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EVALUATION OF AMBIENT AIR BORNE PARTICULATES IN AN INDUSTRIAL ENVIRONMENT

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KEITH L. STANLEY

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EVALUATION OF AMBIENT AIR BORNE PARTICULATES

IN AN INDUSTRIAL ENVIRONMENT

APPROVED BY

James M. Robertson

Larry Canter

Robert Y. Nelson

R. A. Wiley

DISSERTATION COMMITTEE

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CHAPTER I

INTRODUCTION

Air pollution occurs when the atmosphere is burdened with contaminants to the extent that undesirable effects are produced. While natural phenomena can and do contribute to air pollution, that which gives greatest concern arises as a by-product of man's activities in fulfillment of ever-increasing biological, economic, and esthetic needs without adequate environmental evaluations or controls.

Particulate matter commonly found dispersed in the atmosphere is composed of a large variety of substances. Some are toxic at various levels but not at levels generally found in the atmosphere. Evidence suggests other more harmful toxic effects have not yet been recognized, such as from vinyl chloride monomer. In order to evaluate the effects on health of contaminants in air it requires that each be given individual consideration.

Each segment of society has some responsibility for the maintenance of good air quality or prevention of air pollution. Unfortunately a clear definition of these responsibilities usually defies simplicity.

Government has the responsibility of establishing socially desirable or acceptable levels of air quality, equitable emission regulations and enforcement of the same. The theory being that in matters which involve a

determination of broad public interest and which are not controlled by economic incentives, representatives of the people can best define the degree of public need.

Industry frequently encounters air pollution control problems in the course of manufacturing the many products essential to man's health, welfare and physical comforts. The effective solution of such problems is a goal to which industry has shown a growing dedication.

Particulates and Health

The effects of particulate air pollution on health are related primarily to injury to the surface of the respiratory system. The injury may be permanent or temporary and may produce injury itself or may act in conjunction with gases altering their sites or their modes of action.[1]

Many studies clearly indicate that the deposition, clearance and retention of inhaled particles is a very complex process which is only beginning to be understood. Particles can be cleared from the respiratory tract by transfer to the lymph, blood, or gastro intestinal tract but may exert effects elsewhere.

The lowest particulate levels at which health effects appear to have occurred are reported in studies of Buffalo and Nashville. The Buffalo study indicated increased death rates from selected causes in males and females 50 to 69 years old at annual geometric means of 100 $\mu g/m^3$ and over. The study suggests that increased mortality may have been associated with residence in areas with two-year geometric means of 80 $\mu g/m^3$ to 100 $\mu g/m^3$. The Nashville study suggests increased death rates for selected causes at levels above 1.1 cohs. Sulfur oxide pollution was also present during the period studied. In

neither study were the smoking habits of the decedents known.[2]

In addition to the effects on health, suspended particulates affect climate, visibility, materials, economics and vegetation to varying degrees. Particulate-laden air, while it has many similarities from place to place and from time to time, is certainly not identical in all communities or at all times and therefore, neither are the resulting effects.

Epidemiological studies which associate suspended particulate matter and health effects of varying severity can be no better than the instrumentation and methods employed for gathering the data. Conscientious endeavors to learn more about particulate behavior, concentrations, and health effects necessitates an occasional backward look at established procedures and techniques to determine their accuracy and reliability in obtaining useful and meaningful air pollution data.

Reaction to suspended particulates as a nuisance probably occurs at peak concentrations but might also be expected to occur at concentrations considerably below peak concentrations when particle size is entered as a factor. Fine particles whose size ranges from small molecules to those of ordinary dust and sand visible with an optical microscope make up the world of particulates.[3]

Origin of Particulates

The process of particle generation and removal in air are continuous, and depend on the specific sources of pollution on the meteorology and topography of the air basin.[4] The concept of "equilibrium size distribution"[5] of particles in the atmosphere is one of the more recent developments in the study of particulate air pollution. Another development is the

attention being given to the sizes of particles of a given chemical species in the atmosphere[6] because of their toxicological or meteorological significance. The chemical profile of an air basin or air quality control region is individualistic and dependent on the input of particulates from natural, industrial, domestic and mobile sources of pollution.[7]

If knowledge of atmospheric particulate contaminants is to progress, air pollution studies must yield more definitive data than the conventional gravimetric type particulate data. It is necessary to study particles in the air with respect to particle size. Particle size and chemical composition determine the potential of a contaminant to cause response in man or inanimate receptors.

Human activity as it affects the finite, precious and life-sustaining air must be guided by and be in harmony with the system of relationships among the elements of nature to avoid adverse or profound impacts on the air resource.

Because the health of every individual is affected to some degree by the quality of the air he breathes, the need is established for rapid and reliable reporting and forecasting of meaningful air pollution indexes or air contaminant levels, leading to the identification of airborne contaminants.

CHAPTER II

LITERATURE REVIEW

Particulate Air Pollution

Particulate air pollution refers to any matter dispersed in the air, whether solid or liquid in which the individual particles are larger than small molecules but smaller in diameter than 500 microns. Particles in this size range stay in the air anywhere from a few seconds to several months.[1] Particulates larger than approximately 50 microns settle out of the air quite easily, and cause problems through deposition and adhesion. Deposition refers primarily to the mechanism whereby dirt contacts clothing, homes, and other property, while adhesion refers more specifically to respiratory tissue adhesion. Damage due to adhesion in the respiratory tract is considered to be caused by particles from 0.5 to 2.0 microns in diamater. These particles also represent the most difficult particles to collect and analyze by conventional methods.

Aerosols are a special class of particulate. They consist of colloidal suspensions that are larger than molecular size but not large enough to settle out of air under gravity. These particles are considered to be from 0.01 to 50 microns in size. While particles larger than 50 microns in diameter settle out of the atmosphere due to gravity, aerosols tend to remain suspended for relatively long periods of time.[7]

The usual origin of particles smaller than 1 micron in diameter is through condensation and combustion, while larger particles, with the

exception of rain, snow, sleet and hail, are generated from comminution. Particles larger than 10 microns in diameter result from mechanical processes such as wind erosion, grinding, spraying, and the pulverizing of materials by vehicles and pedestrians. Particles between 1 and 10 microns in diameter may include local soil, process dust and combustion products from local industries. Combustion products and photochemical aerosols make up a large fraction of the particles in the range of 0.1 to 1 micron in diameter. Identification of particles below 0.1 micron in diameter is incomplete, however, the typical urban increase over natural levels of particles in this size range seems to be primarily due to combustion. Particles less than 0.1 micron in diameter are characterized by random motions produced by collisions with gas molecules. They are highly concentrated, move rapidly, collide frequently, and through sorption and nucleation of gas molecules and adhesion with other particles grow larger quickly. Settling velocities of particles larger than 1 micron are significant and their motions may deviate from the motions of air.[8]

Evaluation of Suspended Particulate Concentrations

The methods and instrumentation available for collecting and measuring suspended particulate concentrations in air are numerous. New and more or less sophisticated instruments and methods of evaluating particulates are continuously being developed and investigated with the hope of providing greater precision and accuracy in evaluation. These investigations relate to most aspects of particles in the atmosphere.

Measurement of particle size has received considerable attention due to the relationship with health effects. A simple comparator has been developed

which allows the measurement of particle size distribution by unskilled operators. The instrument is designed to accept a 35 mm photograph of the particulate material, produced by an optical or an electron microscope. The photograph is projected onto a translucent screen and particle sizes are compared with a superimposed spot of light projected from the other side. Adjustment of the spot diameter insures that when the particle is counted by operation of a foot switch it is also placed into the appropriate size category.[9] Air pollution and occupational health standards aimed specifically at particles under 2 microns are in the offering. Attention has been shifting readily to fine particles for several reasons: mounting medical evidence continues to show that particles under 2 microns are the ones most damaging to human health; pollution experts agree that these cause reduced air visibility; and some scientists fear that increased atmospheric loading of fine particles could have far-reaching effects on the earth's climate.[10]

Comparisons of particulate data obtained from different measuring methods or instruments is limited. In evaluating the concentration and composition of atmospheric particulate matter, sampling the atmosphere has been normally conducted using standard High Volume air samplers. The impact of particulate pollutants on human health and vegetation cannot be adequately determined by standard High Volume filter data alone.[11] Comparisons of dust count data obtained from different measuring methods have been investigated by Marsh.[12] Dust counts were taken over several months in four different areas which exhibited different average dust loadings. The data from the two light-scattering methods (a forward-angle light-scattering photometer and a particle

counter using the light scattered from individual particles) were found to be consistent and allowed an easy comparison of the four areas sampled. However, the data obtained from two microscopic methods (a settling technique and a membrane filtration technique) did not permit comparison of the areas because the counts overlapped. An experimental particle size distribution curve was used for calibration. The investigation indicates that comparisons between clean rooms can be accomplished using light-scattering systems but not by microscopic methods. According to Steen[13], absorption and scattering of light by particles can give some idea of their total quantity and particle size distribution. The disadvantage of purely optical measuring techniques is that no means are available for subsequent checks of the results obtained.

Measurements of suspended particulate mass to include some breakdown into particle size data is rapidly receiving the attention necessary to cause its incorporation into the National Air Surveillance Network. As demonstrated by Burton, et. al.[14], a four stage, multiorifice, high volume fractionating cascade impactor with backup filter, can be operated as a component of the standard High Volume sampler. The sampler separates particulate matter into five aerodynamic size ranges: 7 microns or larger; 3.3-7 microns; 2.0-3.3 microns; 1.1-2.0 microns; and 0.01-1.1 microns. Field test utilizing duplicate sampling techniques in comparative tests were conducted to determine the feasibility of using the fractionator on a routine basis in field operations. The results of these tests indicated the fractionator could be utilized in field studies without the loss of gravimetric data.

Because the degree of respiratory penetration and retention is a direct function of aerodynamic particle size, knowledge of the particle size

distribution of suspended particulates is essential in assessing the inhalation health hazard.[15] Particle size, composition, and concentration of aerosol constituents determine the extent of visibility reductions, deterioration, soiling of materials and other atmospheric phenomena.[16] The size distribution of suspended particulates is also important in meteorology and geophysics. Particle size distribution of suspended particulates continues to be difficult to obtain due to the lack of available fractionating devices which offer reliability in size resolution of particles, short sampling periods, cost and ease of operation. Lee and Flesch recently described a high volume particle fractionating cascade impactor that overcame many of these disadvantages.[17] The fractionator was adapted from an Anderson cascade impactor[18], a commercially available device used in limited air pollution studies.[19,20]

A successful method of determining particle size distribution of suspended particulate matter in a routine field operation has been demonstrated.[14] Gravimetric determination of particulate matter fractionated by virtue of the aerodynamic dimensions of the particles, indicated that the mass of suspended particulate matter by weight is predominantly submicron in size. Trends in particulate concentrations and particle size distributions appear to be influenced at least in part by seasonal factors and emission sources.[21]

The correlation of coefficient of haze data with gravimetric data has had only limited success. Additional study is needed to determine the relationships of low levels of suspended particulate with mass gravitational levels as collected by the standard High Volume air sampler.

During the past two decades an abundance of technical information dealing with air pollution has been accumulated; however, there is an extraordinary

paucity of data on how particulates collected by different instrumentation and in different localities might compare due to the unique particles and particle characteristics of an area. A search of the air pollution literature can lead to the conclusion that animals, plants and materials are adversely affected by polluted air. Little if any serious damage to human health occurs at the current levels in which pollutants are present in the atmosphere. The question arises, whether humans are really not subject to adverse effects from polluted air, or whether damage to health actually occurs but is not being recognized by the scientific community. A number of circumstances render damage caused by polluted ambient air difficult to identify with its sources.

Air Pollution Implications

Diseases resulting from air pollutants develop slowly and inconspicuously. They are, therefore, difficult to relate to their cause. When pathologists find at autopsy a chronic condition within the kidney, liver or any organ their mission is regarded accomplished. Only in exceptional cases can they pinpoint the original source of a chronic illness.

Those engaged in the speciality of allergy frequently encounter patients in whom air pollution either precipitated or aggravated respiratory illness or an allergic skin disease. Documentation of such cases in a scientific manner is almost insurmountable. Tools to relate an illness to a specific pollutant are lacking. The interpretation of findings gleaned from laboratory tests is difficult. Few physicians have been alerted to the manner in which a specific air pollutant interferes with human health.

The statistical approach for documenting illness resulting from air pollution is effective only in rare instances. Because of the numerous

variables, which are difficult to control, sampling must cover thousands or even millions of individuals. Furthermore, the interaction between airborne agents alters the effect of an individual pollutant. Even so, accurate, reliable and relevant data on particulate air pollutants must be obtainable. Perhaps of equal importance is data to relate instruments and the data they reflect to one another in the geographical area in which they are utilized.

CHAPTER III

PURPOSE AND SCOPE

The primary reason for studying airborne particulates has been to understand their influence on man's health, activities and property. Unfortunately, data of a cause-effect nature are difficult to obtain and much work remains to be accomplished. The complexity of airborne particulates and lack of readily recognizable symptoms of health effects leads to speculative conclusions on their interrelationship.

It has been suggested that most attempts to establish a cause-effect relationship between suspended particulates and health would be premature and futile for two reasons. First, the treatment of symptoms of a condition of health without due search for cause does not contribute to or stimulate research leading to factual information. Second, the manufacturing industry and scientific community have failed to refine or develop the instrumentation for identifying airborne particulates sufficiently to recognize and surmise cause-effect relationships between suspended particulates and health.

The necessity to study the influence of airborne particulates on health is easily established even if it is only based on the attention presently being given the subject. Because of the far reaching implications that the charge of a cause-effect relationship can have, it is necessary that all associated data be of the best quality attainable on existing instrumentation.

Having been charged, perhaps indiscriminately at times, as the point of

origin of the air contaminants mostly responsible for degradation of the air resources, the industrial site serves well as a location for evaluating airborne particulates.

The primary purpose of this study was to determine the adequacy of a linear relationship, developed for available and commonly used field air monitoring equipment, for estimating suspended particulate concentration in an industrial environment within the Oklahoma City Air Quality Control Region. The primary purpose of this study was accomplished by comparing results obtained from instrumentation of varying designs over a twelve month period with individual samples taken at randomly selected time intervals. Within the scope of this study was a specific objective to determine the desirability of using spot tape sampler data to reflect daily particulate pollution concentrations in the Oklahoma City area.

CHAPTER IV

MATERIALS AND METHODS

Particulate air pollution cannot be effectively evaluated without standard methods and equipment that are widely acceptable because they are reliable, accurate and precise. At the present time only a few of the many methods for measuring particulate pollutants are widely accepted and have been proven reliable.[22]

Development and research by numerous government, industry and research laboratories have produced considerable techniques and instrumentation for sampling and analysis of particulate pollutants. A variety of measurement methods has been proposed because some investigators stress economy while others might stress simplicity, convenience, or sophistication. Almost daily new principles are being developed and incorporated into instrumentation. Differences in approach and techniques invariably give slightly different results.

These differences are, many times, difficult to discern because it is rare that different methods can be applied to the exact same sample. Very small differences in sampling techniques can cause important differences in results because the amount of airborne particulate is usually only a very small part of the quantity of air sampled. The need for determining the accuracy and reproducibility of measurement methods for air pollution control is readily recognizable.

Location of the sampling site can have far reaching effects on the overall results reported from an air monitoring station. Residential, commercial and industrial oriented stations yield results typical of the activity near the location.[23]

Sampling Site Selection

Few sites are ideally located for measurement of all pollutants. Most agencies, for purely economic reasons, find it necessary to consolidate sampling equipment for a number of pollutants at a sampling site. Factors which most affect site selection are: geographical distribution of population, location of pollutant emission sources, meteorology and topography. "Field Operation Guide for Automatic Air Monitoring Equipment"[23] was used as a guide for locating the sampling equipment within the confines of the Western Electric property. Equipment availability and security were necessary considerations for selecting this site.

Western Electric Company, 7725 West Reno, Oklahoma City, Oklahoma, served as the sampling site. The geographical location with respect to Oklahoma City and other industry is shown in Figure 1.

The predominance of wind direction being south southeast (SSE) as shown in Figure 2 dictated that the sampling site be on the north property line of the industrial site. On the north property line, high structure interferences were avoided as much as possible by locating the site at a maximum distance from all structures. Industrial activity and future facility development were also considered for site location, Figure 3.

