Energy Conversion and Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Improvement of waste heat recuperation on an industrial textile dryer: Redesign of heat exchangers network and components

Daniele Fiaschi [a,*], Giampaolo Manfrida [a], Luigi Russo [b], Lorenzo Talluri [a]

[a] Dipartimento di Ingegneria Industriale, University of Florence, Viale Morgagni 44, 50135 Florence, Italy
[b] Gesco S.p.A., Z. I. Belvedere n. 83, Ingr. 2, 53034 Colle di Val d'Elsa, SI, Italy

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Heat recovery
Textile dryer
Finned heat exchangers
CFD
Heat exchanger tests

ABSTRACT

The improvement of low temperature exhausts heat recovery network of an industrial textile – drying machine (*Stenter/Rameuse*) is presented.

A complete redesign of the layout of the water – gas heat exchangers network was done. The network was improved changing the original serial configuration of the heat recovery cells to a system with parallel manifolds for the water circuit. The heat transfer layout and the related heat exchangers were modelled with a dedicated thermal design code.

The limited heat transfer coefficient of the internal gas side in the original configuration was improved with a "twin barrel" solution, with water in the outer annulus and exhaust gas in the inner duct equipped with internal longitudinal fins, an effective solution allowing easy fabrication and cleaning.

A second step refinement design of the heat exchangers modules, realized with an OpenFOAM® CFD procedure, allowed the final definition and optimization of the fins size and layout, which were not continuous on the whole length of the module, but staggered on the inner side and shortened to about 1/3 of the length.

Compared to the original version, the new heat exchangers network and the improved thermal design allowed an increase of the heat recovery from the exhausts of about 180%. The adoption of three staggered and segmented fins led to an increase of 97% with respect to the bare pipe.

Finally, the results of the models were validated on a test bench reproducing one full-scale section of the drying machine: the tests gave positive issues, confirming the model predictions and the correct operability of the unit. Particularly, the accuracy of prediction of water temperature was very good (less than 0.5 °C difference between simulation and measurements).

1. Introduction

1.1. Waste heat recovery from textile industry

In the last decade, the energy recovery from waste heat flows at low and medium temperature (90–250 °C) has aroused growing interest, mainly due to the strong push towards energy saving, reducing CO_2 emissions and improving the efficiency of manufacturing processes, industrial and building facilities. The industrial activities, which worldwide account for 38% of primary energy consumption [1], release from 20 to 50% of this energy into waste heat [2]. Cement, glass, metallurgical, food, paper, chemicals and non-metallic minerals are the most intensive sectors. The textile industry, despite being among the least considered, has a relevant overall primary energy consumption (about 87 TW h in USA, [1]) and waste effluent rates levels among the highest referred to total input (40%, [1]). In Italy, many industrial sectors reduced their energy intensity since 1995 [3], but food and textiles production had more limited reductions, indicating an interesting potential for relatively unexplored energy recovery in the medium-low temperatures range. Even considering conservative fractions of overall primary national energy input (5–10%), it can be estimated an annual national theoretical availability of waste heat from textiles of the order of 1–3 TWh, which rises a significant interest. Fabric finishing represents a relevant share of the primary energy consumption in textile production. In the last years, relevant progresses were done towards waste heat recovery and energy saving in wet processes, whereas much less was done in regards of drying processes involving hot air and/or water flows [4]. Moreover, they are among the most energy – intensive operations in the textile industry and the related waste heat recovery has the

* Corresponding author.
E-mail address: daniele.fiaschi@unifi.it (D. Fiaschi).

http://dx.doi.org/10.1016/j.enconman.2017.05.053
0196-8904/

Nomenclature

Symbols

A	surface area [m^2]
C	heat capacity [kJ/K]
Cp	specific heat [kJ/(kg K)]
D	diameter [m]
DP	pressure loss [Pa]
e	roughness [m]
h	fluid/metal heat transfer coefficient [W/(m^2 K)]
H	height [m]
k	conductivity [W/(m K)]
L	length [m]
LMTD	logarithm mean temperature difference [K]
LP	power loss [W]
m	mass flowrate [kg/s]
N	number [ ]
Nu	Nusselt number
NTU	number of thermal units [ ]
Pr	Prandtl number [ ]
Ptc	pitch [m]
Q	heat power [kW]
r	radius [m]
Re	Reynolds number [ ]
T	temperature [C]
th	thickness [m]
u	velocity [m/s]
U	overall heat transfer coefficient [W/(m^2 K)]
V	volume flowrate [m^3/s]

