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Final Report

HEATING MECHANISM OF THE HOLDEN LUMINOUS WALL FURNACE

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ABSTRACT

This is a report of a study to determine the heating mechanism of the Holden Luminous Wall Furnace. It was found that the rapid heating and cooling cycle obtained with this furnace results from the immediate proximity of the gas flame to the refractory lining, the high emissivity of the lining, and low thermal conductivity of the lining.

INTRODUCTION

The problem is to study the heating mechanism of the Holden Luminous Wall Furnace shown in Figure 1. The unique feature of the furnace is a porous refractory lining especially developed to permit gas flow through it. A gas-air mixture, regulated by a mixing valve, flows into the plenum chamber, and thence through the porous bricks into the heating chamber. A pilot flame within the furnace ignites the gas mixture, which burns along the surface of the porous refractory lining. A thermocouple within the furnace controls the temperature by actuating a solenoid valve located either in the gas line or in the gas-air mixture line, depending upon whichever control method is desired.

One of the important characteristics of this furnace is the rapid heating and cooling cycle which is possible. As an example, the Holden Company reports that a solid two-inch cylinder of iron, six inches long, can be heated from 80°F to 2000°F in less than twenty minutes, and can be cooled back down to 1000°F in 16 minutes while in the furnace.

To determine the mechanism by which this rapid heat transfer takes place, it is necessary to consider the methods by which heat can be transferred. This can be accomplished in three ways, which may be separately involved or associated; i.e., heat may be transferred from one location to another by convection, by conduction, or by radiation, singly, or in various degrees of association.

Convection is involved only when fluids—either liquids or gases—are themselves heated in definitely circumscribed regions or when they are in contact with heated solid objects. Convection is a mechanical process involving the bodily transfer or mixing of heated substances.

Conduction is a molecular process of heat transfer through adjacent layers of a medium by the diffusion of the high kinetic energy of the random-moving molecules from the heated regions into successively cooler ones.

Radiation is a third way in which heat may be transmitted away from or to an object, and it involves no material means of transfer, either convective or conductive. Here heat is transferred as electromagnetic waves called infrared radiation. These waves are of the same type as light waves, and the only difference between them is their wavelengths. This is the way sunlight comes to us, and we can feel its longer infrared heat waves as well as see its light waves.

EXPERIMENTS

In order to elucidate the heating mechanism of this furnace in detail, several experiments were conducted. First, a series of comparative temperature measurements were made, utilizing the control thermocouple and a Radiamatic temperature measuring unit. The Radiamatic unit, an infrared sensitive device, was located as shown in Figure 1 so as to view the indicated wall area.

For the first experiment, the control thermocouple was placed very close to the wall in the area viewed by the Radiamatic unit, and the furnace was fired to 2000°F. This experiment was repeated twice, first with the control thermocouple moved out 8 inches from the wall, and then 10.5 inches, but always directly opposite the spot viewed by the Radiamatic unit. The resulting temperatures are given below.

	Control Thermocouple	Radiamatic Unit
Control Thermocouple at wall	2000	2000
Control Thermocouple 8 in. from wall	2000	2020
Control Thermocouple 10.5 in. from wall	2000	2070

The agreement of the radiamatic measurements with the control thermocouple measurements indicates that practically all the heating of objects within the furnace chamber is by radiation. If any appreciable heating had been accomplished by conduction or convection, the Radiamatic unit would have indicated a lower temperature since it is only sensitive to radiant energy. The fact that the control thermocouple indicated the lower temperature at 8 inches and 10.5 inches from the wall in the above experiment is probably due to its "seeing" the unheated bottom of the furnace in addition to the walls, and consequently responding to an integrated or "average" temperature.

The emissivity of the furnace lining was measured next to determine its absorbing and radiating characteristics. This measurement was accomplished by heating a piece of furnace lining and a piece of carbon of known emissivity in an electric furnace and determining their apparent temperature with an optical pyrometer. The emissivity of the porous furnace-lining refractory material was determined to be about 0.7 for the temperature range from 1600°F to 2000°F, which indicates that this material is both a good absorber and emitter of radiant energy. The infrared emission spectrum of the lining material, assuming a graybody emissivity of 0.7, is shown in Figure 2.

CONCLUSIONS

On the basis of the above experiments and other known facts, it was concluded that the heating mechanism of the furnace is as follows:

1. The burning gas-air mixture at the face of the porous furnace lining transfers its heat very rapidly to the surface of the lining by radiation, but primarily by convection and conduction.

