Feasibility Study on A Novel Waste Heat Recovery Process of Industrial Waste Salt Based on High Temperature Melting Dry Method

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Abstract: Industrial waste salt is mainly produced by industrial production processes of pesticides, drug synthesis, printing and dyeing, as well as solid-liquid separations, concentration and crystallization of solution, and sewage treatment, etc. At the present stage, the annual output of waste salt in China has exceeded 2.0×10^7 tons and the high-temperature melting method is considered to be a promising treatment method, but there are problems such as molten salt adhesion and agglomeration, unused high-temperature sensible heat, and waste of water resources. A novel process for waste heat recovery by high temperature melting dry method is proposed in this paper, using a combination of centrifugal granulation and waste heat recovery to dispose high-temperature molten salt and effectively recover heat. Through thermal equilibrium analysis and calculation, the waste heat recovering efficiency of the waste heat recovery using the novel process can reach up to 98%. Taking the annual treatment of 100,000 tons of waste salt as an example, the benefits of effective heat recovery converted to standard coal could be approximately 5 billion. While efficiently utilizing waste heat resources, the novel process brings considerable economic benefits to enterprises, has good industrial application prospects, and helps to advance the process of national hazardous waste solid waste treatment.

1. Introduction

The treatment of industrial waste salt mainly includes the disposal of waste salt and the resource utilization of waste salt. The disposal of waste salt mainly includes the landfill method and the sea discharge method[1]; while the key to the resource utilization of waste salt is to remove toxic and harmful components[2]. The removal methods of organic matter from waste salt are mainly divided into physical methods (salt washing method, extraction method, adsorption method, etc.), heat treatment method (pyrolysis carbonization method, high temperature melting method, etc.), chemical oxidation method (advanced oxidation method, catalytic wet oxidation, hydrothermal oxidation technology, etc.).

The high temperature melting method uses the temperature higher than the melting point of the waste salt (usually 800-1200℃) to completely melt the waste salt into a liquid state, and completely removes the organic matter. Due to the high temperature, this method avoids the softening temperature range of salt, prevents salt from forming circles and agglomeration in equipment and pipelines, and enables the removal effect of organic matter to reach more than 99%[3]. At present, the resource utilization of high-temperature molten industrial waste salt mainly adopts the rotary kiln treatment process (Figure 1), and its main process flow is:

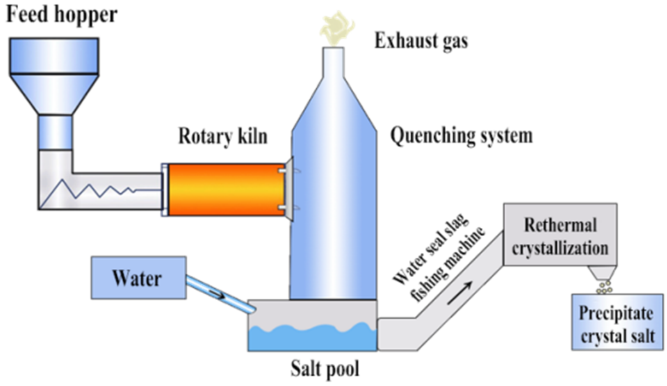

Figure 1 Flow chart of high temperature molten industrial waste salt treatment of traditional rotary kiln

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The waste salt is fed into the rotary kiln from the feeding system, and the organic matter in the waste salt is quickly ignited and removed in the kiln's high temperature environment (800~1200℃), the inorganic matter NaCl is melted and sprayed into the emergency cooling tower for cooling through the molten salt nozzle at the end of the kiln, the condensed salt blocks are crushed into the crusher and broken into blocks, which are fished out by the slagging machine and then removed by the filter with salt bags to remove the insoluble impurities, and the salt is recovered by the evaporator to obtain by-product salt for industrial production; part of the high brine from the brine pool is sent back to the rotary kiln for burning, and the other part is sent back to the emergency cooling tower together with the tail water from the outlet of the salt washing tower to be used as emergency cooling water for the molten salt[4].

In the above-mentioned high-temperature melting process of rotary kiln, the treatment of high-temperature molten salt mainly adopts the water quenching method. However, the water quenching process has some obvious shortcomings: High temperature molten salt (800~ 1200 ℃) has a lot of sensible heat and is wasted without re-recovery; Water quenching high temperature molten salt treatment requires a large amount of water to reduce its high temperature; Some elements in high temperature molten salt and sulfides comes from water quenching will cause environmental pollution[5].

2. The Novel Process for waste heat recovery by high temperature melting dry method

As for the problems of high temperature sensible heat waste and water resource pollution in the high temperature melting water quenching process, this paper innovatively combines high temperature melting method and dry-method waste heat recovery method to effectively solve the problems existing in the traditional high temperature melting process.

