มหาวิทยาลัยสงขลานครินทร์

คณะวิศวกรรมศาสตร์

การสอบกลางภาค ประจำภาคการศึกษาที่ 1 ปีการศึกษา 2556

วันที่ 29 กรกฎาคม 2556 เวลา 13:30-16:30 น.

วิชา 215-666 การเผาไหม้ (Combustion) ห้อง S201

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คำสั่ง

1. ข้อสอบมีทั้งหมด 5 ข้อ ให้ทำทุกข้อ
2. อนุญาตให้นำหนังสือ Applied Combustion ของ Keating และเครื่องคิดเลขเข้าห้องสอบ
3. ให้เขียนคำตอบพร้อมแสดงวิธีทำอย่างละเอียดในสมุดคำตอบ

ทุจริตในการสอบ โทษขั้นต่ำปรับตกในรายวิชานั้นและพักการเรียนหนึ่งภาคการศึกษา

ข้อที่	คะแนนเต็ม	คะแนนที่ได้
1	30	
2	30	
3	30	
4	30	
5	30	
รวม	150	

อาจารย์ ชยุต นันทดุสิต
(ผู้ออกข้อสอบ)

1. A small, low-emission, stationary gas-turbine engine operates at full load at an equivalence ratio of 0.286 with an air flowrate of 15.9 kg/s. The equivalent composite of the fuel is $C_{1.16}H_{4.32}$. Determine the fuel mass flowrate and the operating air-fuel ratio for the engine.

2. A gas stream at 1 atm contains a mixture of CO, CO_2, and N_2 in which the CO mole fraction is 0.10 and the CO_2 mole fraction is 0.20. The gas-stream temperature is 1200 K. Determine the absolute enthalpy of the mixture on both a mole basis (kJ/kmol) and a mass basis (kJ/kg). Also determine the mass fraction of the three component gases.

3. Determine the upper and lower heating values at 298 K of gaseous n-decane $C_{10}H_{22}$ per kilomole of fuel and per kilogram of fuel. The molecular weight of n-decane is 142.284. (Hint: Write the combustion equation for air)

4. Estimate the constant-pressure and constant-volume adiabatic flame temperature for the combustion of a stoichiometric CH_4-air mixture. The pressure is 1 atm and the initial reactant temperature is 298 K. Using the following assumption:

1. Combustion is complete.
2. The product mixture enthalpy is estimated using constant specific heats evaluated at 1200 K (about $0.5(T_i+T_{ad})$), where Tad is guessed to be about 2100K).

5. Consider the dissociation of CO2 as a function of temperature and pressure,

$$CO_2 \leftrightarrow CO + \frac{1}{2} O_2$$

Find the composition of the mixture (mole fraction of CO_2, CO and O_2), that results from subjecting originally pure CO_2 in condition 2500 K and 100 atm.

APPENDIX A

Selected Thermodynamic Properties of Gases Comprising C–H–O–N System

TABLES A.1 TO A.12

Ideal-gas values for standard reference state ($T = 298.15\,\mathrm{K}$, $P = 1\,\mathrm{atm}$) for

$$\bar{c}_p(T),\ \bar{h}^o(T) - \bar{h}^o_{f,\mathrm{ref}},\ \bar{h}^o_f(T),\ \bar{s}^o(T),\ \bar{g}^o_f(T) \qquad \text{for}$$

$$CO,\ CO_2,\ H_2,\ H,\ OH,\ H_2O,\ N_2,\ N,\ NO,\ NO_2,\ O_2,\ O.$$

Enthalpy of formation and Gibbs function of formation for compounds are calculated from the elements as

$$\bar{h}^o_{f,i}(T) = \bar{h}^o_i(T) - \sum_{j\ \text{elements}} \nu'_j \bar{h}^o_j(T)$$

$$\bar{g}^o_{f,i}(T) = \bar{g}^o_i(T) - \sum_{j\ \text{elements}} \nu'_j \bar{g}^o_j(T)$$

$$= \bar{h}^o_{f,i}(T) - T\bar{s}^o_i(T) - \sum_{j\ \text{elements}} \nu'_j\left[-T\bar{s}^o_j(T)\right].$$

SOURCE: Tables were generated from curvefit coefficients given in Kee, R. J., Rupley, F. M., and Miller, J. A., "The Chemkin Thermodynamic Data Base," Sandia Report, SAND87-8215B, March 1991.

