DECLASSIFIED

[redacted]

UNCLASSIFIED

NRL REPORT N-3376

FR-3376

THE TRANSMISSION OF INFRARED RADIATION FROM FLAMES BY CO_2

DECLASSIFIED by NRL Contract Declassification Team
Date: 5 JAN 2017
Reviewer's name(s): [redacted]
Declassification authority: NAVY DECLASS GUIDE/NAVY DECLASS MANUAL, 11 DEC 2012

DECLASSIFIED: By authority of DOD DIR 5200.10
Cite Authority Date
Entered by NRL Code

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

DISTRIBUTION STATEMENT A APPLIES.
Further distribution authorized by UNLIMITED only.

[redacted]

DECLASSIFIED

CONFIDENTIAL

NRL REPORT N-3376

DECLASSIFIED

THE TRANSMISSION OF INFRARED RADIATION FROM FLAMES BY CO_2

J. A. Curcio and D. V. Estes

October 29, 1948

Approved by:

J. S. Sanderson, Head, Radiometry Section
E. O. Hulburt, Superintendent, Optics Division

NAVAL RESEARCH LABORATORY

CAPTAIN H. A. SCHADE, USN, DIRECTOR

WASHINGTON, D.C.

DECLASSIFIED

CONFIDENTIAL

DISTRIBUTION

ONR	
Attn: Code N-482	2
BuShips	
Attn: Code 947	5
BuOrd	
Attn: Code Re4e	5
BuAer	
Attn: Code EL-71	5
Attn: Code TD-4	1
Dir., USNEL	2
Cdr., USNOTS	
Attn: Reports Unit	2
OCSigO	
Attn: Ch. Eng. & Tech. Div., SIGTM-S	1
CO, SCEL	
Attn: Dir. of Engineering	2
RDB	
Attn: Library	2
Attn: Navy Secretary	
Attn: Electronics Committee, Infrared Panel	25
Science and Technology Project	
Attn: Mr. J. H. Heald	2

CONTENTS

ABSTRACT

The transmission of infrared radiation from flames through various pathlengths of CO_2 was determined in the Laboratory. The results show that a considerable amount of flame energy is transmitted in the regions 2.5 μ to 3.5 μ and 4.0 μ to 5.5 μ. For example a pathlength of 15 meters of CO_2 at 760 mm pressure transmitted 20 percent of the energy in the band regions from 4.0 μ to 5.5 μ. Curves are included which show the flame emission through 10, 50, 122, 244, 300, 500, and 1500 cm of CO_2 at pressures of 100, 200, 400, 600, and 760 mm Hg. The integrated absorption coefficients for the two bands have been calculated and are included in tables and graphs.

PROBLEM STATUS

This is an interim report on this problem, work is continuing.

AUTHORIZATION

NRL Problem N04-2R

THE TRANSMISSION OF INFRARED RADIATION
FROM FLAMES BY CO_2

INTRODUCTION

The oxy-propane flame has many emission bands in the infrared. The strongest band emitted by hot carbon dioxide in the flame usually occurs at about 4.4 μ.[1] Other infrared emission bands occur in the 2.8-μ region and are produced by carbon dioxide and water. It is a well known phenomenon that the emission bands are at slightly longer wavelengths than the corresponding absorption bands. For example, the 4.42-μCO_2 emission band corresponds to the CO_2 absorption band at 4.25 μ.

The purpose of these experiments was to determine empirically the attenuation of the CO_2 emission bands by CO_2 gas at room temperature, 24°C, and at various pressures and absorbing pathlengths. The values thus obtained may serve as guides in calculating atmospheric infrared absorption of the radiation from flames at various altitudes corresponding to the pressures investigated in the Laboratory.

Lambert's law states that when a monochromatic beam of radiation, I_o, enters a homogeneous material, the amount transmitted, I, will have an intensity of

$$I = I_o e^{-kt}, \quad (1)$$

where t is the absorbing pathlength and k is the absorption coefficient. From Beer's law this absorption coefficient is in turn proportional to the concentration of the absorbing gas. However, there are serious deviations from these laws first observed by Angstrom[2] in his classic experiment with a two-compartment cell. In this experiment the first compartment was filled with CO_2 and a transmission measurement was made. Then the gas was allowed to expand into the second compartment, which increased the optical pathlength but reduced the pressure, and the transmission was measured again. Angstrom found a considerable decrease in the absorption when the pressure was reduced, notwithstanding the fact that the amount of gas remained constant. When a dry and carbon dioxide-free gas was let into the cell, until the original pressure was restored, the absorption rose to its original value. This is due to the pressure broadening of the individual absorption lines in the band.

---

[1]In certain types of discharges a band at 2.2 μ has been observed to be stronger than the 4.4-μ band. Ginsburg, "Infrared sources for use as radiators in the spectrum band from 1 micron to 25 microns." Syracuse University Physics Report No. 102-5, Oct. 18, 1948.

[2]For a discussion and extensive bibliography on the absorption laws for gases in the infrared, see J. R. Nielson, V. Thornton and E. B. Dale, Rev. Mod. Phys. 16, pp. 307-324, July-October 1944.

A thorough investigation of the effect of pressure and temperature on the infrared absorption coefficients of atmospheric gases is in progress at the Johns Hopkins University under ONR Contract. This study will permit a more refined treatment of high-altitude atmospheric transmission problems, but for the present the assumption is made that the absorption by a known pathlength of CO_2 at any specified pressure will be equal to the absorption of a much longer path of air at that specified pressure containing the same amount of CO_2. Results of current investigations are primarily for use in estimating the transmission of infrared radiation from jet aircraft through the atmosphere to an infrared detection system, and they are thought to be of adequate accuracy for such a purpose.

For example, the transmission of the flame radiation in the 4.0 μ to 5.5 μ region by 600 cm of CO_2 at 200 mm pressure was found to be 46 percent. Atmospheric pressure at 10 km above sea level is 200 mm, and a pathlength of 600 cm of CO_2 at the same pressure in the laboratory corresponds to a 15-km pathlength in air at this altitude, assuming 0.03 percent CO_2 content and a temperature of -50^0C. Thus, at an altitude of 10 km, an airpath of 15 km will transmit approximately 46 percent of the 4.0 μ - 5.5 μ emission band.

EXPERIMENTAL

A Perkin Elmer infrared spectrometer with rock salt prism was used to measure the infrared flame emission and absorption spectra. An auxiliary optical system was used to direct the flame radiation into the spectrometer. The room temperature was kept constant at 24°C. Seven absorption cells provided pathlengths of 10, 50, 122, 244, 300, 600, and 1500 cm. The 10, 50, 122, and 244 cm cells were made of standard pyrex glass tubing 90 mm in diameter and sealed at both ends with polished rock salt windows. The same two windows were attached to the various cells as the experiment progressed. The 300 and 600 cm cells were made of brass tubing 86 mm in diameter. They were blackened internally and provided with suitable stops to prevent reflection from the sides. The 1500-cm cell (Figure 1) consisted of two brass sections, 86 mm in diameter, joined by a brass "V" which had a small included angle of about 4 degrees. This cell was also blackened and diaphragmed. A front-surfaced aluminum mirror was attached to the back end of the "V" connection so as to reflect the parallel light from one cell branch to the other.

The burner used was a National Blowpipe torch adjusted to burn propane and oxygen. The propane was burned at about 0.04 cfm measured by a Fischer and Porter Florator. Enough oxygen was supplied to give maximum energy output at the 4.42-μ region. Under these conditions the oxygen was fed at about 12 psi. The flame was about 1/2 inch in diameter and the radiation came from a section, 1/2 inch long just above the small inner cone, the temperature being about 2800°K.

The radiation from the torch was collimated by means of a 27-cm focal length, F/3.8 parabolic mirror which was ground $10^{0'}$ off axis. The collimated beam traversed the absorption cell and was focused on the slit of the spectrometer by an F/2.0 parabolic mirror whose focal length was 30 cm. A small front-surfaced plane mirror was used in conjuction with the second parabolic mirror. An attempt was made to keep the slit width constant at 0.10 mm corresponding to a spectral band width of .075 μ at 4.4 μ, for all the runs. However, with the longer cells it was necessary to use wider slits. Suitable stops were used in the absorbing cells and in the outside airpath which reduced the collimated beam to 63 mm in diameter.

