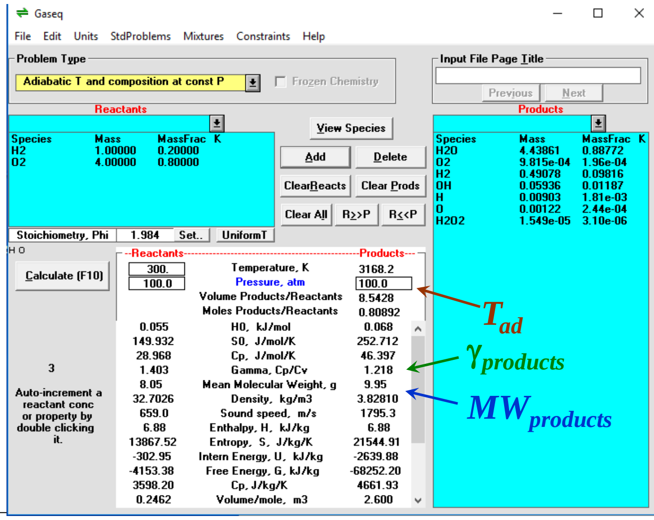
Rocket Propulsion

Reacting Flow Issues

Combustor Calculations

- $c^* \propto (T_o/MW)^{1/2}$
- Must include effect of product dissociation for rocket chamber calculations
  - will decrease T_o and reduce MW
- Peform **adiabatic flame temperature** calculation with full equilibrium products
  - pressure = chamber pressure
  - total enthalpy unchanged

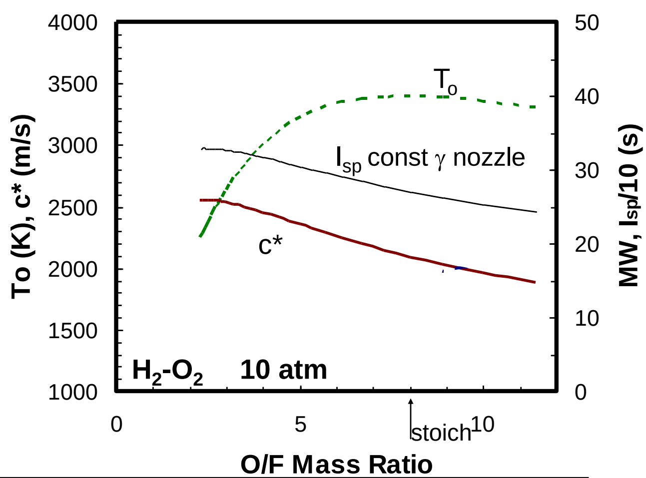
Example Method – Gaseq



Equilibrium Combustor Chemistry

- Peak in T_{ad} near stoichio-metric mixture
- Peak in c* (& $I_{sp} \propto c^* c_\tau$) for rich mixture?

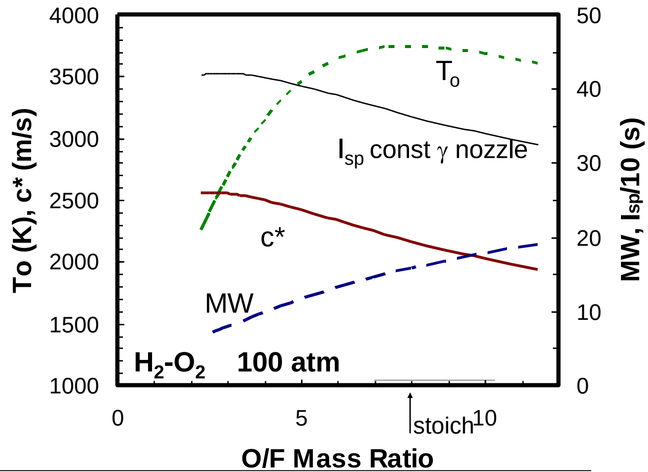
low MW!



