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HEAT UP TIME

FOREWORD

Many specifications use a standard heat up time for steel parts, sometimes as a function of part thickness. It is well known that these times are only approximate and often lead to errors when parts are coated, for example with copper plate. As a result, either excessive time is allowed for heating, or preproduction tests are recommended.

An analysis has been made to determine when extra caution is required. This document summarizes the results of the analysis, and recommends steps that can be taken to limit errors in heat up.

1. SCOPE:

An analysis was made of the effects of various surface conditions on the heat up time of steel bars which are heated in atmosphere furnaces to the temperature range used for steel hardening or normalizing. The purpose was to examine whether a standard heating time for a given section thickness is acceptable.

2. REFERENCES:

There are no referenced publications specified herein.

3. ANALYSIS OF HEAT UP TIME FOR BATCH HEAT TREAT LOADS:

3.1 Conditions of Analysis:

The analysis was made for a load of solid cylinders arranged in soldier fashion with the long axis vertical. Constraints used were:

3.1.1 Atmosphere furnace (nonoxidizing), uniformly at a temperature of 1600 °F (870 °C) before the start of heating.

3.1.2 When the load is charged, the furnace walls drop in temperature to 1100 °F (590 °C), recovering to the 1600 °F temperature at a constant rate in 45 min. Heating time of the core of slowest part (in the center of the load) is calculated as the time to reach within 25 °F (14 °C) of set point, that is, to 1575 °F (857 °C).

NOTE: Calculations were made in English units. Metric equivalents are shown for reference only and are not intended to be exact conversions.

3.1.3 Parts considered had a length/diameter ratio equal to 6 and were maintained at a constant (center to center)/diameter ratio equal to 4. For example, 1 in (25 mm) diameter rounds would be 6 in (150 mm) long and arranged with a center to center spacing of 4 in (100 mm). A 4 in (100 mm) diameter round would be 24 in (610 mm) long and spaced 16 in (410 mm) center to center. This method of assigning the configuration permits the results to be only a function of part emissivity, diameter, and amount of convection.

3.1.4 An open grid type fixture of about 200 lb (90 kg) supported the load.

3.2 Analytical Results:

3.2.1 Figure 1 shows the calculated heating times for various emissivities for rounds from 1 to 4 in (25 to 100 mm) diameter for a furnace with no convection. This would be typical of a vacuum furnace.

3.2.2 Figure 2 shows the same calculation for a furnace with fan circulation (convective heat transfer coefficient h=2).

4. DISCUSSION:

4.1 As can be readily seen from the figures, very bright surfaces (those with low emissivities) tend to heat very slowly compared to darker surfaces. If convection is used in the furnace, the effect is reduced but still not eliminated.

4.2 Typical emissivities of various materials are listed in Table 1. Also shown is the expected heating time of a 4 in round, expressed as hours heating time per inch of thickness, in this case diameter. From this table one can see that heat up time cannot be considered a constant as is presented in most specifications, but varies widely according to the type of furnace, i.e., amount of convection, and the surface emissivity.

4.3 The calculated values were compared with limited reference material and found to be in reasonable agreement, erring perhaps on the conservative side. For example, "Tool Steel Simplified" (publication date unknown) showed that a 1-1/2 in (38 mm) diameter bar heated to 1450 °F (790 °C) in an atmosphere controlled electric furnace required 36 min, whereas Figure 2 would predict about 60 min to 1600 °F (870 °C).

