Advanced Software Tools to Capture Heat Exchanger Cost Savings

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ABSTRACT

This paper will provide a detailed case study to illustrate the use of commercially-available software tools which allow the benefits of heat transfer enhancement technology to be realised in new plant design. CALGAVIN's hiTRAN.SP plug-in tools provide the designer with rigorous thermal/hydraulic models for enhanced heat exchanger sizing. Exchanger Optimizer™ software from HTRI generates detailed capital and operating cost data for life-cycle cost comparison purposes. Used together, these software tools allow heat exchanger designers to reliably quantify cost saving opportunities while retaining full control of the design process.

INTRODUCTION

Although heat transfer enhancement technologies are well-established in the process industry, many opportunities to reduce heat exchanger capital and operating costs are not being exploited. Significant savings may be available but may only be investigated if they can be reliably quantified early enough in the plant design cycle.

In order to capture the available savings, the heat exchanger designer requires software tools which allow reliable models of enhanced heat exchangers to be constructed in the early stages of equipment design. Furthermore, rigorous cost comparison tools are required to quantify the life-cycle cost benefits arising from the use of enhancement techniques.

In this paper, we will focus on the use of the *HTRI Xchanger Suite®* software package [1] to assist in the thermal design of a heat exchanger. Then, we will use HTRI's *Exchanger Optimizer™* package [2] to estimate the purchase, installation and operating costs of the resulting heat exchanger designs and evaluate the cost benefits between the enhanced and non-enhanced designs.

HTRI Exchanger Optimizer is a software package designed to aid in the cost estimation of TEMA Shell-and-Tube and Air-Cooled heat exchangers [2]. The program includes reliable data and correlations to calculate the material, fabrication, shipping, installation, operation and maintenance costs, among others. This tool can be useful for the heat exchanger designer to calculate an order-of-magnitude cost estimate, compare the life-cycle costs of multiple solutions, or estimate the cost of retrofitting or revamping existing equipment. Therefore, the designer is able to explore potentially cost-effective solutions early on in the design process.

We will also consider the use of CALGAVIN's *hiTRAN Thermal Systems* technology in the design of a new heat exchanger. This technology is designed to enhance the tube-side heat transfer coefficient, thereby allowing a smaller heat exchanger to perform the required duty. By using CALGAVIN's *hiTRAN.SP* plug-in for *HTRI Xchanger Suite* [3], it is possible to calculate the performance of this technology for tube-side single-phase applications.

CASE STUDY

Thermal Design using *HTRI Xchanger Suite*

Design Conditions

The objective for this case was to design an air-cooled heat exchanger capable of achieving approximately 23MW of cooling duty for a wax distillate stream. A summary of the process conditions for this heat exchanger is shown in Table 1, below.

Design Condition	Value
Tube-side Fluid	Wax distillate
Flow rate	184 tonne/h
Inlet Temperature	295°C
Required Outlet Temperature	110°C
Design Ambient Air Temperature	27°C
Minimum Air Temperature	-10°C
Tube-side Inlet Pressure	300 kPa
Ambient Air Pressure	1 atm (0m elevation)
Maximum Tube-side Pressure Drop	170 kPa
Tube-side Fouling Factor	0.00053 m^2K/W

Table 1 – Design conditions for a wax distillate air cooler

Additionally, a number of constraints were specified by the end-user, relating to the geometry of the heat exchanger. The tube length was restricted to a maximum of 9.144m (30ft); an even number of tube passes was preferred; and a minimum safety margin of 20% was to be applied, based on the surface area.

In this case there was a further complicating factor, as the wax distillate was found to have a pour point temperature of 46°C. The API 661 standard (ISO 13706:2011) recommends a safety margin of 14°C above the pour point [4] is applied to the inside tube surface temperature, to ensure that the fluid does not begin to harden inside the tubes during operation. Therefore, the requirement was added that the minimum surface temperature must be greater than 60°C under all expected operating conditions.

