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AN INVESTIGATION OF AIRCRAFT HEATERS

VII - THERMAL RADIATION FROM ATHERMANOUS EXHAUST GASES

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WASHINGTON

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ADVANCE RESTRICTED REPORT

AN INVESTIGATION OF AIRCRAFT HEATERS

VII - THERMAL RADIATION FROM ATHERMANOUS* EXHAUST GASES

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SUMMARY

Equations and necessary data for the calculation of the gaseous radiation from water vapor and carbon dioxide in an exhaust gas heat exchanger are presented. A typical calculation is included.

INTRODUCTION

In exhaust gases which contain appreciable quantities of carbon dioxide and water vapor, the thermal radiation from these constituents of the gas to the surroundings is not always negligible.

Hottel and Egbert have compiled the latest data which are useful for the calculation of this radiant fraction. Under conditions normally found in airplane heat exchangers, the most recent corrections proposed by these authors (references 2 and 3) do not greatly change their former suggestions (reference 1).

In this report the emission and absorption of radiant energy is calculated for water vapor and carbon dioxide, and a correction is made to account for the overlapping emission and absorption frequencies of these two gases.

Other constituents of exhaust gases, such as carbon particles, ozone, carbon monoxide, and organic compounds, also emit and absorb energy, but usually their concentrations are small and little is known about their effects. The radiation related to the luminosity of the gases, however, can be calculated. Diatomic nonpolar molecules, such as O_2, H_2, and N_2, do not emit or absorb radiant energy at wavelengths important to radiant heat transfer

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*Capable of emitting and absorbing radiant energy.

SYMBOLS

a_g over-all absorptance factor of gas

C_{CO_2} correction factor for effect of total pressure on CO_2 radiation evaluated from figure 2

C_{H_2O} correction factor for effect of total pressure on H_2O radiation evaluated from figure 4

K correction factor due to presence of both CO_2 and H_2O evaluated from figure 5

L mean beam length which is equal to 0.9 times the diameter for infinite cylinder radiating to walls

P_{CO_2} partial pressure of CO_2 atmospheres

P_{H_2O} partial pressure of H_2O atmospheres

$\left(\frac{q}{A}\right)_{H_2O+CO_2}$ radiant energy interchange due to athermanous gas radiation, Btu/hr ft^2

$^{\circ}R$ Rankine = $^{\circ}F + 460$

T_g absolute temperature of gas, $^{\circ}R$

T_s absolute temperature of surroundings, $^{\circ}R$

$\epsilon(CO_2, T_g, P_{CO_2} L)$ emissivity of CO_2 evaluated from figure 1 at T_g and $P_{CO_2} L$

$\epsilon\left(CO_2, T_s, P_{CO_2} L \frac{T_s}{T_g}\right)$ emissivity of CO_2 evaluated from figure 1 at T_s and $P_{CO_2} L \frac{T_s}{T_g}$

$\epsilon(H_2O, T_g, P_{H_2O} L)$ emissivity of H_2O evaluated from figure 3 at T_g and $P_{H_2O} L$

$\epsilon\left(H_2O, T_s, p_{H_2O} L \frac{T_s}{T_g}\right)$ emissivity of H_2O evaluated from figure 3 at T_s and $p_{H_2O} L \frac{T_s}{T_g}$

ϵ_g over-all emissivity factor of gas

ϵ_s emissivity of surrounding surface

DISCUSSION

To illustrate the use of the charts and equations for the calculation of the radiant energy interchange between gases containing water vapor and carbon dioxide and the surrounding surface, the following example is worked out:

Exhaust gas $t_g = 1300°$ F, $T_g = 1760°$ R

Exhaust pipe or heater walls, $t_s = 900°$ F, $T_s = 1360°$ R

I.D. of exhaust pipe = 0.5 ft (6 in.)

Total pressure = 0.5 atm*

Volume percent H_2O vapor = 15 percent = 0.075 atm

Volume percent CO_2 = 15 percent = 0.075 atm

The radiant energy interchange may be calculated from:

$$\left(\frac{q}{A}\right)_{H_2O + CO_2} = 0.1723 \; \epsilon_s \left[\epsilon_g \left(\frac{T_g}{100}\right)^4 - a_g \left(\frac{T_s}{100}\right)^4\right] \qquad (1)$$

where

$$\epsilon_g = \left[c_{CO_2} \; \epsilon(CO_2, T_g, p_{CO_2} L) + c_{H_2O} \; \epsilon(H_2O, T_g, p_{H_2O} L) - K\right] \qquad (2)$$

and

$$a_g = \left[c_{CO_2} \; \epsilon\left(CO_2, T_s, p_{CO_2} L \frac{T_s}{T_g}\right) \left(\frac{T_g}{T_s}\right)^{0.65} + c_{H_2O} \; \epsilon\left(H_2O, T_s, p_{H_2O} L \frac{T_s}{T_g}\right) \left(\frac{T_g}{T_s}\right)^{0.45} - K\right] \qquad (3)$$

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*Example is evaluated for altitude at which total pressure is 0.5 atm.

