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EMITTANCE ANALYSIS FOR DIFFERENT TEMPERATURES, TOTAL PRESSURES AND MOLAR RATIOS FOR A CO_2-H_2O MIXTURE

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Abstract: *The emissivity of a given surface is the ratio of the energy that is emitted by the surface over the energy emitted by a black surface at the same temperature. It is also possible to calculate the emittance for participating gases such as* CO_2 *or* H_2O*. In this case, it will be the ratio of the total emitted radiation along a certain path in the medium (and not absorbed) over the radiation emitted by a black body at the same temperature. It depends on the path chosen, and varies due to certain characteristics of its state, such as its temperature, total pressure and molar fraction. The present paper aims at analyzing and comparing emittance of mixtures of* CO_2 *and* H_2O *for a different set of combinations of temperatures, ranging from 300 K to 2500 K, considering different pressures of 1.0, 2.0, 5.0 and 10 atm, and molar fractions of 0.1 and 0.2 for both* CO_2 *and* H_2O*. Using this set of choices for temperature (between 300 K and 2500 K) and total pressure (equal and above the atmospheric) one can use the Lorentz profile to calculate the absorption coefficient over the desired spectrum length. Then, using the absorption coefficients it is possible to calculate the emittance values for a specific thermal condition and a certain path length. The idea is to evaluate the influence of each of these variables over the total value of the emittance and compile a database of the results. The emittances are calculated using a Fortran code and uses the high resolution spectral database HITEMP2010 as a base to calculate the absorption coefficients. The results can be later on used to generate, for example, new WSGG correlations and be studied to make new models to facilitate and validate calculations of thermal radiation in* CO_2 */*H_2O *mixtures.*

Keywords: *Thermal radiation; Participating gases; Emittance; HITEMP2010; Spectral lines.*

1. INTRODUCTION

Radiation in a participating medium is a phenomenon that still needs much attention to enhance the tools to predict it in a more efficient manner. It is vast the literature exploring it in different ways to analyze it and explore in other methods, not only to expand our understanding in the subject but also to find a way to execute the calculations needed in a fast and precise way.

One of the main difficulties when studying this field is due to the phenomenon of line broadening in participating gases. It happens when the energy status of the molecules are perturbed due to some factors and it can absorb photons in different wavenumbers. The types of broadening are natural broadening, where it is intrinsic to the uncertainty motion and energy of the molecules and it is usually small comparing to the others and can often be neglected; Doppler broadening, where it is related to the motion of the atoms and it is important only for high temperatures such as higher than 2500 K; Stark broadening, which can be important when there are electric fields; and collision broadening, due to the collisions between the molecules. In the scope of the present study, the main factor is the collision because of the chosen range of pressures and temperatures (Howell *et al*., 2016).

The two chemical species chosen for this study are CO_2 and H_2O. These gases are involved in many processes and important applications in the industry, particularly in combustion systems.

In this paper the goal is to generate the emittance of a combination of CO_2 and H_2O for different temperatures, pressures, molar fractions and paths, and analyze how changing these especifics characteristics affects the emittance.

The emittance is the ratio of the total emitted radiation in a chosen path that is not absorbed by a participating medium, over the radiation emitted by a black body at the same temperature. Participating medium is when the gases that are in the way of the photons interact with them. Such examples are CO_2 and H_2O. The emittances that are computed in the present study can be later explored in future studies to develop new global gas models correlations, in particular for the WSGG (Weighted-Sum-of-Gray-Gases model) coefficients (Hottel *et al.,*1967; Dorigon *et al.*, 2013, Fonseca *et al.,* 2021).