When in operation, the spectrometer was continuously flushed with dry nitrogen. Readings were made, first through evacuated cell and then through the dry commercial grade

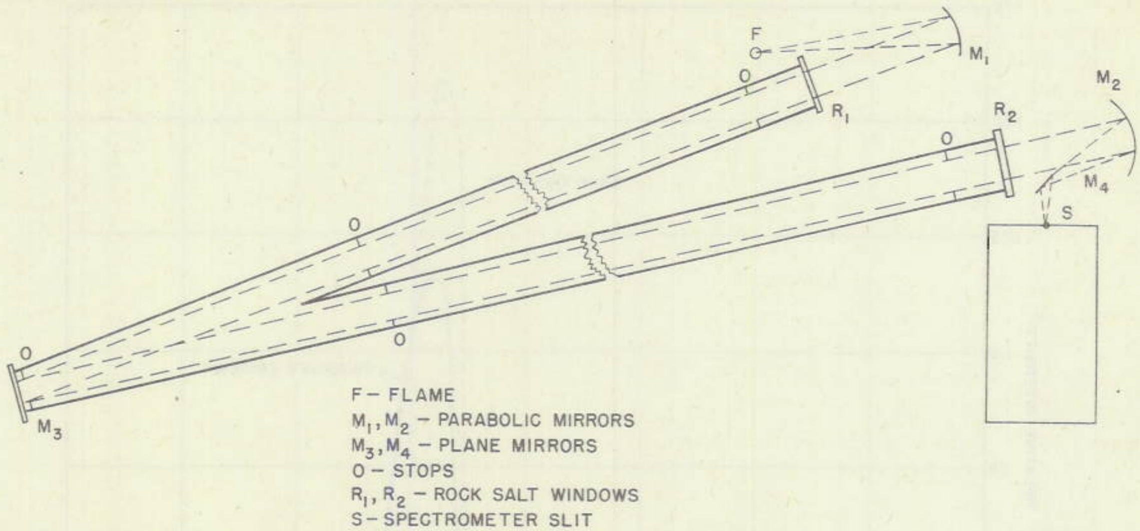

Fig. 1 - Schematic diagram of 1500 cm cell

CO_2 of about 99 percent purity. Measurements were made with each absorption cell at 100, 200, 400, 600, and 760 mm of Hg in that order with two or more runs at each pressure.

In carrying out these experiments it was necessary to have an external optical path of 190 cm which accounted for a surprisingly large percentage absorption of the infrared flame emission. In addition it was discovered that, as the experiment progressed, the CO_2 from the flame combustion considerably increased the CO_2 content in the 190-cm external optical path. To alleviate this condition, a sheet-metal chimney 6 inches in diameter and 5 feet long, with suitable apertures was placed over the flame. The upper end of the chimney was close to a ventilation blower which pulled the combustion gases out of the room. By this method it was possible to maintain fairly stable conditions, and check runs made before and after a series of runs showed small changes in the airpath absorption.

The absorption of the 190-cm airpath was determined by measuring the globar emission through air in the spectrometer optical path which measured about 190 cm. Spectral absorption factors were determined for the 2.8 μ and 4.25 μ regions. Specifically, the globar emission through the absorption bands was determined and the spectal absorption factors were calculated by smoothing out the globar emission envelope at the absorption regions. These spectral absorption factors for CO_2 and water vapor through the 190-cm airpath were then applied to the flame emission bands. Thus it was found that the airpath transmitted 80.6 percent of the CO_2 band from 4.0 μ - 5.5 μ and 88.6 percent of the combined CO_2 and water vapor bands at 2.5 μ to 3.5 μ. Figure 2 shows the flame emission through the air path and also the corrected emission with no absorption. The percentage transmission factors were determined by comparison of the integrated areas under the respective curves. This is valid inasmuch as all subsequent measurements were normalized[3] to compensate for changes in the measured bandwidth with constant slit width.

It should be noted that the CO_2 in the external airpath was at its normal atmospheric pressure. An estimate of its effect is to say that 190 cm of air at 760 mm pressure

[3] W. E. Forsythe - Measurement of radiant energy McGraw Hill (1937).

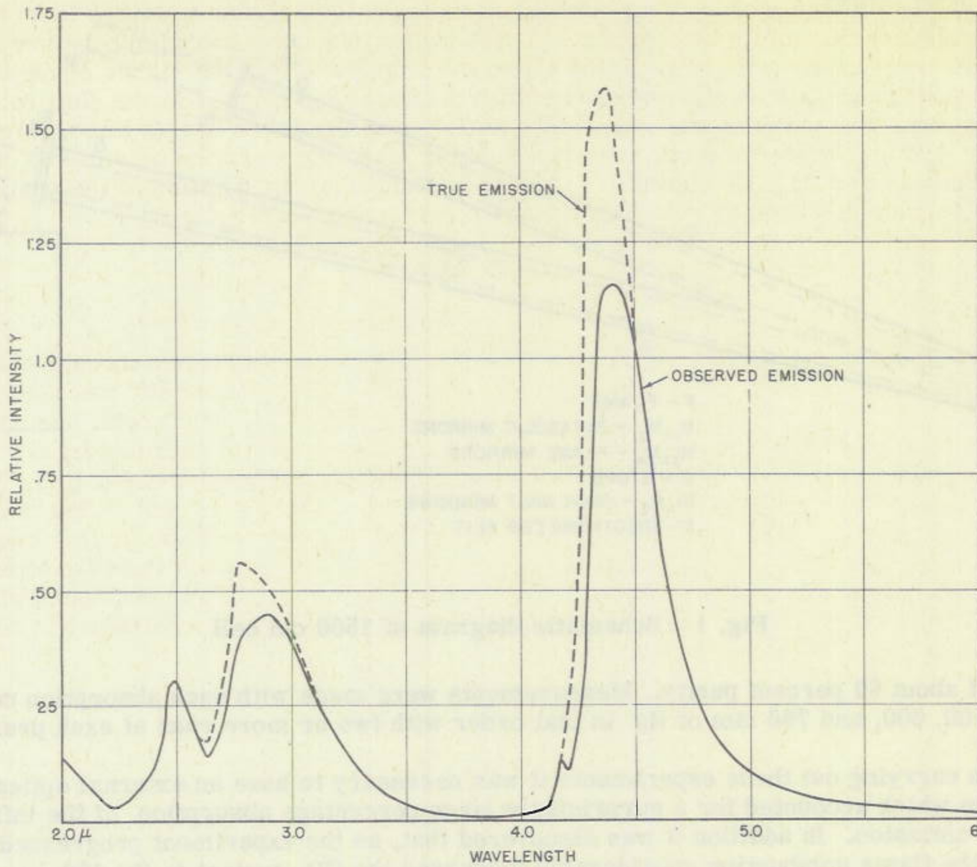

Fig. 2 - Infrared flame emissions showing loss through external 190 cm optical system

corresponds to 0.6 mm path of CO_2 at 760 mm pressure. Except in the short (10 cm) cell this small equivalent pathlength is relatively insignificant so that all the absorption can be attributed to the cell gas without introducing any serious error. The situation is more complicated when an equivalent to the airpath is sought for pressures other than normal atmospheric. This is because of pressure-broadening effects on the individual absorption lines in the bands. However, if one proceeds as before to attribute the whole of the absorption to the cell gas, one can do no more than make the results conservative, especially at the lower pressures in the short cells. In view of this, the same correction factor for absorption by the 190-cm external airpath was applied to all the data, regardless of pressure in the cell. Hence, the transmittance value for any one band at specified pressure and cell length has been reduced by an airpath correction.

DISCUSSION AND RESULTS

Two fundamental[4] absorption bands of CO_2 occur, one at about 4.25 μ and one at 15 μ, and a combination of CO_2 and water vapor bands occurs at about 2.8 μ. An emission band occurs with a peak at about 4.42 μ which corresponds to the 4.25 μ absorption band. When the corrections are made for absorption in the outside airpath, the peak is shifted to about

[4]G. Herzberg. Infrared and Raman spectra of polyatomic molecules. Van Nostrand, (1945).

4.38 μ.[5] The emission band occurs at longer wavelengths because it arises from transitions between thermally excited states. Absorption by a gas at room temperature arises from low level energy changes. In the flame the changes are in the higher energy levels with a consequent shift in the peak; the hotter the flame the greater is the shift to the longer wavelengths. The uncorrected emission peak for readings taken in this Laboratory occured at about 4.42 μ. When corrections were made for airpath absorption outside the cell, the true peak was at 4.38 μ as shown in Figure 2. In addition, the position of the peak emission may be further modified by selfabsorption within the flame itself.[6]

10-Cm Cell

Figure 3 shows the 2.5 μ - 3.5 μ and 4.0 μ - 5.5 μ emission bands through a 10-cm pathlength of CO_2 at various indicated pressures. The spectrometer slit was constant at 0.10 mm and the energy curves were normalized. Integration of the areas under the curve by planimeter between 2.5 μ and 3.5 μ showed a decrease in transmittance from 85 percent at 100 mm pressure to 74 percent at 760 mm pressure. In the region 4.0 μ to 5.5 μ, the transmittance varied from 75 percent at 100 mm pressure to 58 percent at 760 mm. Transmittance values obtained for other pressures are tabulated in Table I. In this region the radiation peak shifted from 4.41 μ with evacuated cell to 4.50 μ when the 10-cm cell was filled with CO_2 at 760 mm pressure. The CO_2 absorption at 4.8 μ was not apparent in any of this series of runs. The 10-cm CO_2 path at 760 mm pressure is equivalent to a 330-meter airpath at sea level.

