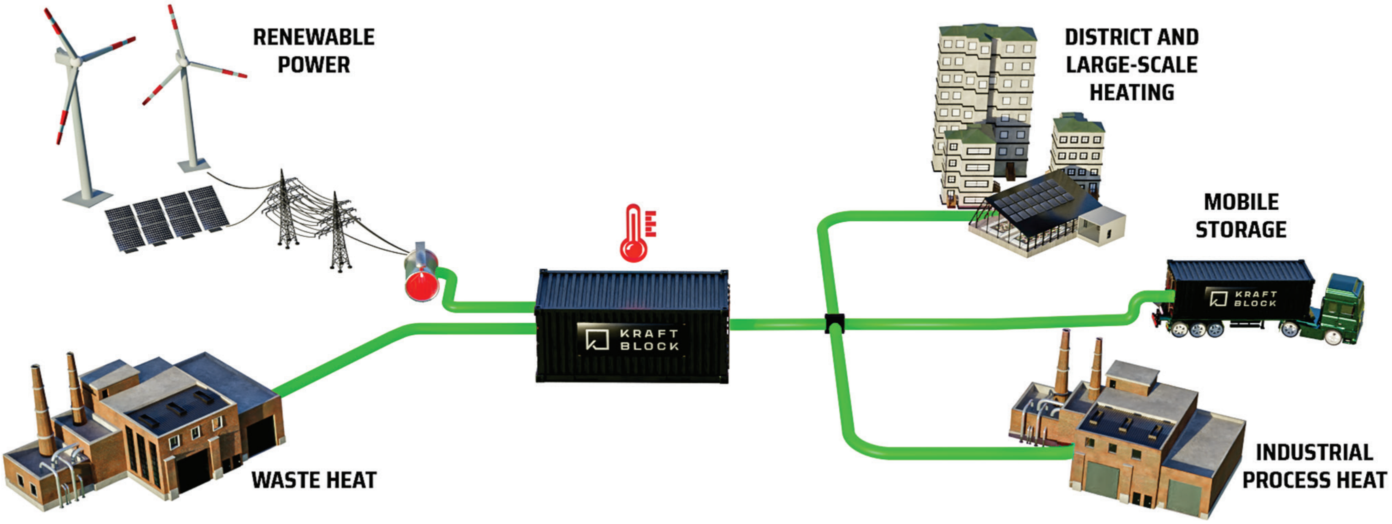


Credit: Kraftblock

Figure 1. Kraftblock's high-temperature heat storage system is widely applicable to numerous thermal processing industries.

Value-add of thermal energy storage systems in the ceramics industry

By Martin Schichtel

Kraftblock (Sulzbach, Germany) has developed a widely applicable high-temperature thermal energy storage system that could help reduce emissions in the ceramics industry.

Thermal energy accounts for approximately 45% of global-energy-related CO_2 emissions worldwide. Specifically, 20% of these emissions comes from industrial heat.[1]

The ceramics industry significantly contributes to these emissions. Each year, the energy consumption for firing ceramics using natural gas is approximately 182 TWh.[2] At an average CO_2 release rate of 0.22t/MWh, this firing results in roughly 40 million tons of carbon dioxide emission every year. As wealth increases and more countries industrialize, a study by the Long Duration Energy Storage Council estimates industrial heat generation will increase by up to 60% by 2050, resulting in even higher levels of emissions.[1]

Since the 1980s, ceramic and glass manufacturers have dedicated themselves to reducing energy consumption.[3] While alternative fuels and heat generation sources are being explored, at present, harnessing waste heat is the most immediately accessible approach to improving efficiency and reducing emissions.

Technologies to improve energy efficiency

Currently, there are two main approaches to achieving a highly efficient combustion process. The first approach uses high-pulse (or high-speed) burners. These burners greatly increase the turbulence inside a furnace by directly returning hot gases back into the combustion chamber via high outflow speeds. The second approach simply uses pure oxygen instead of ambient air for the combustion process, which results in a reduced volume flow and thereby reduced exhaust gas losses. But the energy used for the combustion is still a fossil fuel, resulting in undesirable emissions.

In the last few decades, several components and processes were developed to further improve the efficiency of thermal systems by utilizing waste heat to provide power, refrigeration, and process heat.[4]

Regarding power usages, thermal energy from flue gases can be converted into electricity using thermoelectric, piezoelectric, or thermal photovoltaic technology. Most existing heat-to-electricity conversion systems are used to power sensors or smaller control units. Depending on the quantity and quality of heat, external systems such as Stirling engines, Kalina systems, and organic Rankine cycle engines can convert 5–15% of the heat into electricity. Such systems work well for up to 2 MW of waste heat power. If more waste heat is available, especially at higher temperatures, electrical power is generated by steam turbines with efficiencies between 20% and 45%.