Determining numerical magnitudes

$L = 0.9 \times 0.5 \text{ ft} = 0.45 \text{ ft}$

$$P_{CO_2} L = P_{H_2O} L = 0.075 \times 0.45 = 0.0338 \text{ ft atm}$$

$$P_{CO_2} L \frac{T_s}{T_g} = P_{H_2O} \times L \frac{T_s}{T_g} = 0.075 \times 0.45 \times \frac{1360}{1760} = 0.0261$$

$$\epsilon_s = 0.79 \text{ (average value for oxidized steel)}$$

$$\epsilon(CO_2, T_g, P_{CO_2} L) = 0.052 \text{ (from fig. 1)}$$

$$\epsilon\left(CO_2, T_s, P_{CO_2} L \frac{T_s}{T_g}\right) = 0.047 \text{ (from fig. 1)}$$

$$\epsilon(H_2O, T_g, P_{H_2O} L) = 0.028 \text{ (from fig. 3)}$$

$$\epsilon\left(H_2O, T_s, P_{H_2O} L \frac{T_s}{T_g}\right) = 0.030 \text{ (from fig. 3)}$$

$$C_{CO_2} = 0.78 \text{ (from fig. 2)(for total pressure} = 0.5 \text{ atm)}$$

$$C_{H_2O} = 0.88 \text{ (from fig. 4)(for total pressure} = 0.5 \text{ atm)}$$

$$K = 0.00 \text{ (from fig. 5)}$$

Therefore, from equations (2) and (3):

$$\epsilon_g = 0.78 \times 0.052 + 0.88 \times 0.028 - 0.00 = 0.0651$$

$$a_g = \left[0.78 \times 0.047 \times \left(\frac{1760}{1360}\right)^{0.65} + 0.88 \times 0.030 \times \left(\frac{1760}{1360}\right)^{0.45} - 0.00\right]$$

$$= [0.0433 + 0.0296 - 0.00] = 0.0729$$

Then from equation (1)

$$\left(\frac{q}{A}\right)_{CO_2 + H_2O} = 0.1728 \times 0.79 \left[0.0651 \left(\frac{1760}{100}\right)^4 - 0.0729 \left(\frac{1360}{100}\right)^4 \right]$$

$$= 0.137 \quad [6250 - 2500] = 0.137 \times 3750$$

$$= 512 \text{ Btu/hr ft}^2$$

If this radiant energy interchange took place in an exhaust heater which was 0.5 foot in diameter and 3 feet in length, then

$$q_{(CO_2 + H_2O)} = 512 \; (\pi \times 0.5 \text{ ft} \times 3 \text{ ft})$$

$$= 2410 \text{ Btu/hr}$$

If the thermal output were 50,000 Btu/hr total exchange, then the fraction due to athermanous gas radiation would be 4.8 percent of the total.

In the experiments conducted in the University of California Mechanical Engineering Laboratory on straight and finned double tube heat exchangers (references 4 and 5), the athermanous gas radiation was less than 1 percent of the total transfer, because of the low concentrations of CO_2 and H_2O vapor.

CONCLUSIONS

The radiant interchange taking place in an exhaust gas heat exchanger due to the emission and absorption characteristics of water vapor and carbon dioxide may be calculated, employing gaseous radiation data of Hottel. There are not sufficient data to account accurately for the radiant energy interchange from other gases, such as carbon monoxide and hydrocarbons.

