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DESIGN AND OPERATION OF A SAMPLING INTERFACE FOR CONTINUOUS
SOURCE MONITORS

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Introduction

The capability to accurately and reliably monitor emission levels must be an integral part of any air pollution abatement program. As a consequence of increased environmental and energy conservation concerns and the promulgation of the Federal New Source Performance Standards¹, a wide variety of continuous monitoring instrumentation is now in use. The commercially available monitoring systems generally fall into the categories of either using an "in situ" or "extractive" approach. Analyzer systems utilizing the in situ approach do not require sample conditioning, are generally permanently mounted in the stack or duct, and are dedicated to a single emission stream. Extractive sampling and measurement systems consisting of sample probe, transport lines, gas conditioner and analyzer can be permanently installed to monitor either a single emission stream or multiple streams on a time-shared basis.

Extractive monitoring systems also have considerable utility when temporarily installed on a source for use in: 1) engineering studies to evaluate the performance of control equipment, 2) process optimization studies leading to reduced pollution and better energy utilization, 3) surveys of emission levels for dispersion model input data, 4) instrument evaluation studies, and 5) testing for compliance with various emission standards. Source testing personnel in consulting firms, research organizations, regulatory agencies, or industries who use an extractive monitoring system to periodically carry out the type of surveys mentioned above generally find such a system, with appropriate analyzers, mounted in a mobile vehicle to be of great value. One such mobile laboratory, developed and constructed by the Olympic Research Division of ITT Rayonier Incorporated in 1972², has been recently redesigned to include a much improved sampling interface system for use with up to ten continuous analyzers. This paper describes the basic design features and operational characteristics of this improved system. It should not be inferred that this extractive system can and should be used in all source monitoring situations employing extractive monitors. However, understanding the basic design criteria and the system built to meet those criteria should be of significant value to scientists and engineers involved in designing and specifying extractive emissions monitoring systems.

Design Criteria

The function of a sample interface system is to extract, transport, condition and distribute a representative gas sample to continuous analyzers with minimal alteration of the gas composition. Since the interface system described is to be used on emission sources typical of the forest products industry, it has to be capable of handling a wide variation in flue gas composition. Typical emission sources include oil and hog-fuel fired power boilers, kraft and sulfite recovery furnaces, lime kilns, acid plants, chip digester blow systems, pulp washer hood vent systems and liquor evaporator noncondensable vents. Controlled and uncontrolled emissions from these sources vary widely in moisture content, particulate concentrations, gas composition and individual gaseous component concentrations.

Since most gaseous pollutant analyzers require sample gas which contains a very low level of particulate matter with a dew point less than the analyzer sensing cell or sample line temperature, continuous particulate and moisture removal was to be an integral part of the interface system. It was also necessary that particulate removal and dew point reduction be accomplished with minimal effect on the concentration of the components to be monitored.

The sampling interface system needed to provide a constant flow of stack gas in sufficient volume and under positive pressure to satisfy the combined instrument flow requirements. Also, the response time of the system was to be minimized, therefore making the instrument responses useful for process control and optimization studies. It was desired that the interface system be designed to accommodate the analyzers in a sampling configuration whereby they operate independently of each other. That is, the system would allow an individual instrument to be switched from the monitoring of either stack gas, diluted stack gas, zero air or calibration gas without affecting the gas flow to the other analyzers. It was established early in the design phase of the interface system that automatic zeroing and calibration of the analyzers at fixed time intervals actuated by timers would not be a part of the system. Since the type of survey work conducted with the mobile laboratory generally required routine checks at least once every 24 hours, analyzer zeroing and calibration was to be carried out by the operator.

Other design criteria considered in the construction of the extractive sampling interface system was the need to minimize maintenance requirements by selecting reliable and durable components. Those components which needed routine maintenance and/or replacement were to be positioned for easy accessibility. The use of Teflon or Teflon-coated surfaces was to be maximized, thereby reducing corrosion and the possibility for pollutant losses.

