D1.5

Performance data of the components with measurement protocol and interpretation for the dryer application

THEGREEFA

Thermochemical fluids in greenhouse farming

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

Document references

Project Acronym	**TheGreefa**
Project Title	**Thermochemical fluids in greenhouse farming**
Project Coordinator	**Serena Danesi (ZHAW)**
Project Duration	**October 2020 – September 2023 (36 months)**

Deliverable No./Title	**D1.5 Performance data of the components with measurement protocol and interpretation for the dryer application**
Dissemination level [1]	**PU**
Work Package	**WP1**
Task	**Task 1.6: Lab test for dryer**
Lead beneficiary	**ZHAW (Serena Danesi)**
Contributing beneficiary(ies)	
Due date of deliverable	**31/01/2022**
Actual submission date	**01/02/2022**

[1] PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services

Document history

V	Date	Beneficiary	Short description of contents and/or changes
0	01/02/2022	Serena Danesi (ZHAW)	First release

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

Executive Public Summary

An innovative drying plant based on absorption processes is the object of this deliverable.

The basic principles are explained as well as the main core components of a small demonstration plant installed at the laboratories of the ZHAW, where the technology has been tested.

The scope of the first tests were to understand and to characterise the conditions that can be achieved in the plant, to optimise the setup of the plant. Furthermore, the behaviour of the herbs was analysed during the different phases of the drying process.

In a second steps, batch of herbs was dried in parallel in the dryer of the TheGreefa and in a conventional commercial dryer. The performances were compared as well as the energy consumption.

The deliverable reports at the end considerations and calculations of energy consumption for a more complex plant and an optimisation for the minimised the amount of the drying medium (thermochemical fluid).

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

1. Introduction

Maintaining high product quality is one of the key issues in food drying industries. During the process, food structure and appearance can change as well as the aroma through the modification of important bioactive constituents and the nutrients can deteriorate during drying due to their thermolabile characteristics.

The selection of the process parameters, as the temperature and the duration, influences the quality of dried food. Some agricultural goods like herbs and fruits must be dried immediately after harvesting, in order to avoid their deterioration and rotting. Furthermore, to guarantee the quality, many agricultural drying processes are preferably operated at low/ambient temperatures (e.g. max 35°C), with a short drying process and immediately after harvesting: very energy extensive processes are often required to combined all these characteristics. The renewable energy as driving source is often not possible or not economically feasible due its fluctuation and/or periodically availability.

The technology of TheGreefa is very suitable for these purposes because the drying medium, a concentrated hygroscopic liquid (e.g. salt solutions or alkalis) here called Thermochemical fluid, shorted TCF, can be produced at any time when renewable energies are available and then stored without any losses until the goods shall be dried.

2. Principle

Large-scale drying processes of herbs for food purposes are based on removing moisture from the leaves through dry air. Air dehumidification is mainly carried out by two processes, which are often combined:

1) by heating the air: the relative humidity of the air decreases, while there is no impact on the absolute humidity. The higher the temperature of the air, higher becomes hygroscopic capacity of the air.

2) by compression processes: the air is compressed to its saturation point and the formed condensate is separated. In this case the absolute humidity decreases. The air must be then heated up again to increase its hygroscopic properties, e.g. to decrease the relative humidity.

Both processes require thermal and/or electrical energy. Particularly in the case of seasonally operated processes that have a high energy demand, but limited in a short period, an exclusive use of renewable energies is often not economic with these available technologies. The use of renewable energies is limited by their temporal availability and standard seasonal energy storages are not yet affordable.

TheGreefa technology uses also thermal energy, this is used to produce the drying medium (concentrated TCF), at not to heat the air during the drying of the goods as in conventional processes. Because the concentrated TCF can be stored without loses, the TCF can be regenerated independently of the drying process. The thermal energy needed can also be at low temperature, such as solar energy as shown in the Figure 1. In this way, concentrated TCF can be generated, when renewable energy is available and irrespective of whether the drying process is operating at the time or not. The quote of renewable thermal energy can be increased till 100%.

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

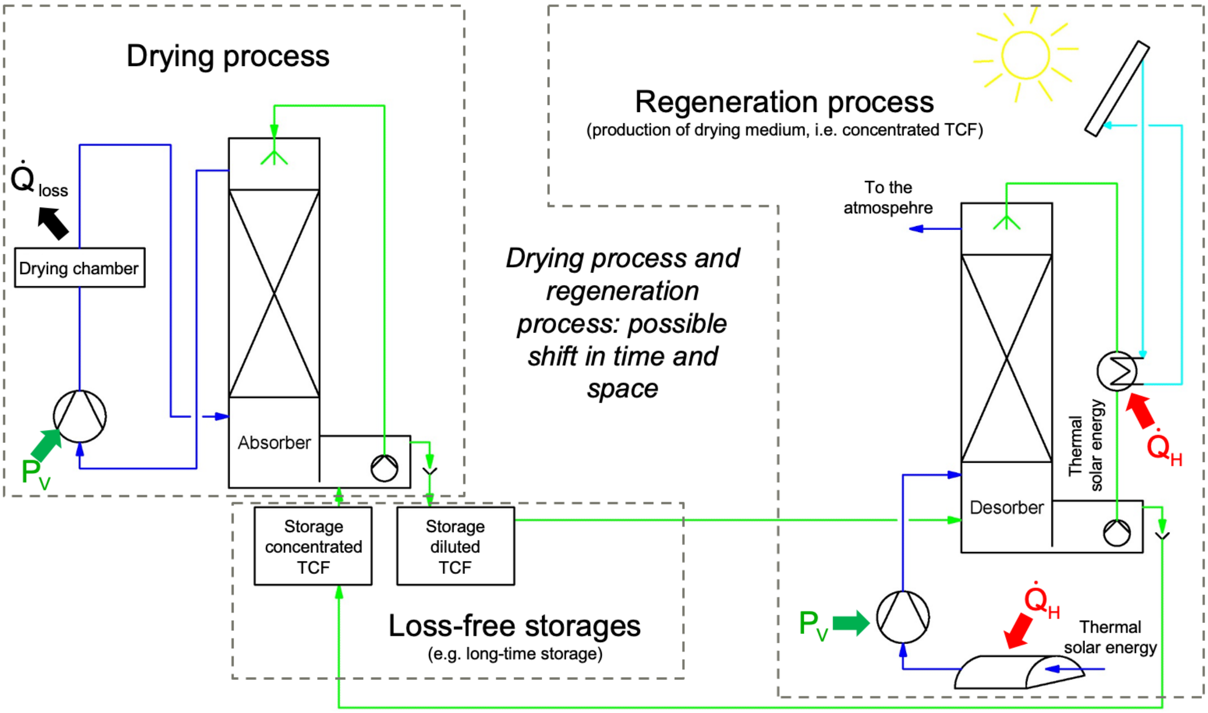

Figure 1: simplified process flow for TheGreefa technology applied to herb drying process and using solar energy as primary thermal energy source

The innovation of the TheGreefa is in preparation of dry air: the innovative components in a drying plant are the absorber, the TCF storages and regeneration (Figure 1), while the drying chamber is the conventional one.

