Scale-up and Design of a Stirred Tank with Vertical Plate Heat Exchangers

Presentation by

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Title: Scale-up and Design of a Stirred Tank with Vertical Plate Heat Exchangers
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Abstract: As reactors increase in size, heat transfer from a jacket alone limits reactor volumetric productivity. Spiral coil heat exchangers are often added within the reactor to supplement heat transfer. Vertical plate heat exchangers called, “plate coils”, are a unique alternative to spiral heat transfer coils in a stirred tank reactor. The vertical design allows the plate-coil to serve as both a baffle and an internal heat transfer surface. Heat transfer is only available for a reactor jacket within the VisiMix model, yet when many wide baffles, the size of plate coils are added to a reactor, the VisiMix model predicts that the turbulent dissipation is similar between the baffles and the bulk. One might assume that under such a condition the heat transfer predicted by the VisiMix for the jacket is the same as one would predict for the vertical plate coils. This turns out to be a valid assumption and this presentation will describe how VisiMix can be used to predict the heat transfer for reactor fitted with plate coils.

Tranter Prime Surface Heat Exchangers can serve as both baffles and heat exchangers

Photos from Tranter Inc. product brochure

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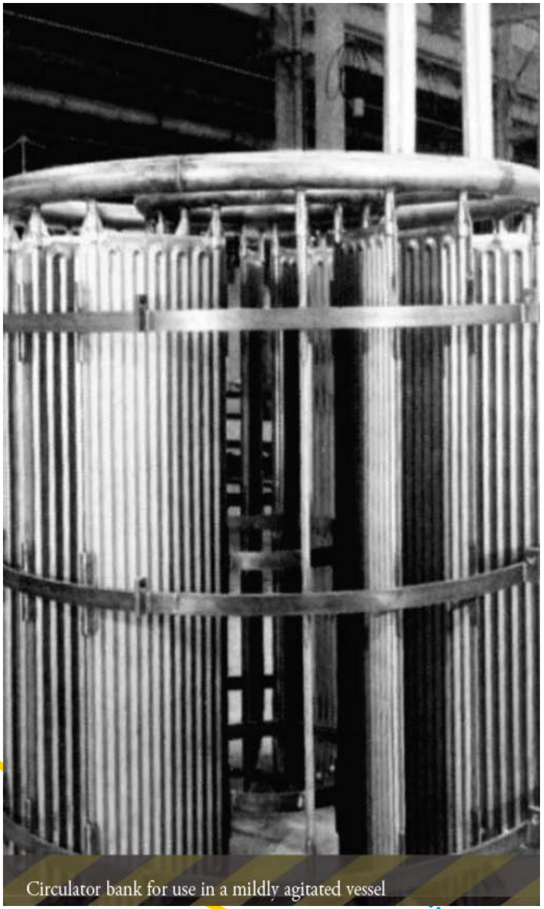

Circulator bank for use in a mildly agitated vessel

Pressure reactors

Standard PLATECOIL® Style 60

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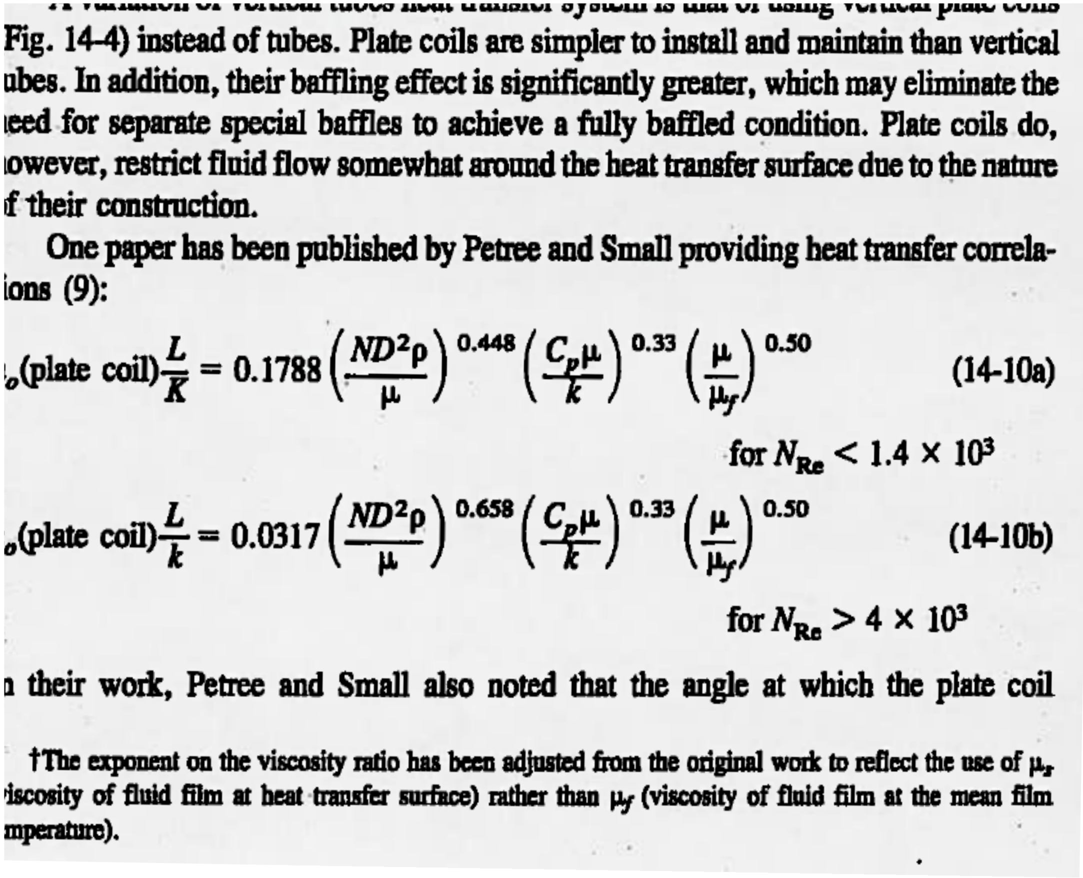
- Plate coils are fabricated by embossing channels on opposing plates and welding plates together.
- Uniform temperature distribution.