Georgia Tech | College of Engineering

Pressure Effects

- Raise p, higher T_{ad} (less dis-sociation)
- Also increases MW
- Slightly higher c*
- I_{sp} higher for same p_e



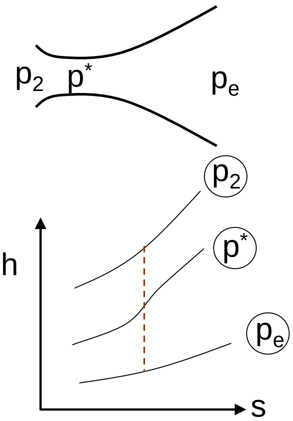
Georgia Tech | College of Engineering

Nozzle Chemistry

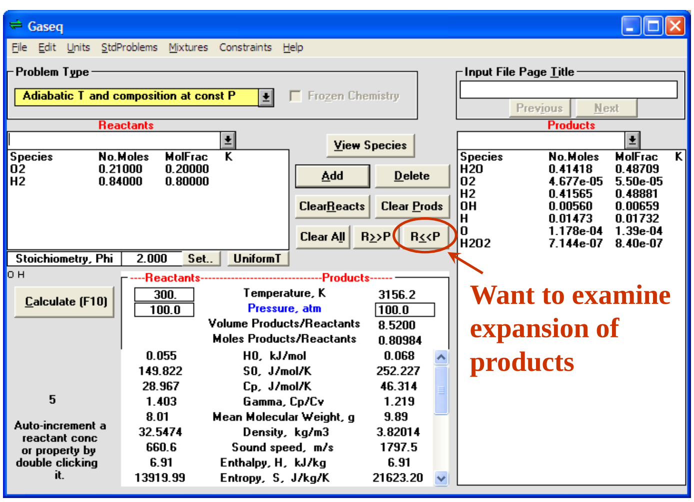
- What happens to chemical composition in nozzle?
- As velocity increases
  - temperature and pressure decrease
  - will lead to change in composition

Isentropic Expansion

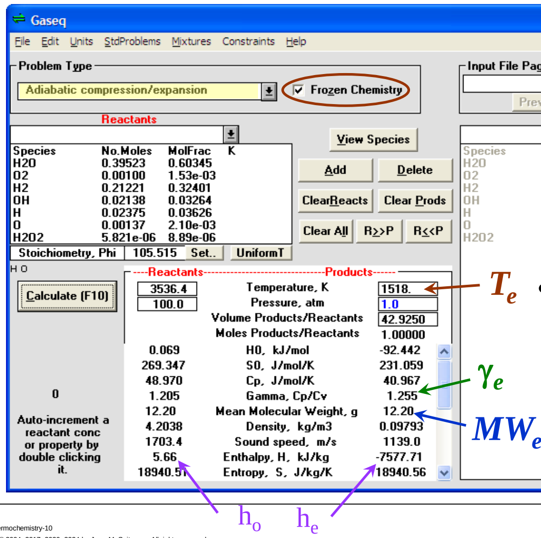
- Constant γ is a very poor assumption for high temperature rocket product gases
  – can't use $p/p_o=(T/T_o)^{\gamma/\gamma-1}$
  – even worse assumption if gas is reacting
- Can still calculate **isentropic** nozzle expansion for two cases
  – flow stays in **equilibrium** through nozzle (***shifting equil.***)
  – flow is **frozen** - composition can not change
  – find h (and thus u) that matches given p and s