The drying system of the TheGreefa is described below. For basic information on the absorption processes, please refer to D1.1, chapter 1, or to the Grant Agreement Document, Part B, chapter 1.3.1 or to the deliverables of the H-DisNet (H2020, Grant agreement 695780).

Drying process: the air circulates in a close system; it is dried in an absorber in counterflow with a concentrated TCF and then is blown in the drying chamber. The humid air return then in the absorber. Because the absorber operates at the ambient pressure, the ventilator must provide just the pressure drop of the air circuit. The air circuit is as in a conventional plant, where the absorber substitutes the compression machine and/or the heat exchanger.

The TCF is pumped from the absorber sump to the top of absorber though a pipe (**Fehler! Ungültiger Eigenverweis auf Textmarke.**), gets into counter-flow contact to the air inside the absorber and then is collected again in the sump. As soon as the TCF becomes too diluted and can no longer absorb moisture from the air efficiently, it is replaced by new concentrated TCF and pumped to the diluted TCF storage tank.

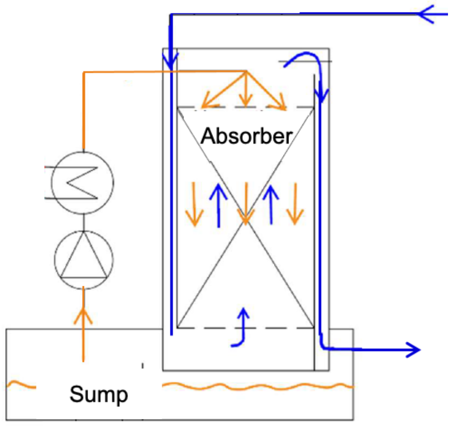

Figure 2: Flow direction inside the absorber/desorber: TCF is yellow, air is blue

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

Loss-free storages: the diluted TCF is stored in the TCF diluted storage until renewable energy is available for the regeneration process, while the concentrated TCF is stored in a separated storage and pumped to the absorber during the drying process as soon as the TCF in the absorber sump becomes too diluted.

Regeneration process: the regeneration process removes excess water from the TCF. Regeneration is the opposite process of absorption. The TCF is taken in contact with ambient air and part of the water in the TCF solution is absorbed by air flowing through the desorber. To force the process, a small amount of low temperature heat is usually required to increase the temperature, thereby decreasing the relative humidity of the air, e.g. increasing its hygroscopicity. The temperature level depends on the vapor pressure equilibrium between air and TCF, in any case it will be below 60°C.

The absorption and desorption could take place in the same column (called absorber) in different time periods. The vapor pressure equilibrium between air and TCF will determine in which direction the water/humidity will flow (from TCF to air or from air to TCF).

The Sankey diagram (Figure 3) shows that the thermal energy is the main energy source for drying process and its decoupling in time and space from the drying process is possible thanks to loss-free storages.

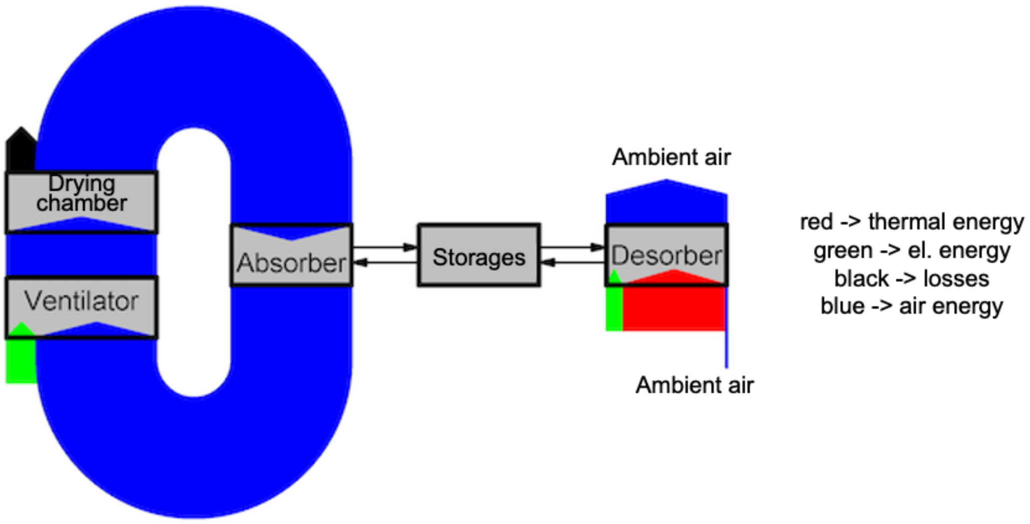

Figure 3: Sankey diagram for of the TheGreefa drying process

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

3. Facility at ZHAW

ZHAW has a small demonstration plant for drying based on absorption process (Figure 4). The system can be divided into the following assemblies (Figure 5):

- The absorber block consists of the absorber itself, the buffer sump, the TCF pump (P2.1), the TCF pipes, the air fan (V2.1) and a water/TCF heat exchanger (W2.1). This block is used for absorption as well as desorption (TCF regeneration)
- The dryer block consists of the drying box and of the air ducts
- The heating block consists of a water circuit with pump (P1.1) and expansion tank, and of an electrical heater (DH1.1)

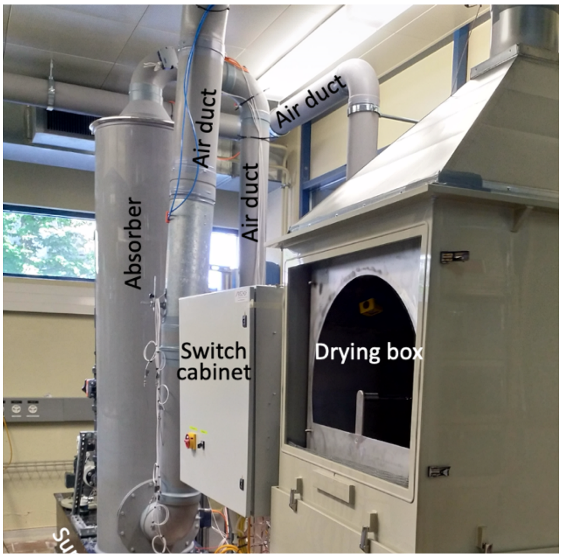

Figure 4: the demonstration plant at the ZHAW used for TheGreefa project

During the drying process, the TCF is pumped into the absorber and then collected in its sump, while air is recirculated between the absorber and the drying box by the V2.1 fan.

The focus of this demonstration plant is on the drying/absorption process. In the regeneration process, the necessary heat is supplied to the TCF in the exchanger W 2.1 by a water circuit heated by electric hater DH1.1. Air is sucked in from and released to the outside environment, the drying box are bypassed.