50-Cm Cell

Figure 4 shows the 2.5 μ - 3.5 μ and the 4.0 μ - 5.5 μ emission bands through a 50-cm pathlength of CO_2 at various indicated pressures. The spectrometer slit was constant at 0.07 mm and the energy curves were normalized. Integration of the areas between 2.5 μ and 3.5 μ shows a decrease in transmittance from 82 percent at 100 mm pressure to 66 percent at 760 mm pressure. The somewhat finer band structure shown in this region is due to the smaller slit width used. At 4.0 μ to 5.5 μ the transmittance varied from 65 percent at 100 mm to 45 percent at 760 mm. Transmittance values for other pressures are tabulated in Table I. In this region the radiation peak shifted from 4.42 μ for the evacuated cell to 4.51 μ when the 50-cm cell was filled with CO_2 at 760 mm pressure. The CO_2 absorption band at 4.8 μ was just apparent, its effect being negligible in the total absorption. The 50-cm CO_2 path at 760 mm pressure is equivalent to 1665 meters of airpath at sea level.

122-Cm Cell

Figure 5 shows the 2.5 μ - 3.5 μ and the 4.0 μ - 5.5 μ emission bands through a 122-cm pathlength of CO_2 at the various indicated pressures. The spectrometer slit was constant at 0.20 mm and the energy curves were normalized. Integration of areas between 2.5 μ and 3.5 μ shows a decrease in transmittance from 80 percent at 100 mm to 66 percent at 760 mm. In the region 4.0 μ to 5.5 μ the transmittance decreased from 63 percent at 100 mm to 45 percent at 760 mm pressure. Transmittance values for other pressures are tabulated in Table I. The radiation peak shifted from 4.42 μ for the evacuated cell to 4.52 μ

---

[5] E. K. Plyler, NBS J. Research 40, 113-120 Feb. (1948).

[6] A. G. Gaydon - Spectroscopy and combustion theory Chapman & Hill, (1942).

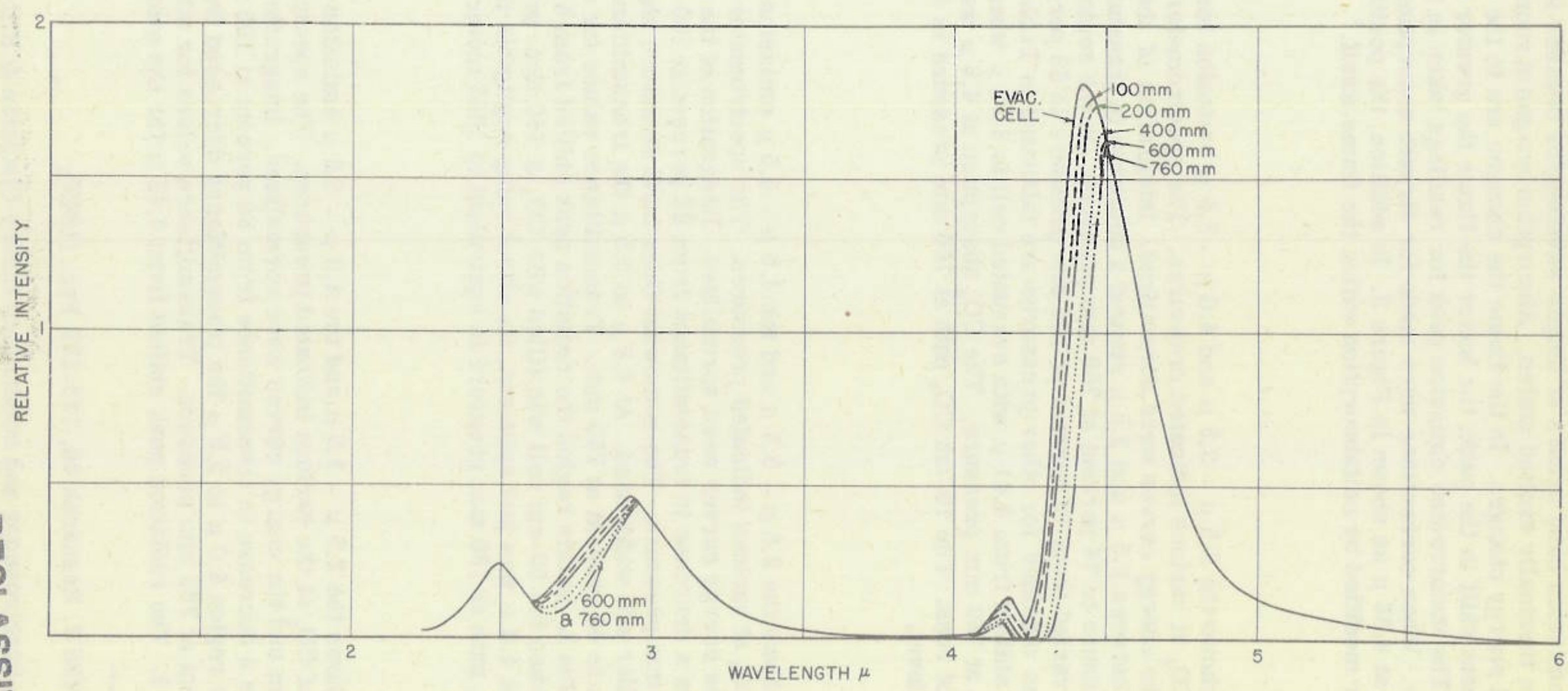

Fig. 3 - Infrared flame emission showing absorption by 10 cm of CO_2 at various pressures

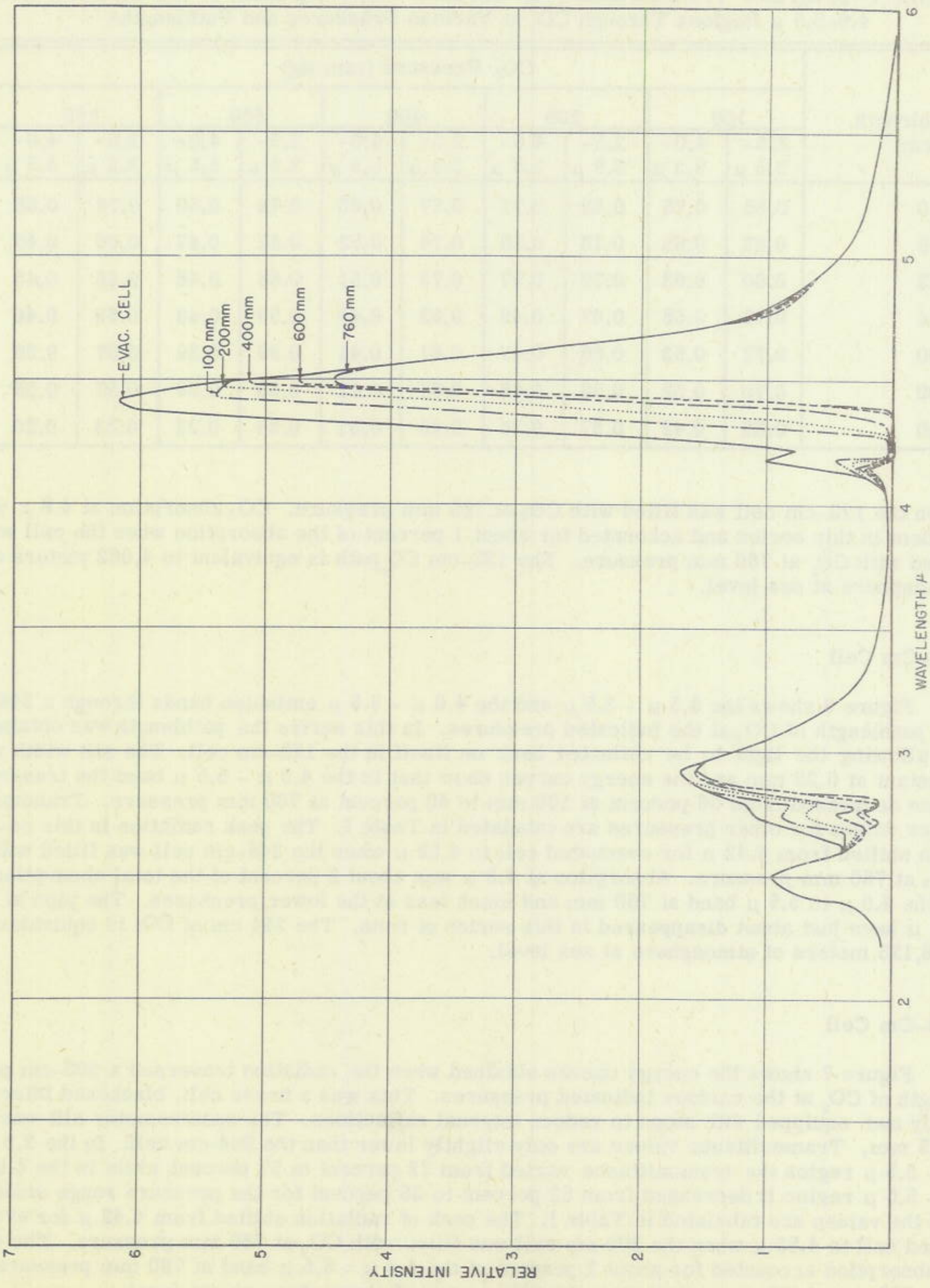

Fig. 4 - Infrared flame emission showing absorption by 50 cm of CO_2 at various pressures

