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AN INSTRUMENTAL SYSTEM FOR THE MONITORING OF VINYL CHLORIDE MONOMER IN PLANT AND LABORATORY WORK ENVIRONMENTS

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Introduction

Within the past several years there has developed a growing awareness of the need to do continuous or sequential sample monitoring of air quality in both laboratory and production work areas. Significant factors contributing to our increased knowledge relating to air quality in polymerization buildings in the PVC industry include the development of suitable instrumentation for the analysis of contaminants and the implementation of these methods, initially on a batch sampling basis. The development of much improved monitoring systems has lead to the ability to do continuous or sequential monitoring (as opposed to batch sampling) by interfacing an analytical instrument with an automatic sampling system. Additionally, the response signal from the analytical instrument now can be feed to a programmable calculator or minicomputer to provide new reporting capabilities such as hourly and shift average concentration levels as well as an instantaneous display and recording of concentration levels at multiple locations.

These much improved sample handling, analytical and data processing capabilities have revealed that the analysis of air quality based on infrequent, batch samples is grossly inadequate. It is also now apparent that even the most advanced instrumental system is not totally adequate because of its limitations in monitoring only from specific, fixed locations, whereas the monitoring needs may frequently be shifted from one location to another. The use of a fixed monitoring system, supplemented by the frequent use of easily portable analyzers having equivalent capabilities, is now recognized as the minimum requirements for both monitoring and maintaining good air quality in polymerization work areas.

As a result of this improved ability to make air quality measurements there has also developed an increased awareness of the many complexities involved in the maintenance of good air quality in an enclosed working area. Good ventilation, the rigid exclusion of leaks and the institution of improved manufacturing procedures are only a part of the practices that must be adhered to. Equally important is the ability to provide early detection and to take immediate corrective action when contaminant levels exceed the criteria established for employee exposure.

Obviously, a monitoring system must therefore be designed to meet the requirements of specific work areas. Preliminary studies must be made to determine excursion limits (maximum and minimum concentrations) of air contaminants and a number of analytical methods must be considered or tested to provide the required measurements. Another important factor is the frequency of sampling and analysis required to provide early warning of high concentration levels and a suitable history of employee exposure. Equally important in the planning stage is proper consideration of data handling since continuous or rapid sequential monitoring from multiple sample locations can produce such a large quantity of data that some means of automated data acquisition, summation, averaging and report writing must be included as a part of the total system.

Instrumental and System Requirements

An instrumental system for the monitoring of vinyl chloride monomer (VCM) in a process or laboratory work area should have the following capabilities or characteristics;

* One ppm detection capabilities (or better),
* Rapid response to changes in concentration levels,
* Linear and reproducible response over a wide concentration range (0 - 1000 ppm),
* Require a minimum of operator attention and maintenance,
* Have the capability of sampling at multiple, remote locations.
* Be compatible with a variety of sampling requirements and data handling methods, such as interfacing to a multi-point recorder, programmable calculator or minicomputer.

Other desirable characteristics of this system should include low or moderate cost, the employment of simple, well accepted concepts and that the hardware and associated electronic equipment be compatible with existing operating and maintenance capabilities in our production plants. It also would be desirable that the instrumentation be of a type currently available from several instrument manufacturers.

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Instrument Selection and Evaluation

Data obtained through the analysis of batch samples (using gas chromatography) and survey analyses (using a portable organic vapor analyzer) are sufficient to suggest that two different types of instrumental capabilities are required to meet all of the criteria for effective monitoring and rapid identification of emission sources. The utility of the portable organic vapor analyzer is already apparent in its ability to rapidly and very specifically identify small leaks in processing equipment. It was an early conclusion that an effective total system must include the capability to monitor with both fixed and portable analyzers. The fixed analyzer should monitor a

sufficient number of sample locations in a building so as to provide a continuous record of concentration levels and equally important provide early detection of concentrations exceeding desired levels. When high VCM levels occurred, the portable analyzer would then be employed to more rapidly identify the source and provide the supplemental capabilities needed for immediate corrective action.

The screening of methods having potential for meeting all of the required performance criteria resulted in a select list of instruments for further testing in a production plant environment:

Table 1

Survey Instruments (Portable)	Monitoring Instruments (Fixed)
1. Gas Chromatograph	1. Gas Chromatograph
2. Infrared w/20m gas cell	2. Combustion-Conductivity
.. Catalytic oxidation	3. Infrared w/20m cell
4. Flame Ionization*	4. Flame Ionization*

*Organic Vapor Analyzer (OVA)

Obviously, the above list includes a number of instruments that are now widely used for the monitoring of air quality. Some of these methods (infrared and gas chromatography) have specific component identifying capabilities and some (catalytic oxidation, flame ionization and combustion-conductivity) give a total response to hydrocarbons or halogens. In the early stages of in-plant testing of these methods it soon became apparent that in a majority of PVC polymerization work areas, specific component identification was not required because the presence of atmospheric contaminants, other than VCM, was of little or no concern. Even in those areas where two or more components are present the

requirement for specific component identification is not required except in those cases where there is a gross difference in the relative toxicity of the individual components.

