TOO COOL

Robert Browning, Heat Transfer Research, Inc., USA, discusses the optimisation of heat exchangers for process cooling in upstream and downstream facilities.

Designing heat transfer systems is a complex process. Identifying the optimal solution through intuition alone is difficult. Each problem can have many alternative solutions, each with its own complex economic and performance interactions. Finding the best solution requires some evaluation of the capital, installation, operating, and maintenance cost of the system. And, with heat transfer equipment accounting for up to 30% of capital and 90% of operating costs for a process plant, finding the optimum solution translates into large savings. This article provides two examples which demonstrate the potential savings that may be realised when using some basic cost analysis during the initial design of the heat transfer systems.

Cooling medium selection

When designing a heat exchanger to cool a process fluid, the first decision is the selection of the cooling medium. When adequate supplies of cooling water are not available, an air cooler is the obvious choice. In most cases, however, respective costs of air and water cooling must be compared before a final decision can be made.

Selection of the most economical heat exchanger in a given service includes the initial capital cost of the heat exchanger, installation costs, maintenance costs and operating costs. For example, the initial cost of a water-cooled shell and tube heat exchanger is much less than that of an air-cooled heat exchanger for the same service. However, the cost of the cooling water supply, including makeup water, chemical treatment, blowdown disposal, water circulation pumps, and the cooling tower and fans, can often offset the lower capital cost of the water-cooled heat exchanger.

Table 1. Economic evaluation for three year period

	Water-cooled	Air-cooled
Size	1066 mm x 6096 mm	4 x 4267 mm x 9754 mm
Type	AEU	Forced draft
Bare surface area	444 m^2	1798 m^2
Purchase price	US$109 000	US$724 000
Installation cost	US$223 000	US$514 000
Operating cost	US$1.323 million	US$163 000
Total cost	US$1.655 million	US$1.401 million

Table 2. Economic evaluation including hot air recirculation system for air cooler

	Water-cooled	Winterised air-cooled
Size	1066 mm x 6096 mm	4 x 4267 mm x 9754 mm
Type	AEU	Forced draft
Bare surface area	444 m^2	1798 m^2
Purchase price	US$109 000	US$1.115 million
Installation cost	US$223 000	US$548 000
Operating cost	US$1.323 million	US$163 000
Total cost	US$1.655 million	US$1.826 million

Table 3. Economic evaluation for system using air cooling and water cooling

	Water-cooled	Air-cooled
Size	838 mm x 6096 mm	1 x 5182 mm x 9754 mm
Type	AEU	Forced draft
Inlet/outlet temperature	85˚C/57˚C	188˚C/85˚C
Bare surface area	257 m^2	350 m^2
Purchase price	US$72 000	US$174 000
Installation cost	US$188 000	US$209 000
Operating cost	US$579 000	US$60 000
Total cost	US$1.282 million	

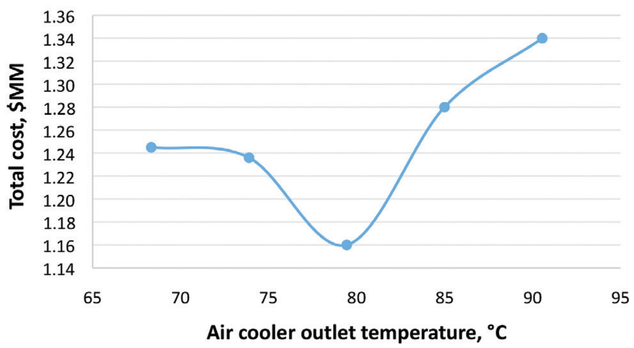

Figure 1. Optimum duty split.

A common rule of thumb indicates that air cooling is more economical than water cooling when the required process fluid outlet temperature is at least 8 - 12˚C above the design ambient air temperature. A rule of thumb may be acceptable for an initial guess, but it should not be used as a basis for design. The optimum configuration depends on the unique economics of the project and the unique process requirements.

A detailed economic evaluation should be performed for each cooling configuration, taking into consideration the initial capital cost, as well as the operating costs. Finding the optimum solution often translates into large savings, making the effort to prepare the economic evaluation worthwhile.

In the following examples, the HTRI ***X****changer Suite*® was used to size the heat exchangers, and Exchanger Optimizer was used to perform the economic evaluations. Exchanger Optimizer is a new software application to help engineers design more cost effective heat exchangers by providing detailed economic evaluations of heat exchanger configurations. This technology allows heat transfer engineers to model and compare several heat exchanger configurations in a single software package. The software can be used to estimate purchase, installation, and operating costs for shell and tube and air-cooled heat exchangers. To provide accurate relative estimates, Exchanger Optimizer provides quantity-based estimates for the heat exchanger purchase price and installation cost. Mechanical calculations are performed for the heat exchanger, piping network, foundation and so forth to estimate material quantities. An extensive materials database is then used to estimate the material costs. To estimate the labour hours, the software models the required activities to manufacture and install the heat exchanger.

