Vertical moving-bed heat exchangers can recover and utilize waste heat from the cooling or heating of bulk solids.

Bulk Solids Heat Transfer and Opportunities for Waste-Heat Recovery

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Photos credit: Solex Thermal Science

Moving-bed heat exchangers can help reduce the carbon footprint and energy costs of some process applications by capturing and repurposing heat that would otherwise be lost.

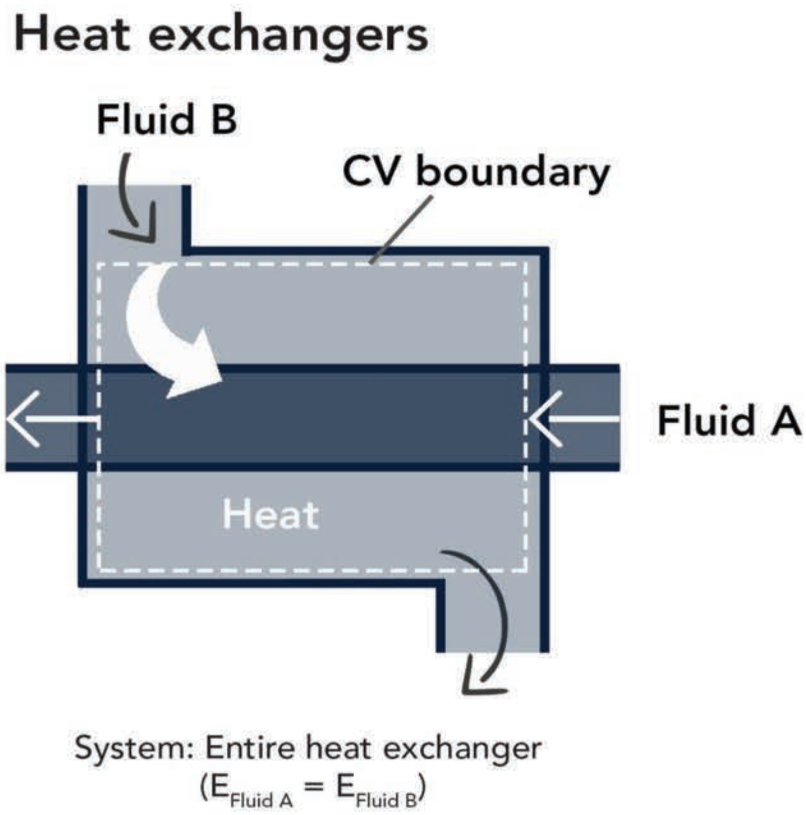
In many industrial processes, bulk granular solids undergo thermal treatment to meet or provide final product specifications. For example, calcination is a high temperature process that removes oxygen and volatiles to produce high quality cement and other refractory materials.

Yet, many of these processes also leave waste heat on the table. Take the slag resulting from metal production as an example. A significant heat input is required for the metal production process. As the slag is cooled from a molten material to a granular solid, a substantial amount of unused heat remains in the bulk solids — at temperatures ranging from 932 to 1,472°F (500 to 800°C). This energy is either wasted — as the hot piles of product are left to cool slowly on their own — or additional energy is spent to cool the product faster. In many cases, water is sprayed on the piles, and the energy is lost.

The concept of useful energy going to waste has become less acceptable in our modern global community because it is in direct opposition to increasingly prominent principles such as environmental, social and corporate governance (ESG). ESG principles reflect the work of businesses, industries and communities to replace energy-intensive and often environmentally unfriendly processes with new ways to achieve the efficient utilization of the primary energy spent while minimizing negative impacts.

Bulk solids heat exchangers, also referred to as moving-bed heat exchangers (MBHE), have been in use for several decades. Waste-heat recovery is driving their use as a technology that can recover thermal energy from granular solids and make it available for reuse in multiple ways. For example, the heat from bulk solids can be exchanged to other working fluids such as water, steam, thermal oil, air or even supercritical carbon dioxide (sCO_2). This exchange allows the thermal energy to be used in other processes in the plant. Or, in cases where the recovered waste heat cannot be used in the production or manufacturing process, the energy recovered above temperatures of 752°F (400°C) can be used to generate electricity in steam or gas turbines, organic Rankine cycles (ORC) and sCO_2 cycles. Even the low grade heat left over from electricity generation can be used to heat other areas of the plant or operate absorption chillers that generate cold (chilled) water. In some scenarios, the low grade heat can be supplied to a plant- or district-heating network.

Before going any further, however, it is important to understand some of the terms and technologies used in these processes.



Heat exchangers are devices in which moving fluid streams exchange energy without mixing.

