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USING PLATE HEAT EXCHANGERS to Process Bulk Solids

Vertical plate heat exchangers offer indirect heat transfer when heating, cooling or drying bulk solids. Because the two streams are separated, contamination does not occur.

By Jamie Zachary,
Solex Thermal Science

The handling of bulk solids has been tossed around for decades — literally. From fertilizer to food products, sugar to sludge pellets, and coffee to catalysts, the practice of heating, cooling or drying has been a part of virtually every industry built around free-flowing materials since the Industrial Revolution.

The technology behind thermally processing bulk materials, however, continues to evolve. Manufacturers and processors seek more efficient and cost-effective solutions to optimize and expand their production lines. Increasing production, minimizing energy consumption and improving product quality are just some of the key drivers.

Within the last 20 to 30 years, indirect plate heat transfer technology has transitioned to the forefront of bulk-solids heating, cooling and drying. It has found use in unlikely places such as polymers, chemicals and even olive pits. Yet many are not aware of the capabilities of these types of plate heat exchangers.

Indirect plate heat transfer technology traces its lineage to traditional plate heat exchangers (PHE), a related heat process technology that remains commonplace. Plate heat exchangers offer indirect heat transfer because the two streams are separated. This means contamination – between the stream being heated, cooled or dried, and the stream effecting heat transfer – does not occur.

Plate heat exchangers are suited for low or medium pressure applications – from 176 to 392°F (80 to 200°C), with pressures up to 25 bar. Common industrial applications for plate heat exchangers include closed-loop secondary circuit, pasteurization and waste heat recovery. Shell-and-tube exchangers, by contrast, excel in high temperature, high pressure applications as well as those involving hazardous chemicals.

While well established, both shell-and-tube and plate heat exchangers have their respective restrictions, including that they are limited to heating or cooling liquids or gas – for example, liquids to liquids, gas to liquids or gas to gas.

Bulk Solids Heat Transfer

Prior to the mid-1980s, industries such as fertilizer and sugar cooled their respective products by direct contact with air. Two technologies dominated the field:

- Rotary drum coolers. In these systems, a falling curtain of product is cooled by a cross-flow airstream in the drum.
- Fluid bed coolers. In these systems, the bulk solid is fluidized by the airstream.

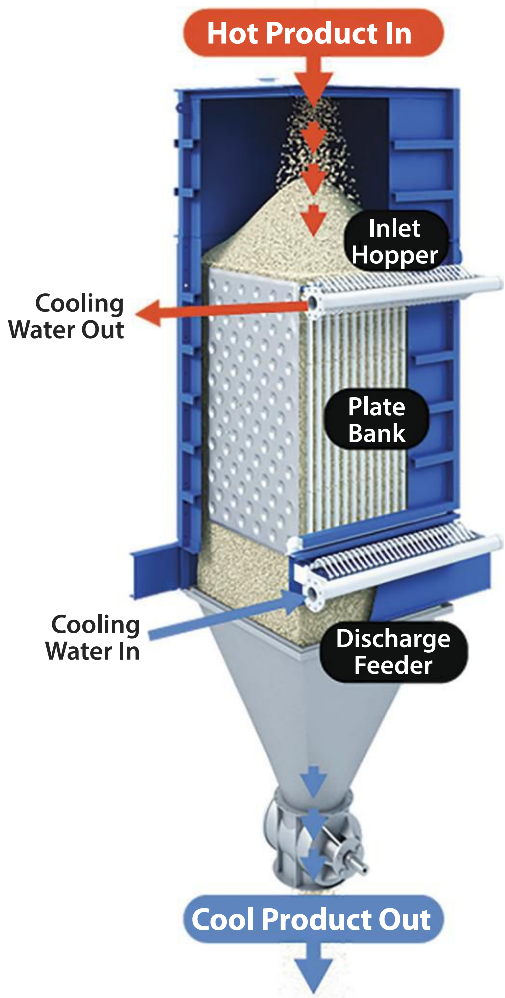
"The challenge with both is that when you're blowing air past a product like fertilizer, you're going to get a lot of dust in the air, resulting in a gas exhaust stream with a lot of dust in it," says Neville Jordison, co-founder of Solex Thermal Science. "That means the exhaust stream must be cleaned before it is emitted.

"The second point is you have to blow a lot of air to fluidize that bed of material. That requires a lot of energy. In a fertilizer plant, the cost to operate multiple 500 kW fans running at 8,000 hours a year at $0.10 per kilowatt hour is substantial."