2. SPECTRAL MODELING

The main equation that describes the variation of the radiative intensity in a participating medium is the radiative transfer equation (RTE). For non-scattering medium, which can be accurately assumed as long as the medium does not have ash or other particles to disperse the radiation rays, it is given by

$$\frac{dI_\eta(x)}{dx} = -\kappa_\eta(x) I_\eta(x) + \kappa_\eta(x) I_{\eta b}(x) , \tag{1}$$

where I_η and $I_{\eta b}$ are the spectral intensity and the blackbody radiation intensity at the local position; and κ_η is the local absorption coefficient for a participating gas. The blackbody radiation intensity can be found by the Plank's distribution

$$I_{\eta b} = \frac{2C_1\eta^3}{exp(C_2\eta/T)-1} , \tag{2}$$

where C_1 is the first Planck's constant and η is the wavenumber. The equation to calculate the absorption coefficient is given by

$$\kappa_\eta = N\, Y C_\eta , \tag{3}$$

where N is the gas molar density, Y is the mole fraction of the gas and the C_η is the absorption cross-section.

The gas molar density can be determined as

$$N = \frac{pN_A}{R_u T} , \tag{4}$$

where p is the pressure, N_A is the avogadro number, R_u is the universal gas constant and T is the temperature.

The equation to find the absorption cross section using the Lorentz profile is the following

$$C_\eta = \sum_{k=1}^{k} \frac{S_k}{\pi} \frac{\gamma_k}{\gamma_k^2 + (\eta - \eta_k)^2} , \tag{5}$$

where S_k is the integrated line intensity, γ_k is the line half width and η_k is the wavenumber. The integrated line intensity is given by the following equation

$$S_k = S_k(T_{ref}) \frac{Q(T_{ref})}{Q(T)} \frac{exp(-C_2E_k/T)}{exp(-C_2E_k/T_{ref})} \frac{[1-exp(-C_2\nu_k/T)]}{[1-exp(-C_2\nu_k/T_{ref})]} , \tag{6}$$

where Q is the total internal partition sums, C_2 is the second Planck's constant, E_k is the energy of the lower state and ν_k is the energy difference between the initial and the final state. The line half width γ_k can be described as

$$\gamma_k = \left(\frac{T_{ref}}{T}\right)^{\eta_c} p_c \gamma_{self,k} + (p - p_c)\gamma_{air,\,k} , \tag{7}$$

where T_{ref} is the reference temperature (296 K), η_c is the temperature dependence coefficient, p_c is the partial pressure of the species c, $\gamma_{self,k}$ is the line self-broadening and $\gamma_{air,k}$ is the broadening caused by air.

The objective of this paper is to analyze the total emittance of different scenarios. To calculate the emittance, one can employ the following equation

$$\epsilon = \frac{\int_{\eta=0}^{\infty} I_{\eta b}(T)[1-exp(-\kappa_{p\eta,a} p_a S)d\eta}{\sigma T^4 / \pi}, \qquad (8)$$

where $\kappa_{p\eta,a}$ is the pressure absorption coefficient, p_a is the partial pressure of the absorbing species, S is the path and σ is the Stefan-Boltzmann constant.

3. METHODOLOGY

The first step was the calculation of the absorption cross-sections of the chemical species within their defined conditions. It was used a Fortran code developed by the study group of the Laboratory of Thermal Radiation at UFRGS (LRT). This code can use the data from a molecular spectroscopic database, like HITRAN2012 (Rothman *et al., 2013*) or, the one used in this study, from high-temperature molecular spectroscopic database (HITEMP2010) to obtain the following parameters: the total internal partition sums (Q), the energy difference between the initial and the final state (ν_k), the energy of the lower state (E_k), the integrated line intensity (S_k), the temperature dependence coefficient (η_c), the line self-broadening ($\gamma_{self,k}$), the broadening caused by air ($\gamma_{air,k}$), the wavenumber (η_k). With this data it is possible to calculate the absorption cross-sections wanted (Rothman *et al.*, 2010).

It was generated the results for temperatures ranging from 300 K to 2500 K in steps of 100 K, for molar fractions of 0.1 and 0.2 for both CO_2 and H_2O, in pressures of 1.0, 2.0, 5.0 and 10 atm.

To calculate the absorption cross-sections over the above specified characteristics, it was used the Lorentz profile, since the use for pressures equals or over 1.0 atm, until the temperatures above 2500 K are within the usage range. For pressures below the atmospheric or temperatures over 2500 K it is recommended the use of the Voigt's profile to correct from the other modes of broadening. The spectral range chosen to evaluate was from 0 to 25000 cm^{-1}; a total of 375000 points were used to discretize the spectrum. The cutoffs used in the calculations using the Lorentz profile were based on the line half-width, with 30000 γ_k for CO_2 and 3000 γ_k for H_2O (Coelho *et al.*, 2021).