Sampling Interface Design and Operation

Based on the criteria described above, the gas sampling interface shown schematically in Figures 1 and 2 was developed and built. Functionally the system can be divided into:

1. the particulate removal and automatic probe backpurge system,
2. the moisture removal system,
3. the constant flow control and sample transport system, and
4. the gas distribution/dilution and calibration modules.

Particulate Removal and Automatic Backpurge System

Particulate removal is accomplished by drawing the stack gases through both a coarse and fine filtering device. The coarse filter is located in the stack ahead of the heat-traced sample line. A variety of in-stack filters is available to cover the wide range of sampling situations.

Several sizes of porous shielded and unshielded stainless steel cylinders with different size removal efficiencies and pressure drop characteristics can be used. The in-stack filter having the lowest pressure drop at the sample flow rate and having a nominal removal efficiency for 5 micrometer particulate matter is generally selected.

Since particulate removal requirements for most analyzers and the moisture removal method used in this interface system call for essentially complete removal of particulates above one micrometer in size, additional filtration beyond that provided by the coarse filter is necessary. A secondary removal device consisting of a 6 x 25 cm cylindrical depth filter of spun glass fiber is located just ahead of the moisture removal system in a thermostatically controlled oven. The filter element is housed in a Teflon-lined, stainless steel shell and a differential pressure gauge (G-3) is placed across the element. When clean, the pressure drop is 25 cm H₂O at a flow of 20 lpm.

The automatic backpurge system is designed to periodically "clean" the coarse particulate filter by utilizing compressed air to backpurge the sample line and filter unit. Rather than occurring at fixed time intervals, backpurging occurs only when needed and is initiated by an electronic sensor (G-2) which measures the vacuum on the suction side of the sample delivery pump. When this vacuum reaches the preset value at which the sample pump can no longer provide the required flow because of particulate build-up on the in-stack filter, backpurging is automatically initiated. A four-way valve (V-1) is rotated 90° by an automatic valve operator and compressed air flows through the sample line and coarse filter while ambient air is being pumped to the analyzers. After the backpurge period is complete (controlled by a 0 to 5 minute timer) sampling is resumed. If irreversible plugging or excessively high particulate loadings cause the suction vacuum to again reach the level which initiates the backpurge cycle within a specified period of time (set by a 0 to 60 minute timer), the system will go into a "shutdown" configuration with ambient air being sent to the continuous instruments. This prevents repeated backpurgings occurring over a short period of time which would result in short periods of marginally useful data.

Moisture Removal System

A number of methods for stack gas dew point reduction have been described.^{3,4} The majority of sampling interface systems utilize condensation techniques for moisture removal and many systems have had problems because of refrigerated chiller failures and internal corrosion caused by the condensate.⁵ The use of permeation distillation moisture removal for stack gases dew point reduction has been reported⁵ and was felt to have definite advantages over the conventional condensation methods. Since moisture is removed in the gas phase, sample loss by dissolution in the condensate can not occur. Also, the lack of condensate reduces the opportunity for corrosion.

The gas interface system shown in Figure 1 utilizes the permeation distillation drying process for stack gas moisture removal. Two dryers (sold by Perma-Pure Products, Inc.) are plumbed in series with one dryer on the suction side of the sample pump and the other on the delivery side. The dryers have a configuration similar to a shell and tube heat exchanger, with the moist stack gas passing through the tube side and purge air flowing countercurrent on the shell side. Continuous drying is accomplished by passing the stack gas through the tube bundle and using an external source of dry air to purge the permeated water vapor from the shell side. To enhance the movement of water molecules across the permeable membrane, the purge air should have a lower dew point, lower pressure, and higher actual volumetric flow rate than the sample (feed) gas.