TABLE I—Integrated Transmittances for Infrared Flame Emission at the 2.5-3.5 μ and 4.0-5.5 μ Regions Through CO_2 at Various Pressures and Pathlengths

Pathlength (cm)	CO_2 Pressure (mm Hg)									
	100		200		400		600		760	
	2.5-3.5 μ	4.0-5.5 μ	2.5-3.5 μ	4.0-5.5 μ	2.5-3.5 μ	4.0-5.5 μ	2.5-3.5 μ	4.0-5.5 μ	2.5-3.5 μ	4.0-5.5 μ
10	0.85	0.75	0.83	0.71	0.77	0.65	0.74	0.60	0.74	0.58
50	0.82	0.65	0.78	0.58	0.74	0.52	0.67	0.47	0.66	0.45
122	0.80	0.63	0.77	0.57	0.73	0.51	0.66	0.46	0.66	0.45
244	0.73	0.56	0.67	0.49	0.62	0.45	0.59	0.43	0.59	0.40
300	0.72	0.53	0.66	0.47	0.61	0.41	0.59	0.39	0.57	0.36
600	0.70	0.52	0.66	0.46	0.61	0.41	0.58	0.38	0.57	0.36
1500	0.63	0.42	0.57	0.36	0.48	0.31	0.36	0.23	0.33	0.20

when the 122-cm cell was filled with CO_2 at 760 mm pressure. CO_2 absorption at 4.8 μ was evident in this series and accounted for about 1 percent of the absorption when the cell was filled with CO_2 at 760 mm pressure. The 122-cm CO_2 path is equivalent to 4,062 meters of atmosphere at sea level.

244-Cm Cell

Figure 6 shows the 2.5 μ - 3.5 μ and the 4.0 μ - 5.5 μ emission bands through a 244-cm pathlength of CO_2 at the indicated pressures. In this series the pathlength was obtained by allowing the light to be reflected back on itself in the 122-cm cell. The slit width was constant at 0.25 mm and the energy curves show that in the 4.0 μ - 5.5 μ band the transmittance decreased from 56 percent at 100 mm to 40 percent at 760 mm pressure. Transmittance values for other pressures are tabulated in Table I. The peak radiation in this region shifted from 4.42 μ for evacuated cell to 4.53 μ when the 244-cm cell was filled with CO_2 at 760 mm pressure. Absorption at 4.8 μ was about 2 percent of the total absorption in the 4.0 μ to 5.5 μ band at 760 mm and much less at the lower pressures. The pips at 4.1 μ have just about disappeared in this series of runs. The 244 cm of CO_2 is equivalent to 8,125 meters of atmosphere at sea level.

300-Cm Cell

Figure 7 shows the energy curves obtained when the radiation traversed a 300-cm pathlength of CO_2 at the various indicated pressures. This was a brass cell, blackened internally and equipped with stops to reduce internal reflections. The spectrometer slit was 0.25 mm. Transmittance values are only slightly lower than the 244-cm cell. In the 2.5 μ - 3.5 μ region the transmittance varied from 72 percent to 57 percent while in the 4.0 μ - 5.5 μ region it decreased from 53 percent to 36 percent for the pressure range studied. All the values are tabulated in Table I. The peak of radiation shifted from 4.42 μ for evacuated cell to 4.53 μ when the 300-cm cell was filled with CO_2 at 760 mm pressure. The 4.8 μ absorption accounted for about 2 percent of the 4.0 μ - 5.5 μ band at 760 mm pressure. The 300 cm of CO_2 is equivalent to 10,000 meters of atmosphere at sea level.

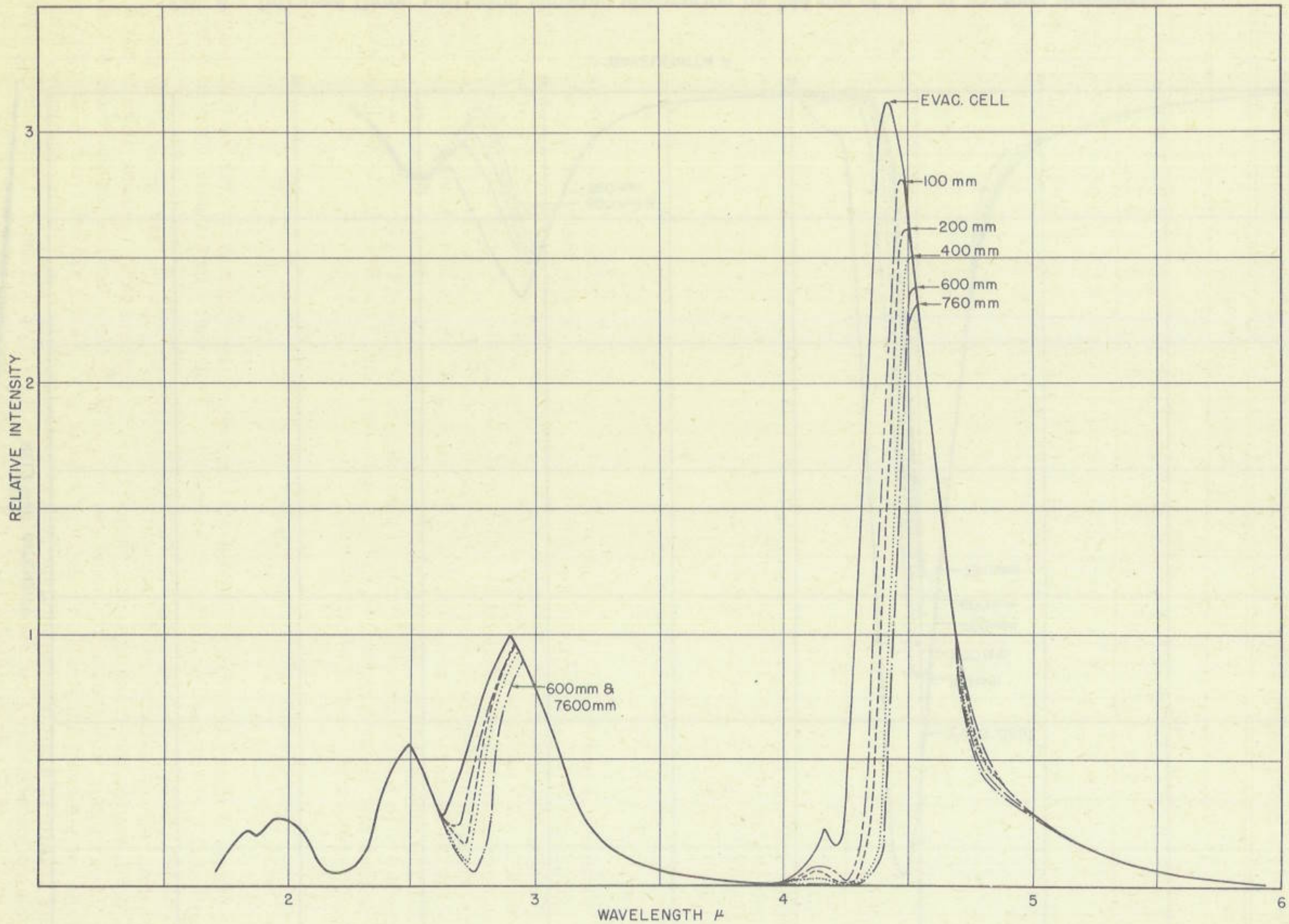

Fig. 5 - Infrared flame emission showing absorption by 122 cm of CO_2 at various pressures