Designing an air-cooled heat exchanger suitable for the above service can prove difficult, as the physical properties of the wax distillate are not favourable for heat transfer – it has a high viscosity (up to 32cP at 60°C), poor thermal conductivity (0.081 W/m-C), and the high pour point. For such cases, this can lead to a large surface area requirement due to the poor tube-side heat transfer rate, and limitations on the tube length and pass arrangement as a result of high frictional pressure drop.

Designing with Empty Tubes

In order to develop a thermal design for this air-cooled heat exchanger which could achieve the requirements, a design model was created using the *Xace* component in *HTRI Xchanger Suite*.

To begin with, the process conditions for the wax distillate and air streams were entered as shown in Figure 1. Additionally, the physical properties of the wax distillate fluid were entered for the full range of temperatures expected within the unit.

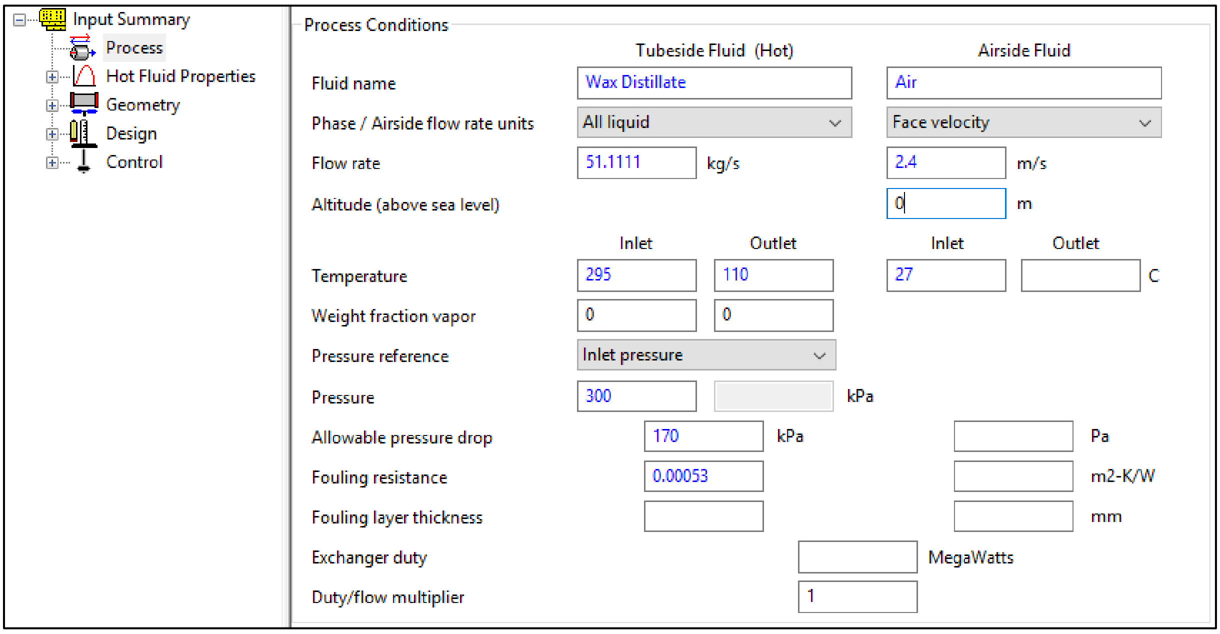

Figure 1 – Process Conditions input screen in *HTRI XChanger Suite*

Next, the program's 'design mode' feature was used in order to rapidly calculate a large array of different design options. The design mode feature allows certain parameters to be fixed or varied within a defined range. The key parameters were entered to define the limits of the air cooler's design, such as the number of tube rows and passes, the air face velocity, and the tube diameter and length. In addition to these, a number of other design features were fixed in advance, such as the specification of the tube fins, the tube wall thickness and the number of fans per bay.

From the resulting range of possible designs, a single option could be identified which best suited the requirements and carried forward to develop a more detailed design. The most suitable design within the limits was found to be an eight-row, eight-pass air cooler with eight bundles in parallel.

However, while the design mode procedure yielded a design which could achieve the specified cooling duty, it was found that the tube-side wall temperatures did not exceed the minimum 60°C even under normal operating conditions. For the condition with the minimum air temperature of -10°C, the wax distillate could be cooled below its pour point in the bottom rows of the unit.