Changing each of the characteristics described here to calculate the absorption cross-section has different reactions in CO_2 and H_2O. For example, increasing the pressure generally causes the erratic oscillations to be smoothen.

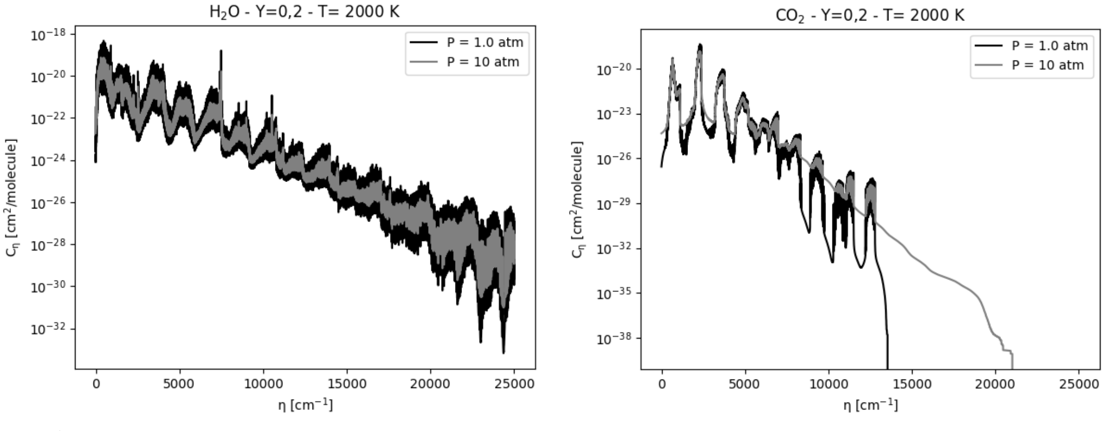

Figure 1. **The impact of increasing the pressure for H_2O on the left and for CO_2 on the right.**

In the other way, increasing the temperature generally elevates the value of the absorption cross-section for the H_2O.

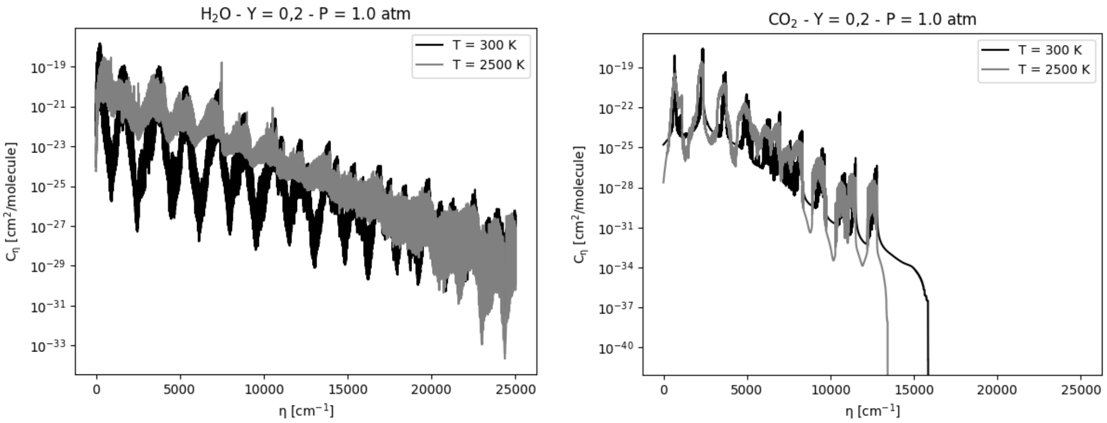

Figure 2. **The impact of increasing the temperature for H_2O on the left and for CO_2 on the right.**

Finally, having the absorption cross-sections, it was possible to calculate the emittances. It was used another Fortran code, and it was generated for paths lengths of the range from 0.001 m to 30 m.

