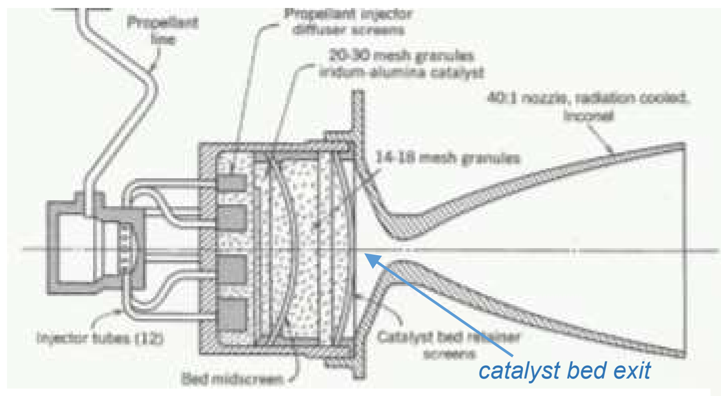
AE4451
Seitzman
Summer 2024

Problem Set #3: Equilibrium Composition and Ramjet Performance

- Homework solutions should be neat and logically presented, see format requirements at http://seitzman.gatech.edu/classes/ae4451/homeworkformat.html.
- For the following problems, YOU MUST include **a sketch** of the flow/system, and *if you employ a control volume analysis*, you must indicate clearly your choice of **control surface**.
- If you use any results or equations from the class notes or text in your solutions, please note and **reference** them (please make sure they are applicable to the problem at hand).
- Try to **solve** the problem **algebraically** first. Only use numbers/values in the final steps of your solution.

1. Hydrazine Decomposition Chamber



From Sutton and Biblarz, Rocket Propulsion Elements, 2010

In many thrusters used for spacecraft attitude control, hydrazine (N_2H_4) is used as the propellant. The hydrazine is stored as a liquid, but before reaching the nozzle, it passes through a heated catalyst bed. There the hydrazine vaporizes and exothermically decomposes (thereby raising the temperature) into ammonia (NH_3) and nitrogen (N_2). However, some of the ammonia can also decompose into H_2 and N_2.

The tables below provide information you may need for this problem; note: the data are based on a value of **1 bar as the standard/reference pressure p°**. In answering the questions below, do not use data from any other sources.

	N_2H_4	NH_3	H
$\Delta\bar{h}^o_{f,1150K}$ (kJ/mol)	88.224	-56.792	223.061
$K_{p,f,1150\ K}$	7.508×10^{-17}	2.450×10^{-4}	7.473×10^{-8}

	N_2	H_2	NH_3
$c_{p,\ 1150K}$ (J/mol)	33.5	30.9	60.0

a) If the gas *exiting* the catalyst bed is at 1150 K and 29 bar, and assuming the gas at the catalyst bed exit is in chemical equilibrium and contains **only** N_2, H_2, and NH_3, determine the mole fractions of each of these gases at the exit.

b) If the inlet conditions and exit pressure remained the same, but the gas was not in chemical equilibrium at the exit, and the NH_3 mole fraction was higher than the value you calculated in part a), would the exit temperature likely be higher, lower or the same (1150 K)? You do not need to calculate a specific number, but an answer by itself is not sufficient; you need to justify your answer.

c) For the same original assumptions (chemical equilibrium, only N_2, H_2, and NH_3 present) would changing the pressure at the exit to 15 bar increase or decrease the mole fraction of NH_3 leaving the catalyst bed, if the *exit temperature remained the same*. You do not need to calculate a specific number, but an answer by itself is not sufficient; you need to justify your answer.

d) In the answer to part a), we assumed that the H atom mole fraction was negligible (very small, i.e., $\chi_H << \chi_{H2}$, χ_{N2} and χ_{NH3}). Estimate χ_H for the original (29 bar) case using the value you found for χ_{H2} and the $K_{p,f}$ information provided in the table.

2. Ramjet Performance

A ramjet engine is being used on an aircraft flying at Mach 2.30 and operating at an altitude where the ambient temperature is 216.7 K and the ambient pressure is 14.24 kPa. The ramjet combustor burns a JP fuel with a heating value of 43.5 MJ/kg at a fuel-air ratio of 0.0350, and has a maximum allowable operating temperature of 2275 K. The gas at the ramjet's nozzle has an exit temperature and pressure of 1221 K and 23.8 kPa, a velocity of 1186.7 m/s, and a molecular weight of 28.5.

a) What is the ramjet's thrust-specific fuel consumption for the given flight and operating conditions?

b) What are the ramjet's propulsive, thermal and overall efficiencies at these conditions?

c) Assuming the ramjet's combustor is operating with a combustion efficiency of 96%, is the ramjet operating at its maximum allowable fuel-air ratio?