The sampling site, as selected and equipped, was incorporated into the national, state and local air monitoring networds. Data were accumulated on

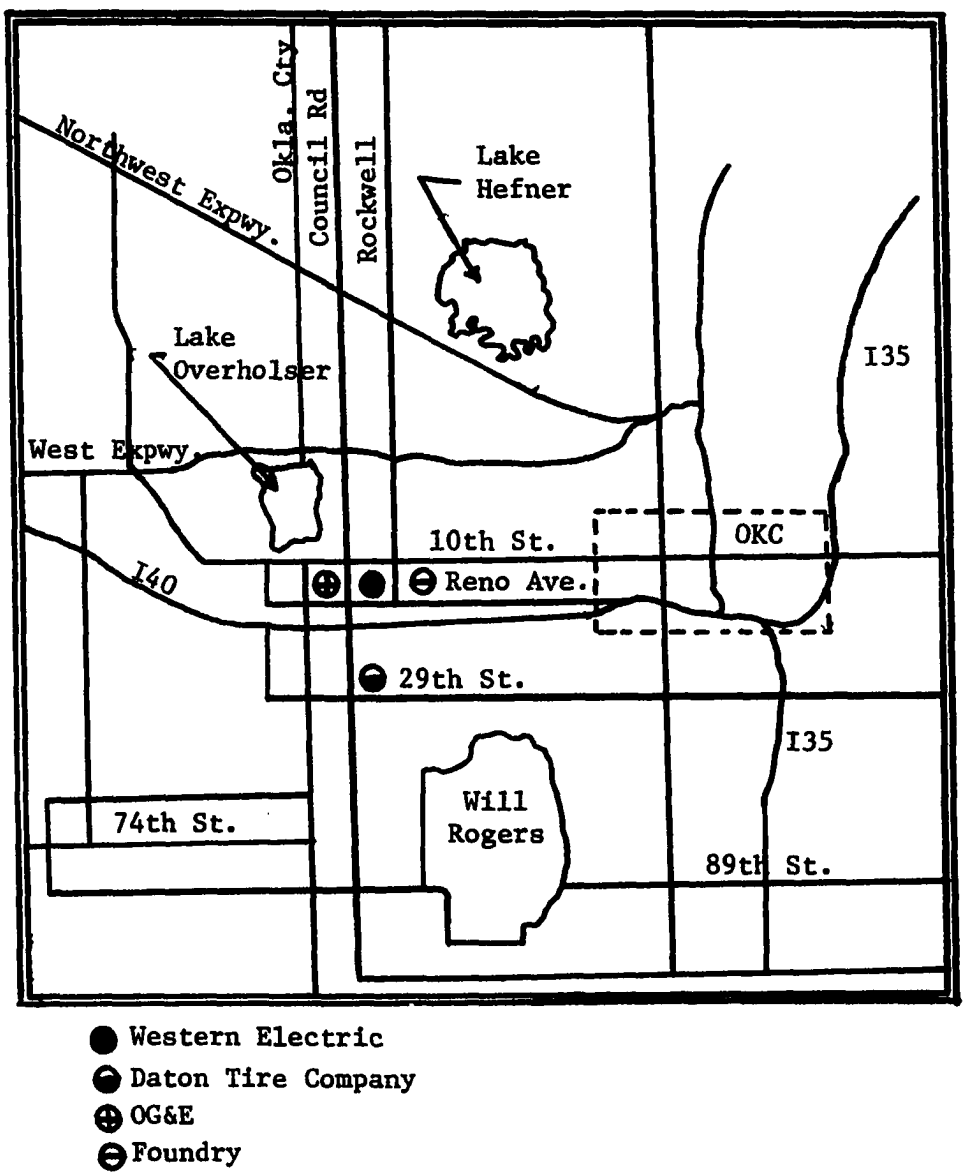
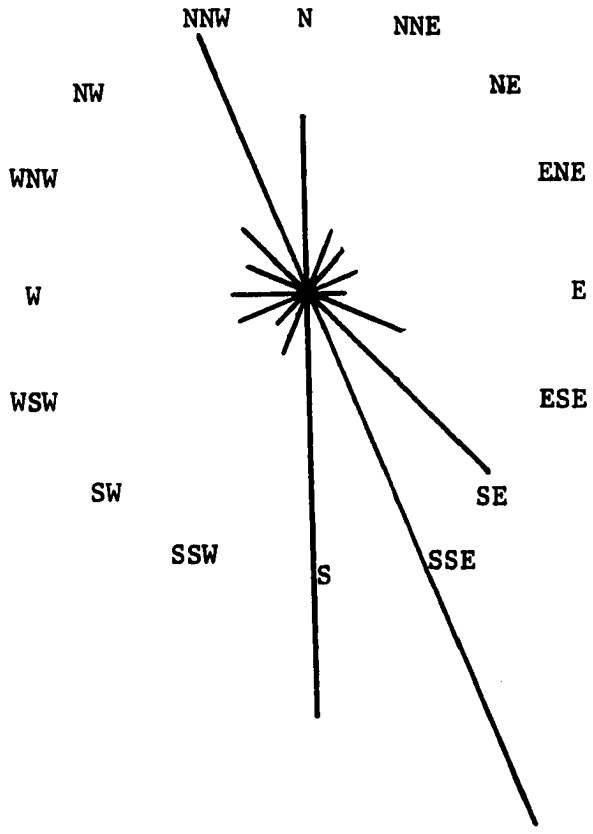


FIGURE 1: Geographical Location of the Western Electric Sampling Station



Scale: 1/8 Inch = 1% of Time for the Direction

FIGURE 2: Wind Rose for the Western Electric Sampling Station
May, 1973 through April 1974

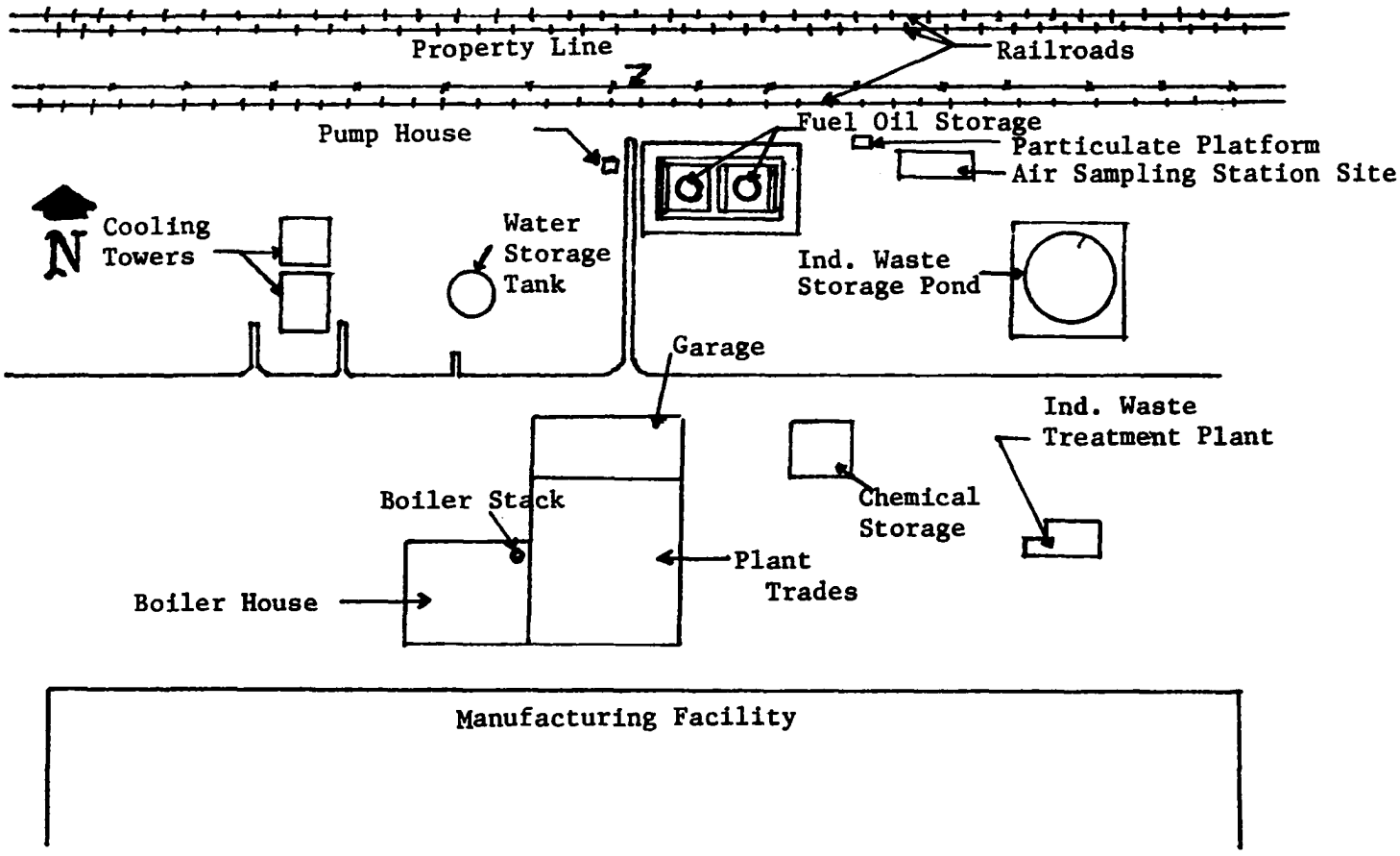


FIGURE 3: Sampling Site Location with Respect to Physical Structures at the Western Electric Air Monitoring Station

all contaminants for which there are national and state ambient air quality standards and then distributed routinely to the regulatory agencies.

Preliminary work to establish the station began in August, 1971, and was completed in September, 1972.

Sampling Equipment Selection

Suspended particulate collecting equipment was selected for its acceptance into the national, state and local air monitoring networks. For this reason all equipment was in close agreement with that of Oklahoma air pollution control regulatory agencies. Sepcifically, field equipment consisted of two (2) high-volume air samplers, two (2) Anderson aerodynamic particle sizing heads, four (4) American Iron and Steel Institute (A.I.S.I.) paper tape samplers and one (1) Research Appliance Company (R.A.C.) fractionation sampler. (Figure 4)

High Volume Air Sampler

The Environmental Protection Agency reference method was used for determination of suspended particulates in the atmosphere.[22]

High Volume air samplers have been in use for more than twenty years for the collection of suspended particulate matter. The physical design of the sampler is based on aerodynamic principles which result in the collection of particles in the size range of .01 to 100 microns.[24]

The High Volume air sampler is an apparatus for collecting a relatively large volume of air (1.5 to 2.0 cubic meters per minute or 60 CFM) and capturing suspended particulate matter on a filter. Concentrations of particulates suspended in the atmosphere are expressed in micrograms per cubic meter of air ($\mu g/m^3$).

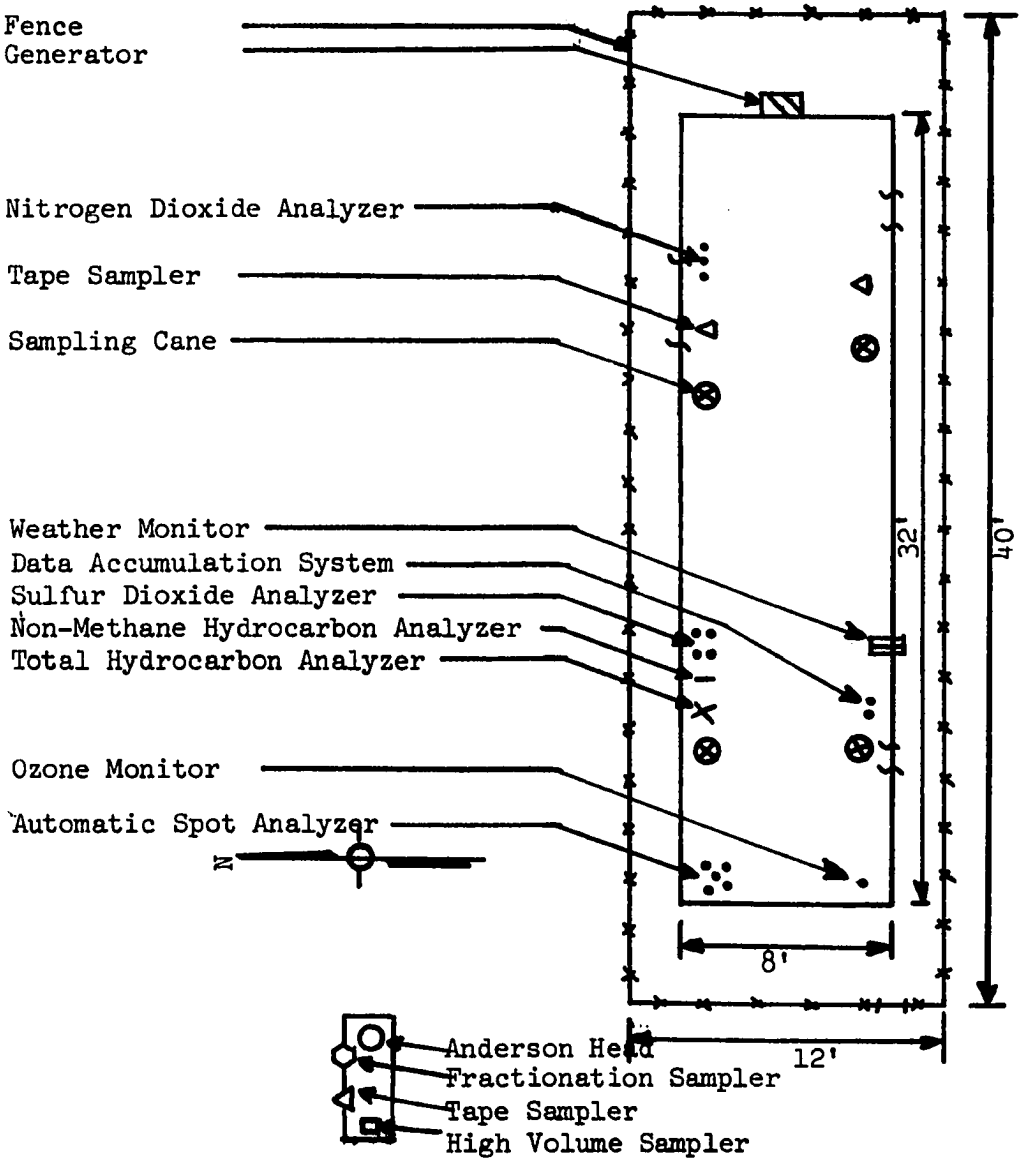


Figure 4: Western Electric Station Layout and Equipment

The General Metal Works, Inc., Model GMWL 2000H sampler consists basically of a motor driven blower and a supporting screen for the filter ahead of the blower unit. During the sampling operation, the sampler was supported in a protective housing so that the 8" x 10" surface of the filter was in a horizontal position. The samplers were modified to incorporate variable transformers for adapting particle sizing heads, a continuous flow device for recording the actual air flow over the entire sampling period, a 7 day clock switch to start and stop the sampler and a running time totalizer.

The units assembled for field use measure 15" x 15" x52" and weigh approximately 70 pounds each. Power requirements are 115 volts A. C., however, voltage was controlled with transformers to supply 85 $\pm$ 5 volts to the blower motors. With sampling rates from 20 to 50 cfm, brush life was approximately 1500 hours.

When the sampler was operated at an average flow rate of 35 cfm for 24 hours, an adequate sample will be obtained even in an atmosphere having concentrations of suspended particulates in the range of 5 $\mu g/m^3$. Weights were determined to the nearest milligram, air flow rates were determined to the nearest 1 cfm; times were determined to the nearest 5 minutes; and mass concentrations are reported to the nearest microgram per cubic meter.

The accuracy with which the sampler measures the time average concentration depends upon the constancy of the air flow rate through the sampler. Concentration and nature of the dust in the atmosphere affects the air flow rate by increasing the air flow resistance at the filter surface.[25] Under these conditions the error in the measured average concentration may be in excess of $\pm$ 50% of the true average concentration, depending on the amount of reduction of air flow rate and on the variation of the mass concentration

of dust with time during the 24 hour sampling period.[26]

A calibrating orifice assembly and water manometer were used for High Volume calibration. The orifice and manometer unit calibrated against a positive displacement meter and a calibration curve established for the air flow versus static pressure data.

The General Metal Works Model GMW-25 Calibration Orifice was utilized to accomplish monthly calibrations. The orifice is attached to the High Volume blower unit after removal of the adapter and the airflow varied by the resistance of supplied plates. Static pressure and High Volume Sampler flow rates were used to prepare the calibration curve as plotted in Figure 5. Type A glass fiber filters, with a collection efficiency of 99% for 0.3 micron diameter particles were conditioned for 24 hours in a filter conditioning environment prior to preweight and post weight.

A filter, preweighed on a Torbal Air Pollution balance, was centered with the rough side up on the supporting screen. The filter was secured by tightening the filter holder sufficiently to avoid air leakage at the edges. For each air sample the following data was recorded, date, time on and time off, and flow rate, as shown in Figure 6. A recorder chart was then positioned, the time on the recorder was set; and the 7 day switch timer was set. The sampler was then turned on briefly to assure it was operating properly.

Following the end of the sampling period, the timer was checked to insure that the sampler operated during the desired time. The exposed filter was then removed, folded in the middle with the exposed side in, placed in a minila folder and then into the envelope and returned to the laboratory for final analysis.

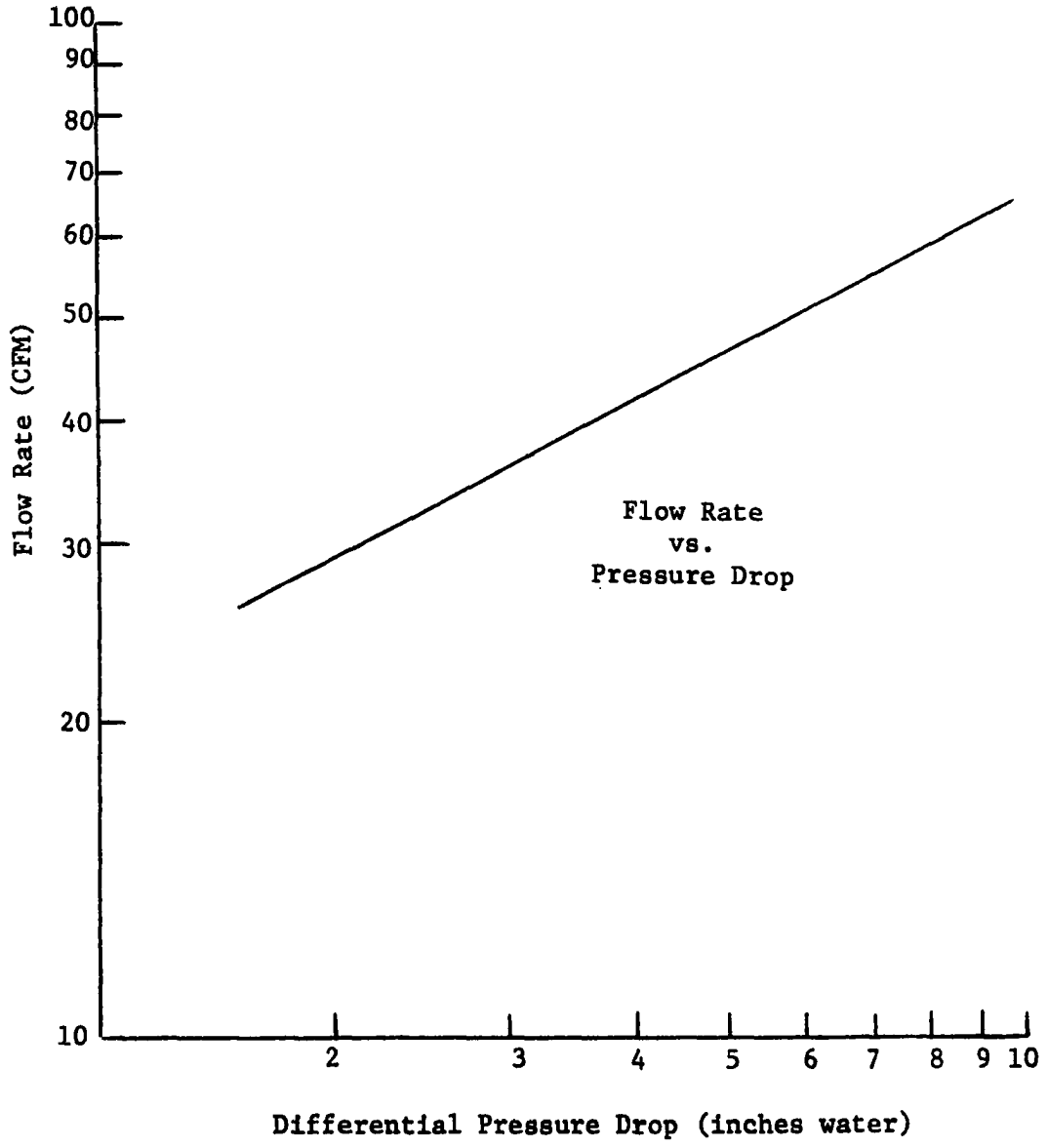


FIGURE 5: Typical Calibration Curve for the Standard High Volume Air Sampler

HIGH VOLUME AIR SAMPLE DATA SHEET

Sampler No. _____ Post Weight _____

Date _____ Pre Weight _____

Time On _____ Gain _____

Time Off _____

Indicated Flow Rate _____

Calculations:

Micrograms per cubic meter _____

FIGURE 6: Typical Information Contained on Manila Envelope for Transporting and Storing High Volume Air Sample Filters

Mass suspended particulate concentration was then calculated by:

$$C = \frac{(W_2 - W_1) \times 10^6}{V}$$

where: C = Mass concentration of suspended particulates - micrograms per cubic meter

W_1 = Initial weight of filter, gram

W_2 = Final weight of filter, gram

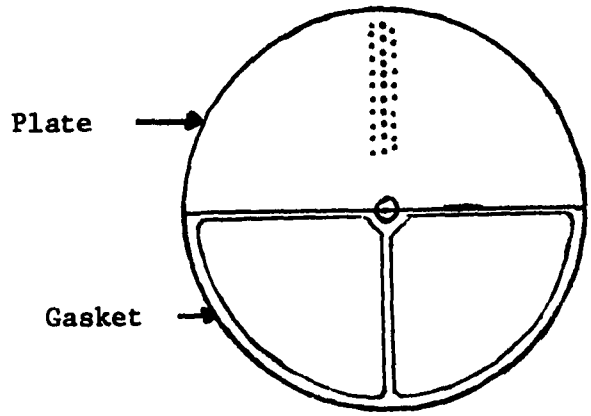
V = Air volume sampled, cubic meters

10^6 = Conversion of grams to micrograms

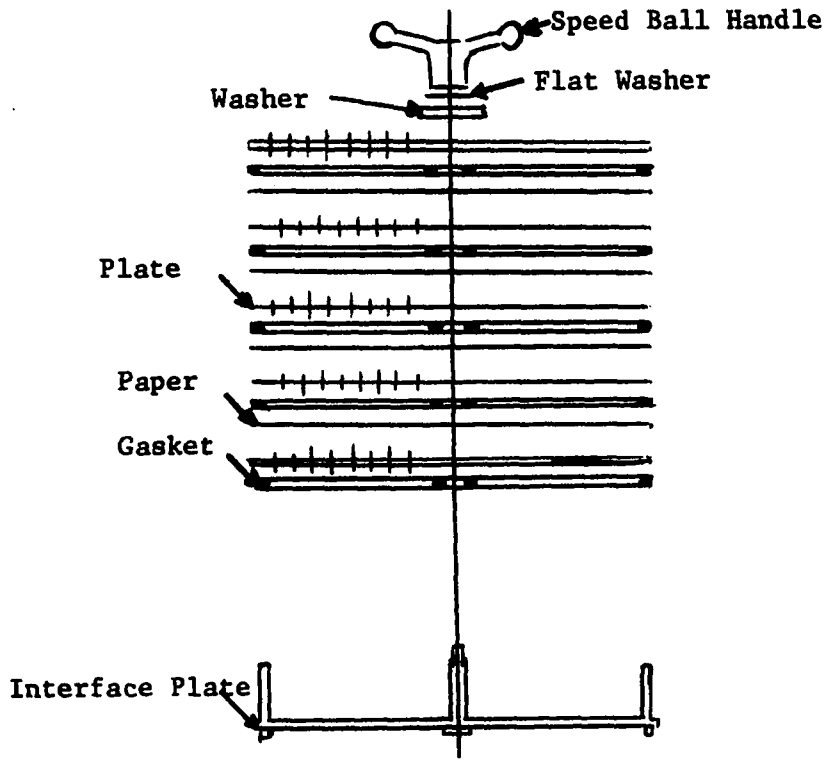
High Volume Sampler Heads

The Anderson Sampling Head was used to separate particulates into five size ranges by aerodynamic particle diameter as follows: 7 microns or larger; 3.3 to 7 microns; 2 to 3.3 microns; 1.1 to 2.0 microns and 0.01 to 1.1 microns.

The Anderson Head Sampling attachment to the High Volume Sampler is a multi-stage, multi-jet cascade impactor. It is constructed of five aluminum plates separated by neoprene rubber gaskets (Figure 6). The diameter of the 300 equally sized and spaced holes on each plate decreases from plates one to four (Figure 7), increasing the flow through velocity of the air stream. The holes are aligned so that the air streams through the holes are directed at the surface (not at the holes) of the plate below. Stages 1 through 4 (plate 2 through 5) are covered with circular glass fiber filters which have holes aligning with the holes in the plates supporting them. Two configurations of filter paper with respect to hole positions are necessary for proper operation, one type for stage 2 and 4 and the other type for stage 1 and 3. Particles which have greater momentum than the critical momentum for each stage,



Half View of Plate and Gasket



Illustrative Section

FIGURE 7: Anderson Head Adapter to the Standard High Volume Air Sampler

will follow the original air stream lines and impinge on the filter while those with less than the critical momentum will follow the bending air streams and pass onto the next stage. The particulate mass, on a particular stage, is determined by the gravimetric procedures for the standard High Volume sampler.[27]

Aerodynamic diameters of 7.0 microns and above; 3.3 to 7 microns; 2.0 to 3.3 microns; 1.1 to 2.0 microns; and 0.01 to 1.1 microns correspond respectively to filters on plates 2, 3, 4, 5 and the backup filter. Indicated diameters do not imply an aerosol of mono-dispersed spheres. Instead the particles, regardless of their individual geometry, respond to conditions imposed in the same way as spheres of a given diameter might be expected to behave aerodynamically.

Jet plates, which range in thickness from 0.25 to 0.050 inches, are held in place by a shoulder bolt and 4 dowel pins press-fitted in the plate. The jet plates are separated by 0.25 inch thick neoprene gasket/spacers. A speed ball type handle allows for both tightening the plates and carrying this head from the field to the laboratory.

The differences in the perforated collection paper are in location of perforations. Type "A" non-hygroscopic fiber glass collection paper was utilized throughout the study. The head was disassembled and assembled in the laboratory to assure the least disturbance of filtering paper. Collection paper was placed on the plates with the rough side up. An interface gasket held down and sealed the 8 x 10 backup filter paper. The backup filter was located below the interface plate on the filter holder and provided the 5th and final stage to collect particles in the submicron size range. The 8 x 10 inch fiberglass backup filter was placed face up on the stainless steel wire screen mesh support.

Two air sampler heads were purchased for alternate usage during transporting and analysis of the samples. In all instances, 24 hour sampling periods were utilized to assure gathering enough particulate for gravimetric analysis and continuity among the various samplers employed.

Calibration of sampler heads was accomplished using a water filled manometer connected across the filter. This was accomplished using a small orifice (0.036 inches) which was drilled in the head and the orifice on the motor housing. The Anderson Head attachment was operated according to the procedure discribed and outlined by Rihm and Blanchard.[28]

Filter Tape Sampler

The filter tape sampler was used to measure suspended particulates in ambient air by drawing air through a section of white filter paper (Whatman No. 4).

One Research Appliance Company (RAC) American Iron and Steel Institute (AISI) Model 5000 and three Model G-2 filter tape samplers were utilized for collecting atmospheric particulates throughout the duration of the data gathering period. Filter tape samplers are automated air samplers used to evaluate the soiling potential of the visible qualities of the ambient atmosphere.

The G-2 model sampler, Figure 8, was comprised basically of a vacuum pump, sampling nozzle, automatic time, and rotameter. The Model 5000 sampler was composed of the same basic components as the G-2 sampler but also included a telemetering module, computer interface module, automatic standardization module, light source, photocell, dual timers, and recorder output.

Air flow and tape calibrations were accomplished on the tape samplers

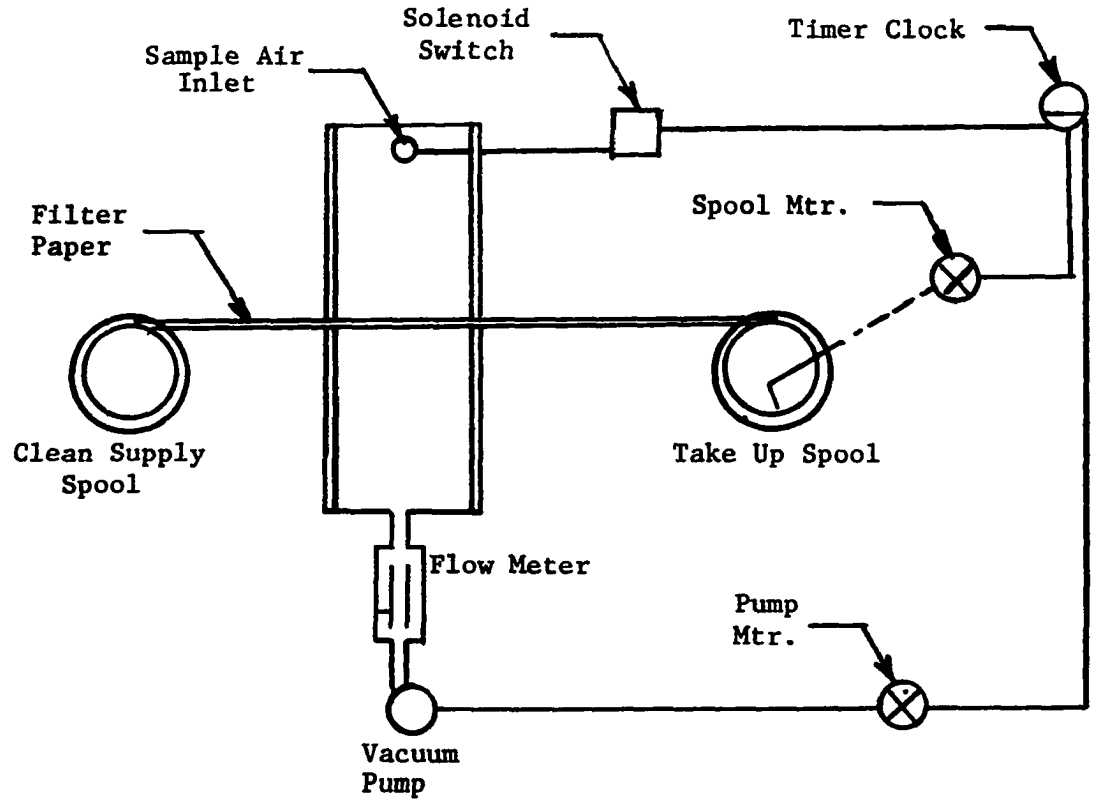


FIGURE 8: Schematic of A.I.S.I. Model G-2 Paper Tape Sampler

during the course of data accumulation. Air flow was determined weekly by use of a laboratory calibrated wet test meter.[29] Direct relationships were then developed between the actual flow of the wet test meter and the indicated flow of the tape sampler rotameter at the desired sampling rate. Tape calibrations were accomplished for each sampling period.

Number 4 Whatman filter paper tape was fed through the sampling nozzle and air was drawn through the tape for a 2 hour time period at 0.25 cubic feet per minute (cfm). Tape indexed on 2 inch centers was advanced automatically by timer following each sampling period. Tapes were removed from samplers following the 24 hour predetermined sampling period when all equipment was operated.

Tape segments, representing 24 hour sampling periods and containing 12 sample spots 1 inch in diameter, were evaluated by two distinct methods. Method I, referred to descriptively by the terminology "standardize advance read method" follows sample collection. This method is used by state and local air pollution control agencies throughout Oklahoma wherever Coefficient of Haze (C.O.H.) determinations are part of the monitoring activities. A semi-automatic transmission spot evaluator, R.A.C. Model 2332A was used for determining the percent transmission of light through the tape. The evaluator was comprised of a light source, photocell, percent transmission meter and advance button to move the tape to the standardize and read position. The "standardize advance read method" attempts to overcome tape inconsistencies by standardization to 100 percent transmission just prior to evaluation of each sample spot, Figure 9.

Method II, referred to descriptively as the "standardize read method", has the advantage of standardizing on the sample spot prior to collection of

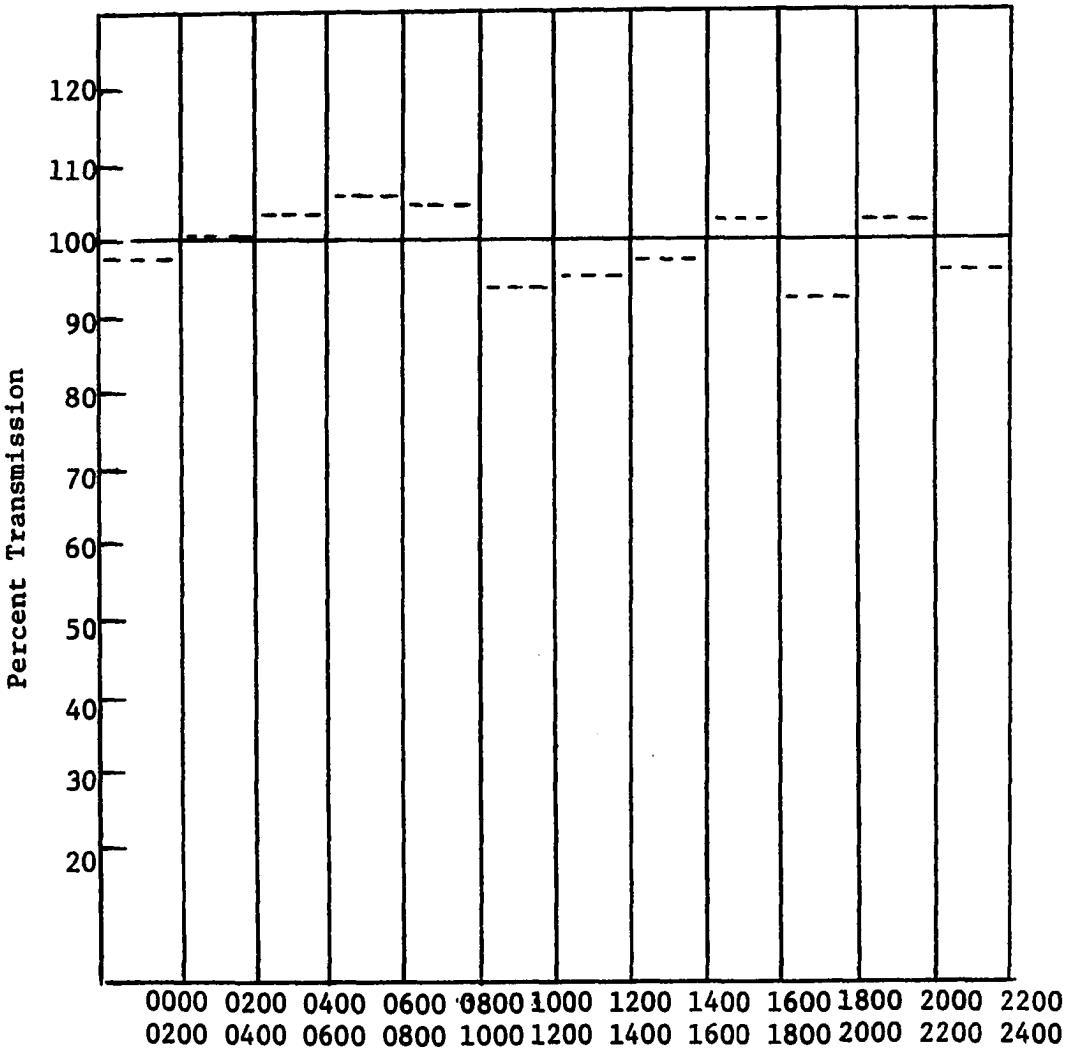


FIGURE 9: Typical "Standardization Advance Read Method" Results of Paper Tape Analysis (Method I)

particulates. A segment of tape approximately 4 inches long was cut from a tape role and placed in a clean envelope. This standardization tape segment was used to set relative percent transmission prior to tape evaluation. An 11 inch strip chart recorder was used to provide a record of clean tape transmission qualities prior to sample collection. Once atmospheric particulates were collected on the tape, the standardization tape was again used to reset relative percent transmission back to the origianl point and the sample tape transmission qualities were redetermined (Figure 10).

Particle cut size as collected by the paper tape samplers was determined by placing a membrane filter in the sampling position for 2 hours at 0.25 cfm. Collected particles were then sized using a calibrated Porton Gradicule. No effort was made to count particles.

Fractionation Sampler

The fractionation sampler described by Lee and Flesch[17,30] and used in the National Air Surveillance Network (NASN) was included in the sampling scheme.

The fractionation sampler collects particles from about 0.5 to 3.5 microns in diameter. Five impactor stages each with a different air inlet geometry separates particles due to progressively increasing velocities and their aerodynamic properties.

Calibration of the pressure drop across the sampler orifice as a function of the flow rate was accomplished by connecting a calibrated dry test meter at the sampler inlet and varying the air flow with an air inlet valve on the vacuum pump. Weekly calibrations were maintained throughout the data gathering period.