TABLE A.13

Curvefit coefficients for $\bar{c}_p(T)$ for the same gases as above.

SOURCE: ibid.

Table A.1 Carbon monoxide (CO), MW = 28.010, enthalpy of formation @ 298 K (kJ/kmol) = −110,541

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
200	28.687	−2,835	−111,308	186.018	−128,532
298	29.072	0	−110,541	197.548	−137,163
300	29.078	54	−110,530	197.728	−137,328
400	29.433	2,979	−110,121	206.141	−146,332
500	29.857	5,943	−110,017	212.752	−155,403
600	30.407	8,955	−110,156	218.242	−164,470
700	31.089	12,029	−110,477	222.979	−173,499
800	31.860	15,176	−110,924	227.180	−182,473
900	32.629	18,401	−111,450	230.978	−191,386
1,000	33.255	21,697	−112,022	234.450	−200,238
1,100	33.725	25,046	−112,619	237.642	−209,030
1,200	34.148	28,440	−113,240	240.595	−217,768
1,300	34.530	31,874	−113,881	243.344	−226,453
1,400	34.872	35,345	−114,543	245.915	−235,087
1,500	35.178	38,847	−115,225	248.332	−243,674
1,600	35.451	42,379	−115,925	250.611	−252,214
1,700	35.694	45,937	−116,644	252.768	−260,711
1,800	35.910	49,517	−117,380	254.814	−269,164
1,900	36.101	53,118	−118,132	256.761	−277,576
2,000	36.271	56,737	−118,902	258.617	−285,948
2,100	36.421	60,371	−119,687	260.391	−294,281
2,200	36.553	64,020	−120,488	262.088	−302,576
2,300	36.670	67,682	−121,305	263.715	−310,835
2,400	36.774	71,354	−122,137	265.278	−319,057
2,500	36.867	75,036	−122,984	266.781	−327,245
2,600	36.950	78,727	−123,847	268.229	−335,399
2,700	37.025	82,426	−124,724	269.625	−343,519
2,800	37.093	86,132	−125,616	270.973	−351,606
2,900	37.155	89,844	−126,523	272.275	−359,661
3,000	37.213	93,562	−127,446	273.536	−367,684
3,100	37.268	97,287	−128,383	274.757	−375,677
3,200	37.321	101,016	−129,335	275.941	−383,639
3,300	37.372	104,751	−130,303	277.090	−391,571
3,400	37.422	108,490	−131,285	278.207	−399,474
3,500	37.471	112,235	−132,283	279.292	−407,347
3,600	37.521	115,985	−133,295	280.349	−415,192
3,700	37.570	119,739	−134,323	281.377	−423,008
3,800	37.619	123,499	−135,366	282.380	−430,796
3,900	37.667	127,263	−136,424	283.358	−438,557
4,000	37.716	131,032	−137,497	284.312	−446,291
4,100	37.764	134,806	−138,585	285.244	−453,997
4,200	37.810	138,585	−139,687	286.154	−461,677
4,300	37.855	142,368	−140,804	287.045	−469,330
4,400	37.897	146,156	−141,935	287.915	−476,957
4,500	37.936	149,948	−143,079	288.768	−484,558
4,600	37.970	153,743	−144,236	289.602	−492,134
4,700	37.998	157,541	−145,407	290.419	−499,684

Table A.1 (continued)

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
4,800	38.019	161,342	−146,589	291.219	−507,210
4,900	38.031	165,145	−147,783	292.003	−514,710
5,000	38.033	168,948	−148,987	292.771	−522,186

Table A.2 Carbon dioxide (CO_2), MW = 44.011, enthalpy of formation @ 298 K (kJ/kmol) = −393, 546

