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Project Summary

A Mathematical Model of Electrostatic Precipitation for the Texas Instruments Programmable 59 Calculator

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A version of EPA's electrostatic precipitator (ESP) model suitable for use on a Texas Instruments Programmable 59 (TI-59) hand-held calculator has been prepared. This version of the model allows calculation of the ESP collection efficiency, including corrections for non-ideal effects and rapping reentrainment in five size bands. Program input data and the individual and total collection efficiencies are printed on a TI Thermal Printer. This model is described in detail including program steps for its use. This version and a full-scale model are compared.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction and Summary

EPA's mathematical model of electrostatic precipitation was first published in 1975. Revision 1 of the model was published in 1978. This model has been widely used to study existing electrostatic precipitators (ESPs) and to predict size requirements and performance levels for new ESPs. However, a computer of the size required to employ the model may not be available to some individuals who desire to use the model. Therefore, EPA sponsored the development of a reduced version of the ESP model which may be used on a programmable hand calculator. A version of the ESP model was developed by Southern Research Institute for use on a Texas Instruments Programmable 59 (TI-59) calculator. The theory of ESP operation on which the model is based and the assumptions used, explained in a previous report, are not repeated here. The user is urged to obtain the earlier report for use with this report in order to understand the procedures.

The TI-59 calculator can write to and read from magnetic cards, allowing a long program to be entered into the unit in one step. This is a necessary function: a program of the complexity of the ESP model requires the reading of many magnetic cards. In addition, the use of the accessory printer for the TI-59 allows the creation of a permanent record for each set of ESP operating conditions modeled. Another advantage of the TI-59 is its capability to vary the memory partition between data storage and program steps to suit a particular program. For the ESP model, 70 data storage locations are required, limiting the number of program steps which can be entered to 400. To fit into 400 spaces, the program is divided into 8 sections, some of which must be read into the calculator more than once to complete the calculation.

The full scale ESP model allows the user many options in the type of data which may be used and in the types of calculations which will be performed. The limited size of the TI-59 severely limits the options. The data must be in a prescribed format. The calculation of the ideal collection efficiency uses estimation procedures rather than the exact calculations available on the full-scale model. The program output is limited to efficiency in each size band and overall collection efficiency. These are printed for the ideal case, the ideal case corrected for several non-ideal conditions not including rapping losses, and the corrected case including rapping losses. As an option, the fraction of the effluent appearing in each size band may be printed for the two corrected conditions to serve as estimates of the particle size distributions at the outlet of the precipitator.

Each of the eight sections of the program occupies a magnetic card. The number of cards which are read into the calculator varies with the desired program output. A minimum of five cards are required to run the model: cards 1-4 for the ideal calculation and card 6 for the no-rap corrections. To include rapping reentrainment, cards 5 and 7 must be added. Card 8 may be added if an estimate of the particle size distribution at the ESP outlet is desired. Once the ideal efficiency has been calculated, it need not be repeated to run additional sets of non-ideal conditions. Only cards 5 through 8 need to be reread. The functions and printed output of each card are described below. The word NEXT, printed at the end of each program segment, signifies that the next card may be read in.

Card 1 is the equivalent of subroutine LNDIST in the full scale program. This card constructs a particle size distribution histogram for a specified log-normal distribution. The mass median diameter (mmd) and geometric standard deviation (σ_p) which define the log-normal curve and six particle size band endpoints are supplied by the user. The calculator computes and stores the average diameters of five size bands and the fraction of the inlet particulate mass which occurs in each band for later use. The fraction of all of the particulate mass in the 0.01 to 1000 μm size range which has diameters outside the range of the five size bands is added to the largest size band. The program steps contained on card 1 occupy one card side. The input data are printed.

Card 2 is used to enter data and calculate constants which will be used throughout the rest of the program. The program on card 2 occupies two card sides. The input data are printed.

Card 3 is used to enter data which is unique to each electrical section of the ESP, including the number of calculation increments, the total collection plate area, the applied voltage, the current, and the wire-to-plate spacing. After the calculations for all of the sections of the ESP have been completed, card 3 is used to calculate the ideal efficiency in each size band and the ideal total efficiency. This card is read in once for each electrical section and once to complete the ideal efficiency calculation. The program material occupies one card side.

If LSECT, the first variable read by card 3, is not equal to zero, the input data are printed. If LSECT equals zero, the printer lists the particle diameter (μm) and ideal efficiency (decimal) for each size band, followed by the total ideal efficiency.

Card 4 calculates the particle charge and the number of particles removed in each size band for each increment of length in the ESP section described by card 3. This card is read in once for each electrical section. This is a two-sided card. However, since card 3 only occupies one card side, it is only necessary to read in side 2 of card 4 once. Side 1 must be read in each time as card 3 writes over this portion. There are no data entered in this segment of the program and no printed output.

