Heat Transfer Piping Materials and Overall Heat Transfer Coefficients

June 30, 2012

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Introduction

In petrochemical plants, CS (carbon steel) is generally used as an equipment material, unless there are issues related to corrosion or other process requirements.

In an actual production plant, it is sometimes necessary to change the material of CS equipment due to originally unexpected causes (such as erosion, or external surface corrosion, etc.).

When this happens, the size of the equipment must often remain similar due to the location where it is installed. Particularly, when the equipment is a heat exchanger, a detailed examination is necessary because changing the material will affect the equipment capacity. It is important, to know beforehand the degree of sensitivity of a material upgrade on the heat transfer capacity.

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Heat Transfer Tube Specifications of General Multi-tubular Heat Exchangers

Material	Thermal Conductivity [W/m/K]	Wall Thickness [mm]
CS (carbon steel)	53	2.0
SUS304	16.7	1.6
SUS316L	16.7	1.6
SUS444	26	1.6
SUS329J4L	20.9	1.6
Ti	17	1.2
Ti	17	0.8

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Overall Heat Transfer Coefficient of a Multi-tubular Heat Exchanger

The overall heat transfer coefficient U[W/m^2/K] of a multi-tubular heat exchanger is expressed by the following equation.

$$\frac{1}{U} = \frac{1}{h_o} + r_o + \frac{l_w}{\lambda_w} \cdot \frac{d_o}{d_m} + r_i \cdot \frac{d_o}{d_i} + \frac{1}{h_i} \cdot \frac{d_o}{d_i}$$

where

h : Film heat transfer coefficient [W/m^2/K],

r : Fouling factor [m^{2}K/W],

l_w : Heat transfer tube wall thickness [m],

λ_w : Thermal conductivity of heat transfer tube [W/m^2/K],

d : Diameter[m]

Also the subscripts are: o: outer, i: inner, m: average.

Approximate values of overall heat transfer coefficients are shown on the next page.

Solutions for R&D to Design

Approximate Values of Overall Heat Transfer Coefficients of Multi-tubular Heat Exchangers

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表 6・14 多管式熱交換器の総括熱伝達係数 $[W \cdot m^{-2} \cdot K^{-1}]$ および汚れ係数 $[m^2 \cdot K \cdot W^{-1}]$ の概略値

U $[W/m^2/K]$ — (r_i+r_o) $[m^2/K/W]$

胴側流体	管側流体	総括熱伝達係数	下記の全汚れ係数を含む
液–液の場合 (Liquid-Liquid System)			
MEA（10～25% 水溶液）	水またはMEA水溶液	790～1 100	0.000 5
燃料油	水	85～ 140	0.001 2
燃料油	油	56～ 85	0.001 4
ガソリン	水	340～ 570	0.000 5
重質油	重質油	56～ 230	0.000 7
重質油	水	85～ 280	0.000 9
灯油または軽油	水	140～ 280	0.000 9
灯油または軽油	油	110～ 200	0.000 9
潤滑油（低粘度）	水	140～ 280	0.000 4
潤滑油（高粘度）	水	230～ 450	0.000 5
潤滑油	油	62～ 110	0.001 1
ナフサ	水	280～ 400	0.000 9
ナフサ	油	140～ 200	0.000 9
有機溶剤 (Organic solvent - Water)	水	280～ 850	0.000 5
有機溶剤	ブライン	200～ 510	0.000 5
有機溶剤 (Organic Solvent - Organic Solvent)	有機溶剤	110～ 340	0.000 4
植物油	水	110～ 280	0.000 7
水	カセイソーダ（10～30%水溶液）	570～1 400	0.000 5
水 (Water - Water)	水	1 100～1 400	0.000 5
凝縮する蒸気–液の場合 (Condensation System)			
アルコール蒸気 (Alcohol Vapor - Water)	水	570～1 100	0.000 4
アスファルト（232℃）	ダウサーム蒸気	230～ 340	0.001 1
ダウサーム蒸気	ダウサーム液	450～ 680	0.000 3
タール	水蒸気	230～ 280	0.001 0
高沸点炭化水素（真空）	水	110～ 280	0.000 5
低沸点炭化水素（大気圧） (Hydrocarbon Vapor - Water)	水	450～1 100	0.000 5
凝縮する蒸気–液の場合（つづき）			
炭化水素蒸気（部分凝縮）	油	140～ 230	0.000 7
有機溶剤（大気圧）	水	570～1 100	0.000 5
不凝縮ガスを多く含む有機溶剤（大気圧）	水またはブライン	110～ 340	0.000 5
不凝縮ガスを少量含む有機溶剤（真空）	水またはブライン	280～ 680	0.000 5
灯　油	水	170～ 370	0.000 7
灯　油	油	110～ 170	0.000 9
ナフサ	水	280～ 430	0.000 9
ナフサ	油	110～ 170	0.000 9
水蒸気	水	2 300～5 700	0.000 1
二酸化硫黄	水	850～1 100	0.000 5
植物油の蒸気	水	110～ 280	0.000 7
ガス–液の場合			
圧縮空気・窒素など	水またはブライン	230～ 450	0.000 9
大気圧の空気・窒素など	水またはブライン	57～ 280	0.000 9
水またはブライン	圧縮空気・窒素など	110～ 230	0.000 9
水またはブライン	大気圧の空気・窒素など	28～ 110	0.000 9
蒸発器の場合 (Evaporation system)			
無水アンモニア	水蒸気（凝縮）	850～1 700	0.000 3
塩　素	水蒸気（凝縮）	850～1 700	0.000 3
塩　素	熱媒油	230～ 340	0.000 [illegible]
プロパン・ブタンなど (Hydrocarbon - Steam)	水蒸気（凝縮）	1 100～1 700	0.000 3
水 (Water - Steam)	水蒸気（凝縮）	1 400～2 300	0.000 3

