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IMPROVEMENT OF THE JACKET SIDE HEAT TRANSFER IN STIRRED VESSELS

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Abstract: *This paper presents several different jacket constructions. These were compared with each other's to find the best jacket side heat transfer coefficient (HTC) in case of same input technological data. Another goal of the paper is to find the effect of the simple modification of the construction. This paper presents several different types of jacket constructions for example a simple jacket, a channeled jacket and a divided jacket. To determine the heat transfer coefficients on the jacket side is fairly difficult; the results calculated by various methods differ significantly. If the jacket construction would modify it causes heat transfer coefficient changing. Previously was developed a construction and a calculation method for heat transfer coefficient (HTC). Based on the transferred heat the different type of jacket construction were compared with each other's to find the best jacket side HTC in case of same input technological data. Another goal of this paper is to find the effect of the simple modification of the construction.*
Keywords: *jacketed vessel, heat transfer, rectangular flow channel*

INTRODUCTION

Many industrial sectors use reactor tanks (vessels), which are fitted from outside with jackets to heat or cool the contents of the vessels. Usually, the flow geometry in this annular space between the outer surface of the vessel and the inner surface of the jacket is relatively simple. Nevertheless, to determine the heat transfer coefficients on the jacket side is fairly difficult; the results calculated by various methods differ significantly.

If the jacket construction would modify it causes heat transfer coefficient changing. Previously was developed a construction and a calculation method for HTC. Based on this construction this paper would like to point out how to improve the heat transfer.

HEAT TRANSFER FROM A JACKET

The inner surface heat transfer coefficient is relatively constant, because jacketed vessel is equipped from inside with an impeller, which can have – according to the requirements of the process – different shapes.

A limited number of publications are available about heat transfer on the jacket side of a stirred vessel. Heat transfer from the outer wall surface of a vessel and a liquid inside the jacket can be described by dimensionless equations of the following form:

$$Nu = C\,Re^{a}\,Pr^{b}\left(\frac{\eta}{\eta_w}\right)^{e} \qquad (1)$$

with

- Nusselt number $Nu = \frac{\alpha d}{\lambda}$ where d is a characteristic dimension
- Reynolds number $Re = \frac{u d \rho}{\eta}$ where u is a characteristic velocity in space of a jacket
- Prandtl number $Pr = \frac{c\eta}{\lambda}$

The exponents of the Reynolds number, the Prandtl number and the viscosity ratio in Eq. (1) have a numerical values depends on the calculation methods. The constant C takes into account all the geometrical effects. The physical properties (c, ρ, η and λ) are to be evaluated at mean liquid temperature and η_w at mean wall temperature.

A simple jacket

Heat transfer calculation methods in a simple jacket are known. In this case, the flow geometry is a simple annular space in the jacket. Lehrer [1] used the Prandtl analogy between momentum and heat transfer and derived the following equation:

$$Nu = \frac{0{,}03\,Re^{0{,}75}\,Pr}{1+\frac{1{,}74(Pr-1)}{Re^{0{,}125}}}\left(\frac{\eta}{\eta_w}\right)^{0{,}14} \qquad (2)$$

The characteristic length d in the Nusselt number and in the Reynolds number is given by

$$d = 1{,}63\delta \qquad (3)$$

where δ is the width of the annular space.

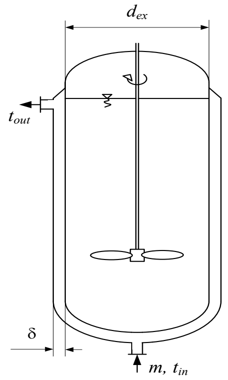

Figure 1. Simple jacket

Stein and Schmidt [2] presented different models and carried out own experimental measurements. They recommended the following procedure to determine the jacket side heat transfer coefficient:

A characteristic length l is calculated from

$$l=\sqrt{\left(\frac{\pi}{2}\right)^2 d_{ex}^2+h_s^2} \quad (4)$$

where d_{ex} is the external vessel diameter and the h_s is the height of jacket.

