Documentation of Flat Premixed Laminar CH_4/Air Standard Flames: Temperatures and Species Concentrations

Peter Weigand, Rainer Lückerath, Wolfgang Meier
Institut für Verbrennungstechnik, Deutsches Zentrum für Luft- und Raumfahrt (DLR),
Pfaffenwaldring 38, D-70569 Stuttgart
E-mail: peter.weigand@dlr.de, rainer.lueckerath@dlr.de, wolfgang.meier@dlr.de

Aims and Motivation

Flat premixed laminar flames offer the advantage of well-defined conditions with respect to flow field, gas concentrations, temperature profiles, and spatial uniformity. They are, thus, ideally suited for fundamental investigations or reference cases in various areas of combustion research. In our studies, they are used as calibration sources for a laser Raman scattering system.

The gas composition in the post-flame region can be accurately calculated by flame simulation codes, e.g., the CHEMKIN/PREMIX computer code from the Sandia National Laboratories [1], and the major species concentrations are very close to chemical equilibrium. A more complicated task is the determination of the temperatures of the gases because the flames are typically not adiabatic due to heat loss to the burner plate. In the investigations described here, Coherent anti-Stokes Raman Scattering (CARS) was used to measure the temperatures of 22 "standard" CH_4/air flames at atmospheric pressure. This study is an extension of the work published earlier for H_2/air flames [2].

Burner and Flames

The burner is a commercially available flat flame burner with a sintered bronze disc (Holthuis & Associates, formerly McKenna Products) [3]. The diameter of the matrix is 60 mm, the annular shroud flow was not used in these investigations. The matrix was cooled by water with an inlet temperature of 16°C at a flow rate of 1 liter/s. Methan (purity 99.5%) and dry air were premixed and supplied to the burner at room temperature. The flow rates were adjusted by calibrated mass flow meters (Brooks 5850 and 5851) and are accurate within ±1%. The reference point within the exhaust gas of the burner and, thus, the measuring location for the temperature was on the axis of the burner 15 mm above the burner plate. This location was chosen because it allows good optical access and because temperature gradients are negligible around this point.

Temperature Measurements

The temperature were measured with the mobile CARS system of our institute employing a USED CARS beam geometry [4-6]. The measuring volume had a diameter of approx. 0.15 mm and a length of 2 mm and was located on the burner axis at h=15 mm above the burner plate. For each flame, a series of 1200 single-pulse CARS spectra was measured from which the average temperature was determined. The accuracy of the temperature measurement is ±2.5%.

Exhaust Gas Composition

The exhaust gas composition was calculated using the "Gaseq" chemical equilibrium program [7] which computed the equilibrium composition for the product temperatures determined by the CARS measurements. The calculated major species mole fractions are displayed in the table, minor species, e.g., radicals or NO, are not listed. Therefore, the sum of the mole fraction is not always unity.

Results

The table shows the data of 22 premixed CH_4/air flames at atmospheric pressure. The CH_4 and air flows are given in standard liters per minute (slpm), i.e., volume flow at T=0 °C and p=1013 mbar. Phi is the equivalence ratio determined from the flow rates and T_ad is the adiabatic flame temperature for this equivalence ratio calculated with Gaseq starting from the unburnt gas mixtures (at T=300 K). The measured temperatures, T_CARS, are lower than T_ad because of heat transfer from the flame to the burner matrix. The heat transfer increases with decreasing distance Δh between the burner plate and the flame front. Δh is typically <1mm and increases with flow rate and decreases with the burning velocity which has its maximum value at phi≈1.1. These relationships explain qualitatively the temperature differences between T_ad and T_CARS as a function of flow rate and phi. The table displays further the mole fractions X of the major species calculated for the exhaust gas temperature T_CARS.

Examplary measurements with an older burner of the same kind revealed temperatures which were systematically lower by an average of 26 K. Earlier measurements in H_2/air flames stabilized on 3 different burners resulted in mean deviations of 11 K and 20 K [1]. Thus, different burners are not expected to behave identically, but the deviations are, from our experience smaller than the temperature measurement uncertainties of 2.5%.

Table

Nr.	CH4 slpm	Luft slpm	Phi	Tad K	T_CARS K	X(O2)	X(N2)	X(H2O)	X(CO2)	X(CO)	X(H2)
1	1.100	15.00	0.70	1838	1706	0.0577	0.7349	0.1367	0.0684	0.0000	0.0000
2	1.310	15.60	0.80	1997	1765	0.0379	0.7279	0.1547	0.0774	0.0001	0.0000
3	1.310	12.40	1.00	2226	1790	0.0005	0.7144	0.1894	0.0942	0.0008	0.0004
4	1.310	11.31	1.10	2211	1754	0.0000	0.6951	0.1886	0.0793	0.0223	0.0147
5	1.310	10.40	1.20	2137	1723	0.0000	0.6764	0.1844	0.0673	0.0406	0.0313
6	1.420	15.00	0.90	2134	1799	0.0185	0.7209	0.1723	0.0862	0.0001	0.0001
7	1.733	20.63	0.80	1997	1828	0.0376	0.7276	0.1546	0.0774	0.0001	0.0001
8	1.733	16.50	1.00	2226	1886	0.0009	0.7138	0.1888	0.0933	0.0016	0.0008
9	1.733	14.96	1.10	2211	1826	0.0000	0.6951	0.1891	0.0788	0.0229	0.0141
10	1.735	15.00	1.10	2211	1818	0.0000	0.6951	0.1890	0.0788	0.0228	0.0142
11	1.733	13.70	1.20	2137	1828	0.0000	0.6763	0.1857	0.0660	0.0419	0.0300
12	1.733	11.80	1.40	1980	1813	0.0000	0.6417	0.1734	0.0484	0.0710	0.0654
13	2.050	15.00	1.30	2057	1878	0.0000	0.6585	0.1809	0.0554	0.0584	0.0466
14	2.287	15.00	1.45	1942	1915	0.0000	0.6336	0.1711	0.0435	0.0786	0.0729
15	2.550	30.30	0.80	1997	1967	0.0371	0.7268	0.1540	0.0770	0.0004	0.0002
16	2.550	27.00	0.90	2134	1976	0.0182	0.7201	0.1716	0.0856	0.0007	0.0003
17	2.550	24.14	1.00	2226	2009	0.0017	0.7128	0.1877	0.0917	0.0031	0.0014
18	2.550	22.00	1.10	2211	1934	0.0000	0.6950	0.1897	0.0780	0.0237	0.0134
19	2.550	20.20	1.20	2137	1883	0.0000	0.6763	0.1863	0.0653	0.0426	0.0293
20	2.550	17.43	1.39	1980	1929	0.0000	0.6433	0.1757	0.0474	0.0715	0.0618
21	3.420	36.18	0.90	2134	2110	0.0183	0.7189	0.1704	0.0844	0.0018	0.0007
22	3.420	32.40	1.00	2226	2100	0.0029	0.7111	0.1860	0.0891	0.0055	0.0023

References

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