"IMPACT OF TEST METHODS ON TEST RESULTS"

by

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Introduction

The title of this presentation "Impact of Test Methods on Test Results" reflects the approach taken toward the evaluation of failures in control technology by most design engineers, plant owners, and control officials. However a test engineer's view might be the converse, i.e., "The Impact of Test Results of Test Methods." The author, through his professional experience, feels qualified to discuss both sides of the issue.

In most cases insufficient control equipment and plant operating data are provided in test reports to completely evaluate a process or the control equipment. The data are vital to the industry since the choice or size of the control equipment may rule an energy recovery process economically impractical.

In addition, the test results due to errors or different methodologies may lead a designer to use 400 SCA rather than 200 in a ESP or 4.98 ΔkPa (20" Δp) rather than 2.49 ΔkP (10"Δp).

Discussion

Since the EPA Test Method 5 for the measurement of particulate emissions became The Law of the Land in December 1971, there has been a continuing controversy between control officials and control equipment designers. To summarize the controversy; EPA's method 5 does not measure particulates as seen by the control equipment. EPA-5 measures dry solid particulates plus considerable fractions of the gas stream, while most control equipment is designed to remove only the dry solid particulates. The condensible fraction and its effect on design of control equipment will depend on the components of a gas stream; at times it can be significant. One of the most serious technological problems that we have is the inadequacy of our testing programs. First we must analyze the three types of test programs and what they contain.

The three types of performance test are as follows:

1. Determination of compliance with regulations.
2. Determination of contract performance.
3. Trouble shooting programs to improve performance of control equipment or to document design data.

The order of presentation represents an increase in the complexity and cost of the test programs.

It is important to note that test programs as discussed in this paper are not interpreted to mean test methods such as EPA-5, ASME, or PTC-27. Although the selection of the test method is important in each of the test programs, each method has an application in these programs.

Field Test Programs

A. Compliance Test

The performance of a compliance test for a regulatory agency is a critically important step in obtaining an operating permit. This type of emission testing is the least complicated of all the test programs.

Many agencies have recently adopted the submittal requirement of a test protocol before the conducting of compliance tests. Before these tests are performed or even before an installation contract is released for bid, the cognizant regulatory agency should be contacted for information regarding intent to test procedures.

The major typical deficiencies of these programs are:

1. Little or no equipment calibration data are requested.
2. Only token process data and control equipment readings are taken. The data taken are sufficient only to prove that the process is operating at or near design capacity, and that the control equipment is operating. If a test result is in question, there generally is insufficient data to evaluate. This type of testing procedure has evolved because it is the control agency's interest only to determine compliance with emission standards; not to trouble-shoot the process.
3. Generally no provisions are made for determining emission or plant performance under transient, or partial load.

B. Contract Performance Test

Contract performance tests differ from the compliance test in that the plant's owners want to ensure that they are obtaining the control equipment they ordered. Likewise, the manufacturer wants to ensure that the equipment, once installed, is being operated and tested within the specification for which it was designed.

The performance of control equipment is affected by many and variable parameters either in the process or the equipment itself. These parameters must be closely monitored during the test.

When performing contract compliance test programs it has been common practice in the industry to prepare a test protocol. With all of the system variables, it is of the utmost importance that the program coordination and responsibility be clarified with all parties. Some contracts for control equipment provide for bonuses if the equipment meets certain emission standards and conversely, penalties for not meeting standards. In order to comply with the objectives of contract performance tests, the following requirements of regulatory compliance tests must be met:

1. The calibration of field test equipment such as pitot tubes, dry gas meter, and pyrometer is required. Plant and control equipment such as recorders and monitors must be calibrated.
2. Sufficient data related to plant and control equipment operating parameters must be collected in order that they can be compared to contract specifications. Representative garbage, ash and fly ash samples may have to be collected and analyzed for chemical composition.
3. Sufficient data must be collected to prove that:
   a) The plant was operating within contract specifications.
   b) The control equipment performed to contract specifications.
   c) The non-controllable variables such as composition of fuel were within acceptable limits.
   d) There were no testing errors.

Recent contracts have specifications indicating the specified number of tests (range 3-30) and the conditions under which they must be performed. Some contracts even state that the control equipment must be retested after a specified operating time.