In order to prevent this condition, a co-current pass arrangement was decided, such that the hottest tube-side fluid was in contact with the coldest air and would exceed 60°C under all operating conditions. A co-current flow arrangement was chosen in preference to using a reduced fin density or plain tubes, as neither of these options provided a sufficient increase in the tube wall temperature. However, as co-current flow is less effective, this required an increase in the number of tubes per bundle and the air face velocity. Lastly, variable-speed fans were specified to reduce the air flow during the winter operating condition, compensating for the lower air temperature. A summary of this final empty tube design is shown in Table 2.

Parameter	Value
Bays in Parallel	8
Bundles per Bay	1
Number of Tubes per Bundle	404 (51/50 per odd/even row)
Number of Tube Rows	8
Number of Tube Passes	8
Flow Pattern	Co-current to crossflow
Tube Length	9.144m (30ft)
Tube Size	25.4mm OD x 2.77mm thick, carbon steel
Tube Fin Geometry	57.15mm OD x 0.4mm base thickness, extruded Aluminium, 394 fin/m
Fans	2 x 2.689m Diameter
Air-side Face Velocity (Standard)	2.4m/s
Heat Transfer Coefficients	141W/m²K (Tube-side); 44W/m²K (Air-side)
Total Finned Surface Area	49668m²

Table 2 – Summary of air cooler design with empty tubes

Designing with hiTRAN Thermal Systems

While the previously-described design achieved the heat transfer, pressure drop and geometry requirements, as anticipated the required surface area was very large. Therefore, it could be expected that such design would have significant plot space requirement, as well as a high capital cost. At this point, the heat exchanger designer may find it useful to consider using technologies to enhance the heat transfer performance.

Heat transfer enhancement had already been applied to the air-side of this heat exchanger, in the form of finned tubes to increase the outside surface area. However, by comparing the relative heat transfer coefficients, it was clear that the tube-side thermal resistance was by far the limiting factor affecting the design of this unit.

Further examination of the calculation results revealed that the high viscosity of the wax distillate fluid led to laminar flow conditions occurring. It is established that laminar flow is not an effective condition for heat transfer [5], therefore using tube-side enhancement technology – such as hiTRAN Thermal Systems – would likely yield a significant benefit. The mechanism by which hiTRAN enhances the tube-side heat transfer is beyond the scope of this paper [6], however it is generally found to significantly increase the heat transfer coefficients for laminar and transitional flow conditions.

CALGAVIN's *hiTRAN.SP* plug-in for *HTRI Xchanger Suite* allows the heat exchanger designer to calculate the tube-side heat transfer coefficient of a heat exchanger equipped with hiTRAN Thermal Systems. Using this plug-in, the heat exchanger design was recalculated with the hiTRAN elements installed, and a 300% increase in overall performance was observed. From this point, the size of the unit could be reduced – within the geometry constraints already established – until the required 20% over-design safety margin was achieved. Table 3 below summarises the heat exchanger design that was achieved after considering the installation of hiTRAN.

Parameter	Value
Bays in Parallel	3
Bundles per Bay	1
Number of Tubes per Bundle	309 (52/51 per odd/even row)
Number of Tube Rows	6
Number of Tube Passes	2
Flow Pattern	Counter-current to crossflow
Tube Length	9.144m (30ft)
Tube Size	25.4mm OD x 2.77mm thick, carbon steel
Tube Fin Geometry	57.15mm OD x 0.4mm base thickness, extruded Aluminium, 394 fin/m, with 197 fin/m for the bottom two rows
Fans	2 x 2.715m Diameter
Air-side Face Velocity (Standard)	2.6 m/s
Heat Transfer Coefficients	1306W/m^{2}K (Tube-side); 42W/m^{2}K (Air-side)
Total Finned Surface Area	12016m^2

Table 3 – Summary of air cooler design with hiTRAN enhancement

The significantly increased tube-side heat transfer with the hiTRAN elements installed allowed for a correspondingly large reduction in the surface area requirement. Furthermore, this also led to an increase in the calculated tube wall temperatures, allowing a more efficient counter-current pass arrangement to be considered. Additionally, the fin density on the lowest two tube rows was reduced in order to decrease the air-side heat transfer coefficient, therefore increasing the inside tube wall temperature.