The specific process of high temperature molten dry waste heat recovery is as follows: the industrial waste salt is melted at high temperature and then enters the molten salt staging pipeline, which is sprayed into the granulation bin through the molten salt nozzle. The heat of the salt particles is absorbed by the water in the waste heat recovery unit in large quantities and cooled down to low temperature salt particles, which are fed into the collection unit by the salt particle conveyor belt. The dry waste heat recovery unit used for this process is shown in the diagram.

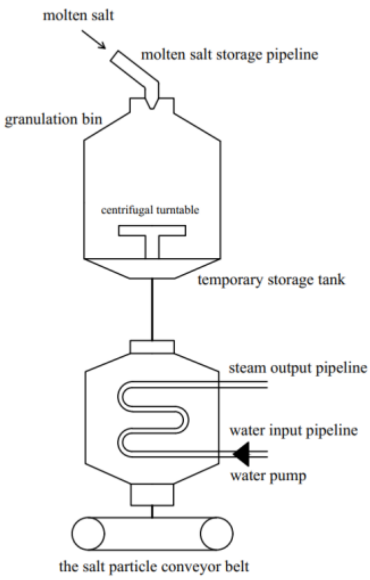


Figure 2 New process of dry-method waste heat recovery device

This process applies dry-method waste heat recovery technology. By granulating the liquid state molten salt, it effectively avoids issues such as heat transfer deterioration and mass transfer issues caused by molten salt agglomeration, adhesion and other problems in high-temperature molten water quenching processes. Additionally, this process can effectively recover waste heat from treated high-temperature salt particles, as well as recover high-temperature molten salt sensible heat, thus avoiding energy dissipation and water waste.

This paper is intended to propose a new high-temperature molten industrial waste salt treatment process, analyze and compare the new dry-method waste heat recovery process with the traditional process, and verify that this process can significantly improve energy efficiency, save resources, and bring considerable economic benefits when put into large-scale industrial production, and can saves energy and resources while treating national hazardous waste, and contribute to the national hazardous waste and solid waste treatment process as well as the development of related industries.

3. Comparative analysis of new dry-method waste heat recovery process and traditional process

3.1 Water quenching process

3.1.1 Thermal equilibrium calculation of water quenching process of molten salt

Taking the treatment of 10 tons of certain industrial waste salt as an example, the high temperature melting temperature of industrial waste salt is mainly 800~1200 ℃, and the molten salt temperature is 1000℃. It is assumed that the salt water equilibrium temperature $t_{salt\ water}$ after water quenching treatment is 70 ℃.

During the heat transfer process after the high-temperature molten salt is in contact with the injection water, the heat released by the molten salt mainly includes the reduction of the internal energy of the molten salt and the solidification heat released when it is converted from liquid molten salt to solid molten salt. For most industrial waste salt, the main element is sodium chloride. Therefore, the melting heat of sodium chloride was chosen for the approximate calculation of the melting heat of waste salt. It is known that the heat of melting λ of sodium chloride is 34.4 kJ/mol and the molar mass M is 58.5 g/mol.

$$n = \frac{m}{M}$$

$$Q_{melt} = \lambda \cdot n$$

n: Molar number of waste salt, mol; M: mass of waste salt, g; Q_{melt}: Melting heat of 10t waste salt, kJ;

The heat balance expression of the heat exchange process of molten salt and water is:

$$Q_{release} = Q_{absorb}$$

That is， $m_{salt}c_{salt}\Delta t_{salt} + Q_{melt} = m_{water}c_{water}\Delta t_{water}$

It is calculated by taking the data into consideration that using water quenching process to treat 10t industrial waste salt requires water supply of m_{water}=76.92t, so the salt water ratio is about 1:8.

That is, to treat 10t of waste salt, the high-temperature sensible heat wasted by cooling the high-temperature molten salt from 1000 ° C to 70 ° C is $Q_{loss} = Q_{relase} = 19830341.9kJ$, and the water resource consumption is 76.92t.

3.1.2 Thermal balance calculation during the salt water evaporation and crystallization process

After the above treatment, the insoluble impurities in the salt water are removed by the filter. And at this time, the temperature of the salt water is 25 ℃ at room temperature. The salt is recycled by the evaporator to obtain the by-product salt, which is reused for industrial production.

The high-concentration-salt water after water quenching can be regarded as saturated salt water approximately, so its specific heat is about $c_{salt\ water}$ = 3.495 kJ/kg · K. For 10t salt, according to the conversion relationship, the mass of high salt water $m_{salt\ water}$=37777.8kg

The heat required for the distillation process is:

$$Q = c_{salt\ water}\Delta Tm = 10958773.1kJ$$

In summary, the water quenching process used in the traditional high-temperature melting method to treat industrial waste salt has approximately 30,789,115 kJ of heat and 76.92 t of water wasted in the water quenching of molten salt and evaporation and crystallization of salt water in the process of treating 10 t of industrial waste salt.