Recently there has been an increasing demand for statistical analysis of source testing data. Very little data analysis can be accomplished when only three tests are performed. Our firm was retained several years ago to conduct a test program which included a contract specification provision that the emission test results from the control equipment must be within a 98% confidence level. A team of independent statisticians were retained. They reviewed the variations in plant and control equipment operations with the variations and errors in testing and concluded, that under these conditions, in order to determine the plant's performance on three similar units, nearly a hundred tests would have to be performed.

C. Special Test Programs

Test programs may be performed to aid in new designs, to determine if control equipment efficiency can be improved, or to determine why such equipment is not performing to design specifications. There are no rules of thumb as regards the extent and duration of such programs; rather, each must be treated individually with an experimental plan developed to deal with each specific problem.

An installtion design may be based upon theoretical concepts or on actual data. However, a plant's operating conditions can change from time of design to time of installation. If this change prevails or the process does not operate in accordance with specifications, certain tests can be carried out to determine if the performance can be improved.

The effects of parameter changes can be illustrated if we look at the sources of the variables which affect the performance of an ESP.

1. Gas velocity through ESP.
2. Gas distribution across the box.
3. Particle re-entrainment.
    a) From hopper
    b) From rapping
4. Gas temperature.
5. Chemical composition of fly ash.
6. Chemical composition of flue gas.
7. Flue gas moisture.
8. Power inputs.
9. Particle size distribution.
10. Particle density.
11. Dust layer thickness on plates.

Very small changes in any one of the above parameters can have drastic effects on an ESP performance. Table I summarizes some of the typical process changes and their effect upon performance.

It must be noted that the limit of sensitivity of some tests are less than those changes affecting the performance of the ESP.

When conducting trouble-shooting programs, some auxillary analyses that are required in addition to the usual source emission tests are:

1. Physical analysis of flyash as resistivity.
2. Chemical analyses of ash and fuel.
3. Particle size.

Though ASME provides methods for these analyses, they are not widely accepted. The application of the most commonly known methods for resistivity and particle size measurements depend upon the desired objectives of the specific program.

EPA Method 5 for particulate measurements has very little application in these programs. The most desirable method uses in-stack filters and provides the fastest and most accurate results. In using this method, the total time required to obtain preliminary test results following completion of testing is only 2 hours (1 hour to dry, and one hour to desicate the filter). The time required to verify test results should be kept as short as possible. Once the results are received the test engineer can determine if another test is needed at a specific operating condition before it changes, or proceed to a new test condition.

If Method 5 is used, it requires a minimum of 24 hours to obtain test results. The method requires the filter to be air dried and the acetone washing to be evaporated at 295°K (70°F).

SPECIAL PROBLEMS ASSOCIATED WITH EMISSION MEASUREMENT PROGRAMS UTILIZING WASTE FUEL

Besides the common stack sampling problems, there are numerous special problems associated with waste fuel testing programs. Some of these special problems are:

1. Determination of charging rates of fuel.
2. Determination of CO_2 and excess air correction.
3. Determination of fuel and residue analysis.

These are discussed as follows.

1. Charging Rates of Fuel

There are two basic types of charging methods:
a) Batch Feed.
b) Continuous.

It is necessary to determine the charging rates for the following reasons:
1. To determine if the unit meets capacity.
2. To determine if the unit complies with emission standards.
3. To calculate theoretical emissions corrected to 50% excess air.

The most predominant problem in correcting concentrations to an excess air basis is the measurement of the total combusted carbon input when using the stoichiometric method. This entails measuring the fuel input and refuse discharge from the process, and performing an ultimate analysis for both. The accuracy of this correction depends upon the accuracy of the measured weight of the fuel input, refuse discharge, and the homogeneity of the fuel.

The advantage of the stoichiometric method is that the result can be checked against CO_2 or O_2 readings, and gas volumes measured by pitot tube and H_2O content of gas. The two disadvantages are the difficulty in obtaining accurate fuel input weights, and the cost and time necessary to obtain and analyze the samples. If all of the inputs are accurate, the stoichiometric method is the most accurate of all methods.