Using historical cost curves to estimate heat exchanger designs is sufficient for project budgeting, but using them for relative economic evaluations can result in erroneous conclusions, for example, that fixed tubesheet heat exchangers are always less expensive than U-tube heat exchangers. Heat exchangers are simply too complex, and have too many variables, to accurately predict the relative price using historical data.

Refinery case study

In a refinery, 236 000 kg/hr of hydrocarbons is to be cooled from 118 to 57˚C. The maximum ambient temperature is 38˚C, and cooling water is available at 29˚C. For water cooling, one shell is required with 444 m^2 of bare surface area. For air cooling, two bays are required with 1798 m^2 of bare surface area.

The details of the sizing and economic evaluation using a three year economic evaluation period are listed in Table 1. Air cooling is the more economical

Table 4. Economic evaluation results for ratings using various tube diameters and number of tuberows											
Design	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Surface area per bay, m^2	286	329	384	360	296	365	332	470	286	393	350
Bay width, m	3.81	3.66	3.66	4.27	4.88	4.42	4.57	4.88	5.94	5.79	6.40
Bundles per bay	1	1	1	1	1	1	1	1	2	2	2
Bays	1	1	1	1	1	1	1	1	1	1	1
Overdesign, %	-0.8	-0.9	2.1	0.4	-0.3	15.2	1.0	0.1	1.9	0.6	0.8
Tubeside pressure drop, Pa	18.2	13.4	11.0	11.5	16.8	23.9	12.9	3.8	18.2	5.3	5.7
Tuberows	5	6	7	7	5	6	6	7	4	5	4
Tube OD, mm	38.1	38.1	38.1	25.4	25.4	31.75	25.4	31.75	25.4	31.75	31.75
Tube length, m	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
Tubepasses	2	2	2	1	1	2	1	1	1	1	1
Outlet line, m	9	9	9	19	19	9	19	19	19	19	19
Purchase price (US$)	158 827	163 632	171 982	178 429	173 955	177 955	176 612	199 665	207 053	218 453	221 730
Installation cost (US$)	241 519	241 832	244 632	248 904	253 700	252 048	253 842	258 696	264 386	269 004	267 295
Total installed cost (US$)	400 347	405 463	416 614	427 333	427 655	430 003	430 454	458 361	471 439	487 457	489 025

configuration, even though the estimated purchase price of US$724 000 for the air-cooled heat exchanger is much higher than the US$109 000 for the water-cooled shell and tube exchanger. The US$1.323 million operating cost of the water-cooled unit dominates the total cost. For the pour point of the process stream (18˚C), a hot air recirculation system is required to prevent freezing in the winter. The inclusion of such a system results in a significant cost increase for the air-cooled exchanger, making the water-cooled heat exchanger the economical choice, as summarised in Table 2.

What if air cooling is used in series with water cooling? As an initial guess, the process temperature is set to 85˚C between the air cooler and water cooler. As an additional benefit, increasing the outlet temperature of the air cooler increases the minimum tube wall temperature and eliminates the need for the hot air recirculation system. Using air cooling with water cooling yields the lowest total cost of US$1.282 million. The results of the rating and economic evaluation for this option are shown in Table 3.

Further optimisation is possible by determining the optimum duty split between the air-cooled and water-cooled units. Figure 1 shows the results of rating various duty splits. A process temperature of 79˚C after the air cooler results in the lowest system cost of US$1.116 million.

Air-cooled heat exchanger optimisation

The optimum air cooler design is one with the lowest sum of purchase, installation, and power costs. An air-cooled heat exchanger requires the optimisation of many variables:

- Tube length.
- Tube OD.

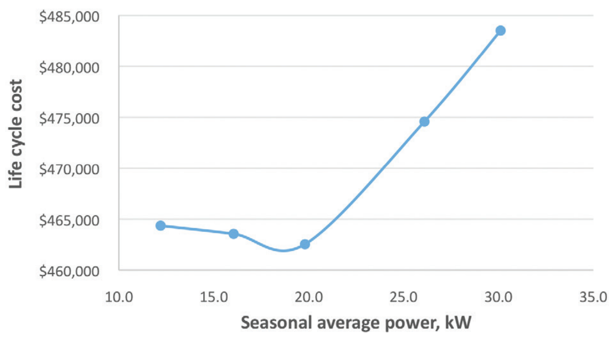

Figure 2. Lifecycle cost as a function of motor horsepower.

- Fin height.
- Fin density.
- Number of tuberows.
- Airside flow rate.
- Number of tubepasses.
- Number of bundles.
- Number of bays.

