3D COMSOL Multiphysics® Model of a Plate Heat Exchanger to Support a Laboratory Teaching Environment

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Introduction: Chemical engineering students and practitioners need an understanding of the flow and heat transfer inside heat exchangers in order to analyze, design, and utilize them efficiently. Because the flow pattern inside of plate type heat exchangers is difficult to visualize, we are developing COMSOL models of a plate heat exchanger for students to study alongside a physical heat exchanger in a laboratory setting. With COMSOL simulations, students can easily adjust flow rates, flow direction, and thermal fluid types as well as internal corrugations to study the effects these parameters have on heat transfer. Post processing capabilities allow students to visualize the velocity, pressure, and temperature profiles inside the exchanger.

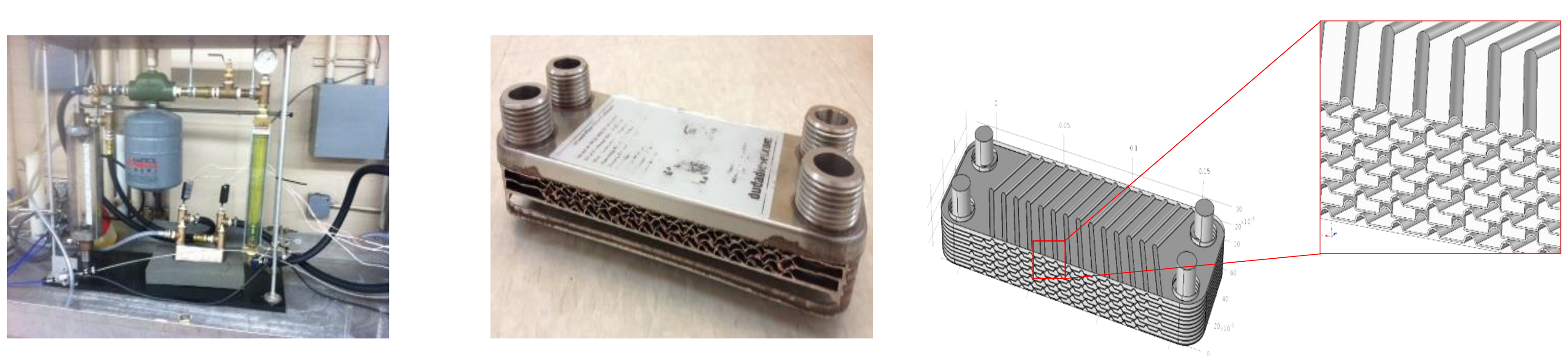

Figure 1. Plate heat exchanger experiment, cut away view of exchanger, and SolidWorks model.

Computational Methods: The heat exchanger geometry was built to manufacturing specifications using the CAD package SolidWorks. Incompressible laminar flow physics was used for both the hot fluid and the cold fluid flow modeling with assigned inlet flow rates and pressure outlet boundary conditions. Heat transfer in fluids physics was used together with the results from the laminar flow studies to calculate the heat transfer and temperature profiles in the exchanger. Models were studied with water in both flow streams as well as with water in the cold stream and ethylene glycol in the hot stream. The stainless steel plates were modeled using the thin thermally resistive layer boundary condition. To provide for faster solution and allow more studies to identify expected trends during a typical lab setting, simplified 4 channel models with different internal plate geometries were built in addition to the realistic 10 plate model with chevron shaped internals shown in Figures 1 and 2.