The two dryers used in the interface system each contain 200 permeable tubes 61 cm in length which are housed in a 2.5 cm OD stainless steel tube. As a consequence of the dryer placements with respect to the sample delivery pump, the feed gas in the primary dryer (dryer on the suction side of the pump) is under vacuum while the feed gas in the secondary dryer is under positive pressure. The purge air is passed countercurrent through each dryer at pressures lower than the feed gas. Dry purge air generated by a heatless desiccant dryer is first passed through the secondary dryer at atmospheric pressure and then passed through the primary dryer under a vacuum maintained by a vacuum pump. The purge air pulled through the primary dryer is expanded across a needle valve (V-5) and its flow rate and pressure are indicated by rotameter R-1 and vacuum gauge G-5. The primary dryer removes the majority of water vapor from the stack gas. Condensate formation in the sample delivery pump heads and sample lines downstream of this dryer is therefore minimized. The secondary dryer was provided as an added measure of moisture removal capability for sampling situations involving extremely moist (>35%) stack gases.

Sample Transport and Automatic Flow Control Systems

Gases are transported through the heated sample lines, particulate and moisture removal systems, and sent to the distribution and dilution module by one of two twin cylinder, Teflon-coated diaphragm pumps. Although two pumps are connected into the system in parallel, only one pump is operated at any one time. The second pump is used as a standby in the case of failure by the first one. In an effort to reduce failure of the pumps caused by corrosion and particulate abrasion, they have been positioned downstream of the particulate removal filters and primary dryer, but upstream of the secondary dryer and distribution/dilution module. The fittings and sample lines on the suction side of the pumps have been sized for minimum pressure drop at a sample flow rate of ~40 lpm. This maximizes the portion of the total suction head developed by the sample pump, which can be developed as pressure drop across the coarse particulate filter.

An automatic flow control system was developed and installed for the purpose of maintaining constant flow through the entire interface system under varying pump suction vacuums and delivery pressures. Under normal operating conditions, the delivery pressure is held constant by a back

pressure regulator (BPR-2, see Figure 2); however, the suction vacuum can vary depending upon the length of the sampling line and the coarse filter plugging rate. Since the pumping capacity is dependent on both the suction vacuum and delivery pressure, and since the suction vacuum varies during the sampling period, the volume flow rate of stack gas through the interface would normally vary. However, a bypass loop around the pump with a motorized needle valve in this bypass loop is used to regulate the quantity of gas being recirculated through the pump. By varying the amount of recirculated gas, the net flow through the interface system is controlled.

The motorized valve in the bypass loop is driven by an automatic control system which generates control signals by comparing the desired flow rate to the actual flow rate. The desired flow rate is set on a ten-turn potentiometer and its resulting signal is compared to the signal generated by a mass flow transducer which measures the actual flow rate. As the in-stack filter begins to plug, the net flow decrease is sensed by the mass flow transducer and a signal is generated by the controller which causes the motorized valve to close. The resulting decrease in the amount of recirculated gas causes an increase in the net flow, thereby restoring this flow to the preset desired level. As the in-stack filter continues to plug and the motorized valve continually adjusts (closes) to restore the desired net flow, a point will be reached when the motorized valve is completely closed. Any further increase in the pump suction vacuum caused by additional in-stack filter blockage will result in a decrease in the net flow rate beyond that which is desired. At this point, the automatic backpurge system is activated and the in-stack filter is cleaned.

After setting up the mobile laboratory to sample a particular emission stream, it is necessary to leak check that part of the interface system on the suction side of the sample delivery pump. This is accomplished by first manually driving the motorized bypass valve closed so that the maximum suction vacuum can be developed by the sample pump. With the pump on and the backpurge system off, the end of the sample line is plugged and valve V-2 is closed. With the internal volume of the sample line and interface system upstream of the pump evacuated, any air in-leakage can be detected by observing any drop off of the vacuum indicated by gauge G-4.

Gas Distribution/Dilution and Calibration Modules

The gas distribution and dilution module illustrated in Figures 2, 3, and 4 is used to transport precisely regulated quantities of sample gases to up to ten continuous pollutant analyzers. This module is equipped with ten, five-way manual selector valves which are used to direct different gases to the analyzers. Stack gas, diluted stack gas, calibration gas or zero air is selected and sent to each monitor by rotating the individual selector valve to the appropriate position. Stack gas and diluted stack gas are made available to the selector valve ports via two Teflon manifolds which are common to all ten valves. Calibration or zero air is transported to each individual valve via ten Teflon lines from the calibration module. The system is designed in such a manner that each of the ten instruments operate independently of the others. That is, an instrument can be switched

from the monitoring of stack gas, diluted stack gas, calibration gas or zero air without affecting the gas flow rates to the other monitors. This is made possible by using back pressure regulators (BPR-2, BPR-3) on the stack gas and diluted stack gas manifolds. These regulators hold the pressure within the manifolds at the preset levels under varying flow rates.