The benefits of vertical indirect heat exchangers vs. direct-contact alternatives include a larger heat transfer area, smaller floor plate, lower energy costs and less environmental footprint.

With the ability to offer more heat transfer area in a smaller, modular design, vertical indirect plate exchangers have gained acceptance as a technology to efficiently and indirectly heat, cool or dry bulks solids.

"The initial thought was, 'Why couldn't a bulk solid pass through a sandwich of plates that had cooling water running inside?'" says



A bank of vertically arranged plates in the exchanger allows free-flowing bulk solids such as fertilizer, sugar and oilseeds to pass through while a separate stream such as water flows counter-currently within the plates. This allows for indirect heating, cooling or drying with the vertical plate heat exchanger. A discharge device at the bottom of the exchanger ensures uniform mass flow and consistent temperature profiles once material exits.

Jordison, noting the technology originated from within the Alberta fertilizer industry. "It was an original concept at that time."

So how does it all work? Or to be more specific, how does the heat transfer process function within vertical plate heat exchangers?

The Role of Time in Bulk Solids Heat Transfer

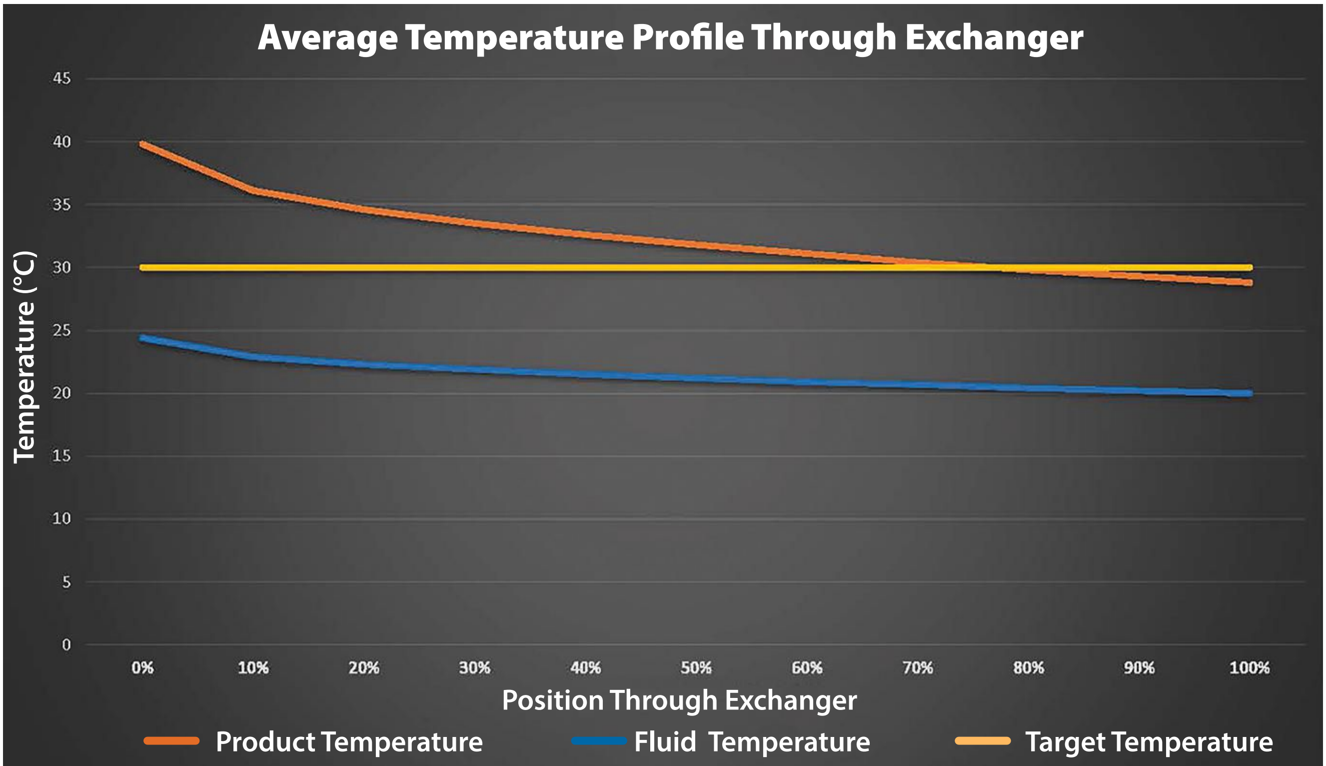
Starting with time, or T minutes, the measure of how long it takes for a bulk solid to pass through the plates factors significantly in the heat transfer process, says Jordison. "Think of it this way: We have a bulk solid that fills the space between the plates. That material then moves slowly down between the plates by gravity. What if I whistled it between the plates in three seconds?" he asks. "It's not going to heat or cool very much. If I coax the material down gently over five minutes, I'm going to get much better results."