Heat transfer coefficients for plate coils were developed by Petree and Small



A variation of vertical tubes heat transfer system is that of using vertical plate coils Fig. 14-4) instead of tubes. Plate coils are simpler to install and maintain than vertical ubes. In addition, their baffling effect is significantly greater, which may eliminate the eed for separate special baffles to achieve a fully baffled condition. Plate coils do, owever, restrict fluid flow somewhat around the heat transfer surface due to the nature f their construction.

One paper has been published by Petree and Small providing heat transfer correla-ions (9):

$$_o(\text{plate coil})\frac{L}{K} = 0.1788\left(\frac{ND^2\rho}{\mu}\right)^{0.448}\left(\frac{C_p\mu}{k}\right)^{0.33}\left(\frac{\mu}{\mu_f}\right)^{0.50} \qquad (14\text{-}10a)$$

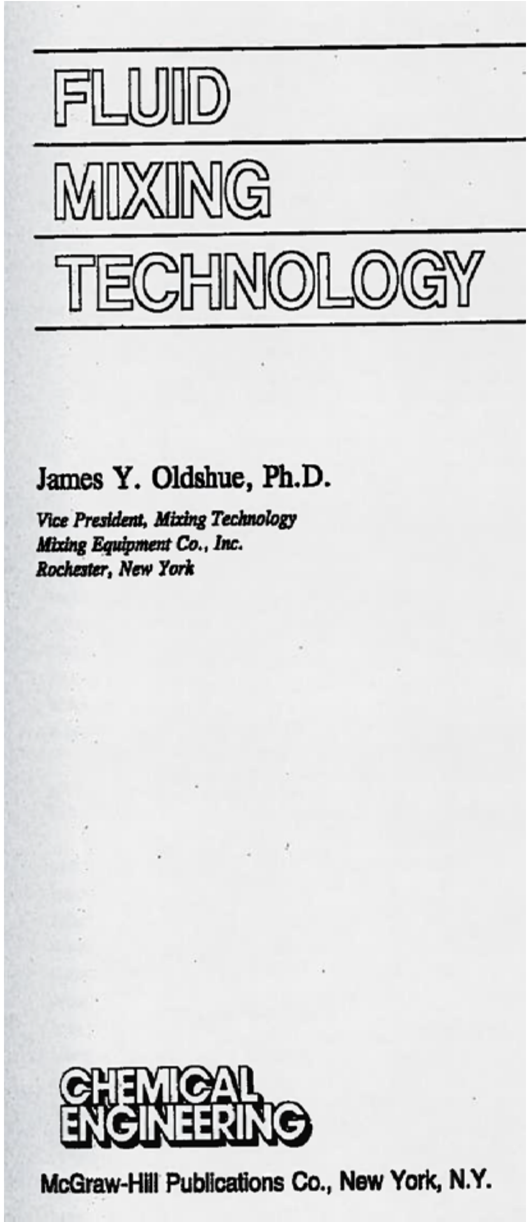
for $N_{Re} < 1.4 \times 10^3$

$$_o(\text{plate coil})\frac{L}{k} = 0.0317\left(\frac{ND^2\rho}{\mu}\right)^{0.658}\left(\frac{C_p\mu}{k}\right)^{0.33}\left(\frac{\mu}{\mu_f}\right)^{0.50} \qquad (14\text{-}10b)$$

for $N_{Re} > 4 \times 10^3$

n their work, Petree and Small also noted that the angle at which the plate coil

†The exponent on the viscosity ratio has been adjusted from the original work to reflect the use of μ_s iscosity of fluid film at heat transfer surface) rather than μ_f (viscosity of fluid film at the mean film mperature).