CONFIDENTIAL

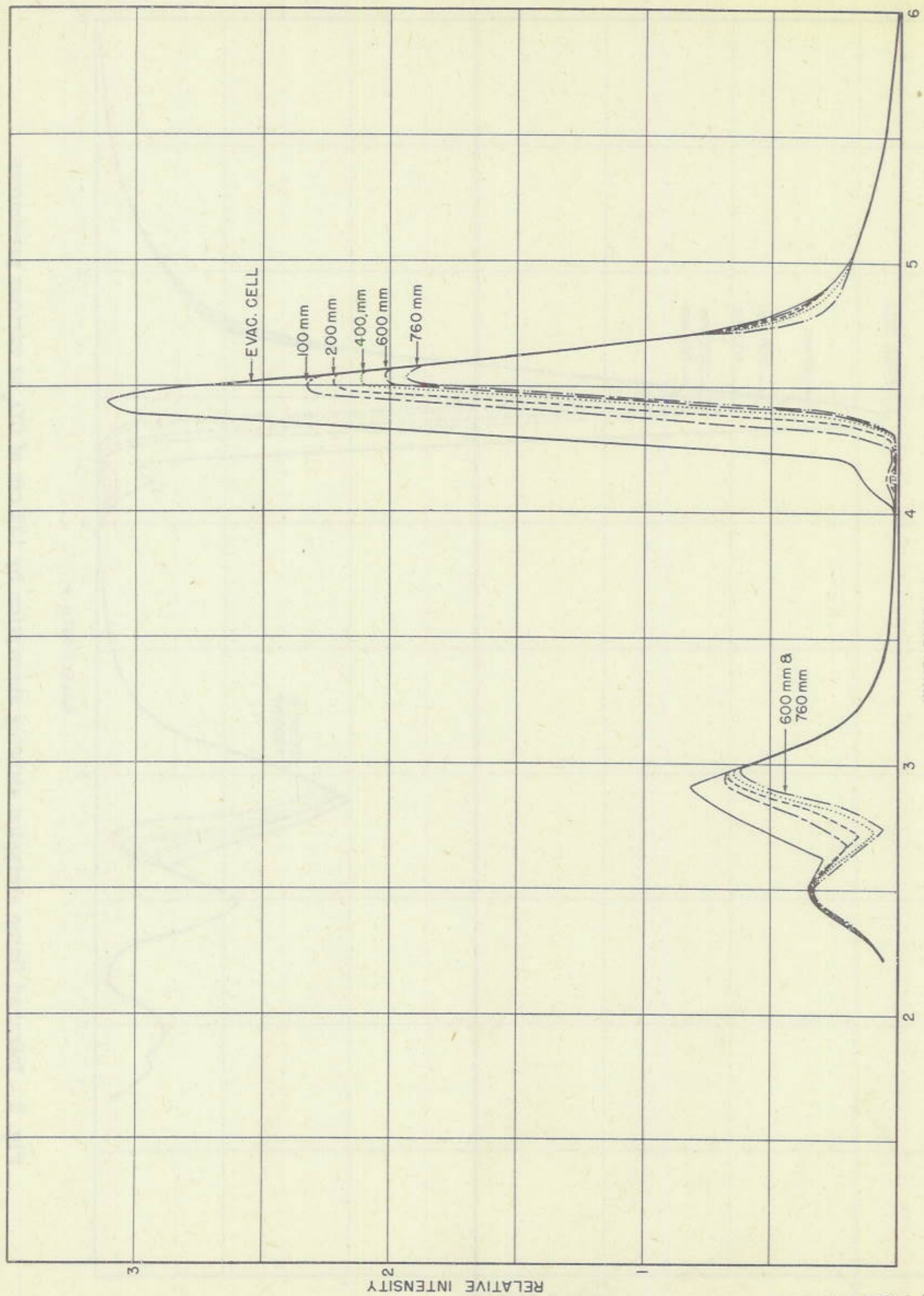

Fig. 6 – Infrared flame emission showing absorption by 244 cm of CO_2 at various pressures

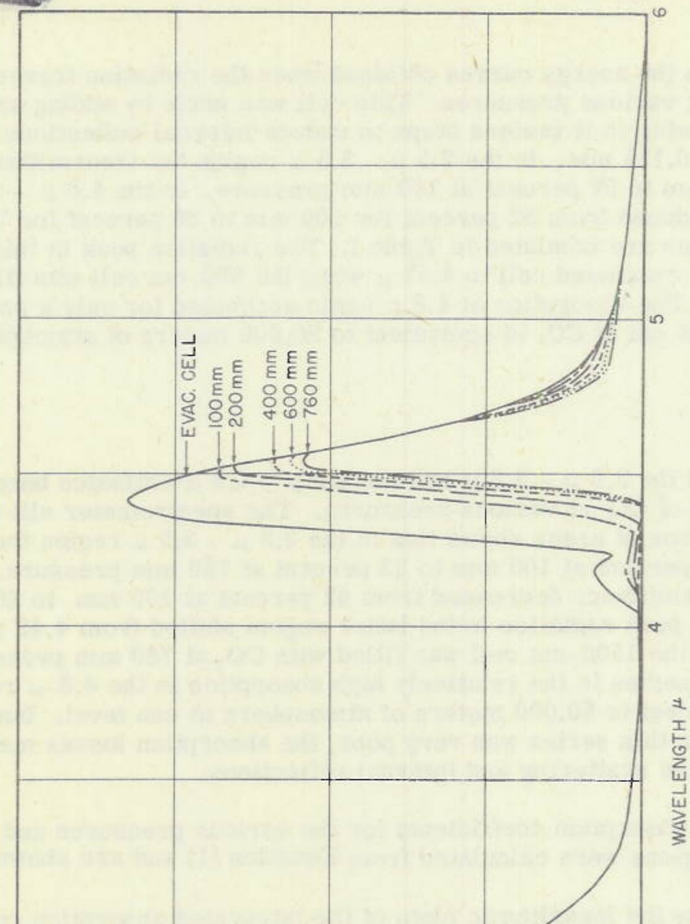

Fig. 7 – Infrared flame emission showing absorption by 300 cm of CO_2 at various pressures

600-Cm Cell

Figure 8 shows the energy curves obtained when the radiation traversed a 600-cm pathlength of CO_2 at various pressures. This cell was made by adding another section to the 300-cm cell, having in it various stops to reduce internal reflections. The spectrometer slit width was 0.125 mm. In the 2.5 μ - 3.5 μ region the transmittance drops from 70 percent at 100 mm to 57 percent at 760 mm pressure. In the 4.0 μ - 5.5 μ region the transmittance is reduced from 52 percent for 100 mm to 36 percent for 760 mm pressure. Transmittance values are tabulated in Table I. The radiation peak in this region shifted from 4.42 μ for the evacuated cell to 4.57 μ when the 600-cm cell was filled with CO_2 at 760 mm pressure. The absorption at 4.8 μ again accounted for only a small percentage of the loss. The 600 cm of CO_2 is equivalent to 20,000 meters of atmosphere at sea level.

1500-Cm Cell

Figure 9 shows the 2.5 μ - 3.5 μ and the 4.0 μ - 5.5 μ emission bands through a 1500-cm pathlength of CO_2 at various pressures. The spectrometer slit was constant at 0.30 mm. Comparison of areas shows that in the 2.5 μ - 3.5 μ region the transmittance decreased from 63 percent at 100 mm to 33 percent at 760 mm pressure. In the 4.0 μ - 5.5 μ band the transmittance decreased from 42 percent at 100 mm to 20 percent at 760 mm pressure. The peak radiation in the latter region shifted from 4.42 μ for evacuated cell to 4.61 μ when the 1500-cm cell was filled with CO_2 at 760 mm pressure. A significant factor in this series is the relatively high absorption in the 4.8-μ region. The 1500 cm of CO_2 is equivalent to 50,000 meters of atmosphere at sea level. Inasmuch as the optical arrangement in this series was very poor, the absorption losses may have been aggravated by excessive scattering and internal reflections.

The integrated absorption coefficients for the various pressures and cell lengths for the two spectral regions were calculated from Equation (1) and are shown in Table II.

Figure 10 shows the logarithmic plots of the integrated absorption coefficients versus pressure for various cell lengths for the 2.5 μ - 3.5 μ region. Figure 11 is a series of similar curves for the 4.0 μ - 5.5 μ region. In Figure 12 the absorption coefficients have been plotted as functions of pathlength at various pressures for the 2.5 μ - 3.5 μ band. Figure 13 is a similar series of curves for the 4.0 μ - 5.5 μ band.

TOTAL EMISSIVE POWER OF THE FLAME

The most intense infrared flame emission bands occur at about 2.8 μ and 4.4 μ, the precise point of peak emission depending on the temperature of the flame and the composition of the optical path between receiver and flame. Other weaker bands occur between 1 μ and 2.5 μ and in the 6 μ region. A weak emission band occurs at 15 μ but is not usually detected because of the strong CO_2 absorption in that region.[7]

A quantitative measure of this infrared radiation was made using a globar at 1448° Kelvin as a source of known black body output. The energy curves for the flame, (13 mm thick), and for globar are shown in Figure 14. The dotted portions of the globar curve indicate the atmospheric absorption bands due to CO_2 and H_2O at 2.8 μ, CO_2 at 4.25 μ, and H_2O at the 6 - μ region. The envelope of the globar radiation curve was drawn over the

---

[7] S. Silverman, G. A. Hornbeck & R. C. Herman, J. Chem. Phys. 16, 155-156, (Feb. 1948).