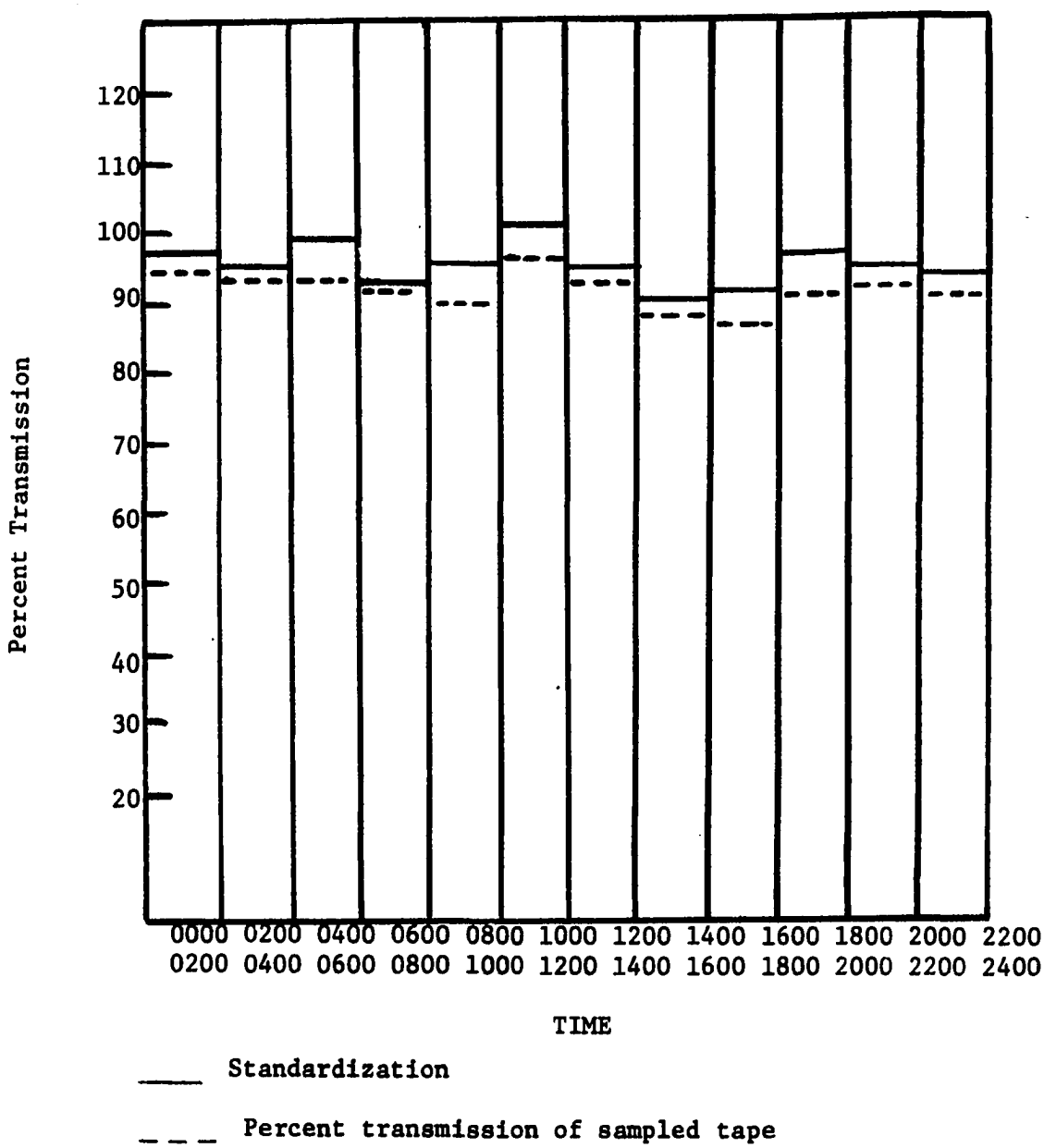


FIGURE 10: Typical "Standardization Read Method" Results of Paper Tape Analysis (Method II)

Lee and Goranson[21] have described a method of operation and analysis of the R.A.C. fractionation sampler (NASN) - National Air Surveillance Network Cascade Fractionation Sampler.

Operation of Equipment

Monitoring equipment was operated at a frequency determined by procedures and circumstances surrounding total unison station operation. Equipment failures and recognized operational errors which occurred during the course of a sample run resulted in voiding the data of the entire sample run.

Sampling time periods which were of 24 hour duration were initiated and terminated by a 7 day skip timer. The timer was programmed to turn equipment on at 0000 hundred hours and off at 2400 hours.

Dispensable filtering materials were maintained at 50 percent relative humidity for a minimum of 24 hours before and after sample collection periods. Care was exercised to avoid handling of filtering material by transporting it inside envelopes suitably sized for the filtering media.

Operation of a Royco Particle analyzer for continuous automated sizing and counting of particles had to be discontinued due to repeated failures of the pump, difficulties in standardization and repeated off scale measurement of particle counts.

Because the weight of particulate collected per stage on the Anderson filters is less than with the standard High Volume sampler, there is greater likelihood for error in the weighing process. It was recognized during the course of data collection that a good possibility exist for reuse of Anderson Head filters.

CHAPTER V

OBSERVATIONS AND DISCUSSIONS

Data Accumulation

Standard High Volume sampling data from the Oklahoma City-County Health Department Air Quality Control Section Air Monitoring Network were incorporated into the data analysis. The data were collected from throughout the Oklahoma County area from 15 network stations, Figure 11. Sample collection dates were not prearranged or coordinated prior to sample collection. Data were chosen selectively from monitoring network data to correspond with Western Electric run dates. Table 1 list the field data as it was tabulated for analysis.

Western Electric and City-County Health Department Data

Suspended particulate concentrations as determined by use of the standard high-volume air sampler ranged from a low of 10.14 micrograms per cubic meter to a high of 291.42 micrograms per cubic meter.

Monthly mean values from the Western Electric (W.E.) site were compared to the monthly mean values from the Oklahoma City-County Health Department (OCCHD) air monitoring network. Regression analysis were used to determine the best straight line fit of the data, Table 2. Regression analyses shown as five significant digits were carried out by computer based on field data of two significant digits. Monthly means of mass suspended particulates at the W. E. station and the OCCHD are plotted in Figure 12 with the line of best fit. The regression analysis with the table of residuals are shown in Table 3 of the Appendix.

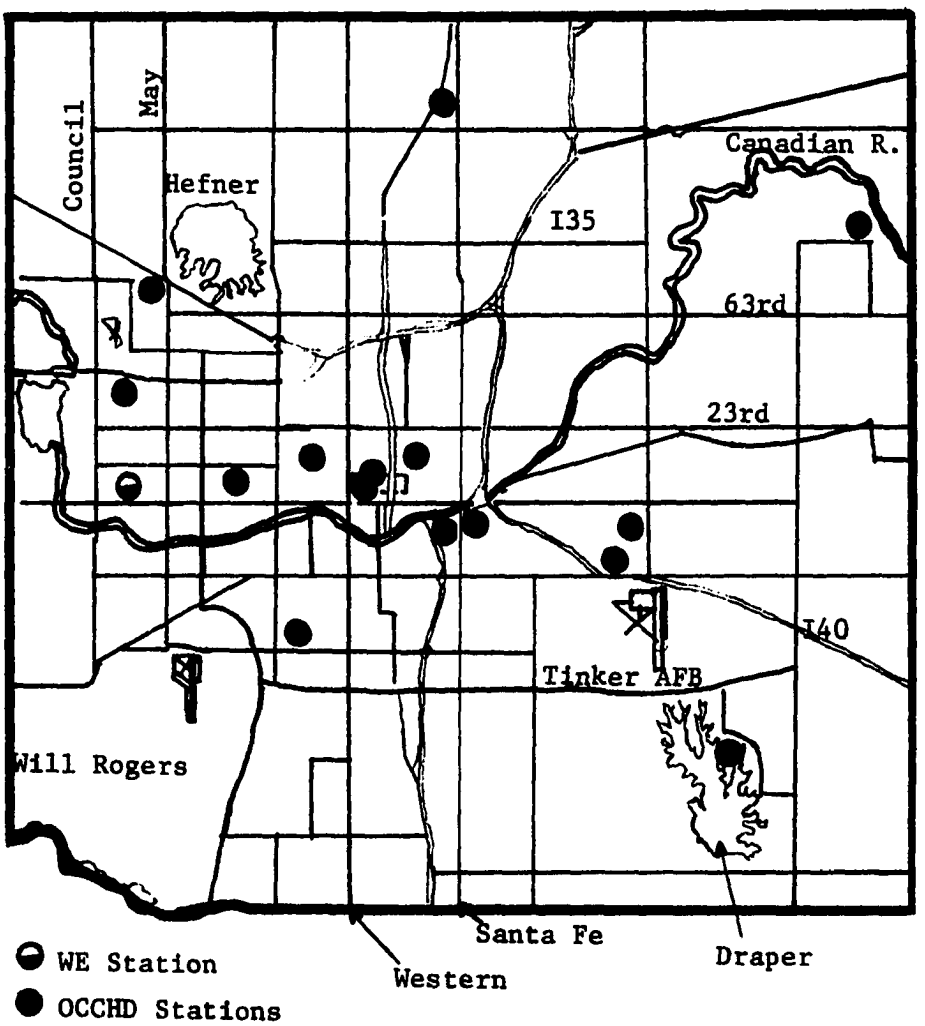


FIGURE 11: Oklahoma City Area Network Monitoring Station Locations

TABLE I: FIELD DATA TABULATION

Date	Standard Hi Vol $\mu g/m^3$	Anderson Head $\mu g/m^3$	Fractionation Sampler $\mu g/m^3$	% Transmission Method II	% Transmission Method I	Mon. Means Western Electric $\mu g/m^3$	Mon. Means City-County Health Dept (15 stations) $\mu g/m^3$
5-22-73	10.14	21.95	6.36	98.8	98.3	118.69	111.85
5-26-73	291.42	351.66	139.64	85.6	89.7	n = 3	n = 14
5-30-73	54.52	61.43	30.07	94.0	93.3		
6-1-73	84.28	112.07	56.37	92.8	94.2		
6-5-73	45.70	44.30	21.91	95.4	95.0		
6-7-73	67.11	69.53	36.23	93.3	95.3		
6-9-73	78.80	89.76	46.36	93.0	91.1		
6-13-73	47.33	56.88	22.13	94.4	92.1	78.10	75.32
6-15-73	90.33	106.31	36.39	92.6	94.4	n = 11	n = 44
6-20-73	98.91	88.28	41.38	91.8	93.0		
6-22-73	123.59	128.74	60.53	89.1	88.0		
6-26-73	90.66	98.01	48.47	92.1	94.1		
6-28-73	76.27	81.31	45.70	93.4	93.0		
6-30-73	56.16	59.31	36.81	95.7	93.0		
7-4-73	68.51	70.13	32.73	94.3	94.8		
7-6-73	66.05	68.90	37.28	94.5	91.1		
7-10-73	71.36	73.16	33.36	93.8	92.5	73.17	75.37
7-12-73	79.29	66.25	30.67	94.9	91.1	n = 6	n = 44
7-19-73	96.18	94.30	40.73	91.4	89.6		
7-28-73	57.60	53.00	25.39	95.6	97.3		
8-4-73	126.30	133.40	53.70	88.8	93.1		
8-8-73	91.64	95.40	50.66	91.8	90.2		
8-10-73	84.36	157.90	43.23	92.4	91.6		
8-15-73	82.85	76.92	44.86	92.3	92.7	105.66	98.64
8-17-73	66.84	59.70	21.29	94.3	94.6	n = 8	n = 40
8-21-73	80.51	95.88	46.19	92.9	90.2		
8-23-73	180.42	186.62	119.63	87.1	89.6		
8-30-73	132.36	128.37	62.86	88.4	91.7		
9-5-73	42.91	41.32	19.00	96.8	97.0		
9-7-73	42.67	45.98	19.76	96.7	98.8		
9-11-73	90.98	86.20	39.46	91.9	91.2		
9-13-73	39.97	36.40	21.91	97.2	93.3	63.51	54.10
9-15-73	65.31	67.56	38.80	94.4	93.2	n = 9	n = 30
9-18-73	94.33	102.38	56.38	91.6	94.5		
9-21-73	79.05	80.44	39.99	93.1	96.1		
9-25-73	73.24	68.05	25.74	93.9	91.1		
9-27-73	43.32	38.57	19.84	96.7	94.2		
10-2-73	57.96	51.98	21.69	95.2	97.3		
10-4-73	32.86	26.04	12.19	97.8	95.0		
10-6-73	38.50	44.39	23.19	97.1	95.7		
10-9-73	59.59	61.56	32.11	95.2	95.1		
10-11-73	42.67	42.30	17.22	96.8	97.3		
10-12-73	28.45	33.23	15.91	98.2	96.4		
10-16-73	54.10	52.61	25.01	95.6	93.3	59.85	76.16
10-18-73	66.29	83.84	42.31	94.4	91.6	n = 12	n = 46
10-20-73	64.33	73.08	33.43	94.6	97.2		
10-23-73	65.07	75.30	36.23	94.6	96.2		
10-25-73	143.05	127.02	58.84	87.9	90.1		
10-27-73	35.29	29.31	13.10	97.5	99.0		
10-30-73	88.04	89.99	39.33	92.2	93.6		
11-1-73	129.84	136.59	83.51	88.6	89.8		
11-6-73	43.82	45.12	27.91	96.7	96.0		
11-10-73	79.98	77.24	43.24	93.3	91.7	69.17	64.77
11-15-73	92.37	99.31	48.17	91.7	91.7	n = 6	n = 13
11-20-73	27.12	27.95	10.13	98.3	96.5		
11-25-73	43.93	45.36	23.01	96.7	94.3		
1-15-74	68.42	86.20	54.29	94.2	97.1	62.41	58.63
1-19-74	77.98	97.12	51.62	93.1	94.9	n = 3	n = 8
1-22-74	40.85	40.85	24.86	96.8	93.8		
4-18-74	138.80	156.47	125.61	88.3	86.5	119.18	81.93
4-22-74	186.50	194.88	134.62	86.9	88.7	n = 3	n = 15
4-24-74	32.24	43.09	13.37	97.7	95.6		

TABLE 2

LINEAR REGRESSION OF WESTERN ELECTRIC AND OKLAHOMA CITY - COUNTY HEALTH DEPARTMENT MONTHLY MEAN SUSPENDED PARTICULATES

X Mean . . . 83.30441 - W.E. Station

Y Mean . . . 77.41996 - OCCHD Stations

Intercept . 25.66888

Reg. Coefficient . . . 00.62122

Std. Error of Reg. Coef. 16380

Correlation Coefficient 00.82014

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	1832.00415	1832.00415	14.38347
Deviation from Reg.	7	891.58117	127.36872	
Total	8	2723.58117		

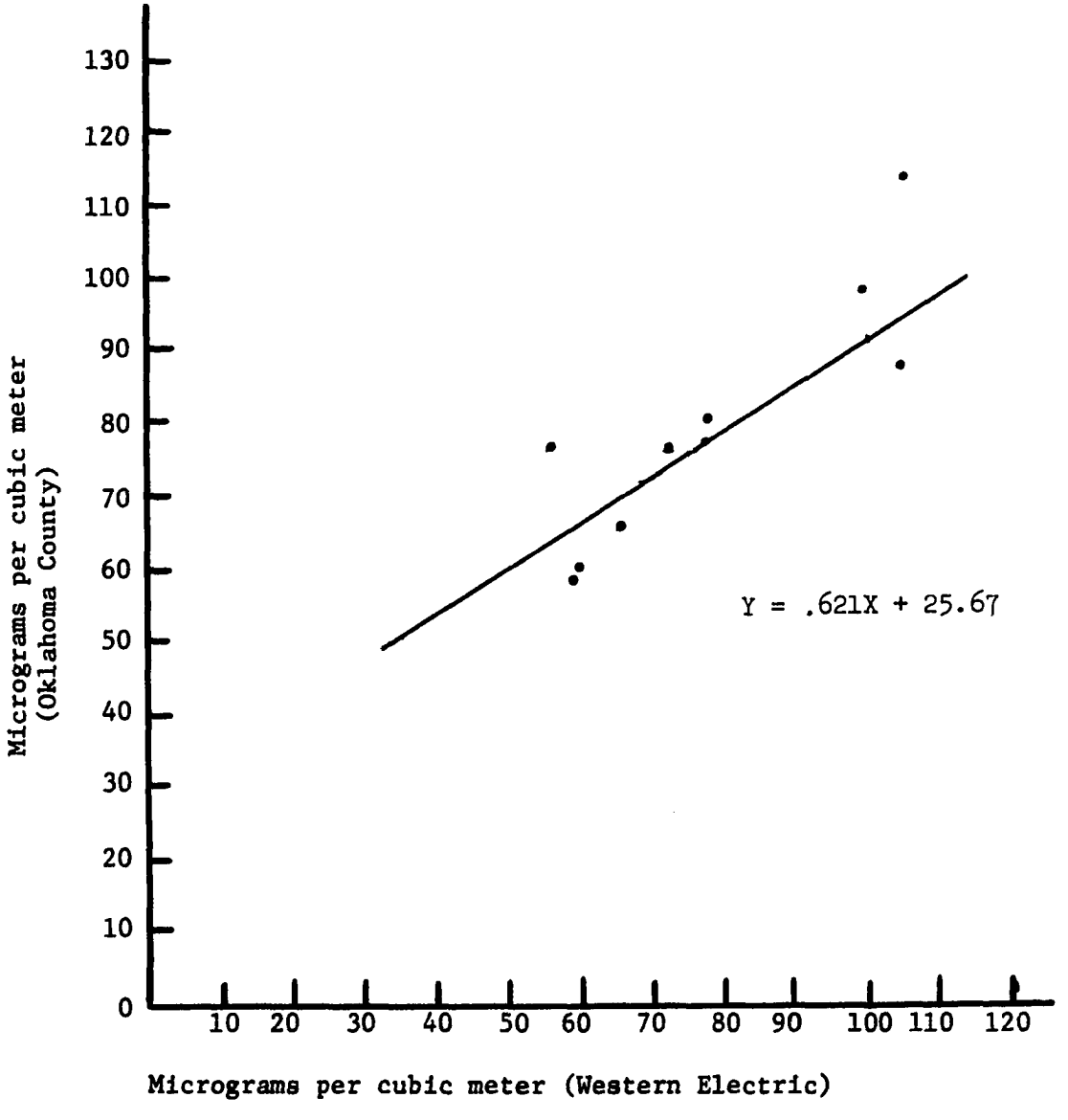


FIGURE 12: Monthly Means of Mass Suspended Particulates at Western Electric Versus Monthly Means of 15 Oklahoma County Monitoring Stations with Line of Best Fit

The correlation coefficient of 0.82014 and "F" value of 14.38 indicate significant relationship between the W. E. monthly mean particulate concentrations and the OCCHD monthly mean particulate concentrations. Suspended particulate study data therefore adequately represents the average of Oklahoma County suspended particulate concentrations. The significant correlation between data does not suggest a homogenous particulate concentration throughout Oklahoma County. Individual OCCHD monitoring stations data indicate heterogenic mass suspended particulate concentrations characteristic of their residential, commercial or source-oriented location.