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
200	32.387	−3,423	−393,483	199.876	−394,126
298	37.198	0	−393,546	213.736	−394,428
300	37.280	69	−393,547	213.966	−394,433
400	41.276	4,003	−393,617	225.257	−394,718
500	44.569	8,301	−393,712	234.833	−394,983
600	47.313	12,899	−393,844	243.209	−395,226
700	49.617	17,749	−394,013	250.680	−395,443
800	51.550	22,810	−394,213	257.436	−395,635
900	53.136	28,047	−394,433	263.603	−395,799
1,000	54.360	33,425	−394,659	269.268	−395,939
1,100	55.333	38,911	−394,875	274.495	−396,056
1,200	56.205	44,488	−395,083	279.348	−396,155
1,300	56.984	50,149	−395,287	283.878	−396,236
1,400	57.677	55,882	−395,488	288.127	−396,301
1,500	58.292	61,681	−395,691	292.128	−396,352
1,600	58.836	67,538	−395,897	295.908	−396,389
1,700	59.316	73,446	−396,110	299.489	−396,414
1,800	59.738	79,399	−396,332	302.892	−396,425
1,900	60.108	85,392	−396,564	306.132	−396,424
2,000	60.433	91,420	−396,808	309.223	−396,410
2,100	60.717	97,477	−397,065	312.179	−396,384
2,200	60.966	103,562	−397,338	315.009	−396,346
2,300	61.185	109,670	−397,626	317.724	−396,294
2,400	61.378	115,798	−397,931	320.333	−396,230
2,500	61.548	121,944	−398,253	322.842	−396,152
2,600	61.701	128,107	−398,594	325.259	−396,061
2,700	61.839	134,284	−398,952	327.590	−395,957
2,800	61.965	140,474	−399,329	329.841	−395,840
2,900	62.083	146,677	−399,725	332.018	−395,708
3,000	62.194	152,891	−400,140	334.124	−395,562
3,100	62.301	159,116	−400,573	336.165	−395,403
3,200	62.406	165,351	−401,025	338.145	−395,229
3,300	62.510	171,597	−401,495	340.067	−395,041
3,400	62.614	177,853	−401,983	341.935	−394,838
3,500	62.718	184,120	−402,489	343.751	−394,620
3,600	62.825	190,397	−403,013	345.519	−394,388
3,700	62.932	196,685	−403,553	347.242	−394,141
3,800	63.041	202,983	−404,110	348.922	−393,879
3,900	63.151	209,293	−404,684	350.561	−393,602
4,000	63.261	215,613	−405,273	353.161	−393,311
4,100	63.369	221,945	−405,878	353.725	−393,004
4,200	63.474	228,287	−406,499	355.253	−392,683
4,300	63.575	234,640	−407,135	356.748	−392,346
4,400	63.669	241,002	−407,785	358.210	−391,995
4,500	63.753	247,373	−408,451	359.642	−391,629
4,600	63.825	253,752	−409,132	361.044	−391,247
4,700	63.881	260,138	−409,828	362.417	−390,851

Table A.2 (continued)

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
4,800	63.918	266,528	−410,539	363.763	−390,440
4,900	63.932	272,920	−411,267	365.081	−390,014
5,000	63.919	279,313	−412,010	366.372	−389,572

Table A.3 Hydrogen (H_2), MW = 2.016, enthalpy of formation @ 298 K (kJ/kmol) = 0

