakeholders.

An industrial drier, with a thermal capacity of 30 kW was installed in 2019 in the SINTEF laboratory and equipped with R744 heat pump. Two thermal energy storages were used to match the energy demand of the batch drier to the heat pump. The energy storages are charged by the heat pump and then used to dehumidify and re-heat the drying air. This demonstration unit for heat pump drying was tested during 2020 for climate neutral drying of organic apples and seaweed. The results show that the drying process is faster due to the more efficient de-humidification by the heat pump. At the same time the process is completely free of climate gas emissions. The investigation will continue until beginning of 2021 and will focus on optimalization of the control parameters and energy efficiency.

Additional features of the drier are that a camera as well as different sensors for monitoring drying conditions are used to upload real time information for the smart control and optimization system which is in the cloud. The expectation is that a self-learning could-system can optimize the drying process without the help of human manpower. The SusOrgPlus vision is hereby that different driers are connected to the same cloud and that e.g. the manufacturer in Germany can automatically get optimized drying conditions based on own results but also process experience from other driers. The project partners in Germany and Italy are currently developing this system and it is the intention to demonstrate the potential at the demonstration unit of SINTEF.

A proof-of-concept investigation demonstrated the potential of surface temperature controlled drying and compare processing time as well as product quality for the different event triggered control strategies. It was found that the decreased drying time resulted in fact in an improved product quality.

2 Methods

2.1 Experimental campaign description

The campaign consisted of five experiments which are listed in Table 1. The aim of the campaign was to compare the drier in heat pump mode and electric heating mode, and to vary important operating parameters. Previous tests have been made for maximizing the heat pump performance, while the current campaign was aimed to maximize the overall energy efficiency of the drying process.

Since the energy efficiency of the drier is the focus of the current study, the product quality was not assessed. A humidified absorbance material was therefore used instead of apples (used in the previous report D2.2). By using the humidified absorbance material, the experimental procedure was simplified, and the experiments became more reproducible. The absorbance material was soaked in water, absorbing approximately water 9 times its dry weight, corresponding to 90 % moisture content. The cabinet was filled with 35 kg of product, resulting in 31.5 kg water.

In electric heating mode, the dryer is operated in an open loop, meaning that it sucks in fresh air and dumps the humid air, see Figure 1. A cross heat exchanger is installed for recovering heat. When ran in electric heating mode, the parameters that can be varied in the drier are temperature and humidity of the air entering the drying section, and the mass flow rate of air. The drier can also be programmed with varying temperature and humidity of the air over time, enabling feedback-based operation. All electric heating mode experiments presented in this study had fixed air temperature and humidity and mass flow rate over the entire drying period.

During heat pump mode, the dryer is operated in a closed loop, meaning that the air is circulated. The drying air temperature and humidity are dependent on the heat pump operation and the condition of the airstream after the drying section. The heat pump extracts heat from the airstream after the drying section, simultaneously removing water from the humid by condensation. The heat is thereby upgraded by the heat pump and transferred to the airstream before the drying section, resulting in maintaining the high drying temperature and low humidity air needed for efficient drying. However, the condition of the drying air is directly linked with air condition of the air after the drying section, resulting in the drying air condition being dependent on the actual drying process, i.e. water content and temperature.