Comparison of Fixed Monitoring Instruments

The following discussion relating to the evaluation of various types of fixed analyzers for monitoring VCM, will be limited to a general comparison of the relative merits of the methods. Additional detail becomes unnecessary because of obvious, unreconcilable problems involved in use of several of the methods. A more concise summary of the advantages and disadvantages of the various methods investigated is given in Table 2.

Total Hydrocarbon Analyzer

The use of a total hydrocarbon analyzer having a flame ionization detector is the preferred method for the monitoring of VCM with a fixed analyzer for several reasons;

1. Outstanding sensitivity (as low as 0 - 1 ppm full scale; 0.01 ppm minimum detection)
2. Linear response (±2% full scale)
3. Good reproducibility (±2% full scale)
4. Rapid response time (almost instantaneous)

Additionally, the total hydrocarbon analyzer also fills the requirements for unattended operation, minimum maintenance requirements and moderate cost (under $2,000 w/o recorder).

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Infrared and Gas Chromatograph Analyzers

Although the infrared and gas chromatographic methods are acceptable

COMPARISON OF FIXED MONITORING INSTRUMENTS

Method	Advantages of Method	Disadvantages of Method[1]
Total Hydrocarbon Analyzer with Flame Ionization Detector	1. Outstanding sensitivity (0-1 ppm full scale) 2. Linear response (±2% full scale) 3. Good reproducibility (±2% full scale) 4. Rapid response time (almost instantaneous) and cycle time 5. Easy to operate, low maintenance requirements 6. Moderate cost ($2000 w/o recorder)	1. Not specific for VCM
Gas Chromatograph	1. Good sensitivity (low ppm) 2. Acceptable response; good reproducibility 3. Specific for VCM	1. Longer cycle time (5-10 min 2. More complex equipment 3. More difficult to operate and maintain 4. More expensive
Infrared Spectrometer w/20m Gas Cell	1. Excellent sensitivity [0.7 ppm MDL[2]] 2. Acceptable response; good reproducibility 3. Specific for VCM	1. Longer cycle time (5-10 min 2. More complex equipment 3. More difficult to operate and maintain 4. More expensive
Combustion-Conductivity Method	1. Good sensitivity (low ppm) 2. Specific for halogens	1. Not specific for VCM 2. Longer cycle time 3. Requires excessive operator attention and maintenance 4. Not commercially available

(1)

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...y ... arbon ...ed ...rh Ionization Detector	2. Linear response (±2% full scale) 3. Good reproducibility (±2% full scale) 4. Rapid response time (almost instantaneous) and cycle time 5. Easy to operate, low maintenance requirements 6. Moderate cost ($2000 w/o recorder)	
nromatograph	1. Good sensitivity (low ppm) 2. Acceptable response; good reproducibility 3. Specific for VCM	1. Longer cycle time (5-10 min.) 2. More complex equipment 3. More difficult to operate and maintain 4. More expensive
red Spectrometer Gas Cell	1. Excellent sensitivity [0.7 ppm MDL(2)] 2. Acceptable response; good reproducibility 3. Specific for VCM	1. Longer cycle time (5-10 min.) 2. More complex equipment 3. More difficult to operate and maintain 4. More expensive
stion-Conductivity d	1. Good sensitivity (low ppm) 2. Specific for halogens	1. Not specific for VCM 2. Longer cycle time 3. Requires excessive operator attention and maintenance 4. Not commercially available

s compared with the Total Hydrocarbon Analyzer

inimum Detection Limit

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in terms of many of the desired performance features, they have the following disadvantages when compared to the total hydrocarbon analyzer;

1. Longer cycle time (2 - 10 minutes)
2. More complex equipment
3. More difficult to calibrate, operate and maintain
4. More expensive (2 to 3 times)

The obvious advantage of infrared and gas chromatography is the ability to measure several components in batch or sequential air samples.

Combustion-Conductivity Analyzer

Although the use of combustion-conductivity was considered as a candidate in the screening of possible acceptable methods, no direct investigation was made to obtain comparative performance data for several reasons. No commercial instruments employing this concept are now available. Also, this method has been extensively explored and used by the Dow Chemical Company for the past ten years. Based on Dow's evaluation(1), this method is a highly acceptable and usable procedure and fills many of the criteria for the monitoring of VCM or other halogenated hydrocarbons in plant work areas. In comparing the combustion-conductivity method with the total hydrocarbon analyzer there are, however, a number of disadvantages;

1. It is a more complex system,
2. More difficult to operate and maintain,
3. More expensive, not commercially available.