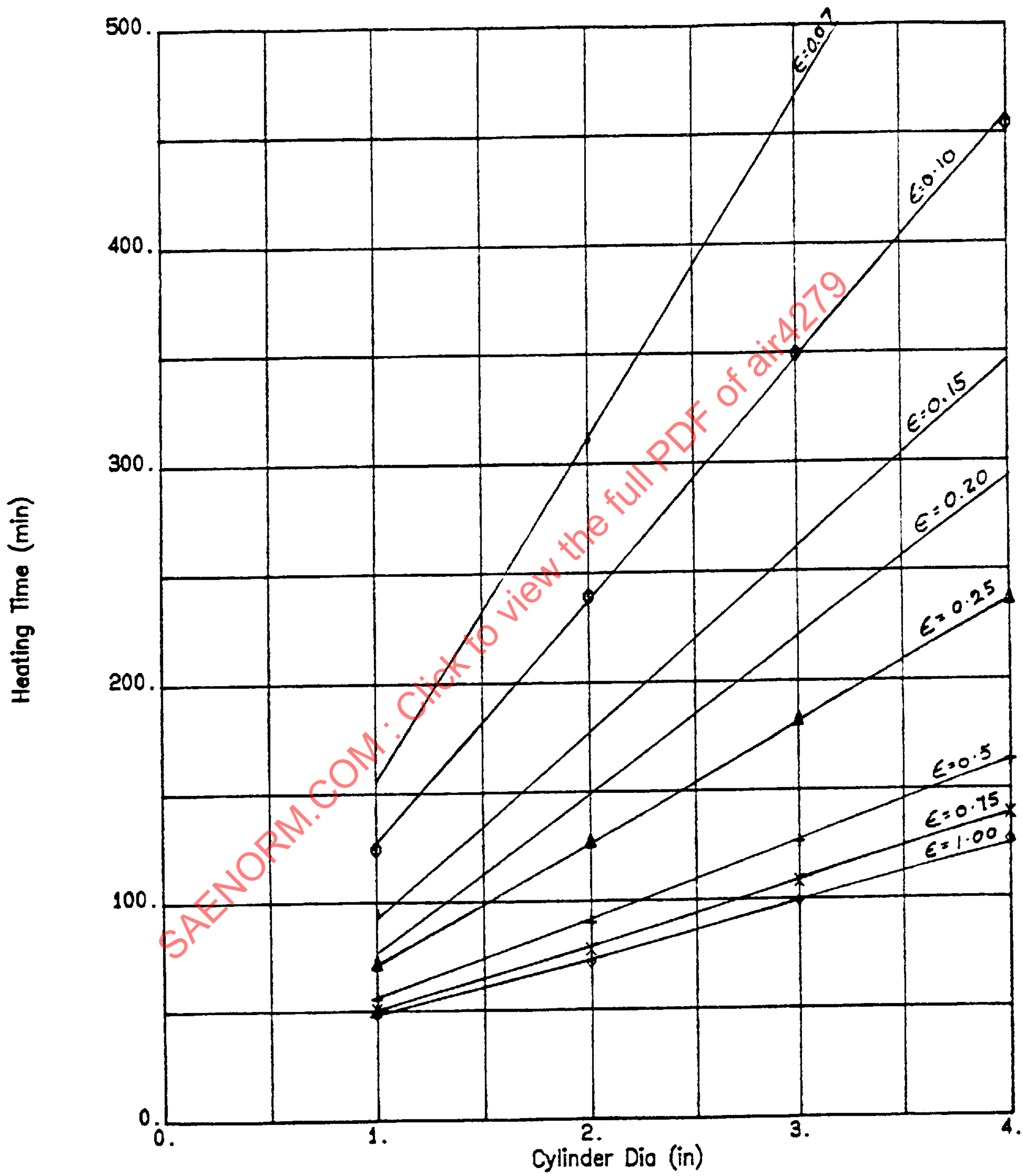

FIGURE 1 - Heating Time to a Furnace Temperature of 1600 °F for Vertical Cylinders Heated in a Vacuum Type Furnace (h=0) as a Function of Surface Brightness (Emissivity)