A characteristic diameter d is calculated from

$$d=2\delta \quad (5)$$

The Nusselt number is given from the following equation:

$$Nu=\left(Nu_A^3+Nu_B^3+Nu_C^3+Nu_D^3\right)^{\frac{1}{3}}\left(\frac{\eta}{\eta_w}\right)^{0,14} \quad (6)$$

where

$$Nu_A^3=3,66^3 \quad (7)$$

$$Nu_B^3=1,62^3\,Re\,Pr\left(\frac{d}{l}\right) \quad (8)$$

$$Nu_C^3=0,664^3\,Pr\left(Re\left(\frac{d}{l}\right)\right)^{1,5} \quad (9)$$

$$Nu_D^3=0,0115^3\,Re^{2,7}Pr\left(1-\left(\frac{2300}{Re}\right)^{2,5}\right)^3\left(1+\left(\frac{d}{l}\right)^{\frac{2}{3}}\right)^3 \quad (10)$$

Channeled jacket

It this case some baffles was built in the jacket. Let to inspect the effect of the baffles. At this case the flow geometry section is rectangular and the fluid flow as in the helical coil. A HTC calculation method was developed previously [3] for this type of jacket side geometry. Based on this, the Nusselt number is given from the following equation:

$$Nu=0,23Re^{0,633}Pr^{0,326} \quad (11)$$

The characteristic dimension d in the Nusselt number and in the Reynolds number is thermal equivalent diameter, which is given by

$$d=4\frac{A}{K}=4\frac{\delta h_c}{h_c}=4\delta \quad (12)$$

where $A=\delta\times h_c$ is the flow section, K is normally the wetted perimeter, but in this case, the heat transfer occur only on one side of the rectangle, so $K=h_c$.

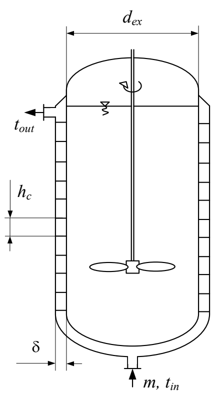

***Figure 2**. Channeled jacket*

This equation can be improved if consider the viscosity of the laminar film next to the wall:

$$Nu=0,23Re^{0,633}Pr^{0,326}\left(\frac{\eta}{\eta_w}\right)^{0,14} \quad (13)$$

Let us examine in this specific case the heat transfer coefficient α on the jacket side of a stirred vessel. The jacket is equipped with radial inlet tube placed at the bottom of the jacket. The contents of the vessel are cooled by mean of water flowing through the annular space or the rectangular section of the jacket. The data given below are available:

Outside vessel diameter	$d_{ex}=4\,m$
Width of annular space	$\delta=40\,mm$
Height of jacket	$h_s=4\,m$
Height of rectangular channel	$h_c=500\,mm$
Jacket side mass flow rate	$m=150\,kg/s$
Inlet water temperature	$t_{in}=14°C$
Mean water temperature	$t_m=\sim20°C$
Prandtl number	$Pr=7$
Mean jacket wall temperature	$t_w=\sim40°C$

***Table 1**. Calculation results*

	Re	Nu	α, $W\,m^{-2}\,K^{-1}$
Annular space Lehrer	$23x10^3$	106	644
Annular space Stein and Schmidt	$19x10^3$	174	1292
Rectangular section	$12x10^5$	3242	9785

The results shows that a quite big difference between the first and second rows in Table 1. However, the HTC for rectangular channel is greater than the others because of the velocity. Obviously, the higher velocity causes higher pressure drop for rectangular channel.

Divided jacket

Another possibility for modifying the jacket construction is to divide the jacket side for several parts. In this case the total mass flow is also divided, so the mass flow for one part will be smaller than the original construction. If the jacket would divided into two parts, the flow velocity would be halved, the pressure drop decrease by four times. In case of three parts, the velocity decreasing 1/3, the pressure drop decrease 1/9 of the original.

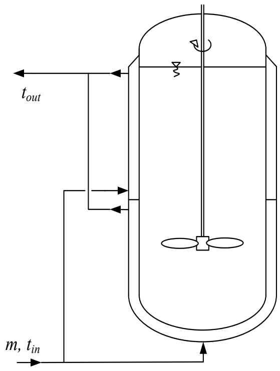

***Figure 3**. Divided jacket for two parts*

The velocity decreasing effect of Reynolds number, which is also effect the Nusselt number. The previous equation can be used to calculate the HTC (eq. 2, eq. 6, eq. 11 and eq. 13).

***Table 2**. Divided jacket calculation results*

Rectangular section	Re	Nu	α, W m^{-2} K^{-1}
Jacket without divide	$12x10^{6}$	3242	9785
Jacket divided two parts	$6x10^{6}$	2090	6310
Jacket divided three parts	$4x10^{6}$	1617	4881

SUMMARY AND CONCLUSIONS

This research investigated several different jacket constructions which are used for heat transfer. The paper pointed out baffled jacket more efficient than the simple jacket in the view heat transfer. The increased pressure drop caused by the baffled jacket would be decreased by divided jacket.

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