Subscripts

a	air
crit	critical value
e	exhausts
EH	exhausts side
fin	referred to fin
g	gas
HE	heat exchanger
i	referred to ith component
in	inner
L	laminar
out	outer
SP	set point
std	standard
U	overall heat transfer coefficient [W/(m^2 K)]
w	water

Greeks

δ	difference
η	efficiency
ε	effectiveness
λ	height – pitch ratio
σ	solidity

Acronyms

HE	heat exchanger

potential to significantly reduce the energy consumption of finishing processes [5]. Nevertheless, the issue of waste heat recovery from drying textile machines is not very extensively discussed in literature [4–6], which is preferably oriented towards higher energy-intensive industrial processes.

In textile industrial driers, generally, warm air or combustion gases are impinged on the humid fabric and then vented to the atmosphere: the exhaust stream still has an attractive heat content, which, however, cannot be directly recovered recirculating the exhausts to the process, because they are loaded of humidity and pollutants coming from the fabric (fibres, chemicals and dust). Rather, this heat is recovered through a surface heat exchangers network (recuperators), which exploits the heat content of the exhaust to preheat the fresh dry air to be continuously circulated to the drying process [5,6].

1.2. Heat exchangers (recuperators)

The current industrial geometry for the exhausts/water heat recuperators is a double concentric pipe, with exhausts in the inner tube and water in the annulus. This is not actually an efficient configuration from the heat transfer point of view, but it is relatively simple, cost effective and easy to periodically clean from the dust and particles carried out from the drying fabric. A finned double pipe configuration would be more effective, especially with a proper design of the fins size and shape. An accurate design is required because the simple geometry of finned tubes can only offer moderate improvements compared to more complicated geometries. On the other hand, the simple solution is appreciated because of the limited cost and easiness of cleaning.

The literature is rich of studies on the performance improvement of double-pipe heat exchangers. In a very recent review [7], the key point appears to be to enhance the overall heat transfer coefficient while minimizing the friction losses; the applied solutions imply surface or geometrical modifications or inserts like turbolators, twisted tapes, and extended surfaces, which promote the action of secondary flows. When dealing with heat recovery from exhaust gas flows, as for example from Diesel engines, the adoption of gas side finned heat exchangers is convenient because they couple manufacturing simplicity and modest additional costs (compared to simple, less effective bare-pipe configurations) to an appreciable enhancement of the heat transfer effectiveness, at the price of moderate pressure losses [8]. For this reason, an accurate design of the fins is worth to ensure the highest possible exploitation of the heat exchangers. In this view, Hatami et al. [9] proposed the optimization of an internally finned heat exchanger for the heat recovery from the exhausts of a Diesel engine combining central composite design to CFD. Dealing with CFD techniques as a tool to improve the geometry of finned double pipe heat exchangers, Cavazzuti et al. [10] also remarked that few studies are available on the design and optimization of heat exchangers using the open source code OpenFOAM. They adopted the code to predict the heat transfer rate of finned concentric pipes heat exchangers for industrial recuperative burners. One of few examples is that of Selma et al. [11], who used this code for the optimization of a heat pipe exchanger to improve the energy efficiency of a building ventilation system. However, in a recent review on the use of CFD in heat exchangers design [12] there is no mention on the use of this open source code.

From a survey of the technical literature, it appears that a significant gap exists on the subject of waste heat recovery from commercial fabric drying machines, which are, as above remarked, among the main sources of waste heat in textile industry. On the other hand, the issue of waste heat recovery from exhaust flows is extensively discussed in relation to power plants and boilers for heat generation, but very scarcely for this type of machines,