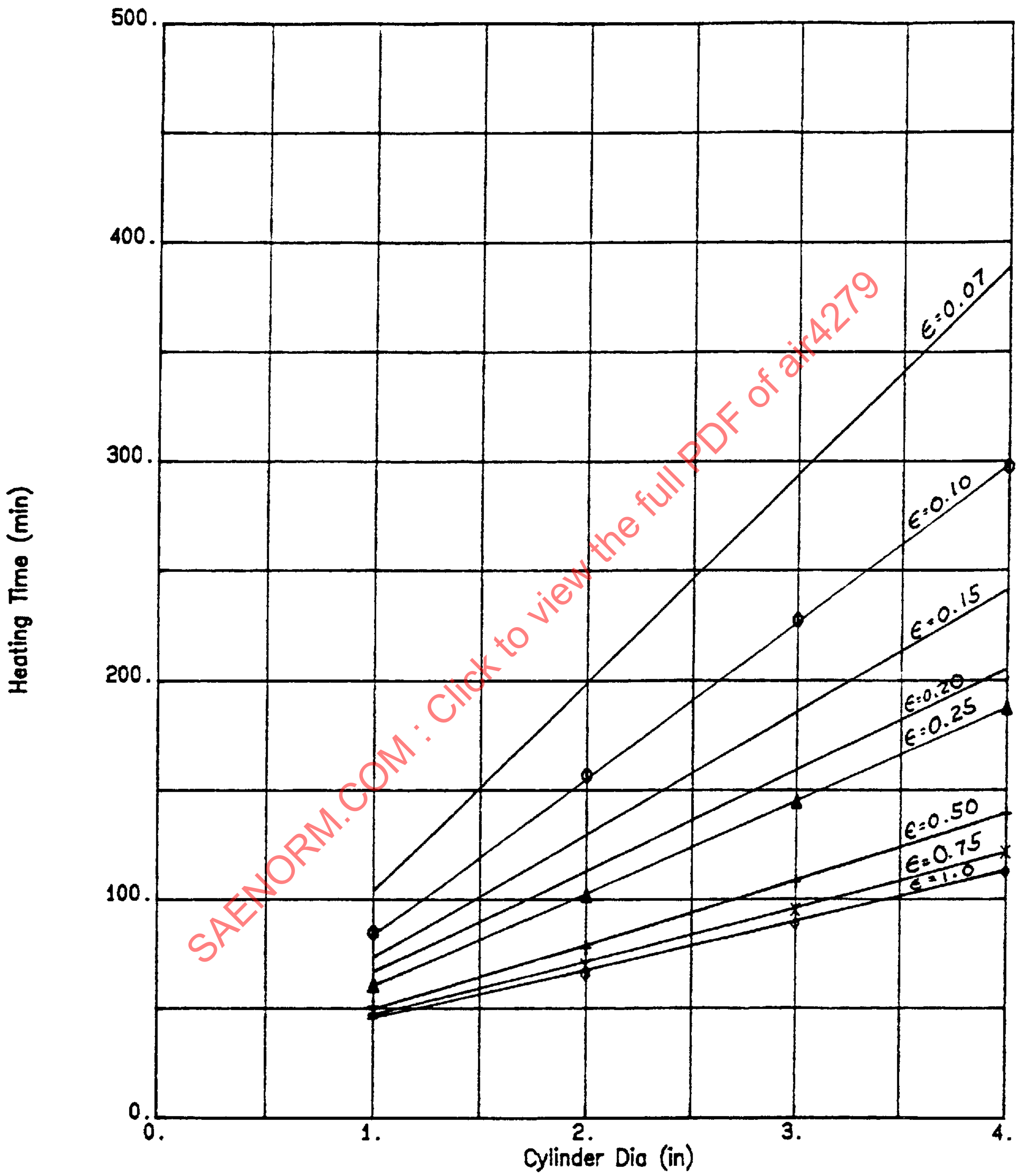

FIGURE 2 - Heating Time to a Furnace Temperature of 1600 °F for Vertical Cylinders Heated in a Convection Type Atmosphere Furnace (h=2) as a Function of Surface Brightness (Emissivity)

TABLE 1 - Emissivities of Various Metal Surfaces and Effect on Heating Rate (to 1600 °F)

		Emissivity	K Factor[1]	Example for 4 in Round Expected Heating Rate[2] (hr / in of thickness) No Convection	High Convection
1.	Clean, cold rolled steel	0.18 - 0.2	1	1.3	0.9
2.	Hot rolled, forged or cast steels, cleaned of scale	0.4	1	0.7	0.6
3.	Coated, smooth steels (alum. or galv.)	0.40	1	0.7	0.6
4.	Copper plate on steel	0.07	1	2.7	1.6
5.	Clean, smooth stainless steel	0.20 - 0.30	.85	1.2	0.9
6.	Oxidized stainless steel	0.78	.85	0.67	0.6
7.	Sandblasted stainless steel	0.60	.85	0.75	0.66
8.	Clean, smooth titanium sheet	0.30 - 0.40	.5	1.6	1.4

NOTES:

1. For materials of low conductivity (5, 6, 7, 8), adjustment must be made in the figures for this effect. This is done using K. K factor = conductivity of this material divided by conductivity of steel.
2. Heating time for steel from figure divided by conductivity factor.
3. For steel which has been oxidized, then reduced in the furnace, use values for sandblasted stainless steel.
4. For copper plate oxidized, then reduced in the furnace, use values for clean, cold rolled steel.

EXAMPLE: Heating an oxidized stainless steel, 4 in diameter to 1600 °F in a convection furnace:

a. Heating time from Figure 2, for .78 emissivity - approximately 130 min
b. Divide by 4 (inches), convert to hours (divide by 60)
c. Divide result by 0.85 (K)
d. Result is 0.64 h/in