

A Study of the Principle of Advanced Energy-Saving Furnaces

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Abstract

Concerns with rising energy cost and deteriorating environment are driving thermal treatment equipment innovation to the birth of a new generation of furnaces, which we call “green furnaces”. This new generation green furnace promises more energy savings and less material consumption, which contribute to reduced pollution and higher production throughput. Through study of the energy-saving principle of green furnaces, this article tried to establish a simplified mathematic model to simulate furnace heat loss. Based on this model, some basic guidelines for designing energy saving green furnaces were proposed.

Keywords: energy-saving, thermal treatment, furnaces

Introduction

As we were writing this paper, the price of crude oil was hovering around \$130 USD per barrel and was poised to go even higher. Meanwhile, the concept of global warming is gaining wider acceptance and generating concerns among the public. To address the above situations, energy intensive companies with lots of thermal treatment processes are looking for ways to cut energy consumption and to reduce the emission of greenhouse and other undesired gases. This poses a huge challenge for thermal treatment equipment manufacturers. A new generation furnace, which is now called green furnace and is endowed with great potential to save energy, cut material consumption, and step up production throughput, has been studied for decades.

In this paper we studied the energy saving principle of these green furnaces and established a simplified mathematic model to simulate furnace heat loss. Using the model as a design guide, we tried to design and fabricate more energy-efficient furnaces.

How to reduce energy consumption in thermal treatment process

Saving energy has long been a research subject for thermal treatments, and now it's getting urgent. To accomplish, people typically address their research from a system point of view and their efforts can be summarized into two categories, the materials/processes approach and the equipment approach:

A. Materials/Processes Approach

This approach modifies the thermal treatment process through the entailment of lower temperature and the use of better materials. In the area of treatment technology, research has been focused on fast-firing and low-firing-temperature techniques. Fast-firing refers to a decrease in heat treatment time, which is always done by optimizing the temperature profile. Decreasing the treatment temperature, or low-firing-temperature, is another choice, which is usually done by optimizing the material contents. New materials have been designed

in such a way as to reduce the required peak temperature and/or soaking time. An example would be blending glass powder with clay to reduce firing temperature, in which case the energy consumption is reduced by 40%. Although such techniques help cut energy consumption, they have to be handled by the process engineers and sometimes only make sense for mass production.

B. Equipment Approach

Low energy consumption furnaces are devised to accomplish more energy savings. This approach improves the energy efficiency of furnaces by renovating the furnace design, especially the design of heating technique, control technique, inside structure, fixture, and the choice of insulation materials.

The research on heating technique has started and evolved along with human evolution. Nowadays, most heating is done through either gas firing or electrical resistance heating, while a few decades ago, people paid more attention to microwave heating and infrared heating. Since infrared radiation penetrates the treated material more easily, it decreases treatment time and energy consumption, especially for temperatures beyond 1000°C. That's the reason why infrared heating is used more often at the present. Although microwave heating performs much better on the same parameters as in infrared heating, the cost of the system, including the protection fixture, is too high. In addition, there is yet to be a proper way to control the amount of microwave energy radiated to the treated material.

The precise control of power in accordance with the requirement of the treated material creates another route for energy savings. Control with mechanical relay makes the temperature inside the furnace unstable, thus consuming more energy. Now mechanical relay has been replaced by electronic switches, typically for products like solid state relay (SSR) and solid state electronic power module. Even with electronic relay control, there are many different driving mechanisms such as phase trigger mode and zero trigger mode. The phase mode is normally more accurate than the zero mode, but it uses more power and generates noise on the power lines. In the 1990s, however, new zero trigger method, sometimes known as single wave zero trigger mode, was invented and it has nearly the same capability of accurate control as phase mode does. As a result, more and more furnace manufacturers have come around to single zero trigger mode.

To save energy by renovating the inside structure of furnaces has great potential as well, although many manufacturers have not paid enough attention to it. It is expected to be the next competition hotspot in future thermal treating industry.