(1) Raymond M. Donahue, "Dow Halogenated Hydrocarbon Analyzer", Instruments Systems Research Laboratory Report, The Dow Chemical Company, Midland, Michigan.

In summary, it can be said that the evaluation of candidate methods was limited to the types of hardware currently available from a number of instrument manufacturers. A suitable method was readily identified. No preference can be stated for one instrument supplier over another.

A primary objective in the screening evaluations was to identify a suitable instrumental method and to then expedite in-plant testing to finalize the design of a total system. The Bendix 8401 Total Hydrocarbon Analyzer was the particular instrument selected for the in-plant testing phase, although similar instrumentation from another supplier could also be considered.

Comparison of Portable, Survey Instruments

The screening of candidate method (summarized in Table 3) for use as a portable analyzer for VCM was largely influenced by prior, successful use of the flame ionization method as a portable monitor. It also soon became apparent that the comparisons relating to methods for fixed monitoring were, in most cases, translatable to the portable monitoring evaluations.

It should be emphasized that the most important features required in a portable VCM monitoring instrument are rapid response (almost instantaneous), outstanding sensitivity (1 ppm or better detection capabilities) and the equipment should be light weight and easy to handle and operate. Good linearity over a wide range of concentrations and reproducibility are desirable features, although not as critical as with the fixed monitor. Keep in mind that the major function of this instrument is to find leaks and emission sources as opposed to the continuous, quantitative requirements of the fixed analyzer. It also is desirable that the instrument be explosion proof or suitable for use in a Class I, Group D area.

COMPARISON OF PORTABLE SURVEY INSTRUMENTS

Method	Advantages of Method	Disadvantages of Method[1]
Organic Vapor Analyzer (OVA) with flame ionization detector	1. Good sensitivity (low ppm) 2. linear response (1-1000 ppm) 3. Good reproducibility 4. Rapid response (almost instantaneous) 5. Light weight; easily portable 6. Easy to operate and maintain 7. Moderate cost (<$3,000)	1. Not specific for VCM 2. Not approved for use in a Class I, Group D work ar
Gas Chromatography	1. Good sensitivity (low ppm) 2. Acceptable response; good reproducibility 3. Specific for VCM 4. Excellent for multi-component mixtures	1. Lacks instantaneous respon for leak detection 2. Not as easily portable as
Infrared Spectrometer w/20m Gas Cell	1. Excellent sensitivity [0.7 MDL[3]] 2. Linear response; good reproducibility 3. Specific for VCM 4. Good for multi-component mixtures	1. Lacks instantaneous respor for leak detection 2. Not easily portable 3. Not explosion proof; requi exclosure with N_2 or air purge
Catalytic Oxidation	1. Easily portable 2. Explosion proof 3. Good response at high concentrations	1. Lacks sensitivity (not reliable below 50 ppm) 2. Bad zero level drift

(1) as compared with the Organic Vapor Analyzer

(2) Requires Hot Work Permit

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Organic Vapor Analyzer (OVA) with flame ionization detector	1. Good sensitivity (low ppm) 2. Linear response (1-1000 ppm) 3. Good reproducibility 4. Rapid response (almost instantaneous) 5. Light weight; easily portable 6. Easy to operate and maintain 7. Moderate cost (<$3,000)	1. Not specific for VCM 2. Not approved for use in Class I, Group D work
Gas Chromatography	1. Good sensitivity (low ppm) 2. Acceptable response; good reproducibility 3. Specific for VCM 4. Excellent for multi-component mixtures	1. Lacks instantaneous response for leak detection 2. Not as easily portable as
Infrared Spectrometer w/20m Gas Cell	1. Excellent sensitivity [0.7 MDL(3)] 2. Linear response; good reproducibility 3. Specific for VCM 4. Good for multi-component mixtures	1. Lacks instantaneous response for leak detection 2. Not easily portable 3. Not explosion proof; requires exclosure with N_2 or air purge
Catalytic Oxidation	1. Easily portable 2. Explosion proof 3. Good response at high concentrations	1. Lacks sensitivity (not reliable below 50 ppm) 2. Bad zero level drift

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(1) as compared with the Organic Vapor Analyzer

(2) Requires Hot Work Permit

(3) Minimum Detection Limit

Table 3

Portable Organic Vapor Analyzer

The portable flame ionization instrument (Century Organic Vapor Analyzer) gives an almost instantaneous response to changes in VCM concentrations. It has excellent sensitivity (<1.0 ppm minimum detection limits) and gives a linear readout over a wide range of concentrations. The instrument is light weight, compact and easily transportable. It provides an excellent method for the detection and location of small leaks in processing equipment. Although the Century OVA is rated as being intrinsically safe for use in most PVC processing areas it has not yet been approved by Factory Mutual, or other rating agencies, for use in a Class I, Group D area. Such approval is expected however by mid-1974. Standard work practices involving the use of non-rate equipment in such areas need to be rigidly adhered to (such as air testing and the issuing of a Hot Work Permit).