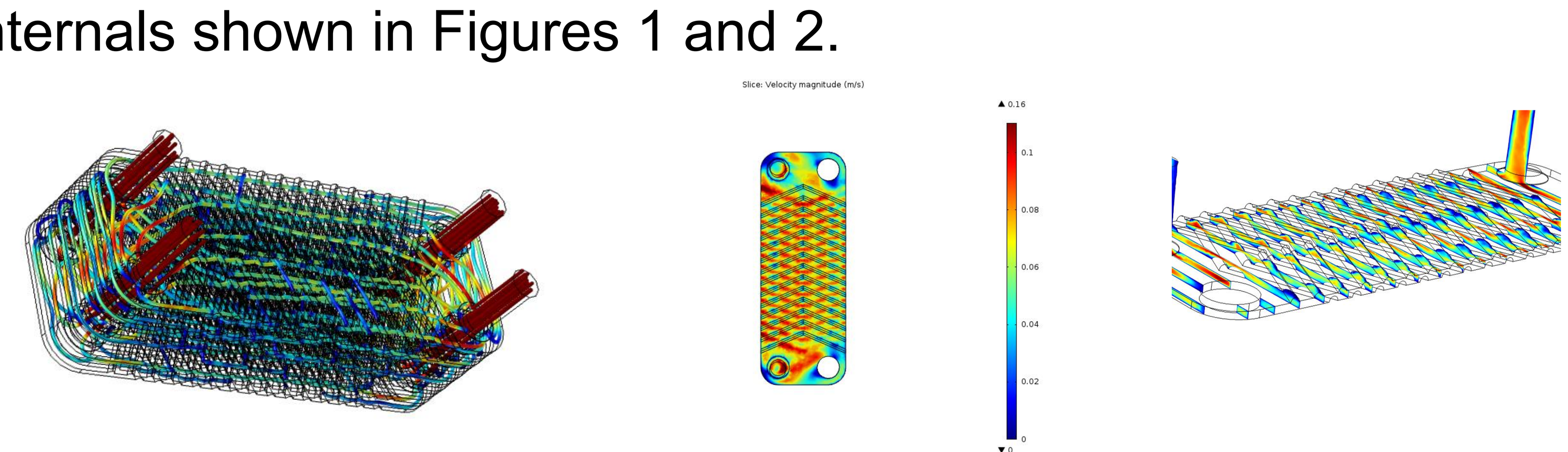

Figure 2. Complex flow pattern inside 10 plate exchanger with chevron shaped internals.

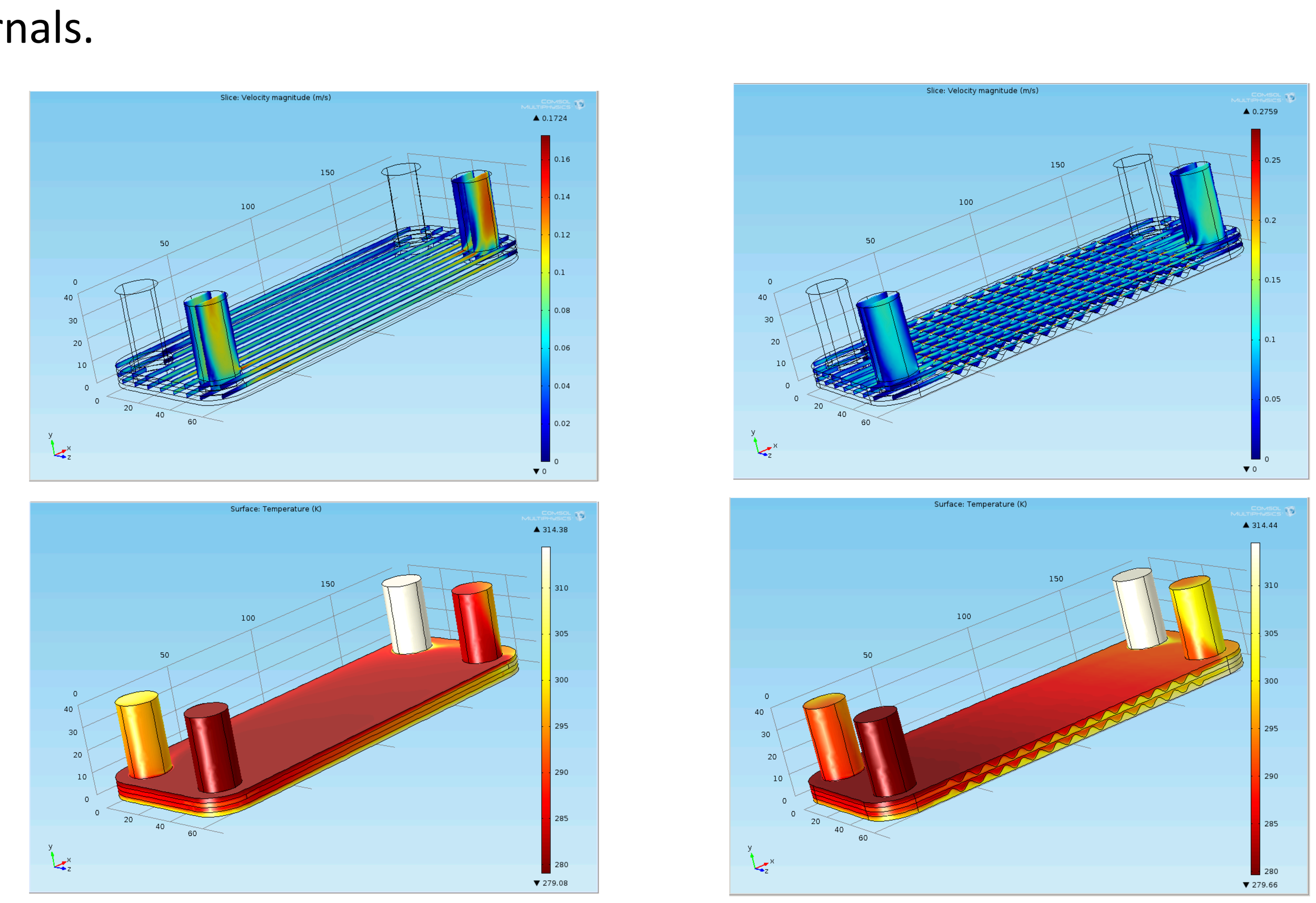

Figure 3. Simplified four channel models with and without internal corrugations; velocity and temperature plots with 1 L/min water in countercurrent flow.