If a particular pollutant concentration present in the undiluted stack gas exceeds the available ranges of its respective monitor, diluted stack gas can be generated and sent to that monitor. Dilution is achieved by drawing off a regulated flow of stack gas ahead of a back pressure regulator (BPR-1). This regulator maintains the pressure upstream of it at a fixed level which is higher than the pressure of the gas in the manifolds. By keeping the pressure drop across the stack gas and dilution air rotameters (R-6, R-8 and R-9) fixed, stable dilution ratios of from 1:1 to ~20:1 at volume flow rates of 4 lpm to ~10 lpm are possible.

The flow of sample gas to each instrument is monitored by ten rotameters. Because the pressures in the stack gas, diluted stack gas and zero air manifolds along with the pressures of the calibration gases are maintained at the same level, the delivery rate of any of these gases to an instrument is the same for each gas. Consequently, the flow to each individual analyzer does not need to be adjusted each time the analyzer is switched from one gas to another. Since most analyzers are not sensitive to minor variations in flow rate, the system described above provides sufficient flow control for the majority of analyzers under all sampling configurations. For those analyzers whose response is critically flow dependent (e.g., Barton Titrator), flow controllers which provide constant flow under varying upstream and constant downstream pressures have been included for two of the ten instrument channels.

The calibration module consists of ten manually operated selector valves which are used to selectively route calibration gases or zero air to the distribution and dilution module. Zero air is provided to one port of each selector valve via a common zero air manifold whose pressure is regulated by a pressure reducing regulator (PRR-2). Two different pressurized calibration gas tanks can be connected to each valve, thereby giving some flexibility to the choice of span gas used for calibrating each specific monitor.

According to the emission monitoring requirements set forth by the EPA⁷, calibration and zero gas mixtures should be introduced into an extractive sampling system as near the probe as is practical. This requirement is made to assure accurate results by compensating for any dilution or absorption of the pollutant by the interface system. Although the interface system described here is used for short-term survey work and was not designed to satisfy the emission monitoring requirements for new sources, concerns of possible stack gas alteration because of dilution and/or absorption have been addressed. The high volume of gas extracted by the interface system to meet the ten continuous analyzer flow requirements and to minimize the system response time makes injection of the zero and span gases at the probe impractical. For this reason, the leak check procedure described earlier is routinely performed to insure against dilution by

air-infiltration. Potential absorption of pollutants by the interface components has been minimized by the use of Teflon, glass, Teflon-coated metals, and small amounts of stainless steel. Also, frequent water flushing of the sample lines removes any particulate matter which may collect on the internal surfaces and cause pollutant loss by absorption.

Sampling Interface Performance

The sampling interface has been operated under both laboratory and field testing trials. Of prime interest were the system's capabilities for moisture removal and its influence on the transport of sulfur dioxide gas mixtures. With respect to the permeation distillation method of moisture removal, during laboratory tests a single dryer (Model PD-1000-24S) reduced the moisture content in a 40 lpm gas stream containing as much as 30% V/V water vapor to less than 1%. However, this removal capability was only achieved after a 30 minute to one hour conditioning period⁹ with a purge air to feed gas actual volumetric flow rate ratio of 3:1. Even after the conditioning period, the single dryer demonstrated a brief period of very low moisture removal efficiency when initially exposed to the moist gas stream. With the use of the two dryers in series in the interface system, the conditioning requirement and initial period of poor moisture removal efficiency does not exist. The interface system has been satisfactorily operated on several different emission sources and laboratory generated moist gases with water vapor contents exceeding 35% V/V. The purge air to feed gas flow rate ratio is maintained at 3:1 in the primary dryer by operating the purge side under approximately 63 cm Hg vacuum.