Portable Gas Chromatograph

The use of a portable gas chromatograph having a flame ionization detector has a number of distinct advantages including the ability to specifically separate and measure VCM in the presence of other organic vapors. This advantage, however, is responsible for several undesirable features of the method, namely increased analysis time and additional requirements for operation and calibration of the instrument. The inability to provide an almost instantaneous response is sufficient to preclude the gas chromatograph as an effective method for VCM leak detection. Its primary utility is in providing analysis of batch samples in work areas where multi-component mixtures are present.

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Portable Infrared Analyzer

The infrared instrument (Wilkes Scientific Corp. Miran Gas Analyzer)

evaluated as a portable VCM analyzer had excellent sensitivity (0.7 ppm minimum detection). The major disadvantages of this method is the lag in response time (several minutes) due to the 5 liter volume of the variable path length gas cell and the time required for flushing between samples. This limitation makes this method insensitive in rapidly detecting changes in VCM concentrations when the sample probe is moved from one location to another. The instrument is too bulky to conveniently use as a portable analyzer. It also is not explosion proof. In the in-plant evaluation the instrument was mounted in an air tight box and kept under a positive pressure using a N_2 purge. This seriously limits the mobility of the instrument. It was also found that the housing for the detector is not light proof and that there is a change in zero level when the instrument was exposed to direct sunlight.

Portable Catalytic-Oxidation Analyzer

The Catalytic Oxidation method (Bacharach Instrument Company's J-W Analyzer) did not meet our performance criteria for several reasons, the most important being lack of sensitivity (minimum detection limit of 10 ppm) and baseline (zero level) drift. The instrument is apparently responsive to temperature changes or other exposure conditions and over a relatively short period of time the zero level can change in amounts equivalent to 100 ppm of VCM.

In summary, it was concluded, based on the evaluation of these several methods, that the Organic Vapor Analyzer equipped with a flame ionization detector is the preferred type of instrumentation for use as a portable analyzer for VCM in ambient air.

The Total Instrumental Monitoring System

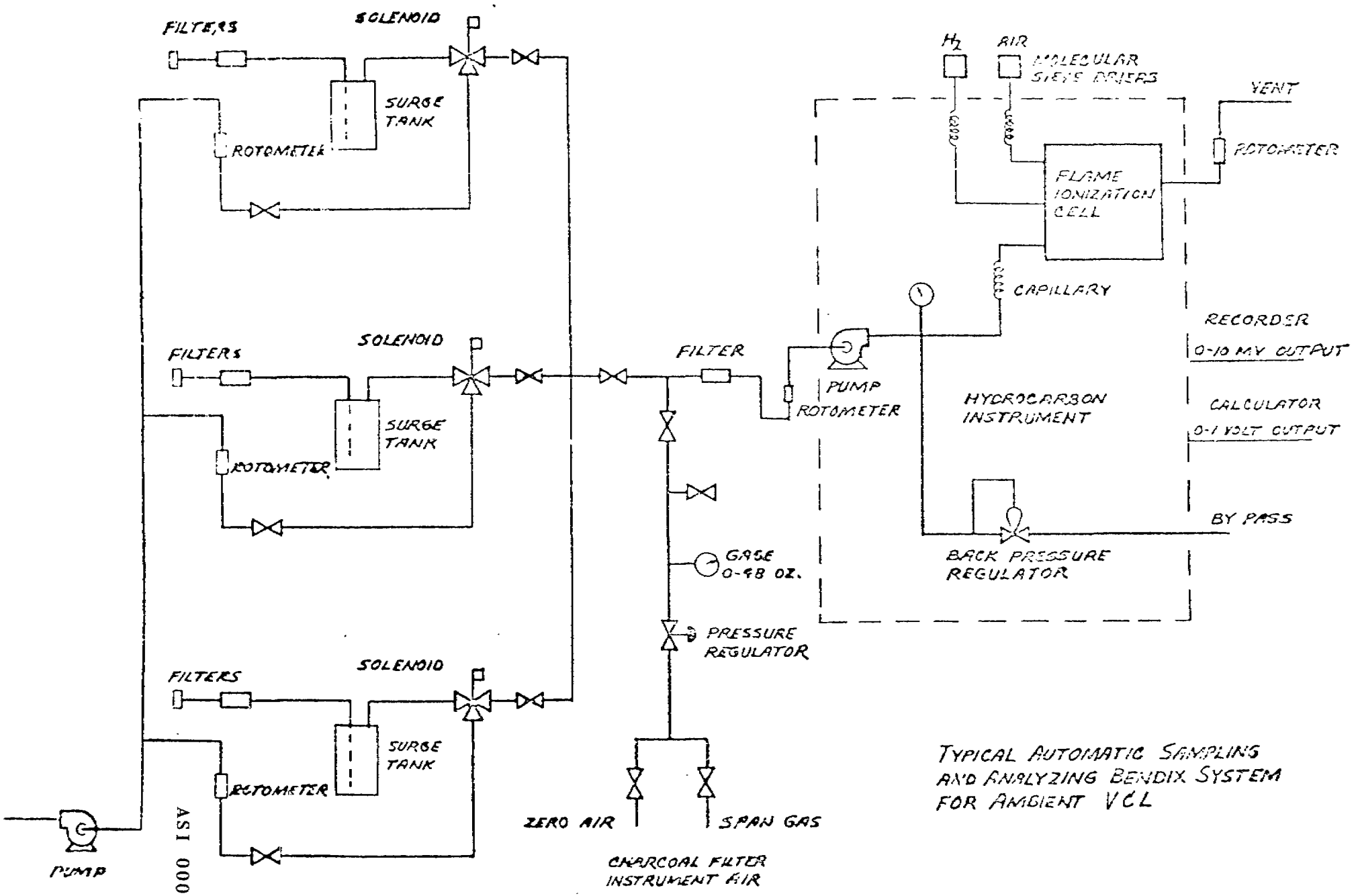
A total instrumental system for the monitoring of VCM in ambient air includes, in addition to the flame ionization instrument, an automatic, multi-point gas sampling system, a multi-point recorder, and other means of data collection such as a programmable calculator or mini-computer and the necessary hardware for interfacing these components. A basic diagram of the instrument and sampling system is shown in Figure 1.