Card 5 is the same as card 1. The routine is used again at this point so that a particle size distribution for rapping reentrainment may be formed. If no rapping information is desired, this card is omitted. The full scale model has a built in log-normal rapping size distribution with a mmd of 6.0 μm and a σ_p of 2.5 which may be used with this routine in the absence of other data.

Card 6 adjusts the ideal collection efficiencies to compensate for several non-ideal conditions. These conditions include gas sneakage around the collection regions of the ESP and the velocity distribution associated with the inlet gas flow, but exclude rapping. In addition there is an empirical correction to the migration velocities of particles with diameters less than 4.5 μm. This correction was derived from comparisons with migration velocities measured in full-scale ESPs where the model predicted values which were too low for small particle sizes. Card 6 has two starting points: the first is used if rapping reentrainment is to be calculated later, and the second is used if no rapping information is desired or if a rapping correction has previously been calculated and the non-rapping conditions are being changed for the same rapping conditions. The program information on this card occupies two card sides. The printer lists the input data for this card, following which, the particle diameter (μm) and adjusted efficiency (decimal) for each size band and the total adjusted efficiency are printed.

Card 7 computes the rapping adjustments to the efficiencies calculated by card 6. Before card 7 can be run, card 5 must have been run to establish a rapping puff size distribution. The information on this card occupies one side. No data is entered in this portion of the program. The printer lists the particle diameter (μm) and adjusted efficiency, including rapping (decimal) for each size band, followed by the total adjusted efficiency including rapping.

Card 8 allows the user to estimate the size distributions of the ESP effluent for the no-rap and rapping conditions. This routine prints the fraction of the particles by mass which occurs in each size band, in order of increasing size, for inlet gas flow, adjusted no-rap outlet gas flow (card 6), and adjusted outlet gas flow including rapping (card 7). The fraction printed for the largest size band in the inlet distribution will appear to be larger than it should since all of the mass which lies outside the range of the five size bands is included in the largest band. In normal use, only a small portion of the mass will come from particles smaller than the five size bands. Most of the extra mass will be in size bands larger than the largest size band and will be collected in the ESP. However, this effect may also show up in the outlet fractions which are based on the inlet fraction.

Conclusions

The procedure described in this report provides a mechanism for modeling ESP performance on a programmable calculator. The program is limited in that it provides collection efficiency information only. The full-scale model, designed for a large computer, also prints migration velocities, particle charges, outlet size distribution, and other data. Of these, only the migration velocities are available in the hand calculator version. They are not printed but may be retrieved from the calculator memory. The other variables are not available. Some, such as particle charge, are calculated but are written over by other variables. Others are not calculated at all due to the limited memory size.

Another limitation of the calculator version of the ESP model is that it uses only the estimation procedure available in the full-scale model. For several calculations, the full-scale model offers the choice of a rigorous calculation for maximum accuracy or an estimation to save time. In the calculator version, the limiting factor is memory size, which necessitates the use of the shorter estimations. An additional limitation is the use of only five size bands, again due to the limited memory size.

The time required to model a three-section ESP (5.5 m long) is about 37 minutes for the ideal calculation or 51 minutes for the ideal case plus three sets of non-ideal conditions. It required 4 minutes to run the equivalent full-scale model on a DEC PDP-15 computer, which is not a fast computer. However, the run time for the PDP-15 does not include the time required to enter the data, an estimated 45 minutes. Data entry time is included in the figures shown for the TI-59 version. Therefore the times required to run the two versions are comparable. The time required to run the rigorous calculation (rather than estimates) with 16 size bands on the full-scale model is 1.25 hours plus 45 minutes for data entry.

In spite of its limitations the calculator verison achieves close agreement with the full-scale version. For the purposes for which it was intended, the calculation of ESP efficiencies on a programmable calculator, the calculator version of the model performs very well. Therefore, it is a useful tool for ESP model users operating on a low budget, requiring quick turn around time, or desiring only efficiency information.

Recommendations

This version of the ESP model allows the calculation of ESP efficiencies on a relatively low-cost hand-held calculator. This serves as a useful function in that it provides the use of the ESP model to people who may not have access to a larger computer, whether due to high operational costs, remote location, or quick turnaround required on certain projections. For the same reason, a study to identify other important programs which may be scaled down to fit on low cost, easily portable, programmable calculators may be beneficial.

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The complete report, entitled "A Mathematical Model of Electrostatic Precipitation for the Texas Instruments Programmable 59 Calculator," (Order No. PB 83-261 669; Cost: $14.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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