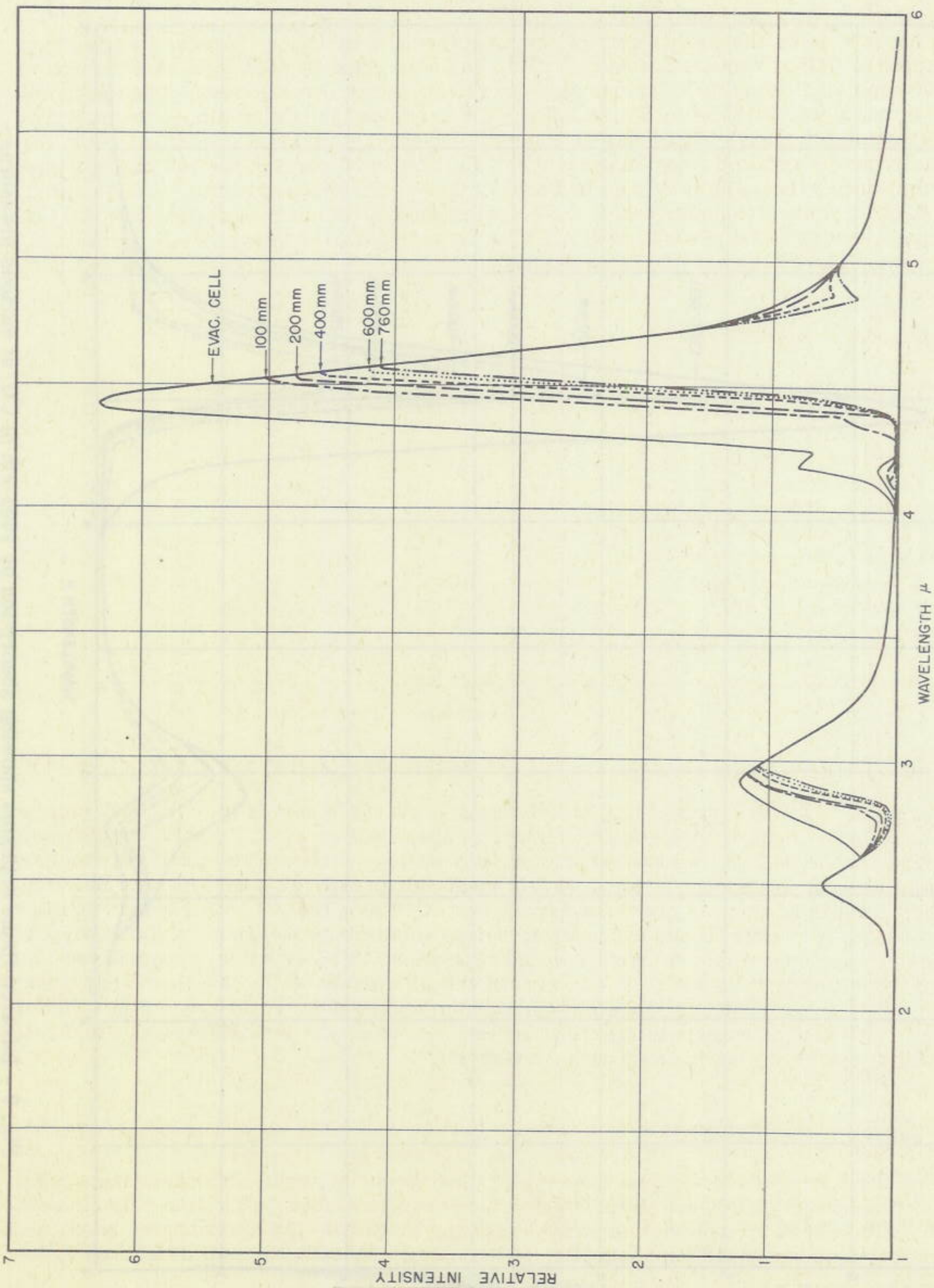

Fig. 8 – Infrared flame emission showing absorption by a 600-cm of CO_2 at various pressures

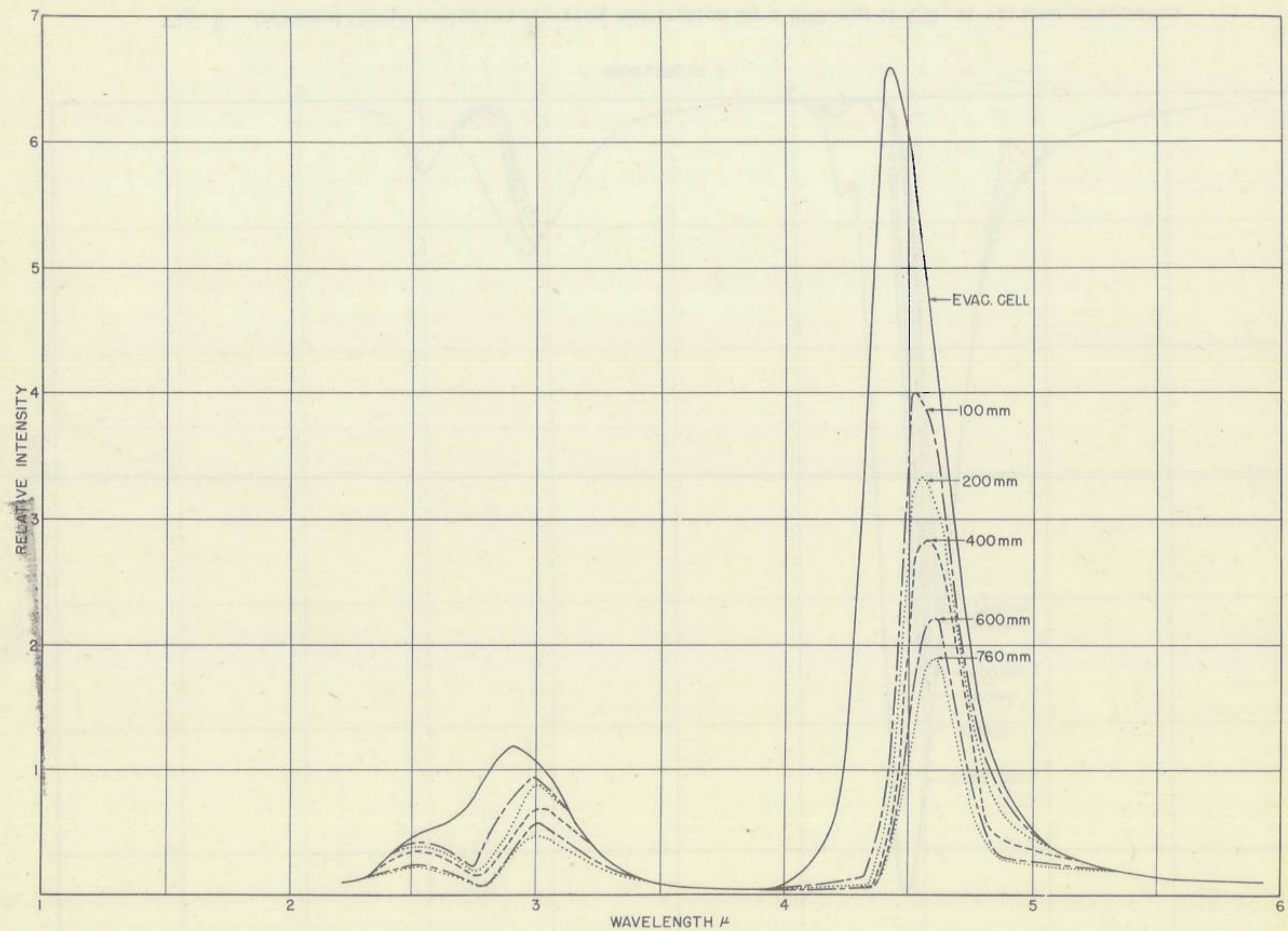

Fig. 9 - Infrared flame emission showing absorption by 1500-cm of CO_2 at various pressures

TABLE II– Integrated Absorption Coefficients

Pathlength (cm)	CO_2 Pressure (mm Hg.)				
	100	200	400	600	760
	2.5 μ - 3.5 μ Band				
10	.01670	.01920	.02680	.03000	.03070
50	.00400	.00510	.00600	.00800	.00822
122	.00184	.00213	.00261	.00339	.00344
244	.00127	.00163	.00195	.00216	.00218
300	.00112	.00138	.00163	.00179	.00187
600	.00060	.00069	.00082	.00092	.00094
1500	.00030	.00037	.00049	.00068	.00075
	4.0 μ - 5.5 μ Band				
10	.02820	.03380	.04370	.05110	.05460
50	.00850	.01106	.01320	.01502	.01588
122	.00381	.00465	.00555	.00645	.00657
244	.00241	.00291	.00330	.00349	.00375
300	.00214	.00252	.00294	.00318	.00340
600	.00110	.00128	.00149	.00162	.00171
1500	.00057	.00068	.00079	.00098	.00109

bands, and spectral absorption factors were determined which were applied to the flame emission through the same optical path. Thus the dotted flame curve represents emission without correction for absorptions, while the solid flame curve is the true emission.

