Applied Thermal Engineering 53 (2013) 397–404

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Opportunities and barriers for efficient energy use in a medium-sized brewery

Barbara Sturm [a,*], Stephan Hugenschmidt [b], Sharon Joyce [a], Werner Hofacker [b], Anthony P. Roskilly [a]

[a] Sustainable Energy and Power Research Group, Newcastle Institute for Research on Sustainability, Newcastle University, Stephenson Building 2nd Floor, Newcastle upon Tyne NE1 7RU, UK
[b] Department of Thermal Process Engineering, University of Applied Sciences Konstanz, 78462 Konstanz, Germany

ARTICLE INFO

Article history:
Received 9 December 2011
Accepted 2 May 2012
Available online 11 May 2012

Keywords:
Case study
Brewing industry
Energy efficiency
Process optimisation
Best available techniques
Economic evaluation

ABSTRACT

Since the 1970s prices for fuel and raw materials have steadily risen. This development has put the brewing industry under pressure to reduce production costs by intensifying their production process. Additionally in recent years environmental concerns over green house gas emissions and climate change have arisen amongst consumers and legislative requirements are getting stricter. Because of these developments, small and medium-sized breweries are increasingly forced to apply strategies for economic, environmental and social sustainability, too.

This paper gives an overview over the state of the art in the brewing industry commonly realised in large breweries and presents important barriers to efficiency in smaller companies. The production process of a typical medium-sized brewery in the UK was analysed to identify principal measures to reduce energy and water demand. The case study also examines the particular problems preventing the brewery from realising these measures. The analysis of the process shows that even basic and easily applicable efficiency measures have so far been neglected. Improving insulation and implementation of basic heat recovery measures could potentially reduce energy demand by 20% and would result in a payback period of 1.3 years.

1. Introduction

Producing beer is a very energy intensive process accounting for up to 8% of total production costs [1]. Therefore competitiveness is increased by reducing specific energy and raw material consumption. Extensive research has been directed towards developing efficient technical equipment. Innovative solutions reducing the amount of waste heat and wastewater are widely available. These technologies have been established by large breweries and international brewing groups during the last decades. But there is still a lot of potential in small and medium-sized breweries as the brewing process of many of them is out of date [2].

1.1. The brewing process

Regardless of the type of beer that is produced, the basic process of beer production remains the same. The first step is malting, where the structure of the cereal is changed to enable the starch in it to be more readily converted into sugar. The produced malt (typically made from barley) is ground. The brewing process starts with the mashing process. Here the brewing water (hot liquor, 60 °C–80 °C) and the ground malt are added. The mixture is called mash. While constantly stirred the mash is then heated to a maximum temperature of around 75 °C subject to the method applied. At different temperature levels enzymes convert the starch of the malt into sugars. Alternatively, only parts of the mash are boiled externally. This procedure is called "decoction mashing". Mashing is the key step for controlling wort composition and extract yield to name but a few.

The mash is then transferred to the lauter tun or wort filter to separate the sweet wort from the spent grain. By trickling hot water through the grain (sparging) the remaining sugars are extracted from the grain and the wort is washed out. The wort is then run off into the kettle or copper where hops are added and the mixture is boiled. Several factors such as length, intensity, temperature and pressure of wort boiling are of great importance for the taste and quality of the beer. When the boiling process is finished, a hot wort solid–liquid separation process is conducted in order to separate coagulated proteins and other suspended particles. The wort is

* Corresponding author.
E-mail address: BarbaraSturm@daad-alumni.de (B. Sturm).