Results: Figure 3 shows velocity and temperature result plots for the simplified four channel models with water at 1 L/min. Internal corrugations increase the heat transfer by increasing the surface area and the local velocity. Table 1 shows how flow pattern, internal corrugations, and flow rate affect the performance of the heat exchanger. The heat transfer coefficient increases with increasing velocity and increased corrugations, but at the expense of increased pressure drop. Figure 4 shows the temperature profile for adjacent channels near the center of the four channel exchanger without corrugations for both co-current and countercurrent flow. This clearly illustrates why countercurrent operation is preferred due to higher average driving force.

Table 1. Results for 4 channel exchanger with water in both streams, with and without internal corrugations. $T_{c,in}$ = 280.15, $T_{h,in}$ = 313.15 K.

$$Q = \dot{m}\, C_P\, (T_{out} - T_{in}) = U\, A\, \Delta T_{LM}$$

Direction	Plate Area	Flow rate	ΔP	Tc,out	Th,out	Q	U	Efficiency
	cm²	L/min	Pa	K	K	W	W/m²K	%
Co	Straight 382	1	56	288.5	304.6	580	618	25.2
Counter	Straight 382	1	56	290.0	303.1	689	783	30.0
Counter	Straight 382	2	154	287.5	305.8	1018	1036	22.1
Counter	Straight 382	3	289	286.1	307.0	1244	1209	18.0
Counter	Corrugated 423	1	414	297.3	295.9	1195	1788	52.0
Counter	Corrugated 423	3	2780	297.0	296.3	3525	5160	51.1

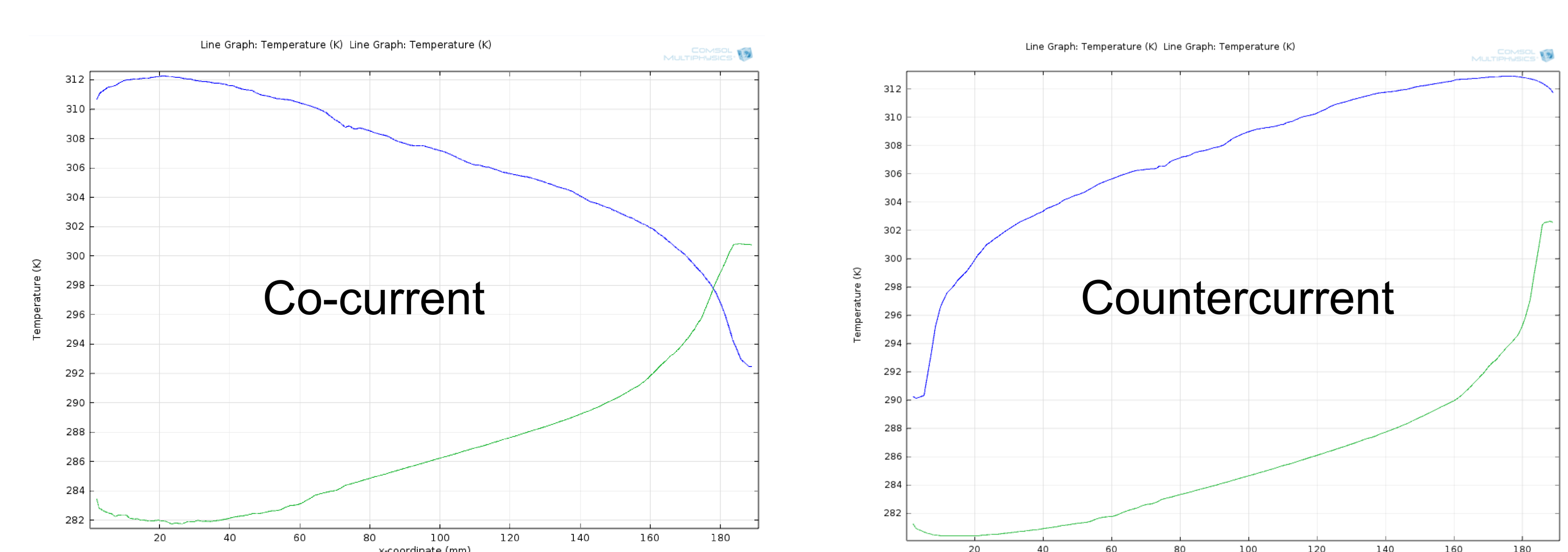

Figure 4. Temperature profiles in adjacent channels near center of 4 channel heat exchanger in co-current and countercurrent flow at 1 L/min water both streams.

Future Work: Our plans for this work include using the models to develop and test correlations for heat transfer coefficients and exchanger efficiency with different internal geometries and an extension to turbulent flow. It is also of interest to match the model and experimental results more accurately to illustrate the value of simulation in predicting quantitative results in complex systems.

Conclusions: Simulations allow students to investigate quickly a wide range of operating conditions and learn their effects on heat exchanger performance. Visualizing the velocity, pressure, and temperature profiles inside the exchanger provides a deeper understanding of the process. In particular, temperature profiles illustrate why countercurrent is preferred over co-current operation and velocity profiles illustrate why heat transfer coefficients increase with increasing flow rate and increasing internal corrugations.

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