Development of a Rapid Cooling Kiln with Stable Operation in Anhydrous Gypsum Production Facility

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Abstract:

Gypsum board is excellent in fire resistance, sound insulation, and dimensional stability, and is widely used as a building material. In recent years, a large amount of waste gypsum board (hereinafter referred to as waste gypsum board) has been generated due to the demolition of old buildings, and this amount is anticipated to increase in the future. Consequently, effective utilization methods such as reuse have been researched. In 2014, our company developed and launched a facility for producing anhydrous gypsum from waste gypsum board, as anhydrous gypsum is commonly used as a cement setting retarder. However, the process of cooling anhydrous gypsum in a system in the facility considerably damages the system, requiring frequent repairs. To address this issue, we have developed an indirect-type cooling kiln with improved cooling capacity and durability and began operating it. This paper reports the outline and features of the kiln.

1. Introduction

Gypsum board contains about 20% crystal water in a stable form, which gives it excellent fire resistance, sound insulation, dimensional stability, and ease of construction. Gypsum board has been widely used in buildings such as ordinary houses and office buildings since it was first used for the interior and ceiling of the former Imperial Hotel in 1923. In particular, wooden buildings in Japan have a service life of about 20 years, which is shorter than that of buildings in Europe and the United States, and the frequent demolition of old buildings generates a large amount of waste gypsum board, increasing the amount of waste gypsum board year by year[1)2)]. Referring to the fact that the annual shipment of gypsum boards has reached 4 million tons, it is now predicted that the amount of waste gypsum board generated will soon approach the value. As a result, there is concern that the final disposal sites in local governments will become overburdened, and the rising disposal costs will lead to social problems such as illegal dumping.

Japan has achieved economic growth under a social system of mass production, mass consumption, and mass waste. In recent years, additional social issues such as resource depletion and environmental destruction have emerged. For these reasons, there is a strong demand for recycling waste gypsum boards and using them effectively, for example, as agricultural fertilizers and civil engineering and construction materials, for which large demand is expected.

Against this backdrop, our company has developed an anhydrous gypsum production facility that can recycle waste gypsum boards in large quantities as a raw material for cement. This anhydrous gypsum production facility was constructed based on the principle of generating anhydrous gypsum by heating waste gypsum, which is gypsum dihydrate, to 1,000°C, and thermally eliminating the water of crystallization. This high-temperature anhydrous gypsum is then cooled to 200°C using a screw-type cooling system. Unfortunately, the high-temperature anhydrous gypsum has caused significant thermal damage to the cooling system, necessitating frequent repairs and maintenance.

To address these issues, we have developed a new indirect-kiln-type cooling system with improved