The incinerator is a particularly difficult problem in that most incinerators have no method of weighing the fuel (refuse) input except by counting crane bucket loads. York Research recently participated in an extensive incinerator design study in which crane bucket loads of garbage were accurately weighed. One of the results of the study was that during any one-hour period, the actual weight differed by at least 25% from the calculated value. The method for calculating the weight input is usually to weigh 2 or 3 bucket loads in a dump truck and then use the average weight per bucket for the test period. There recently has been a substantial improvement in this method of weighing which involves the installation of an ammeter on the crane motor. A calibration curve can be developed for amperes vs. weight. The accuracy of this system depends largely on the operator recording the data, and frequent calibrations are required. At this time, we do not have any long term data on this system. During a recent study conducted in Sweden, this method proved to be within 4-5% of the results calculated from a heat rate.

2. CO_2 and Excess Air Correction

Historically, emission standards corrected to various common bases have been developed for the normal operating conditions of individual processes. The purpose of these corrections is to compare emissions from a common reference of similar processes of different capacities, or from boilers operating under different combustion parameters.

As an example, one commonly used correction for dilution effects adjusts measured volumes to 12% CO_2. This factor was derived from normal operating conditions found in stoker-fired boilers around the turn of the century. 12% CO_2 operation was employed to assure maintenance of safe conditions with the limited combustion controls then available.

A second reason for correcting to these common bases has been to prevent the reduction of emission concentrations by the addition of dilution air.

A number of the most commonly used bases in correcting concentrations to standardized flue gas volumes are:

1. 50% excess air.
2. 12% CO_2 (F_c factor)*
3. 3% O_2
4. 15% O_2
5. 7% O_2
6. 454 kg (1000 lbs.) of flue gas at 50% excess air
7. Total air (F factor).

These corrections apply to measurements of gaseous and particulate emissions in the following terms:

1. gr/SCF (wet or dry gas basis).
2. gr/ACF (wet or dry gas basis).
3. lb/1000 lb of flue has (wet or dry basis).
4. lb/MMBTU heat input.
5. ppm.

It should be noted that all of the above examples are concentration values which are independent of total mass emission rates.

The correction factor to 12% involves errors introduced from the measurement technique, which is generally an Orsat device. These errors are magnified when attempting to measure low CO_2 values using the normal triplicate analysis. Figure I illustrates these errors as they affect

*Contribution of CO_2 from auxiliary fuel for incinerators, or unburned carbon from combustion sources must be subtracted.

correction to 12% CO_2. If, rather than using a CO_2 correction, the emission concentration is corrected to a total air or 50% excess air basis, errors are again introduced. Figures II and III illustrate these errors. Theoretically, the excess air correction has a smaller error associated with it than the 12% CO_2 correction.

The correction factor; such as 50% excess air, F factor, and adjusting to various O_2 levels, are dependent upon accuracy of total or excess air measurements. The following is a summary of the inputs that will affect the accuracy of various techniques for the measurement of total or excess air.

1. Weight of fuel input.
2. Total combustion of fuel.
3. Gas stratification.
4. Flue gas analysis.
5. Fuels analysis.
6. Sampling errors.
7. Total gas volume measurements such as pitot tube measurement.

Two problems which are particularly relevant with regard to incinerators in correcting to 50% excess air involve the collecting of the weight and representative samples of the fuel input, and the residue. In practice, the collection of the residue sample is usually the most difficult, and may be the most important aspect of determining the conversion factor. In applications of the carbon-mole method of stoichiometric calculation for gas volume in fossil-fired boilers, the carbon content of the bottom is considered to be the same as the fly ash sample. Fly ash samples are rather easy to collect and analyze in comparison to bottom ash samples. Due to the relatively poor combustion efficiency of most municipal incinerators, this assumption is not valid. The grate ash will be significantly different in composition than the fly ash. This problem was illustrated in a study conducted by our firm during a testing program on several incinerators to determine contract compliance for scurbbers. Differences were noted between calculated gas volumes by stoichiometric excess air calculations, and pitot tube measurements. Large variations were visually noted in the residue. These varied from periods where significant amounts of unburned paper were observed in comparison to times when no combustibles were present.

