BASIC Programs for Steam Plant Engineers

Boilers, Combustion, Fluid Flow, and Heat Transfer

V. Ganapathy

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Preface

Over the past ten years, I have had the opportunity to author over one hundred short articles and three books of interest to steam plant engineers, covering such topics as heat transfer, heat recovery equipment design, boiler calculations, fluid flow, and steam plant equipment sizing. With the plethora of hand-held and personal computers, I thought that it would be helpful to steam plant engineers if several of the shorter and more frequently made calculations could be performed by computer. The result is this volume, which has thirty useful programs written in BASIC. The programs run directly on the IBM PC and compatible systems. The programs can also be modified to run on hand-held computers such as the Sharp, TRS-80, and Texas Instruments models.

These programs are based on my years of experience, having engineered the systems discussed in the text. In contrast, many programs on the market are developed by software engineers who are experts on programming, but lack sufficient knowledge of steam plants and processes and the needs of design and operating engineers. For instance, the programs on combustion calculations and boiler efficiency take into account the effect of relative humidity, an important factor which could easily be overlooked by engineers with inadequate engineering experience. Flue gas analysis is reported on a dry and wet basis, which is helpful in figuring excess air, flue gas density, and gas properties. Efficiency of boilers is determined using ASME PTC procedures and is reported on a lower as well as on a higher heating value basis.

The programs on calculation of pressure drop and heat transfer coefficients inside tubes require only easily available data such as flow per tube, fluid pressure, temperature, and pipe size. Reference to steam tables or properties of air, water, and flue gas is avoided, enabling field engineers to obtain the data with ease, thus saving considerable time. Predicted pressure drop may be compared with the measured value to see if the equipment malfunctioned.

In recognition of the widespread use of finned tubes in boilers and heaters, a number of programs are presented to predict heat transfer and pressure drop in these types of equipment. Various fin geometries can be evaluated to study alternates.

Furnaces and heat transfer equipment are routinely lined with several layers of insulation. Engineers are often required to predict temperature profiles across the various layers and heat loss under varying conditions of ambient temperature and wind velocity. Program 3.9 performs this calculation, handling any number of layers.

Steam properties after throttling or after expansion are important to those involved in valve and pipe sizing and steam turbine selection. Programs 4.1 and 4.2 perform these involved calculations. Steam blowing is a routinely performed operation in boiler plants. Program 4.5 predicts the steam flow rate during a sonic flow situation, when steam escapes to atmosphere.

Estimating the performance of fire tube and water tube waste heat boilers and economizers is vital for engineers involved in their design and operation. Programs 5.1 through 5.3 predict the exit gas temperature and duty at any inlet conditions of gas flow and temperature. Plant engineers can then check to see whether their equipment is functioning properly.

The data required by these programs are easily available to all practicing design and field engineers. The results are practical and useful information for design and performance evaluation of steam plant equipment. Each program listing includes theory, correlations used, logic, listing, and examples, along with a printout of results. In addition, a table of nomenclature has been included with each program. This helps relate the variables used in the text with those in the computer so the programs can be modified to run on other computers. One can also obtain the value of any variable by pressing the appropriate key. A look at the brief synopsis at the beginning of each program will reveal to the user the amount of practical information that can be obtained.

The aim of this volume is to present workable BASIC programs of interest to steam plant designers, consultants, and operators. As with any project, there is always room for some improvement. Therefore, comments from readers on the style and approach of the programs are always welcome.

V. Ganapathy

Diskette to accompany *BASIC Programs for Steam Plant Engineers*: I have prepared a diskette (for IBM PC and compatibles) containing all of the programs discussed in this book. If you would like to purchase a copy, or need more information, please contact me at the following address:
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Contents

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Fuels, Combustion, and Efficiency of Boilers and Heaters

PROGRAM 1.1 COMBUSTION CALCULATIONS FOR SOLID AND LIQUID FUELS

Input

Carbon
Hydrogen
Oxygen
Nitrogen
Sulfur
Moisture
Excess air
Ambient temperature
Relative humidity

Output

Wet flue gas analysis
Dry flue gas analysis
Molecular weight of flue gas
Density of flue gas
Dry air required per pound of fuel
Wet air per pound of fuel
Dry flue gas produced per pound of fuel
Wet flue gas produced per pound of fuel
Higher and lower heating values of the fuel

Remarks

Results are helpful in predicting the performance of fired heat transfer equipment.

Given the ultimate analysis of solid or liquid fuels, excess air, ambient temperature, and relative humidity, this program performs detailed combustion calculations and prints out the dry and wet flue gas analysis, dry and wet air quantities, and dry and wet flue gas produced, along with the flue gas molecular weight and density. These data are useful for heat transfer calculations and to estimate performance of boilers, heaters, and combustion related equipment. Heating values of the fuel are also printed out.

