EMISSIONS OF AIR POLLUTANTS FROM FOSSIL BOILERS AND GAS TURBINE ENGINES AS CALCULATED BY PEPSE

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ABSTRACT

Atmospheric emissions of a selected group of air pollutants can be calculated by PEPSE. In order to perform the calculations, it is necessary to have a PEPSE model. The model may be simple or complex, and the calculations may refer to items in the model, or they may be performed without specific reference to the model. The versatility of this application is similar to the older, existing fossil boiler efficiency calculations. The calculations are based on methods published by the United States Government's Environmental Protection Agency.

INTRODUCTION

Emissions of air pollutants are important considerations for power plants today. In many instances monitoring of emissions from a plant is mandated by law. In such cases, power plants have already installed, or soon will, continuous emissions monitoring systems (CEMS). Some installations may be permitted to operate without CEMS, but they still are required to provide pollutant reporting to the EPA. In some cases this reporting can be based on calculations. A method of calculating such emissions has been published by the EPA, Reference 1. This method is based on EPA's database for various types of plants. The specific data used herein were taken from the EPA's current "Air CHIEF" CD-ROM that was obtained by order from the US Government Printing Office. The CD is available at nominal fee via World-wide-web, or by telephone order.

The purpose of this paper is to describe the basis and the method of calculations and to present some examples as illustrations of the application of the method.

BACKGROUND

According to the Air CHIEF documents, "The air emissions data for pollutants or emissions sources contained in Air CHIEF tools may be used to provide preliminary, order-of-magnitude estimates of source emissions; however, they should not be considered substitutes for actual source tests. The emissions data in Air CHIEF should be used with further caution because the data are of varying quality. The emissions data in the AP42 document have been gathered from source tests, material balance studies, and engineering estimates."

Additionally, the EPA report states, "These estimates are based on emissions test data from 52 units obtained from extensive emission tests by the EPRI, DOE, the Northern States Power Company, and EPA. The data are considered to be generally representative of fossil fuel utility steam electric generating units as a whole. Because of small sample sizes for specific boiler types and control scenarios, there are uncertainties in the data."

The EPA's method of calculation is based on aver values of key "criteria" pollutants that have been emitted in the past from the various types of processes.

Because the EPA's information is a compendium of avers, it may or may not be accurate for a specific individual installation. As might be surmised, the creation and the transporting of air pollutant emissions are consequences of extremely complex phenomena. Factors that can influence emissions include the design and condition of the equipment being used in the process, the operating load, whether upset operating conditions exist, variations of the quality of the fuel, and many others. It should be obvious that this method can give only "ballpark" estimates of the emission of pollutants. Among other shortcomings, it cannot adequately represent emissions during upset, off-normal, or startup operations. It is not intended as a substitute for continuous emissions monitoring. In spite of these limitations, this method is better than having no way to estimate the emissions.

Along with the quantitative estimation of emissions, most of the EPA's tabulated data also includes an indication of the quality, or "grade", of the information. The grades are reported via assigned letters "A" through "E", with A signifying the data with the most confidence and E signifying the data with the least confidence. Assignment of these grades is somewhat subjective. The underlying scheme is based on an evaluation of the size of the data base from which the numbers are derived, the amount of experience with a specific process, whether the value is based on a calculation or a measurement, whether the data are experimental or theoretical, and so forth.

Versions 64 and GT3.0 of PEPSE presently under development have been programmed with the capabilities described here. The example models that are included in this report have been created using the version GT3.0 version of PEPSE. The two versions will be available for public distribution in July of 1999.

EMISSIONS OF POLLUTANTS FROM FOSSIL-FUEL BURNING SYSTEMS

The United States Government's Environmental Protection Agency, EPA, has published a method for calculating pollutant emissions for a broad range of fossil-fuel combustion sources, Reference 1, called "AP42" in this discussion. Among the emissions sources reported in AP42 are utility boiler power plants and gas turbine engines. This method has been programmed in PEPSE. Note that the source terms that are included here are for "point sources", i.e. that relate to the combustion of the fuel and accounting for pollutant control devices in some cases. The calculations in PEPSE do not include pollutants, such as particulate matter, that occur as a result of coal piles or fuel crushing or handling equipment or other distributed sources.