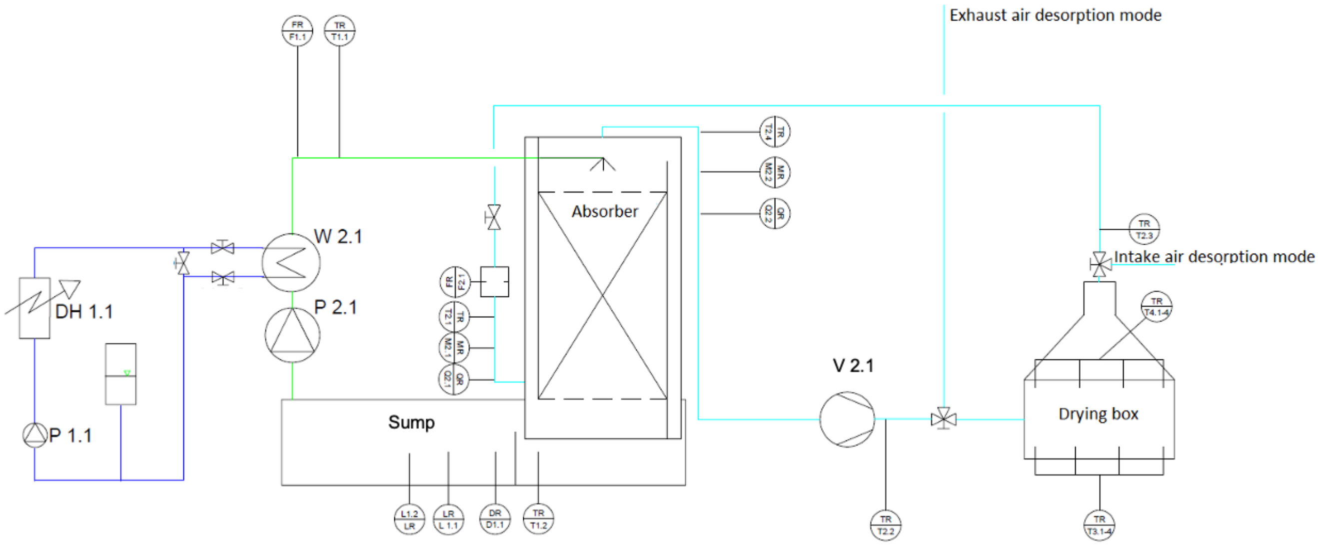

Figure 5: P&ID of the demonstration plant at the ZHAW used for TheGreefa

The plant is operated manually, a continuous measurement recording system (LabView) is installed.

In case the TCF becomes too diluted, the sump is emptied by a portable pump. Two TCF tanks, each 1 m^3, are located next to the plant.

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

The fix measurement points (Table 1) allow a complete energy balance of the plant. Within the dryer box, additional sensors are installed, in order monitor the uniformity of the temperature.

The CO_2 concentration is recorded to monitor the reactivity of TCF used with CO_2 in the air.

Table 1: Fixed measurement points

L1.1 /L1.2	TCF	Level detection «high» / «low»	Endress & Hauser, FTW 31/325
DR1.1		Density measurement	Endress & Hauser, FML 621
F1.1		Flowmeter	ABB, MID, FEP 610
T1.1/ T1.2		Temperature «inlet» / «outlet»	SAWI PT100, 4-Leiter, Klasse A
Q2.1 /Q2.2	Air	CO_2-Measurement, absorber «inlet» / «outlet»	Vaisala CO_2, ±3.5%
M2.1/ M2.2		Humidity, absorber «inlet» / «outlet»	Jumo Kapazitiv, ±3%rH
F2.1		Flowmeter	HESCO V-Control 200
T2.1 / T2.4		Temperature, absorber «inlet» / «outlet»	Jumo PT1000, Class B
T2.2/T 2.3 / T3.1-T3.4		Temperature, drying box «inlet» / «outlet» - in the drying box	SAWI PT100, 4-wires Class A

The absorber and drying chambers are the core components. The design of the absorber is the same as the absorbers installed in the Wangen greenhouse, demonstrator 1 and shown below.

Absorber:

The absorber has the same construction of the absorbers installed in the greenhouse Wangen (Figure 6), see also the D1.1 or the deliverables of the H-DisNet (H2020, Grant agreement 695780). The aim in TheGreefa project is to demonstrate the functionality of adsorption processes in drying, not its optimisation.

Main design features and operating data:

- Scrubber diameter: 0.5 m
- TCF inside the absober/sump: 0.4 m^3
- Packing: Pall-Ring 15, 1.3 m fill height
- TCF distributor: Perforated floor distributor
- Demister: Wire knitted demister
- Gas velocity (empty absorber): 1 m/s
- TCF flow density: 12 $m^3/(h\ m^2)$

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

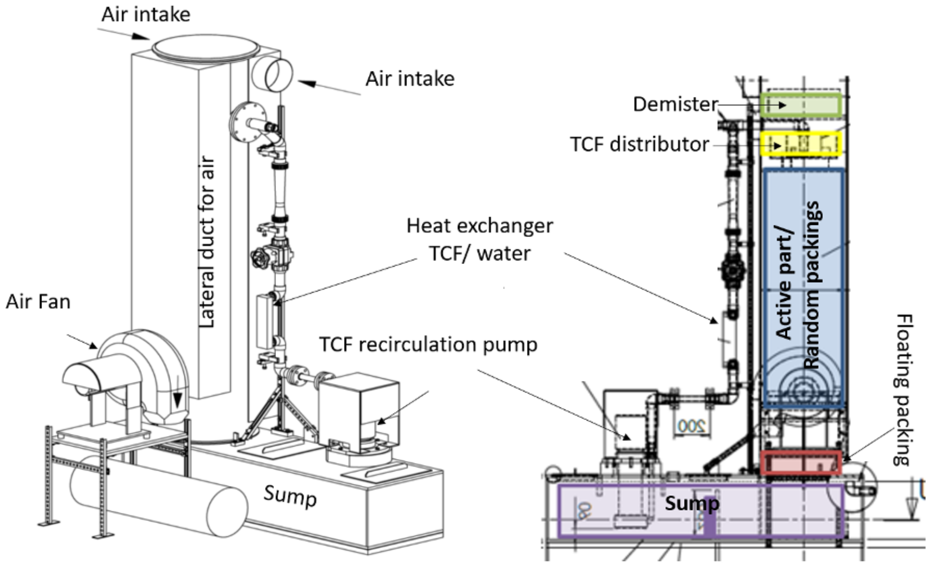

Figure 6: drawings of the absorbers used in TheGreefa in the ZHAW demonstrators

Drying box:

The drying box reproduces the floor of a real drying chamber and has been built for this demosntrtion facility. The perfored ground assures the distribution inside the chamber. The first chamber installed has a parallelepiped shape, but during the first tests, it was found that there were strong inhomogeneities in temperature and humidity inside the box. It was therefore decided to replace it with a cylindrical-shaped one in which an automatic mechanism for turning the herbs is installed (Figure 7). It reproduces what happens in real cases where the herbs are turned by hand to allow drying on both sides and to avoid dead zones (for example in the cornes).

- Filling volume of drying box: 0.39 m^3
- Length and diameter: 990 mm x 600 mm
- Agitator: shaft made of S235 with 3 freely rotating, self-aligning agitator arms

Figure 7: herbs inside the drying box of TheGreefa with the mechanism to turn the herbs (left) and its drawing (right)

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

Material: the TCFs are corrosive, so plastic material is used. This is also possible because the process is working at ambient/low temperature. The only no-plastic component is the heat exchanger, which is Alloy 316. The heat exchanger is used during the regeneration. can absorber more water from the TCF) and during the drying process.

