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An experimental study on the heat transfer performance in a batch scraped surface heat exchanger under a turbulent flow regime

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ABSTRACT

Heat transfer during scraping of the thermal boundary layer is a commonly encountered phenomenon. The most notable device where scraping heat transfer occurs inherently is a *Scraped Surface Heat Exchanger* (SSHE), which is widely used in the chemical and food industries. The present study involves an experimental heat transfer investigation into an SSHE operating in a batch mode. The main goal of this research is to investigate the impact of the scraping effect on heat transfer. We examined the influence of the rotational speed of the scrapers, blade-to-wall gap width and the type of gaseous working fluid on the heat transfer process. The obtained results of the heat flux and heat transfer coefficient are in the range of $500 \div 1500\ \mathrm{W/m^2}$ and $20 \div 45\ \mathrm{W/(m^2\ K)}$, respectively. Experimental results show a linear dependence of the heat flux and heat transfer coefficient on rotational speed in a turbulent regime. Based on the experimental results, non-dimensional correlation for the Nusselt number is proposed as $Nu = 1.765 Re_r^{0.496} Pr^{0.33}$. The comparison with the mathematical models and experimental correlations available in the literature is also studied. From the experiment it was found that in the turbulent flow regime, rotational speed plays an important role during the heat transfer process, while the gap width is of minor significance.

1. Introduction

1.1. Heat transfer enhancement via surface scraping

Heat transfer enhancement techniques can be divided into passive and active [1]. An advantage of the active technique is the possibility to achieve higher heat transfer coefficients [2], however additional energy has to be continuously delivered to the system. One of the active techniques is surface scraping. This technique is especially used in chemical and food industries for the thermal treatment of viscous fluids. Nevertheless, this is also very promising for applications where low-viscous fluids are used, such as air, water, etc. As it was reported by Hagge and Junkhan [3], an almost tenfold heat transfer enhancement was achieved in an air heat exchanger using the analyzed technique.

The surface scraping technique has been known for almost 90 years from the pioneering work of Huggins [4] who investigated the impact of scraping via mechanical blades (scrapers) on heat transfer performance. However, the present theory suffers due to a lack of models for providing accurate heat transfer coefficient estimations. Despite the simple idea of the surface scraping technique, the phenomena of disturbing and renewing of the thermal boundary layer, that accompany the surface scraping process, are very complex. Mathematical treatment of these phenomena is a problematic task and for this reason explanations of the mechanisms responsible for heat transfer enhancement during surface scraping is still an unsolved issue. A general idea of the heat transfer enhancement is discussed on the basis of Fig. 1, where a simple heat transfer through a cylindrical wall is presented. Fig. 1a) shows the temperature distribution for the time just before the scraper's pass. In the vicinity of the wall, the temperature boundary layer develops and is characterized by large temperature gradients. This layer constitutes the main part of the overall wall thermal resistance. The idea is to mechanically remove this layer with the use of a scraper and consequently, increase the heat transfer. This effect is shown in Fig. 1b), where the temperature distribution is depicted for the time just after the scraper has passed. It is visible that surface scraping results in an increased wall temperature. This is due to the hotter fluid particles inflow in the place of the removed near-wall fluid. This, in turn, results in the increase of the temperature gradient in the wall and consequently, the heat flux increases as well.

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Nomenclature

c_p	specific heat at constant pressure, J/(kg K)
D	cylinder diameter, m
D_s	scrapers diameter $D_s = D - 2\delta$, m
f	inverter frequency, Hz
h	heat transfer coefficient, W/(m^2 K)
k	thermal conductivity, W/(m K)
n	rotational speed, rpm (unless otherwise stated)
N	number of scrapers
Nu	Nusselt number, $Nu = hD/k_m$
Pr	Prandtl number, $Pr = c_p\eta/k$
p	number of motor poles
Re_D	rotational Reynolds number, $Re_D = nD^2\rho/\eta$
Re_r	rotational Reynolds number, $Re_r = nD_s^2\rho/\eta$
s	motor slide
t	temperature, °C
u	velocity, m/s
q''	heat flux, W/m^2