A system was established to collect residue samples before it was quenched by the plant's system. The collected samples were quenched with known amounts of clean water. Samples were collected every half hour, 24 hours/day for two weeks. The combustible content remaining varied from 0-100%, with the average being close to 50%. The fly ash samples were measured and found to have consistent values of much lower combustible content than the residue. Based upon an analysis of the garbage, the ultimate CO_2 should have been 19.5% and 50% excess air corresponding to 13.0% CO_2. When the garbage analysis was corrected for the carbon content of the ash, the CO_2 values for ultimate and 50% excess air became 13.5 and

9.0 respectively. The change in the ultimate CO_2 was caused by the selective combustion of elements of the garbage (C, H, N, S and O). The fuel (garbage) being charged into the incinerator had the characteristics of coal, while the fuel being combusted had those of natural gas.

3. Fuel and Residue Analysis

We have already discussed the problems encountered in trying to measure the quantity of refuse burned and in obtaining a representative sample. Since garbage is composed of a wide variety of materials, obtaining a representative sample for analysis requires the mixing, quartering and drying of the material prior to analysis. The exact procedures are documented in papers by Elmer Kaiser and York Research.

The EPA has recently published a technique for calculating total pollutant emission "E" based upon "F" factor which represents a ratio of the volume of dry flue gas generated to the calorific value of fuel combusted. These values are published and found to be relatively constant for a particular type of fuel. As an example, even if one considers the very wide range of materials encountered in typical municipal refuse, it is shown by Mr. Roger Shigehara of EPA in Table III that the standard deviation calculated for the "F" factor is only 2.93%. Emission rates are calculated using the "F" factor, the concentration of the pollutant "C", and the total air, as follows:

$$E = CF\ 2090/20.9 - \%\ O_2$$

The "F" factor shown in Table II appears to solve some of the analytical problems involved in incinerator test programs. It will eliminate one of the reasons for measurement of the feed rate and garbage analysis.

DATA ANALYSIS

The most important aspect of any program is the analysis of the data. A carefully executed program can be rendered worthless if insufficient data is gathered and if inadequate time is spent on data analysis. The goals of the program must be first established in the planning stage. Individuals responsible for gathering these data must be made aware of exactly what is needed. These requirements vary with the purpose of the testing program.

Careful analysis of the operating data and log books can often yield the explanation for the scatter of results. Quite often the scatter is attributed to test error. Frequently costly tests must be repeated. Careful inspection of the process and operating data can indicate changes which have been the cause for the scatter. This careful inspection of process data is generally overlooked by the manufacturers or owners. Unfortunately, it has been the general rule that if any of the parties involved in the test program do not agree with the test results, they simply blame the testing engineers and find fault with the test.

If a compliance test is performed on a control system by a regulatory agency, testing consultant or manufacturer; the probable specific reasons for not meeting desired performance levels may not be obtained. By definition, a compliance test is designed only to determine compliance with regulatory standards. Conversely, contract compliance testing calls for a more detailed analysis of results. Following verification of data, it is necessary to determine if all specifications for the equipment contract have been met. This type of program calls for a more rigorous recording of plant operating data than is necessary for a regulatory compliance testing program.

Trouble-shooting a piece of equipment requires the most involved data analysis. These programs require that the best possible plant and control equipment operating data be gathered as well including observations of any unusual occurances. The testing program should be structured so that all necessary data are available for complete analysis of the problem.

From the data a series of graphs can be made to facilitate analysis of the problem. These graphical analysis have advantages in that they show trends. And they can also show time lags between changes in various parameters and the effects on performance. Figure IV is a graph showing the effects that sulfur changes had on a recent ESP evaluation program. If the typical 3 test program had been performed, any 3 test set of data would have shown the unit I either as passing or failing.

RECOMMENDATIONS

With the importance placed on current environmental laws and regulations a need for more intensive and thorough testing programs have evolved. However, no guidelines for these programs have been developed.

Unfortunately, most of the data we have available today has evolved from regulatory or contract testing based upon three test runs. Statistically, three tests cannot be used with high confidence levels for data quality assurance programs.

We have identified the following areas in which research is needed to improve testing and data gathering methods, and the quality of test results, related to the utilization of waste products for fuel:

1. Develop a standard source testing reporting format.
2. Identify the key process and control equipment parameter that must be measured during test programs.
3. Identify how many test runs are required to evaluate equipment performance.
4. Identify process or load condition in which the test must be run.
5. Develop alternative to the use of the orsat for measurement of excess air.
6. Develop alternative methods for measuring particulate emission.
7. Conduct a research program to confirm the accuracy and application of an F factor garbage.