Absorption or adsorption chillers are used to feed a refrigerating or cooling system. Such chillers are comparable to vapor compression cycles. Typically, the electric motor and compressors are replaced by a thermal compressor system, so that thermal energy is used instead of mechanical energy. These types of chillers use lithium bromide for space conditioning, or a mixture of water and ammonia for other applications, such as warehouses, cooling chambers, and so on.[5]

To use thermal energy as heat, heat exchangers, heat pumps, and thermal storage systems are the technologies of choice. The well-known recuperative and regenerative burners, which directly reuse heat from flue gases to preheat the combustion air, are currently the best use of waste heat because they offer the highest efficiencies. These latter systems comprise a type of intermediate thermal energy storage system.

For other processes, heat exchangers transfer thermal energy from the flue gas to pure air, thermal oil, steam, or simply hot water. The efficiency is determined by the surface area, the transfer coefficient, and the temperature of the receiving media. Typical structures for heat exchangers are pipe bundle, plate, double pipe, lamella, spiral, fin-tube, or even rotational heat exchangers.

Heat exchangers face several drawbacks that hinder their usage in the ceramics industry. For one, all types of heat exchangers are generally limited to an upper operation temperature of 700–800°C. Systems that can withstand even higher temperature are costly and rarely found in application.

Besides a limited temperature range, heat exchanger performance is frequently affected by contamination in the combustion air. Burning fossil fuels in ambient air results in various contaminations, such as carbon monoxide, nitrogen oxides, and carbon black, as well as several ashes. These “solid-state” contaminants might stick to the surface of the heat exchanger or even block the interconnection. Additionally, flue gases in the ceramic and glass industry can be contaminated by fluorine, sulphur, boron, lead, and other substances. In combination with often present humidity, these contaminates frequently cause corrosion problems.

According to a study by the French-German Institute for Environmental Research,[6] contamination from flue gases depends strongly on the type of ceramic being produced. Sintering of roofing tiles released the highest quantity of fluorine (up to 120 mg/m^3), followed by refractories, floor tiles, sanitaryware, and porcelain. Similar results were found for ammonia (refractories was highest, up to 2,500 mg/m^3) or organic contamination (up to 250 mg/m^3 for floor tiles or grinding materials). All these measurements are related to heat production and utilization.

Instead of heat exchangers, a thermal energy storage system developed by Kraftblock (Sulzbach, Germany) offers a more effective way of using waste heat in the ceramics industry (Figure 1).

Kraftblock’s thermal energy storage system

Kraftblock has developed a widely applicable high-temperature thermal energy storage system that can store thermal energy up to 1,300°C. It includes all necessary components needed to operate a storage unit, such as state-of-the-art charging and discharging units that are designed on a project-by-project basis. This customized design approach makes it possible to serve a wide range of thermal processing industries with the same basic storage unit, from batch processes to continuously running systems.

The thermal energy stored in Kraftblock’s system is stored between 350°C and 1,300°C. Up to 1.2 MWh of thermal energy can be stored per cubic meter of filling. This energy can be used for different applications, including

- Process heat (also with other heat transfer media),
- Refrigeration (adsorption or absorption chillers),
- Compressed air generation,
- Electricity generation (or as support for existing organic ranking cycle engines), and
- Feeding into heat networks.

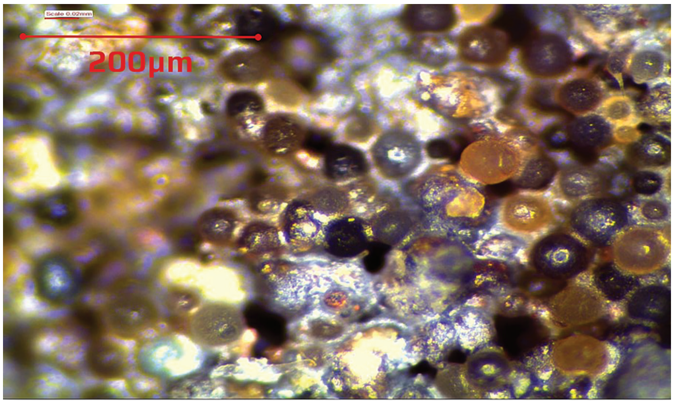
This wide range of applications is made possible by, among other things, the specially developed storage material (Figure 2). The storage material was developed according to many sustainability criteria and contains up to 85% recycled materials.

Steel slag is a main component of Kraftblock’s storage material. The usage of steel slag to store thermal energy is not a new idea. The European Union Slagstock project already showed that steel slags can be used to store thermal energy.[7]

In the Slagstock project, pure slag (1–3 cm diameter) was charged by molten salt (T_{max} = 560°C) and exhibited a not-well-

Credit: Kraftblock

Figure 2. Kraftblock heat storage granules.