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
200	28.522	−2,818	0	119.137	0
298	28.871	0	0	130.595	0
300	28.877	53	0	130.773	0
400	29.120	2,954	0	139.116	0
500	29.275	5,874	0	145.632	0
600	29.375	8,807	0	150.979	0
700	29.461	11,749	0	155.514	0
800	29.581	14,701	0	159.455	0
900	29.792	17,668	0	162.950	0
1,000	30.160	20,664	0	166.106	0
1,100	30.625	23,704	0	169.003	0
1,200	31.077	26,789	0	171.687	0
1,300	31.516	29,919	0	174.192	0
1,400	31.943	33,092	0	176.543	0
1,500	32.356	36,307	0	178.761	0
1,600	32.758	39,562	0	180.862	0
1,700	33.146	42,858	0	182.860	0
1,800	33.522	46,191	0	184.765	0
1,900	33.885	49,562	0	186.587	0
2,000	34.236	52,968	0	188.334	0
2,100	34.575	56,408	0	190.013	0
2,200	34.901	59,882	0	191.629	0
2,300	35.216	63,388	0	193.187	0
2,400	35.519	66,925	0	194.692	0
2,500	35.811	70,492	0	196.148	0
2,600	36.091	74,087	0	197.558	0
2,700	36.361	77,710	0	198.926	0
2,800	36.621	81,359	0	200.253	0
2,900	36.871	85,033	0	201.542	0
3,000	37.112	88,733	0	202.796	0
3,100	37.343	92,455	0	204.017	0
3,200	37.566	96,201	0	205.206	0
3,300	37.781	99,968	0	206.365	0
3,400	37.989	103,757	0	207.496	0
3,500	38.190	107,566	0	208.600	0
3,600	38.385	111,395	0	209.679	0
3,700	38.574	115,243	0	210.733	0
3,800	38.759	119,109	0	211.764	0
3,900	38.939	122,994	0	212.774	0
4,000	39.116	126,897	0	213.762	0
4,100	39.291	130,817	0	214.730	0
4,200	39.464	134,755	0	215.679	0
4,300	39.636	138,710	0	216.609	0
4,400	39.808	142,682	0	217.522	0
4,500	39.981	146,672	0	218.419	0
4,600	40.156	150,679	0	219.300	0
4,700	40.334	154,703	0	220.165	0

Table A.3 (continued)

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
4,800	40.516	158,746	0	221.016	0
4,900	40.702	162,806	0	221.853	0
5,000	40.895	166,886	0	222.678	0

Table A.4 Hydrogen atom (H), MW = 1.008, enthalpy of formation @ 298 K (kJ/kmol) = 217,977

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}_f^o(298))$ (kJ/kmol)	$\bar{h}_f^o(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}_f^o(T)$ (kJ/kmol)
200	20.786	−2,040	217,346	106.305	207,999
298	20.786	0	217,977	114.605	203,276
300	20.786	38	217,989	114.733	203,185
400	20.786	2,117	218,617	120.713	198,155
500	20.786	4,196	219,236	125.351	192,968
600	20.786	6,274	219,848	129.351	187,657
700	20.786	8,353	220,456	132.345	182,244
800	20.786	10,431	221,059	135.121	176,744
900	20.786	12,510	221,653	137.569	171,169
1,000	20.786	14,589	222,234	139.759	165,528
1,100	20.786	16,667	222,793	141.740	159,830
1,200	20.786	18,746	223,329	143.549	154,082
1,300	20.786	20,824	223,843	145.213	148,291
1,400	20.786	22,903	224,335	146.753	142,461
1,500	20.786	24,982	224,806	148.187	136,596
1,600	20.786	27,060	225,256	149.528	130,700
1,700	20.786	29,139	225,687	150.789	124,777
1,800	20.786	31,217	226,099	151.977	118,830
1,900	20.786	33,296	226,493	153.101	112,859
2,000	20.786	35,375	226,868	154.167	106,869
2,100	20.786	37,453	227,226	155.181	100,860
2,200	20.786	39,532	227,568	156.148	94,834
2,300	20.786	41,610	227,894	157.072	88,794
2,400	20.786	43,689	228,204	157.956	82,739
2,500	20.786	45,768	228,499	158.805	76,672
2,600	20.786	47,846	228,780	159.620	70,593
2,700	20.786	49,925	229,047	160.405	64,504
2,800	20.786	52,003	229,301	161.161	58,405
2,900	20.786	54,082	229,543	161.890	52,298
3,000	20.786	56,161	229,772	162.595	46,182
3,100	20.786	58,239	229,989	163.276	40,058
3,200	20.786	60,318	230,195	163.936	33,928
3,300	20.786	62,396	230,390	164.576	27,792
3,400	20.786	64,475	230,574	165.196	21,650
3,500	20.786	66,554	230,748	165.799	15,502
3,600	20.786	68,632	230,912	166.954	9,350
3,700	20.786	70,711	231,067	166.954	3,194
3,800	20.786	72,789	231,212	167.508	−2,967
3,900	20.786	74,868	231,348	168.048	−9,132
4,000	20.786	76,947	231,475	168.575	−15,299
4,100	20.786	79,025	231,594	169.088	−21,470
4,200	20.786	81,104	231,704	169.589	−27,644
4,300	20.786	83,182	231,805	170.078	−33,820
4,400	20.786	85,261	231,897	170.556	−39,998
4,500	20.786	87,340	231,981	171.023	−46,179
4,600	20.786	89,418	232,056	171.480	−52,361
4,700	20.786	91,497	232,123	171.927	−58,545