3.2 Dry-method waste heat recovery process

3.2.1 Pinch analysis and calculation

Considering the actual working conditions and improving the heat exchange efficiency, the minimum heat exchange temperature difference is set equal to 10℃, and the steam mass flow rate is assumed to be 0.0278kg/s. Combined with the above flow parameter results, the pinch point heat exchange curve is drawn. Based on the maximum waste heat recovery efficiency, the obtained curve is scaled by iterative calculation until the difference between the values of the two adjacent iterations is less than the allowable value, that is, the following iterative convergence criteria are met:

$$\max \left|\frac{m_{i+1} - m_i}{m_i}\right| < \varepsilon$$

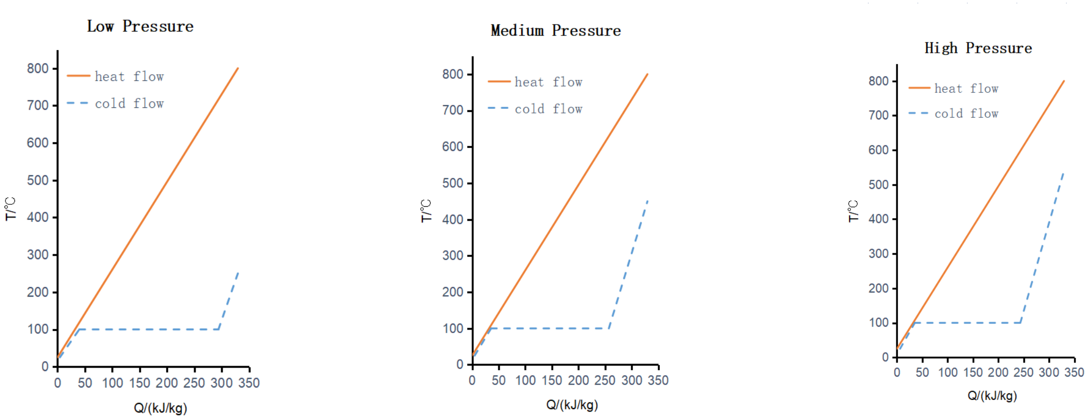
Where m is the steam mass flow rate, the subscripts i and i + 1 indicate the number of iterations, and ε is the allowable relative deviation, usually between 10^{-3} and 10^{-6}.

At the same time, according to the pinch point theory, the calculation formula of heat recovery efficiency in the heat exchange process is:

$$\eta = \frac{\text{Heat recovery load}}{\text{Total heat load}} \times 100\%$$

Where the total heat load is all the heat energy contained in the high-temperature molten salt, and the heat recovery load is the heat energy effectively recovered after heat exchange by the cold and hot flows (that is, the horizontal coordinate of the cold and hot flows coincides in the heat exchange curve).

The heat transfer curves of cold and heat flows under low, medium and high steam pressures are shown in Figure 3 (a) (b) (c). It can be seen that the high temperature melting dry-method waste heat recovery process has high heat recovery efficiency.



(a) (b) (c)

Figure 3 Heat exchange curve of cold and heat flows

3.2.2 Economic benefit analysis

The high-temperature melting and dry-method waste heat recovery process is used for the resource utilization of industrial waste salt. Taking the annual treatment of 100,000 tons of waste salt as an example, the heat recovered by the three kinds of flows is converted into 4.147 million tons, 3.983 million tons and 3.859 million tons of standard coal respectively. Calculated at 1200 yuan per ton of standard coal, the annual economic benefits that can be generated are 4.98 billion yuan, 4.787 billion yuan and 4.63 billion yuan, which ensures that while saving energy, it will bring considerable economic benefits to enterprises and have good industrial market application prospects.

4. Conclusion

The high-temperature melting dry-method process waste heat recovery system proposed in this paper uses high-temperature molten salt for centrifugal granulation treatment. While ensuring the purity of waste salt recycling, it effectively solves the agglomeration and adhesion during the high-temperature melting process of waste salt. As well as heat transfer and mass transfer deterioration, the waste of water resources is avoided; the waste heat recovery of high-temperature salt particles is carried out to effectively recover a large number of high-temperature salt particles with sensible heat, and the energy efficiency of the system is improved; the optimal heat exchange mass flow rate is designed to ensure the maximum recovery of heat and improve the heat recovery efficiency;Through heat balance analysis and calculation, the system waste heat recovery efficiency can reach 98%. Taking the annual treatment of 100,000 tons of waste salt as an example, the annual heat recovery of the three kinds of flows is equivalent to 4.147 million tons, 3.983 million tons, and 3.859 million tons of standard coal, respectively. Calculated at 1200 yuan per ton of standard coal, the annual economic benefits that can be 4.98 billion yuan, 4.787 billion yuan, and 4.63 billion yuan, ensuring that while saving energy, it will bring considerable economic benefits to enterprises and have good industrial application prospects.

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