2. The furnace lining rapidly transfers this heat in the form of infrared radiation to the work in the furnace.

Amplifying on paragraph 1, the radiation emitted by a natural gas flame as reported by Plyler and Humphreys* is shown in Figure 3. It can be seen from this spectrum that most of the infrared radiation is concentrated into two wavelength regions (2.8 and 4.3 microns). Since the furnace lining has good black-body characteristics, it absorbs this radiation available from the gas flame, and is also heated rapidly by conduction and convection from the same flame.

The conclusions of paragraph 2 result from the agreement of the Radiamatic measurements with the control thermocouple measurements which indicate that practically all the heating within the furnace is by radiation. Also, the emission data of Figure 2 as obtained from the emissivity tests show that the heated lining is an efficient radiator, making possible a fast temperature-control response.

Equally important, the porous lining is a poor heat conductor so that only the face is appreciably heated by the gas flame. Furthermore, the gas-air mixture passing through the porous lining tends to cool the portions other than the heated surface. This cooling action is accentuated even further when the control

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*Plyler, E. K., J. Research NBS, 40, 113 (1948); Plyler, E. K., and Humphreys, C. J., J. Research NBS, 40, 449 (1948).

thermocouple regulates only the gas flow, allowing the air to flow continuously through the lining. Thus the lining has little opportunity for heat retention, and therefore contributes little to the furnace temperature except while the gas is burning.

It is the combination of the three conditions, the immediate proximity of the gas flame to the refractory lining, the high emissivity of the lining, and the low thermal conductivity of the lining, which accounts for the rapid heating and cooling cycle possible with the Holden Furnace.