Overview: Bulk Solids and Heat Transfer

Terms such as "heat transfer" and "waste-heat recovery" are clear to most. Yet, the same cannot be said for "bulk solids." Bulk solids, by definition, are an accumulation of loose and mainly dry particles. These materials make up more than 80 percent of the items transported around the world. In fact, each of us handles bulk solids daily, whether that be using table salt, sugar, flour, pepper or pet food.

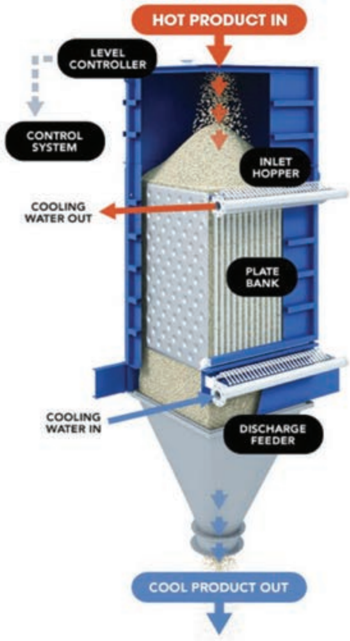
At a wider perspective, bulk solids include everything from oilseeds, grains and minerals to chemicals, plastics, cement, metals and sand. The individual materials can vary in shape and size, and they can be in the form of powders, granules, particles, tablets, pellets and crystals.

Before many bulk solids end up as a final product such as sugar, they typically move through a number of processing steps that involve heating, cooling or drying. This then requires some form of heat transfer in a heat exchanger.

Conventional technologies for heat exchange from bulk solids include fluid beds, rotary drums and fixed- or moving-bed heat exchangers. For fluid-bed and rotary-drum technologies, the heat transfer media, or working fluid, is in direct contact with the solids.

While heat exchangers used to be limited to "a component that allows the transfer of heat from one fluid (liquid or gas) to another fluid," indirect bulk-solids heat exchangers that allow heat transfer between solids and fluids (liquid or gas) have become commonly available.

For indirect bulk-solids heat exchangers, the heat exchange is realized by conduction across the surface of plates or tubes. There is no contact between the solids and the working fluid within the moving-bed heat exchanger while the granular solids flow by gravity through the unit. The arrangement is comparable to a silo that is continuously fed and discharged. In principle, the plates can be heated or cooled with any heat transfer media, including water, thermal oil and steam. The indirect bulk-solids heat exchanger does not include any moving parts besides the discharge device. The discharge device ensures uniform mass flow and, as such, consistent heating or cooling of the solids.



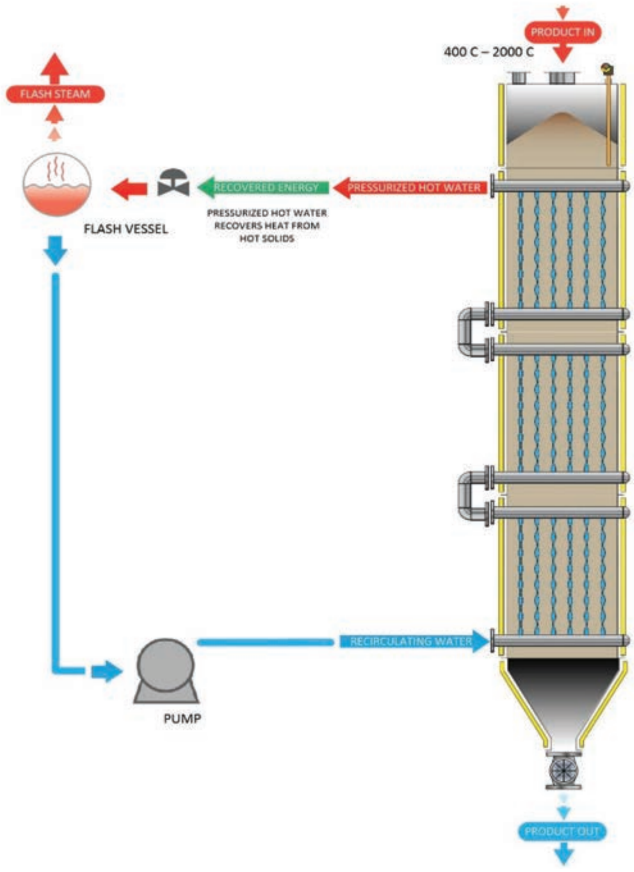
Indirect bulk-solids heat exchangers use conduction, meaning there is no contact between the solids and the working fluid as the granular solids flow by gravity through the unit.