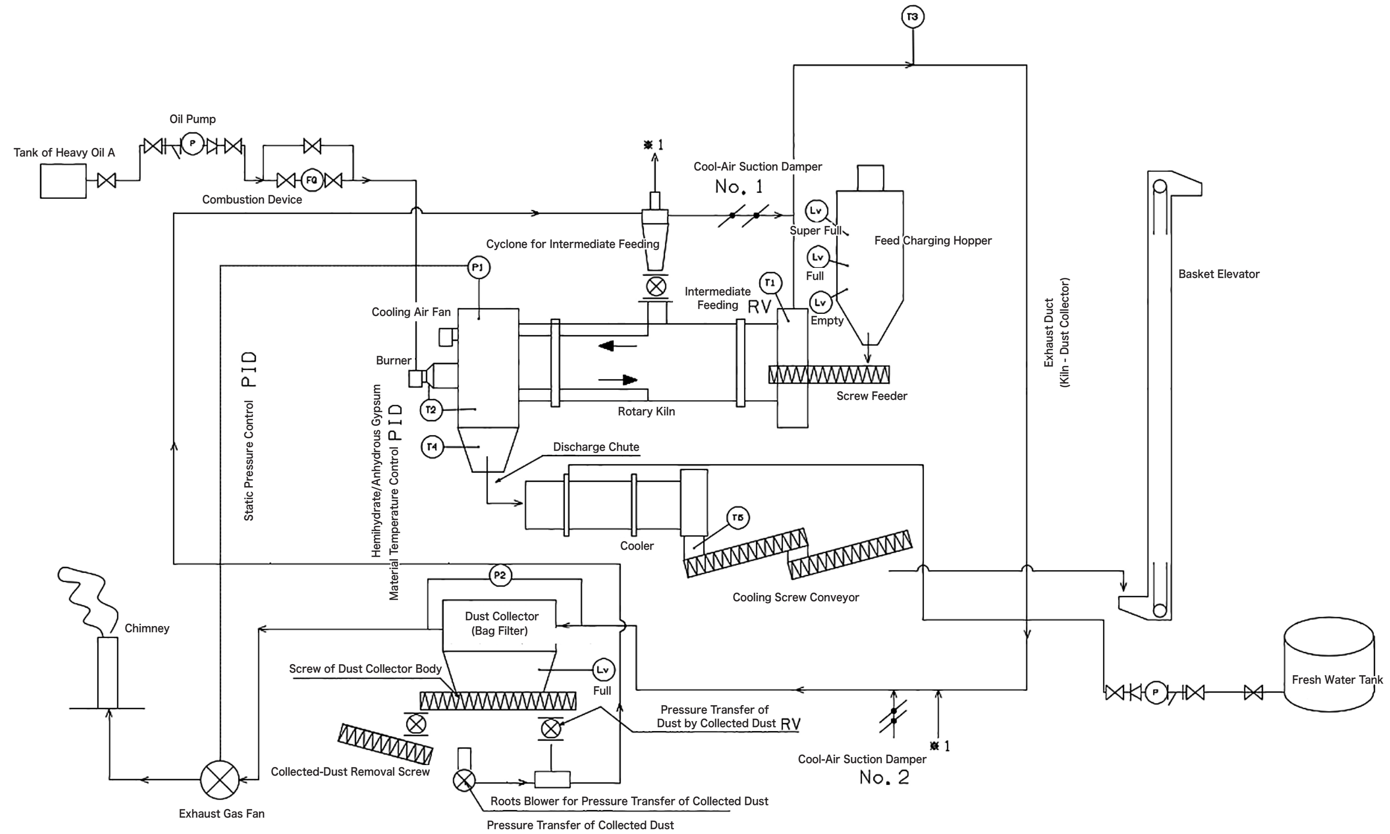

Figure 2-1: System Flow Diagram in Facility for Type-II Anhydrous Gypsum

durability and maintainability and have put it into operation. In this paper, we report the outline and features of the new system.

2. Gypsum

Gypsum is a mineral whose main component is calcium sulfate and is divided into three types: gypsum dihydrate ($CaSO_4 \cdot 2H_2O$: calcium sulfate dihydrate), gypsum hemihydrate ($CaSO_4 \cdot 1/2H_2O$: calcium sulfate 1/2 hydrate), and gypsum anhydrite ($CaSO_4$: calcium sulfate). Gypsum hemihydrate is divided into alpha and beta types, while anhydrous gypsum is divided into types III, II, and I. Type III further consists of alpha and beta forms. Of these, we will describe gypsum hemihydrate and anhydrous gypsum[3)].

2.1 Gypsum Hemihydrate

Gypsum hemihydrate, also called calcined gypsum, exists in α-type and β-type as mentioned above. The α-type has a dense structure and high grain density and is stronger when hardened than the β-type. Due to these properties, the α-type is used for medical purposes including plaster which is a treatment tool for fractures. The α-type is produced by pressurized firing, generally through steaming in an autoclave (pressure cooker), making it difficult to produce it using a kiln. The β-type is porous, has a smaller grain density than the α-type, and is used as a building material for gypsum boards and similar applications. Unlike the α-type, the β-type does not require pressurization, making its production possible with a kiln. In addition, by heating gypsum hemihydrate at 180°C or higher, it is possible to produce anhydrous gypsum, in which the water of crystallization has been thermally removed[4)].

