

ChE problems for teachers

1. Submitted by Professor R. B. Bird, University of Wisconsin.

Hydrostatic Pressure Distribution in Incompressible Fluids. Consider a beaker of liquid which, for all practical purposes, can be considered to be incompressible; let its density be ρ_0 . It is desired to obtain an expression for the pressure in the liquid as a function of position. Take the origin of coordinates to be at the liquid-air interface, with the positive z-axis pointing away from the liquid; let the pressure at the liquid-air interface be $p(0)$. A friend comes to you with the following comments:

- I. "By simplifying the equation of motion for an incompressible fluid at rest, I get $0 = -dp/dz - \rho_0 g$; I can solve this and get $p = p(0) - \rho_0 g z$. That seems reasonable — the pressure increases as one goes deeper and deeper into the liquid."
- II. "But, on the other hand, the equation of state of any fluid is $p = p(\rho, T)$. If the system is isothermal, then $p = p(\rho)$. If, furthermore, the fluid is incompressible $p = p(\rho_0) = \text{constant}$. This tells me that the pressure is constant throughout the field — which I don't believe!"

Clearly your friends need help. Explain.

2. Submitted by Professor Dave Chittenden, University of New Hampshire.

Computer Solution for the Adiabatic Flame Temperature. Find the adiabatic flame temperature for combustion of the following natural gas mixture: CH₄, 86.6%; C₂H₆, 7.9%; C₃H₈, 2.7%; C₄H₁₀, 1.3%; N₂, 1.5%. This dry gas is mixed with 130% theoretical air which contains 0.043 lb H₂O/lb dry air. The gas-air mixture enters the

burner at 500°K and 4 atmospheres pressure. Dissociation of water and carbon dioxide in the flue gases must be considered.

Solution:

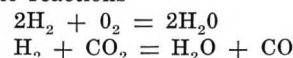
To do this type of computation, a general computer program in Fortran IV-G has been developed and tested on an IBM 360 Model 40 computer. To use the program, one keypunches a few IBM cards containing a description of the problem, and then the data cards are submitted along with a machine language program deck for processing.

The data needed for the calculation of the adiabatic flame temperature are as follows:

1. Number of hydrocarbon species in the gas mixture being burned.
2. Pressure in the burner.
3. Percent theoretical air (Must be equal to or greater than 100%).
4. Absolute humidity of the incoming air.
5. Number of moles of each hydrocarbon and of nitrogen in the fuel stream.
6. Heats of combustion at 291°K for all of hydrocarbon gases burned. (The heats to be used assume that gaseous water is formed in standard state reaction.)
7. Specific heats of all components in the range between 291°K and the flame temperature as a function of temperature.
8. Inlet reactant temperatures, which may be different for each reactant.

When the adiabatic flame temperature is calculated, a number of assumptions are made:

1. The process of combustion is adiabatic.
2. There is no secondary air. The hydrocarbons are completely converted using only the primary air.
3. The only combustion products are carbon dioxide, carbon monoxide, water, hydrogen, oxygen and nitrogen. These products are at the equilibrium conversions controlled by the equilibrium constants for the reactions



THEORETICAL FLAME TEMPERATURE (01A)

GENERAL CASE FOR NATURAL GAS MIXTURE

PRESSURE = 4.00 ATMOSPHERES
4 HYDROCARBON(S)

PERCENT THEORETICAL AIR = 130.00
0.04300LB H₂O PER LB DRY AIR

Input Data

THE DATA DESCRIBING THE REACTING HYDROCARBONS IS TABULATED BELOW

FORMULA	HEAT OF COMB.	ENT MOLES	MOLES C	MOLES H ₂	ENT TEMP
CH ₄	-0.189700E 06	0.866	1.000	2.000	500.000
C ₂ H ₆	-0.336732E 06	0.079	2.000	3.000	500.000
C ₃ H ₈	-0.484100E 06	0.027	3.000	4.000	500.000
C ₄ H ₁₀	-0.630620E 06	0.013	4.000	5.000	500.000
N ₂		0.015			

Input Data

CAL/GMMOLE

DEGREES KELVIN

FORMULA OF HYDROCARBON OR EQUIVALENT HYDROCARBON
C 1.157 H 4.284

ENTERING MIXTURE BASED ON ONE MOLE ENTERING HYDROCARBON OR HYDROCARBON MIXTURE
MOLES OXYGEN 2.8964 MOLES NITROGEN 10.9109 MOLES WATER 1.0258