4. Sodium hydroxide

A wide variety of TCFs can be used to dehumidify the air. In the previous H2020 project H-DisNet, different TCF were investigated and the advantages and disadvantages were compared: the magnesium chloride ($MgCl_2$) solution was the best choice considering the hygroscopic performance, cost and availability. It is used in the other applications of TheGreefa, however it is not very well suitable for the drying processes.

The lowest achievable air humidity at the equilibrium with the TCF depends on the chemical composition of the TCF, its temperature and concentration: the $MgCl_2$-solution can dehumidify the air down to 35% relative humidity (not below) at 20°C, which is too high for drying purposes: here 10% as maximum relative humidity is required. The Table 2 lists potential TCFs with a dehumidification potential below 20% relative humidity at 20°C.

Considering various other characteristics such as cost, toxicity and availability, NaOH proves to be the most suitable TCF for such applications. This also confirmed by a feasibility study carried out by ZHAW for Innosuisse (Nr. 34634.1 INNO-EE), which analysed also the required volume of TCF and the potential energy savings.

A peculiarity of the NaOH is its affinity to carbon dioxide (CO_2): during the process, the CO_2 of the air is absorbed and reacts in the solution with NaOH to form sodium carbonate (Na_2CO_3). As reported in the next sections, this reaction is more significant during the regeneration, while for the drying process the impact is quite limited.

Table 2: Equilibrium humidities of saturated TCF at 20°C

Salt (TCF)	Chemical compounds	Air humidity at the equilibrium, 20°C
Caesium fluoride	CsF	3.38 %rH
Lithium bromide	LiBr	6.61 %rH
Zinc bromide	$ZnBr_2$	7.94 %rH
Sodium hydroxide	NaOH	8.91 %rH
Potassium hydroxide	KOH	9.32 %rH
Lithium chloride	LiCl	11.31 %rH
Calcium bromide	$CaBr_2$	16.50 %rH

5. Measurements and interpretation

Temperature

First tests were carried out to understand the temperature trend during the drying process, using wet fabrics placed inside the drying box (Figure 8).

An initial temperature drop can be seen due to the strong absorption of water inside the drying box. The absorption process in the absorption heats up (condensation), the air at the outlet is warmer than the air at the inlet, while the drying process in the drying box cools down (evaporation), the air at the outlet is cooler than the air at the inlet. Added to this is the heating effect of the fan.

If you want to dry at lower temperatures, you can cool the TCF in the W2.1 heat exchanger. For the herbs analysed, this is not necessary.

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

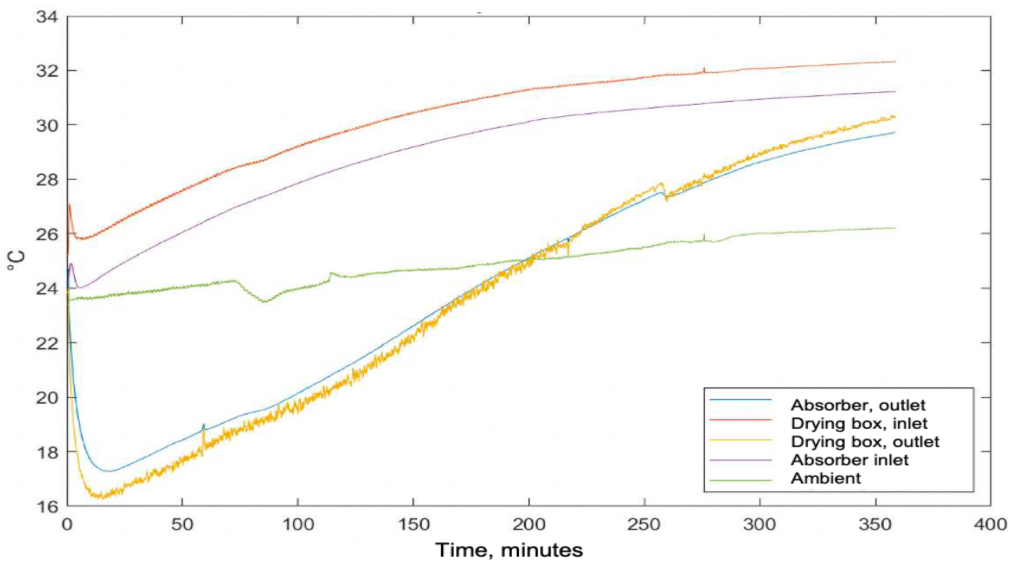

Figure 8: Temperature during drying tests in TheGreefa

Drying behaviour of the herbs

The duration of the drying process depends on the condition of the material to be dried and the condition and flow rate of the drying air. The physics behind them can help to better understand these relationships.

Mass transfer coefficients "b" describe the mass flow of a substance through a surface "A" (in this case the surface of the herbs) depending on the driving force.

The driving force for transfer of the water from the herbs into the air is the difference of the partial pressure of the water vapour of the drying air and the water vapour pressure of the herbs to be dried.

This difference can be written as a concentration difference with the help of the gas constant:

$$\Delta c = \frac{p_{herbs} - p_{air}}{R\,T}$$

The mass flow of water is then:

$$\dot{m}_w = \Delta c \; b \; A$$

The model of the drying process (Left, Figure 9) foresees that the water on the surface of the herbs evaporates first. During this phase, a constant mass flow of water can be expected (green section). As soon as the leaf surface dries out and is no longer completely wetted, the surface with water decreases, but the driving force remains the same (yellow section). According to the above equations, the mass flow decreases until the surfaces are completely dry, the concentration difference remains constant. As soon as the herbs reach a degree of dryness, its water vapour pressure decreases and the mass flow of water decreases to a minimum (red area).

This model has been validated by measurements as shown on the right diagram in Figure 9. The data comes for drying of nettle leaves.

The sudden increase in the wet surface visible on the real case is due to the manual turning of the leaves inside the box so that both surfaces are exposed to the airflow. The corresponding increase in the water flow show the positive impact of the turning on the drying process, e.g. on the duration of the process. The turning must be

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

done very carefully so as not to damage the leaves themselves, so a compromise must be found based on the experience of the dryer operator.

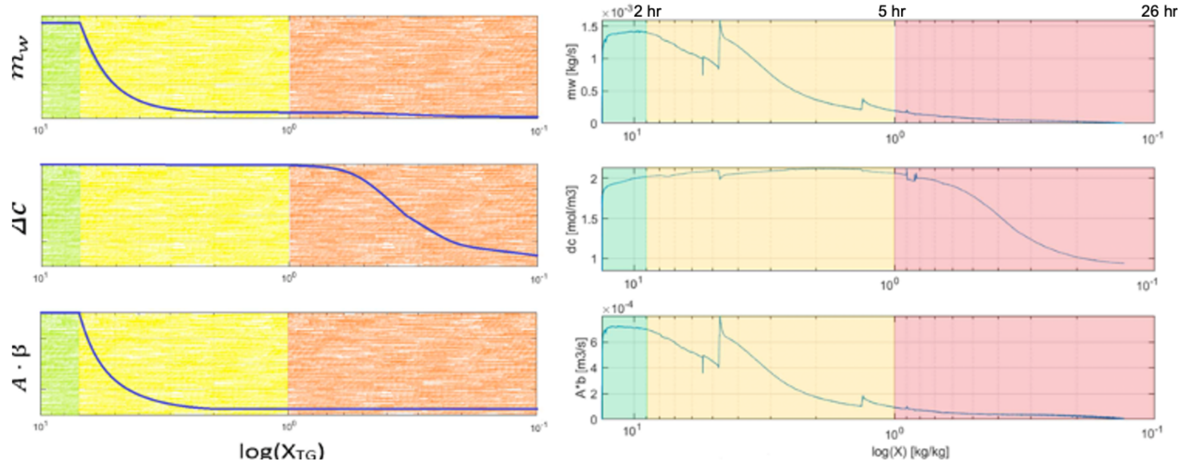

Figure 9. The x-axis shows the water loading of the drying material with a logarithmic scale, the y-axes (from top to bottom) show the mass flow of water, the concentration difference of water and the wetted surface of the material to be dried multiplied by the constant mass transfer coefficient β. Left picture: model; right picture: data from the tests