Incorporation of variable voltage transformers into the standard High Volume air samplers, in order that all samples could be collected at the same rate, might significantly improve the correlation obtained between similar source orientated stations.

Anderson Head versus Standard High Volume

Field evaluation at the W. E. station indicated the Anderson Head adapter correlated well with the standard High Volume air sampler when total suspended particulates concentration are compared. Laboratory studies[31] have indicated that the aerodynamic size distribution predicted by the manufacturer of the Anderson head adapter was essentially correct.

Aerodynamic separation of suspended particles by size and weight provides data that are unobtainable with the standard High Volume air sampler. Information on suspended particulate size is important in evaluating health effects, source identification and assessing results of state air pollution control agency implementation plans.

Total suspended particulate data collected at the W. E. station which relates the standard High Volume sampler with the Anderson Head are shown in Table 4 and Figure 13. The complete data for the linear regression analysis with the table of residuals is shown in Table 5 of the appendix.

The line of best fit for the 62 parallel paires of samples is:

$$Y = 1.11729\ X + -3.7738$$

where X is the standard High Volume sampler results and Y is the Anderson Head modification. The correlation coefficient was 0.96756.

Rihm and Blanchard have reported a correlation coefficient of 0.98 and a line of best fit for 82 parallel pairs of samples of:

$$Y = 0.965\ X + 0.51$$

where X is the standard High Volume sampler result and Y is the Anderson Head.[28]

The high correlation between the 24 hour standard High Volume sampler and the Anderson Head indicates that the Anderson Head adequately reproduces standard High Volume sampler results on the basis of total particulate weight.

Similarities in correlation coefficients suggest similar performance of the Anderson Head when correlated with the standard High Volume sampler in varying ambient atmosphere. The equation developed outside Oklahoma could be used to predict standard High Volume levels with approximately the same reliability as the equation developed within Oklahoma. The basic difference in equations is the mean annual particulate concentration.

Standard High Volume versus Fractionation Sampler

Suspended particulate pollutant characterization in ambient air was extended by the comparison of the standard High Volume sampler with the fractionation sampler. The reliability of the fractionation sampler has been

TABLE 4

LINEAR REGRESSION OF STANDARD HIGH VOLUME SAMPLER (X) WITH ANDERSON HEAD (Y)

X Mean	77.53721
Y Mean	82.85781
Intercept	03.77381
Reg. Coefficient	01.11729
Std. Error of Reg. Coef.	00.03765
Correlation Coefficient .	00.96756

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	151275.53167	151275.53167	880.27661
Deviation from Reg.	60	10311.00197	171.85000	
Total	61	171586.53167		

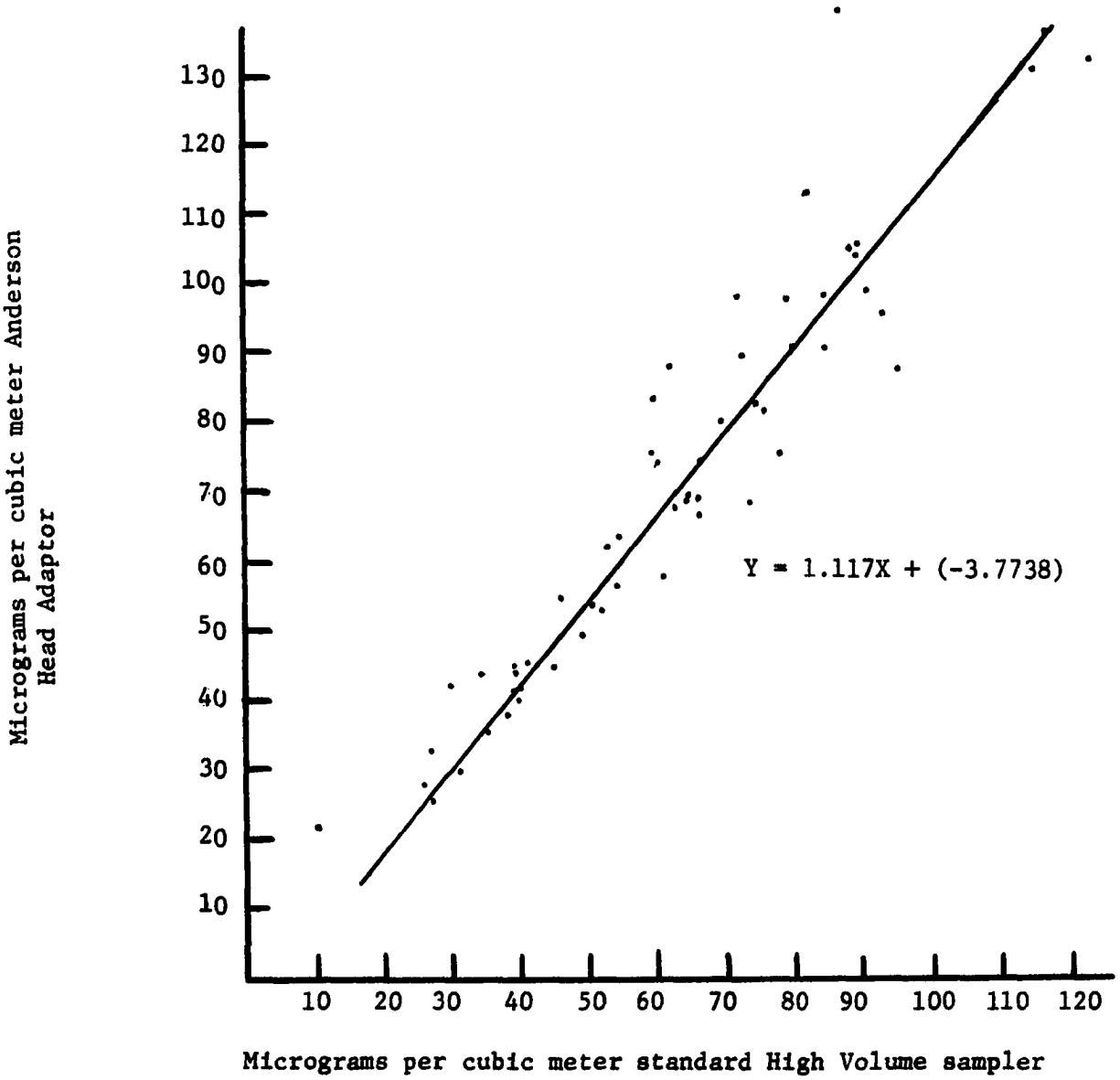


FIGURE 13: Mass Concentration of Suspended Particulates Standard High Volume Sampler versus Anderson Head Adapter with Line of Best Fit

established by Lee and Flesch.[17]

A linear regression was established between the standard High Volume sampler and the fractionation sampler (Table 6) for the W. E. station.

A line of best fit for the 62 pairs of samples is:

$$Y = 0.5769\ X + -2.54956$$

where X is the standard High Volume sampler results and Y is the fractionation sampler (Figure 14). The linear regression analysis with the table of residuals is shown in Table 7 in the Appendix.

The correlation coefficient between the two samplers was 0.89511, indicating a satisfactory degree of association between the methods of collecting suspended particulates.

During a recent study conducted in England[32], suspended particulate concentrations were determined with a standard High Volume sampler and a fractionation sampler concurrently. The site was non-urban, selected to provide "background" measurement of particulate levels. Regression equations were developed so that concentration measurements of the High Volume sampler (X) could be converted to equivalent measurements made with the fractionation sampler (Y):

$$Y = 0.507\ X + 29.158$$

The correlation coefficient between the two samplers was reported to be 0.94, indicating a high degree of collection method association.

Although both studies show a significant association between the standard High Volume sampler and the fractionation sampler methods of suspended particulate collection there are marked differences in the estimating equation of linear regression. The England study[32] indicates there exists a marked

TABLE 6

LINEAR REGRESSION OF THE STANDARD HIGH VOLUME SAMPLER (X) WITH THE FRACTIONATION SAMPLER (Y)

X Mean	77.53721
Y Mean	42.18714
Intercept	02.54956
Reg. Coefficient	00.57697
Std. Error of Reg. Coef.	00.03710
Correlation Coefficient .	00.89511

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	40340.53135	40340.53135	241.85308
Deviation from Reg.	60	10007.86135	166.79766	
Total	61	50348.39071		

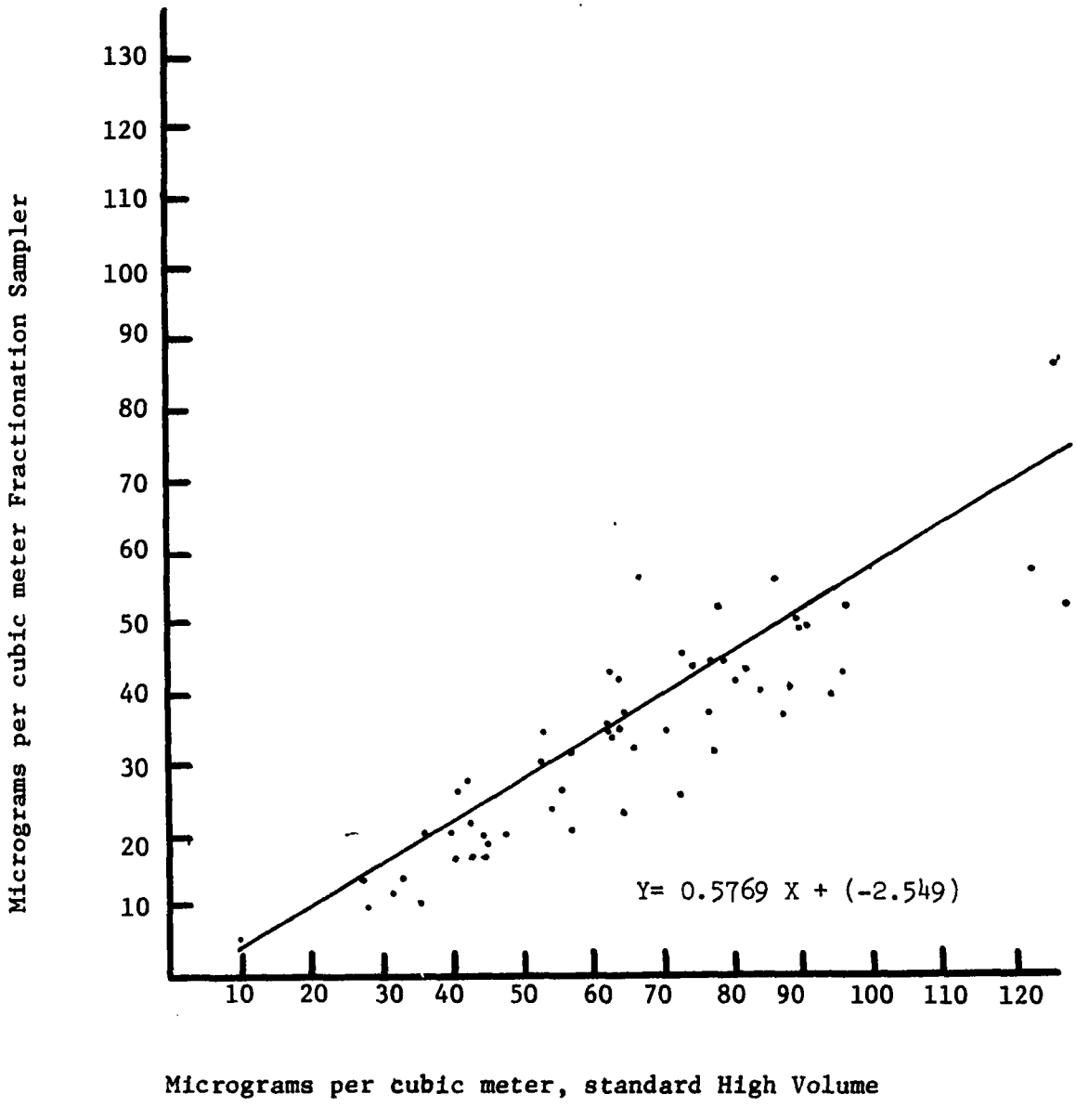


FIGURE 14: Mass Concentration of Suspended Particulates of the Standard High Volume Sampler versus Fractionation Sampler with Line of Best Fit

dependence of the fractionation sampler on particulate concentrations. Low atmospheric concentrations measured with the fractionation sampler yield higher results than the High Volume sampler while higher atmospheric concentrations similarly yield lower results. Lower particulate concentrations were measured at the W. E. station with the fractionation sampler at moderate atmospheric concentration when compared with the High Volume air sampler. These results can be explained in part by wall losses, particle characteristics, wind interference with collection of the particles in the lower size range and flow rate errors.

The differences in the regression equations suggest that it would be inappropriate to use equations developed outside an air pollution control district for estimating particulate concentrations between the High Volume sampler and the fractionation sampler.

The particle size distribution of ambient airborne suspended particulates as collected by the fractionation sampler is shown in Figure 15 by comparing percent cumulative mass less than the particle diameter with particle size.

Circuit board failure of the Cahn electrobalance resulted in the discontinuance of individual stage weighings. It was necessary after the first 20 sample weighings to collectively weigh all stages using the Torbal torsion balance. Therefore, the particle size information gained was from samples collected between May 22, 1973, and July 28, 1973. It must be noted that some weighing sensitivity was lost as a result of electrobalance failure.

Particle size fractionation characteristics were calculated using equations developed by Mercer[33] and by Ranz and Wong[34] (Table 8).

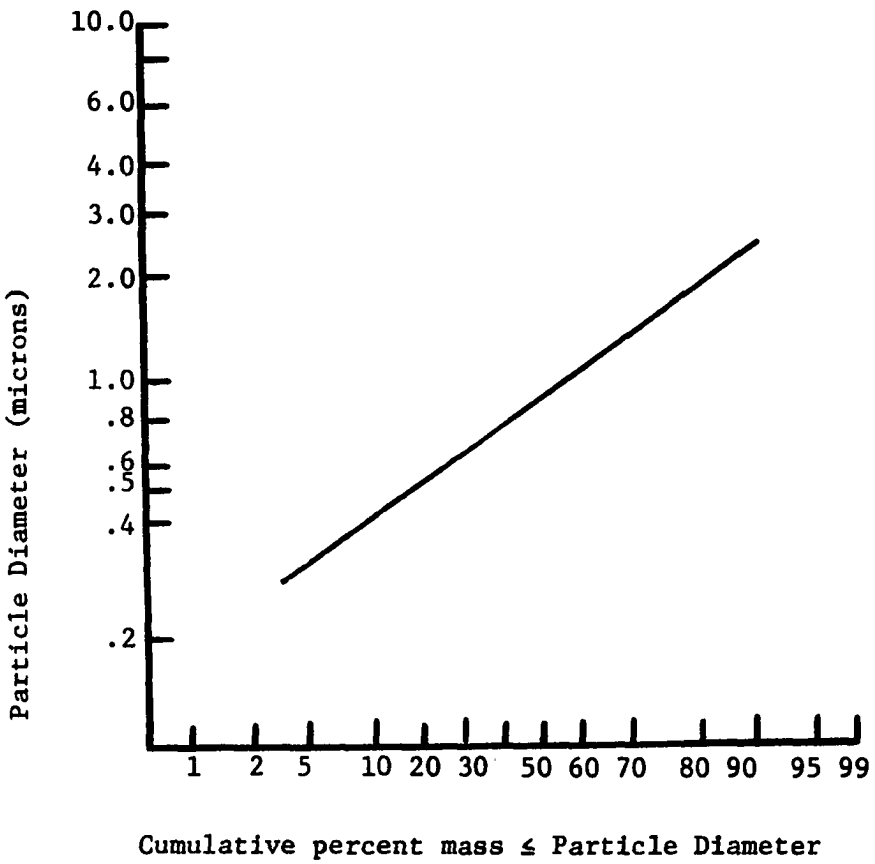


FIGURE 15: Particle Size Distribution for Ambient Airborne Suspended Particulates, Fractionation Sampler, Western Electric Station

TABLE 8

EFFECTIVE CUTOFF DIAMETER FOR FRACTIONATION SAMPLER AS A FUNCTION OF FLOW RATE

Impactor Stage	Effective Cutoff Diameter, microns
1	$\frac{7.22}{C.F.M.}$
2	$\frac{4.92}{C.F.M.}$
3	$\frac{3.38}{C.F.M.}$
4	$\frac{2.19}{C.F.M.}$
5	$\frac{1.40}{C.F.M.}$

Paper Tape versus Standard High Volume

Average percent transmission values obtained from paper tape analysis by Method I and Method II were compared to 24 hour average standard High Volume suspended particulate concentrations (Table 9). Percent transmission values are representative of the singular case of collection circumstances, namely 24 hour averages of two hour sample runs with a one inch sampling nozzle at 0.25 CFM.

Method I with a correlation coefficient of -0.66736 does not adequately represent suspended particulate concentrations obtained by the standard High Volume sampler. The lack of correlation (Table 10, Apppendix)can be attributed to tape variability which was not accounted for in the Method I standardization. By passing clean paper tape through the transmitter, it was found that as much as 6 percent transmission variability per inch of tape was not uncommon.

Method II, which requires more time for standardizing but eliminates paper tape variability, more realistically represents the suspended particulate concentrations (Table 11, Appendix) collected with the standard High Volume sampler. Method I requires no means of recording paper tape variability which may be included in final results as particulate.

Pedace and Sansone[35] have developed an experimental relationship between a C.O.H. analyzer and ambient suspended particulate concentrations. Suspended particulates were collected on membrance filters and compared with 2 hour samples collected on paper tape. A correlation coefficient of -0.93 was obtained, and this compares favorably with the -0.92799 correlation coefficient obtained in this study using Method II.