In recent years, gypsum hemihydrate has been increasingly used as a soil conditioner, due to its hydraulic properties, by mixing it with cement as an additive. However, gypsum hemihydrate is highly hygroscopic and absorbs moisture from the atmosphere, returning to gypsum dihydrate.

Photo 2-1: Facility for Producing Type-II Anhydrous Gypsum

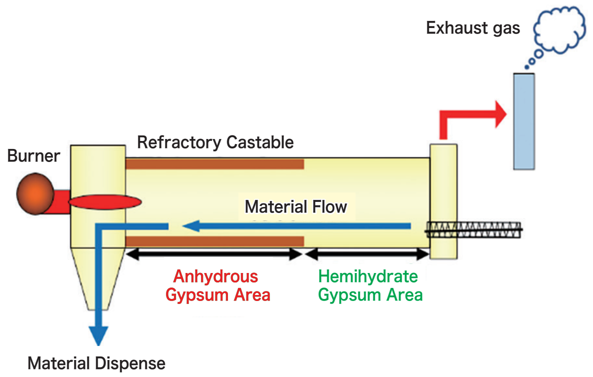

Figure 2-2: Inside of Sintering Kiln

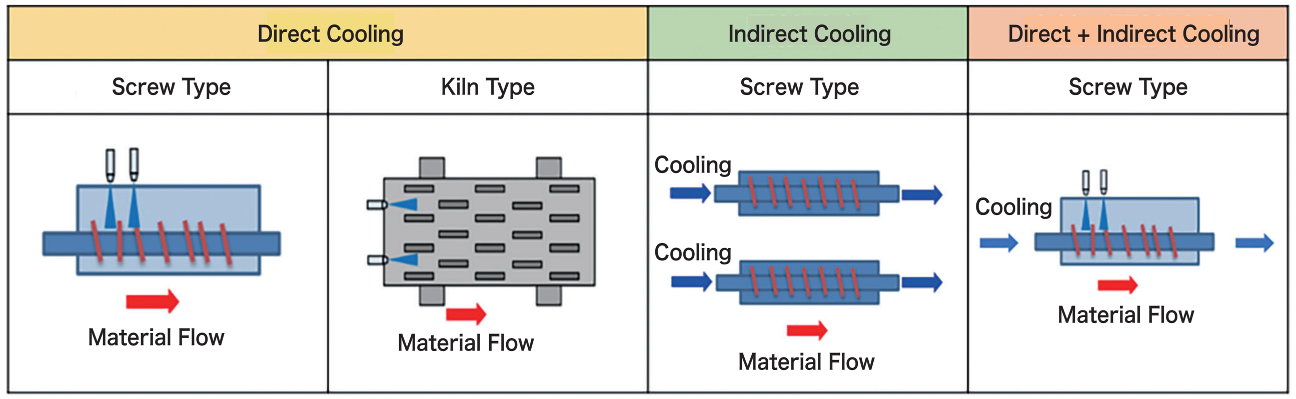

Figure 2-3: List of Conventional Cooling Techniques

Therefore, quality control of gypsum hemihydrate is difficult, and gypsum hemihydrate is recommended to be used immediately after production[5].

2.2 Anhydrous Gypsum

As mentioned above, there are three types of anhydrous gypsum: type III, type II, and type I. Type III is further classified into type α and type β. Type III anhydrous gypsum is produced by heating at temperatures between 180 and 215°C and absorbs moisture from the air to return to gypsum hemihydrate. Due to its hygroscopicity, it is used as a drying agent for paints and resins, for example. Type II anhydrous gypsum is obtained by heating at 330°C or higher and is also called inactive anhydrous gypsum because it does not return to hemihydrate even when water is added. These properties allow it to be stored for a long period and to be produced and stored in the amount required. Thus, Type II anhydrous gypsum has room for operational adjustments. Type I anhydrous gypsum is produced by heating at 1180°C or higher. Both types II and I are not hygroscopic, and they are widely used in building materials as construction fillers[4].