The results that emerge from use of the method are estimated quantities of key pollutants and an indication of the quality (grade) of the estimate. The specific pollutants considered are:

SOX	(SO2 for fuel oil and gas fired boilers)
NOX	
CO	
CO2	
PM	particulate matter (PM-10s particulate solid for GT's, sizes smaller than 10 micron)
PM-10c	particulate condensibles for GT's, sizes smaller than 10 micron
TOC	total organic compounds (hydrocarbons), for gas turbine engines
SO3	for fuel oil fired boiler
N2O,	greenhouse gas, gas fired boiler, lignite fluid bed

SPECIFIC SOURCES AND FUELS INCLUDED IN PEPSE FROM AP42

AP42 covers a broad range of processes, of which electricity generation applications represent a part. Those that have been programmed in PEPSE are as follows, organized according to type of fuel, type of combustion application, and type of pollutant mitigation measures. The terminology

that is used here is taken from AP42. The emissions sources that are included here are taken from AP42. None of the electric power generation related sources in AP42 have been left out. The types of fuel are summarized here. A complete list, including the methods of burning and pollutant control strategies, is provided in the Appendix.

- Bituminous coal burning boilers
- Anthracite coal burning boilers
- Lignite coal burning boilers
- Fuel oil fired boilers
- Gas fired boilers
- Gas fired gas turbine engines
- Oil fired gas turbine engines

METHOD OF CALCULATION

The method of calculation uses an average "emission factor" for each pollutant. The calculating equation is

$$EM = A \times EF \times (1 - ER/100),$$

where

EM = emission rate
A = "activity" rate (e.g. flow rate of fuel)
EF = emission factor (a fractional value of activity rate)
ER = overall emission reduction efficiency, %

The AP42 publication includes tabulations of EF values for each pollutant, type of burning system, and type of fuel, as well as pollutant control device, as listed in the preceding section and in the Appendix. The factors in AP42 were assembled by the EPA based on available data from

the industry and, as such, are necessarily averages. These tabulated factors have been programmed in PEPSE, along with the equation above.

In situations where you have your own database for emissions, we have provided an option for you to input the value(s) of emission factors. When you do that, your value overrides the built-in EPA value(s). You must also specify your measure of the quality grade(s), by assigning any single letter in the input with each emission factor that you input. These grades are printed as part of the table of results.

As indicated in the equation above, the calculation needs an "activity rate". This is a measure of the size of the installation. For example, the activity rate for coal is measured in tons/hour burned and the activity rate for a gas-fired boiler is in million cubic feet/hour. An SI units option is also available. The emission factor, then, must be consistent with this measure of the activity. As an example, the emission factor for SOX from coal would be in units of pounds of SOX per ton of coal. The resultant EM of SOX would then be lbm/hr. If you choose to enter your own values of emission factors, it is necessary to observe the units that apply for that specific source. The units differ for oil fired boilers and other sources.

INPUTS NEEDED BY PEPSE

A PEPSE model may include up to 10 separate emission sources, for example 10 gas turbine engines or a combination of gas turbine engines and conventional fossil furnaces. Of course, you may also use as few as a single one (or none) of these sources in your model.

There are mainly two separate ways to use this emission calculation module; this gives great flexibility. This flexibility is similar to the application of the heat loss boiler efficiency calculation that has been available for several years in PEPSE. In the first way of use, you can apply the calculation without specific reference to the model in which it appears, i.e. not directly related to heat balance modeling of the emission source(s). As an example, you could have a heat balance

model of a steam turbine cycle and an add-on, side calculator of emissions. In this approach, you input the emission-related data directly to enable PEPSE to calculate the emissions.