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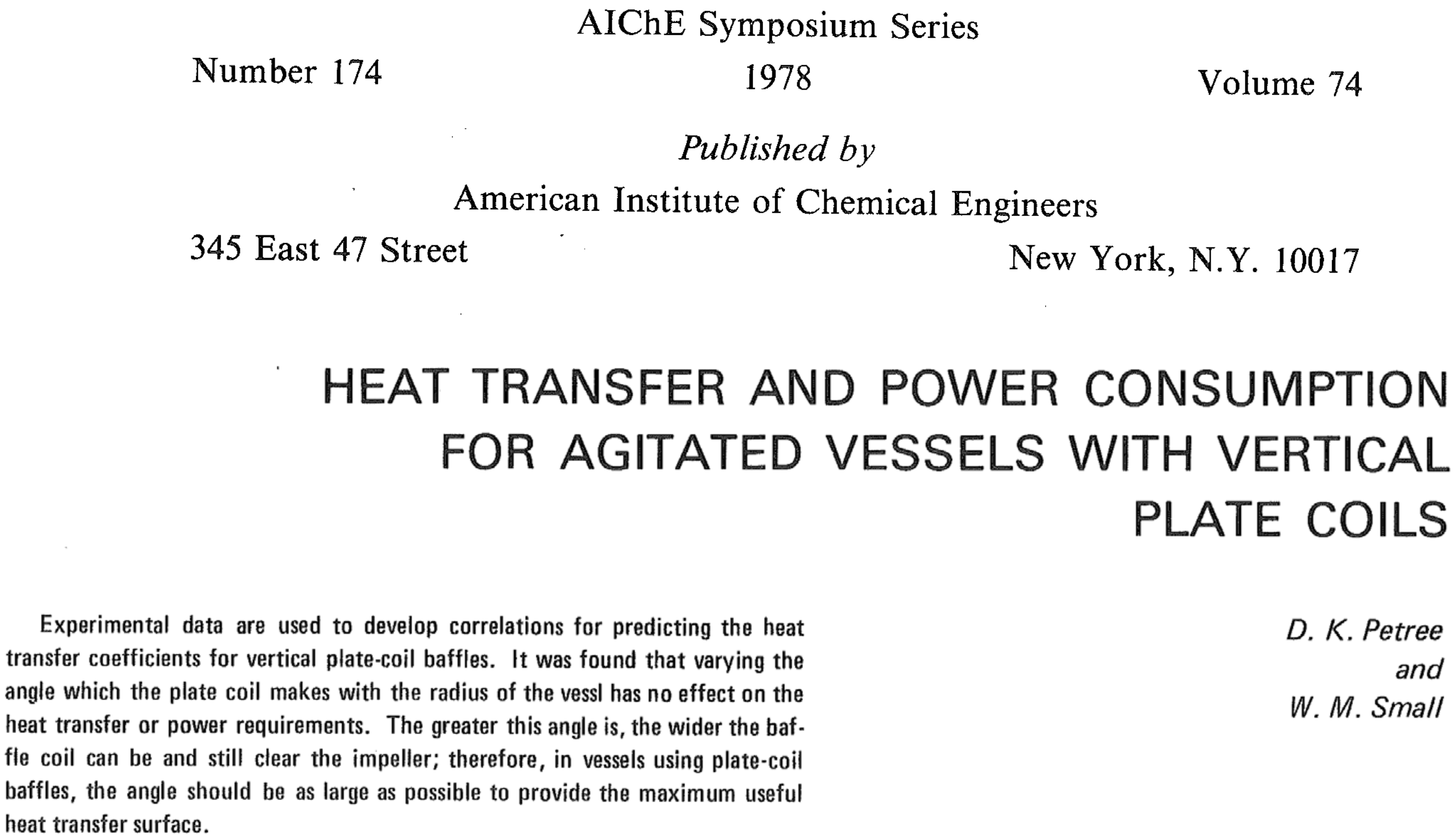

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HEAT TRANSFER AND POWER CONSUMPTION FOR AGITATED VESSELS WITH VERTICAL PLATE COILS

Experimental data are used to develop correlations for predicting the heat transfer coefficients for vertical plate-coil baffles. It was found that varying the angle which the plate coil makes with the radius of the vessl has no effect on the heat transfer or power requirements. The greater this angle is, the wider the baffle coil can be and still clear the impeller; therefore, in vessels using plate-coil baffles, the angle should be as large as possible to provide the maximum useful heat transfer surface.

D. K. Petree
and
W. M. Small

Note that I always go back to the original to make sure there was no typo errors!

TABLE 1. DIMENSIONS OF VESSEL, IMPELLERS, AND PLATE COILS

(See Figure 1)

Vessel

$H = 36$ in.
$D_t = 18$ in.

Impellers

$N_i = 2$
$N_b = 6$
$C_{i1} = 9$ in.
$C_{i2} = 18$ in.
$D_i = 6$ in.
$L_i = 1.75$ in.
$W_i = 0.75$ in.

Plate coils

$N_{Pass} = 4$ (parallel)
$N_a = 4$
$L_c = 35$ in.
$W_c = 5.375$ in.
$C_b = 0.75$ in.
$C_w = 0.125$ in.–1.25 in.
$\theta = 0$–60 deg
$X = 0.0625$ in.
$d_{hi} = 0.444$ in
$A_o = 3.182$ ft^2

TABLE 2. RANGES OF VARIABLES IN THIS STUDY

N_{Re}: 0 to 2.47×10^5
N_{Pr}: 5.224 to 4.140×10^4
N_{Vif}: 1.044 to 1.581
N: 0 to 500 rev/min
μ: 1.93 to 7094 lb$_m$/ft-hr (0.80 to 2931 cp)
θ: 0 to 60 deg