Consider another scenario: A product is 212°F (100°C), and it needs to be cooled to 104°F (40°C) with 77°F (25°C) water running counter currently through the plates. If that product only spends a couple of seconds running past the cooling water, it will likely only decrease in temperature by a couple of degrees. But with a few minutes' residence time, the product has a better chance at coming out at the desired 104°F (40°C), Jordison added.

"Once I know the input, the desired output temperature of the solid particles, and the temperature of the cooling liquid, I can start to determine the amount of time that I'll need the particles to be between the plates," says Jordison.

Plate spacing factors into managing that time. For example, plates spaced farther apart are going to increase T minutes, while plates closer together will take less time. The standard plate distance in vertical exchangers for products such as urea granules, sugar crystals and plastic pellets ranges between 0.78 and 1.58" (20 to 40 mm).

Volume similarly affects plate spacing as well as size – and, by extension, time. For example, imagine needing to cool 100 tonnes per hour of urea granules from 212 to 104°F (100 to



In this cooling application, a product at 104°F (40°C) is fed into the top of exchanger with the target output of 86°F (30°C). At the same time, a fluid at 68°F (20°C) is fed counter-currently into the plates from the bottom. As the product passes through the exchanger, the temperature is uniformly decreased until the product reaches its target temperature.

40°C) with 77°F water. The plates will need to be close enough to not adversely affect uniform flow, notes Jordison, yet far enough that it does not negatively impact performance.