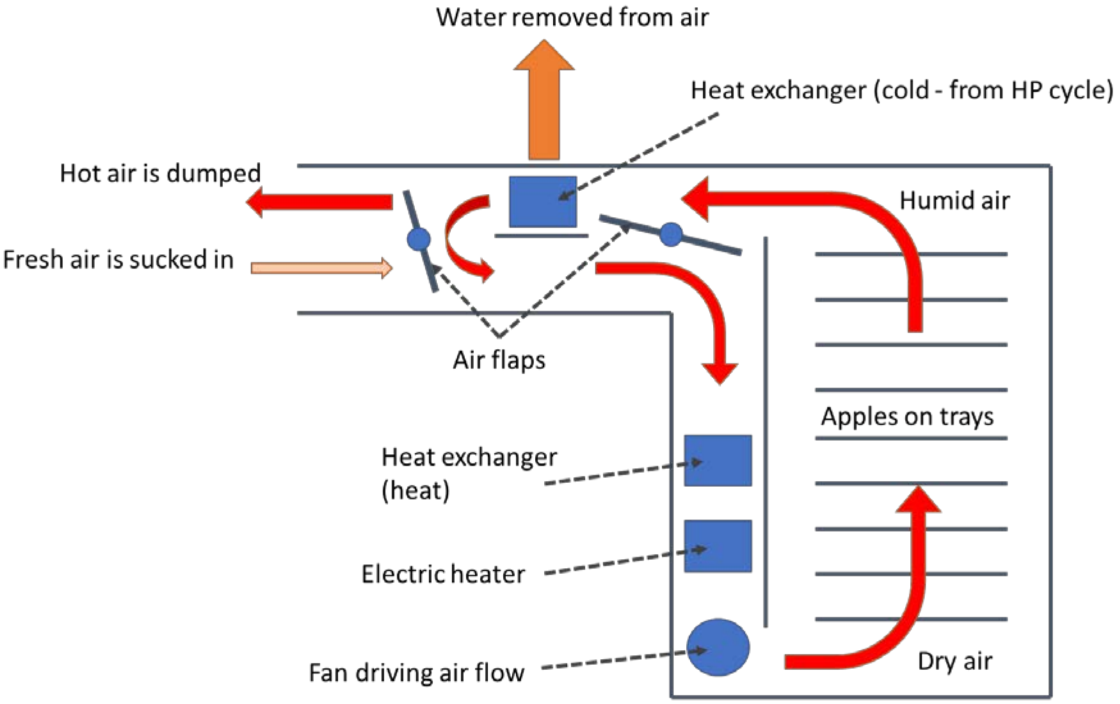

Figure 1 Schematic of the modified drying cabinet "Hohenheim HT8"

During heat pump mode the drier was programmed to electrically heat the air to 60 $^{\circ}$C for 20 min before starting. For both modes, the mass flow rate of the airstream can be regulated by adjusting the fan speed. All experiments were conducted with minimum humidity possible on the drying air, meaning that the water was removed at the highest rate possible.

2.2 Important parameters

The performance of the dryer is evaluated by the specific moisture extraction rate ($SMER$) in kg/kWh, calculated as the water removal rate Δx in kg/h and the power consumption W_{tot} in kW.

$$SMER = \frac{\Delta x}{W_{\mathrm{tot}}}, \tag{1}$$

A drying process with higher $SMER$ extracts water from the product with less energy compared to a case with lower $SMER$. The drying cabinet stands on weight cell, continuously weighing the product during the drying process. Combined with power measurements the $SMER$ is calculated continuously.

Table 1: Experimental campaign specification (*achieved temperature from HP mode).

Experiment name	Temperature setpoint [degree C]	Fan speed (%)	Other
EL1	60	100	
EL2	60	100	Without cross heat exchanger
EL3	40	100	Without cross heat exchanger

HP1	39*	100	
HP2	38*	60	

3 Results

3.1 Temperature and humidity of drying air

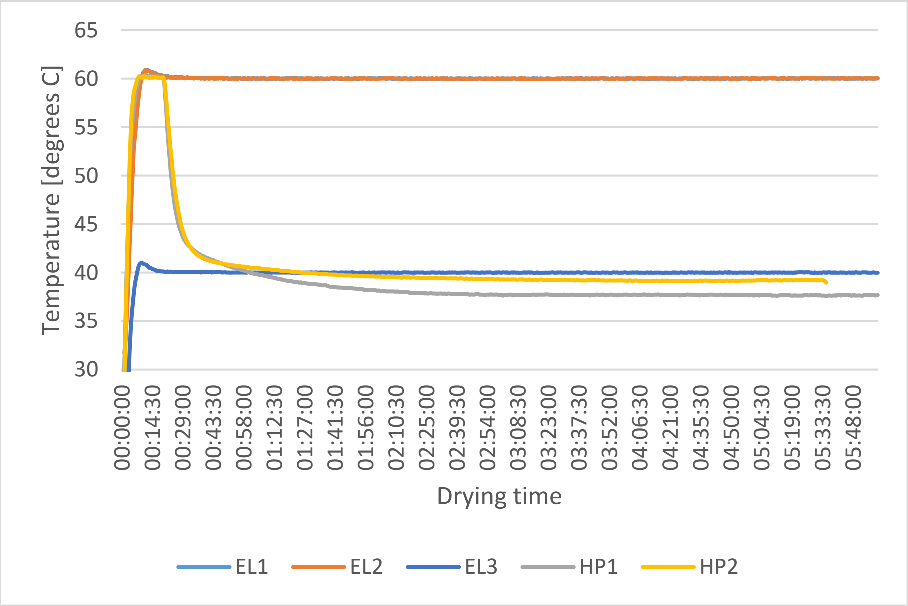

Figure 2: Air temperature before drying section.