Potential sulfur dioxide losses across the interface system were evaluated during laboratory and limited field testing. The testing program involved the simultaneous monitoring of a gas mixture containing SO₂ both before and after it passed through the interface system using the EPA Reference Method 6⁹. During the laboratory phase of testing, gas mixtures containing a nominal SO₂ level of 200 ppm and moisture contents of <1%, ~11%, ~22%, and ~34% were generated and passed through the interface system. The SO₂ was added by passing the gas stream (prior to the SO₂ addition) through a temperature controlled water bath. Moisture levels were determined by the condensation technique similar to EPA Method 4⁹. Oil-fired power boiler flue gases containing nominal SO₂ and moisture concentrations of 700 ppm and ~10%, respectively, were simultaneously tested and the results of both laboratory and field tests are reported in Table I.

Table I. Interface system SO₂ loss test results.

Approx. Moisture Content, % (V/V)	Range of SO ₂ Concentrations, ppm (V/V)	Number of Simultaneous Tests	Mean Difference (Out - In), ppm (V/V)	Is Difference Significant at 95% Level?
<1 ^a	165-210	6	1	No
11 ^a	176-192	4	6	No
22 ^a	158-194	7	4	No
34 ^a	129-224	6	2	No
10 ^b	626-738	5	45	Yes

^a Laboratory generated gas mixtures

^b Oil-fired power boiler flue gases

The summarized results indicate that the differences in the SO₂ levels measured in the gas entering and leaving the interface system were not significant except for the case when oil-fired power boiler flue gases were monitored. In this case, the gas leaving the system showed a higher concentration of SO₂ in all five test runs than the gas entering the system. This discrepancy may have been caused by improper application of the Method 6 testing procedure, or possibly by irreversible absorption of SO₂ in the isopropanol bubbler which was only used in the "entering gas" sampling train. Since the mean differences (level out - level in) at all moisture contents were at least slightly positive, SO₂ losses across the interface did not exist. Similar testing of the Perma-Pure Dryer has been reported¹⁰ and the results indicated no losses of SO₂ and H₂S at moisture levels of 4, 8 and 12%

Conclusions

An extractive interface system for continuous source monitors has been designed and fabricated. Continuous stack gas particulate removal is accomplished by both coarse and fine filtering devices with an automatic backpurge system for cleansing the coarse filter when necessary. Two permeation distillation dryers are used for moisture removal and have demonstrated the capability to reduce water vapor contents of greater than 35% (V/V) to less than 1% (V/V) on a continuous and reliable basis. Sample transport pumps coupled with a motorized valve and automatic controller function to transport a constant supply of gas to the distribution/dilution module of the interface system. This module, along with the calibration module, is used to route precisely regulated quantities of either stack gas, diluted stack gas, zero air or calibration gases to the analyzers. Based on laboratory and field wet chemical testing results, no SO₂ losses across the interface system were detected. Functional testing of the interface subsystems and components has demonstrated considerable versatility, ease of operation and good accessibility for maintenance.

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Captions

1. Figure 1. Gas sampling interface system schematic - sample transport, particulate and moisture removal systems.
2. Figure 2. Distribution/dilution module and calibration module schematics.
3. Figure 3. Photograph of front view of interface control panel.
4. Figure 4. Photograph of opened up view of interface panel showing back pressure regulators, selector valves, dryers, Teflon manifolds, etc.
5. Table I. Interface system SO₂ loss test results.