The effort to save energy by renovating fixtures or by choosing a different kind of furnace grows very slowly in the industry. It can be explained by the habit of different users and particular industry sectors. On the one hand, engineers are more likely to choose the kind of furnaces they had experience with in the past. On the other, furnace manufacturers are very reluctant to take the risk by recommending new designs.

Adopting advanced insulation material to save energy is a new advancement in the furnace industry. From the 1980s, research sprouted in this direction and a few exciting progresses have been made since then. For example, furnace manufacturer HengLi began to custom-design furnaces of this kind in the 1990s, and today, they have successfully applied this technique in belt conveyor furnaces, push tunnel furnaces, elevator kilns and box kilns. So far, they have installed hundreds of HengLi "green furnaces" in more than twenty different countries. These furnaces saved considerable amount of energy for their customers.

Principle of advanced insulation furnace

At present, most of the advanced insulation materials used by this type of furnace are special ceramic fibers and fiber formed bricks. These materials have low density and low thermal capacity. With low thermal capacity, the furnace warms up and cools down very quickly and loses less heat to the environment.

In order to quantify the furnace heat loss, we established a simplified mathematic model to simulate the process.

Typical furnace structure

Basically there are two types of furnaces, one being the batch type for period working, and the other the continuous type. Some good examples of batch type furnace are elevator type kiln and box type furnace, their typical structures shown in Fig.1 and Fig.2. The continuous type includes belt conveyor type and push tunnel type. Their typical structure is shown in Fig.3

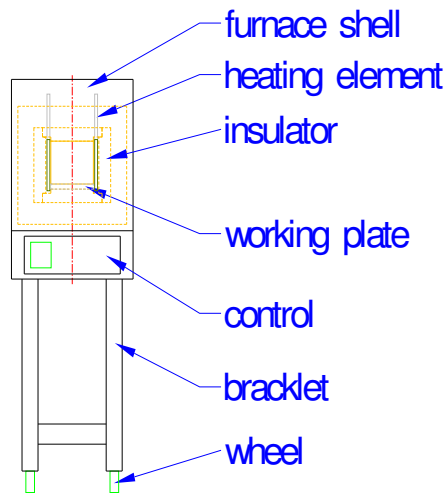


Fig. 1 Typical box oven structure



Fig. 2 Typical elevator kiln

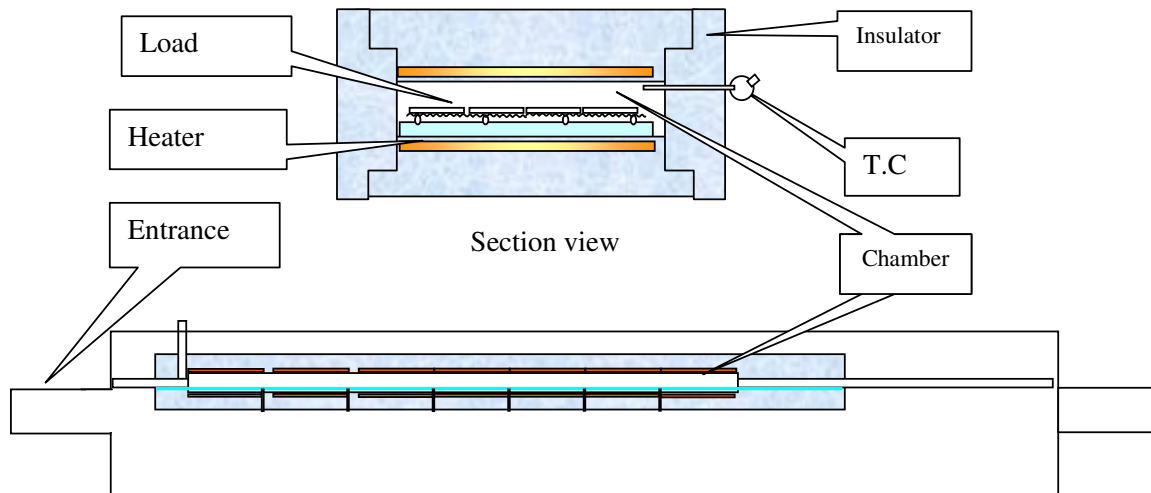


Fig3: Typical tunnel furnace structure

Simplified Heat Loss Model

In order to quantify the yield loss, we decided to model the heat loss with a method very similar to those used by electrical circuits.