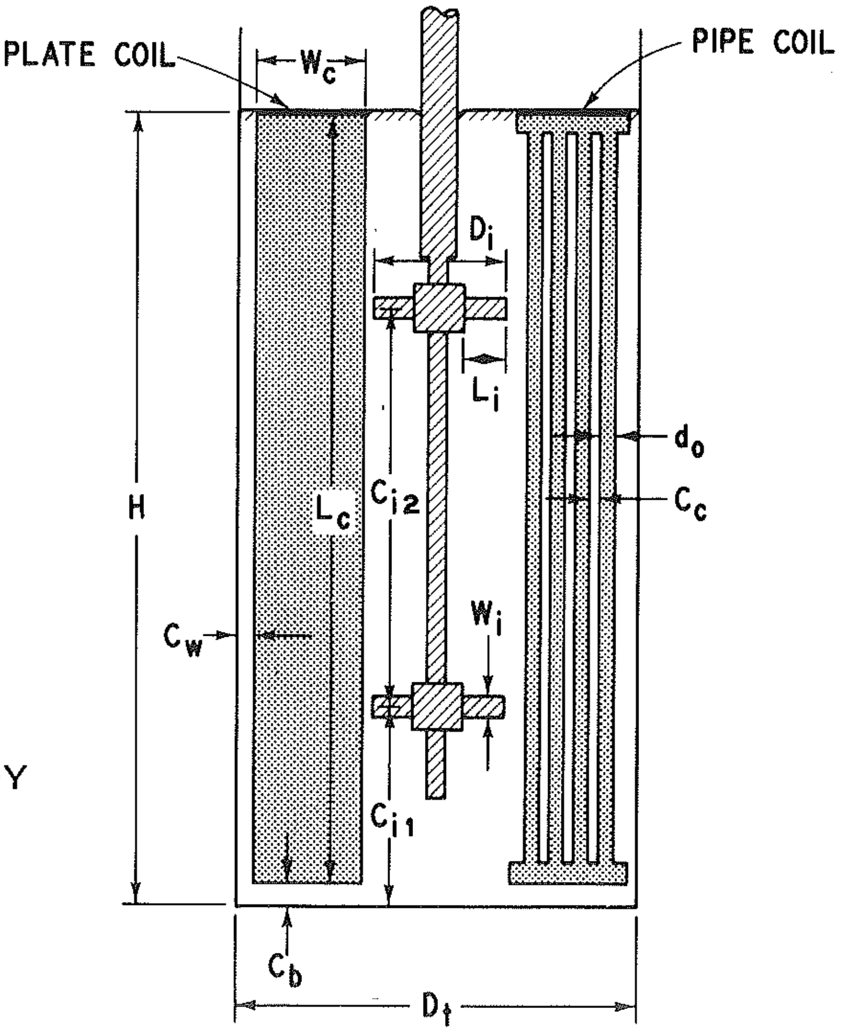


Fig. 1. Test section dimensions (see Table 1).

1. The following correlations were established for forced convection heat transfer between vertical plate coils and fluids in deep vessels stirred with dual, six-blade, flat-blade turbine impellers:

$$N_{Nu} = 0.1788\, N_{Re}^{0.448}\, N_{Pr}^{0.33}\, N_{Vif}^{0.50} \text{ for } \begin{cases} N_{Re} \leqslant 4 \times 10^3 \\ N_{Re} > (N_{Re})_{\min} \end{cases} \qquad \text{(I)}$$

$$N_{Nu} = 0.0317\, N_{Re}^{0.658}\, N_{Pr}^{0.33}\, N_{Vif}^{0.50} \text{ for } \begin{cases} N_{Re} \geqslant 4 \times 10^3 \\ N_{Re} > (N_{Re})_{\min} \end{cases} \qquad \text{(II)}$$

where for both Equations (I) and (II)

$$(N_{Re})_{\min} = 980\,(\mu/\rho)^{-0.85}, \text{ and } \mu/\rho = \text{ft}^2/\text{hr} \qquad \text{(III)}$$

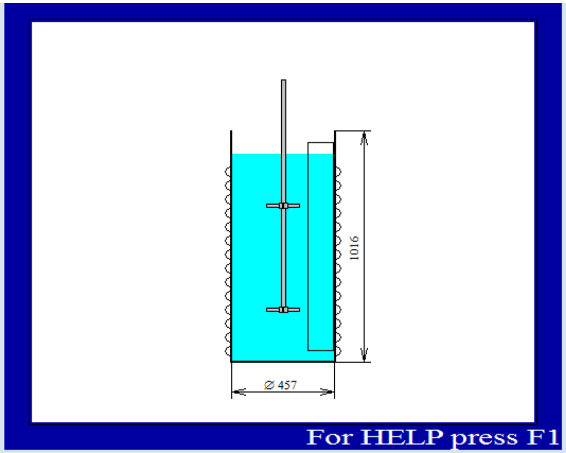
Equation (III) must always be checked using the viscosity and density of the stirred fluid at the average bulk temperature to ensure that the system is in the forced convection regime. Natural convection is the dominant mechanism for heat transfer for Reynolds numbers below $(N_{Re})_{\min}$.

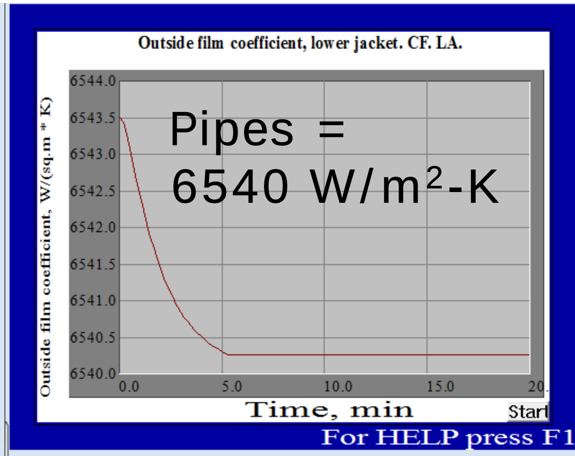
Physical Properties chosen in this evaluation to maintain turbulent flow in the reactor			
Viscosity cP	**Density kg/m³**	**Thermal Conductivity W/m-K**	**Heat Capacity J/kg-K**
5 to 20	1000	0.35	2100