Capital Cost Evaluation using *HTRI Exchanger Optimizer*

Once the empty tube and hiTRAN-enhanced designs has been completed, the *Exchanger Optimizer* program was used to demonstrate the potential cost savings by choosing a hiTRAN-enhanced design over the empty tube option.

First, as the design phase was completed using *Xchanger Suite* , the key information from design files could be directly imported into the *Exchanger Optimizer* program, as shown in Figure 2. With the geometries of both design options specified, a common basis for the comparison of the fabrication and installation costs was set: it was assumed that the unit would be fabricated and installed in Europe, with all prices reported in Euro. The program could then estimate the costs by using typical material, labour and shipping rates for different regions, although these values can be specified if the designer has more accurate or specific information available.

To estimate the operating costs, the *Exchanger Optimizer* provides the ability to specify the costs of the utilities required to operate the heat exchanger, as well as costs associated with the maintenance of the unit. In this case, the fan motor power calculated in *Xchanger Suite* was combined with the default cost per unit of power in Europe, evaluated over a period of ten years. It was assumed that the fans would always be operating at the full design power; reduced power operation during the winter condition was not evaluated. Similarly, maintenance costs considered outside the scope of this analysis.

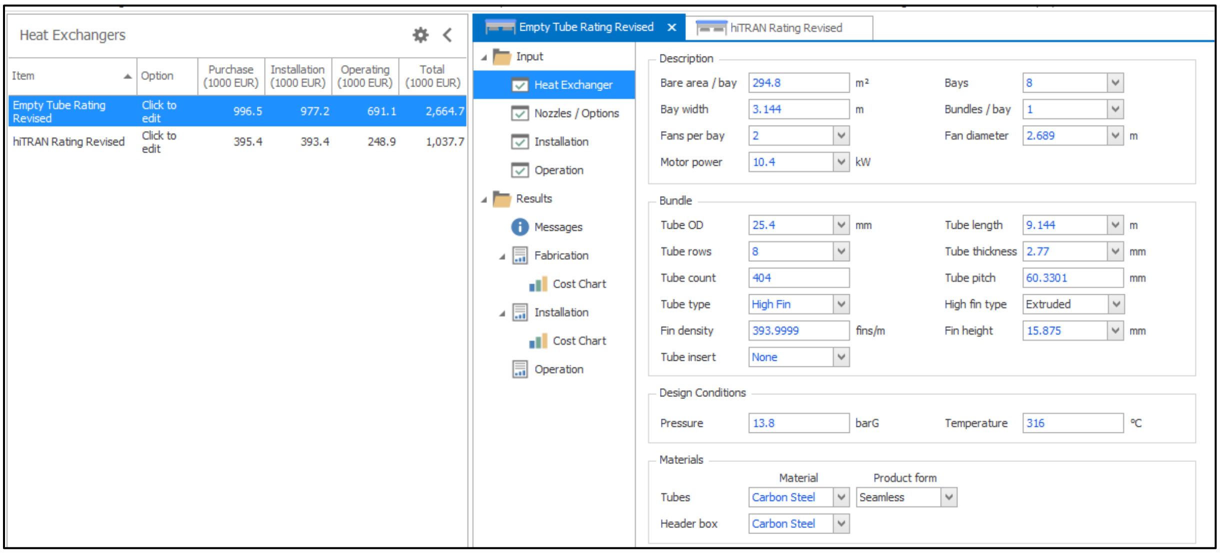

Figure 2 – Heat exchanger design input screen in *HTRI Exchanger Optimizer*

Lastly, for the hiTRAN-enhanced option, the price of the hiTRAN tube inserts was included in the purchase cost of the tube bundle. For other forms of tube-side enhancement technology, it is possible for the heat exchanger designer to specify the price per unit length for the tube inserts – for example, based on a quotation from the supplier or from previous experience. The *Exchanger Optimizer* also makes a correction to account for the additional labour costs required to install tube inserts.