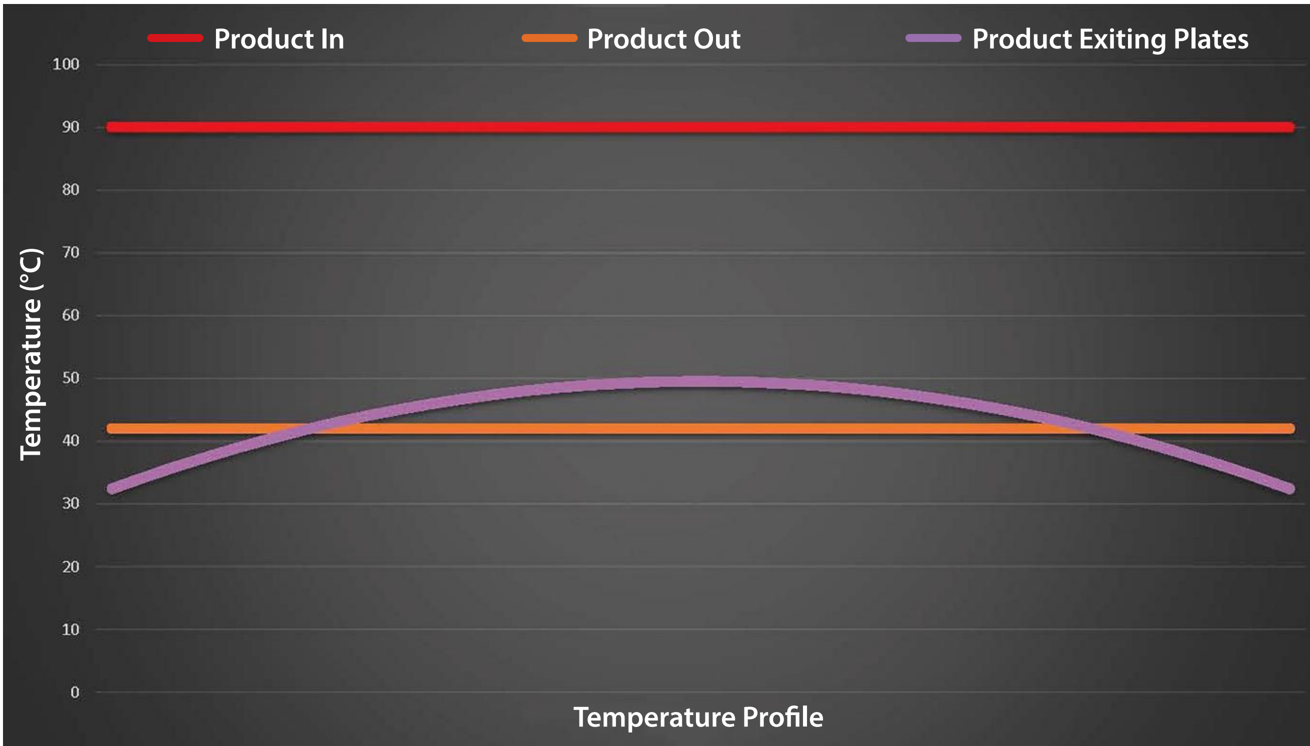
Product Properties Affect Heat Transfer

Product characteristics such as specific heat capacity and thermal conductivity also factor into determining the time a product needs to be in the exchanger. Specific heat is a key parameter because it is the measure of how much heat has to be removed in a cooler or added in a heater. The specific heat of most bulk solids is widely known; however, there may be an additional heat load to consider due to a crystal structure change or if there is a drying mechanism also taking place.

"Specific heat is also temperature dependent, generally increasing with temperature," says Jordison.

Thermal conductivity, meanwhile, is a measure of a material's ability to conduct heat. Materials with low thermal conductivity are better at insulating, or stopping heat transfer. Materials with high thermal conductivity tend to transfer heat more easily.

The thermal conductivity of a bulk material generally is not a reported material property. It will vary with particle size, shape and size distribution. As such, it needs to be measured using laboratory techniques that consider the variables.



In this cooling application, a product at an average temperature of 194°F (90°C) is fed to an exchanger with a target average output of 107°F (42°C). The curved line shows the temperature profile between the plates, with the coldest product against the plates and the warmest in the middle. As the product travels vertically through the exchanger, the curved line begins to flatten out to the target output temperature.

Jordison notes that the opportunity to get creative comes when putting these heat exchangers into practice. Just as in a plate heat exchanger, a vertical plate exchanger for bulk solids has a bank of plates assembled as a module. Recognizing that the product flows by gravity, multiple banks are assembled into a tower. As many as six or eight modules are stacked this way for large capacity installations. The design of the compact banks provides for better product flow and reduced floor space requirements.

A major difference between a heat exchanger for a liquid or gas, and one for bulk solids, is that in a liquid exchanger, the flow pattern is turbulent. This leads to high efficiency heat transfer. In a bulk-solids exchanger, there is no equivalent turbulent flow on the solids' side of the exchanger. The particles flow by gravity with no side-to-side movement.

"Bulk solids are also not good at sharing," says Jordison. "They tend to be stubborn when migrating heat from one particle to the next because of the insulating air space between the particles."

What this means is that particles against the heat transfer plate will rapidly approach the temperature of that medium while particles in the middle of the flow channel will heat or cool more slowly. To resolve this from an engineering perspective, offsetting vertical banks could be used. With such a design, the materials along the plates would drop into the middle of the channel in the next bank, and vice versa, until the material temperature is uniform at discharge.

Temperature profiles of the moving bed of particles can be plotted as the bed flows between the exchanger plates. Some manufacturers have proprietary thermal modeling software to analyze the temperature profiles as a product flows through the plates. Such software can help optimize the design of exchangers.

Uniform Mass Flow

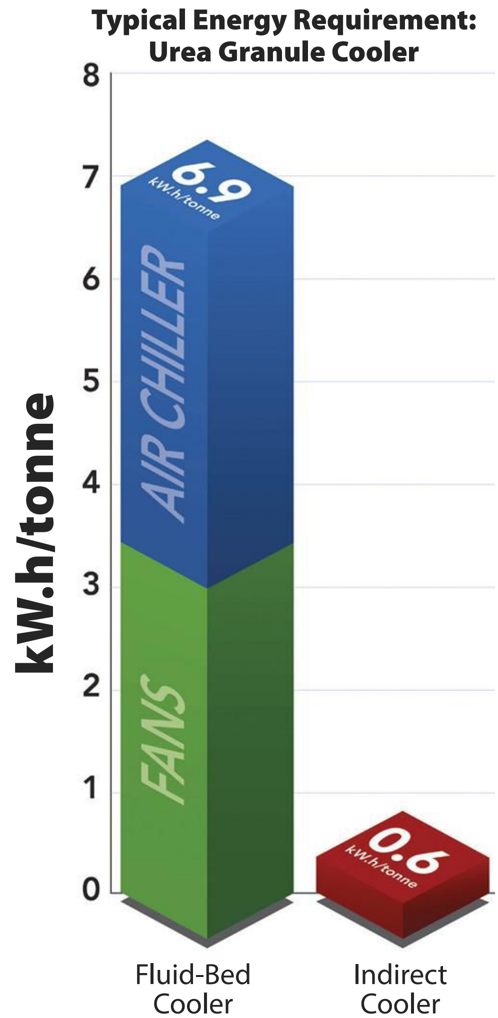
Lastly, uniform temperature depends on mass flow – or to be more specific, uniform mass flow. The bulk-solids industry tends to consider solids flow as being mass flow – where all the product is moving when taken out of the unit. Yet, by this definition, the product may not all be moving at the same velocity. This can create nonuniform heat transfer rates and, therefore, undesirable temperature variations in the discharging solids stream.