Waste-Heat Utilization by Heating Bulk Solids

The opportunities that exist with waste heat are not limited to use for processes in other parts of the plant. Sometimes, the heat recovered from the hot product or airstream at the discharge from a thermal processing step such as a calciner can be looped back to preheat the feed material entering the thermal processor. By capturing and reusing the energy, the thermal efficiency of this processing step can be improved greatly. It also may help to debottleneck this piece of equipment.

This energy-recovery approach is common in the oilseeds industry. The cold seeds are heated with waste heat coming from vapors generated during the cooking process, or from steam condensate or flash steam coming from other processes. For this preheating step, the oilseeds are heated from ambient temperature to the desired processing conditions — typically between 140 and 194°F (60 and 90°C). This reduces the overall energy consumption for preheating, providing a good return on investment for the installation a MBHE.

Also, it is possible to recover the thermal energy from cooling bulk solids and use it in another process step where bulk solids need to be heated. In many process applications, the temperature levels and heat loads do not match. By integrating heat pumps into the system, the desired temperature levels on the hot or cold side of the system can be adjusted to meet the desired process conditions on both ends. For this option — and depending on the exact temperatures — heat pump systems have coefficients of performance (COPs) well above two. As a result, they can provide a highly efficient double-acting energy boost: reducing the temperature on the cold side and increasing the temperature on the hot side.



A common energy-recovery loop design for cooling high temperature bulk solids such as ash, petroleum coke or graphite is shown.

Efficiency of Bulk Solid Heat Transfer

The heat balance around any heat exchanger is straightforward: the amount of thermal energy that enters a bulk-solids heat exchanger is the same amount of thermal energy that leaves it. So, if the heat exchanger is perfectly insulated, the heat transfer efficiency, or thermal efficiency, is perfect.

Consequently, the only way the thermal efficiency is less than perfect is through heat losses via the casing or shell. This is influenced by the amount of insulation that is put around the exchanger.

The tipping point — or effectiveness of the heat transfer — is the amount of energy that can be transferred from or to the solids, and to or from the working fluid. No different than in any other heat exchanger, it is the heat transfer surface area that defines the amount of energy that is transferred (along with the effectiveness of heat transfer across the surface). As such, indirect bulk-solids heat exchangers typically are configured for counterflow heat transfer to maximize heat transfer effectiveness.

An important consideration in evaluating efficiency is the temperature difference that can be achieved between the solids and the working fluid. To illustrate, suppose low temperature heaters or coolers are operating with product inlet temperatures of 302 to 392°F (150 to 200°C) or below. The temperature difference between the solids and the working fluid typically will be between 18 and 27°F (10 and 15°C).

For applications where the product temperature is 752°F (400°C) and above, the difference in the working fluid temperature typically will be around 90 to 180°F (50 to 100°C), but it can be much higher. For example, if water is used to cool granules that are entering the heat exchanger at 1832°F (1,000°C), the temperature differential with the water can easily be 1440°F (800°C).

To achieve the desired outcomes for any bulk-solid heat exchange process, careful consideration is essential when sizing the heat exchanger. In addition, relevant technical demands as well as economic feasibility and return on investment must be taken into consideration.

In an oilseeds installation, three heat recovery loops are used to recover waste heat and recirculate it to preheat the seeds.

Example: Energy Recovery Feasibility

So, when is energy recovery feasible? There is no general answer to this, but a quick example can illustrate the potential savings around primary energy costs.

Consider a waste-heat stream of about 100,000 kcal/hr (~120 kW) that can be recovered from bulk solids cooling. Utilizing the waste heat from a production plant that is operating continuously for approximately 320 days a year would result in about 780 gcal/hr (920 MWh) of available energy.

Depending on the primary energy source, the cost for energy will vary. However, considering an average cost for energy of around $0.05 for 1 mcal/h (0,042 €/kWh), utilizing the available energy would result in a direct cost savings for the plant's energy bill of $46,000 (39.000€) per year. These figures easily can be multiplied to get a feeling for larger plants and the corresponding savings.

In addition to monetary savings, there is a very real environmental component of utilizing waste heat. By reducing the input — particularly when the input energy is generated from fossil fuels — there is also a considerable impact on the reduction of greenhouse gas emissions.

Take again the example above and consider that the primary energy being replaced is from oil or natural gas. The greenhouse gas emission reduction is around 500 tonnes of carbon dioxide per year.

In conclusion, moving-bed heat exchangers, or MBHEs, are a proven technology; however, their full potential has not yet been realized in all production processes. Technologies like this can effectively recover and utilize waste heat either from the cooling or heating of bulk solids.

About the Author

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