From partial pressure of carbon dioxide and water vapor, one can estimate nonluminous heat transfer coefficients. Dry fuel gas analysis helps the engineer to figure excess air for combustion

TABLE 1.1A Equations Used for Combustion Calculations

$$SVP = 0.08 + 281 \times 10^{-9} T^{3.25} \tag{1}$$

$$M = \frac{0.622 \times SVP \times RH}{14.7 - SVP \times RH} \tag{2}$$

$$w_{da} = 100(2.664C + 7.937H_2 + S - O_2)\frac{E}{23} \tag{3}$$

$$w_{wa} = w_{da}(1 + M) \tag{4}$$

$$w_{wg} = \frac{3.66C + 8.94H_2 + W + w_{da}M + 2S + 0.77w_{da} + N_2 + 0.23w_{da}(E-1)}{E} \tag{5}$$

$$w_{dg} = w_{wg} - (8.94H_2 + W + w_{da}M) \tag{6}$$

$$F = 0.08318C + 0.03125S + \frac{8.94H_2 + W + w_{da}M)}{18} + \frac{0.77w_{da} + N_2}{28} + \frac{0.23w_{da}(E-1)}{32E} \tag{7}$$

$$CO_2' = \frac{8.318C}{F} \tag{8}$$

$$O_2' = \frac{23w_{da}(E-1)}{32EF} \tag{9}$$

$$N_2' = \frac{0.77w_{da} + N_2}{28F} 100 \tag{10}$$

$$H_2O' = \frac{8.94H_2 + W + w_{da}M}{18} 100 \tag{11}$$

$$SO_2 = \frac{3.125S}{F} \tag{12}$$

$$MW = \frac{44CO_2' + 32O_2' + 28N_2' + 18H_2O' + 64SO_2'}{100} \tag{13}$$

$$\rho_g = 0.002636MW \tag{14}$$

TABLE 1.1A (Continued)

$$O'_{2d} = \frac{O'_2}{100 - H_2O'} 100 \quad (15)$$

$$CO'_{2d} = \frac{CO'_2}{100 - H_2O'} 100 \quad (16)$$

$$N'_{2d} = \frac{N'_2}{100 - H_2O'} 100 \quad (17)$$

$$HHV = 14{,}500C + 62{,}000\left(H_2 - \frac{O_2}{8}\right) + 4000S \quad (18)$$

$$LHV = HHV - 9720H_2 - 1110W \quad (19)$$

control purposes. Knowing the density of flue gas aids in estimation of flue gas velocity in ducts.

Table 1.1A shows the equations used for performing the combustion calculations. Table 1.1B gives the nomenclature used, and Fig. 1.1 shows the listing of the program along with the results. An example illustrates the use of the program.

Example

A coal fired boiler operates under the following fuel conditions (fraction by weight):

Carbon = 0.728
Hydrogen = 0.048
Oxygen = 0.062
Nitrogen = 0.015
Sulfur = 0.022
Moisture = 0.035, rest ash
Excess air = 25%
Ambient temperature = 80°F
Relative humidity = 0.60 (60%)

Perform detailed combustion calculations.