4. RESULTS AND DISCUSSION

In this section the results will be presented and analyzed. The first is about a fixed mixture of CO_2 and H_2O and both with a molar fraction of 0.1, in the second the molar fraction is changed for both to 0.2, in the third the molar fractions are different for each chemical species, 0.1 for H_2O and 0.2 for CO_2, and in the fourth the values of the molar fractions are changed, 0.2 for H_2O and 0.1 for CO_2. The images of graphs are for a 1.0 m path.

4.1. $H_2O + CO_2$ Mixture with a Molar Fraction of 0.1 for Both

The results are shown in the Tables 1, 2, 3 and 4 for a combination of some temperatures and paths, each of the tables representing different pressures. Figure 3 shows the emittance for different temperatures and pressures for a 1.0 m path.

Tables 1, 2, 3 and 4 show that increasing the path independently of the temperature increases the emittance. Also, analyzing Figure 3 together, the effect of increasing the pressure, one can see that it also increases the emittance for all the cases.

Table 1. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.1 for both at 1.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.66048 E-02	0.43680 E-02	0.27310 E-02	0.12030 E-02	0.55281 E-03	0.27306 E-03
0.1 m	0.14212	0.11274	0.88322 E-01	0.56115 E-01	0.33217 E-01	0.19298 E-01
1.0 m	0.32805	0.30263	0.25093	0.18200	0.12191	0.79335 E-01
10 m	0.54470	0.56512	0.52337	0.43288	0.33635	0.25325
20 m	0.60976	0.64412	0.61225	0.52151	0.42378	0.33372
30 m	0.64698	0.68942	0.66201	0.57401	0.47939	0.38729

Table 2. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.1 for both at 2.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.12819 E-01	0.85148 E-02	0.53645 E-02	0.23757 E-02	0.10971 E-02	0.54378 E-03
0.1 m	0.22539	0.18317	0.13288	0.84913 E-01	0.51844 E-01	0.31376 E-01
1.0 m	0.44000	0.42619	0.35516	0.26331	0.18143	0.12130
10 m	0.66475	0.68974	0.64908	0.54710	0.44201	0.34582
20 m	0.73039	0.76880	0.73037	0.63644	0.54007	0.44177
30 m	0.76990	0.81470	0.77244	0.68688	0.59817	0.50036

Table 3. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.1 for both at 5.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.30330 E-01	0.19691 E-01	0.12743 E-01	0.57756 E-02	0.26955 E-02	0.13442 E-02
0.1 m	0.35337	0.31708	0.22373	0.14343	0.89068 E-01	0.55365 E-01
1.0 m	0.59926	0.59075	0.51149	0.39359	0.28447	0.20021
10 m	0.84708	0.86126	0.79439	0.69170	0.59219	0.48782
20 m	0.92381	0.93165	0.85642	0.77218	0.68604	0.58425
30 m	0.95980	0.96121	0.88750	0.81428	0.73446	0.63393

Table 4. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.1 for both at 10 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.56650 E-01	0.34991 E-01	0.23399 E-01	0.11025 E-01	0.52408 E-02	0.26397 E-02
0.1 m	0.46388	0.43869	0.32126	0.21127	0.13387	0.84573 E-01
1.0 m	0.72986	0.71012	0.63246	0.49926	0.37595	0.27628
10 m	0.97460	0.96525	0.88337	0.78915	0.69629	0.59087
20 m	0.99722	0.99266	0.92987	0.85597	0.77329	0.67020
30 m	0.99966	0.99770	0.95008	0.88854	0.81144	0.70953