The line of best fit for the 62 pairs of samples analyzed by Method II is:

$$Y = -13.38588\ X + 1331.10034$$

TABLE 9

LINEAR REGRESSION OF THE C.O.H. SAMPLER (X)
WITH STANDARD HIGH VOLUME SAMPLER (Y)

	Method I	Method II
X Mean	93.52235	93.64813
Y Mean	77.53721	77.53721
Intercept	1075.74780	1331.10034
Regression Coefficient	-10.67350	-13.38588
Std. Error of Regression Coefficient .	1.53768	0.69383
Correlation Coefficient	-0.66736	-0.92799

where X is the percent transmission and Y is the estimated ambient suspended particulate concentration.

In order to identify short time mass concentrations of suspended particulates collected by the C.O.H. sampler, the paper tape was cut into segments approximately two inches long for pre-weight and pre-standardization. It was intended that after collecting the sample on the tape segments they would again be subjected to weighing and post transmission data. Failure of the Cahn electrobalance resulted in limited data being obtained.

A R.A.C. Automatic Spot Evaluator with automatic printout capability was tested for its reproducibility in standardizing the reading of clean paper tapes. No significant difference was found between tape printouts. Problems were experienced in microswitch mechanical functioning for indexing and advancing the tape. These problems were overcome and the unit was intended to be modified for use with the Method II analysis procedure. However, major problems with the automatic printout system resulted in the instrument being temporarily dropped from the monitoring station.

Coefficients of Haze analyzers were also simultaneously used to collect suspended particulates from within a mobile air monitoring station at the sampling site. A 2 inch glass sampling manifold was used to transport particulates to C.O.H. analyzers to determine the "manifold effect" on particulate collection. Lack of particulate collection and concentration relationships were apparent from raw data scanning. Particle dropout and moisture are the suspected causes of failure to collect suspended particulates.

Anderson Head versus Fractionation Sampler

Suspended particulate concentration data collected with the Anderson Head was compared with the fractionation sampler concentration data (Table 12).

TABLE 12

LINEAR REGRESSION OF THE ANDERSON HEAD (X)
WITH THE FRACTIONATION SAMPLER (Y)

X Mean	82.85781
Y Mean	42.18714
Intercept	-0.50282
Regression Coefficient . .	00.51521
Std. Error of Reg. Coef. .	00.02773
Correlation Coefficient .	00.92299

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	42892.93760	42892.93760	345.19378
Deviation from Reg	60	7455.45411	124.25755	
Total	61	50348.39071		

The line of best fit for the 62 pairs of samples is:

$$Y = 0.51521\ X + -0.50282$$

The high correlation coefficient 0.92200 between the two samplers indicates a significant relationship of the methods of collection. The linear is shown in Table 13 of the Appendix.

Anderson Head, Fractionation and C.O.H. Comparisons

Results obtained from suspended particulate concentration data obtained from the Anderson Head and fractionation sample were compared with the C.O.H. analysis using Method I and Method II. Correlation coefficient and line of best fit equations are presented in Table 14.

Statistical analysis for the linear regressions with table of residuals is shown in Tables 15, 16, 17, and 18 of the Appendix.

The correlation coefficients indicate that data analyzed from the coefficient of haze instruments using Method II can adequately represent total suspended particulate concentrations collected by means of the Anderson Head adapter and fractionation samplers.

Fractionated Mass Comparisons

Stages 1 through 5 of the Anderson Head adapter were compared individually with the standard High Volume air sampler to determine if there was a linear correlation (Table 19).

None of the stages 1 through 5 correlation coefficients are as high as the correlation coefficient obtained for the Anderson Head adapter considered as a unit.

Mean concentration of suspended particulate collected from stages 1 through 5 of the Anderson Head adapter showed the greatest mass of particulates

TABLE 14

COMPARISON OF ANDERSON HEAD (X) AND FRACTIONATION SAMPLER (X)
WITH C.O.H. ANALYZER (Y) METHODS I AND II

C.O.H. (Y)	Anderson Head (X)	Fractionation Sampler (X)
Method I		
Correlation Coefficient	-0.62478	-0.67744
Line of Regression	Not applicable	Not applicable
Method II		
Correlation Coefficient	-0.87846	-0.86317
Line of Regression	Y = -0.05274X + 98.01805	Y = -0.09283X + 97.56468

TABLE 19

STAGES 1 THROUGH 5 ANDERSON HEAD ADAPTER (X) WITH THE STANDARD HIGH VOLUME SAMPLER (Y)

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
X Mean	26.20960	12.42770	6.96191	6.63740	30.64928
Y Mean	77.53721	77.53721	77.53721	77.53721	77.53721
Correlation Coefficient	00.77963	00.87815	00.67657	00.56844	00.65737
Line of Best Fit	Y=1.22315X +45.47883	Y=4.92965X +16.27292	Y=7.09181X +28.16456	Y=6.57342X +33.90795	Y=1.23378X +39.72254

to be on stage 1 and stage 5 (Figure 16).

The larger mean values of stage 5 suggest considerable numbers of particles in the size range of 0.01 to 1.1 microns. High concentration of stage 4 suggests that particles may have sifted to stage 5. Lee and Gorenson[36] have shown that 60 to 70 percent of the cumulative percent mass may be less than 1.0 micron in size, but varies depending on the area of collection. The percentage of size distribution of suspended particulate mass equal to or less than 1 and 2 microns is shown in Figure 17 for the Anderson Head adapter.

The fractionation sampler was compared by linear regression with stages 3 through 5 collectively of the Anderson Head adapter (Table 20).

The line of best fit for the regression is:

$$Y = 0.90638\ X + 6.01097$$

A significant relationship was established between the fraction sampler and stages 3 through 5 collectively of the Anderson Head adapter to the standard High Volume air sampler. The high correlation coefficient (0.93923) indicates that the Fractionation sampler can be used to predict the three final stages of the Anderson Head. Statistical analysis and residuals are shown in Table 21 of the Appendix.

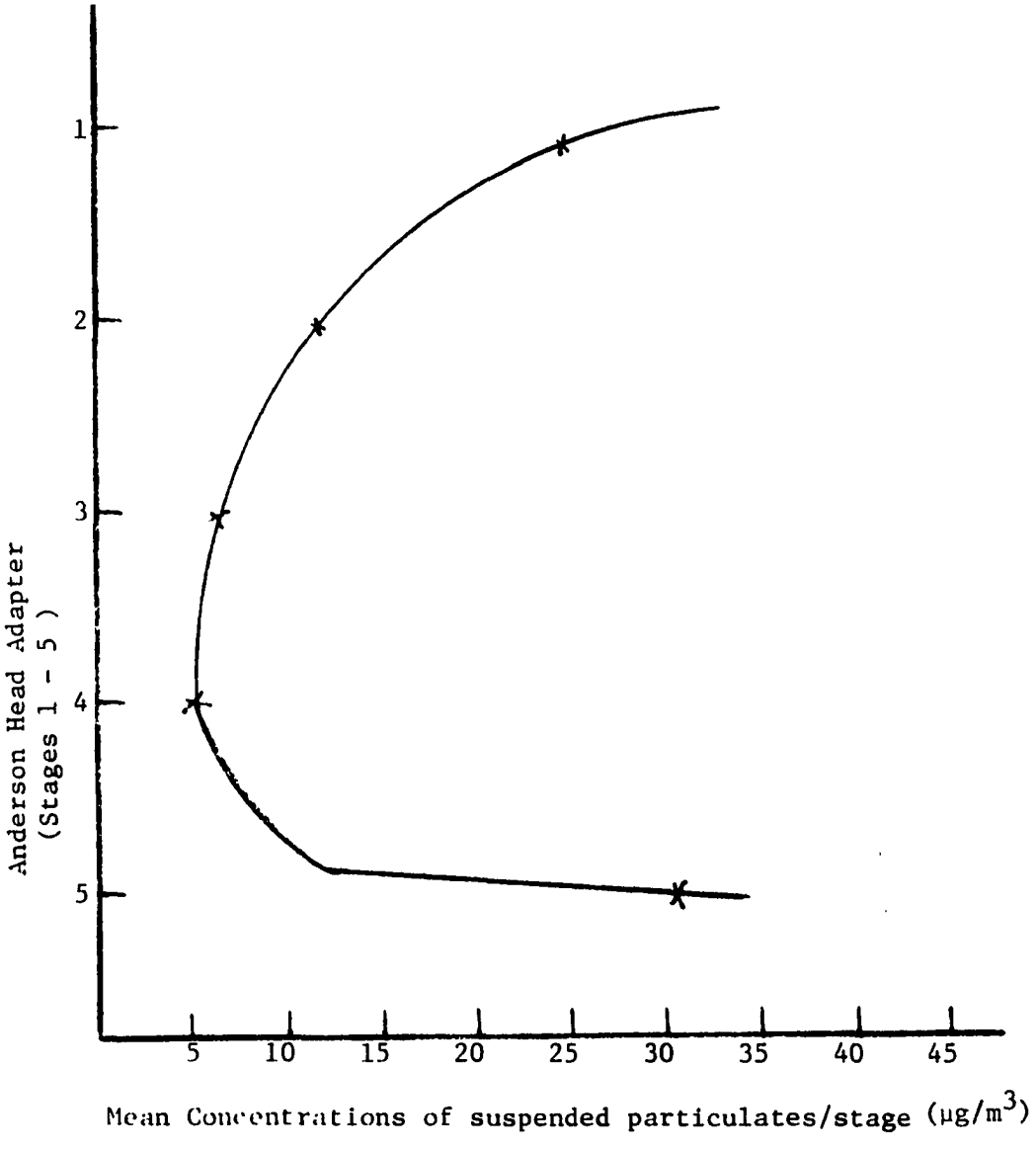


FIGURE 16: Average Mass Concentrations by Stage of the Anderson Head Adapter

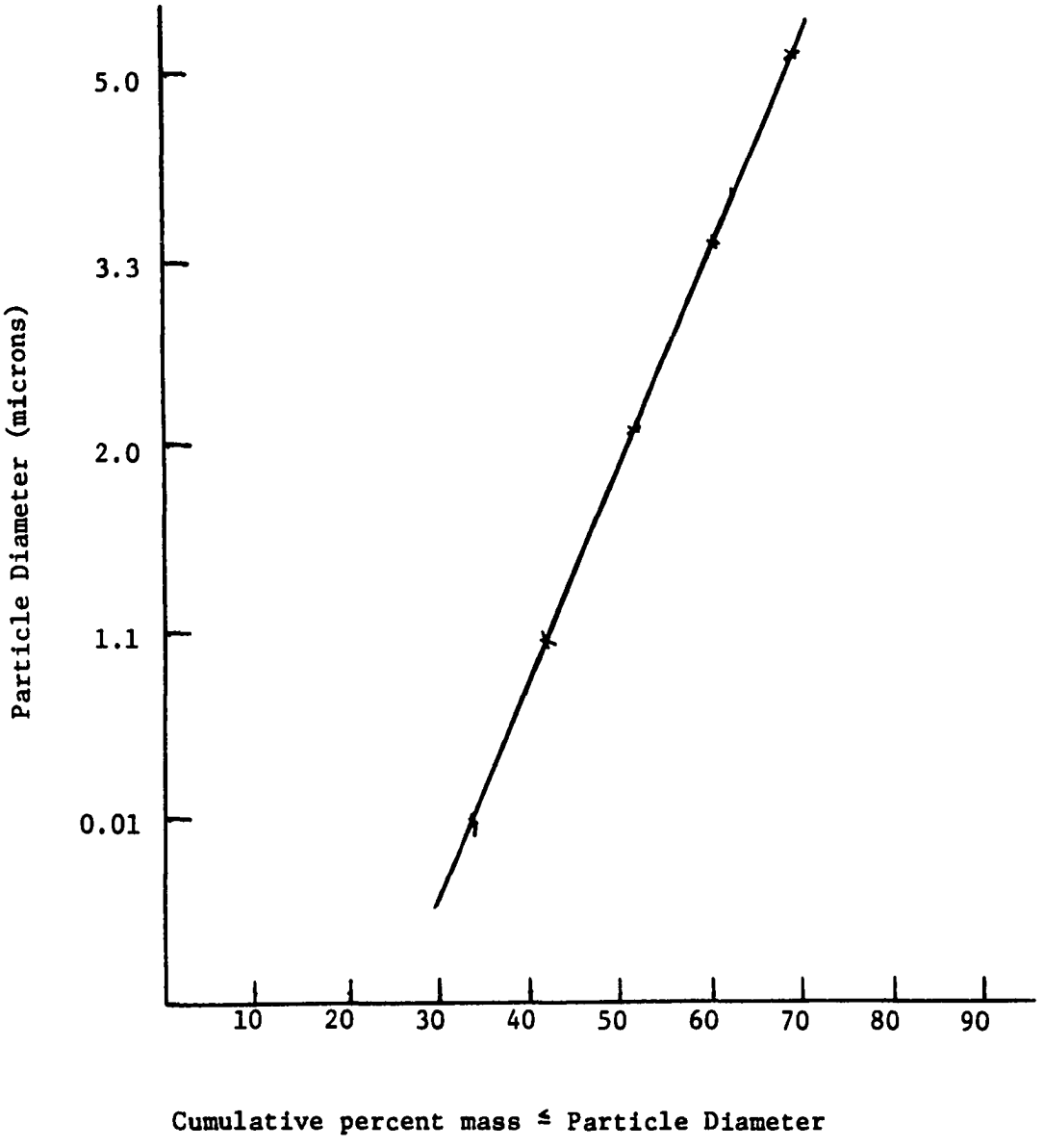


FIGURE 17: Particle Size Distribution for the Anderson Head Adapter at the Western Electric Station

TABLE 20

LINEAR REGRESSION OF THE FRACTIONATION SAMPLER (X) WITH STAGES 3 THROUGH 5 COLLECTIVELY OF THE ANDERSON HEAD ADAPTER (Y)

X Mean	42.18714
Y Mean	44.24860
Intercept	06.01097
Regression Coefficient . .	00.90638
Std. Error of Reg. Coef. .	00.04276
Correlation Coefficient .	00.93923

CHAPTER VI

SUMMARY AND CONCLUSIONS

This research was designed to investigate the linear relationship of commercially available air monitoring equipment for measuring mass concentrations of suspended particulates in the field when subjected to Oklahoma ambient airborne particulates, weather conditions and geography at an industrial site. The approach was to use commercially available equipment representative of equipment utilized by the Oklahoma Air Pollution Control agencies and to collect paired samples of the same time interval. Analysis of airborne contaminants at the industrial site included determination of mass concentrations of suspended particulates, particle size fractions of mass concentrations and transmittance qualities of suspended particulates.

Based on the results of field measurements and the range of data observed, the following conclusions have been drawn:

1. The relationship between monthly mean suspended particulate mass concentrations obtained at the Western Electric air monitoring station and the Oklahoma City-County Health Department air monitoring network stations is linear ($Y = 0.62X + 25.67$) when data is collected using the standard High Volume air sampler. The adequate reflections (correlation coefficient of 0.82) of county wide average mass concentrations of suspended particulates at the Western Electric station is apparently the result of influence from commercial, residential and industrial sources. The concentrations are in similar proportion to the averaging effect which individually located

commercially, residential and industrial sources have on the overall Oklahoma County air monitoring network.

2. Mass concentrations of suspended particulates collected with the Anderson Head attachment to the standard High Volume sampler are linearly related (Y = 1.12X - 3.77) and will adequately reproduce mass concentrations of suspended particulates collected with the standard High Volume sampler at the Western Electric station (correlation coefficient of 0.97). The Anderson Head attachment to the standard High Volume sampler can be substituted for the standard High Volume sampler without changing the total mass concentration of suspended particulate data. This would provide for a gain of particle size information by the monitoring networks.

3. Linear relationships between mass concentrations of suspended particulates collected by size fraction per stage of the Anderson Head according to their aerodynamic behavior and the standard High Volume air sampler were not statistically significant. The search for a meaningful relationship did not include non-linear relationships.

4. Based on a correlation coefficient of 0.90, a moderate degree of association between the fractionation sampler and the standard High Volume sampler was established for the Western Electric station. The line of best fit was:

$$Y = 0.58X - 2.55.$$

5. The relationship (correlation coefficient of 0.93) between the mass concentration of suspended particulates collected by the standard High Volume sampler and transmittance of suspended particulates collected on

paper tape is linear (Y = -13.39X + 1131.10). It is possible to estimate the mass concentration of suspended particulates by careful optical evaluation of suspended particulates deposited on paper tape when tape variability is taken into consideration (Method II, "standardization read method").

6. Optical evaluation of paper tape by Method I which does not account for paper tape variability did not exhibit a satisfactory association to mass concentrations of suspended particulates collected by the standard High Volume sampler, Anderson Head adapter and fractionation sampler to be of value.

7. The Anderson Head adapter to the standard High Volume sampler was found to have a high degree of association (correlation coefficient of 0.92) with the fractionation sampler. Both samplers are suitable for estimating mass concentration of suspended particulates at the Western Electric station. The line of best fit for the study data is:

$$Y = 0.52X - 0.50$$

8. The relationship between transmittance of suspended particulates collected by paper tape and concentration of suspended particulates collected by the Anderson Head adapter (correlation coefficient of -0.88) and the fractionation sampler (correlation coefficient of -0.86) are sufficiently high to be of value. Careful optical evaluation methods which account for tape variability (Method II) can be used successfully at the Western Electric station for estimating mass concentration of suspended particulates by use of a linear relationship. The line of regression for the Anderson Head and fractionation sampler is:

$$Y = -0.05X + 98.02$$

and

$$Y = -0.09X + 97.56$$

respectively.

9. Stages 3 through 5 of the Anderson Head adapter, when considered collectively, exhibit a high degree of association (correlation coefficient of 0.94) to the fractionation sampler considered as a while. This is because stages 3 through 5 of the Anderson Head collects particles of the approximate sizes collected by the fractionation sampler. The line of best fit for this regression is:

$$Y = 0.91X + 6.01$$

10. Identification of the percent cumulative mass of suspended particulates less than one micron at the Western Electric station was determined to be approximately 40 percent using the Anderson Head attachment to the standard High Volume sampler and 60 percent using the fractionation sampler. Higher values in cumulative mass less than one micron with the fractionation are likely the result of the more efficient backup filter.

Further work is needed to determine if similar but quantitatively different relationships exist for other stations located within the Oklahoma County air monitoring network which are primarily affected by residential, commercial or industrial sources.

The use of 5 filters for each 24 hour run of the Anderson Head attachment is costly. Additional study to determine the feasibility of reuse after weighing could reduce cost by one half or more if data can be collected to establish reliability.