TABLE 1.1B Nomenclature Used in Combustion Calculations

Nomenclature	Program symbol	Description and units
CO_2'	I	%Carbon dioxide in wet flue gas
O_2'	J	%Oxygen in wet flue gas
N_2'	K	%Nitrogen in wet flue gas
H_2O'	L	%Water vapor in wet flue gas
MW	A35	Molecular weight of flue gas
SO_2'	Q	%Sulfur dioxide in wet flue gas
M	M	Moisture in air (lb/lb fuel)
SVP	P	Saturated vapor pressure (psia)
T	T	Ambient temperature (°F)
RH	R	Relative humidity (fraction)
ρ_g	D	Gas denisty at 60°F (lb/ft^3)
O_{2d}	U	%Oxygen in dry flue gas
CO_{2d}	V	%Carbon dioxide in dry flue gas
N_{2d}	A45	%Nitrogen in dry flue gas
C	C	Carbon in fuel (fraction)
H_2	H	Hydrogen in fuel (fraction)
S	S	Sulfur in fuel (fraction)
O_2	O	Oxygen in fuel (fraction)
N_2	N	Nitrogen in fuel (fraction)
F	F	Moles of wet flue gas
W	W	Moisture in fuel (fraction)
w_{da}	A	Dry air for combustion (lb/lb fuel)
w_{wa}	B	Wet air for combustion (lb/lb fuel)
w_{dg}	Z	Dry flue gas (lb/lb fuel)
w_{wg}	G	Wet flue gas (lb/lb fuel)
E	E	Excess air factor; 1.25 means 25%
HHV	HHV	Higher heating value (Btu/lb)
LHV	LHV	Lower heating value (Btu/lb)

```
10  PRINT"COMBUSTION CALCULATIONS-SOLID,LIQUID FUELS"
20 INPUT"CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,MOISTURE,(fractions),EXCESS AIR%
="; C,H,O,N,S,W,E
25 INPUT"RELATIVE HUMIDITY(fraction),AMBIENT TEMP=";R,T
30 P=.08+281*10^-9*T^3.25:M=.622*P*R/(14.7-P*R)
35 HHV=14500*C+62000!*(H-.125*O)+4000*S:LHV=HHV-9720*H-1110*W
40 A=(2.664*C+7.937*H+S-O)*(100+E)/23:B=A*(1+M)
50 A30=8.939999*H+W+A*M:G=3.66*C+A30+2*S+.77*A+N+.23*A*E/(100+E):Z=G-A30
60 F=.08318*C+.03125*S+(A30/18)+((.77*A+N)/28)+.23*A*E/32/(100+E)
70 I=8.318*C/F:J=23*A*E/32/F/(100+E):K=((.77*A+N)/(28*F))*100:L=(A30/18/F)*100
80 Q= (.03125*S/F)*100:A35=(44*I+32*J+28*K+18*L+64*Q)/100:D=.002636*A35
90 U=100*(J/(100-L)):V=100*(I/(100-L)):A45=100*(K/(100-L))
95 PRINT" "
100 PRINT"RESULTS-COMBUSTION CALCULATIONS"
105 PRINT" "
110 PRINT"FUEL DATA-fractions"
120 PRINT"CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,MOISTURE"
130 PRINT USING"###.###";C,H,O,N,S,W
140 PRINT "REL-HUM-fraction=";R;"EXCESS AIR % =";E
145 PRINT" "
150 PRINT"WET FLUE GAS ANALYSIS %"
160 PRINT"CARBON DIOXIDE=";I;"OXYGEN=";J;"NITROGEN=";K
170 PRINT"SULFUR DIOXIDE=";Q;"WATER VAPOR=";L
180 PRINT" "
190 PRINT"AIR-GAS QUANTITIES-Lb/Lb fuel"
200 PRINT"DRY AIR REQD=";A;"WET AIR REQD=";B
210 PRINT"DRY GAS PRODUCED=";Z;"WET GAS PRODUCED=";G
220 PRINT" "
230 PRINT"DRY FLUE GAS ANALYSIS  %"
240 PRINT"CARBON DIOXIDE=";V;"OXYGEN=";U;"NITROGEN=";A45
250 PRINT" "
260 PRINT"MOLECULAR WEIGHT=";A35;"FLUE GAS DENSITY,Lb/cu ft-60 F=";D
265 PRINT" "
270 PRINT"HEATING VALUES-BTU/LB:HHV=";HHV;"LHV=";LHV
275 PRINT" "
280 END
```

```
RESULTS-COMBUSTION CALCULATIONS

FUEL DATA-fractions
CARBON,HYDROGEN,OXYGEN,NITROGEN,SULFUR,MOISTURE
  0.728  0.048  0.062  0.015  0.022  0.035
REL-HUM-fraction= .6 EXCESS AIR % = 25

WET FLUE GAS ANALYSIS %
CARBON DIOXIDE= 13.29994 OXYGEN= 3.912859 NITROGEN= 74.97235
SULFUR DIOXIDE= .1509983 WATER VAPOR= 7.663852

AIR-GAS QUANTITIES-Lb/Lb fuel
DRY AIR REQD= 12.39331 WET AIR REQD= 12.55727
DRY GAS PRODUCED= 12.83642 WET GAS PRODUCED= 13.46451

DRY FLUE GAS ANALYSIS  %
CARBON DIOXIDE= 14.40382 OXYGEN= 4.237624 NITROGEN= 81.19501

MOLECULAR WEIGHT= 29.57248 FLUE GAS DENSITY,Lb/cu ft-60 F= 7.795305E-02

HEATING VALUES-BTU/LB:HHV= 13139.5 LHV= 12634.09
```

FIG. 1.1 Listing of program 1.1, with results.

Solution

Key in the program, a listing of which is shown in Fig. 1.1. In the RUN mode, the screen asks for the data in the same order; they are fed in. Then the computer goes on to solve the equations shown in Table 1.1A and prints out the results.

It is seen that the wet flue gas produced is 13.464 lb/lb fuel, wet air required is 12.557 lb/lb fuel, and flue gas density is 0.077 lb/ft^3 at 60°F. Dry and wet gas analysis are also obtained.

Any data or result may be obtained by pressing the appropriate key (see Table 1.1B). Heating values of the fuel are also printed out. It is seen that the higher heating value is 13,139 Btu/lb.

Reference

V. Ganapathy, *Applied Heat Transfer*, Pennwell Books, Tulsa, Oklahoma, 1982, pp. 5-20.

PROGRAM 1.2 COMBUSTION CALCULATIONS FOR GASEOUS FUELS

Input

Volume of constituents of gaseous fuel
Excess air
Ambient temperature
Relative humidity

Output

Higher heating value (Btu/ft^3)
Higher heating value (Btu/lb)
Lower heating value (Btu/ft^3)
Lower heating value (Btu/lb)
Molecular weight of fuel
Molecular weight of flue gas
Dry and wet flue gas analysis
Wet air required for combustion
Wet flue gas produced
Water dew point