"In mass flow, all the particles could be moving, but they could be flowing faster and, for example, funneling in the center of the heat exchanger," says Ashley Byman, a process and technology specialist at Solex Thermal Science. "When that happens, it will impact the heat transfer performance and the ability to create consistent temperature profiles once the particles come out on the other end. Remember, time is important."

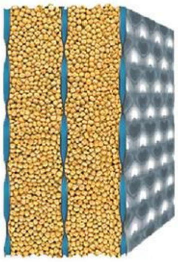
Uniform flow means all of the product is moving at the same velocity and, thus, all solid particles spend the same amount of time in the heat exchanger. The determining factor of when there is flow is whether the stresses are greater than the strength.

The stresses are due to gravity and the weight of the product above, otherwise called product head. The strength is the shear strength of the bulk solid – something that holds the solid particles together, which can be measured on a shear cell tester.

"Think of a sandcastle. If it has enough sheer strength, it will hold its shape," says Byman. "Yet if there's a stress acting on it – if the weight is great enough to overcome the strength – it will flow. It will break away from the walls and slide down."



In urea granule applications, indirect heat exchangers consume up to 90 percent less energy than direct-contact alternatives such as fluid beds. (Energy consumption based on estimated operating power requirements, typical for a 3,600 tonnes per day urea plant in a U.S. Gulf Coast location.)



In a vertical bulk-solids heat exchanger, material passes between the plates through gravity while a fluid runs counter-currently within the plates. A discharge device at the bottom helps to ensure uniform mass flow and a consistent output temperature.

A shear cell tester works by measuring the force required to move a cylindrical sample of material sideways over a surface of desired roughness, or over itself, with various consolidation pressures. This test helps determine the wall angles on the discharge hopper that are needed to obtain mass flow. These discharge devices can run the gamut from gate and vibrating to circle and screw feeders.

"If you want a high flow rate, you might use a discharge gate feeder," says Byman. "If you have high temperatures, a vibrating feeder is not a good choice because the motors cannot handle high temperatures. If there is any sort of air differential pressure in the system such as during drying, you need a rotary valve as the discharge feeder. If you have a horizontal distance to convey the product and you have a short height required, you would use a screw conveyor. The variables that will determine the discharge device that is best suited for the application are many."

Case In Point: Sugar Refinery

A sugar refinery in Sweden had increased production by 40 percent over a three-year period. At the increased production rate of 85 tonnes per hour, the cooling capacity of the plant's existing equipment was no longer adequate. As a result, the temperature of outgoing sugar had increased to between 95 and 104°F (35 and 40°C). This was a problem because the recommended temperature to prevent caking and maintain product quality in storage was 86°F (30°C) or lower.

Following a two-week pilot test, a vertical indirect plate cooler was installed. At full capacity, the equipment met or exceed the expected cooling duty. It cooled 85 tonnes per hour of sugar from 104 to 77°F (40 to 25°C) with cooling water supplied at 60.8°F (16°C).

Sugar quality was improved on three fronts:

- The relative humidity of the cooled sugar was lower than expected, which helped to prevent caking and improve quality. (Sugar absorbs water.)
- The cooler minimized abrasion and breaking, resulting in less sugar dust and a higher quality product.
- With the degree of cooling achieved, there was no caking or clumping, so no sugar was sent back to remelt.

With few moving parts and easy operation, maintenance costs are low. Also, with less than 100 kW installed electrical power (including new conveyors, dry cooler fans and cooling water pump associated with the cooler installation), operating costs were low. Lastly, given that the equipment did not use any air in contact with the sugar, there were no dust emissions that required additional equipment for removing the dust.

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