Greek symbols

η	dynamic viscosity, Pa s
δ	blade-to-wall gap width, m
ρ	density, kg/m^3
τ	contact time, s
ϕ	correction factor

Subscripts

b	bulk fluid parameters
cr	critical
C	cold
H	hot
m	mean parameters at $(t_b - t_w)/2$
w	wall parameters

Abbreviations

HTC	Heat Transfer Coefficient
$K-K$	Kern and Karakas' model
$K-L-H$	Kool, Latinen and Hariot's model
$P-B$	Penney and Bell's model
SSHE	Scraped Surface Heat Exchanger

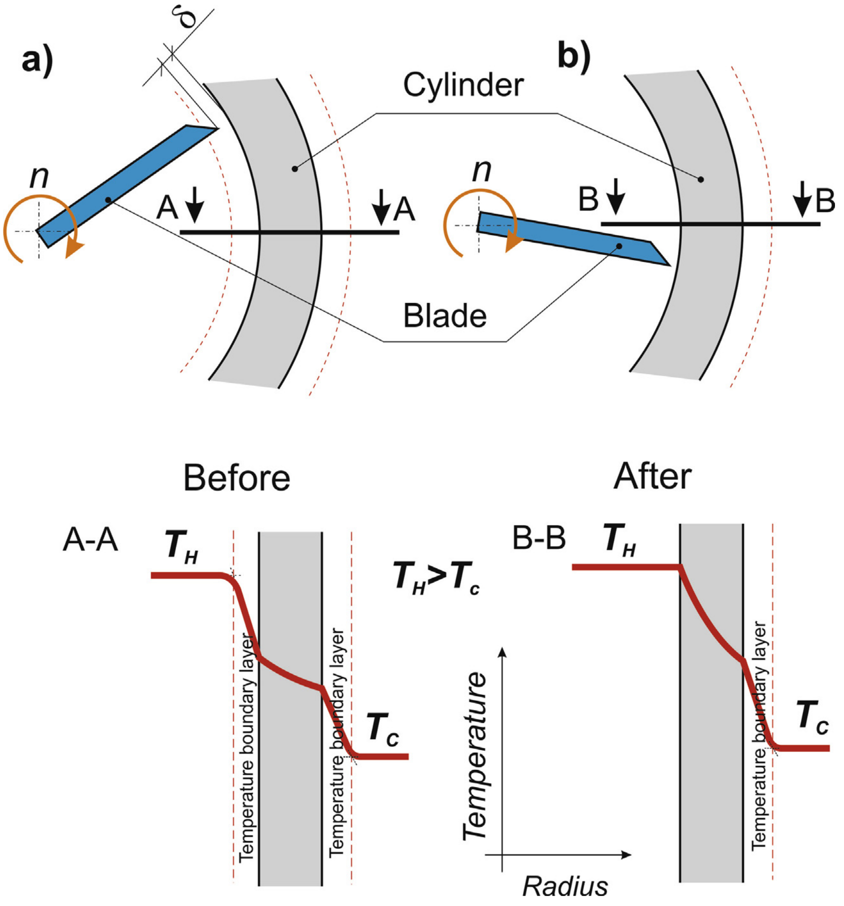

Fig. 1. Temperature distribution in the wall just before (a) and just after (b) scraper's pass.

The surface scraping technique is directly used in a *Scraped Surface Heat Exchanger* (SSHE) [5,6]. A SSHE consists of three main parts, presented in Fig. 2: cylinder (stator), blades (scrapers) and shaft (rotor). Scrapers, mounted on the rotating shaft, can be fixed, or its position is adjusted according to the balance of the hydrodynamic and centrifugal forces. During the shaft rotation, the scrapers move in the vicinity of the wall and continuously scrape off the thermal boundary layer and thus promote a better mixing pro-