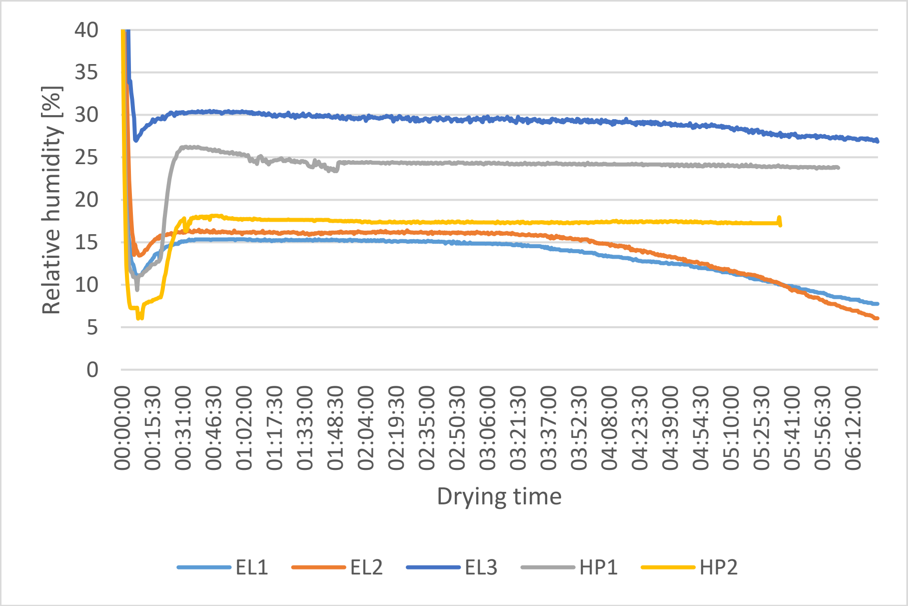

Figure 3: Air relative humidity before drying section.

3.2 Power consumption

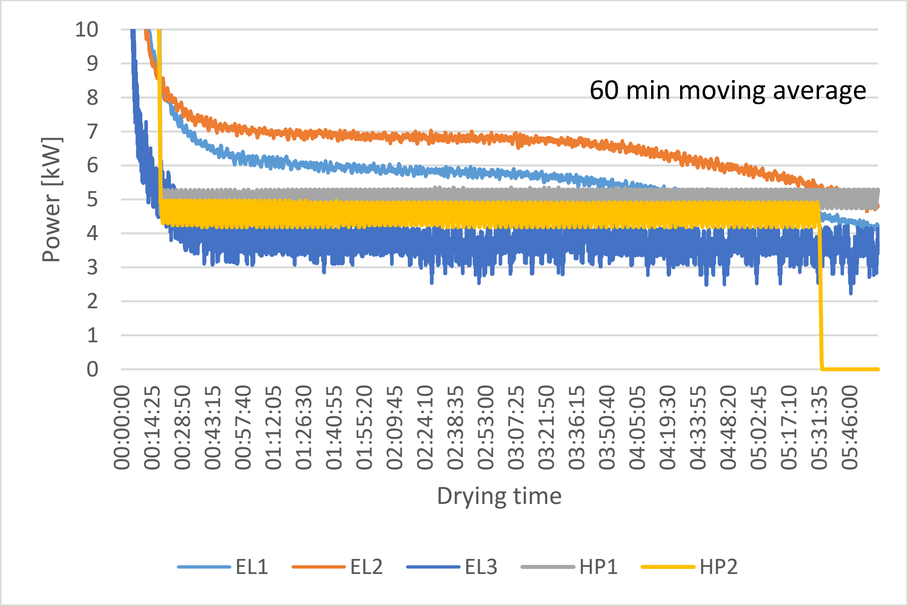

Figure 4: Total power consumption.