［Perry, R. H.：“Chemical Engineers' Handbook”, 6th ed., p. 10-44, McGraw-Hill Kogakusha (1984)］

“Kagaku Kougaku Binran 6th ed.” p.389 (*in Japanese*)

Influence of Materials on Overall Heat Transfer Coefficients

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The representative systems shown below are taken from the previous table. The inside and outside film heat transfer coefficients are obtained from the approximate values of the overall heat transfer coefficients by assuming that carbon steel heat transfer tubes are used. Assuming that these values and that the fouling factors do not change, the overall heat transfer coefficients are recalculated to investigate the extent of the influence of changing only the heat transfer piping material.

	U (Approximate Value) $[W/m^2/K]$	Total (Inner+Outer) Fouling Factor $[m^2K/W]$
Liquid-Liquid System		
Organic solvent - Water	280 ～ 850	0.0005
Organic Solvent - Organic Solvent	110 ～ 340	0.0004
Water - Water	1100 ～ 1400	0.0005
Condensation System		
Alcohol Vapor - Water	570 ～ 1100	0.0004
Hydrocarbon Vapor - Water	450 ～ 1100	0.0005
Evaporation system		
Hydrocarbon - Steam	1100 ～ 1700	0.0003
Water - Steam	1400 ～ 2300	0.0003

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Influence of Materials on Overall Heat Transfer Coefficients

The calculation results are shown in the table below.

	CS → SUS304/SUS316L		CS → SUS444		CS → SUS329J4L		CS → Ti (0.8mm)		CS → Ti (1.2mm)	
Liquid-Liquid System	U' [W/m^2/K]	U'/U	U' [W/m^2/K]	U'/U	U' [W/m^2/K]	U'/U	U' [W/m^2/K]	U'/U	U' [W/m^2/K]	U'/U
Organic solvent - Water	276 ~ 810	0.953 ~ 0.984	278 ~ 833	0.980 ~ 0.993	277 ~ 823	0.968 ~ 0.989	279 ~ 843	0.992 ~ 0.997	277 ~ 827	0.973 ~ 0.991
Organic Solvent - Organic Solvent	109 ~ 333	0.981 ~ 0.994	110 ~ 337	0.992 ~ 0.997	110 ~ 336	0.987 ~ 0.996	110 ~ 339	0.997 ~ 0.999	110 ~ 336	0.989 ~ 0.996
Water - Water	1034 ~ 1295	0.925 ~ 0.940	1072 ~ 1355	0.968 ~ 0.975	1055 ~ 1328	0.949 ~ 0.959	1089 ~ 1382	0.987 ~ 0.990	1062 ~ 1338	0.956 ~ 0.965
Condensation System										
Alcohol Vapor - Water	552 ~ 1034	0.940 ~ 0.968	562 ~ 1072	0.975 ~ 0.987	558 ~ 1055	0.959 ~ 0.978	567 ~ 1089	0.990 ~ 0.995	560 ~ 1062	0.965 ~ 0.982
Hydrocarbon Vapor - Water	439 ~ 1034	0.940 ~ 0.975	445 ~ 1072	0.975 ~ 0.989	442 ~ 1055	0.959 ~ 0.983	448 ~ 1089	0.990 ~ 0.996	443 ~ 1062	0.965 ~ 0.985
Evaporation system										
Hydrocarbon - Steam	1034 ~ 1547	0.910 ~ 0.940	1072 ~ 1634	0.961 ~ 0.975	1055 ~ 1595	0.938 ~ 0.959	1089 ~ 1673	0.984 ~ 0.990	1062 ~ 1610	0.947 ~ 0.965
Water - Steam	1295 ~ 2029	0.882 ~ 0.925	1355 ~ 2181	0.948 ~ 0.968	1328 ~ 2111	0.918 ~ 0.949	1382 ~ 2252	0.979 ~ 0.987	1338 ~ 2138	0.930 ~ 0.956

The following can be observed from the above table:

- When the material is changed from CS to SUS or titanium, the heat transfer coefficient decreases in both cases.
- In systems where the film heat transfer coefficient is large and the overall heat transfer coefficient is greater than 800 [W/m^2/K], the order of this reduction reaches about 5 to 10%.
- Austenitic stainless steel and duplex stainless steel are about the same, there is a slight decrease for ferritic stainless steel and it is comparable to that of titanium having a wall thickness of 1.2 mm.

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Conclusion

- In petrochemical plants, it may happen that materials must be changed and upgraded after plant operation has started. In such situations, it is important to know the degree of the sensitivity of material upgrades for heat exchangers beforehand, because this will affect equipment performances.

- In general, changing from carbon steel to a corrosion-resistant material, such as stainless steel, will reduce the heat exchange capacity by several percent. In particular, care should be taken for systems in which the overall heat transfer coefficient exceeds 800 [W/m^2/K]. This may lead to a reduction of more than 10%.