The Flame Ionization Instrument in a Fixed Monitoring System

This unit is designed for unattended operation over long periods of time without the necessity for adjustment or any type of manual operation. The instrument is housed in a metal case suitable for either bench or rack mounting (16½" X 8½" X 18") and weighs approximately 40 pounds. The analyzer utilizes all solid state electronic components mounted on plug-in type printed circuit boards.

The utility requirements include a 115 volt power supply (150 watts) and a cyclinder of hydrogen for the operation of the burner in the analyzer. The hydrogen consumption rate is about 45cc/min.

The analyzer package (see Analytical Flow Description, Figure 2) includes an internal sample pump and sample pressure regulator as well as the necessary capillary flow controls and indicating pressure gauges to provide a very stable flow of hydrogen, air and sample gas. The analytical components in contact with the sample should be either glass or stainless steel to minimize corrosion. Some of the components in the flame ionization cell bonnet and guiderods) should be Teflon coated to prevent corrosion from the HCl produced from the combustion of VCM.



TYPICAL AUTOMATIC SAMPLING AND ANALYZING BENDIX SYSTEM FOR AMBIENT VCL

Figure 1

Analytical Flow Description

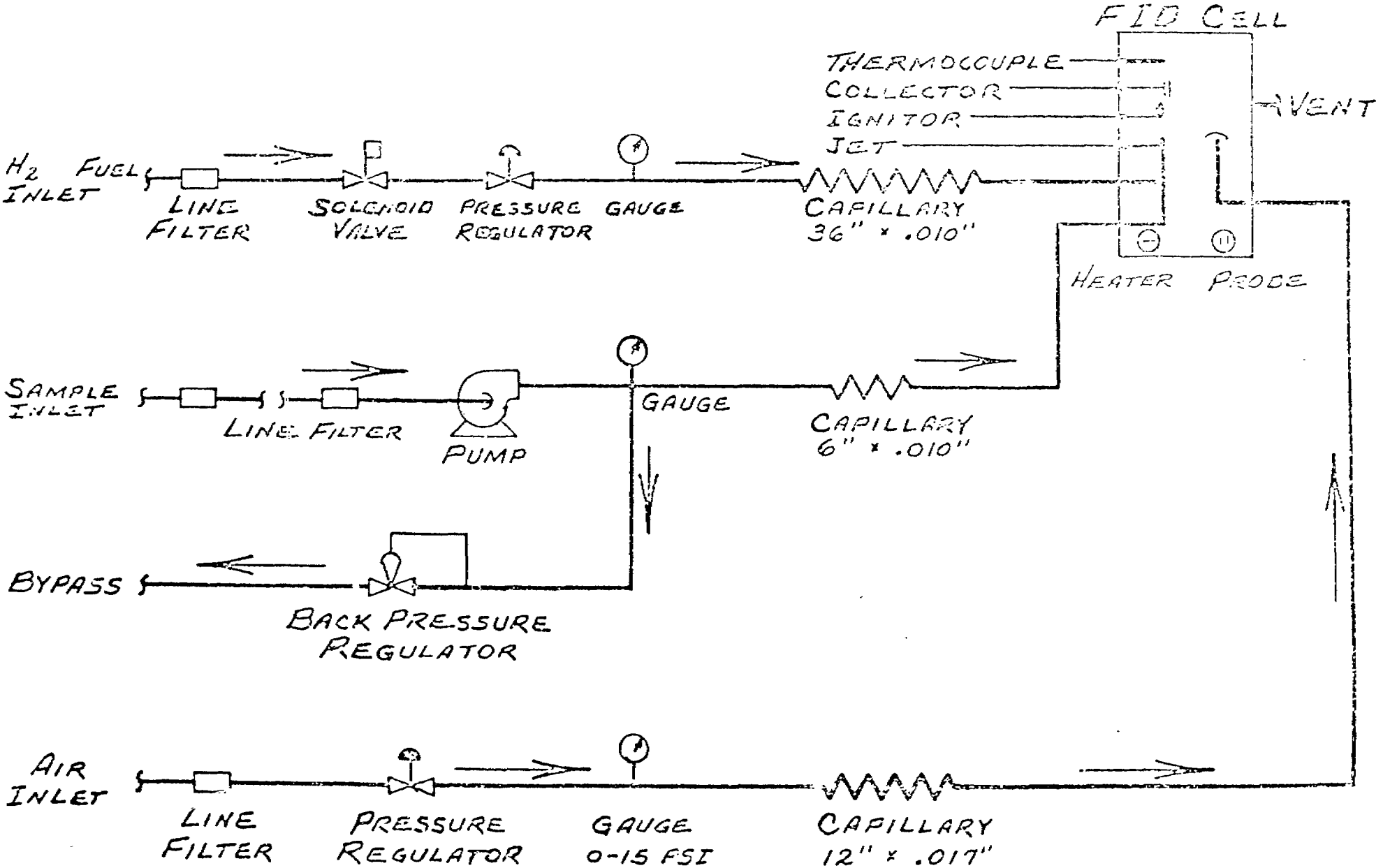


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Figure 2

This type of analyzer can operate over a wide range of temperature and humidity conditions without adverse effect on measurement accuracy. The sample is introduced at a controlled rate into the flame ionization cell where a hydrogen flame is burning in an atmosphere of air. As the sample enters the flame a percentage of the molecules are ionized, forming positive and negative ions. The extent of ionization depends on the compounds present (composition and structure) and the temperature of the flame. As a general rule, compounds must have carbon-carbon or carbon-hydrogen bonds to be detectable. The degree of ionization is roughly proportional to the number of carbon atoms per molecule. Inorganic materials such as hydrogen, oxygen, nitrogen and water are not ionized. The positive ions formed in the flame are collected on a negative electrode producing a signal that can be measured using the output of an electrometer preamplifier.

The Automatic Sampling System