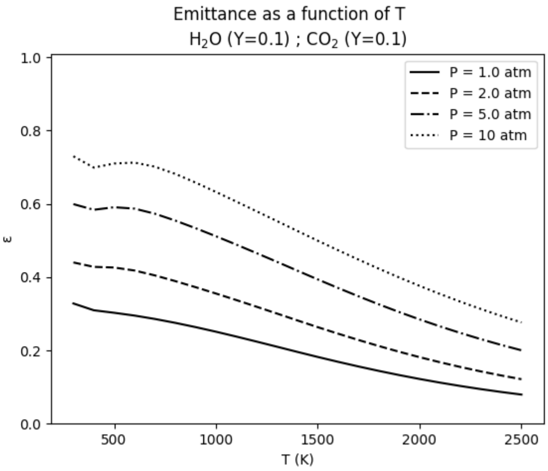

Figure 3. **Emittance as a function of the temperature for $H_2O + CO_2$ mixture with a molar fraction of 0.1 for both and different pressures, for 1.0 m path.**

In addition, examining the emittance graph, it is possible to notice that increasing the temperature, starting from 300 K, the emittance decreases, but at a temperature around 500 K it increases again and then starts to decrease indefinitely. This initial erratic phenomena of the emittance in lower temperatures is even more accentuated in more elevated pressures.

4.2. $H_2O + CO_2$ Mixture with a Molar Fraction of 0.2 for Both

The results are shown in Tables 5, 6, 7 and 8 for a combination of some temperatures and paths, each of the tables representing different pressures. Figure 4 shows the emittance for different temperatures and pressures for a 1.0 m path.

Tables 5, 6, 7 and 8 show the same results as the other section, that increasing the path independently of the temperature increases the emittance. Also, analyzing Figure 4 together, the effect of increasing pressure, one can see that once again it also increases the emittance for all the cases.

In addition, examining the emittance graph, it is possible to notice the same phenomena that increasing the temperature, starting from 300 K, the emittance decreases, but at a temperature around 500 K it increases again and then starts to decrease indefinitely. This initial erratic phenomena of the emittance in lower temperatures also proves to be even more accentuated in more elevated pressures.

Table 5. **Emittance values for some paths and temperatures for H_2O + CO_2 mixture with a molar fraction of 0.2 for both at 1.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.12122 E-01	0.80230 E-02	0.52547 E-02	0.23712 E-02	0.10977 E-02	0.54414 E-03
0.1 m	0.20218	0.16660	0.12719	0.82723 E-01	0.50843 E-01	0.30917 E-01
1.0 m	0.40793	0.39503	0.33709	0.25440	0.17724	0.11931
10 m	0.62553	0.65762	0.62684	0.53373	0.43323	0.34029
20 m	0.68666	0.73320	0.70818	0.62290	0.53044	0.43523
30 m	0.72167	0.77734	0.75068	0.67354	0.58855	0.49365

Table 6. **Emittance values for some paths and temperatures for H_2O + CO_2 mixture with a molar fraction of 0.2 for both at 2.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.23251 E-01	0.15352 E-01	0.10172 E-01	0.46430 E-02	0.21661 E-02	0.10791 E-02
0.1 m	0.29739	0.25926	0.19003	0.12384	0.77121 E-01	0.47908 E-01
1.0 m	0.52504	0.52278	0.45405	0.35122	0.25280	0.17647
10 m	0.74976	0.77963	0.73989	0.64559	0.54792	0.44751
20 m	0.82217	0.85655	0.80716	0.72951	0.64570	0.54686
30 m	0.86636	0.89676	0.84089	0.77461	0.69827	0.60063

Table 7. **Emittance values for some paths and temperatures for H_2O + CO_2 mixture with a molar fraction of 0.2 for both at 5.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.53480 E-01	0.33659 E-01	0.23097 E-01	0.10984 E-01	0.52346 E-02	0.26383 E-02
0.1 m	0.43676	0.41417	0.30980	0.20760	0.13264	0.84034 E-01
1.0 m	0.68536	0.67818	0.61201	0.48973	0.37136	0.27387
10 m	0.93788	0.94037	0.86123	0.77727	0.69049	0.58755
20 m	0.98525	0.98125	0.91141	0.84599	0.76902	0.66798
30 m	0.99619	0.99250	0.93559	0.88042	0.80807	0.70785