An important insight from these diagrams is the drying rate. The nettle leaves were dried to the residual moisture required by the tee manufacturer, 12%. After 2 hour the water in the leaves is reduced from 20 kg to 9.5 kg, in the next 3 hours is removed further 1 kg water and the leaves are not wet anymore (end of the yellow sector), but then other 21 hours are necessary to remove the remain 0.9 kg and reaching the required rest humidity. The increase of the difference in the water vapour pressure, i.e. of the concentration, can to speed up the removing of the last part of the humidity.

In the last phase of the process the water vapor pressure on the herbs becomes very low and a high level of dryness is required for the air. This is shown in Figure 10 where the x- axis reported the water content of the leaves, the drying process start on the right of the x-axis and ends on the left.

The water vapour pressure above the herbs has been determined placing herbs of different drying states in a sealed jar and processing the value of the temperature/humidity sensor inside the jar (that means when the water vapour partial pressure of the air and above herbs are in equilibrium).

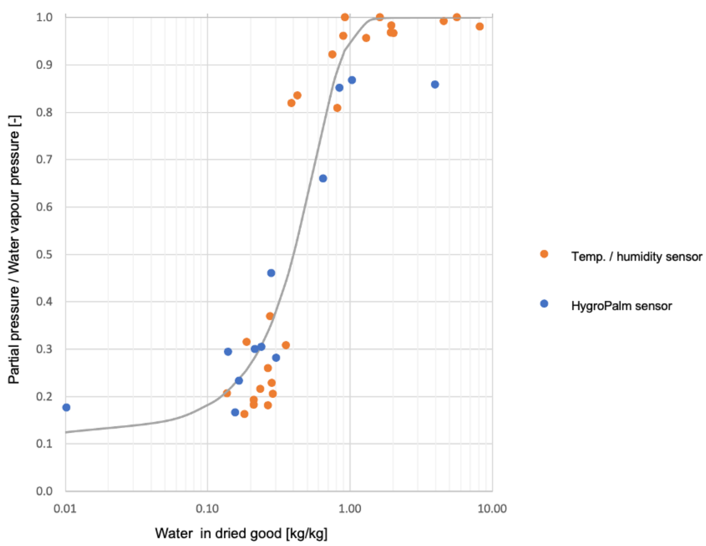

Figure 10: Water vapour pressure above the herbs

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

Sodium carbonate

As explained in the previous section, the NaOH can reacts with the CO2 and produce carbonate ions. As a result of the reaction, the TCF is diluted: water is formed, while NaOH disappears, e.g. is converted in sodium carbonate. If the solubility limit of the sodium carbonate is exceeded, it crystallises as a hydrate and precipitates:

$$2\ NaOH + CO_2 \Rightarrow Na_2CO_3 + H_2O$$

From the stoichiometric reaction conversion, the conversion is 1.8 g NaOH per 1 g CO2.

At a CO_2 content of 450 ppm in the air, there are 0.82 g CO_2 in one cubic metre of air.

During the drying process, the air circulates in a closed system, 2.5 g CO_2 are thus absorbed from the enclosed air volume of 3 m^3, which corresponds to a loss of 5 g NaOH. This is 0.002 % of the NaOH stored in the system (450 kg of 50% NaOH).

In the desorption process with an air flow rate of 500 m^3/h, a maximum of 400 g CO_2 per hour can be absorbed. This would correspond to a conversion of 1.4 % of the treated caustic during an 8-hour regeneration. Based on CO_2 measurements before and after the absorber, a NaOH turnover of 4.36 kg was determined during an 8-hour desorption, which corresponds to a reduction of the NaOH content of 1.07 % (Figure 11).

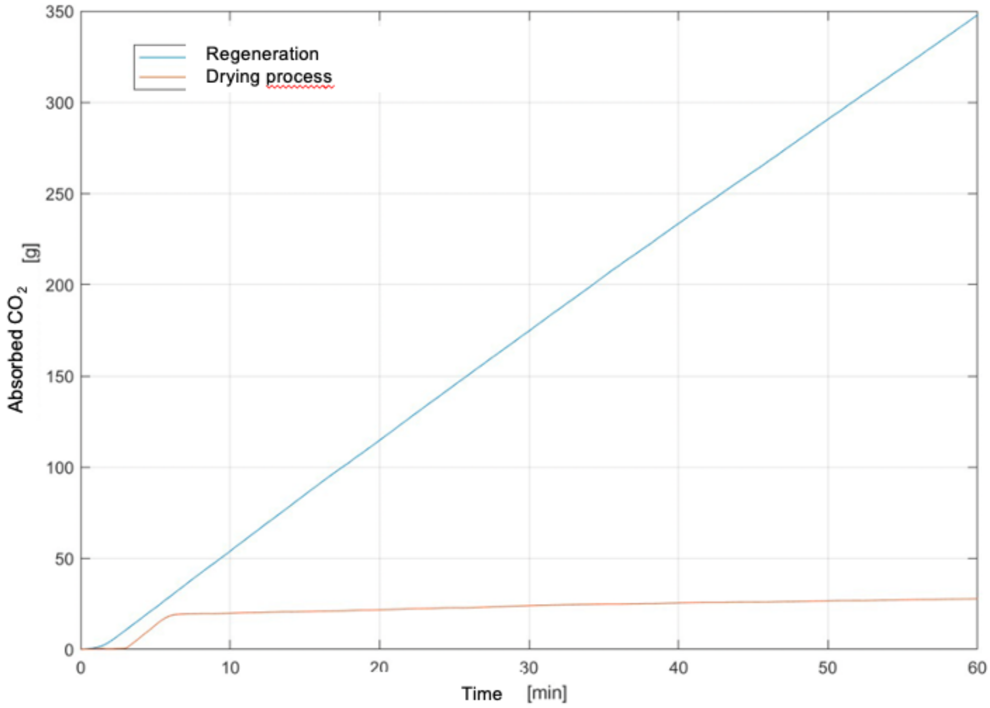

Figure 11: CO2 absorber by NaOH

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

6. Drying process in TheGreefa and in a conventional plant

The first phase of tests served to understand the behavior of the herbs during the drying process, to measure the humidity and temperature trends inside the drying box: it was possible to optimize some parameter and create process reproducibility.