PERCENT COMBUSTIBLE GAS BY VOLUME = 6.32

GENERAL FORM OF THE SPECIFIC HEAT EQUATION
 $CP = A + B*T + C*(T)**2 + D*(T)**3$

CONSTANTS IN THE SPECIFIC HEAT EQUATIONS FOR THE REACTING HYDROCARBONS.
 CP UNITS ARE CAL/GMMOLES-DEG. KELVIN

	A	B	C	D
CH4	0.47500E 01	0.30000E-02	0.33630E-06	-0.16450E-09
C2H6	0.94400E 00	0.37350E-01	-0.19930E-04	0.42200E-08
C3H8	-0.96600E 00	0.72790E-01	-0.37750E-04	0.75800E-08
C4H10	0.94500E 00	0.88730E-01	-0.43800E-04	0.83600E-08

Input Data

THE DATA DESCRIBING ALL OTHER COMPOUNDS IS TABULATED BELOW

	HEAT OF DISSOC. CAL/GMMOLE	ENT. TEMP KELVIN	A	B	C	D
H2O	0.57830E 05	500.00	0.832000E 01	-0.653000E-03	0.270000E-05	-0.614500E-09
CO2	0.67960E 05	500.00	0.770000E 01	0.530000E-02	-0.830000E-06	0.0
H2	0.0	500.00	0.664000E 01	0.492000E-03	0.319000E-06	-0.740000E-10
O2	0.0	500.00	0.673000E 01	0.408000E-03	0.486000E-06	-0.123400E-09
N2	0.0	500.00	0.673000E 01	0.408000E-03	0.486000E-06	-0.123400E-09
CO	0.0	500.00	0.673000E 01	0.408000E-03	0.486000E-06	-0.123400E-09

TOTAL MOLES IN THE EQUILIBRIUM MIXTURE
 15.90913

FINAL MIXTURE COMPOSITION, MOLE PERCENT

CO2	H2O	CO	H2	O2	N2
7.22799	19.89369	0.04454	0.01823	4.23272	68.59292

PERCENT DISSOCIATION OF CARBON DIOXIDE = 0.61
 PERCENT DISSOCIATION OF WATER = 0.09

ACTUAL K = 0.264E 04 COMPOSITION K = 0.265E 04

THEORETICAL FLAME TEMPERATURE = 2016.619 DEGREES KELVIN

- The fuel contains only hydrocarbons and nitrogen. The air contains exactly 79 mole % N₂ and 21 mole % O₂.
- The properties of the reactant and of the product gases are calculated as mixtures of ideal gases.
- The flame temperature must be between 2500°K and 1900°K. This range includes the flame temperatures of all major hydrocarbons likely to be in a fuel gas.

The accuracy of the results obtained with this program is limited only by the validity of the above assumptions and the accuracy of the input data. The program user should try to insure that his specific heat data is

valid for the temperature range of the problem he is doing.

The results of computation for the above problem are shown in the figure. The input data read from cards is printed on the output as indicated. The other results are calculated by the program except for the specific heats of the output gases which are stored in the program.

Further information about the program can be obtained from Dr. David H. Chittenden, ChE Department, University of New Hampshire, Durham, New Hampshire 03824.

LETTERS (Continued from p. 109)

For the 40 graduate-inclined schools

$$P = 4.07 + 0.00B + 0.17M + 0.51D \quad (4)$$

and for the 57 undergraduate schools

$$P = 2.56 + 0.11B + 0.08M + 0.27D \quad (5)$$

One immediately notices that in Eq. 4 the coefficient of B is zero. This result may not be as outlandish as it appears at first blush. It indicates that in graduate-oriented programs the number of undergraduates may not appreciably affect the number of full-time professorial schedules. One may speculate that this is the result of a growing and perhaps regrettable practice of relegating undergraduate instruction to persons without professorial rank; i.e., instructors and graduate assistants. This practice may be dictated by necessity in rapid-growth situations.

If one compares the coefficients of D in Eqs. 4 and 5, one notices that graduate-inclined schools require more

professional time per doctoral degree granted than do undergraduate-inclined schools. The situation is reversed in the case of bachelor's degrees.

In conclusion, we wish to remind the reader that no great accuracy is claimed for this study. It represents a first attempt to analyze the relationship between the number of full-time professorial schedules and the number and kinds of degrees granted. Considering the nature of the variables, it is indeed surprising that the indicated degrees of correlation and stability exist. It would be interesting to follow the study with future ones, not only in chemical engineering but in other disciplines as well.

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