Table 8. **Emittance values for some paths and temperatures for H_2O + CO_2 mixture with a molar fraction of 0.2 for both at 10 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.95748 E-01	0.57889 E-01	0.39788 E-01	0.20136 E-01	0.99211 E-02	0.50915 E-02
0.1 m	0.55791	0.53431	0.42158	0.29457	0.19511	0.12737
1.0 m	0.82608	0.80631	0.72823	0.59642	0.47350	0.36513
10 m	0.99866	0.99482	0.93273	0.85902	0.77570	0.67180
20 m	0.99998	0.99926	0.96330	0.91091	0.83757	0.73647
30 m	0.99999	0.99964	0.97477	0.93402	0.86783	0.77075

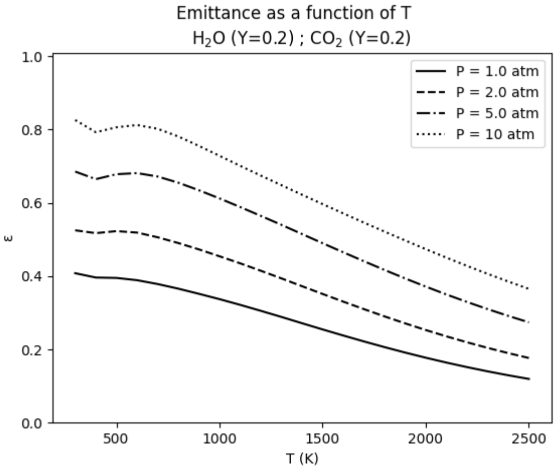

Figure 4. **Emittance as a function of the temperature for $H_2O + CO_2$ mixture with a molar fraction of 0.2 for both and different pressures, for 1.0 m path.**

4.3. $H_2O + CO_2$ Mixture with a Molar Fraction of 0.1 for H_2O and 0.2 for CO_2

The results are shown in Tables 9, 10, 11 and 12 for a combination of some temperatures and paths, each of the tables representing different pressures. Figure 5 shows the emittance for different temperatures and pressures for a 1.0 m path.

Table 9. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.1 for H_2O and 0.2 for CO_2 at 1.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.83657 E-02	0.63642 E-02	0.47576 E-02	0.21537 E-02	0.98673 E-03	0.48166 E-03
0.1 m	0.16045	0.12776	0.10212	0.67837 E-01	0.42081 E-01	0.25609 E-01
1.0 m	0.34768	0.32062	0.26908	0.20029	0.13651	0.89618 E-01
10 m	0.56950	0.59500	0.54598	0.44736	0.34659	0.26049
20 m	0.63860	0.68026	0.63644	0.53647	0.43487	0.34137
30 m	0.67968	0.72899	0.68581	0.58917	0.49099	0.39524

Table 10. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.1 for H_2O and 0.2 for CO_2 at 2.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.15981 E-01	0.12086 E-01	0.91775 E-02	0.42091 E-02	0.19447 E-02	0.95425 E-03
0.1 m	0.24417	0.20098	0.14806	0.97671 E-01	0.61245 E-01	0.38073 E-01
1.0 m	0.46304	0.44731	0.37346	0.28013	0.19538	0.13208
10 m	0.69872	0.73135	0.67514	0.56208	0.45276	0.35318
20 m	0.77267	0.81421	0.75468	0.65192	0.55137	0.44923
30 m	0.81654	0.85903	0.79519	0.70234	0.60894	0.50701

Table 11. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.1 for H_2O and 0.2 for CO_2 at 5.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.37079 E-01	0.26025 E-01	0.20654 E-01	0.99100 E-02	0.46842 E-02	0.23276 E-02
0.1 m	0.37606	0.33640	0.24154	0.15961	0.10117	0.63519 E-01
1.0 m	0.62953	0.62257	0.53522	0.40779	0.29440	0.20791
10 m	0.89316	0.90335	0.82051	0.70914	0.60356	0.49473
20 m	0.95923	0.95919	0.88076	0.78924	0.69556	0.58901
30 m	0.98317	0.97923	0.91029	0.83022	0.74246	0.63740