3. Facility for producing Type II Anhydrous Gypsum

Our anhydrous gypsum production facility is equipped with a dry heating area and a calcination area. Once the material enters the facility, it flows in one direction, first being processed into gypsum hemihydrate and ultimately discharged as anhydrous gypsum.

The system flow diagram is shown in **Figure 2-1**, and an overall view of the facility is shown in **Photo 2-1**.

With reference to **Figure 2-1**, we describe the flow in the facility to produce Type II anhydrite gypsum. First, the material is fed through a feeding screw into the calcination kiln, where the material is dried, heated, and calcined. When the material reaches

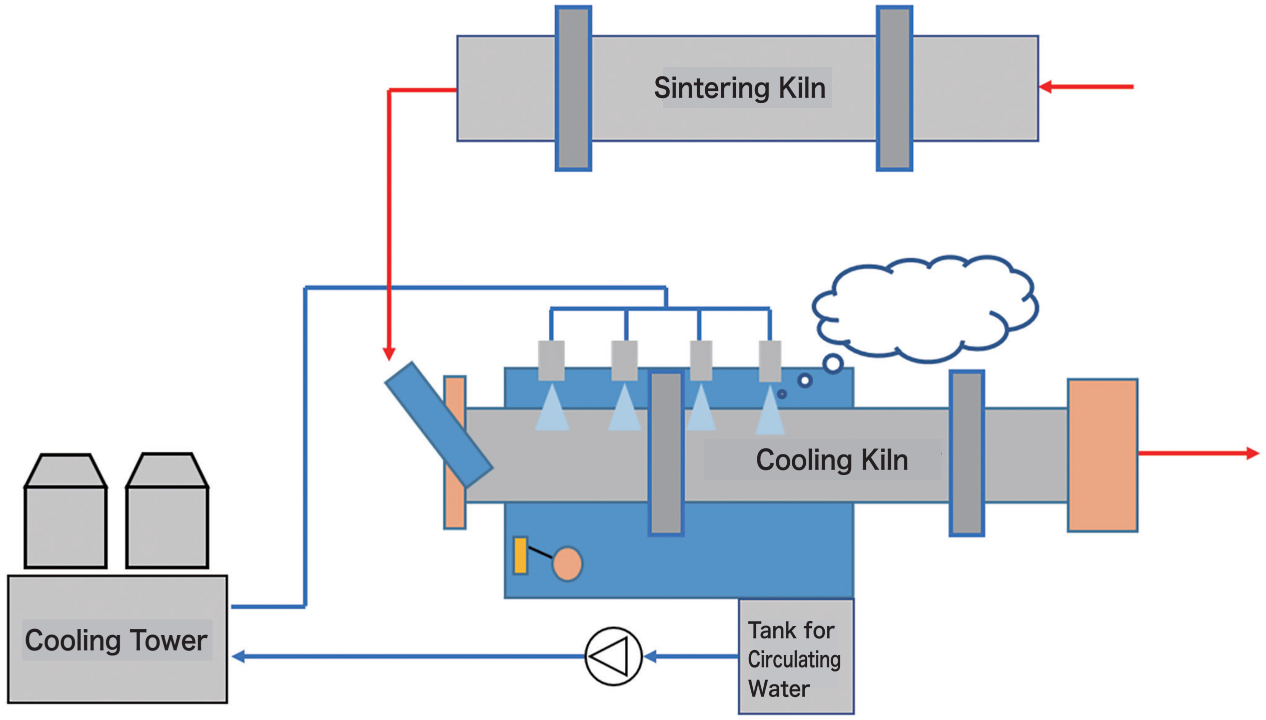

Figure 3-1: Flow Diagram of Indirect-Cooling Kiln Technique

1000°C, it passes through a discharge chute and is fed into the cooling system. Ancillary equipment is located downstream of the cooling system, and the material is cooled to below the heat resistance temperature of each piece of equipment, 200°C, to prevent thermal damage to the ancillary equipment. The cooled material passes through a screw and is sent to an elevator at the end of the flow.

