Applied Energy xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Improved energy efficiency in juice production through waste heat recycling

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HIGHLIGHTS

- A heating system at a juice production was investigated and improved.
- Different impacts of drying cycle improvements at the energy usage were explored.
- The total heat use for drying could thereby be decreased with 52%.
- The results point out a significant decrease of heat consumption with low investment costs.

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Renewable energy resources
Pinch analysis
Drying
Thermodynamic
Psychrometrics

ABSTRACT

Berry juice concentrate is produced by pressing berries and heating up the juice. The by-products are berry skins and seeds in a press cake. Traditionally, these by-products have been composted, but due to their valuable nutrients, it could be profitable to sell them instead. The skins and seeds need to be separated and dried to a moisture content of less than 10 %wt (on dry basis) in order to avoid fermentation. A berry juice plant in the north of Sweden has been studied in order to increase the energy and resource efficiency, with special focus on the drying system. This was done by means of process integration with mass and energy balance, theory from thermodynamics and psychrometry along with measurements of the juice plant. Our study indicates that the drying system could be operated at full capacity without any external heat supply using waste heat supplied from the juice plant. This would be achieved by increasing the efficiency of the dryer by recirculation of the drying air and by heat supply from the flue gases of the industrial boiler. The recirculation would decrease the need of heat in the dryer with about 52%. The total heat use for the plant could thereby be decreased from 1262 kW to 1145 kW. The improvements could be done without compromising the production quality.

1. Introduction

The demand for Nordic wild berries (in particular bilberries, lingonberries and cranberries) has increased steadily, since they are considered a healthy and tasty part of the diet. Currently, only the juice is sold, while the press cake (the skins and seeds) is composted. Increased competition along with rising energy prices has prompted the industry to improve the resource and energy efficiency. Higher competiveness can be achieved by increasing the product values. It has been found that the skins and seeds contain antioxidants [1], making them an added-value product to the berry juice itself. In particular, the berry seeds consist of 20%wt oil, which has a significant commercial value for health care and cosmetic use. Increased energy efficiency is also in the interest of the European Union, which can be seen in the 20–20–20 goals (20% increased energy efficiency, 20% increased renewables and 20% reduced carbon dioxide emissions until 2020 compared to the values in 1990). The objective is to reduce the global temperature rise.

The aim of this paper is to propose how the berry industry processes can be developed into an energy and resource efficient integrated process, optimizing the energy usage while separating and drying the berry skins and seeds. In particular, recirculation of heat and drying air will be investigated. However, in order to maintain a high quality of the seeds and skins, the maximum air temperature was limited to 90 °C [2]. Furthermore, in order to prevent moulding and fermentation, the moisture content of the skins and seeds should not exceed 10%. The juice factory that was studied in this paper was owned by the dairy company Norrmejerier and is located in Hedenäset in the north of Sweden, close to the Finnish border.

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http://dx.doi.org/10.1016/j.apenergy.2014.01.092
0306-2619/

Nomenclature

Symbols

$\dot{m}$	dry air (kg/s)
x	Abs. moisture content (kg water/kg dry air)
P	pressure (Pa)
h	specific enthalpy (J/kg)
ϕ	relative humidity (%RH)
t	temperature (°C)
r	latent heat (J/kg)
c_p	specific heat (J/kg K)
Q	power (W)
β	drying efficiency (%)

Subscripts

i	point i
1	entering air
2	after the burner, point 2
2′	after the mixing point, point $\acute{2}$
3	exiting air
w	water vapor
v	vapor
d	dry air
s	saturated
air	air
max	maximum
rec	recirculation

There has been a lot of research on food drying in general and berry drying in particular. A review of the effectiveness, qualities, and energy efficiencies for different drying techniques for berries can be found in [3]. However, most of the research does not include separation of skins and seeds. Separation and berry qualities are discussed in [4], but then the energy aspect was not considered.

The rotation dryer and separator that was used in the experiments was provided by the company Aromtech. Aromtech uses dried berry seeds to produce dietary supplements. An overview of the effectiveness of different convective dryers can be found in [5]. Hot air is circulated through the dryer, absorbing some of the moisture of the wet press cake. The air goes in one direction and the press cake in the reverse direction, while the drum is rotating. The rotation causes the press cake to fall through the drying air, thus increasing exposure time and the surface area between the press cake and the drying air. The drying efficiency depends on the air flow, air temperature and the size and density of the dried particles. When the particles are dried, they become less dense and eventually, the seeds pour out of the dryer, while the skins follow the air flow out. If the air flow is too high, skins will be blown out before they have been properly dried.

Section 2 introduces the setup for the Pinch analysis [6,7], a description of the dryer, the methodology and experimental setup. Section 3 contains the theory and calculations using thermodynamics and psychrometrics [8,9]. Section 4 presents the results and the discussion and the conclusions can be found in Section 5.

2. Material and methods

2.1. Process analysis and process integration

The study is made partly through experiments on the dryer, partly through modelling of the juice plant and the drying process. To evaluate the amount of recoverable heat, the process integration tool Pinch analysis was used. The focus in process integration is optimizing the system as whole instead of the individual units. The total energy usage was investigated for three different cases:

- Case A – the reference case, where the juice plant and the dryer has not been improved or changed.
- Case B – recirculation of drying air in the dryer, in order to better use the energy in the drying air.
- Case C – recirculation of drying air along with a heat exchanger between the exhaust gas of the steam boiler and the heating air for the dryer.

In Case A, an oil burner provides the necessary heat for the drying process. This is the current situation. Case B needs only a small investment (some pipes and air flow splitting devices). Case C requires an additional investment in the form of a heat exchanger attached to the flue gas pipes. The hot and cold streams from the boiler and the drying system were used to find the possible pinch heat. The energy need for the drying system was given by the results from the experimental measurements.

2.2. Experimental measurements of drying process

Experimental data were collected during 40 days. Each experimental day lasted about 7.5 h. Three repeatability tests were done. The experimental setup allows calculating the amount of energy used and analyse the losses depending on the drying conditions.

The current drying process (Case A) is illustrated in Fig. 1 with material and air flow. In Fig. 2, the Mollier diagram of the process is schematically illustrated, showing the enthalpy, the absolute humidity and the temperature for the air state at the points 1–3.

The drying process proceeds in the following order; the drying cycle starts with a flow of cold and dry outdoor air (point 1). Between points 1–2, the drying air is heated by a burner (a ThermoBetox 120 [10]) through a heat exchanger. During the heating step, the absolute moisture content is constant, which will result in a vertical line in the Mollier diagram (Fig. 2). After point 2, a circulation fan transports the air through the rotating dryer drum, where the drying process takes place. After the drying drum, the skins are separated from the drying air by two particle separators. Point 3 is directly after the skin separation. After point 3, a fan transports the air to the outside. The dryer is a counter current dryer. The dryer partly separates the skins from the seeds. The remaining seeds and skins fuse together to form larger particles called pellets. The seeds and the pellets exit the dryer nearby the incoming air, while the skins follow the air out of the dryer.

The experimental sampling was done with an Intab PC-logger 3100 logger system [11] using the software LabView [12]. The sampling interval was 2 s and the data was averaged over 3 samplings. The dry and wet bulb temperature was sampled in point 3 and the relative humidity and the dry bulb temperature were measured in point 1. The temperature close to the drum wall was measured close to the entry point of the drying air (point 2). Between the burner and the dryer, two air iris valves were installed, one to control air flow into the dryer and one to control the amount of by-pass air evacuated before the dryer. Together, these two valves allow regulation of the temperature and the flow of the incoming air. In point 2, the dry bulb temperature was sampled and also the