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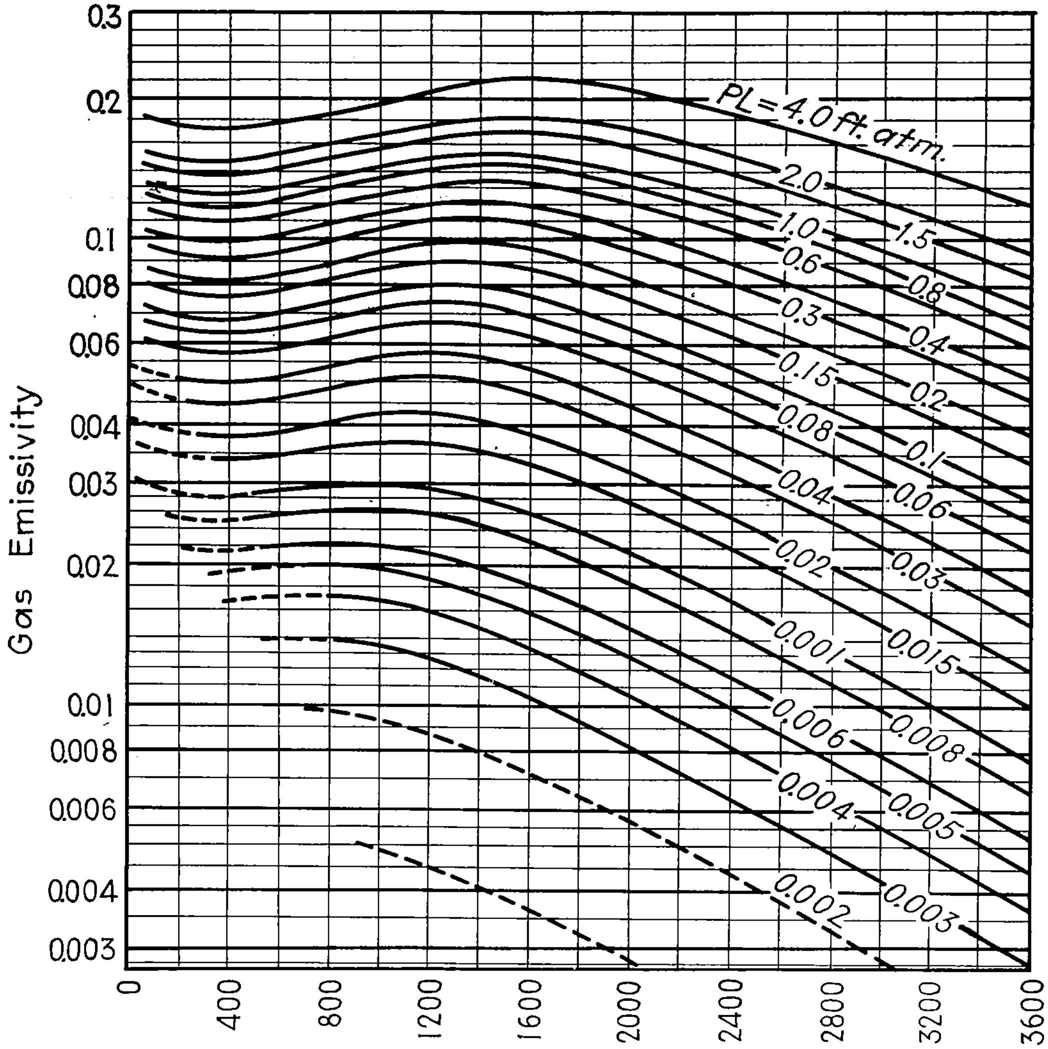
NOTE: The figures of this report have been reproduced from "Radiant Heat Transmission from Water Vapor," by H. C. Hottel and R. B. Egbert, appearing in vol. 38, no. 3 of the Transactions of the American Institute of Chemical Engineers, with the permission of the authors. The ordinates of figures 2, 4, and 5 have been changed as indicated below:

Fig. 2, ordinate is renamed C_{CO_2}

Fig. 4, ordinate is renamed C_{H_2O}

Fig. 5, ordinate is renamed K

The coordinates of figures 1 and 3 remain unchanged.



(This is figure 22 of reference 3)

Figure 1.- Working plot of carbon dioxide radiation.

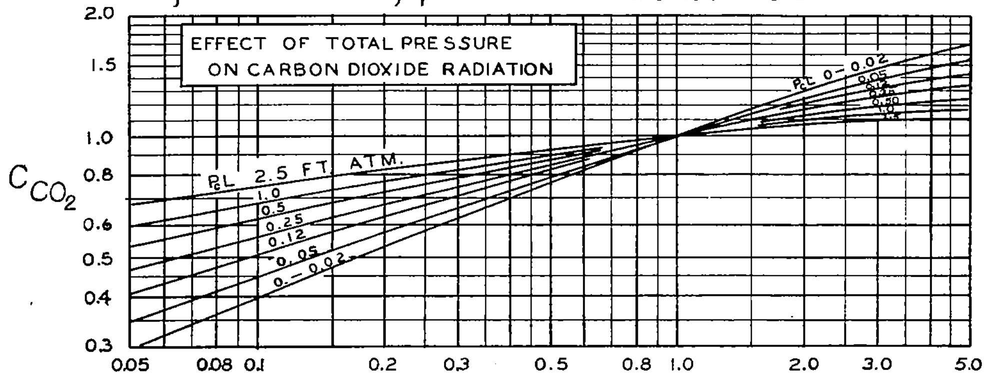


Figure 2.- Correction for effect of total pressure on carbon dioxide radiation.