Additional work to include the variation of sampling rate of the Anderson Head attachment which would change the particle size collected per stage could prove to be more reliable in estimating High Volume suspended particulates

by stage.

Failure of weighing equipment (Cahn electrobalance) resulted in the loss of much of the particle sizing information which could have been gained otherwise. Further study is needed to better define mass concentrations of particle sizes collected for each stage of the fractionation sampler.

Further study to identify short time mass concentration of suspended particulates using the paper tape sampler and High Volume sampler is needed.

Simultaneous short time data on the mass concentration of suspended particulates and transmittance can be gained using the C.O.H. analyzer and electrobalance. However, further study is needed to determine what relationship and usefulness the data may have in estimating short time mass concentrations of suspended particulates.

It is recommended that additional study be undertaken to compare transmittance type data to mass concentrations of suspended particulates as collected by sampling stage of the fractionation sampler and Anderson Head adapter. If a reliable relationship can be established short time transmittance data could be used to project mass concentration of particle size.

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APPENDIX

Note: Regression analyses shown as five significant digits were carried out by computer based on field data of two significant digits.

TABLE 3

STATISTICAL ANALYSIS WITH RESIDUALS FOR MONTHLY MEAN STANDARD HIGH VOLUME WESTERN ELECTRIC (Y) VERSUS MONTHLY MEAN STANDARD HIGH VOLUME ,OKLAHOMA CITY-COUNTY HEALTH DEPARTMENT (X)

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
OCCHD (X)	83.30441	24.35940	0.82014	0.62122	0.16380	3.79255
W.E. (Y)	77.41996	18.45123				

Intercept . . . 25.66888

Multiple Correlation . . 0.82014

Std. Error of Estimate . . 11.28577

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	1832.00415	1832.00415	14.38347
Deviation from Reg.	7	891.58117	127.36872	
Total	8	2723.58545		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	111.85000	99.40249	12.44751
2	75.32000	74.18684	1.13316
3	75.37001	71.12419	4.24582
4	98.65000	91.30789	7.34211
5	54.10000	65.12310	-11.02309
6	76.16000	62.84941	13.31057
7	64.77000	68.63926	-3.86926
8	58.63000	64.43975	-5.80974
9	81.93000	99.70690	-17.77690

TABLE 5

STATISTICAL ANALYSIS WITH RESIDUALS FOR THE STANDARD HIGH VOLUME (X) AND ANDERSON HEAD ATTACHMENT (Y), WESTERN ELECTRIC

5/22/73 to 4/24/74

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	77.53721	44.57106	0.96756	1.11729	0.03765	29.66946
(Y)	82.85781	51.46804				

Intercept . . . -3.77381

Multiple Correlation . . . 0.96756

Std. Error of Estimate . . . 13.10915

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	151275.53167	151275.53167	880.27661
Deviation from Reg.	60	10311.00197	171.85000	
Total	61	161586.53167		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	21.95000	7.55551	14.39448
2	351.66003	321.82721	29.83282
3	61.43000	57.14089	4.28910
4	112.07000	90.39149	21.67851
5	44.30000	47.28639	-2.98638
6	69.53001	71.20758	-1.67756
7	89.76000	84.26872	5.49128
8	56.88000	49.10757	7.77243

TABLE 5 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	106.31001	97.15109	9.15892
10	88.28001	106.73744	-18.45743
11	128.74002	134.31222	-5.57220
12	98.01000	97.41979	0.49021
13	81.31001	81.44197	-0.13195
14	59.31000	58.97325	0.33675
15	70.13000	72.77180	-2.64180
16	68.90000	70.02325	-1.12324
17	73.16000	75.95607	-2.79606
18	66.25001	84.81620	-18.56619
19	94.30000	103.68725	-9.38725
20	53.00000	60.58215	-7.58214
21	133.40002	137.34005	-3.94003
22	95.40000	98.61476	-3.21475
23	157.90002	90.48086	67.41915
24	76.92001	88.79376	-11.87375
25	59.70000	70.90592	-11.20591
26	95.88000	86.17929	9.70071
27	186.62002	197.80786	-11.18783
28	128.37002	144.11084	-15.74081
29	41.32000	44.16914	-2.84913
30	45.98000	43.90100	-11.67732
31	86.20001	97.87733	-11.67732
32	36.40000	40.88430	-4.48430
33	67.56001	69.19647	-1.63645
34	102.38000	101.62025	0.75975
35	80.44000	84.54805	-4.10804
36	68.05000	78.05657	-10.00657
37	38.57000	44.62724	-6.05723
38	51.98000	60.98438	-9.00438
39	26.04000	32.94036	-6.90036
40	44.39000	39.24189	5.14811
41	61.56000	62.80556	-1.24555
42	42.30000	43.90100	-1.60099
43	33.23000	28.01311	5.21688
44	52.61000	56.67163	-4.06163
45	83.84001	70.29141	13.54860
46	73.08000	68.10151	4.97848
47	75.30000	68.92831	6.37168
48	127.02000	156.05468	-29.03467
49	29.31000	35.65538	-6.34538
50	89.99000	94.59249	-4.60249
51	136.59002	141.29528	-4.70526
52	45.12000	45.18588	-0.06587
53	77.24000	83.35255	-6.11254
54	99.31001	99.43037	-0.12036
55	27.95000	26.52711	1.42288
56	45.36000	45.30877	0.05122
57	86.20001	72.67124	13.52876

TABLE 5 (Continued)

Case No	Y Value	Y Estimate	Residuals
58	97.12001	83.35255	13.76745
59	40.85000	41.86753	-1.01752
60	156.47000	151.30621	5.16378
61	194.88000	204.60101	-9.72101
62	43.09000	32.24765	10.84235

TABLE 7

STATISTICAL ANALYSIS WITH RESIDUAL FOR THE STANDARD HIGH VOLUME (X) AND FRACTIONATION SAMPLER (Y), WESTERN ELECTRIC 5/22/73 TO 4/24/74

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	77.53721	44.57095	0.89511	0.57697	0.03710	15.55162
(Y)	42.18714	28.72948				

Intercept . . . -2.54956

Multiple Correlation . . . 0.89511

Std. Error of Estimate . . . 12.91501

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	40340.53135	40340.53135	241.85308
Deviation from Reg	60	10007.86135	166.79766	
Total	61	50348.39071		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	6.36000	3.30091	3.05908
2	139.64001	165.59127	-25.95126
3	30.07000	28.90687	1.16312
4	56.37000	46.07753	10.29246
5	21.91000	23.81799	-1.90799
6	36.23000	36.17093	0.05906
7	46.36000	42.91572	3.44427
8	22.13000	24.75845	-2.62845

TABLE 7 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	36.39000	49.56819	-13.17819
10	41.38000	54.51861	-13.13861
11	60.53000	68.75825	-8.22824
12	48.47000	49.75860	-1.28860
13	45.70000	41.45599	4.24401
14	36.81000	29.85311	6.95689
15	32.73000	36.97870	-4.24870
16	37.28000	35.55934	1.72065
17	33.36000	38.62306	-5.26306
18	30.67000	43.19844	-12.52844
19	40.73000	52.94348	-12.21348
20	25.39000	30.68395	-5.29395
21	53.70000	70.32185	-16.62184
22	50.66000	50.32404	0.33596
23	96.13000	46.12368	50.00631
244	44.86000	45.25246	-0.39246
25	21.29000	36.01515	-14.72515
26	46.19000	43.90235	2.28765
27	119.63000	101.54750	18.08250
28	62.86000	73.81828	-10.95827
29	19.00000	22.20824	-3.20824
30	19.76000	22.06977	-2.30977
31	39.46000	49.94323	-10.48323
32	21.91000	20.51195	1.39804
33	38.80000	35.13240	3.66760
34	56.38000	51.87608	4.50392
35	39.9900	43.05997	-3.06996
36	25.74000	39.70777	-13.96776
37	19.84000	22.44480	-2.60480
38	21.69000	30.89166	-9.20166
39	12.19000	16.40969	-4.21968
40	23.19000	19.66381	3.52619
41	32.11000	31.83212	0.27787
42	17.22000	22.06977	-4.84977
43	15.91000	13.86525	2.04475
44	25.01000	28.66455	-3.65455
45	42.31000	35.69783	6.61217
46	33.43000	34.56696	-1.13696
47	36.23000	34.99391	1.23608
48	58.84000	79.98611	-21.14610
49	13.10000	17.81172	-4.71172
50	39.33000	48.24694	-8.91694
51	83.51000	72.36433	11.14567

TABLE 7 (Continued)

Case No.	Y Value	Y Estimate	Residuals
52	27.91000	22.73329	5.17670
53	43.24000	42.44261	0.79738
54	48.17000	50.74522	-2.57521
55	10.13000	13.09788	-2.96788
56	23.01000	22.79675	0.21324
57	54.29000	36.92678	17.36322
58	51.62000	42.44261	9.17738
59	24.86000	21.01969	3.84030
60	125.61000	77.53398	48.07602
61	134.62002	105.05549	29.56451
62	13.37000	16.05197	-2.68196

TABLE 10

STATISTICAL ANALYSIS WITH TABLE OF RESIDUALS FOR THE STANDARD HIGH VOLUME (Y) AND METHOD I ANALYSIS OF C.O.H. (X) WESTERN ELECTRIC 5/22/73 TO 4/24/74

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	93.52235	2.78681	-0.66736	-10.67350	1.53768	-6.94128
(Y)	77.53721	44.57095				

Intercept . . . 1075.74780

Multiple Correlation . . . 0.66736

Std. Error of Estimate . . . 33.46883

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	53970.97666	53970.97666	48.18136
Deviation from Reg	60	67209.79708	1120.16308	
Total	61	121180.76580		

Residuals

Case No.	Y Value	Y Estimate	Residuals
1	10.14000	26.54263	-16.40263
2	291.42004	118.33464	173.08538
3	54.52000	79.91014	-25.39013
4	84.28001	70.30389	13.97612
5	45.70000	61.76506	-16.06505
6	67.11000	58.56313	8.54686
7	78.80000	103.39180	-24.59180
8	47.33000	92.71830	-45.38830

TABLE 10 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	90.33000	68.16922	22.16078
10	98.91000	83.11206	15.79794
11	123.59001	136.47958	-12.88955
12	90.66000	71.37130	19.28870
13	76.27000	83.11206	-6.84205
14	56.16000	83.11206	-26.95205
15	68.51000	63.89988	4.61001
16	66.05000	103.39180	-37.34180
17	71.36000	88.44880	-17.08881
18	79.29000	103.39180	-24.10179
19	96.18000	119.40205	-23.22204
20	57.60000	37.21613	20.38387
21	126.30000	82.04480	44.25521
22	91.64001	112.99789	-21.35788
23	84.36000	98.05505	-13.69505
24	82.85000	86.31414	-3.46414
25	66.84001	66.03456	0.80545
26	80.51000	112.99789	-32.48789
27	180.42001	119.40205	61.01795
28	132.36001	96.98764	35.37236
29	42.91000	40.41806	2.49194
30	42.67000	21.20588	21.46412
31	90.98001	102.32438	-11.34437
32	39.97000	79.91014	-39.94013
33	65.31001	80.97738	-15.66737
34	94.33000	67.10180	27.22819
35	79.05000	50.02429	29.02569
36	73.24000	103.39180	-30.15179
37	43.32000	70.30389	-26.98388
38	57.96000	37.21613	20.74387
39	32.86000	61.76506	-28.90506
40	38.50000	54.29364	-15.79363
41	59.59000	60.69779	-1.10779
42	42.67000	37.21613	5.45387
43	28.45000	46.82221	-18.37221
44	54.10000	79.91014	-25.81013
45	66.29000	98.05505	-31.76504
46	64.33000	38.28338	26.04661
47	65.07000	48.95688	16.11311
48	143.05001	114.06530	28.98469
49	35.29000	19.07105	16.21894
50	88.04000	76.70805	11.33195
51	129.84002	117.26739	12.57261
52	43.82000	51.09156	-7.27155
53	77.98001	96.98764	-19.00763

TABLE 10 (Continued)

Case No	Y Value	Y Estimate	Residuals
54	92.37001	96.98764	-4.61763
55	27.12000	45.75480	-18.63480
56	43.93000	69.23663	-25.30662
57	68.42001	39.35079	29.06921
58	77.98001	62.83247	15.14753
59	40.85000	74.57339	-33.72338
60	138.80001	152.48980	-13.68979
61	186.50003	129.00814	57.49189
62	32.24000	55.36105	-23.12105

TABLE 11

STATISTICAL ANALYSIS WITH RESIDUALS FOR THE STANDARD HIGH VOLUME (Y) AND METHOD II ANALYSIS OF C.O.H. (X) WESTERN ELECTRIC 5/22/73 TO 4/24/74

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	93.64813	3.08994	-0.92799	-13.38588	0.69383	-19.29257
(Y)	77.53721	44.57095				

Intercept . . . 1331.10034

Multiple Correlation . . . 0.92799

Std. Error of Estimate . . . 16.74452

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	104358.03143	104358.03143	372.20355
Deviation from Reg.	60	16822.73832	280.37896	
Total	61	121180.76580		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	10.14000	8.57460	1.56539
2	291.42004	185.26828	106.15174
3	54.52000	72.82672	-18.30671
4	84.28001	88.88993	-4.60992
5	45.70000	54.08654	-8.38654
6	67.11000	82.19699	-15.08699
7	78.80000	86.21260	-7.41259
8	47.33000	67.47244	-20.14243

TABLE 11 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	90.33000	91.56707	-1.23707
10	98.91000	102.27583	-3.36582
11	123.59001	138.41769	-14.82766
12	90.66000	98.26002	-7.60002
13	76.27000	80.85832	-4.58831
14	56.16000	50.07073	6.08926
15	68.51000	68.81111	-0.30110
16	66.05000	66.13377	-0.08377
17	17.36000	75.50405	-4.14405
18	79.29000	60.77948	18.51051
19	96.18000	107.63001	-11.45009
20	57.60000	51.40940	6.19059
21	126.30000	142.43350	-16.13348
22	91.64001	102.27583	-10.63582
23	84.36000	94.24421	-9.88421
24	82.85000	95.58288	-12.73288
25	66.84001	68.81111	-1.97110
26	80.51000	87.55126	-7.04126
27	180.42001	165.18945	15.23056
28	132.36001	147.78778	-15.42776
29	42.91000	35.34638	7.56361
30	42.67000	36.68485	5.98515
31	90.98001	100.93714	-9.95713
32	39.97000	29.99190	9.97809
33	65.31001	67.47244	-2.16243
34	94.33000	104.95295	-10.62295
35	79.05000	84.87413	-5.82412
36	73.24000	74.16537	-0.92536
37	43.32000	36.68485	6.63515
38	57.96000	56.76368	1.19631
39	32.86000	21.96049	10.89949
40	38.50000	31.33057	7.16942
41	59.59000	56.76368	2.82631
42	42.67000	35.34638	7.32361
43	28.45000	16.60602	11.84398
44	54.10000	51.40940	2.69059
45	66.29000	67.47244	-1.18243
46	64.33000	64.79530	-0.46530
47	65.07000	64.79530	0.27470
48	143.05001	154.48071	-11.43069
49	35.29000	25.97610	9.31389
50	88.04000	96.92135	-8.88134
51	129.84002	145.11062	-15.27060

TABLE 11 (Continued)

Case No	Y Value	Y Estimate	Residuals
52	43.82000	36.68485	7.13515
53	77.98001	82.19699	-4.21698
54	92.37001	103.61428	-11.24427
55	27.12000	15.26755	11.85244
56	43.93000	36.68485	7.24514
57	68.42001	70.14958	-1.72956
58	77.98001	84.87413	-6.89412
59	40.85000	35.34638	5.50361
60	138.80001	149.12643	-10.32641
61	186.50003	167.86660	18.63342
62	32.24000	23.29896	8.94103

TABLE 13

STATISTICAL ANALYSIS WITH RESIDUALS FOR THE ANDERSON HEAD ADAPTER (X) AND FRACTIONATION SAMPLER (Y) WESTERN ELECTRIC 5/22/73 TO 4/24/74

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	82.85781	51.46779	0.92299	0.51521	0.02773	18.57939
(Y)	42.18714	28.72948				

Intercept . . . -0.50282

Multiple Correlation . . . 0.92299

Std. Error of Estimate . . . 11.14708

Analysis of Variance for the Regression

Source of Variation	Degress of Freedom	Sum of S Squares	Mean Squares	F Value
Attributable to Reg.	1	42892.93760	42892.93760	345.19378
Deviation from Reg.	60	7455.45411	124.25755	
Total	61	50348.39071		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	6.36000	10.80624	-4.44624
2	139.64001	180.67929	-41.03928
3	30.07000	31.14711	-1.07711
4	56.37000	57.23783	-0.86782
5	21.91000	22.32140	-0.41139
6	36.23000	35.32039	0.90960
7	46.36000	45.74328	0.61671
8	22.13000	28.80286	-6.67286

TABLE 13 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	36.39000	54.27017	-17.88016
10	41.38000	44.98076	-3.60076
11	60.53000	65.82655	-5.29654
12	48.47000	49.99385	-1.52384
13	45.70000	41.38967	4.31032
14	36.81000	30.05485	6.75515
15	32.73000	35.62952	-2.89952
16	37.28000	34.99580	2.28420
17	33.36000	37.19063	-3.83063
18	30.67000	33.63047	-2.96047
19	40.73000	48.08238	-7.35237
20	25.39000	26.80381	-1.41381
21	53.70000	68.22747	-14.52746
22	50.66000	48.64912	2.01087
23	96.13000	80.85035	15.27964
24	44.86000	39.12786	5.73213
25	21.29000	30.25578	-8.96578
26	46.19000	48.89643	-2.70642
27	119.63000	95.64746	23.98254
28	62.86000	65.63592	-2.77591
29	19.00000	20.78605	-1.78604
30	19.76000	23.18697	-3.42697
31	39.46000	43.90910	-4.44909
32	21.91000	18.25116	3.65883
33	38.80000	34.30541	4.49459
34	56.38000	52.24535	4.13465
35	39.99000	40.94143	-0.95143
36	25.74000	34.55786	-8.81786
37	19.84000	19.36919	0.47080
38	21.69000	26.27828	-4.58828
39	12.19000	12.91349	-0.72349
40	23.19000	22.36777	0.82222
41	32.11000	31.21409	0.89590
42	17.22000	21.29096	-4.07096
43	15.91000	16.61792	-0.70792
44	25.01000	26.60287	01.59287
45	42.31000	42.69318	-0.38317
46	33.43000	37.14942	-3.71942
47	36.23000	38.29320	-2.06320
48	58.84000	64.94036	-6.10035
49	13.10000	14.59826	-1.49826
50	39.33000	45.86178	-6.53178
51	83.51000	69.87101	13.63899