Generally, longer tubes result in a lower cost because the header width and number of bays are minimised. If the air cooler is installed on a pipe rack, the maximum tube length is usually limited to the pipe rack width plus 60 cm. In some cases, a shorter tube length is necessary to achieve adequate fan coverage or to obtain a very low pressure drop, if required.

A tube diameter of 25.4 mm usually results in the lowest cost, but larger diameters are sometimes more economical. Such diameters should be investigated for condensing applications and for cooling viscous fluids. In cooling a viscous liquid, a larger diameter tube and a greater number of tubepasses can result in a large performance improvement. Tube lengths have an upper limit of 18.3 m, the common maximum standard length from tube mills.

Fin heights can range from 12.7 - 15.875 mm, and fin density can range from 236 - 433 fins/m. In most cases, the standard fin height is 15.875 mm, and the standard density is 394 fins/m. With the current cost of aluminum, it rarely makes sense to use a shorter fin height or smaller fin density. In cases where airside resistance is controlling, 433 fins/in. can be used, but often this density is not allowed in all plants because it is harder to clean.

The tube pitch should allow a minimum of 6.3 mm between the fin tips. Again, a smaller value such as 3.2 mm between the fin tips can be used, but doing so makes the bundle harder to clean, increases the airside pressure drop, and is not permitted in some plants.

The number of tubepasses can range from 1 - >20 for processes with high viscosity. The number of tubepasses is usually increased as needed to use the allowed pressure drop, and increase the tubeside heat transfer coefficient. The distribution of tubes does not need to be uniform. For instance, an air cooler with six tuberows and two tubepasses can have four tuberows in the first pass and two tuberows in the second. This arrangement is particularly advantageous when the properties of the fluid change dramatically as the fluid cools, such as in a condenser or in cooling a viscous fluid.

Most air-cooled heat exchangers operate economically with four to six tuberows. Using fewer than four tuberows is rarely cost effective because the airside performance drops significantly. The addition of more tuberows allows for more heat transfer area in the same bay width. The disadvantage is that the additional area is less effective. Adding tuberows while maintaining a constant motor power results in a reduction in air flow, a lower airside heat transfer coefficient, and a lower overall mean temperature difference. Increasing the number of tuberows is a tradeoff between increasing the cost of the tube bundle and minimising the cost of the structure and fan drive system. When the tube bundle cost is controlling, such as with high alloy materials, a design with four tuberows is often the most economical.

The airside flow rate can be adjusted to improve the airside heat transfer coefficient, or the overall mean temperature difference. Increasing the airside flow rate causes a rapid increase in the motor horsepower requirements, therefore increasing the operating cost. Care should also be taken to ensure that the selected fan can meet the airside performance requirements, including maximum noise level. Designers often limit the airside pressure drop to 175 - 200 Pa to avoid difficulty with fan selection and noise levels.

The maximum bundle width is sometimes determined by shipping considerations or by manufacturing limitations. Most manufacturers can fabricate bundles up to 4.3 m in width, with a few capable of up to 4.9 m width. A bay larger than 4.9 m requires two bundles per bay. The maximum fan diameter for most air-cooled heat exchanger manufacturers is 4.9 m, which puts a practical limit on the maximum bay width to achieve at least 40% fan coverage.

Gas treatment plant case study

At a gas treatment plant, 10 400 kg/hr of regenerator overhead is to be condensed from 115 - 49°C. The allowable pressure drop is low at 24 Pa. As cooling water is not available at the plant, an air-cooled heat exchanger is the only choice. The cooler is installed on a 9.1 m pipe rack, and the maximum tube length is 9.7 m.

Finding the ideal solution is very difficult because many of the design variables are interrelated. To make the problem manageable, optimisation can be carried out in two parts, keeping the motor horsepower constant at approximately 15 for each motor, but varying the tube diameter or the number of tuberows.

A series of ratings were performed in ***X****changer Suite* using various tube diameters and a number of tuberows. The economic evaluation was performed using Exchanger Optimizer. The results are summarised in Table 4.

For the designs with one tubepass, the outlet line requires additional length due to the layout of the equipment, and because the nozzles are placed at opposite ends of the heat exchanger. The additional piping cost is accounted for in Exchanger Optimizer by specifying an outlet line length of 19 m.

For a condenser with a low pressure drop, using a larger tube diameter and increasing the number of tubepasses is an economical option. Using two bundles per bay can be safely ruled out, as those designs have the largest cost.

Further optimisation can be carried out by adjusting the air flow rate and calculating the life cycle cost. Figure 2 shows how the lifecycle cost of design 1 varies as the motor horsepower increases. The design with the largest motor power consumption almost always has the lowest purchase price, but is rarely the most cost effective over an entire lifecycle. The minimum lifecycle cost is the design with an average power consumption of 19 HP.

Conclusion

Designing heat transfer systems is an iterative process that often provides multiple solutions. In these cases, an economic evaluation should be performed to find the design with the lowest cost or highest return on investment.