(This is figure 21 of reference 3. Ordinate scale renamed)

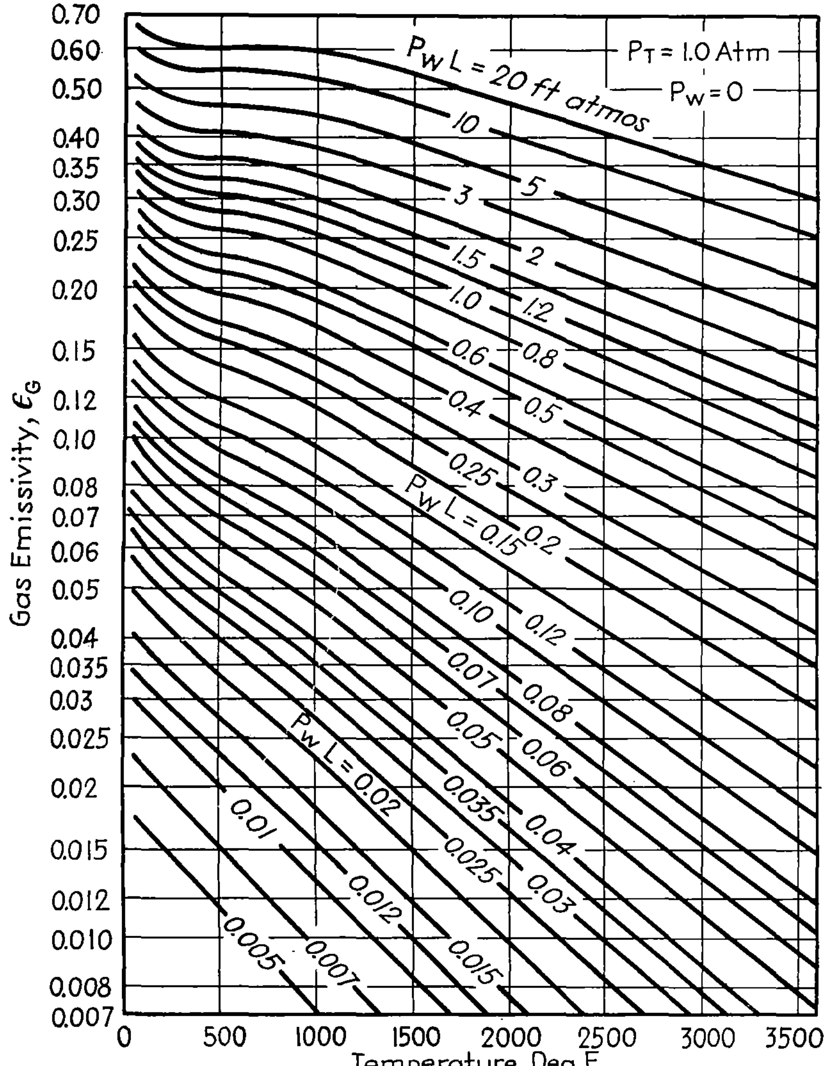


Figure 3.- Final working plot of water vapor emissivity, for $P_W=0$. (This is figure 18 of reference 3)