Integration of area under the curves out to 10 μ shows that the flame infrared radiation was equal to 7.3 percent of the globar radiation at 1448°K. Treating the globar as a black body at 1448°K, its radiation was determined by the Stefan-Boltzman law,

$$w = \sigma T^4,$$

where

w = globar energy in watts/cm^2 sec,

σ = Stefan constant = 5.735×10^{12} watts/cm^2 deg^4, and

T = absolute temperature of globar = 1448°K

$$w = 25.2 \text{ watts/cm}^2.$$

Then,

total flame radiation = .073 x 25.2

= 1.85 watts/cm^2.

The 2.5 μ - 3.5 μ band was found to be 27 percent of the total radiation while the 4.0 μ - 5.5 μ band was found to be 63 percent of the total; the remaining 10 percent was due to the small bands between 1 μ and 2.5 μ.

CONFIDENTIAL

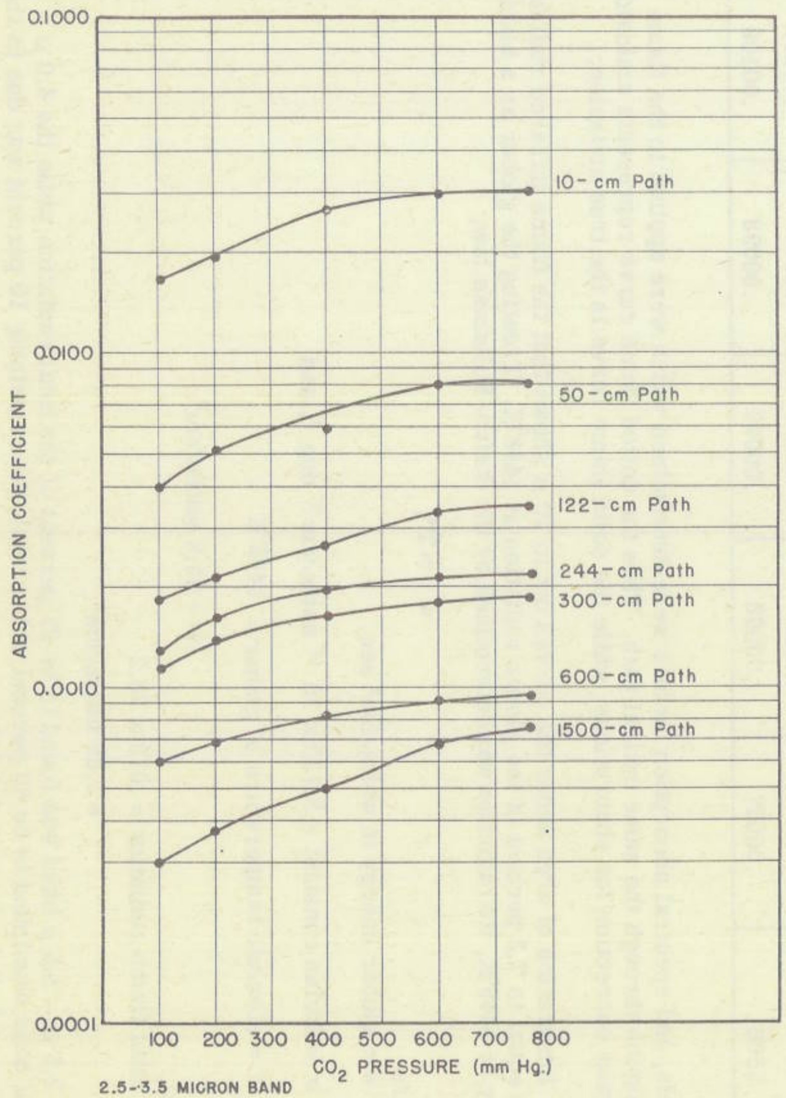

Fig. 10 - Absorption coefficients as function of pressure in the 2.5 μ to 3.5 μ region

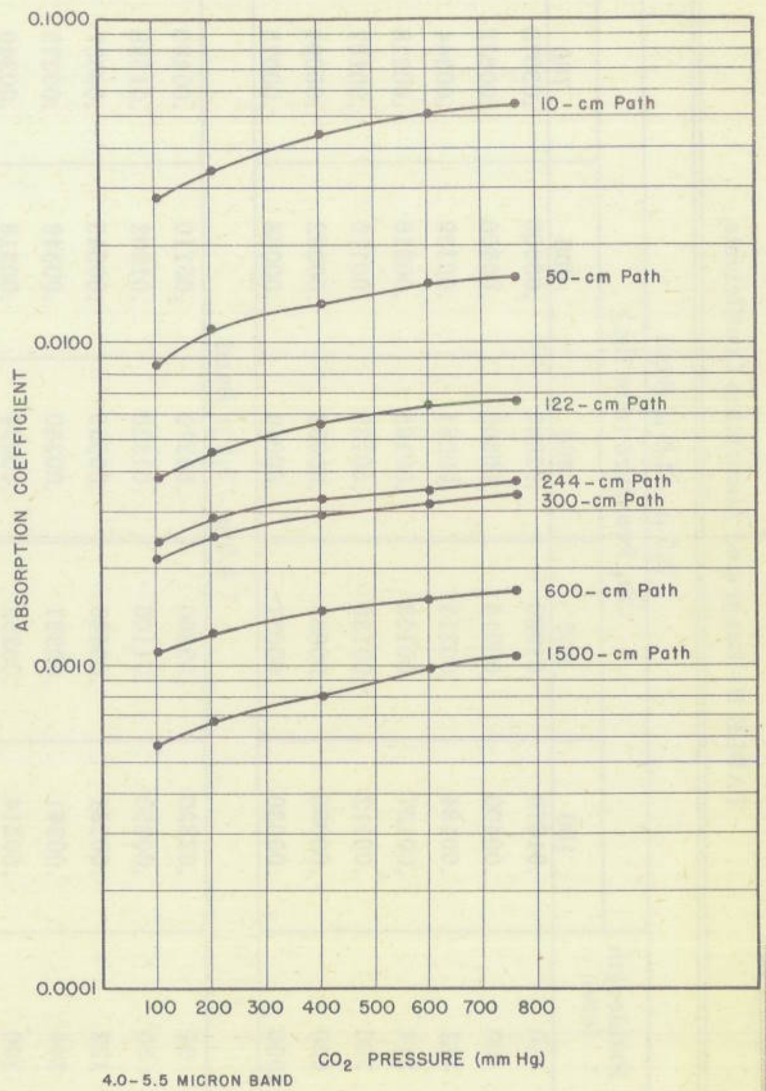

Fig. 11 - Absorption coefficients as function of pressure in the 4.0 μ to 5.5 μ region

CONFIDENTIAL

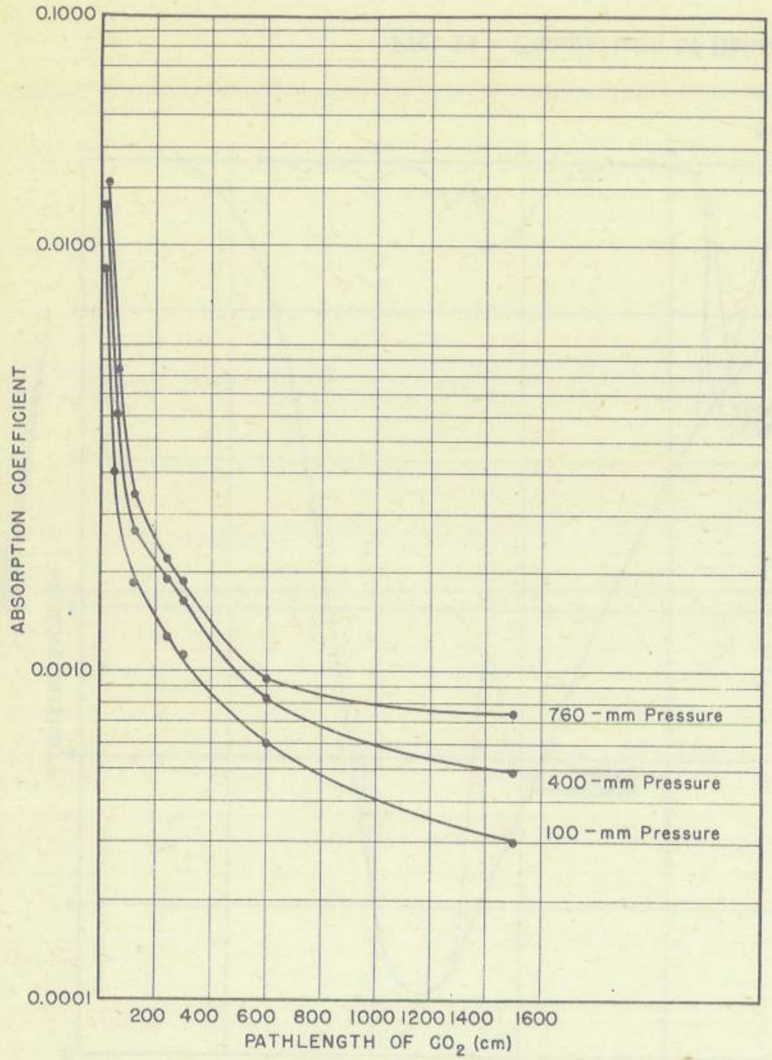

Fig. 12 - Absorption coefficients as function of CO_2 pathlength for the 2.5 μ to 3.5 μ region