In the second phase, three batchs of herbs have been dried. Herbs from the same harvest were also dried simultaneously in a commercial facility of Holderhof Produkte AG. This served as benchmark for the performance of TheGreefa's process. The dryer in Holderhof utilizes a compression humidifier.

The same conditions of Holderhof's drying chamber have been reproduced in the drying box, so that the difference between TheGreefa's and the Holderhof's was just the dry air preparation system. The two systems had the same:

- air velocity through the perforated floor
- thickness of the wetted material by the perforated floor
- specific air quantity per material to be dried
- closed air circuit
- residual moisture in the final product

The herbs in Holderhof were turned manually, in the TheGreefa mechanical.

The TheGreefa plant was loaded with 23 kg of nettles, which were chopped into pieces of a maximum of 10 cm to ensure that the material to be dried was wound up on the agitator and dried regularly. Air temperature and humidity at inlet and outlet of the drying box are reported in Figure 12. The system heats up in the initial phase from 25°C room temperature until an equilibrium is reached at 30°C.

The herbs are dried at a quite constant and low temperature. The air initially transports up to 6 g of water per kg of air.

After 36 h, 5.9 kg of nettles with a residual moisture of 10.5% could be removed.

A high concentrated NaOH-solution (50%) has been used, the concentration decreased only slightly at the end of the drying process. An optmisation of the TCF management is described in the next section.

The conventional plant was loaded with 1'600 kg of nettles, heated up from 18 degrees ambient temperature to over 40 degrees. The air initially transports up to 2 g of water per kg of air. After 70 h, 450 kg of nettles could be removed with a residual moisture of 12.6%.

A comparison between the two processes in reported in Figure 13. The performance in term of drying potential and duration of TheGreefa are similar or better to/than a conventional process. The next decision criteria will be to evaluate the energy consumption and the quote of renewable energy.

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

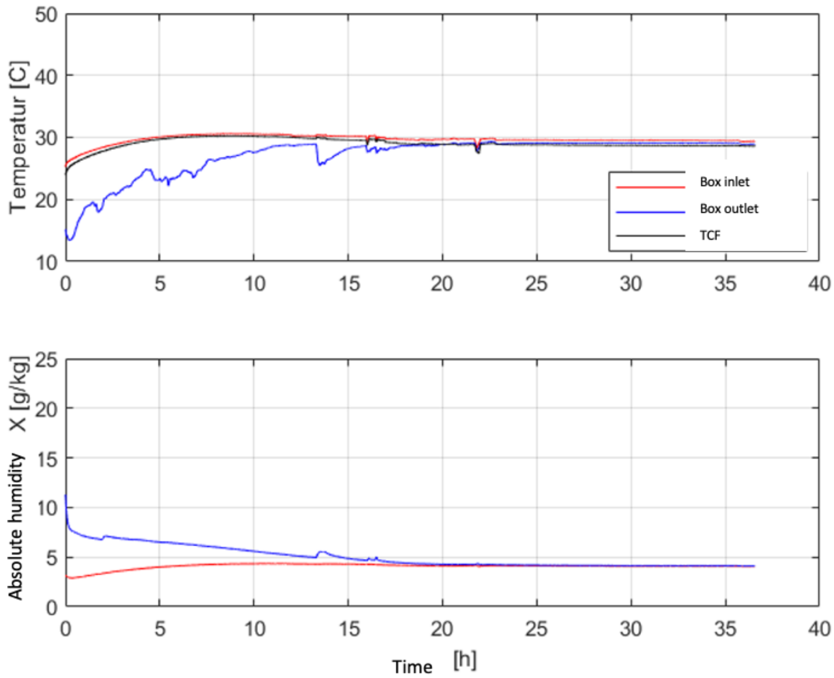

Figure 12: temperature and absolute humidity in the TheGreefa dryer

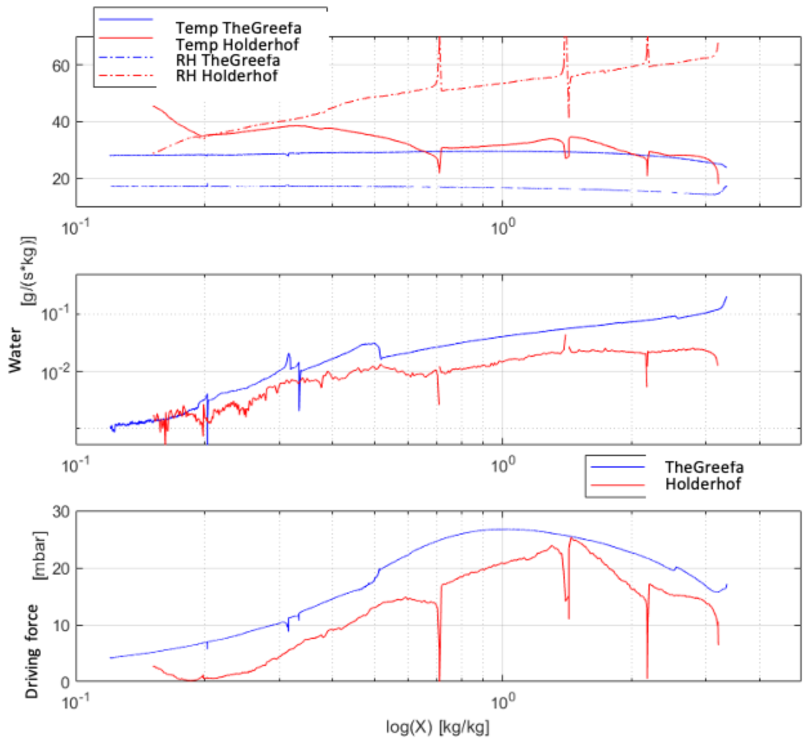

Figure 13: Comparison between TheGreefa dryer and Holderhof dryer

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

7. Optimisation of TCF management

The concentration of TCF used in the laboratory tests was 50% at the beginning of the drying process and 44% at the end. It was never replaced during the whole drying process.

The absorption power was therefore higher at the beginning than at the end. As explained in section 5, in the final stages it is more difficult to remove the relative humidity, as the vapour pressure above the herbs is very low and the driving force (difference of the water vapour pressure between the air and the herbs) decreases.

A high concentration of TCF is not strictly necessary at the beginning of the drying process, while it is essential in the final stages. For this reason, here is propose a process starting with a diluted TCF. The TCF is then replaced in the following phases with more and more concentrated TCF. This can be achieved if the TCF used in the last step of a drying of a batch of herbs is reused in an earlier step of the process for another batch of the herbs and so on. Only when the TCF is so diluted that it can no longer absorb will it be sent for regeneration or to the diluted TCF storage. This concept and value for the case of the previous section was simulated and is illustrated in Figure 14for a process with 6 steps.