The calculations provided a detailed, itemised breakdown of the various components which make up the total costs of the two design options. A summary of the total purchase, installation and ten-year operating costs for these options is presented in Figure 3 below.

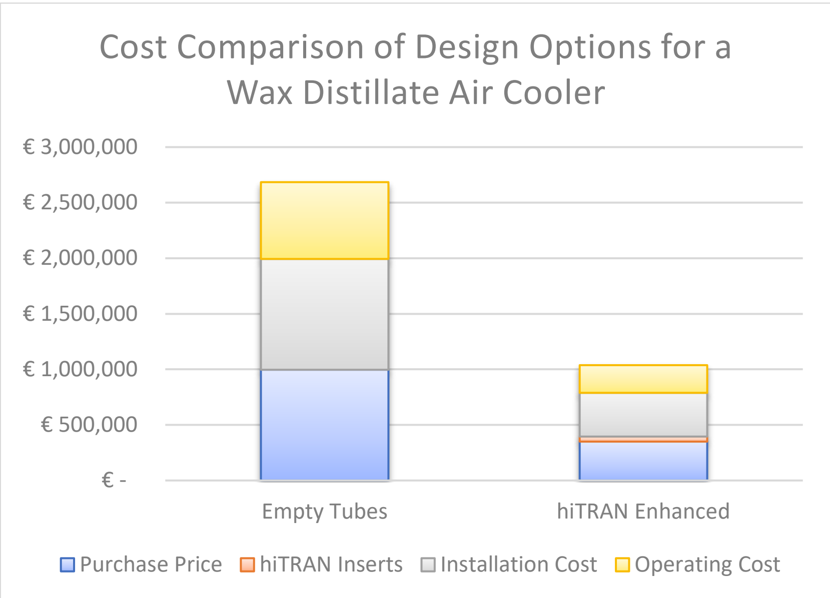

Figure 3 – Comparison of costs between empty-tube and hiTRAN-enhanced designs

As could be anticipated from the difference in size, the heat exchanger design with the tube-side hiTRAN enhancement has significantly lower costs than the empty tube alternative. In this case, the total costs – including the ten-year operating costs – would have been approximately the same as the purchase price alone of an empty tube unit. Furthermore, the additional cost of the hiTRAN inserts made up a relatively small fraction of the total cost of the enhanced unit.

CONCLUSION

Through using a combination of *HTRI Xchanger Suite*, CALGAVIN's *hiTRAN.SP* plug-in and *HTRI Exchanger Optimizer*, it was possible to develop and optimise a heat exchanger design to provide a certain cooling duty for a wax distillate stream. This design was optimised by calculating the effect of tube-side heat transfer enhancement, and the capital cost savings which could be obtained were estimated.

As demonstrated in this case, the *hiTRAN.SP* plug-in allows the heat exchanger designer to evaluate the technical suitability of CALGAVIN's hiTRAN technology for a given application. The plug-in allows the designer to calculate the heat transfer enhancement possible for a given pressure drop, and further optimise to specify a smaller heat exchanger that can perform the required duty.

The *Exchanger Optimizer* program was used to demonstrate the financial benefits of using hiTRAN technology in a new wax distillate cooler design. The example presented here shows how this tool can be used to provide a reasonable order-of-magnitude cost estimate, and relatively compare the capital costs of different design options. However, the *Exchanger Optimizer* can be more generally useful to the heat transfer engineer. By providing realistic estimates of the capital and life-cycle costs of a given heat exchanger design, the program gives the ability to compare multiple, technically suitable solutions from a financial perspective. This could range from comparing different configurations of the same basic heat exchanger design (such as presented in this case); evaluating the life-cycle costs from using different heating and cooling utilities (for example, comparing air-cooling against water cooling or hot oil to condensing steam); to determining whether retrofitting or replacing existing units would be most cost-effective.

An advantage of the above tools is that they are available for the heat exchanger designer to use independently, affording the ability to evaluate many different alternatives from technical and financial perspectives. Therefore, this avoids the necessity to rely upon third-parties to provide information such as thermal performance data, equipment designs and material quotations for each case to be evaluated. As a result, the designer is able to retain full control of the design process to find an optimal solution.

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