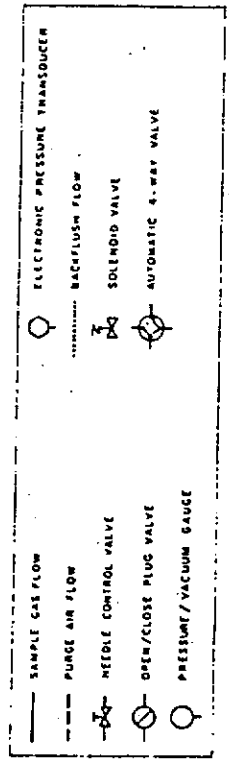
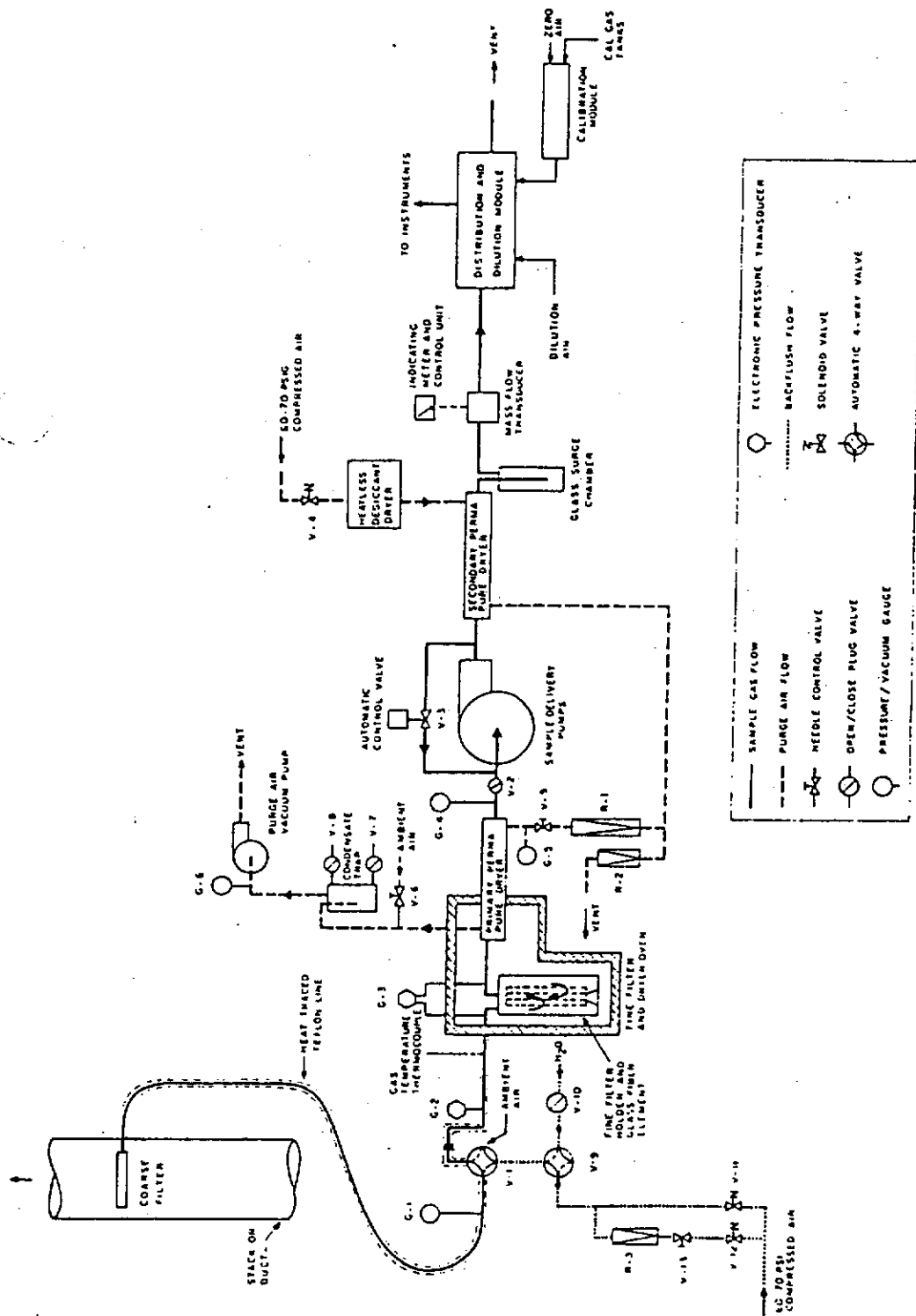


Figure 1. Gas sampling interface system schematic - sample transport, particulate and moisture removal systems.