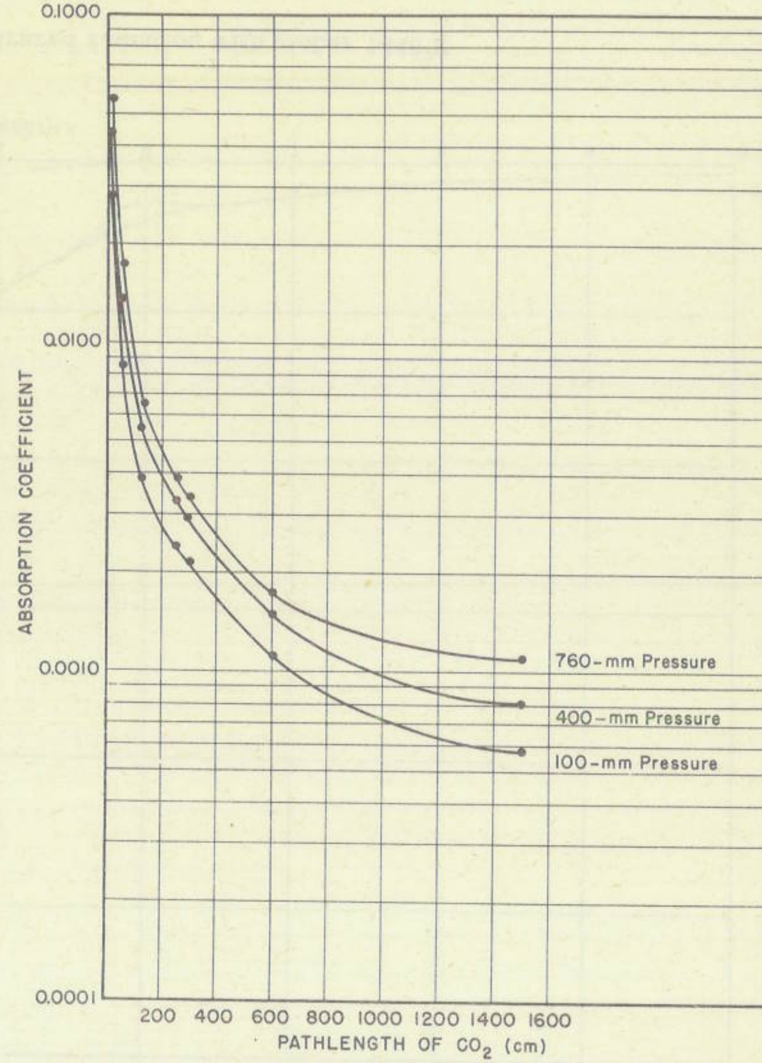

Fig. 13 - Absorption coefficients as function of CO_2 pathlength for the 4.0 μ to 5.5 μ region

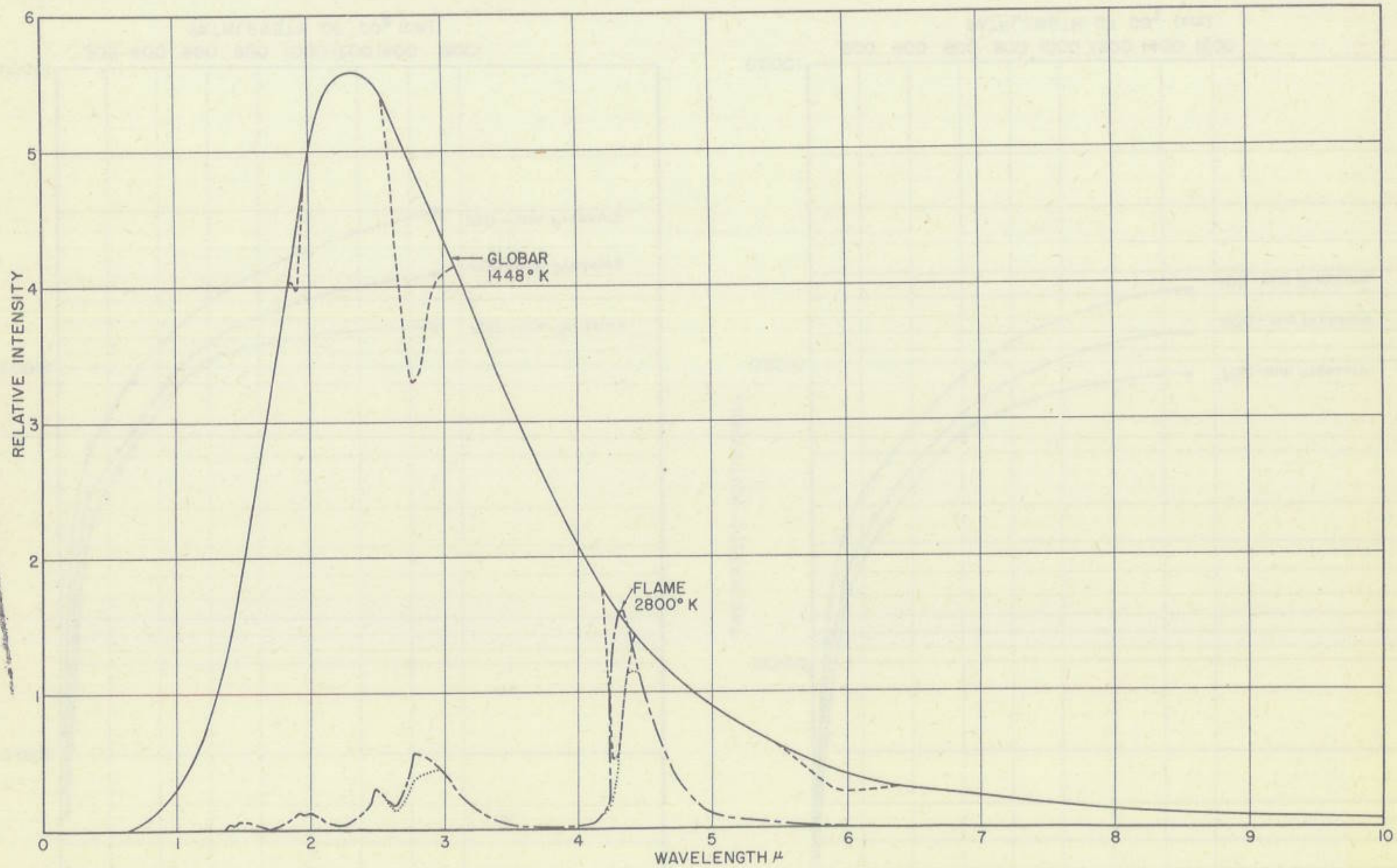

Fig. 14 - Comparison of flame infrared radiation with globar 1448°K

Thus,

radiation in 2.5 μ = 3.5 μ band = .27 x 1.85
= 0.50 watts/cm^2

radiation in 4.0 μ = 5.5 μ band = .63 x 185
= 1.17 watts/cm^2

The ratio of the intensity of the 2.5 μ - 3.5 μ band to the intensity of the 4.0 μ - 5.5 μ band was found to be about 0.43. The band at 15 μ was not detected because of the absorption losses. However, when detected in other experiments, it has been found to be very weak compared to the 4.4 μ band, thus being a negligible factor in the total radiation measurement.

CONCLUSION

From the results of the experiment it is seen that, in the laboratory, CO_2 transmits a considerable amount of infrared flame radiation. For example, at 1500 cm CO_2 path, corresponding to a 50-km atmospheric path, the CO_2 transmitted about 20 percent of the 4.0 μ - 5.5 μ band. In terms of energy it amounts to 0.20 x 1.17 or 0.234 watts/cm^2.

It should be emphasized that the absorption obtained for the 2.5 μ - 3.5 μ region in this series of experiments was due to CO_2 only. It does not portray the true situation as it exists in the atmosphere in this particular wavelength region, especially at lower altitudes where the the water vapor absorption in this region is high.

What the situation will be for energy transmission in actual outdoor atmospheric conditions, can only be conjectured. But the indications are that, with a suitable detector system, a projectile flame could be detected at ranges which may be of military interest and value.

* * *