Credit: Kraftblock

Figure 3. Microscopic view into the storage material.

defined charging and discharging behavior. Due to a low heat conductivity (less than 0.8 W/mK), a lagging effect was observed. In other words, when a higher temperature from the core of the particles in the first slag layer was discharged, it caused particles in the second slag layer to partially charge again. This process resulted in a very inefficient cycle behavior. The lagging effect was even worse when air was used as the heat transfer media due to the different fluid dynamics of gases and liquids.

In the Kraftblock system, the steel slag acts as a capacity filler. It gets milled down to less than 200 µm to reduce the latency in the heat transfer. At this point, the conductivity still is rather low (less than 0.8 W/mK), and so the Kraftblock team combined the slag powder with an inorganic phosphate binder.

Phosphate binders, specifically monoaluminium phosphate, are well known in the refractory industry. This material also is used as a highly conductive protective coating for graphite electrodes in aluminum melts. In all cases, the "binder" must be sintered above the expected application temperature. The phosphate binder undergoes a chemical reaction that causes it to harden during the materials production process; so, all thermal granule production takes place at room temperature.

The round-shaped grains in Figure 3 are the milled slag particles, while the intergranular white layers are the hardened phosphatic binder, which transports the heat into the core of the storage pellets. There is even a protective layer of phosphate on the outer shell of the pellets, which provides high stability against chemical corrosion, especially during the condensation phase of the process. Overall, this composition makes the Kraftblock storage material completely stable, both thermally and chemically.

The storage material is placed into modular storage containers, generally 10 or 20 feet wide. Individual storage modules can be delivered as "turn-key" systems and can also be used as mobile heat storage units. This approach proves useful in two cases:

1. There is so much waste heat that the potential cannot be used internally in the plant. In this case, the "recycled" waste heat can be sold to external third parties.

2. Heat source and sink are located so far apart in the plant that laying pipe systems is too complex, expensive, and/or comes with big losses. In this case, mobile storage units can move the heat within the plant.

Credit: Kraftblock

Figure 4. Example of a 10-foot Kraftblock storage that can store 4.2 MWh of waste heat at a max 600°C.

A third argument for a modular high-temperature storage system is scalability. Modules can be interconnected to build stationary "large-scale" storage systems—which can even be expanded with additional modules in a second stage.

Ideally, heat is taken directly from the flue gas and transferred to the material. In this case, the storage unit is integrated into the waste heat system as a "bypass"—if possible, without a heat exchanger. The cooled flue gas is fed back into the actual process at a suitable point, which is why the system can usually comply with all environmental regulations. The same applies to decoupling of the heat into the useful process, as this step is done by connecting a suitable heat exchanger. Variants are possible here. Of course, exhaust gas values—particularly dust load, sulphur, nitrogen oxides, and fluorine content—are accounted for during concept development.

Application examples

A simple example of an application for the Kraftblock system is its use as an external recuperator or regenerator with better storage properties. In this case, a waste heat output of approximately 500 kW at a usable temperature level of about 600°C is available from a gas-fired batch furnace, according to combustion calculations. Thus, during the heating and soak phases, about 4 MWh of waste heat can be stored.

Based on these parameters, a small 10-foot system (Figure 4) can be charged and discharged at a rate of 1 MW per hour (i.e., it will take 4 hours to reach maximum storage capacity). An additional suction-pull blower, coupled to the furnace control system, adjusts the delivery pressure accordingly. After loading of the storage tank is completed (during the soak phase or beginning of the cooling phase of the furnace), the heat is retained until the next furnace run.

During discharging, the furnace chamber is preheated to 300°C. The remaining storage energy is used to generate heat and process water, which corresponds to cascading heat utilization. Thus, the primary energy demand for the kiln plus heating water can be reduced by about 20%, and up to 30% of CO_2 generation can be avoided.

Depending on local conditions, the stored energy could first be used to support or completely replace the heating system for the drying process. This three-way cascade makes efficiency considerations and potential savings even more interesting. Plus, this type of storage can be used to transport heat to a remote location as well. “Waste heat” gains commercial value by selling to third parties.

A good alternative to decarbonizing a process is the complete electrification of heat. In this case, the fossil-fired system is replaced with a combined power-to-heat and thermal storage system. The power-to-heat system converts electricity—preferably generated from renewable sources—to heat. Ideally, this conversion only takes place for three to four hours every day when prices are low. From this point on, the stored heat could discharge up to 24/7.

For low-temperature applications, PepsiCo is building such a system in the Netherlands with Kraftblock and Dutch energy supplier Eneco.[8] This system, which should be operational by the end of 2023, will replace a fossil-fired boiler used to make deep fried snacks.

These applications and the possible combination of multiple technologies show the potential of high-temperature thermal energy storage systems to help the ceramics industry become more sustainable and efficient in the future.

About the author

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