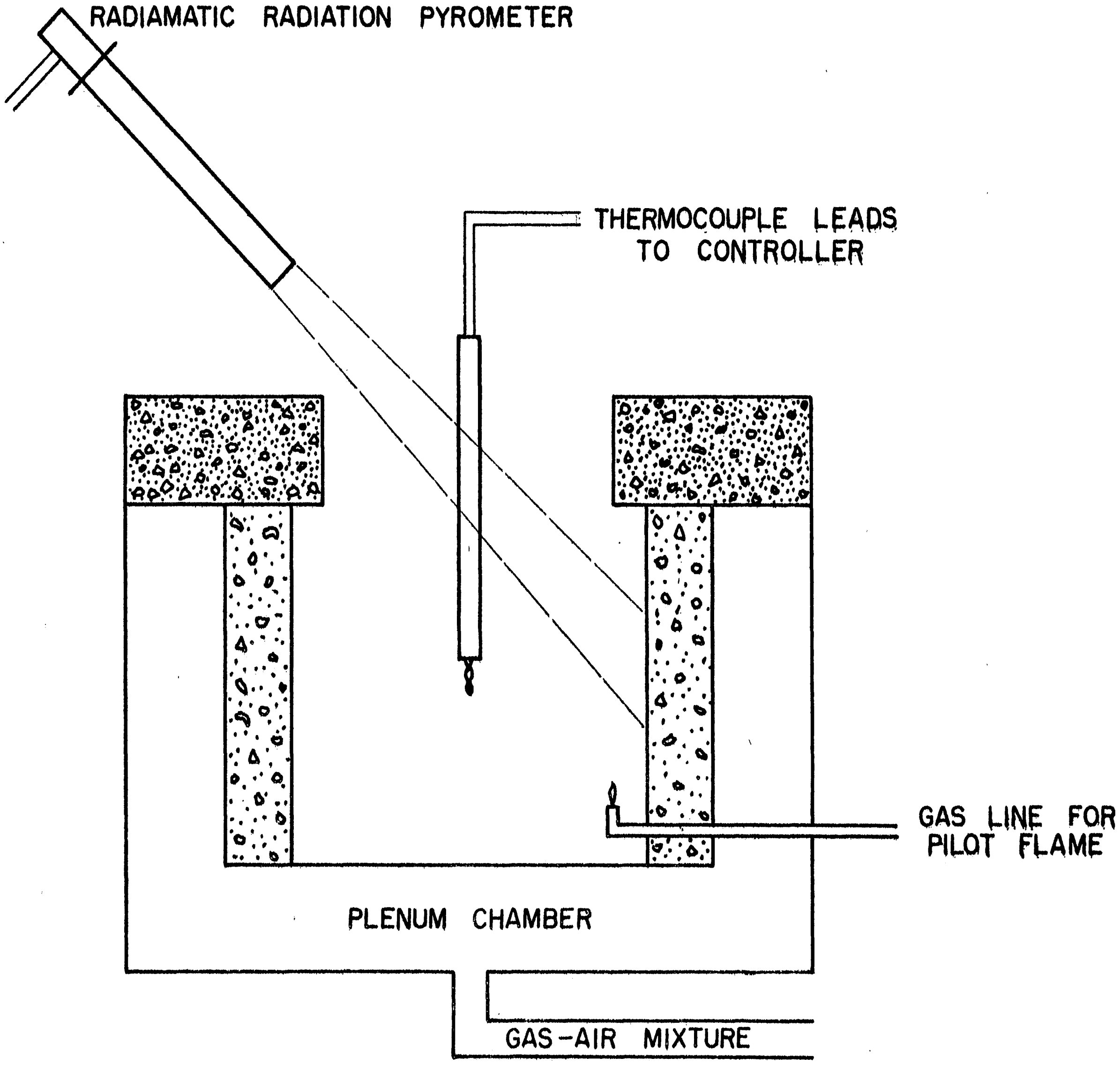

FIGURE 1. HOLDEN LUMINOUS WALL FURNACE.

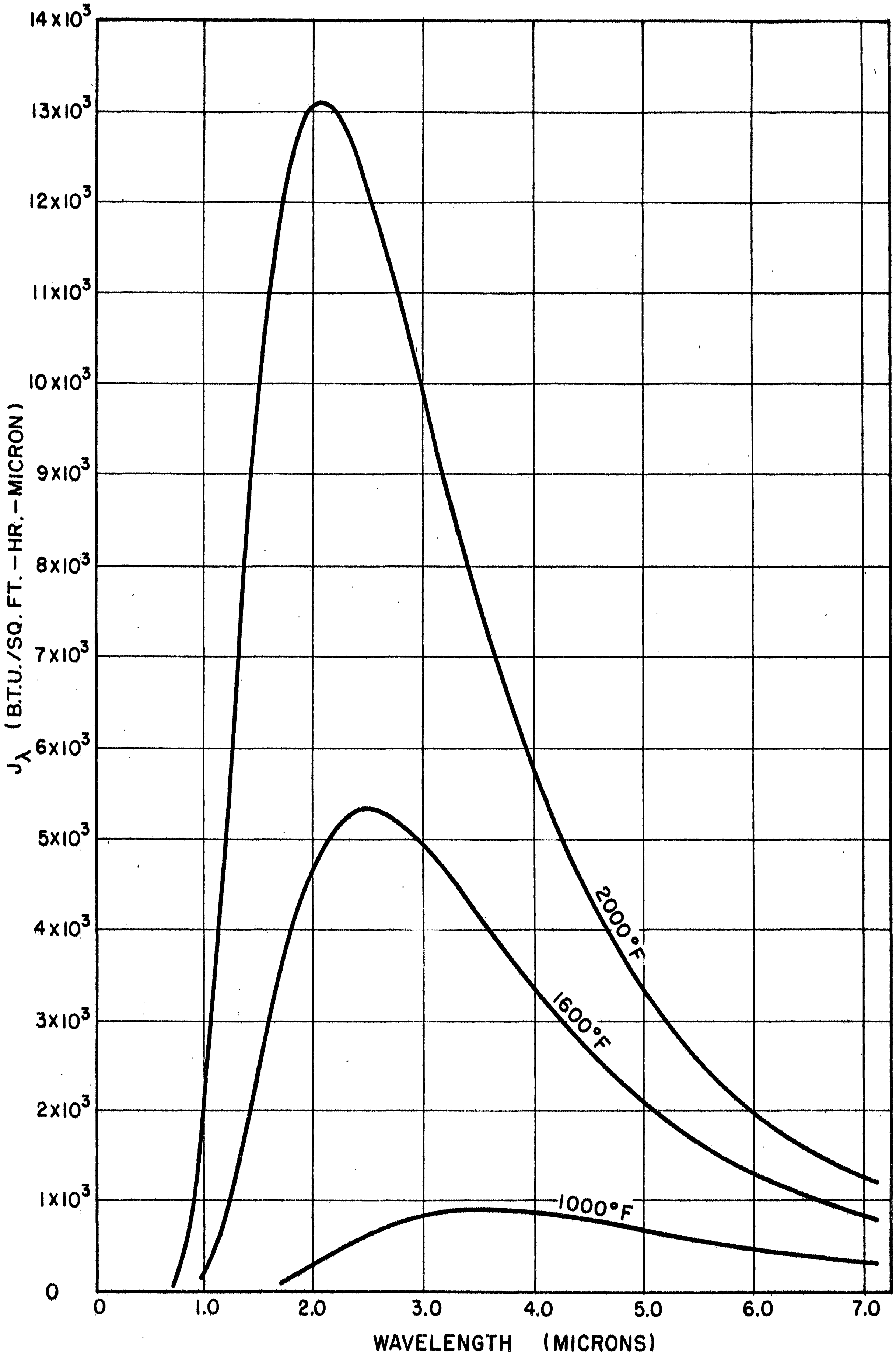

FIGURE 2. EMISSION SPECTRA OF THE HOLDEN REFRACTORY LINING.