We know for a fact that R_2 is a function of the furnace surface area S_{sa} and air's thermal conductivity λ_{air} . R_2 is directly proportional to S_{sa} and inversely proportional to λ_{air} .

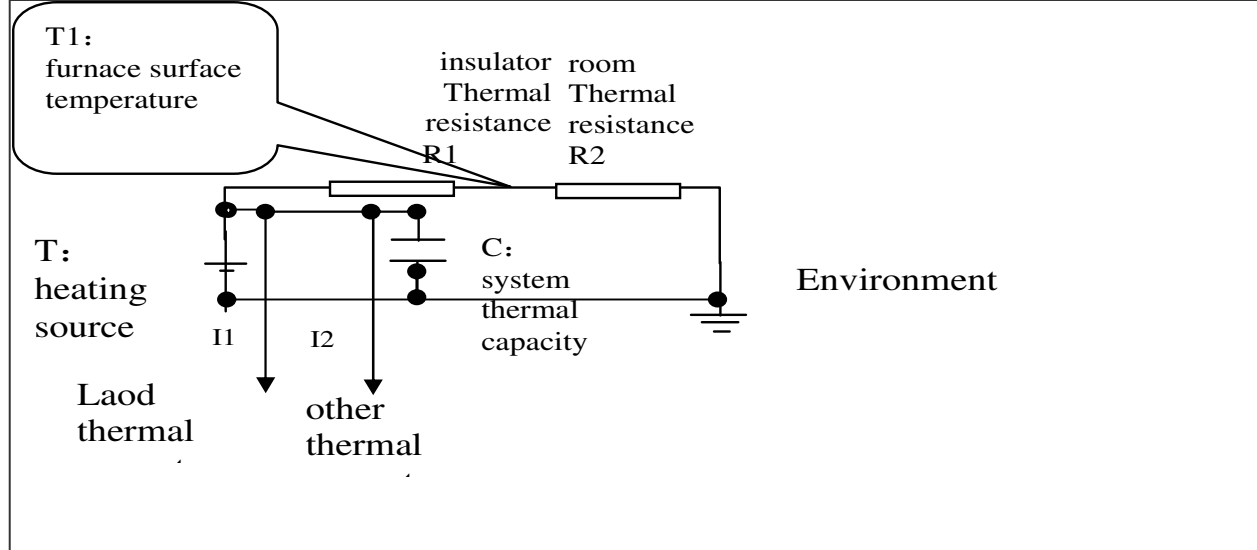


Fig. 4 Simplified Model of Furnace Heat Loss

Where:

T : relative temperature of the heating elements to the surrounding environment

T_1 : relative surface temperature of the furnace body to the surrounding environment

R_1 : insulation layer's thermal resistance

R_2 : thermal resistance between furnace body and the surrounding environment

C : system thermal capacity, which includes all the insulation and construction material

I_1 : heat loss due to the load and its fixture or carrier

I_2 : other heat losses besides I_1 , like those from insulation layers, door and T.C holes etc.

Environment represents the temperature of the room where furnace is installed.

We use P to represent the energy consumption of the furnace. From the model shown in Fig 4, we are able to simulate P with the following equation:

$$P = T/(R_1 + R_2) + I_1 + I_2 + f(C, t) \\ = (T - T_1)^2 / R_1 + T_1^2 / R_2 + T(I_1 + I_2) + f(C, t)$$

In this equation, $f(C, t)$ is the energy absorption rate of the furnace system. For a batch furnace, $f(C, t)$ will approach 0 as time goes on.