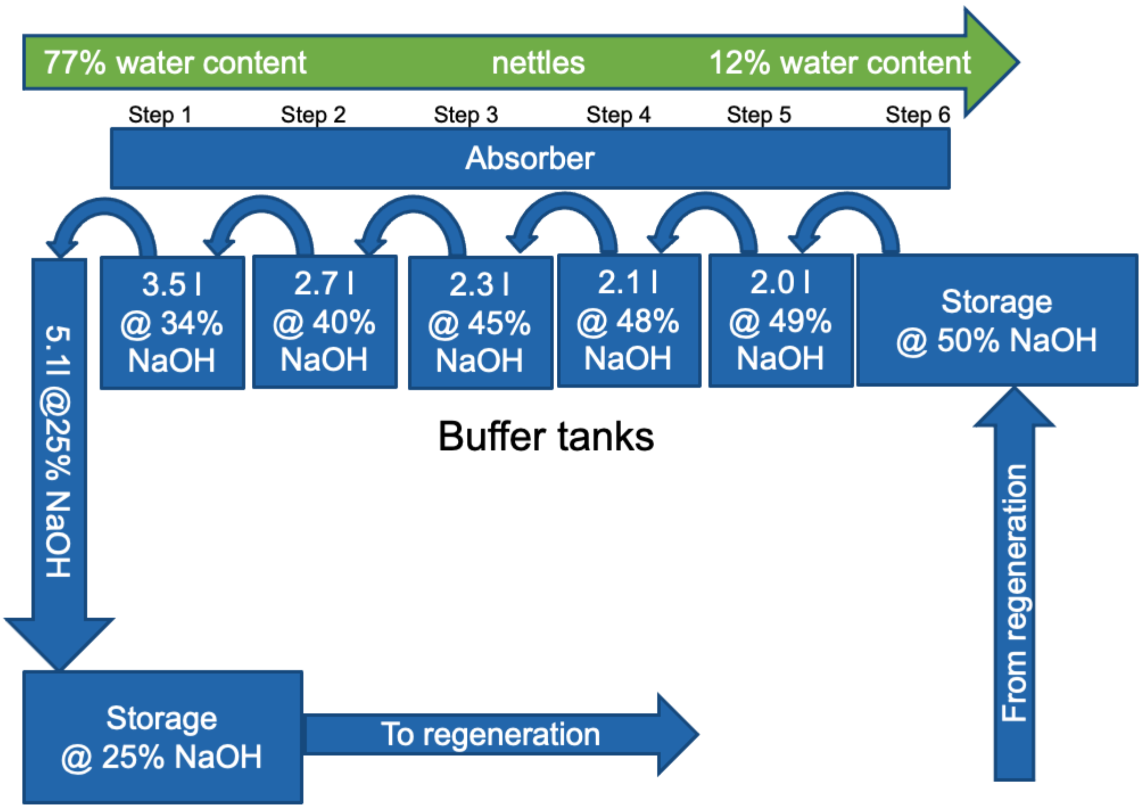

Figure 14: Multi-steps drying process, specific data per kg of dried nettles

A multi-steps process increases the driving force, making it possible to reduce the duration of the drying process and reduce the total amount of TCF (Figure 15). A reduction of the electrical and thermal energy required in regeneration is also expected.

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

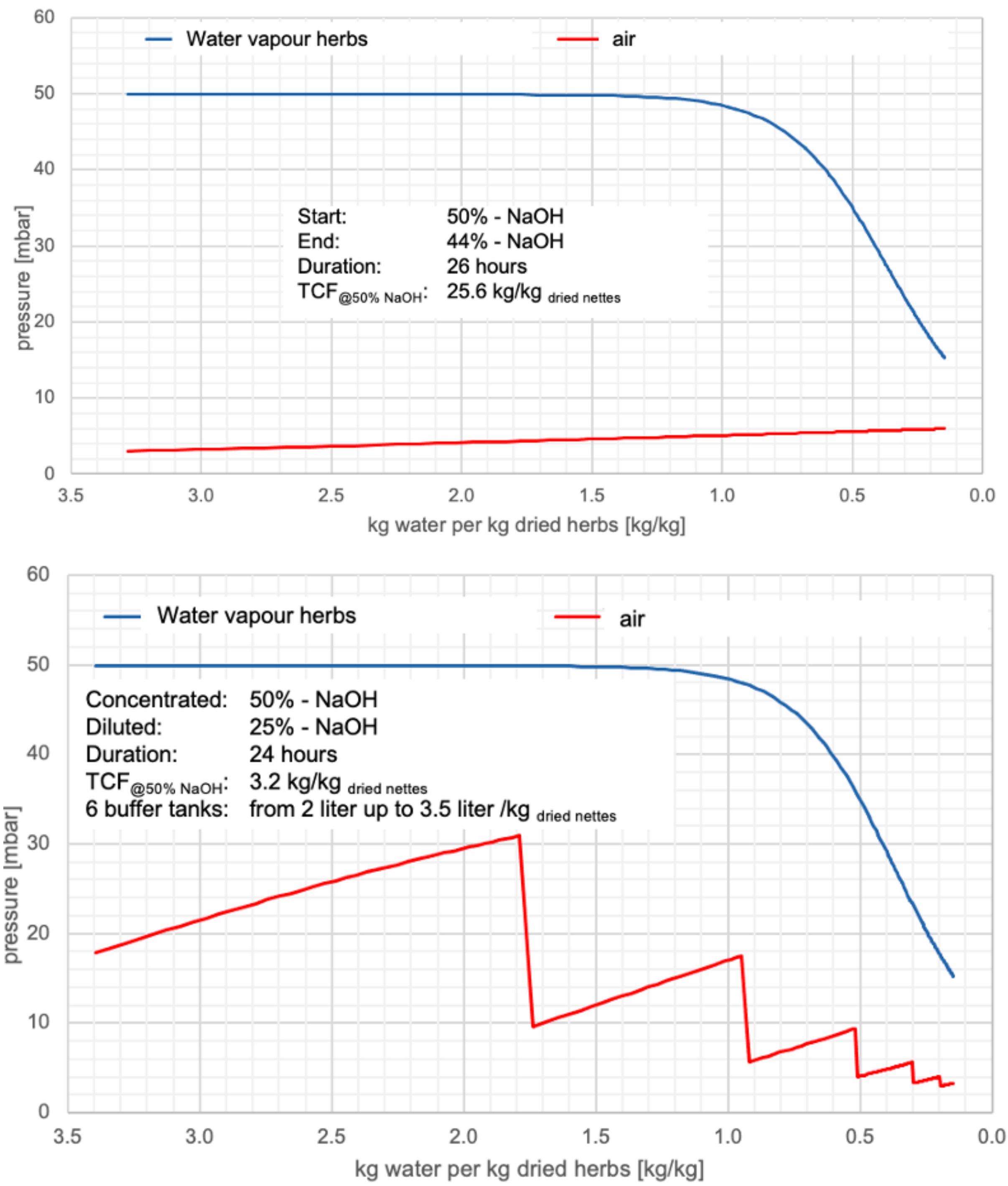

Figure 15: comparison between a single step and a multi-step drying process. The reference case is the case of section 6. The values are per kg of dried herbs.

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.

8. Energy

To understand the energy performance of TheGreefa, the specific energy consumed during the drying test in TheGreefa is evaluated on basis on the measurement data and compared to that consumed in the reference plant in Holderhof. As already mentioned, the system at TheGreefa is not yet optimised, for example the air fan and the TCF pump are components that were present in the laboratory, not specially selected for TheGreefa and have a very low efficiency under the operating conditions of TheGreefa. Despite this, TheGreefa's drying process consumes less energy per kg of dried herbs, as shown in Figure 16The blue and grey parts indicate the electrical consumption: the energy required from the ventilator (the ventilator of TheGreefa had an efficiency lower than 10%) is blue, grey is for TheGreefa the energy of the TCF pump, in Holderhof is the energy of the compression dehumidifier. The orange part is the thermal energy required for the regeneration of the TCF. This energy can be supplied entirely by renewable energy, as solar energy, and can be shifted in time (and also space). That means, no thermal energy is introduced to the TheGreefa plant during the drying process. The effective energy required for the drying process is the sum of the blue and grey parts.