Typical VisiMix results

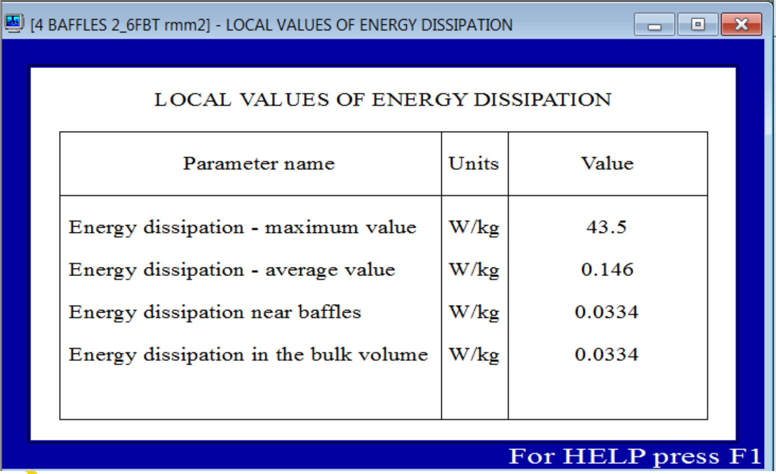
N=200 rpm

Viscosity =10 cP



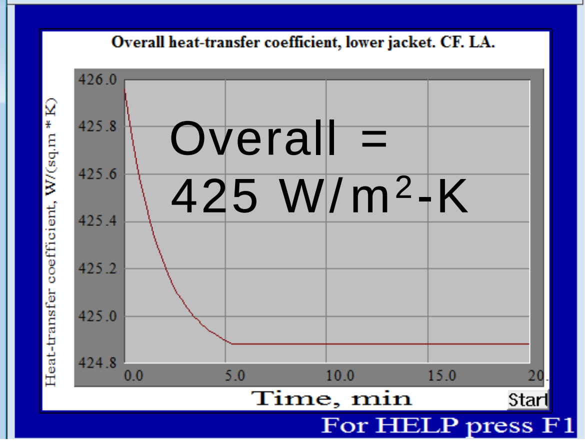

Outside film coefficient, lower jacket. CF. LA.

Pipes = 6540 W/m^2-K

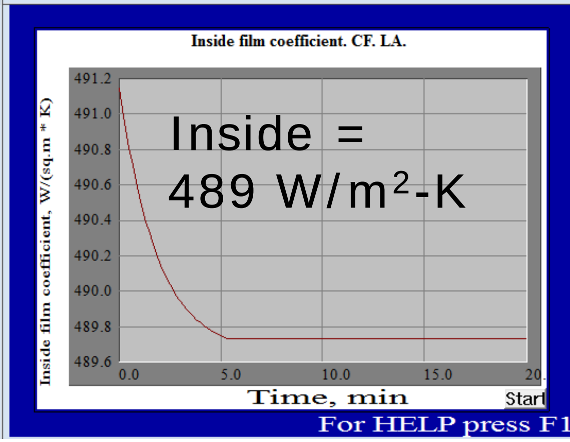


LOCAL VALUES OF ENERGY DISSIPATION

Parameter name	Units	Value
Energy dissipation - maximum value	W/kg	43.5
Energy dissipation - average value	W/kg	0.146
Energy dissipation near baffles	W/kg	0.0334
Energy dissipation in the bulk volume	W/kg	0.0334