3.1 Sintering kiln

Figure 2-2 shows the inside of a sintering kiln, with a material being fed from the right of the figure. The drying-heating area is provided with a lifter to produce gypsum hemihydrate. In this area, the material is scraped up for free fall to be dispersed in a veil shape to increase the surface area. This allows the surface water to dry in a short period, and the material to be heated to 180°C, thereby efficiently producing gypsum hemihydrate.

In the sintering area where anhydrous gypsum is produced, the refractory castable is heated by the hot air from the burner combustion and the radiant heat from the flame. Then, the hemihydrate that has undergone the drying-heating area passes through the space with the burner flame and the heat-stored refractory castable. As a result, the hemihydrate is heated to 1000°C to be anhydrous gypsum.

3.2 Cooling System

3.2.1 Conventional techniques

Our company has adopted four types of cooling techniques so far. Each of them has its own advantages and disadvantages. These techniques are selected for use based on the heating temperature range of the target material and the system configurations. Hereinafter, we will describe the features of the conventional cooling techniques, as listed in **Figure 2-3**.

(1) Direct Cooling Technique

The direct cooling technique we have adopted includes a screw type and a kiln type, as shown in **Figure 2-3**. In both types, water is sprayed directly through a nozzle onto the material inside the screw or kiln.

The advantages of these types include the full use of the sensible and latent heat of water and the fact that they do not need a cooling tower or similar equipment to control the temperature of the cooling water. Furthermore, the mechanical

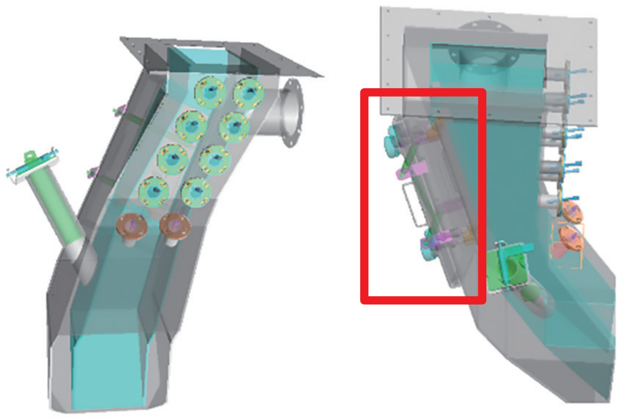

Figure 3-2: A 3D Model of Feeding Chute

Photo 3-1: Cooling Kiln

structures used facilitate maintenance.

Their disadvantages include that the direct spraying of water may cause the water to adhere to gypsum when it condenses and that the water reacts with sulfur oxides that are produced by the thermal decomposition of gypsum to produce sulfuric acid, which can cause severe corrosion inside the flue and equipment. In particular, in the kiln type, the material is dispersed inside and the surface area is increased so that the sprayed water can come into contact with the entire material. As a result, the heat exchange conditions may vary depending on the grain size and the dispersed state of the material. The adverse effect is even more pronounced when the grain size distribution of the material changes. If a material that has drastically changed in physical shape is used, troubles due to adhesion can occur.

(2) Indirect Cooling Technique

The indirect-cooling technique with a screw we have adopted is a technique of indirectly cooling the material by circulating water through a double-structure screw shaft and a jacketed screw trough.

The advantages include that, since the material does not come into contact with water vapor, no deterioration of the material occurs due to water vapor.

The disadvantages include that, since the material is cooled indirectly through the steel material, the latent heat of the water cannot be fully used for cooling, requiring a larger amount of water than for direct cooling. In addition, the water is reused by being cooled in a cooler, and thus the water-circulation path can be complex and the installation area of the path can be large. In this technique, the heat exchange between the material and the steel material matters, and the contact area and heat transfer coefficient therebetween affect the cooling efficiency.

(3) Direct + Indirect Cooling Technique

The direct + indirect cooling technique we have adopted is a technique that uses both indirect cooling and direct cooling. In the direct cooling, water runs through the hollow portion between a jacket and a shaft of a double-structured screw, while in the direct cooling, water is sprayed directly onto the product.