3.3 Specific moisture extraction rate

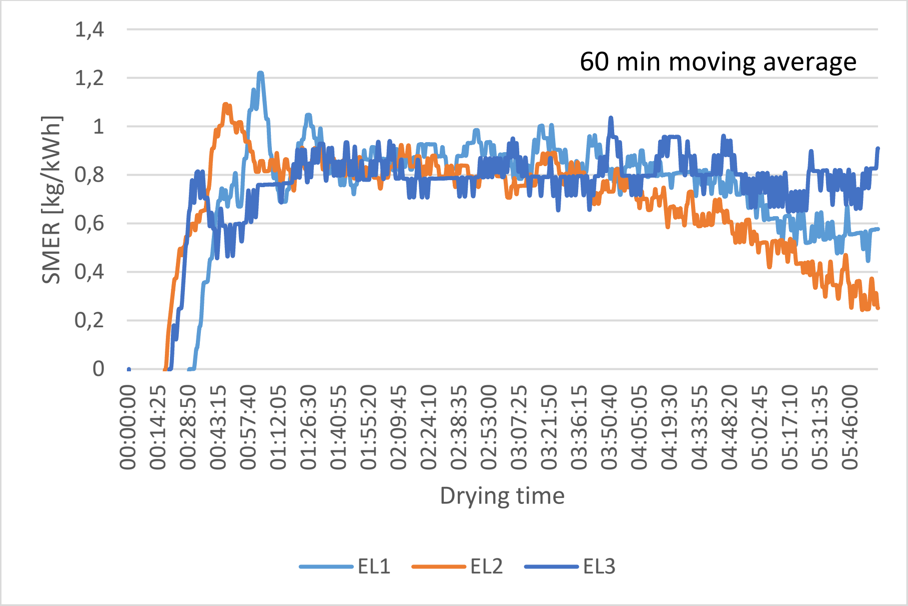

Figure 5: Specific moisture extraction rate (SMER) for electric heating mode.

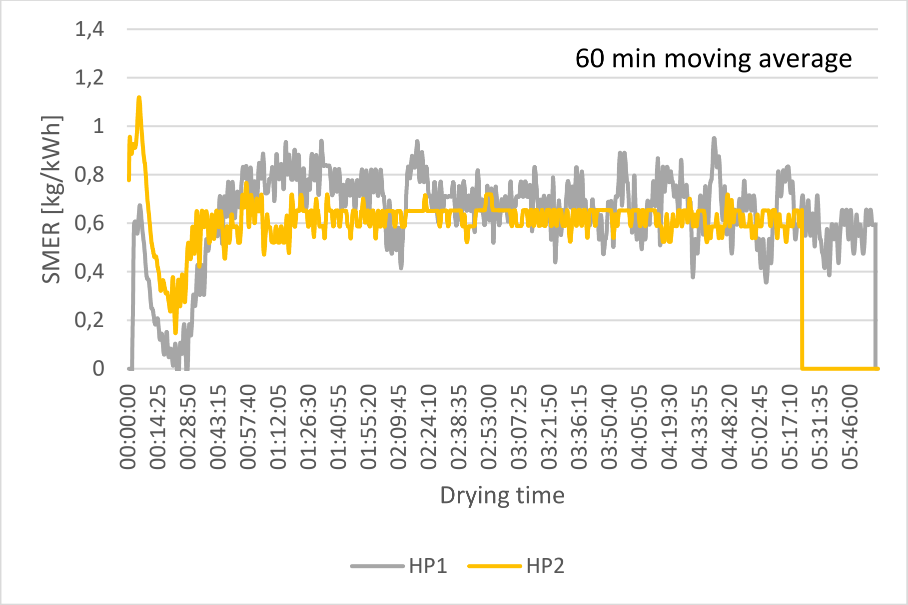

Figure 6: Specific moisture extraction rate (SMER) for heat pump mode.