TABLE I

SUMMARY OF VARIABLES EFFECTING ESP PERFORMANCE

Parameter	Condition	Effect	Sensitivity of Measurement
H20	Increase flue gas moisture from 10% to 13%	Increase efficiency from 98 to 99%	± 1% absolute by condensation technique
Gas Volume	Increase gas volume 2.6% from optimum design condition	Decrease efficiency from 99.1% to 98.8%	Pitot tube ± 5% error
Gas Temperature	Increase temperature from 422°K to 428°K (300°F to 310°F)	Decrease efficiency from 99.1% to 99.0%	error ± 8°K (± 15°F)
Chemical Composition	Increase Na content of garbage from 1% to 2%	Decrease resistivity of fly ash from 10^{12} to 10^{11}	Not established

These results are based upon typical design data for 99% efficiency ESP and a typical garbage with less than 0.5% S content.

Conversion factor: $(°K) = 5/9(°F - 32) + 273.15$

Error Resulting In Conversion Of Orsat Readings
To 12% CO_2 or F_c Factor (.4% Std. Deviation)

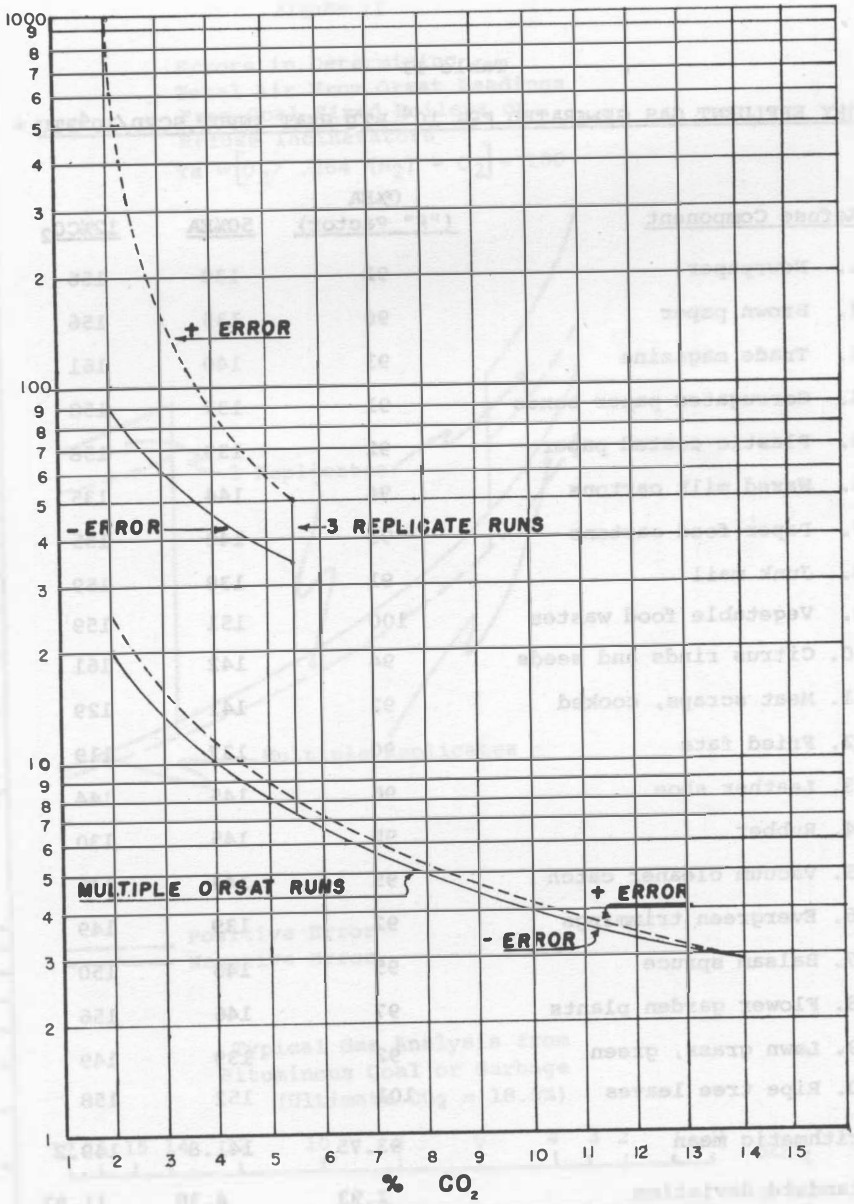


Figure I

Table II

DRY EFFLUENT GAS GENERATED PER 10^4 BTU HEAT INPUT, SCFD/10^4BTU *

Refuse Component	0%EA ("F" Factor)	50%EA	12%CO_2
1. Newspaper	92	139	156
2. Brown paper	90	135	156
3. Trade magazine	93	140	161
4. Corrugated paper boxes	91	137	158
5. Plastic coated paper	92	139	158
6. Waxed milk cartons	94	144	135
7. Paper food cartons	93	140	155
8. Junk mail	91	138	159
9. Vegetable food wastes	100	151	159
10. Citrus rinds and seeds	94	142	161
11. Meat scraps, cooked	92	141	129
12. Fried fats	90	137	119
13. Leather shoe	96	145	144
14. Rubber	95	145	130
15. Vacuum cleaner catch	95	144	142
16. Evergreen trimmings	92	139	149
17. Balsam spruce	95	143	150
18. Flower garden plants	97	146	156
19. Lawn grass, green	92	139	149
20. Ripe tree leaves	101	152	158
Arithmetic mean	93.75	141.8	149.2
Standard deviation	2.93	4.38	11.92

*Conversion factor: (SCFD/10^4 BTU) = 0.00268 (m^3/MJ)