The advantages include that, by using both direct and indirect cooling, cooling can be completed in a shorter period than with a screw for indirect cooling, and that the latent heat of water is used, thereby reducing the size of the system.

The disadvantages include that the system is subject to heat damage and other effects from both direct and indirect cooling, leading to its low durability. In addition, the installation space and the number of pieces of the system increase. As a result, troubles are

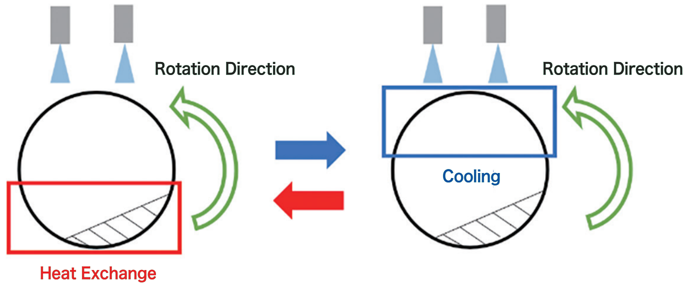

Figure 3-3: Cooling Mechanism

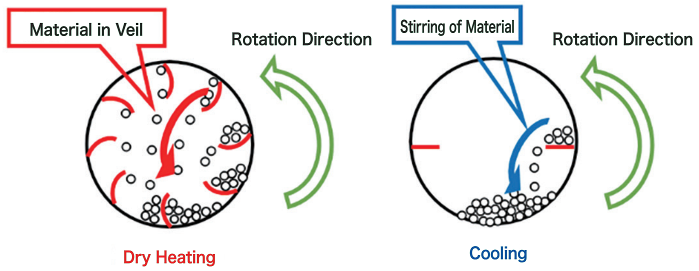

Figure 3-4: Behaviors of Material in Rotary Kiln

more likely to occur and repairs of the equipment are more frequently required.

3.2.2 New Technique

Figure 3-1 illustrates a flow diagram of the newly-developed indirect-cooling kiln technique.

This cooling technique has the same cooling ability as the conventional techniques but uses an indirect-cooling kiln to improve durability. With the conventional direct + indirect cooling technique with a screw, stable operation was difficult depending on the degree of damage to the equipment caused by heat load and/or the frequent troubles arising from the complex structure. To avoid these problems, the indirect-cooling kiln has a structure that is as simple as possible. This technique enables the temperature control of the material by adjusting the kiln' s rotation speed as needed. Therefore, for various materials to be cooled, the temperature can be appropriately controlled by changing the rotation speed.

Photo 3-2: Inside of Cooling Kiln

Photo 3-3: Water Spraying

(1) Feeding Chute

The sintered anhydrous gypsum, which is at a temperature of nearly 1000°C, passes through a feeding chute to enter the cooling kiln. A double air-cooling system is used to cool the chute. SUS310S was selected, for its durability, as the material for the steel of the chute.

This double air-cooling system uses a cooling fan to supply air to the gap in the double structure to restrain the temperature of the steel shell from rising. With this configuration, the temperature of the trough is limited from rising above 600°C, at which point the steel becomes red hot, so that we can use it safely. The air-cooling system we adopted also reduces problems arising from a complex structure and downsizes the installation space.

One concern with this chute is that the material, when falling, tends to hit one point on the chute intensively. Therefore, damage to the chute is anticipated due to localized wear. To address this issue of wear, the chute was designed to be inspected

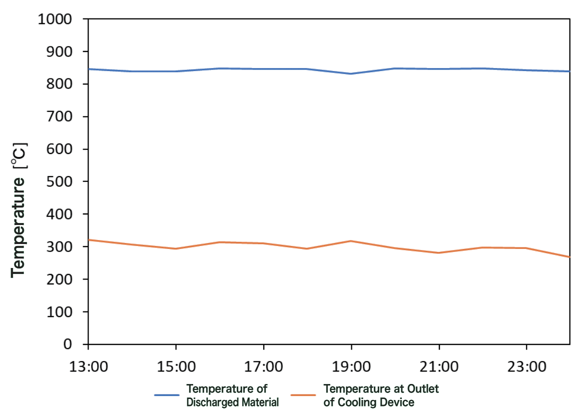

Figure 4-1: RUN1 Operation Data (Conventional Technique)