1359-4311/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2012.05.006

Nomenclature

A	heat transfer area [m^2]
CAL	calandria
CT	conditioning tank
E	energy [MJ]
e	specific energy consumption [MJ/hl]
e_{el}	specific electrical energy consumption [MJ/hl]
e_{th}	specific thermal energy consumption [MJ/hl]
FIT	feed in tariff
FV	fermentation vessel
H_{ev}	evaporation heat [MJ/kg]
H_{rec}	heat recovered [MJ/hl]
H_{SG}	heat demand to increase grain temperature from ϑ_{grain} to ϑ_{mash} [MJ/hl]
H_{tr}	transmission losses of the vessel [kWh]
$\dot{H}_{tr,b}$	heat transmission bottom [kW]
$\dot{H}_{tr,m,ga}$	heat transmission gas-filled area [kW]
$\dot{H}_{tr,m,li}$	heat transmission in the fluid-filled middle part of the cylinder [kW]
$\dot{H}_{tr,t}$	heat transmission top of the vessel [kW]
L	height of vessel [m]
MT	mash tun
P	degree Plato, correlation specific gravity/weight in a solution [°P]
RHI	renewable heat incentive
RO	reverse osmosis
ROI	return of investment [a]
r_{in}	inner radius [m]
r_j	radius j [m]
r_{out}	outer radius [m]
s_j	thickness of layer j [m]
v	specific fresh water consumption [hl/hl]
V_{beer}	volume of beer [hl]
V_w	volume raw water [hl]
v_{ww}	specific wastewater discharge [hl/hl]
WC	wort copper
WP	whirlpool
$\alpha_{in,ga}$	heat transfer coefficient gas – layer 1 [W/(m^2 K)]
$\alpha_{in,li}$	heat transfer coefficient liquid – layer 1 [W/(m^2 K)]
α_{out}	heat transfer coefficient outer layer – surrounding [W/(m^2 K)]
λ_j	thermal conductivity of layer j [W/(m K)]
ϑ_{grain}	initial temperature of grain [°C]
ϑ_{in}	inside temperature [°C]
ϑ_{mash}	mashing temperature [°C]
ϑ_{out}	outside temperature (surrounding) [°C]

then cooled to a specific temperature depending on the type of beer that is produced. When this temperature is reached, yeast is added to the wort. During the following fermentation process the sugar in the wort is fermented by the action of the yeast producing alcohol and carbon dioxide gas. This step is defining for the taste of the resulting beer and its alcohol content. Some of the CO_2 produced is dissolved in the beer.

After the main fermentation, lasting between three and seven days depending on the type of beer produced, the maturation or conditioning stage begins. The beer is held at conditioning temperature for a period of several days to over a month. After maturing the beer can be treated in different ways. Usually it is filtered again before being filled into bottles, kegs or cans.

The performance of the production process of a brewery is commonly expressed by specific energy consumption e and specific water consumption v. They are calculated by dividing the amount of energy (E) or fresh water (V_w) respectively by the volume of final beer (V_{beer}):

$$e = \frac{E}{V_{beer}}, \quad (1)$$

$$v = \frac{V_w}{V_{beer}} \quad (2)$$

It is common to distinguish between specific thermal energy (e_{th}) and specific electricity consumption (e_{el}). Individual circumstances of a brewery can have a major effect on the amount of energy, water and raw materials required to produce beer. The main factors are:

- *Production capacity*: Larger breweries are generally more energy efficient. This is due to economies of scale, load factors and the up-to-date production process. Pearson and Wisner [3] describe it as situations in which increases in product capacity produce lower unit costs by making additions to plant, equipment, labour force, or other facilities. While these additions to capacity generally produce increases in fixed costs, these added production expenses are covered by improvements in per unit costs.
- *Type of beer*: Different types of beer may have significantly different energy requirements. In particular, lagers require higher electricity use than ales. Lager is fermented at 4–13 °C while ale is fermented at higher temperatures (16–24 °C). Furthermore, the fermentation and storage of lager needs more time, and therefore less energy is required for cooling when brewing ales. Moreover lagers often are pasteurised and bottled while the majority of ales are sold in kegs and not pasteurised.
- *High gravity versus low gravity brewing*: Low gravity brewing involves wort with up to 10 °P while in high gravity brewing it is up to 20 °P. In high gravity brewing following fermentation and maturation, the beer is diluted with gravity liquor (water). The advantages of high gravity brewing are: better utilisation of brewing equipment, lower beer processing loss, more chemical and flavour stability to name but a few. Disadvantages are longer fermentation times, different flavour characteristics and poorer hop utilisation [4].
- *Type of packaging*: The packaging of beer into returnable bottles (38–50 kJ per bottle) consumes almost three times the amount of fuel and electricity for each hectolitre than is required for cask-conditioned beer (1 MJ per 50 l cask) [5].

Specific energy consumption of the British brewing industry has constantly decreased over the last 30 years and in 2005 it was 146 MJ/hl which is 56% less than in 1976 (Fig. 1). At the same time specific water consumption has dropped by 43% and in 2005 the UK brewing industry used 5.0 hl/hl (Fig. 1).

Both trends clearly show that a significant improvement in efficiency has taken place in the British brewing sector. A trend to further reduction in energy and water consumption appears to be referring to still existing potentials. Both these developments are due to improved processing and heat recovery especially in large internationally operating brewing companies, needing to maintain competitiveness on the mass market. Also the change of the market demand over the last 30 years led to the closing down of many old and inefficient mid-sized ale breweries.