The interfacing of the automatic sampling sytem to the flame ionization instrument is shown schematically in Figure 1, including the manifold for the zero and span gas cylinders necessary for calibration of the instrument. It should be noted that sample pumps are included in both the analyzer and sampling system. The sampling system pump continuously pulls samples from six remote locations to the instrument inlet manifold. This reduces lag time to a few seconds. The sample valves are operated by a mechanical switching device in the multi-point recorder on a 2 minute cycle. The concentration level (ion current calibrated for VCM) is recorded on the strip chart recorder and a suitable signal is provided for a continuous digital read-out.

Sample points can be located up to 150 ft. from the instrument. The location and number of sample points required should be determined by an

analysis of building ventilation patterns and many other factors including process equipment locations that can result in VCM emissions and employee work area definitions. Sample points in employee work areas should be located at about breathing level (approximately 5 feet above the floor). The lines from the sample point to the sampling system manifold are 3/8" OD polypropylene tubing and contain two filters to prevent the introduction of polymer or dust into the sampling system or analyzer. The balance of the components in the sampling system are constructed of stainless steel. A one liter surge tank is included in each sample line. This addition was made to prevent the recording of rapid changes in concentration levels that apparently occur as a result of rapid vertical movement of thin VCM layers in the atmosphere. The surge tank provides sufficient mixing and compositing action (30 seconds) to smooth out the instrument and recorder response to these types of spikes.(2)

Recorder and Data Collection

A variety of options are available for the collection and recording of data from the VCM analyzer system. The system shown schematically in Figure 3 is capable of handling a single analyzer with 6 sample points. This system consists of a six-point recorder, a digital readout meter, digital clock and a 110 volt AC to 5 volt DC converter and other required hardware for interfacing to a programmable calculator (Wang Model 720C). ASI 00023337

Concentration levels are recorded by the 6-point recorder during each sampling cycle. Additionally, a signal is provided to the digital read-out meter and the programmable calculator. The calculator stores and averages data from each sample point to provide hourly and shift reports that are typed

(2) This phenomenon is not completely understood. It suggests that transport of VCM in air may be much like the waving action of a heavy smoke.