Table 12. **Emittance values for some paths and temperatures for H_2O + CO_2 mixture with a molar fraction of 0.1 for H_2O and 0.2 for CO_2 at 10 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.68061 E-01	0.43228 E-01	0.34984 E-01	0.18010 E-01	0.88277 E-02	0.44749 E-02
0.1 m	0.49469	0.46343	0.34107	0.22905	0.14795	0.94623 E-01
1.0 m	0.77400	0.75516	0.66426	0.51578	0.38623	0.28314
10 m	0.99109	0.98321	0.90765	0.80771	0.70645	0.59576
20 m	0.99958	0.99713	0.94664	0.87024	0.78026	0.67288
30 m	0.99998	0.99904	0.96151	0.89934	0.81642	0.71122

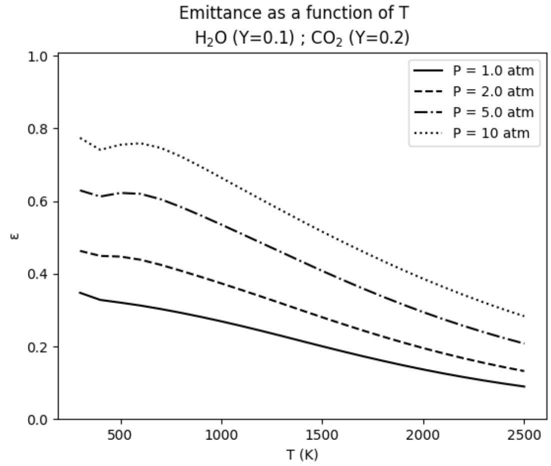

Figure 5. **Emittance as a function of the temperature for H_2O + CO_2 mixture with a molar fraction of 0.1 for H_2O and 0.2 for CO_2 and different pressures, for 1.0 m path.**

Tables 9, 10, 11 and 12 show the same results as the other section, that increasing the path independently of the temperature increases the emittance. Also, analyzing Figure 5 together, the effect of increasing the pressure, one can see that once again it also increases the emittance for all the cases.

In addition, examining the emittance graph, it is possible to notice the same phenomena that increasing the temperature, starting from 300 K, the emittance decreases, but at a temperature around 500 K it increases again and then starts to decrease indefinitely. This initial erratic phenomena of the emittance in lower temperatures is even more accentuated in more elevated pressures.

4.4. H_2O + CO_2 Mixture with a Molar Fraction of 0.2 for H_2O and 0.1 for CO_2

The results are shown in Tables 13, 14, 15 and 16 for a combination of some temperatures and paths, each of the tables representing different pressures. Figure 6 shows the emittance for different temperatures and pressures for a 1.0 m path.

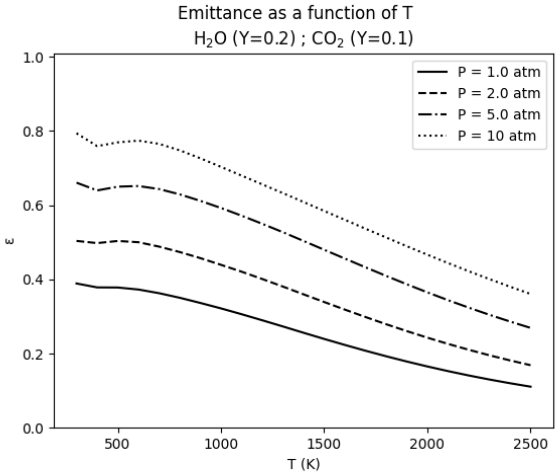

Figure 6. **Emittance as a function of the temperature for H_2O + CO_2 mixture with a molar fraction of 0.2 for H_2O and 0.1 for CO_2 and different pressures, for 1.0 m path.**

Table 13. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.2 for H_2O and 0.1 for CO_2 at 1.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.10361 E-01	0.60269 E-02	0.32283 E-02	0.14207 E-02	0.66385 E-03	0.33556 E-03
0.1 m	0.18393	0.15177	0.11378	0.71284 E-01	0.42135 E-01	0.24687 E-01
1.0 m	0.38896	0.37806	0.32173	0.23938	0.16519	0.11067
10 m	0.60394	0.63079	0.60874	0.52361	0.42637	0.33557
20 m	0.66224	0.70113	0.68968	0.61268	0.52316	0.43049
30 m	0.69412	0.74272	0.73293	0.66327	0.58127	0.48918