The second way of use would have a real connection with the heat balance model to which the emissions calculation is appended. For example, the model may be of a coal-burning fossil boiler. Provisions are available in the input protocol of the emissions calculator to signal the location in the PEPSE model where the fuel activity rate and composition information are to be obtained for the calculation.

General descriptions of use of PEPSE are contained in Reference 2.

SIMPLE EXAMPLE PEPSE MODEL WITH EMISSIONS AS THE ONLY RESULT OF INTEREST

In the simplest possible application, you can create an emission calculator that includes only an Input and an Output component that are connected by a stream. As such, the two-component model may or may not have any association whatsoever with the calculation of emissions. An example of such a model is shown in Figure 1.

The emissions of pollutants from any source depend on many factors. Among these are the rate of burning and the composition of the fuel. In this paper no attempt has been made to obtain real examples of the rate or composition. Rather, the values were chosen simply to illustrate the calculations. Because of this there is no realism attached to the specific results of emission flows or activities that are tabulated herein.

Table 1 shows a portion of an input file that has been completed for this application of the emissions calculator. Included in the table are sufficient “comment” statements in order to guide interpretation of the inputs. The source description entered in the example tells the type of fuel, the type of burning, the activity rate, and the carbon, sulfur, and ash mass fractions. The numerical values used in the example are not claimed to be typical or representative. Rather they

Figure 1

Simple Source-Sink Model For Access To Emissions Calculator

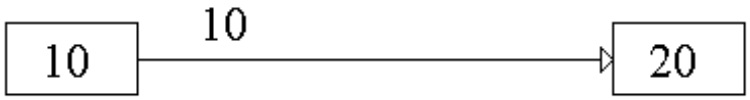

Table 1

Example Inputs For Simple Model, Fluid Bed Combustor

Burning Lignite Coal, Emissions Calculations

```
*
*       EMEPA
920000     1
*
*       SOURCE 1 - LIGNITE, PC-FIRED, DRY BOTTOM, WALL-FIRED
*       ITFUEM  ITBREM  ACOEM  CARBEM  SULFEM  ASHEM  ISODEM  ILGSOX  ILGNOX  ILGPM
920131     3        1        10.       .01       .01       .01
*
*       ERFSOX  ERFNOX  ERFCO  ERFCO2  ERFPM
920134  1200.      500.      12.      3200.      250.
```

have been selected to give rounded, easy-to-check results. You should use actual values in your model.

SUBMODEL OF A GAS TURBINE ENGINE TO INCLUDE EMISSIONS CALCULATIONS

A schematic of a gas turbine model that includes emissions calculations is shown in Figure 2. Note that this is merely an example. The model that you use may be as detailed and complex as you need it to be for your heat balance purposes. Table 2 shows a portion of an input file that has been completed for the emissions calculator for this application. You can see that the inputs include the master switch to activate the EPA emissions calculations, as well as a description of the emissions source. In this case the IDFUEM points to the component in the model with ID=10. Additional information about the source tells the type of fuel and the type of burning (GT engine). The activity rate and the composition are obtained by PEPSE from component 10 in the heat balance calculations.. The numerical values used in the example are not claimed to be typical or representative. Rather they have been selected to give rounded, easy-to-check results. You should use actual values in your model.

EXAMPLE OUTPUTS FROM THE EMISSIONS CALCULATIONS

The table of output from a PEPSE run, summarizing the emissions, for the “model” of Figure 1, with the inputs of Table 1, is shown in Table 3. Listed in this summary are the type of fuel being burned, the method of burning, the pollution control strategies, if any, the flow rates of pollutants, SOX, NOX, CO, CO2, PM (particulate matter), and others. Also shown are the “grades”, the measures of confidence in the results that were obtained from AP42 for each pollutant.

The table of output from a PEPSE run, summarizing emissions, for the gas turbine model of Figure 2, with the inputs of Table 2, is shown in Table 4. Note that the specific pollutants given may differ slightly from one source type to another. This is constrained by the data that are available in the AP42 document.

