Modelling of Combustion Processes – Theory and Application 7.5 ECTS

Ladokcode: 42K13C
The exam is given to: KMARE 15h, KMARE 15h1

ExamCode:

Date of exam: June 2, 2016
Time: 9.00-13.00
Latest day for result:
Means of assistance:
Calculator, Dictionary, Mathematical tables

Total amount of point on exam: 50
Requirements for grading:
Grade F: Less than 17 points
Grade FX: Minimum 17 points
Grade E: Minimum 20 points
Grade D: Minimum 25 points
Grade C: Minimum 30 points
Grade B: Minimum 35 points
Grade A: Minimum 40 points

Additional information:

Next re-exam date:

The marking period is, for the most part, 15 working days, plus up to 5 working days for administration, otherwise it's the following date:

Important! Do not forget to write the ExamCode on each paper you hand in.

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Phone numbers: 073-2305964

1. Heat can be transferred in different modes (ways).
    a. What is the driving force for all modes of heat transfer? (1p)
    b. List the three most common modes of heat transfer and describe how heat is transferred and the necessary requirements to achieve each particular heat transfer. (3p)

2. Sometimes it is needed to use numerical methods to solve the transport equations (most likely in real situations). Show how the common steady state heat equation in one dimension (1d) could be expressed in a nodal network (that is to estimate derivatives)
Heat equation: $\frac{d}{dx}\left(k\frac{dT}{dx}\right) = 0$ (3p)

3. Hot air (250°C) flows through a 3 m long pipe with inner diameter of 25 mm at an average velocity of 15 m/s. It has been found that the Nu number for this internal flow is:

$$Nu_D = 0.023Re_D^{0.8}Pr^{0.3}$$

    a. Set up the heat balance for a control volume of size dx (where dx is the length) (3p)
    b. Derive an expression for the temperature change over the whole pipe (it will be an expression that includes the unknown heat transfer coefficient) (3p)
    c. Find the rate of heat transfer from the steam to the pipe if the pipe wall temperature is 150°C. (4p)
    d. What will the exit temperature of the steam be? (2p)

4. Explain Wien´s displacement law. (2p)

5. A spherical aluminum shell with an inside diameter of 2 m is evacuated and used as a radiation test chamber.
    a. If the inner surface is coated by carbon black and maintained at 600 K, what is the irradiation on a small test surface placed in the chamber? (2p)
    b. If the surface were not coated and maintained at 600 K, what would the irradiation be? (2p)

6. The Navier Stoke equation is often used when it comes to transport processes. What is represented in each term with the equation and when it is used? (3p)

$$\sum \boldsymbol{F} = \iint_{c.s.} \rho \boldsymbol{v}(\boldsymbol{v} \cdot \hat{\boldsymbol{n}})dA + \frac{\partial}{\partial t} \iiint_{c.v.} \rho \boldsymbol{v} dV$$

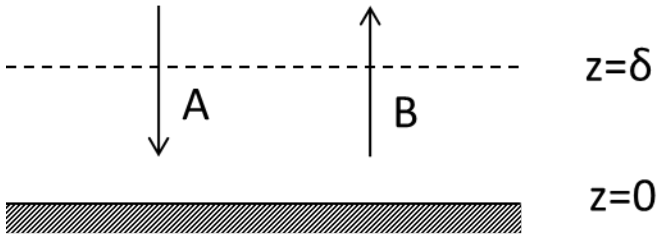
7. Many flow dependent correlations depend on the Reynold number (Re). Show how the Re number is constructed (what parameters are included) and describe also the physical meaning with the correlation. (3p)

8. The diffusivity of oxygen is used in the assignment on combustion of a char particle. Is the diffusivity dependent on the temperature and the pressure? If so, explain how it varies at increased temperature and increased pressure. (2p)

9. The surface (at z=0) is a catalytic surface where gas specie A reacts and form gas specie B. To reach the surface, A has to diffuse through a stagnant film and the reaction that follows is very rapid in comparison to the diffusion. The formed product, specie B, then diffuses back to the gas bulk flow.