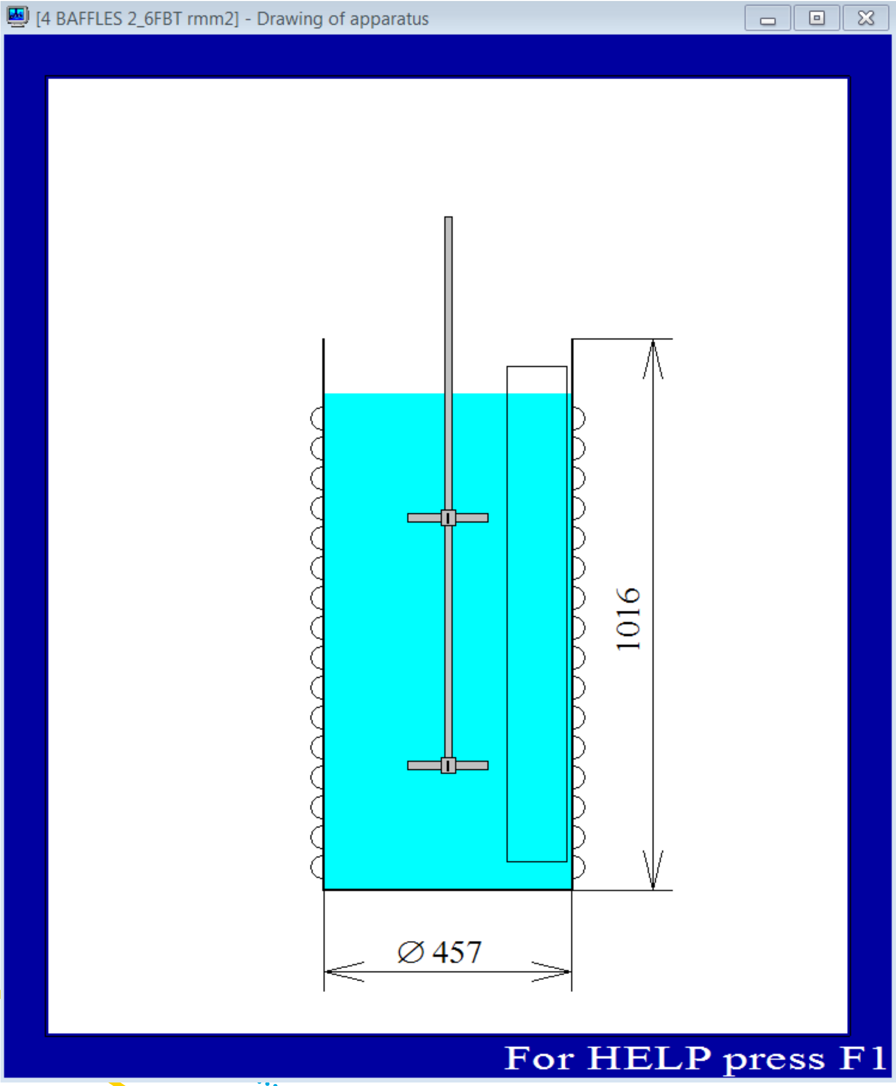

Overall heat-transfer coefficient, lower jacket. CF. LA.

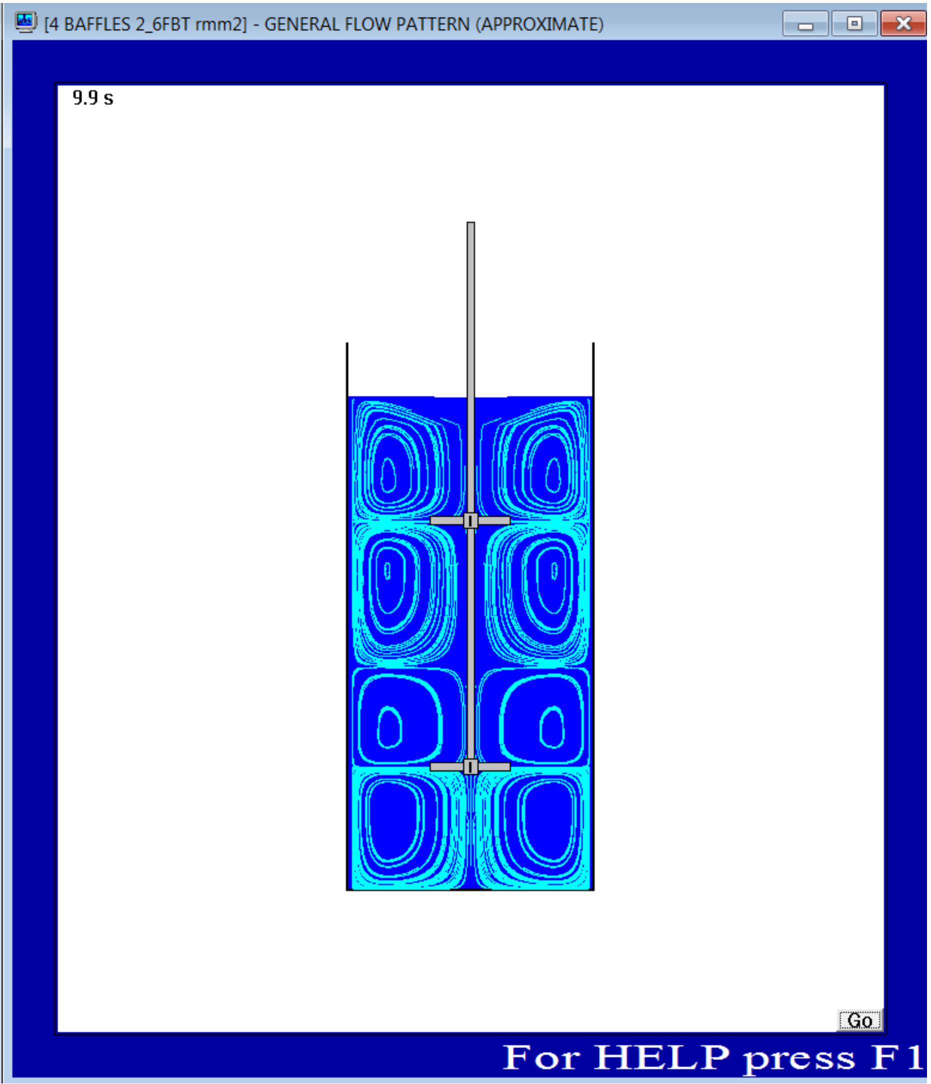
Overall = 425 W/m^2-K


Inside film coefficient. CF. LA.

Inside = 489 W/m^2-K

Geometry and flow pattern


[4 BAFFLES 2_6FBT rmm2] - Drawing of apparatus


[4 BAFFLES 2_6FBT rmm2] - GENERAL FLOW PATTERN (APPROXIMATE)

Water flow in the coils and HTC estimates

Turbulent flow in a tube $\mathrm{Re} > 10{,}000$

$$h = 0.026 \bullet \left(\frac{k}{D}\right) \bullet \left(\frac{\rho \cdot V \cdot D}{\mu}\right)^{0.8} \bullet \left(\frac{\mu \cdot Cp}{k}\right)^{1/3} \bullet \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

h = heat transfer coefficient, W/(m^{2}K)　k = thermal conductivity, W/(m K)