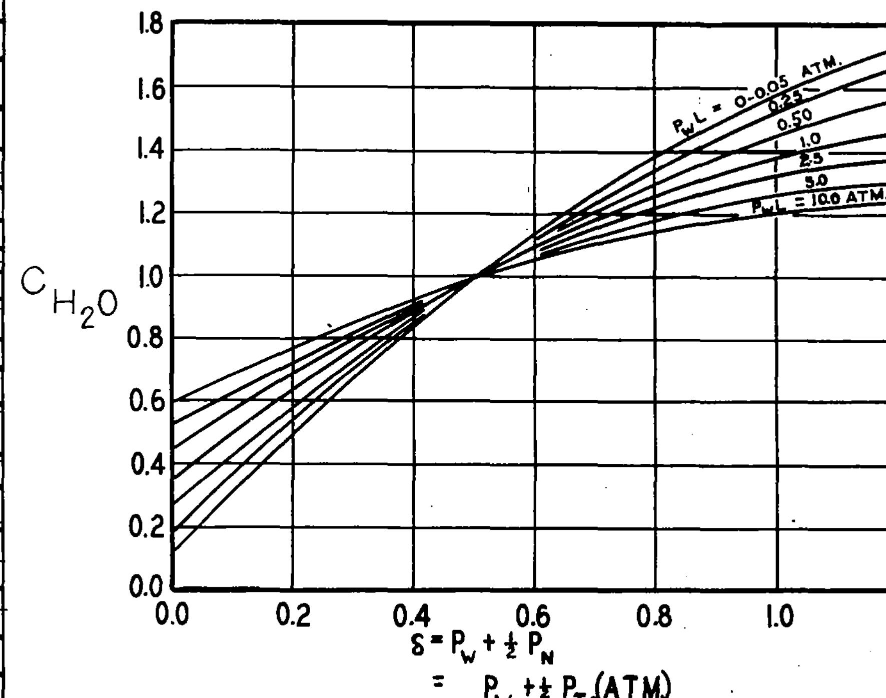


Figure 4.- Correction for effect of total pressure and partial prressure on water vapor radiation.

(This is figure 20 of reference 3. Ordinate scale renamed)

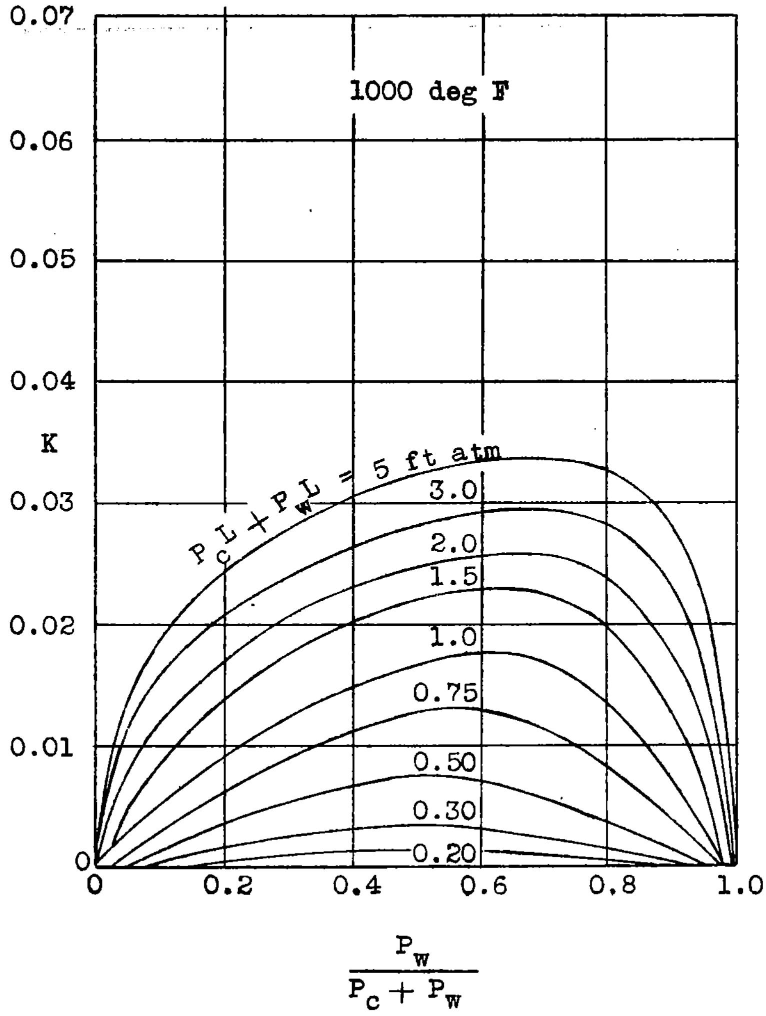


Figure 5.- Correction for superimposed radiation from mixtures of carbon dioxide and water vapor.

Ordinate scale renamed.

This figure taken from figure 19 reference 3.

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ABSTRACT:

Equations and necessary data for calculations of gaseous radiation from water vapor and carbon dioxide in exhaust gas heat exchanger. Radiant interchange taking place in an exhaust gas heat exchanger because of emission and absorption characteristics of water vapor and carbon dioxide, may be calculated by employing gaseous radiation data by Hettel. Experiments on straight and finned double tube heat exchangers showed that athermanous gas radiation was less than 1% of total transfer because of low carbon concentrations of CO_2 and H_2O vapor.

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