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A simple method of calculating the time needed to heat a load of parts to a given temperature can be used to estimate time to heat for production schedules, or to estimate furnace times.

Calculating heating times of furnace loads

In this column, I will discuss different ways to determine the time required to heat a load to the desired temperature.

INTRODUCTION

The heating time is the time required for the coldest location in a part — usually its center — to reach the selected austenitizing temperature. This information is critical to determine the start of soaking at temperature to ensure that proper transformation has occurred. In the case of a part being heated to the austenization temperature, it is important that the start of soaking and the length of time at soak be adequate so that complete transformation to austenite can occur.

One of the simplest methods is to use a thermocouple at the center of a test piece of similar thickness. As the part is heated, the temperature of the center is monitored, and the start of soaking begins when the part center reaches some desired temperature, usually within 10-25° F (6-14°C) of the desired set point. The reason the desired furnace set point is not used is because the temperature of the center of part approaches the set point asymptotically.

This method is accurate and is often specified in specifications such as AMS 2750 Pyrometry [1]. It is important for determining exactly when soak times are initiated if used in a production load. If this is done for many different thicknesses, a graph of different thicknesses can be plotted against time to estimate heating times to setpoint. This would have to be done for different furnaces. This data is useful for scheduling purposes, and production planning.

If the furnace is a simple box furnace, the use of a thermocouple is somewhat simple to implement, as there are few mechanical constraints. However, if the furnace is an integral quench furnace, with an outer and inner door, this process becomes much more cumbersome, and more likely to fail, as the movement of the load, or the action of the doors, can cause thermocouple breakage. An analytical method is needed.

HEAT INPUT METHOD

In this method, a very simple heat balance is used between the supplied heat of the furnace per unit time, and the energy necessary to heat the part (or load) to the desired temperature. The first step is to calculate heat required to heat the part to the desired temperature (Equation 1):

$$Q = M_p C_p (T - T_i)$$

Equation 1

Where Q is the heat required (Joules), M_p is the weight of the parts (kg), and C_p is the specific heat of the material (W/Kg-°C), T is the desired set point temperature, and Ti is the initial temperature (°C).

The specific heat of steel changes as a function of temperature [2] (Equation 2):

$$C_p = 425 + 7.73x10^{-1}T - 1.69x10^{-3}T^2 + 2.22x10^{-6}T^3$$

Equation 2

However, for simplicity, an average temperature between the initial temperature and desired temperature is often used. For instance, the specific heat capacity of steel at 450°C is 633 J/kg·°C. This assumes an initial temperature of 20°C, and a desired temperature of 870°C.

The heat is supplied by the furnace. In an electric furnace, the furnace power (P) is rated in watts (or kilowatts). One watt is equal to 1 Joule per second. One KW is equal to 1,000 Joules per second. So, for instance, a furnace rated at 100KW can provide energy at the rate of 100,000 Joules per second.

After calculating the heat required (Joules), it is a simple matter of dividing the heat required by the heat input (Joules per second) to get the time to heat in seconds (Equation 3):

$$t = \frac{Q}{aP} = \frac{M_p C_p (T - T_i)}{aP}$$

Equation 3

Where *t* is the time (s), *Q* is the heat required to heat the part or load, *a* is an efficiency factor.

Not all the heat from the heating elements goes into heating the part. Some of the heat is used to compensate for heat losses to the shell and outside environment, with the balance used for heating the furnace load. Therefore, some efficiency factor is required to allow for environmental losses. This efficiency can be estimated by taking the power required by a temperature-soaked empty furnace at the desired temperature and dividing it into the full power of the furnace. For well-insulated furnaces, this is approximately 80 percent or better. For poorly insulated furnaces, the efficiency is much worse, at 20-50 percent.

This equation is best suited for calculating the time required for a furnace load, but can be used for a single part. However, the results will be overly optimistic, as heat conduction is not considered. This will be discussed in a later column.

EXAMPLE

A furnace rated at 100KW, with an efficiency of 80 percent, is needed to heat a furnace load of 500 kg of steel parts to 870°C from ambient of 20°C. How long will it take to heat the parts to temperature? Therefore:

- M_p = 500 Kg
- C_p = 633 J/Kg·°C (calculated previously)
- T = 870°C
- T_i = 20°C

» a = 0.8
» P = 100,000 J/s

First calculate the heat required to heat the parts (Equation 4):

$$Q = M_p C_p (T - T_i) = (500\ Kg)\left(633 \frac{J}{Kg} \cdot °C\right)(870 - 20°C)$$

$$Q = 269{,}025\ KJ$$

Equation 4

Now we calculate the time required (Equation 5):

$$t = \frac{Q}{aP} = \frac{269{,}025\ KJ}{(0.8)100\ KJ/s} = 3362.8\ s \approx 0.93\ hrs$$

Equation 5

The time required to heat the 500Kg load of steel from ambient to 870°C, in a furnace rated at 100KW, with a furnace efficiency of 80 percent is 3,362.8 seconds, or 0.93 hrs.

CONCLUSION

In this article, I demonstrated a simple method of calculating the time needed to heat a load of parts to a given temperature. This method can be used to estimate time to heat for production schedules, or to estimate furnace times. However, there are limitations to this method. Part thickness, and the density of the load can affect load heating times. However, this simple method is useful for "back of the envelope" calculations.

Should you have any questions, or comments regarding this article, or suggestions for further articles, please contact the editor or author.

REFERENCES

[1] SAE International, "AMS 2750H Pyrometry," SAE International, Warren, OH, 2024.

[2] CEN (European Committee for Standardization), "Eurocode 3: Design of steel structures - Part 1-2: General rules - Structural fire design, EN 1993-1-2," European Committee for Standardization (CEN), Brussels, Belgium, 2005.

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