Figure 2

Gas Turbine Engine Model That Includes Calculations Of Emissions

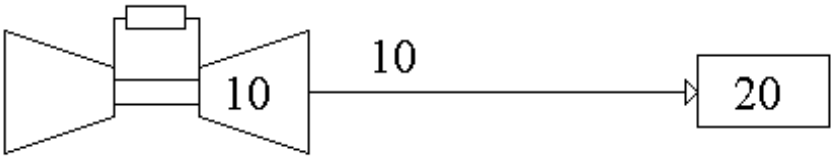

Table 2

Example Inputs For Gas-Fired Gas Turbine Engine, Emissions Calculations

```
*
*        EMEPA
920000      1
*
*        SOURCE 4 - GAS-FIRED GT, WATER INJ NOX CONTROL (.8 WATER/FUEL)
*
*        IDFUEM
920401     10
*        ITFUEM   ITBREM   AGTEM   SULFEM
920461      5         16         10.        .01
```

Table 3

Example Output For Simple Model, Furnace Burning Lignite Coal, Emissions Calculations

VERSION GT3E CREATED 11 MAY 99 DATE 05/11/99. Page 1
C:\PEPSE\CHKV64\EMLIGNI - CASE 1 - LIGNITE FUEL (NO EM CONTROLS)

POLLUTANT EMISSIONS BY EMISSION-FACTOR METHOD OF EPA
(EM = A x EF x (1 - ER/100))

FOR SOURCE 1 -- LIGNITE FIRED FOSSIL BOILER
OF TYPE – PULVERIZED COAL, DRY BOTTOM, WALL-FIRED

FUEL ACTIVITY RATE = 1.00000E+01 TONS/HR

EMISSION MATERIAL	REFERENCE (TON/YR)	ANNUAL (TON/HR)	FLOW RATE (LBM/HR)	GRADE	EF (LBM/TON)	ER (PERCENT)
SOX	1.200E+03	1.314E+03	3.000E+02	C	3.000E+01	0.0
NOX	5.000E+02	4.862E+02	1.110E+02	C	1.110E+01	0.0
CO	1.200E+01	1.095E+01	2.500E+00	C	2.500E-01	0.0
CO2	3.200E+03	3.180E+03	7.260E+02	B	7.260E+01	0.0
PM	2.500E+02	2.234E+02	5.100E+01	E	5.100E+00	0.0

Table 4
Example Output For Gas-Fired Gas Turbine Engine, Emissions Calculations

VERSION GT3E CREATED 11 MAY 99 DATE 05/11/99. Page 6
C:\PEPSE\CHKV64\EMGTENGS-GAS TURBINE ENGINE, COMPONENT POINTER FOR "ACTIVITY"

POLLUTANT EMISSIONS BY EMISSION-FACTOR METHOD OF EPA
(EM = A x EF x (1 - ER/100))

FOR SOURCE 4 -- GAS-FIRED GAS TURBINE ENGINE
OF TYPE – WATER INJ (.8 WATER/FUEL) NOX CONTROL

FUEL ACTIVITY RATE = 3.00000E+03 MILLION BTU/HR

EMISSION MATERIAL	ANNUAL (TON/YR)	FLOW RATE (LBM/HR)	GRADE	EF (LBM/MILL BTU)	ER (PERCENT)
SOX	1.235E+03	2.820E+02	C	9.400E-02	0.0
NOX	1.840E+03	4.200E+02	C	1.400E-01	0.0
CO	3.679E+03	8.400E+02	C	2.800E-01	0.0
CO2	1.432E+06	3.270E+05	B	1.090E+02	0.0
PM-10s	2.536E+02	5.790E+01	E	1.930E-02	0.0
PM-10c	2.970E+02	6.780E+01	E	2.260E-02	0.0
N2O	3.942E+01	9.000E+00	E	3.000E-03	0.0

SUMMARY

This report has presented the rationale, the methods of calculation, and some examples of application of a new tool available in PEPSE. This tool computes the flow rates of key air pollutants that are emitted from a broad range of types of electricity generation stations. The underlying calculations are based on average values of "emissions factors" that have been published by the EPA in their AP42 document.