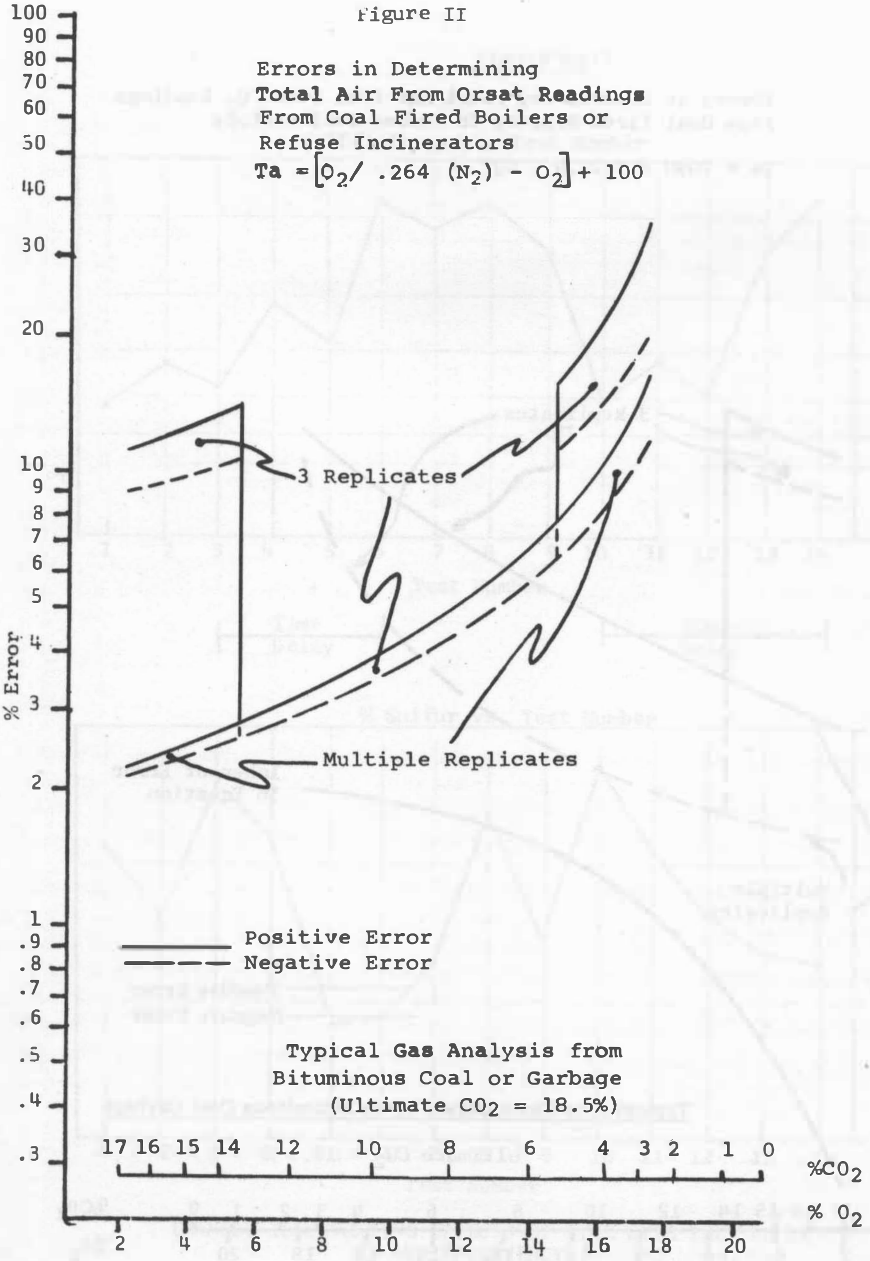


Figure II

Errors in Determining **Total Air From Orsat Readings** From Coal Fired Boilers or Refuse Incinerators

$Ta = \left[O_2 / .264\,(N_2) - O_2\right] + 100$

Figure III

Errors in Determining Total Air From Orsat O_2 Readings From Coal Fired Boilers Or Refuse Incinerators