   a. Determine the concentration profile in the stagnant film if the reaction is according to A→ B. This includes determining the boundary conditions as well as the solving the mass balance together with the definition of the flux. (6p)

   b. How would the full explicit expression for the flux change if the reaction instead is: A → 3 B? (2 p)



10. The Thiele modulus expresses the relationship between two phenomena in mass transfer.

$$\phi_n = \sqrt{\frac{k_n R^2 C^{n-1}}{D_e}}$$

a. Explain these phenomena and describe each term in the Thiele modulus. (3p)

b. If a process has a value of the Thiele modulus, what does it mean? (2p)

c. How will the Thiele modulus look like for a first order reaction? (1p)

11. The combustion of the wood particle A is kinetically controlled whereas the combustion of the wood particle B is diffusion controlled. Both particles have a spherical geometry. The difference in combustion regime is explained by the difference in diameter of the two particles. Which of them is the larger one? Explain! (3p)

Thermodynamic properties of Air

T (K)	ρ (kg/m^3)	c_p (kJ/kgK)	$k\cdot10^3$ (W/mK)	$\mu\cdot10^7$ (Pas)	$\nu\cdot10^6$ (m^2/s)	Pr (-)
300	1.1614	1.007	26.3	184.6	15.89	0.707
350	0.9950	1.009	30.0	208.2	20.92	0.700
400	0.8711	1.014	33.8	230.1	26.41	0.690
450	0.7740	1.021	37.3	250.7	32.39	0.686
500	0.6964	1.030	40.7	270.1	38.79	0.684
550	0.6329	1.040	43.9	288.4	45.57	0.683
600	0.5804	1.051	46.9	305.8	52.69	0.685