TABLE 13 (Continued)

Case No	Y Value	Y Estimate	Residuals
52	27.91000	22.74388	5.16611
53	43.24000	39.29273	3.94727
54	48.17000	50.66363	-2.49362
55	10.13000	13.89756	-3.76756
56	23.01000	22.86753	0.14246
57	54.29000	43.90910	10.38089
58	51.62000	49.53530	2.08470
59	24.86000	20.54389	4.31610
60	125.61000	80.11357	45.49643
61	134.62002	99.90316	34.71685
62	13.37000	21.69798	-8.32798

TABLE 15

STATISTICAL ANALYSIS WITH RESIDUALS FOR THE ANDERSON HEAD ADAPTER (X)
AND METHOD II ANALYSIS OF C.O.H. (Y)
WESTERN ELECTRIC 5/22/73 TO 4/24/74

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	82.85781	51.46779	-0.87846	-0.05274	0.00370	-14.24136
(Y)	93.64813	3.08994				

Intercept . . . 98.01805

Multiple Correlation . . . 0.87846

Std. Error of Estimate . . . 1.48863

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	449.45068	449.45068	202.81640
Deviation from Reg.	60	132.96286	2.21604	
Total	61	582.41357		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	98.80000	96.86039	1.93960
2	85.60000	79.47148	6.12852
3	94.00001	94.77822	-0.77821
4	92.80000	92.10746	0.69253
5	95.40000	95.68165	-0.28164
6	93.30000	94.35102	-1.05102
7	93.00001	93.28410	-0.28408
8	94.40000	95.01818	-0.61817

TABLE 15 (Continued)

Case No	Y Value	Y. Estimate	Residuals
9	92.60000	92.41125	0.18875
10	91.80000	93.36215	-1.56214
11	89.10000	91.22828	-2.12828
12	92.10000	92.84898	-0.74897
13	93.40000	93.72975	-0.32974
14	95.70001	94.89003	0.80998
15	94.30000	94.31938	-0.01937
16	94.50001	94.38424	0.11576
17	93.80000	94.15957	-0.35957
18	94.90000	94.52401	0.37599
19	91.40000	93.04466	-1.64465
20	95.60000	95.22282	0.37718
21	88.80000	90.98251	-2.18251
22	91.80000	92.98664	-1.18664
23	92.40000	89.69038	2.70962
24.	92.30000	93.96127	-1.66127
25	94.30000	94.86946	-0.56945
26	92.90000	92.96133	-0.06132
27	87.10000	88.17568	-1.07568
28	88.40000	91.24780	-2.84779
29	96.80000	95.83882	0.96118
30	96.70001	95.59306	1.10694
31	91.90000	93.47184	-1.57183
32	97.20001	96.09831	1.10170
33	94.40000	94.45492	-0.05491
34	91.60000	92.61851	-1.01850
35	93.10000	93.77563	-0.67562
36	93.90000	94.42907	-0.52906
37	96.70001	95.98385	0.71615
38	95.20001	95.27661	-0.07659
39	97.80000	96.64469	1.15530
40	97.10000	95.67691	1.42309
41	95.20001	94.77136	0.42864
42	96.80000	95.78714	1.01286
43	98.20001	96.26548	1.93452
44	95.60000	95.24339	0.35661
45	94.40000	93.59631	0.80369
46	94.60000	94.16380	0.43620
47	94.60000	94.04672	0.55328
48	87.90000	91.31900	-3.41899
49	97.50001	96.47222	1.02778
50	92.20001	93.27197	-1.07196
51	88.60000	90.81428	-2.21427

TABLE 15 (Continued)

Case No	Y Value	Y Estimate	Residuals
52	96.70001	95.63841	1.06159
53	93.30000	93.94439	-0.64439
54	91.70001	92.78042	-1.08041
55	98.30000	96.54396	1.75604
56	96.70001	95.62574	1.07426
57	94.20001	93.47184	0.72816
58	93.10000	92.89593	0.20407
59	96.80000	95.86361	0.93638
60	88.30000	89.76580	-1.46580
61	86.90000	87.74006	-0.84005
62	97.70001	95.74546	1.95454

TABLE 16

STATISTICAL ANALYSIS WITH RESIDUALS FOR THE FRACTIONATION SAMPLER (X) AND METHOD I ANALYSIS OF C.O.H. (Y) WESTERN ELECTRIC 5/22/73 TO 4/24/74

Equipment Variable	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	42.18714	28.72948	-0.67744	-0.06571	0.00921	-7.13389
(Y)	93.52235	2.78681				

In ercept . . . 96.29461

Multiple Correlation . . . 0.67744

Std. Error of Estimate . . . 2.06691

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	217.41912	217.41912	50.89244
Deviation from Reg.	60	256.32788	4.27213	
Total	61	473.74694		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	98.30000	95.87666	2.42334
2	89.70001	87.11834	2.58166
3	93.30000	94.31860	-1.01860
4	94.20001	92.59033	1.60968
5	95.00001	94.85482	0.14518
6	95.30000	93.91380	1.38620
7	91.10000	93.24812	-2.14811
8	92.10000	94.84036	-2.74035

TABLE 16 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	94.40000	93.90328	0.49671
10	93.00001	93.57537	-0.57536
11	88.00001	92.31695	-4.31694
12	94.10000	93.10946	0.99053
13	93.00001	93.29148	-0.29147
14	93.00001	93.87568	-0.87567
15	94.80000	94.14379	0.65620
16	91.10000	93.84480	-2.74479
17	92.50001	94.10240	-1.60238
18	91.10000	94.27917	-3.17916
19	89.60000	93.61808	-4.01808
20	97.30000	94.62614	2.67385
21	93.10000	92.76577	0.33422
22	90.20001	92.96554	-2.76553
23	91.60000	89.97755	1.62245
24	92.70001	93.34669	-0.64668
25	94.60000	94.89556	-0.29556
26	90.20001	93.25929	-3.05928
27	89.60000	88.43327	1.16673
28	91.70001	92.16384	-0.46383
29	97.00001	95.04605	1.95396
30	98.80000	94.99610	3.80389
31	91.20001	93.70155	-2.50154
32	93.30000	94.85482	-1.55482
33	93.20001	93.74491	-0.54490
34	94.50001	92.58967	1.91033
35	96.10000	93.66671	2.43328
36	91.10000	94.60313	-3.50312
37	94.20001	94.99084	-0.79083
38	97.30000	94.86927	2.43072
39	95.00001	95.49356	-0.49354
40	95.70001	94.77070	0.92930
41	95.10000	94.18453	0.91546
42	97.30000	95.16302	2.13697
43	96.40000	95.24909	1.15090
44	93.30000	94.65110	-1.35110
45	91.60000	93.51426	-1.91426
46	97.20001	94.09779	3.10221
47	96.20001	93.91380	2.28620
48	90.10000	92.42800	-2.32800
49	99.00001	95.43376	3.56625
50	93.60000	93.71008	-0.11007
51	89.80000	90.80685	-1.00685
52	96.00001	94.46054	1.53947

TABLE 16 (Continued)

Case No	Y Value	Y Estimate	Residuals
53	91.70001	93.45315	-1.75314
54	91.70001	93.12918	-1.42916
55	96.50001	95.62893	0.87107
56	94.30000	94.78253	-0.48252
57	97.10000	92.72700	4.37300
58	94.90000	92.90246	1.99754
59	93.80000	94.66096	-0.86096
60	86.50001	88.04031	-1.54029
61	88.70001	87.44822	1.25178
62	95.60000	95.41601	0.18399

TABLE 17

STATISTICAL ANALYSIS WITH RESIDUALS FOR THE ANDERSON HEAD ADAPTER (X)

AND METHOD I ANALYSIS OF C.O.H. (Y)

WESTERN ELECTRIC 5/22/73 TO 4/24/74

E uipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	82.85781	51.46779	-0.62478	-0.03383	0.00545	-6.19828
(Y)	93.52235	2.78681				

Intercept . . . 96.32545

Multiple Correlation . . . 0.62478

Std. Error of Estimate . . . 2.19398

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	184.93176	184.93176	38.41870
Deviation from Reg.	60	288.81524	4.81358	
Total	61	473.74694		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	98.30000	95.58287	2.71713
2	89.70001	84.42869	5.27131
3	93.30000	94.24725	-0.94725
4	94.20001	92.53408	1.66592
5	95.00001	94.82676	0.17324
6	95.30000	93.97323	1.32676
7	91.10000	93.28884	-2.18884
8	92.10000	94.40118	-2.30117

TABLE 17 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	94.40000	92.72895	1.67105
10	93.00001	93.33891	-0.33889
11	88.00001	91.97013	-3.97012
12	94.10000	93.00975	1.09025
13	93.00001	93.57470	-0.57469
14	93.00001	94.31896	-1.31895
15	94.80000	93.95292	0.84707
16	91.10000	93.99453	-2.89453
17	92.50001	93.85043	-1.35041
18	91.10000	94.08419	-2.98419
19	89.60000	93.13525	-3.53524
20	97.30000	94.53244	2.76756
21	93.10000	91.81248	1.28752
22	90.20001	93.09803	-2.89802
23	91.60000	90.98364	0.61636
24	92.70001	93.72322	-1.02320
25	94.60000	94.30578	0.29422
26	90.20001	93.08180	-2.88179
27	89.60000	90.01203	-0.41203
28	91.70001	91.98265	-0.28263
29	97.00001	94.92758	2.07243
30	98.80000	94.76992	4.03007
31	91.20001	93.40928	-2.20927
32	93.30000	95.09402	-1.79402
33	93.20001	94.03987	-0.83985
34	94.50001	92.86190	1.63810
35	96.10000	93.60414	2.49586
36	91.10000	94.02330	-2.92329
37	94.20001	95.02061	-0.82060
38	97.30000	94.56695	2.73304
39	95.00001	95.44450	-0.44448
40	95.70001	94.82371	0.87629
41	95.10000	94.24285	0.85714
42	97.30000	94.89442	2.40557
43	96.40000	95.20126	1.19874
44	93.30000	94.54563	-1.24563
45	91.60000	93.48912	-1.88911
46	97.20001	93.85313	3.34687
47	96.20001	93.77803	2.42198
48	90.10000	92.02833	-1.92832
49	99.00001	95.33387	3.66613
50	93.60000	93.28106	0.31893
51	89.80000	91.70457	-1.90457
52	96.00001	94.79902	1.20098

TABLE 17 (Continued)

Case No	Y Value	Y Estimate	Residuals
53	91.70001	93.71240	-2.01239
54	91.70001	92.96575	1.12011
55	96.50001	95.37989	1.12011
56	94.30000	94.79090	-0.49090
57	97.10000	93.40928	3.69072
58	94.90000	93.03985	1.86015
59	93.80000	94.94348	-1.14347
60	86.50001	91.03202	-4.53201
61	88.70001	89.73260	-1.03259
62	95.60000	94.86770	0.73229

TABLE 18

STATISTICAL ANALYSIS WITH RESIDUALS FOR THE FRACTIONATION SAMPLER (X)
AND METHOD II ANALYSIS OF C.O.H. (Y)
WESTERN ELECTRIC 5/22/73 TO 4/24/74

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg. Coef	Computed T Value
(X)	42.18714	28.72948	-0.86317	-0.09283	0.00701	-13.24261
(Y)	93.64813	3.08994				

Intercept . . . 97.56468

Multiple Correlation . . . 0.86317

Std. Error of Estimate . . . 1.57305

Analysis of Variance for the Regression

Source of Variables	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	433.94384	433.94384	175.36669
Deviation from Reg.	60	148.46969	2.47449	
Total	61	582.41357		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	98.80000	96.97422	1.82577
2	85.60000	84.60083	0.99917
3	94.00001	94.77304	-0.77302
4	92.80000	92.33142	0.46858
5	95.40000	95.53060	-0.13060
6	93.30000	94.20117	-0.90116
7	93.00001	93.26072	-0.26071
8	94.40000	95.51017	-1.11016

TABLE 18 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	92.60000	94.18630	-1.58630
10	91.80000	93.72305	-1.92305
11	89.10000	91.94522	-2.84521
12	92.10000	03.06483	-0.96482
13	93.40000	93.32199	0.07801
14	95.70001	94.14732	1.55268
15	94.30000	94.52609	-1.22608
16	94.50001	94.10368	0.39633
17	93.80000	94.46760	-0.66760
18	94.90000	94.71734	0.18266
19	91.40000	93.78340	-2.38339
20	95.60000	95.20753	0.39247
21	88.80000	92.57930	-3.77929
22	91.80000	92.86152	-1.06152
23	92.40000	88.64019	3.75981
24	92.30000	93.39997	-1.09997
25	94.30000	95.58816	-1.28816
26	92.90000	93.27650	-0.37649
27	87.10000	86.45851	0.64149
28	88.40000	91.72889	-3.32888
29	96.80000	95.80076	0.99923
30	96.70001	95.73020	0.96980
31	91.90000	93.90130	-2.00129
32	97.20001	95.53060	1.66940
33	94.40000	93.96257	0.43743
34	91.60000	92.33049	-0.73048
35	93.10000	93.85209	-0.75209
36	93.90000	95.17503	-1.27502
37	96.70001	95.72277	0.97723
38	95.20001	95.55102	-0.35101
39	97.80000	96.43298	1.36701
40	97.10000	95.41177	1.68823
41	95.20001	94.58366	0.61634
42	96.80000	95.96600	0.83399
43	98.20001	96.08763	2.11238
44	95.60000	95.24281	0.35719
45	94.40000	93.63671	0.76329
46	94.60000	94.46112	0.13888
47	94.60000	94.20117	0.39883
48	87.90000	92.10211	-4.20210
49	97.50001	96.34849	1.15152
50	92.20001	93.91337	-1.71336
51	88.60000	89.81179	-1.21179
52	96.70001	94.97357	1.72644

TABLE 18 (Continued)

Case No	Y Value	Y Estimate	Residuals
53	93.30000	93.55036	-0.25036
54	91.70001	93.09268	-1.39266
55	98.30000	96.62423	1.67576
56	96.70001	95.42848	1.27153
57	94.20001	92.52452	1.67549
58	93.10000	92.77240	0.32760
59	96.80000	95.25672	1.54327
60	88.30000	85.90333	2.39666
61	86.90000	85.06687	1.83313
62	97.70001	96.32344	1.37657

TABLE 21

STATISTICAL ANALYSIS WITH RESIDUALS FOR THE FRACTIONATION SAMPLER (X) AND ANDERSON HEAD ADAPTER STAGES THREE, FOUR AND FIVE (Y) WESTERN ELECTRIC 5/22/73 TO 4/24/74

Equipment Variables	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std Error of Reg Coef	Computed T Value
(X)	42.18714	28.72948	0.93923	0.90638	0.04276	21.19337
(Y)	44.24860	27.72461				

Intercept . . . 6.01097

Multiple Correlation . . . 0.93923

Std. Error of Estimate . . . 9.5929

Analysis of Variance for the Regression

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Reg.	1	41362.57041	41362.57041	449.15893
Deviation from Reg.	60	5525.33692	92.08894	
Total	61	46887.90635		

Residuals

Case No	Y Value	Y Estimate	Residuals
1	0.00000	11.77555	-11.77555
2	69.02000	132.57806	-63.55805
3	33.97000	33.26586	00.70413
4	62.41000	57.10369	5.30631
5	23.21000	25.86978	-2.65978
6	37.41000	38.84916	-1.43916
7	50.40000	48.03080	2.36919
8	26.24000	26.06919	0.17081

TABLE 21 (Continued)

Case No	Y Value	Y Estimate	Residuals
9	35.93000	38.99419	-3.06419
10	40.01000	43. 1703	-3.50703
11	61.50000	60.87423	0.67576
12	53.00000	49.94327	3.05673
13	51.29000	47.43260	3.85739
14	39.17000	39.37487	-0.20486
15	32.38000	35.67683	-3.29682
16	38.40000	39.80087	-1.40087
17	32.01000	36.24784	-4.23784
18	31.05000	33.80969	-2.75968
19	40.40000	42.92788	-2.52788
20	26.50000	29.02399	-2.52399
21	55.20000	54.68365	0.51634
22	52.70000	51.92825	0.77175
23	109.32000	93.14140	16.17860
24	47.27000	46.67123	0.59877
25	24.90000	25.30783	-0.40782
26	48.80000	47.87672	0.92327
27	130.45001	114.44137	16.00862
28	67.90000	62.98609	4.91390
29	20.83000	23.23221	-2.40221
30	23.16000	23.92106	-0.76106
31	40.34000	41.77677	-1.43677
32	22.07000	25.86978	-3.79978
33	40.58000	41.17856	-0.59856
34	60.58000	57.11275	3.46724
35	44.51000	42.25716	2.25283
36	27.46000	29.34122	-1.88122
37	23.50000	23.99357	-0.49357
38	25.01000	25.67038	-0.66038
39	15.08000	17.05976	01.97975
40	27.71000	27.02995	0.68004
41	34.70000	35.11487	-0.41487
42	18.51000	21.61885	-3.10885
43	17.04000	20.43149	-3.39149
44	28.21000	28.67956	-0.46956
45	47.30000	44.35997	2.94003
46	38.75000	36.31129	2.43871
47	41.21000	38.84916	2.36084
48	64.87001	59.34245	5.52755
49	17.78000	17.88456	-0.10456
50	42.55000	41.65895	0.89105
51	87.67001	81.70288	5.96713
52	33.23000	31.30807	1.92192

TABLE 21 (Continued)

Case No	Y Value	Y Estimate	Residuals
53	44.38000	45.20290	-0.82289
54	56.48000	49.67136	6.80864
55	12.26000	15.19261	-2.93261
56	28.44000	26.86680	1.57319
57	66.21000	55.21841	10.99158
58	58.74000	52.79837	5.94162
59	24.89000	28.54360	-3.65360
60	132.31002	119.86152	12.44848
61	138.85000	128.02804	10.82196
62	17.32000	18.12929	-0.80928