D = pipe diameter, m　ρ = fluid density, kg/m^2　μ = liquid viscosity, kg/(m s)

b = bulk; w = wall

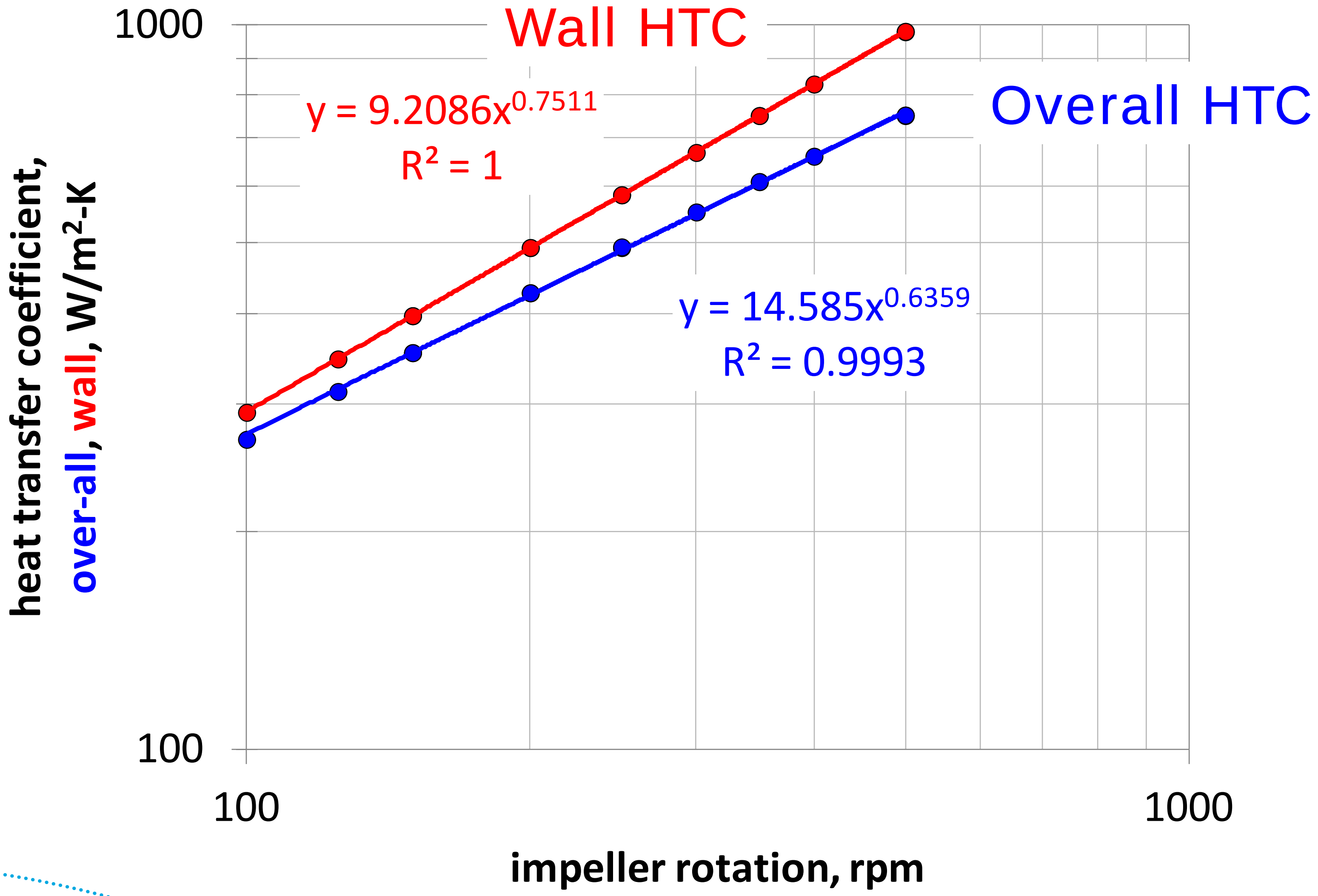
Inputs	
Physical Properties	
Bulk density of fluid (kg/m^3)	**986.8**
Bulk thermal conductivity of liquid (W/m-K)	**0.680**
Bulk viscosity of liquid (kg/m-s)	**0.000542**
Film viscosity of liquid (kg/m-s)	**0.000542**
Heat capacity of bulk liquid (J/kg-K)	**4288.749**
Tube	
Diameter (m)	**0.0127**
Length (m)	**0.9**
Flow	
Velocity (m/s)	**1.000**

Calculations	
Reynolds number	23139
Prandlt number	3.418
Viscosity ratio	1.000
L/D ratio	71
K	0.026
a	0.800
b	0.333
c	0.140
Nusselt number	121.44
Comparison	
Correlation coil HTC (W/m^2-K)	**6499**
VisiMix coil HTC (W/m^2-K)	**6540**

