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Research paper

Waste heat and water recovery opportunities in California tomato paste processing

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HIGHLIGHTS

- The potential to recovery waste heat in tomato paste processing is examined.
- Heat transfer from evaporator condensate to tomatoes in the hot break is modeled.
- Processing facility data is used in model to predict heat recovery energy savings.
- The primary benefit of heat recovery is reduced use of natural gas in boilers.
- Reusing condensate after heat recovery yields additional electricity savings.

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ABSTRACT

Water and energy efficiency are important for the vitality of the food processing industry as demand for these limited resources continues to increase. Tomato processing, which is dominated by paste production, is a major industry in California – where the majority of tomatoes are processed in the United States. Paste processing generates large amounts of condensate as moisture is removed from the fruit. Recovery of the waste heat in this condensate and reuse of the water may provide avenues to decrease net energy and water use at processing facilities. However, new processing methods are needed to create demand for the condensate waste heat. In this study, the potential to recover condensate waste heat and apply it to the tomato enzyme thermal inactivation processing step (the hot break) is assessed as a novel application. A modeling framework is established to predict heat transfer to tomatoes during the hot break. Heat recovery and reuse of the condensate water are related to energy and monetary savings gained through decreased use of steam, groundwater pumping, cooling towers, and wastewater processing. This analysis is informed by water and energy usage data from relevant unit operations at a commercial paste production facility. The case study indicates potential facility seasonal energy and monetary savings of 7.3 GWh and $166,000, respectively, with most savings gained through reduced natural gas use. The sensitivity of heat recovery to various process variables associated with heat exchanger design and processing conditions is presented to identify factors that affect waste heat recovery.

1. Introduction

The finite nature of freshwater and fossil fuels, along with financial and regulatory incentives, motivate development of strategies to recover and reuse waste heat and water in the food processing industry. In California, where over 90% of processing tomatoes in the United State are grown and processed, accounting for 35% of global tomato processing, there are compelling reasons

Abbreviations: TWC, tomato water condensate; 2SHB, two-stage hot break; WEN, water-energy nexus.

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Nomenclature

A	heat transfer area (m^2)
C	heat capacity rate (kJ/s °C)
Co	utility cost ($/kWh)
c_p	specific heat capacity (kJ/kg °C)
C_r	heat capacity ratio
E	energy savings (kWh)
L	length of each tube pass (m)
$\dot{m}$	mass flow rate (kg/s)
M	tomato moisture content (kg water/kg fresh weight)
n	number of tubes per tube pass
N	number of tube passes
NTU	number of transfer units
q	heat transfer rate (kW)
Q	total heat recovered (kWh)
r	fraction of tomato water recovered
R	tube radius (m)
S	seasonal monetary savings ($)
T	temperature (°C)
t_s	length of processing season (h)
U	overall heat transfer coefficient (kW/m^2 °C)
V	flow velocity (m/s)
w	fraction of tomato moisture removed
W	water energy intensity (kWh/kg)

Greek symbols

γ	cooler tower heat rejection efficiency (kW/kW cooling)
ε	effectiveness of heat exchanger
η	boiler efficiency
ρ	crushed tomato density (kg/m^3)

Subscripts

B	boiler
CT	crushed tomatoes
E	electricity
FW	freshwater
i	inner
in	inlet
max	maximum value
min	minimum value
NG	natural gas
o	outer
out	outlet
P	groundwater pumps
RTWC	recovered tomato water condensate
T	cooling towers
WT	wastewater treatment
WW	wastewater

to improve resource efficiency in tomato processing. Specifically, climate change and increasing demand for water in areas where tomatoes are grown and processed will strain future water use [1–3]. Moreover, greenhouse gas emissions for large food processors in California are regulated and financial incentives exist for decreasing carbon dioxide emissions. Under California's cap-and-trade policy, production costs for California tomato processors are predicted to rise 7–21% [4]. As a result, there is a need for increased water and energy efficiency in the tomato processing industry.

Recovery of waste heat generated during tomato processing and subsequent use of that energy for process heating may be an avenue to decrease steam use and, by extension, lessen the amount of natural gas burned in boilers. Displacing a fraction of natural gas use through application of recovered waste heat lowers the amount of purchased fuel required for processing and offsets greenhouse gas emissions, both of which provide financial benefits to the tomato processor. Waste heat recovery has been employed before in the food processing industry, primarily in boilers and drying processes where the recovered heat is reused in those same unit operations [5]. Recovery and reuse of low-grade waste heat in food processing has proven more challenging, as it is difficult to find useful applications for it [5,6]. While general potential sinks have been identified for low-grade waste heat in food processing facilities, there are few examples of these recovery techniques in

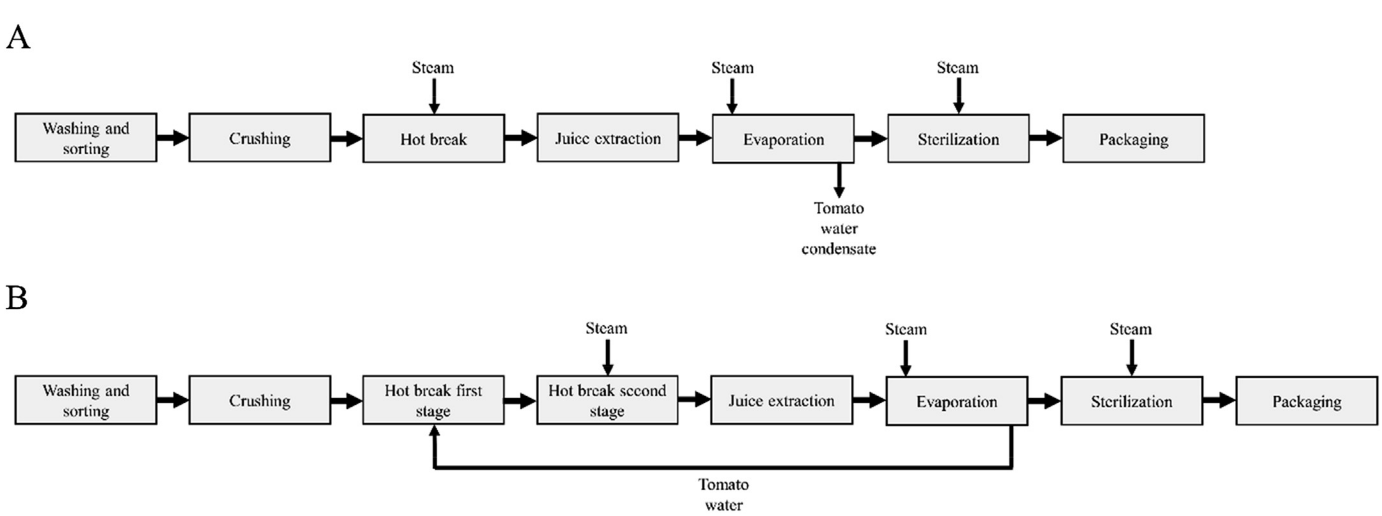

Fig. 1. Flow diagram of processes in tomato paste production under (A) conventional processing and (B) processing with recovered waste heat from tomato water condensate applied to the hot break.