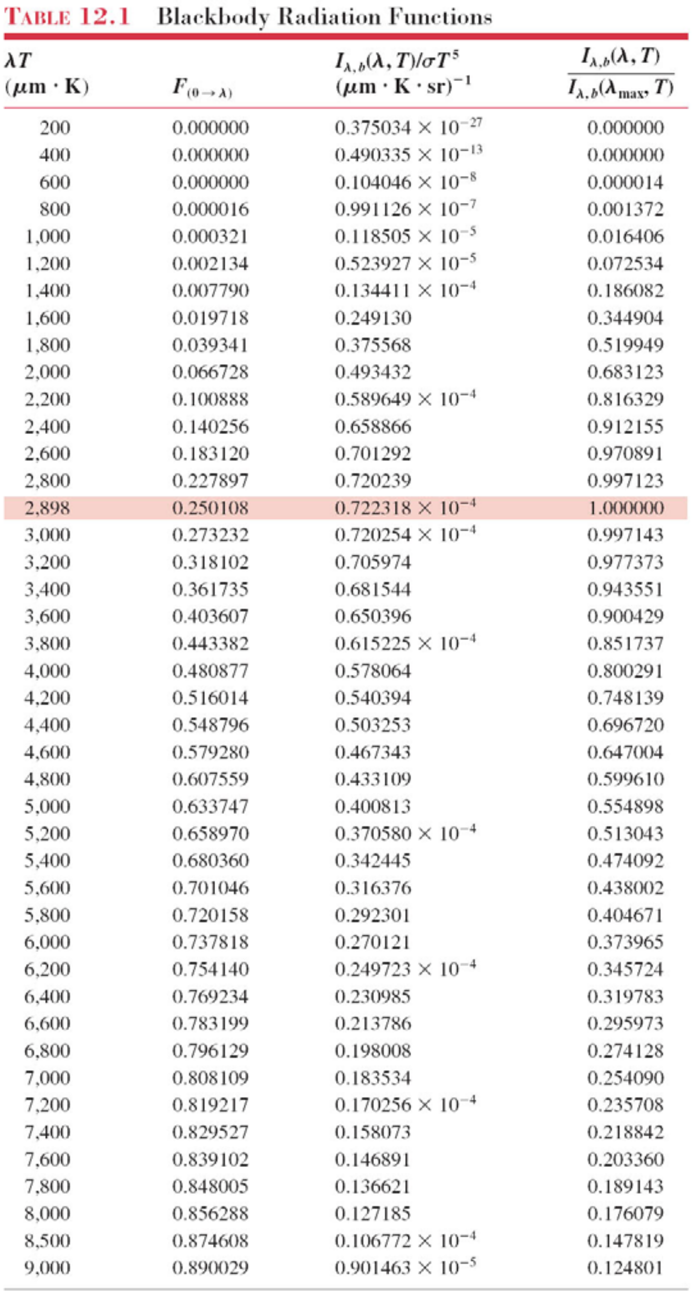


TABLE 12.1 Blackbody Radiation Functions

λT (μm · K)	$F_{(0\rightarrow\lambda)}$	$I_{\lambda,b}(\lambda,T)/\sigma T^5$ (μm · K · sr)$^{-1}$	$\dfrac{I_{\lambda,b}(\lambda,T)}{I_{\lambda,b}(\lambda_{\max},T)}$
200	0.000000	0.375034×10^{-27}	0.000000
400	0.000000	0.490335×10^{-13}	0.000000
600	0.000000	0.104046×10^{-8}	0.000014
800	0.000016	0.991126×10^{-7}	0.001372
1,000	0.000321	0.118505×10^{-5}	0.016406
1,200	0.002134	0.523927×10^{-5}	0.072534
1,400	0.007790	0.134411×10^{-4}	0.186082
1,600	0.019718	0.249130	0.344904
1,800	0.039341	0.375568	0.519949
2,000	0.066728	0.493432	0.683123
2,200	0.100888	0.589649×10^{-4}	0.816329
2,400	0.140256	0.658866	0.912155
2,600	0.183120	0.701292	0.970891
2,800	0.227897	0.720239	0.997123
2,898	0.250108	0.722318×10^{-4}	1.000000
3,000	0.273232	0.720254×10^{-4}	0.997143
3,200	0.318102	0.705974	0.977373
3,400	0.361735	0.681544	0.943551
3,600	0.403607	0.650396	0.900429
3,800	0.443382	0.615225×10^{-4}	0.851737
4,000	0.480877	0.578064	0.800291
4,200	0.516014	0.540394	0.748139
4,400	0.548796	0.503253	0.696720
4,600	0.579280	0.467343	0.647004
4,800	0.607559	0.433109	0.599610
5,000	0.633747	0.400813	0.554898
5,200	0.658970	0.370580×10^{-4}	0.513043
5,400	0.680360	0.342445	0.474092
5,600	0.701046	0.316376	0.438002
5,800	0.720158	0.292301	0.404671
6,000	0.737818	0.270121	0.373965
6,200	0.754140	0.249723×10^{-4}	0.345724
6,400	0.769234	0.230985	0.319783
6,600	0.783199	0.213786	0.295973
6,800	0.796129	0.198008	0.274128
7,000	0.808109	0.183534	0.254090
7,200	0.819217	0.170256×10^{-4}	0.235708
7,400	0.829527	0.158073	0.218842
7,600	0.839102	0.146891	0.203360
7,800	0.848005	0.136621	0.189143
8,000	0.856288	0.127185	0.176079
8,500	0.874608	0.106772×10^{-4}	0.147819
9,000	0.890029	0.901463×10^{-5}	0.124801
9,500	0.903085	0.765338	0.105956
10,000	0,914199	$0.653279 \text{ x } 10^{-5}$	0.090442
10,500	0.923710	0.560522	0.077600
11,000	0.931890	0.483321	0.066913
11,500	0.939959	0.418725	0.057970
12,000	0.945098	$0.364394 \text{ x } 10^{-5}$	0.050448
13,000	0.955139	0.279457	0.038689
14,000	0.962898	0.217641	0.030131
15,000	0.969981	$0.171866 \text{ x } 10^{-5}$	0.023794
16,000	0.973814	0.137429	0.019026
18,000	0.980860	$0.908240 \text{ x } 10^{-6}$	0.012574
20,000	0.985602	0.623310	0.008629
25,000	0.992215	0.276474	0.003828
30,000	0.995340	$0.140469 \text{ x } 10^{-6}$	0.001945
40,000	0.997967	$0.473891 \text{ x } 10^{-7}$	0.000656
50,000	0.998953	0.201605	0.000279
75,000	0.999713	$0.418597 \text{ x } 10^{-8}$	0.000058
100,000	0.999905	0.135752	0.000019