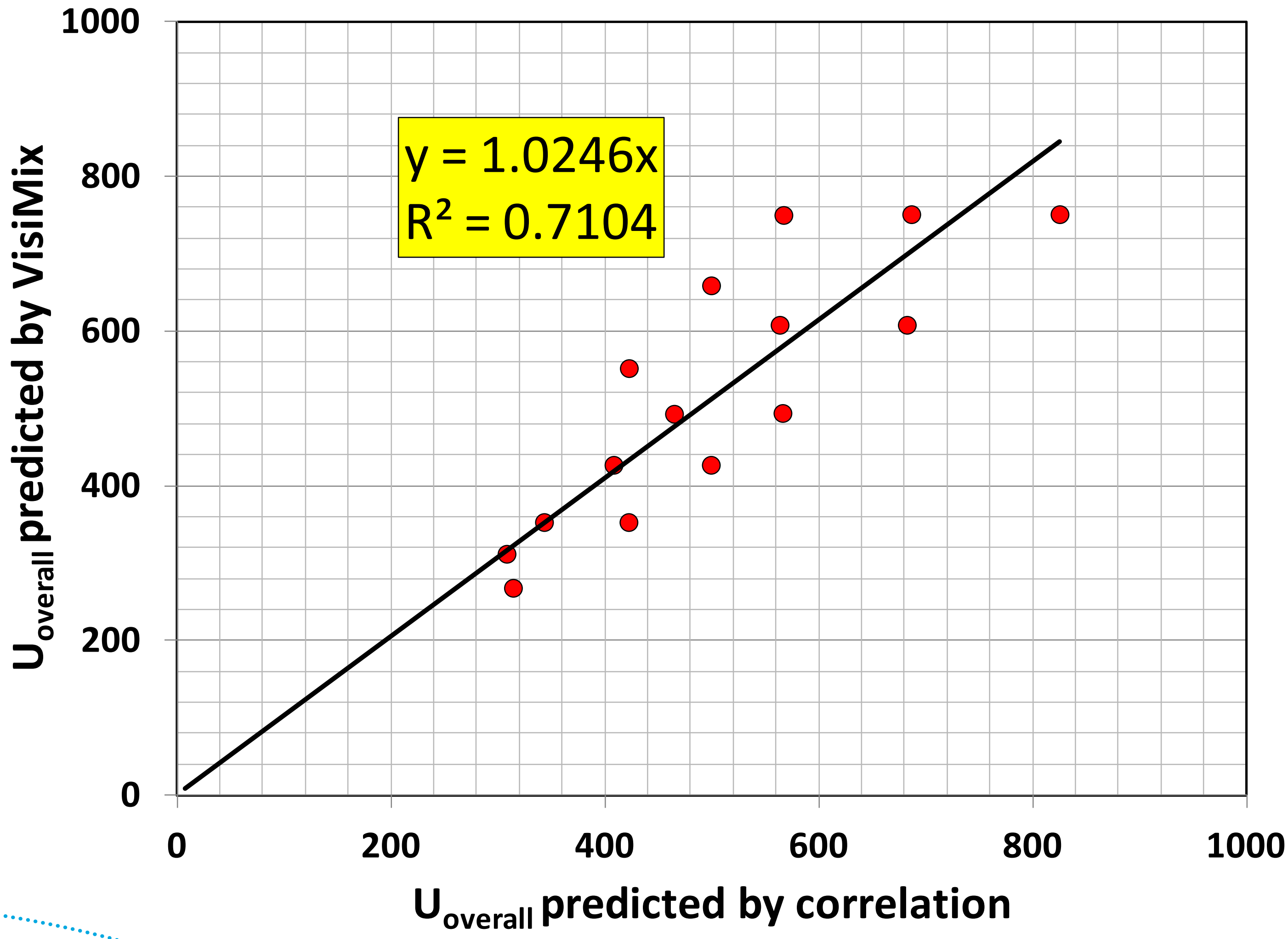
Summary with selected conditions

			Energy Dissipation			Correlation	VisiMix	Correlation	VisiMix	
Re	Pr	Viscosity cP	Baffle W/kg	Bulk W/kg	Average W/kg	Inside HTC W/m²-K	Inside HTC W/m²-K	Overall HTC W/m²-K	Overall HTC W/m²-K	Diff. Corr. vs VisiMix Overall HTC
5,806	120	20	0.114	0.114	0.489	473	667	422	552	-27%
7,742	120	20	0.271	0.271	1.16	571	829	499	659	-28%
9,677	120	20	0.531	0.531	2.26	662	979	567	750	-28%
4,839	60	10	0.00824	0.00824	0.0354	334	346	308	312	-1%
5,806	60	10	0.0143	0.0143	0.0611	376	397	343	353	-3%
7,742	60	10	0.0339	0.0339	0.145	455	493	408	427	-5%
9,677	60	10	0.0663	0.0663	0.283	526	583	465	493	-6%
13,548	60	10	0.182	0.182	0.776	657	750	563	608	-8%
19,355	60	10	0.533	0.533	2.26	831	980	686	751	-9%
7,742	30	5	0.00424	0.00424	0.0181	331	292	314	268	16%
11,613	30	5	0.0143	0.0143	0.0611	472	397	422	353	18%
15,484	30	5	0.0341	0.0341	0.145	571	493	499	427	16%
19,355	30	5	0.0667	0.0667	0.283	661	583	566	494	14%
27,097	30	5	0.183	0.183	0.776	825	750	682	608	12%
38,710	30	5	0.536	0.536	2.26	1043	980	825	751	9%

VisiMix HT coefficients follow the same trends, $N^{2/3}$ to $N^{3/4}$, as conventional HT correlations



The VisiMix wall HTC estimates correlate reasonably well with the experimental plate coil correlation



Conclusions

- Plate coils can offer a great advantage during the design of new larger reactors
  - Baffles to maintain similar energy dissipation W/m^3
  - Heat transfer to maintain similar heat removal W/m^3
- VisiMix heat transfer estimates for the wall can be used to predict the HTC for a plate coil by matching
  - material physical properties,
  - the plate coil flow geometry and flow rate with jacket and,
  - agitation rates

Thank you…
tell me more