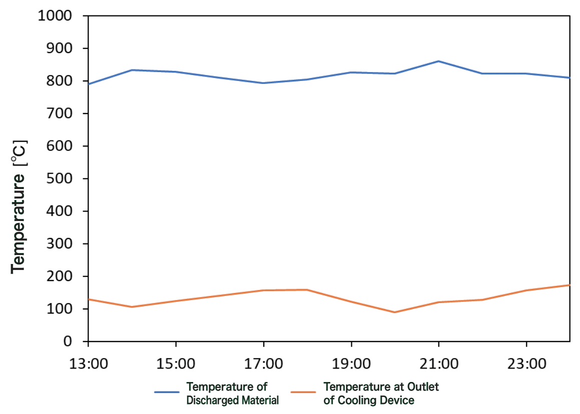

Figure 4-2: RUN2 Operation Data (New Technique in Winter)

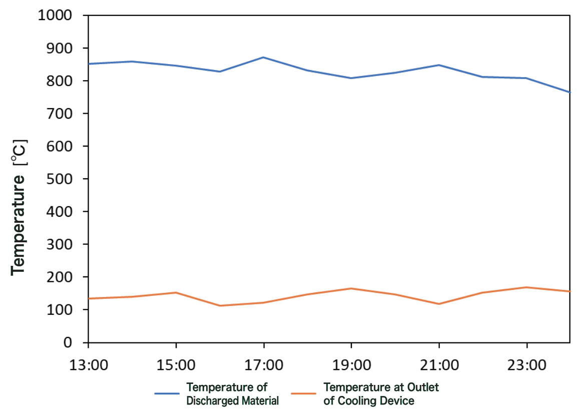

Figure 4-3: RUN3 Operation Data (New Technique in Summer)

regularly, and a structure as illustrated in **Figure 3-2** was used for the chute to allow for easy replacement of the trough. This structure was designed to allow for more permanent use because regular maintenance and part replacement are possible by replacing some of the troughs even if the chute becomes worn or damaged by heat. Depending on the properties of the target material, clogging of the material may occur inside the chute. Therefore, in this design, an air injection nozzle was installed at the accumulation point for pulse operation at regular intervals to prevent accumulation.

(2) Cooling Kiln

A cooling kiln is a device configured to rapidly cool a sintered material, and we used an indirect-cooling kiln technique. **Photo 3-1** shows a photo of the actual device.

In the cooling kiln, water is sprayed onto the steel material of the kiln for indirect cooling, and two support rollers are located, on the input side of a material, to be in an environment that comes into contact with water. The friction drive that we have traditionally used is difficult to use in an environment that comes into contact with water. Hence, we adopted a chain drive for directly driving part of the main body that is located on the discharge side of the material and does not come into contact with water. The drum rollers and support rollers, which come into contact with water, were both made of stainless steel.

As shown in **Figure 3-3**, the high-temperature material fed into the cooling kiln loses heat to the kiln steel, lowering the temperature of the material. The high-temperature kiln steel is cooled from the outside by the sensible and latent heat of water, and then the high-temperature material loses heat again to the kiln steel. This heat exchange is repeated to cool the material. During operation, continuous cooling of the material is conducted through this series of steps.

In addition, in the cooling process, water is sprayed onto the top of the kiln and flows downward along the kiln surface. Consequently, the kiln is configured to maximize the use of the sensible heat of the water. Moreover, the configuration allows almost no water to be discharged, which leads to minimal running costs.

Figure 3-4 shows the behaviors of the material during dry heating and cooling inside the rotary kiln. During dry heating, the material is lifted by the lifter and dispersed in veils as it falls, so that the surface area of the material is increased for more efficient exchange with the hot air.