Principle of energy saving

The heat loss model and energy consumption equation have enabled us to find out the factors that may reduce the system's energy consumption.

In our experience, we would design a furnace's insulation according to the furnace temperature T and furnace surface temperature T_1 . To keep the same T_1 , for a furnace lined with dense castables or conventional firebrick, the insulator will be thicker than required by advanced insulator furnaces. So S_{sa} is significantly decreased. Another advantage is that the new material makes C decrease significantly, too.

We call P_s the energy consumption of a green furnace and P_c the energy consumption of a conventional furnace. Consequently, the energy consumption reduction can be modeled as:

$$P_s - P_c \\ = (T - T_1)^2 / R_1 + T_1^2 / R_{2s} + T(I_1 + I_2) + f(C_s, t) - \\ ((T - T_1)^2 / R_1 + T_1^2 / R_{2c} + T(I_1 + I_2) + f(C_c, t)) \\ = T_1^2 (1/R_{2s} - 1/R_{2c}) + f(C_s, t) - f(C_c, t)$$

Since green furnace has small S_{sa} , it makes R_{2s} larger and $(1/R_{2s} - 1/R_{2c})$ less than 0. Meanwhile, the decrease in C_s makes $(f(C_s, t) - f(C_c, t))$

less than 0 before the entire furnace reaches designed temperature. The smaller t is, the larger the difference will be. From this analysis, we know P_s is smaller than P_c , which is the reason for green furnace's energy savings.

Guidelines to designing a green furnace

From the above examinations, we come to the conclusion that energy savings could be materialized by:

- A. reducing the total surface area
- B. reducing the heat capacity of the furnace system and the energy needed for furnace to reach working temperature.

The second approach is very useful for batch furnaces, since these furnaces are normally utilized in experimental or small lot productions. For a conventional high temperature batch furnace, normally it would take 4 hours or more to reach the desired temperature. For green furnaces instead, 1 hour is enough, which translates into huge energy savings.

To further illustrate the above principle, we would like to examine the two furnace models we have designed and fabricated. The following tables are intended to show two sets of comparisons between a conventional furnace and the new green furnace.

Table 1- Comparison between typical thick film conveyor firing furnace HSK 3006 and RSL3006

Model	HSK3006 (green type)	RSL3006 (conventional type)
Working Dimension	300mm*50mm*3000mm (W*H*L)	
S (m2)	7.02	9.12
Decreasing Rate	23%	

Table 2 - Comparison between typical ceramic sintering push furnace GTL4025-12-13H and GT K 4025-12-13

Model	GTL4025-12-13H (green type)	GTL4025-12-13H (conventional type)
Working Dimension	400mm*250mm*6000mm (W*H*L)	
S(m2)	17.88	22.2
decreasing rate	19%	

Our analysis above has only considered energy savings due to reduced surface area. Other factors such as low overall thermal capacity contribute to even more energy savings. With onsite test, we verified that our design could achieve 20% energy savings for continuous furnaces and up to 40% for batch furnaces.

To summarize, based on our study and our manufacturing experience, we would recommend the following design guidelines:

- A. With the same surface temperature, the smaller the total surface area is, the more energy savings there will be;
- B. For batch furnace or tunnel furnace in period working mode, the less system thermal capacity is, the more energy savings there will be;
- C. The less the thermal capacity of firing fixtures and carriers is, the more efficient energy savings will be.

Conclusion

There are many potential ways to make a green furnace, among which advanced insulation and lining material are good choices. To get the real savings, we have to evaluate the furnace design and approach from a system point of view. More insulation does not translate into more energy savings.

Based on our analysis, we identified two major contributing factors, namely total surface area and furnace thermo capacity, as most important in the reduction of furnace energy consumptions.

The heat loss model also suggests that there may be other solutions to the design. For example, if it is a very large furnace, I_2 has to be considered carefully. The major waste of energy may be generated from I_2 , or heat losses from insulation layers, furnace door and T.C holes. The furnace door and fixtures, therefore, should be optimized accordingly.

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