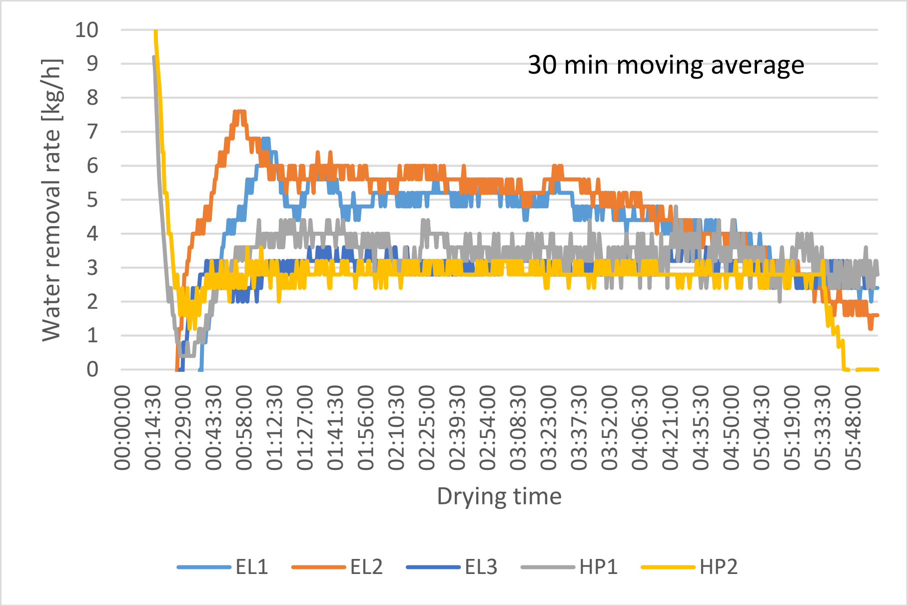

Figure 7: Water removal rate.

4 Discussions

Figure 5 compares all electric heating mode runs. Between 1:10:00 and 04:00:00 drying time, the SMER is seen to be close to 0.8 for all three cases. Meaning that removing the cross-heat exchanger at the outlet did not affect the SMER, also reducing the temperature from 60 ^{0}C to 40 ^{0}C did not affect SMER.

Figure 6 shows the SMER for the two heat pump runs. HP1 had fan speed of 100 %, while HP2 had fan speed of 60 %. The effect of reducing the mass flow rate of the circulating air is shown as a slight reduction in SMER, concluding that in HP mode 100 % fan speed is more energy efficient.

Comparing the SMER of EL3 and HP1 in Figure 5 and Figure 6, respectively, an assessment of the water removal efficiency between the two modes can be performed for similar conditions. The temperature of the air entering the drying sections is approximately 40 ^{o}C for both cases and the fan speed is 100 %. The relative humidity for EL3 and HP1 are similar at 15-17%. This results in having the same drying process in both cases. While EL3 dumps the air through the outlet, HP1 cool the air, reducing the humidity in the air. The SMERs for EL3 and HP1 are 0.8 and 0.7, respectively. The HP mode is therefore considered to be marginally less efficient at removing water.

Figure 7 shows the water removal rate for all cases. A clear difference can be observed between the 60 ^{o}C and 40 ^{o}C drying cases, where the former has water removal rates of approximately 5-6 kg/h. Comparing the 40 ^{o}C drying cases to each other, EL3 is seen to have a water removal rate of approximately 3 kg/h, while HP1 has 3.5 kg/h. Heat pump mode therefore completes the drying process in shorter time compared to electric heating mode.

5 Conclusions

A number of drying experiments were performed to analyse the assessment and the heat pump dryer performance, using apples as the main food product. The main results showed a uniform drying on each tray, both horizontal and vertical and it is possible to dry approx. 100 Kg of apples in one batch, taking 5-6 hours. Since the drying chamber is rather short (short tunnel) only a small temperature glide over the trays was observed, and the increase in relative humidity of the drying air was smaller than expected. This was not considered in the design phase, unfortunately. By running the drying system in bypass control, it was expected a decrease in drying time compared to normal drying. Compared to normal mode, the drying process was the same for the heat pump drying but compared to conventional drying, the decrease in drying time was approx. 15% due to the heat pump.

The use of CO_2 as a refrigerant has shown to be not the most efficient solution for energy recovery from drying air with low relative humidity. Using another natural refrigerant may affect the efficiency of the system positively.