During cooling, the cooling efficiency greatly depends on the contact area between the material and the kiln steel. Accordingly, lifters are installed in such a way that the material is stirred at a low frequency to facilitate heat exchange with the kiln steel. As shown in **Photo 3-2**, the number of lifters is fewer than in dry heating to prevent the scattering of dust generated when the material falls due to frequent stirring and to maintain the necessary contact area for efficient cooling. This configuration allows the material to be cooled evenly and efficiently.

(3) Water Spray Device

The water spray device aims to make the most of the latent heat of water to rapidly cool the material in a downsized space. Therefore, the nozzle was selected and optimally installed so that water can be sprayed widely and uniformly in a small space.

The water-spray nozzles generally have a fan shape or a cone shape, and the fan-shaped nozzles allow water to cover a relatively wide area. This device we used was configured with a wide-angle fan-shaped nozzle at an even larger spray angle than that of the fan-shaped nozzles for allowing water to cover a wider area. This nozzle has a path of a large diameter for foreign substances, making it less likely to become clogged with any substances passing therethrough. Additionally, the nozzles are positioned to be staggered on some of the surfaces, allowing the fewer number of nozzles to cover wider areas.

To prioritize running costs, we adopted a water-spraying technique that uses a one-fluid nozzle under pressure as the sole power source. A pumping lifter was attached to the outside of the kiln to allow any water that does not evaporate and accumulates in the water tank after running along the kiln surface to be reused, thereby protecting the kiln steel. The water accumulating in the water tank below the drum after spraying is discharged when it reaches a certain level. The water is cooled by about 10 to 20°C by a cooling tower that constantly uses circulating water to conserve water. **Photo 3-3** shows the system during water spraying and the pumping lifter.

4. Operation of Indirect-Cooling Kiln

Here, we compare RUN1, which uses the conventional direct + indirect cooling technique with a screw, and RUN2, which uses the new indirect-cooling kiln technique. The operation data for RUN1 are shown in **Figure 4-1**, and RUN2 in **Figure 4-2**.

As shown in **Figure 4-1**, with the direct + indirect cooling technique with screw, the temperature at the outlet of the cooling device fluctuated between the upper 200°C and 300°C, indicating that it was not sufficiently cooled to below 200°C, which is the heat resistance temperature of the auxiliary equipment. As shown in **Figure 4-2**, with the indirect-cooling kiln technique, the temperature at the outlet fluctuated between 100°C and 150°C, and the auxiliary equipment operated stably without any issues.

Figure 4-3 shows the data for RUN3 with the new technique, comparing the operations in summer and winter. In the summer operation of RUN3, the water temperature was 20°C higher, and the sensible heat of the water was not utilized as effectively for cooling as in the winter operation of RUN2. As shown in **Figure 4-3**, the temperature at the outlet of the cooling device was on average 10°C higher compared to that of the winter operation. However, the cooling capacity was sufficient, and the temperature remained below the heat-resistant threshold of 200°C. Therefore, we started the operation of this technique in December 2022. According to the operational data throughout the year, it has been operating stably.

5. Future Plans

The primary material targeted by this cooling technique is gypsum. However, we believe this equipment can be widely used for materials that should avoid direct contact with water, such as coke, iron ore, and alumina powders. By integrating this new equipment into our existing series, we believe we can propose suitable cooling technique for a broader range of materials in various fields.

We have reported on one equipment model this time. As a future plan, we will expand our lineup in the future to include equipment scaled up to the optimum output for the plant capacities (ranging from 0.5 to 10 t/h).

6. Summary

The rapid indirect-cooling technique developed by our company has made it possible to stably and rapidly cool gypsum that is at 1000°C. Conventional cooling systems required regular maintenance due to the spiral screw and the thermal damage caused by the double structure, making stable operation difficult. These issues have been addressed by the simple structure and easier material-temperature control, facilitating stable operation throughout the year.

Some users have also reported that the maintenance frequency has been reduced, allowing for longer continuous operation of the system and leading to improved productivity.

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