Example Method – Gaseq



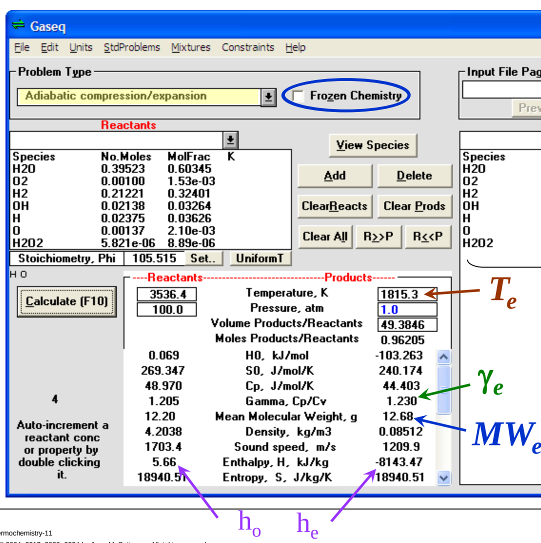
Example – Frozen Chemistry



- For p_e= 1atm

Georgia Tech College of Engineering

Example – Shifting Equilibrium

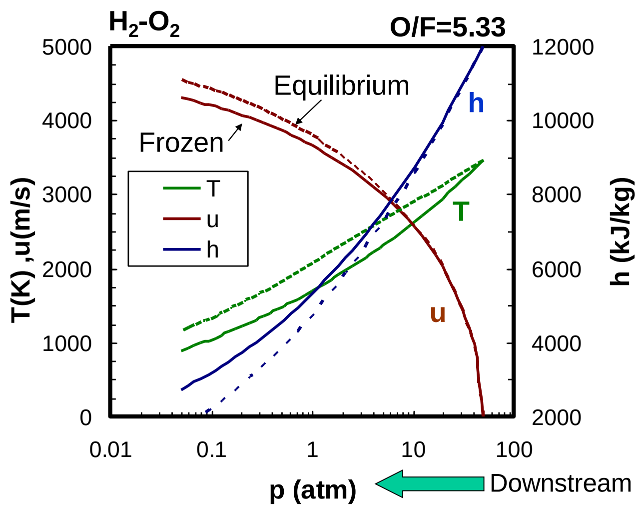


- Exit composition

Georgia Tech | College of Engineering

Frozen and Shifting Equilibrium

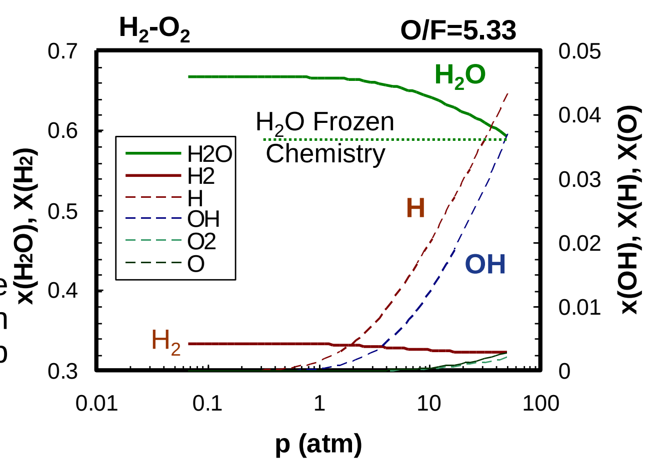
- Both cases have same entropy
- T drops faster for frozen flow
- u_e (Isp) lower for frozen flow



Georgia Tech | College of Engineering

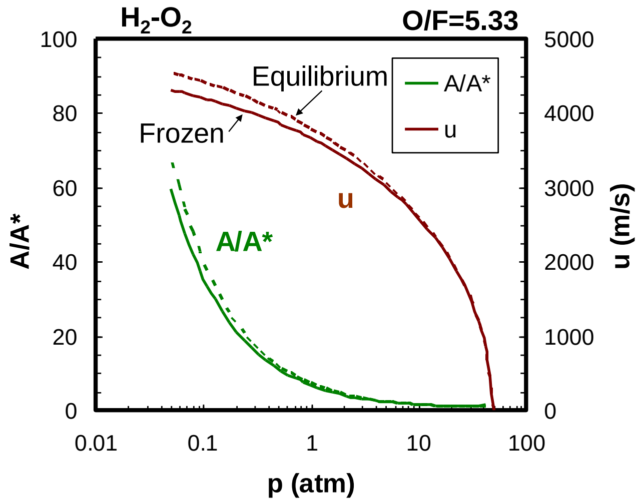
Shifting Equilibrium Composition

- As T drops, minor species recombine (H,OH)
- Chemical energy converted to thermal energy
- T does not have to drop as much to reach same p (c_p effectively higher)



Area Ratio

- Compared to equil. case, frozen case requires
  - larger expansion ratio to achieve same u_e
  - lower expansion ratio to achieve same p_e



Nonequilibrium Nozzle Flow

- For adiabatic nozzles, I_{sp} will fall between the **frozen and equilibrium limits** ⇒ not isentropic! – **nonequilibrium flow**
  - chemistry isn't so fast compared to nozzle expansion rate, so composition can't stay in equilibrium, but not so slow to be frozen
    - τ_{chem} vs. τ_{flow}
  - tends to get more frozen later in the nozzle colder & lower p⇒ low reaction rates ⇒ τ_{chem} long AND velocity high ⇒ τ_{flow} short
- Can solve nonequilibrium by
  - including RATES in conservation/flow equations