Data Collection System

Flame Ionization Instrument

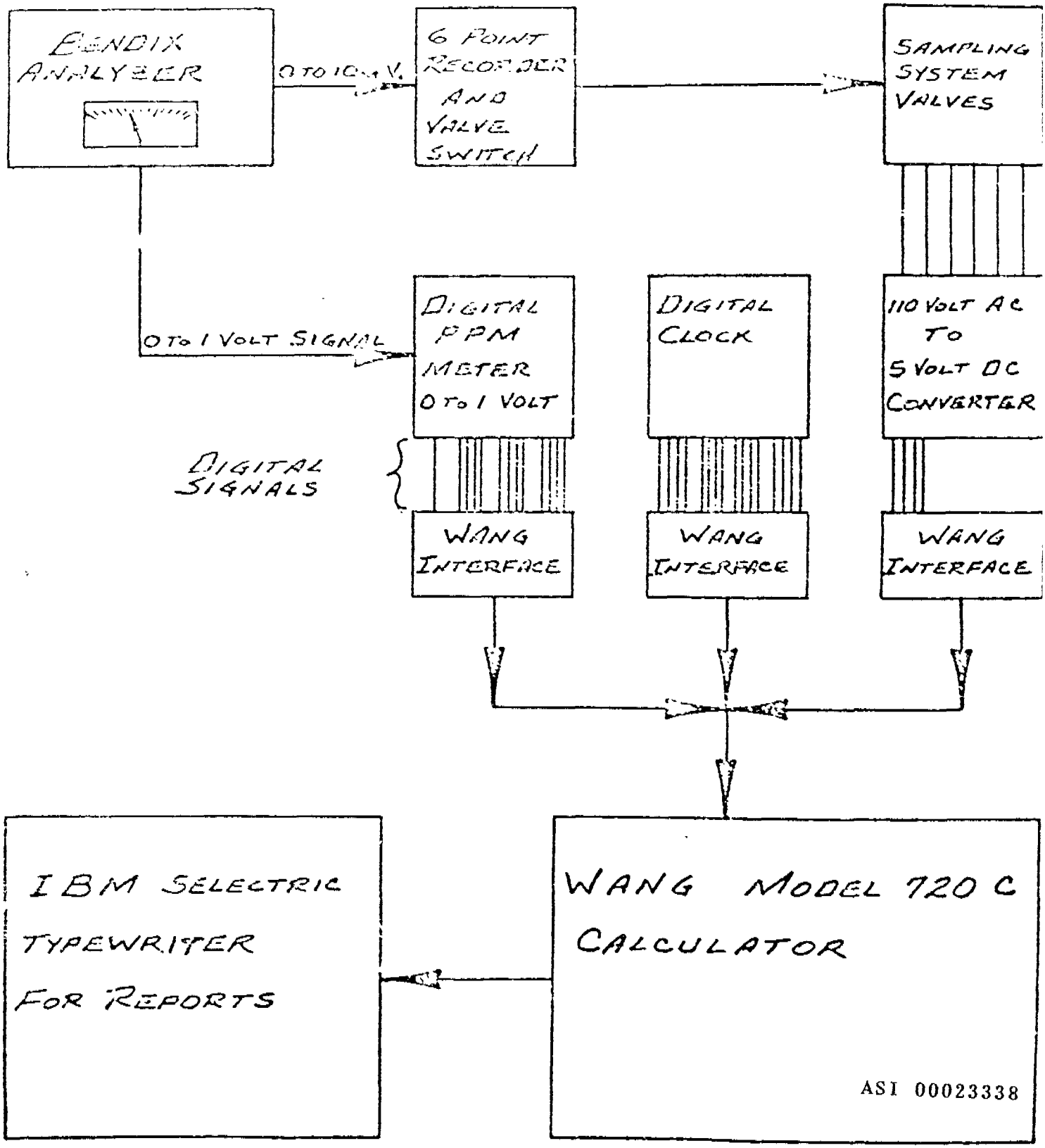

Figure 3

out on an IBM typewriter. The hourly report is an average of concentration levels at each sample point in ppm. The shift report includes an 8 hour average of concentration level at each sample point plus a summary of maximum peak levels and time of occurrence for each hour during the shift period. The shift report also includes a summary of percent of time that VCM concentration level exceeded the maximum allowable concentration of 50 ppm.

Fixed Station Monitoring vs. Personal Monitoring

The use of fixed station monitors for the sampling and analysis of ambient air in a production plant is only one approach that can be used in determining an employee's exposure index. The obvious disadvantage of fixed station monitoring is its fixed nature as opposed to mobile personnel. Multiple station sampling capabilities are, therefore, essential to cover all of the areas of employee exposure. Additionally, the determination of a Time Weighted Average for an employee must include a calculation of concentration vs. time to obtain a total exposure index. This accuracy of this method is obviously dependent on the ability to measure the concentration levels in all areas of exposure and also to accurately estimate the amount of time the employee spends in each work area.