Table 14. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.2 for H_2O and 0.1 for CO_2 at 2.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.20089 E-01	0.11781 E-01	0.63592 E-02	0.28100 E-02	0.13187 E-02	0.66871 E-03
0.1 m	0.27881	0.24192	0.17594	0.11190	0.68176 E-01	0.41448 E-01
1.0 m	0.50372	0.50356	0.43919	0.33893	0.24283	0.16861
10 m	0.72282	0.74364	0.72021	0.63536	0.54092	0.44304
20 m	0.79045	0.81932	0.78898	0.71893	0.63903	0.54317
30 m	0.83346	0.86200	0.82337	0.76408	0.69234	0.59778

Table 15. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.2 for H_2O and 0.1 for CO_2 at 5.0 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.46732 E-01	0.27328 E-01	0.15190 E-01	0.68520 E-02	0.32469 E-02	0.16552 E-02
0.1 m	0.41490	0.39603	0.29485	0.19401	0.12213	0.76746 E-01
1.0 m	0.66072	0.65001	0.59246	0.47977	0.36500	0.26914
10 m	0.91128	0.91180	0.84075	0.76504	0.68406	0.58449
20 m	0.97219	0.96641	0.89202	0.83470	0.76430	0.66630
30 m	0.99070	0.98448	0.91821	0.87067	0.80455	0.70680

Table 16. **Emittance values for some paths and temperatures for $H_2O + CO_2$ mixture with a molar fraction of 0.2 for H_2O and 0.1 for CO_2 at 10 atm pressure.**

	300 K	500 K	1000 K	1500 K	2000 K	2500 K
0.001 m	0.84347 E-01	0.49663 E-01	0.28215 E-01	0.13158 E-01	0.63377 E-02	0.32577 E-02
0.1 m	0.52996	0.51195	0.40561	0.28128	0.18428	0.11926
1.0 m	0.79398	0.76942	0.70331	0.58451	0.46643	0.36063
10 m	0.99611	0.98820	0.91441	0.84712	0.77076	0.67009
20 m	0.99992	0.99829	0.95231	0.90331	0.83495	0.73577
30 m	0.99999	0.99939	0.96805	0.92898	0.86624	0.77038

Finally, Tables 13, 14, 15 and 16 show the same results as the other sections, that increasing the path independently of the temperature increases the emittance. Also, analyzing Figure 6 together, the effect of increasing the pressure, one can see that once again it also increases the emittance for all the cases.

In addition, examining the emittance graph, it is possible to notice the same phenomena that increasing the temperature, starting from 300 K, the emittance decreases, but at a temperature around 500 K it increases again and then starts to decrease indefinitely. This initial erratic phenomena of the emittance in lower temperatures is even more accentuated in more elevated pressures.

5. CONCLUSIONS

From the emittance values found for the different scenarios simulated it is possible to notice that the emittance value increases for all scenarios with the increase of the path length. Also, the same behavior happens with the increase of the pressure for all the cases. At last, with the increase of the temperature, the inverse behavior happens, the emittance values decrease for all the cases, at least from 600 K.

Comparing the first and the second cases, it is possible to see that increasing the molar fraction of both H_2O and CO_2 makes the emittance also to increase, independently of the path, pressure or temperature. Now comparing the first and the third case, we can also see an increase of the emittance with the increase to 0.2 molar fraction of CO_2, but if we compare the second and the third case we can see that to achieve higher emittance it is more effective to increase both H_2O and CO_2. The same behavior happens if one compares the second and fourth cases.

At last, comparing the third and the fourth case, each one increasing just one of the chemical species, one can see that case four, with the increase of only H_2O makes the emittance to increase more than the other way around, that is, increasing only CO_2.

In summary, analyzing the results, increasing the path length or the molar fraction, raises the emittance value. On the other hand, increasing the temperature leads to a reduction of the emittance value. For further studies, one can expand the range of the variables approached, implement Voigt's profile and consider other chemical species.

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