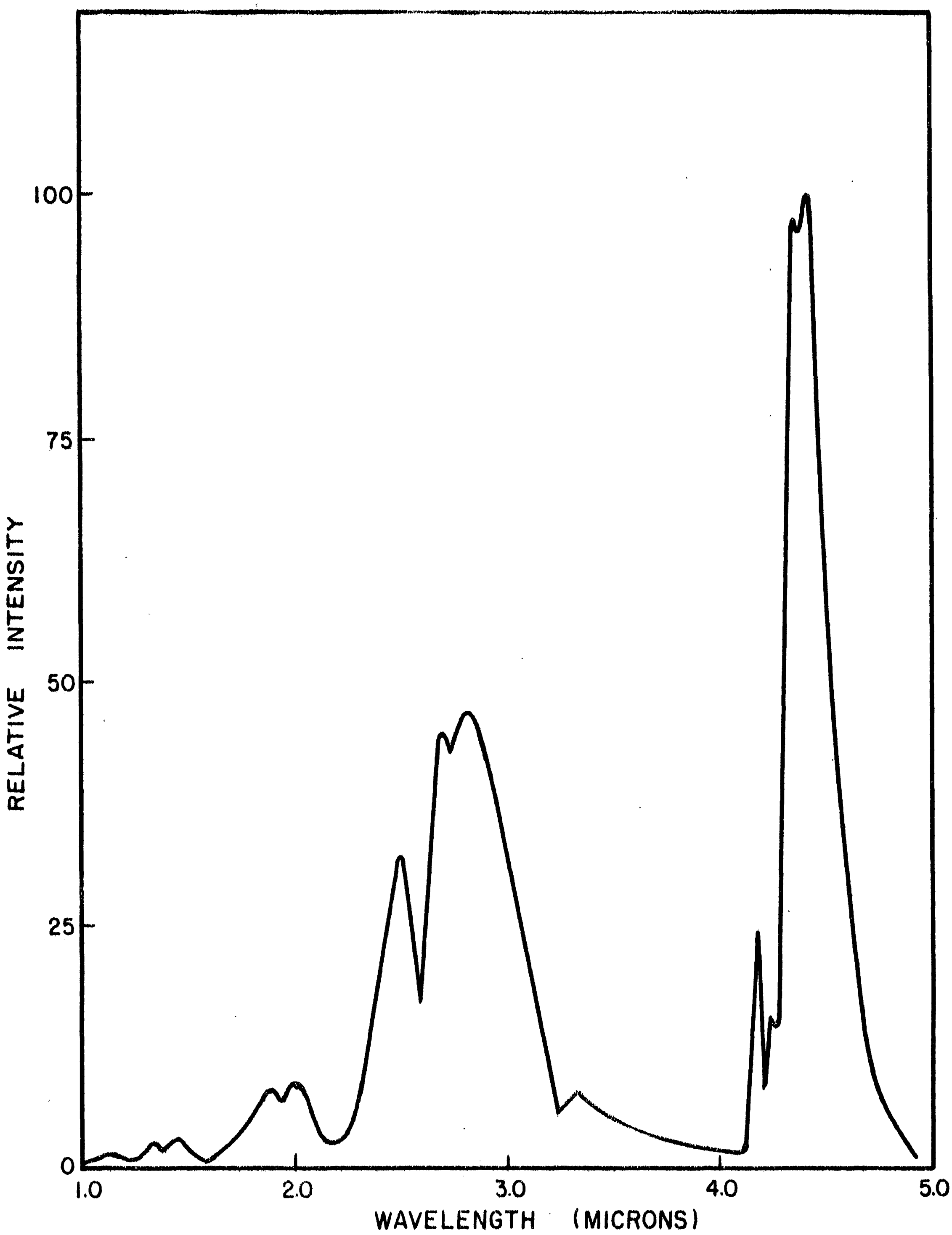

FIGURE 3. INFRARED EMISSION SPECTRUM OF A NATURAL GAS FLAME.