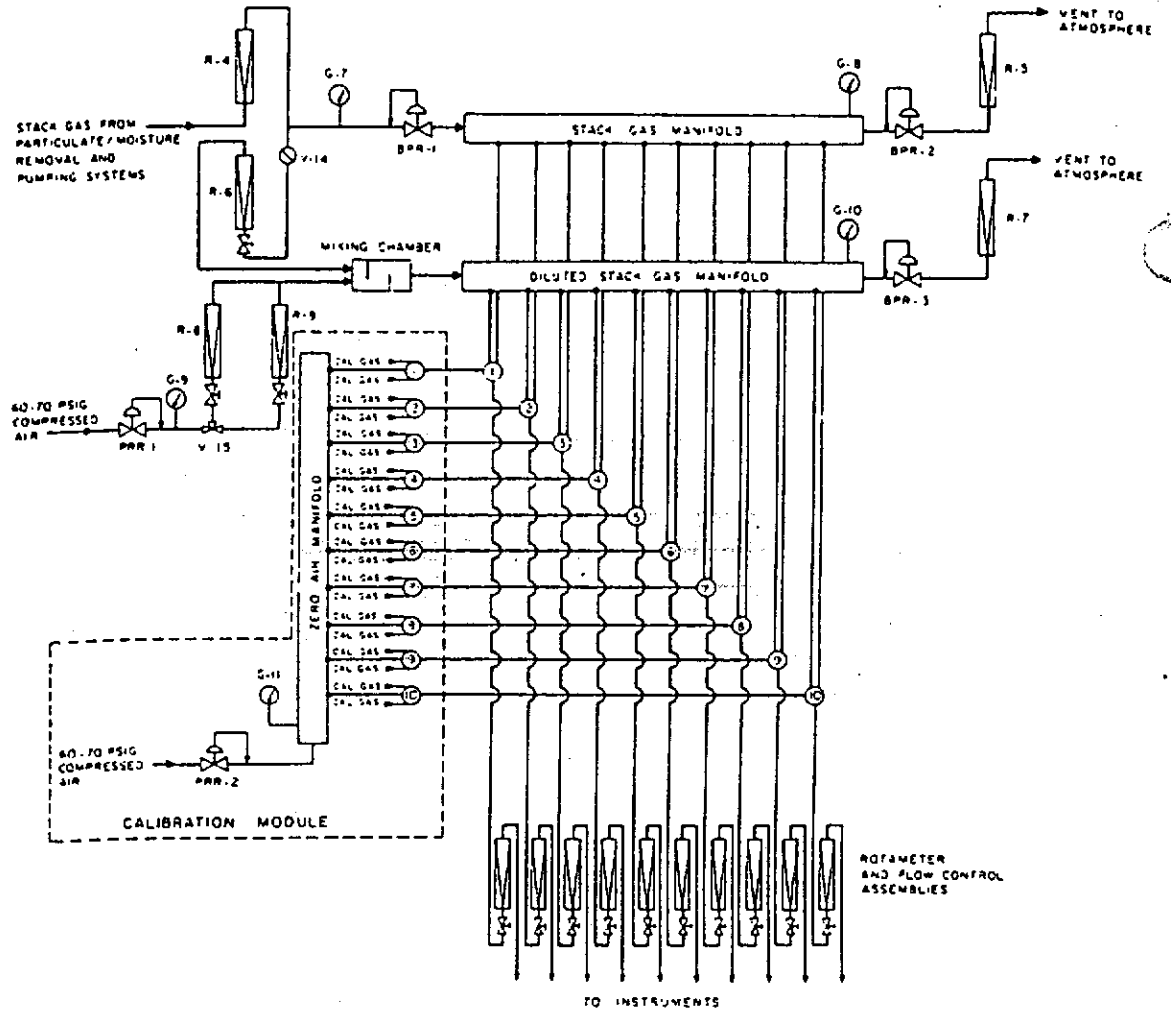


Figure 2. Distribution/dilution module and calibration module schematics.