$Ta = 2090 / (20.9 - O2)$

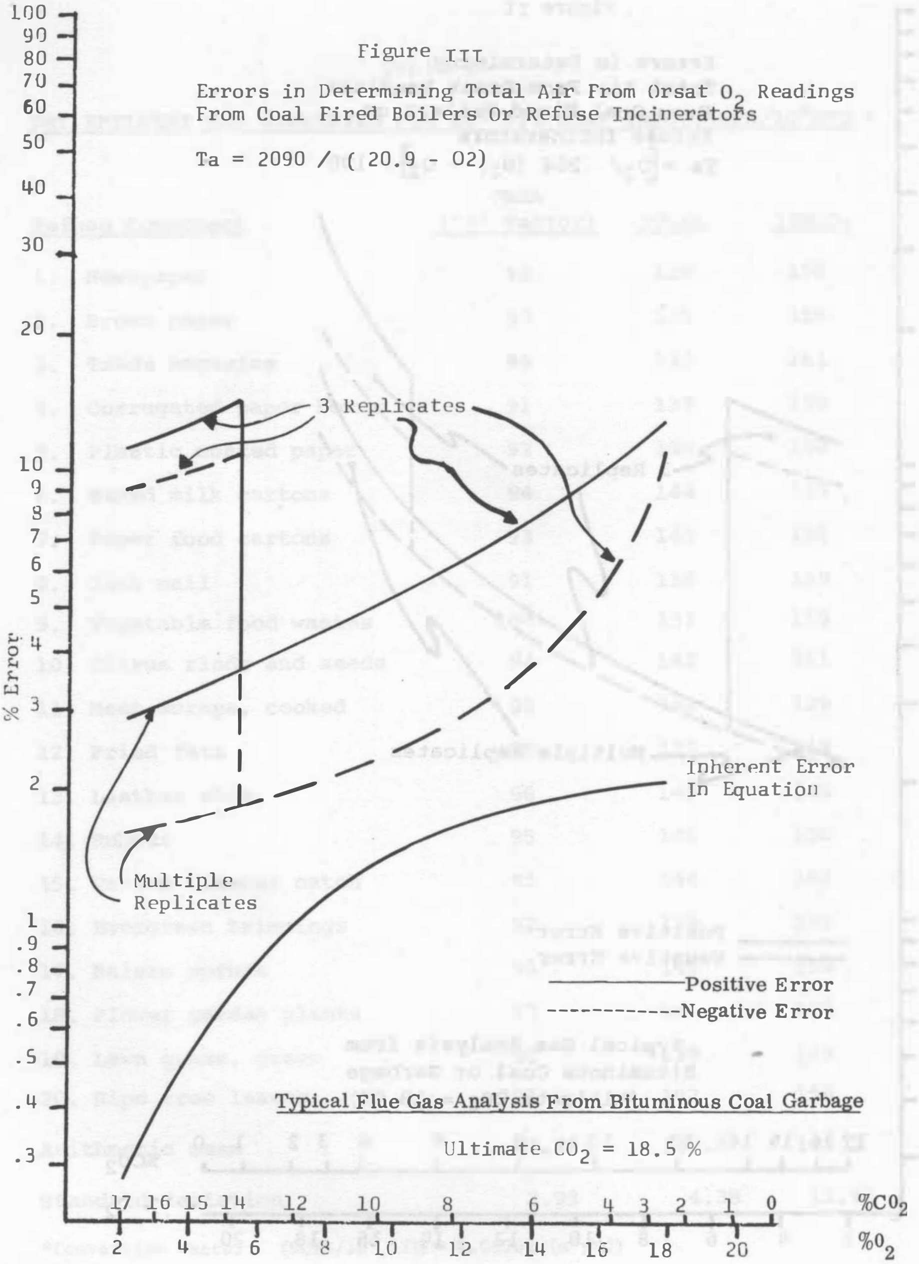
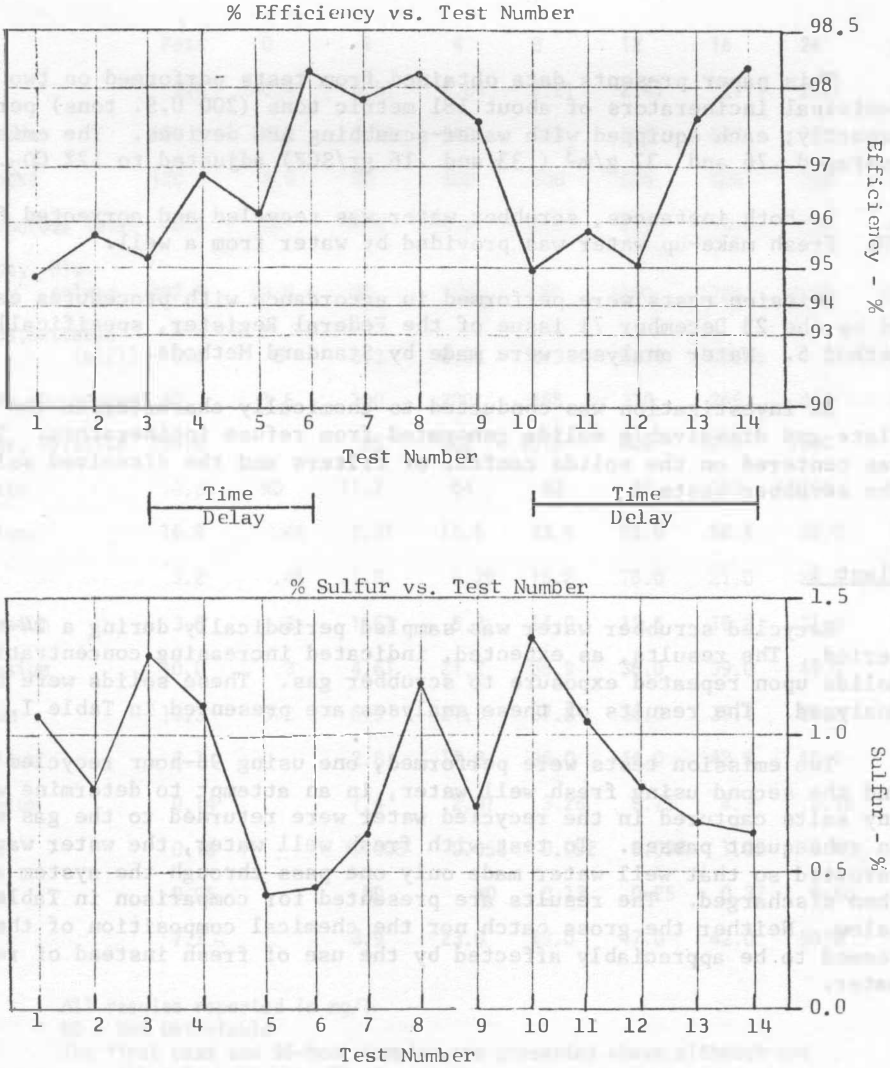


FIGURE IV



EXAMPLE ILLUSTRATING EFFECTS OF TIME WITH THE SULFUR AND EFFICIENCY