Table A.4 (continued)

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
4,800	20.786	93,575	232,180	172.364	−64,730
4,900	20.786	95,654	232,228	172.793	−70,916
5,000	20.786	97,733	232,267	173.213	−77,103

Table A.5 Hydroxyl (OH), MW = 17.007, enthalpy of formation @ 298 K (kJ/kmol) = 38,985

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
200	30.140	−2,948	38,864	171.607	35,808
298	29.932	0	38,985	183.604	34,279
300	29.928	55	38,987	183.789	34,250
400	29.718	3,037	39,030	192.369	32,662
500	29.570	6,001	39,000	198.983	31,072
600	29.527	8,955	38,909	204.369	29,494
700	29.615	11,911	38,770	208.925	27,935
800	29.844	14,883	38,599	212.893	26,399
900	30.208	17,884	38,410	216.428	24,885
1,000	30.682	20,928	38,220	219.635	23,392
1,100	31.186	24,022	38,039	222.583	21,918
1,200	31.662	27,164	37,867	225.317	20,460
1,300	32.114	30,353	37,704	227.869	19,017
1,400	32.540	33,586	37,548	230.265	17,585
1,500	32.943	36,860	37,397	232.524	16,164
1,600	33.323	40,174	37,252	234.662	14,753
1,700	33.682	43,524	37,109	236.693	13,352
1,800	34.019	46,910	36,969	238.628	11,958
1,900	34.337	50,328	36,831	240.476	10,573
2,000	34.635	53,776	36,693	242.245	9,194
2,100	34.915	57,254	36,555	243.942	7,823
2,200	35.178	60,759	36,416	245.572	6,458
2,300	35.425	64,289	36,276	247.141	5,099
2,400	35.656	67,843	36,133	248.654	3,746
2,500	35.872	71,420	35,986	250.114	2,400
2,600	36.074	75,017	35,836	251.525	1,060
2,700	36.263	78,634	35,682	252.890	−275
2,800	36.439	82,269	35,524	254.212	−1,604
2,900	36.604	85,922	35,360	255.493	−2,927
3,000	36.759	89,590	35,191	256.737	−4,245
3,100	36.903	93,273	35,016	257.945	−5,556
3,200	37.039	96,970	34,835	259.118	−6,862
3,300	37.166	100,681	34,648	260.260	−8,162
3,400	37.285	104,403	34,454	261.371	−9,457
3,500	37.398	108,137	34,253	262.454	−10,745
3,600	37.504	111,882	34,046	263.509	−12,028
3,700	37.605	115,638	33,831	264.538	−13,305
3,800	37.701	119,403	33,610	265.542	−14,576
3,900	37.793	123,178	33,381	266.522	−15,841
4,000	37.882	126,962	33,146	267.480	−17,100
4,100	37.968	130,754	32,903	268.417	−18,353
4,200	38.052	134,555	32,654	269.333	−19,600
4,300	38.135	138,365	32,397	270.229	−20,841
4,400	38.217	142,182	32,134	271.107	−22,076
4,500	38.300	146,008	31,864	271.967	−23,306
4,600	38.382	149,842	31,588	272.809	−24,528
4,700	38.466	153,685	31,305	273.636	−25,745

Table A.5 (continued)

T(K)	$\bar{c}_p$ (kJ/kmol-K)	$(\bar{h}^o(T) - \bar{h}^o_f(298))$ (kJ/kmol)	$\bar{h}^o_f(T)$ (kJ/kmol)	$\bar{s}^o(T)$ (kJ/kmol-K)	$\bar{g}^o_f(T)$ (kJ/kmol)
4,800	38.552	157,536	31,017	274.446	−26,956
4,900	38.640	161,395	30,722	275.242	28,161
5,000	38.732	165,264	30,422	276.024	−29,360