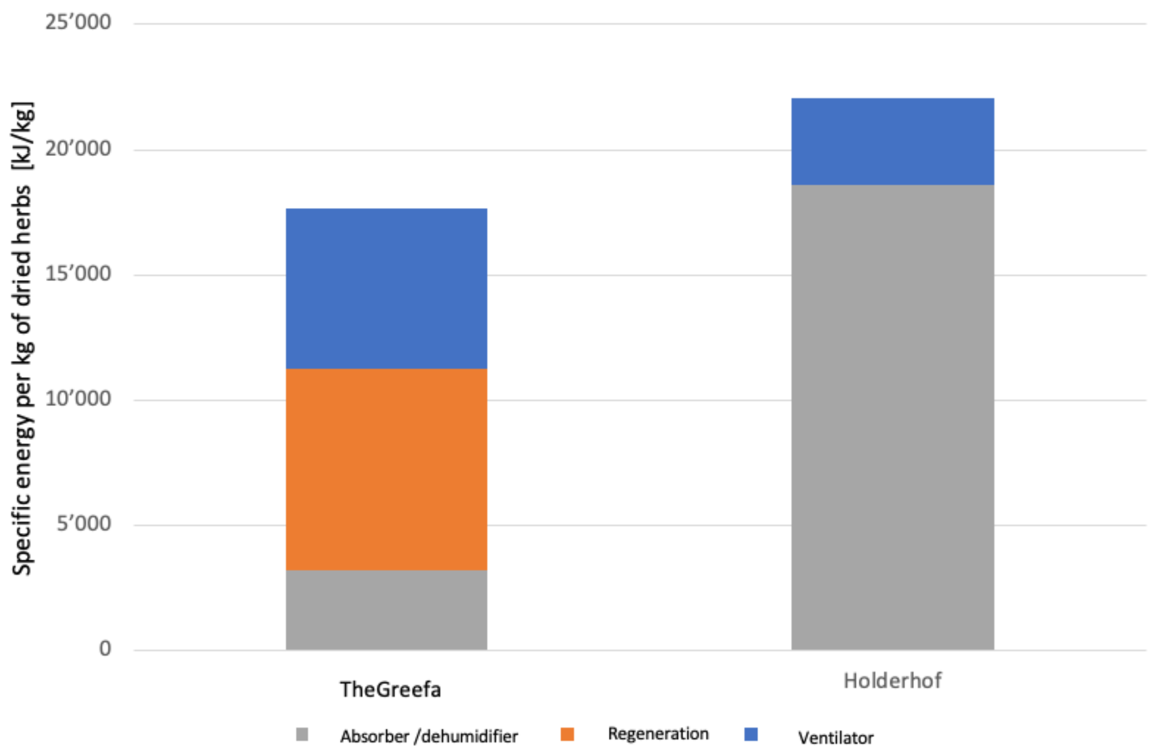

Figure 16: Measured energy consumption in TheGreefa and in Holderhof per kg of dried herbs

The specific energy consumption of a whole plant, including the regeneration of the TCF, has been estimated and compared with the real plant in Holderhof (Figure 17). In the TheGreefa process the consumption of the pumps and ventilator are ricalculated based on the dates of the TheGreefa demonstrator, but considering the fan and pump optimised for these operating points of TheGreefa. Furthermore, as no data were available for regeneration, which is not part of this task, it was assumed that the absorber also acts as a desorber, so the consumption of pumps and fan remains the same. The thermal energy instead corresponds to the latent energy of the evaporated water.

This project has received funding from the European Union’s Horizon 2020 research and innovation Programme under grant agreement 101000801.

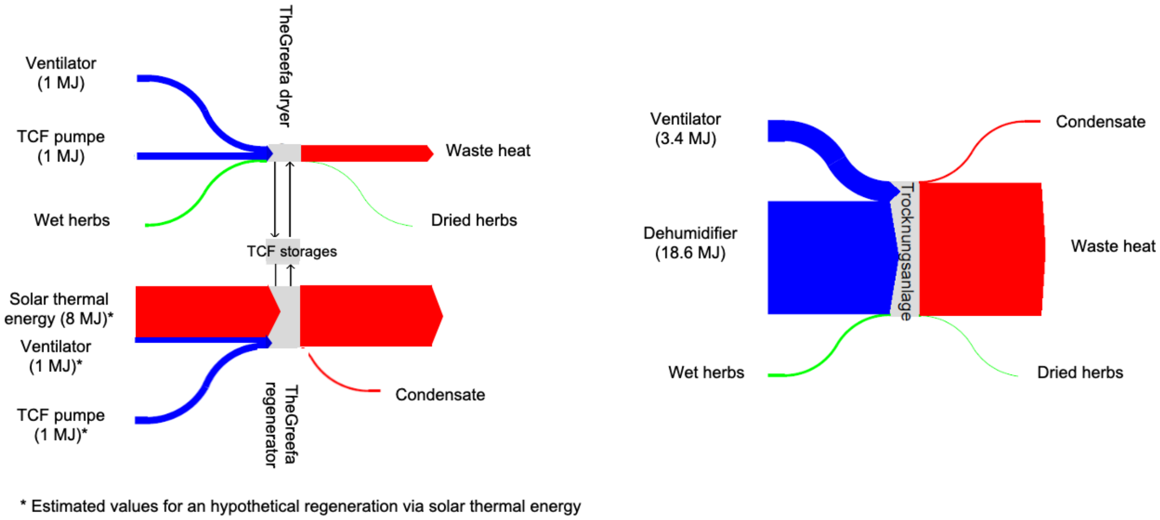

Figure 17: simulated energy consumption for whole TheGreefa drying process (left); energy consumption in holderhof. The values are per kg of dried herbs,

9. Conclusions

The specific energy demand of TheGreefa is slightly lower than that of conventional drying with a dehumidifier. It must be emphasised that the great advantage of TheGreefa is not only that the process required less energy than a conventional plant, but above all the thermal energy required is decoupled from the drying process and can be completely renewable energy or low temperature waste heat that would otherwise not be used. The TCF can indirectly store thermal energy for long time without energy losses.

The system can withstand the highly concentrated sodium hydroxide solution and the undesired by-product sodium carbonate can be easily separated.

A ZHAW department analysed independently of TheGreffa project both the herbs dried in TheGreefa plant and those dried in the conventional plant. The dried material has a very good quality; a hay/straw note was found in the Holderhof samples, but not in the samples of TheGreefa. There are no residues of NaOH and no odour notes from previous dryings.

It could be demonstrated that TheGreefa low-temperature dryer is suitable for drying herbs. Herbs are a very delicate material to dry and therefore it is assumed that TheGreefa dryer can easily be applied to the drying of other materials.

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement 101000801.