In comparing the use of a fixed station monitor with a personal monitor (a portable device worn by each individual) there are also some obvious advantages in using the fixed station concept. Firstly, it provides an instantaneous display of concentration level and obviously provides the best signal (alarm) for instituting corrective action. On the other hand, the personal monitor provides only a history of events that are averaged out over a period of hours. Most types of personal monitoring devices will only reveal an overexposure to

a toxic substance after it has occurred. The fixed station monitor can warn you before overexposure occurs. The other obvious disadvantage of the personal monitor is that it must be worn by the individual which can create problems due to bulk, weight, vibration or just because it's a continuous reminder of the problem. A comparison of the costs of the two methods will, in general, show that a fixed station monitoring system will have an initially higher hardware cost while the personal monitor will have a higher sustaining analytical cost, particularly when measurements are required for large numbers of employees.

Although the evaluation of personal monitoring equipment was not a specific objective relating to the previously described instrumental evaluations, the need for this capability is now most obvious. The ultimate evaluation of a fixed station monitoring system in measuring an employee's exposure index must include some means of personal monitoring. The acceptance of a fixed station system is dependent on obtaining reasonable agreement with data obtained from a personal monitoring program. Several methods of personal monitoring are detailed in the literature(3)(4)(5). Each of these methods, however, may require some further refinement or need to be modified to meet specific monitoring requirements in PVC production work areas.

Summary

An analysis of the problems relating to the monitoring of vinyl chloride

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(3) A. A. Allemang and R. A. Goudeau, "Monitoring Personnel Exposure to Chlorinated Hydrocarbons in an Industrial Work Environment", Personal Communication, Dow Chemical Co., March 30, 1973.

(4) E. . Palmes and A. F. Gunnison, "Personal Monitoring Device for Gaseous Contaminants", J. of Amer. Ind. Hyg. Assoc., pp. 78-81, Feb. 1973.

(5) Edward D. Baretta, et.al., "Monitoring Exposures to Vinyl Chloride Vapor: Breath Analysis and Continuous Air Sampling", J. of Amer. Ind. Hyg. Assoc., Vol. 30, p. 537-544, Nov.-Dec., 1969.

monomer (VCM) in laboratory and production work areas has shown that two different types of monitoring capabilities are required; a fixed analyzer with multi-point remote sampling capabilities and a portable analyzer for rapid area survey analyses and leak detection.

An evaluation of commercially available instrumental methods has revealed that the flame ionization method for monitoring low concentrations of VCM in ambient air has distinct advantages over other procedures investigated. These advantages include outstanding sensitivity (0.01 ppm minimum detection), and good linearity and response (±2%) over a wide range of concentrations (0 - 1000 ppm). Additionally, the analyzer is moderate in cost (approximately $2,000) and can be easily interfaced to a multi-point sampling system and continuously operated on a two minute per-sample-point cycle for long periods of time with a minimum of operator attention or maintenance.

A fixed monitoring system utilizing a flame ionization instrument (Bendix 8401 Total Hydrocarbon Analyzer) has been in continuous operation in a PVC poly building, at the B.F.Goodrich Chemical Company plant in Avon Lake, Ohio, for approximately six months. This system which includes, in addition to the analyzer and a six point sampling system, a multi-point recorder, interfacing hardware and a programmable calculator for data reporting on a hourly and shift basis. The operation of this system has been essentially trouble free during this period and has provided the types of measurements required to determine VCM concentrations in a multi-story building and to minimize employee exposure levels.

An important adjunct to this system is the portable survey instrument that has outstanding utility in rapidly determining the source of VCM leaks

in processing equipment. This instrument (Century Organic Vapor Analyzer[6]) also uses the flame ionization principle. It is light weight, easily portable and has sensitivity and linear response roughly equivalent to the fixed analyzer. Equally important, and highly essential in leak detection, is this instrument's instant response to VCM.

Recommendations

The previously described evaluation of various instrumental methods and the subsequent testing of a total system in a plant working environment has been sufficient to conclude that these procedures can be easily applied to a variety of work areas where the monitoring of VCM in ambient air is a criteria for employee health and safety. It, therefore, can be recommended that the identified methods, or their equivalent, be adopted as standard industry practices. Standard operating procedures detailing the start-up, operation, calibration and instrument maintenance are included in Appendix I (Fixed Analyzer) and Appendix II (Portable Analyzer).

Acknowledgments

The author would like to recognize the contributions of the large number of people who participated in this work. A particular debt of gratitude is owed to L. W. Salzer for his wisdom in selecting specific instrumental methods for testing; to M. D. Rider for his invaluable contributions to the in-plant testing; and to M. E. Forsythe for his assistance in interfacing the analytical and data collection systems.

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(6) Century Systems Corporation; Arkansas City, Kansas.