REFERENCES

1. "Compilation of Air Pollutant Emission Factors, Volume 1, Fifth Edition, AP-42", Chapters 1 and 3, PB95-196028, Office of Air Quality Planning and Standards, Office of Air and Radiation, U.S. Environmental Protection Agency, Research Triangle Park, NC, 27711, January 1995. Available through web site www.citation.com/ap42/.

2. PEPSE and PEPSE-GT Volume 1 – User Input Description, G. L. Minner, et al, 1998.

APPENDIX

This appendix provides a complete list of the types of fuels and the methods of burning that have been extracted from AP42 and programmed in PEPSE for pollutant emissions calculations. The terminology used here is taken from AP42.

Bituminous coal burning boilers:

- pulverized coal, dry bottom, wall-fired
- pulverized coal, dry bottom, cell-fired
- pulverized coal, dry bottom, tangentially-fired
- pulverized coal, wet bottom
- cyclone furnace
- spreader stoker
- spreader stoker, multiple cyclones, reinjection
- spreader stoker, multiple cyclones, no reinjection
- overfeed stoker
- feed stoker, multiple cyclones
- underfeed stoker
- underfeed stoker, multiple cyclones
- fluid bed combustion, circulating bed
- fluid bed combustion, bubbling bed

Anthracite coal burning boilers:

- listed in AP42 only as PC firing
- listed only as stoker firing
- listed only as fluid bed combustion

Lignite coal burning boilers:

- pulverized coal, dry bottom, wall-fired
- pulverized coal, dry bottom, tangentially-fired
- cyclone furnace
- spreader stoker
- overfeed stoker
- fluid bed combustion

In addition other considerations apply for lignite-fired boilers, including, sodium content of the fuel, and the of the plant and mitigation equipment used. These are as follows:

Sodium content in lignite fuel's ash, i.e.

- unknown, or "normal"
- low sodium (i.e. Na2O<2%)
- high sodium (i.e. Na2O>8%)

Age and SOX pollutant control strategy for lignite boiler. Note that subpart D designates boilers constructed after August 17, 1971 with heat greater than 250 million Btu/hr. Subpart Da designates boilers constructed after September 18, 1978, and with heat input greater than 250 million Btu/hr.

- none of the items below apply
- Subpart D, pulv coal, spray dryer
- Subpart D, pulv coal, wet scrubber
- Subpart Da, pulv coal, spray dryer
- Subpart Da, pulv coal, wet scrubber

- and NOX pollutant control strategy for lignite boilers.

- none of the items below apply, default
- Subpart D, pulv coal, tangential, overfire air
- Subpart D, pulv coal, wall-fired, overfire air and low NOX burners
- Subpart Da, pulv coal, tangential, overfire air

- age and PM (particulate matter) pollutant control strategy for lignite boilers.

- none of the items below apply
- Subpart D, baghouse
- Subpart D, wet scrubber
- Subpart Da, wet scrubber
- fluid bed (circulating or bubbling), limestone addition.

Fuel-oil fired boilers:

- No. 6 "normal firing"
- No. 6 tangential firing
- No. 5 normal firing
- No. 5 tangential firing
- No. 4 normal firing
- No. 4 tangential firing
- No. 6 oil fired
- No. 5 oil fired
- distillate oil fired
- No. 4 oil fired

Gas-fired boilers:

- uncontrolled
- low-NOX burners controlled
- flue gas recirculation controlled

Gas-fired gas turbine engines:

- no pollutant controls
- water injection NOX control @ .8 water/fuel ratio
- steam injection NOX control @ 1.2 steam/fuel ratio
- water injection, selective catalytic reduction

Oil-fired gas turbine engines:

- no pollutant controls
- water injection NOX control @ .8 water/fuel ratio