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At-sea Incineration: Evaluation of Waste Flow and Combustion Gas Monitoring Instrumentation Onboard the M/T Vulcanus

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At-sea Incineration: Evaluation of Waste Flow and Combustion Gas Monitoring Instrumentation Onboard the M/T Vulcanus

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Engineering liaison to adapt test equipment for use onboard the M/T Vulcanus was facilitated by the management of Ocean Combustion Services, B.V., of the Netherlands. Installation of this equipment was accomplished through the assistance of the ship's officers and crew. Assistance in equipment logistics was received from United Marine Services of Antwerp, Belgium. Cooperation by the members of the French Atomic Energy Commission team is acknowledged during the performance of the EPA supported experiments onboard the M/T Vulcanus.

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The authors are indebted to the many individuals of all of these organizations for their contribution.

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1. INTRODUCTION, BACKGROUND AND SUMMARY

1.1 INTRODUCTION

This report describes a program conducted by the U. S. Environmental Protection Agency (EPA)* onboard the M/T Vulcanus to measure waste flowrates and concentrations of CO, CO_2, and O_2 in the combustion gas during incineration of industrial chemical waste. Specific objectives of the program were:

- Evaluate two types of waste flowmeters (operating on ultrasonic and vortex shedding principles) in order to provide a more reliable and accurate method of monitoring waste flowrates for incineration onboard vessels.

- Evaluate a CO, CO_2, O_2 measurement system installed to provide routine monitoring of combustion efficiency during waste incineration.

To accomplish these goals, the following tasks were performed:

- Evaluation and selection of available flow measurement devices, on-line gas analyzers for CO, CO_2, and O_2, and gas conditioners

- Procurement, assembly, and checkout of the selected flow measurement and combustion gas analysis systems

- Shipment of all equipment to Europe and installation onboard the M/T Vulcanus while in port for waste loading

- Operation of all equipment daily during waste incineration in the designated North Sea burn area

- Analysis of data collected and determination of post-test condition of all equipment

A brief background of the requirements for shipboard instrumentation and a summary of the overall results of this evaluation are presented in this section. Subsequent sections describe the M/T Vulcanus, selected instrumentation, installation and operation of equipment, and detailed test results.

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*Contract No. 68-02-2660

1.2 BACKGROUND

The M/T Vulcanus, chartered by Ocean Combustion Services, B. V., of the Netherlands, has been incinerating chemical wastes since 1972. The U. S. EPA had previously contracted with TRW, Inc., to provide environmental monitoring onboard the Vulcanus for the incineration of organochlorine wastes in the Gulf of Mexico (Reference 1) and the destruction of Herbicide Orange off Johnston Island in the Pacific Ocean (Reference 2). TRW personnel provided and operated the combustion gas sampling systems for these burns and also became familiar with the existing instrumentation and measurement methods used onboard the ship.

During at-sea incineration onboard the M/T Vulcanus, the total amount of waste burned is usually determined by manually sounding (measuring with a tape) the liquid level in each of 15 cargo tanks of known volumetric capacity. A relatively accurate sounding of the tanks is accomplished at dockside before and after each burn period. Accuracy of at-sea measurements is questionable because the ship is subject to roll and pitch conditions. If sea conditions become sufficiently rough, tank sounding becomes impractical and at times unsafe. Another inaccuracy inherent in determining flow rates through tank depletion is the fact that a residual quantity of waste is present in each tank following a burn. This volume is increased during rough sea conditions because of sloshing and periodic movement of the waste away from the drainage line in the tank bottom.

For these reasons, a more reliable, direct, and accurate method of establishing and monitoring waste feed rates is desirable. An evaluation of commercially available flow measurement devices was conducted as part of this overall program. As a result of this study (Reference 3), two different types of flowmeters, ultrasonic and vortex shedding meters, were selected for evaluation onboard the M/T Vulcanus. The objective of this evaluation was to determine the capability of each of these meters to withstand the at-sea environment and accurately and continuously measure waste flowrate during incineration.

Experience in monitoring the incineration of organochlorine waste and Herbicide Orange onboard the Vulcanus has shown that combustion efficiency is a good indication of waste destruction efficiency. Combustion efficiency is one of the regulatory criteria for governing waste incineration at sea. CO and CO_2 are the critical species to be determined in order to calculate combustion efficiency. Effluent O_2 concentration is also a relative indication of combustion efficiency. A CO, CO_2, and O_2 monitoring system for incineration effluents from at-sea incineration was evaluated from the standpoint that the monitoring system would be a standard piece of equipment onboard the ship and operation would be accomplished routinely by regular shipbased personnel.

1.3 SUMMARY

The following are key accomplishments and conclusions of this test program:

1) The $CO/CO_2/O_2$ monitoring equipment performed satisfactorily throughout the test burns onboard M/T Vulcanus. Equipment problems encountered were minor in nature and easily resolved.

2) The combustion efficiency during the first burn was 99.983 ± 0.023%,* which was well within the Intergovernmental Maritime Consultative Organization (IMCO) requirement of 99.95 ± 0.05%. Third burn combustion efficiency was 99.983 ± .017, demonstrating the consistency of the measurement instrumentation and combustion gas composition.

3) Both the ultrasonic and vortex waste flowmeters performed satisfactorily, showing good agreement in flow readings and requiring no maintenance.

4) Several days of training of personnel most likely to operate the equipment (e.g., Chief Engineer) were sufficient to operate the $CO/CO_2/O_2$ monitoring equipment satisfactorily. Only a few hours of training were required in the operation of flowmeters.

5) The maximum duration of continuous $CO/CO_2/O_2$ equipment operation was 12 hours. Based upon equipment performance, it is assumed that continuous 24-hour operation can be achieved. Operator time can be reduced significantly by adding automatic calibration capability to each of the combustion gas analyzers.

6) Flowmeters were operated 24 hours per day without any problems. All flowmeters were left on board, after the TRW crew departed the ship, for operation by the ship's crew.

7) The estimated cost for purchase and installation of a $CO/CO_2/O_2$ monitoring system based on 100% spare analyzer and gas conditioner capability (using M/T Vulcanus experience) is approximately $40,000.

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*90% confidence that 99% of all data are within this range.

8) The estimated cost for the waste flowmeters per waste flow line (M/T Vulcanus used 3 waste flow lines) is approximately $6,000 for an ultrasonic and $3,000 for a vortex flowmeter, including recording equipment.

9) Based upon experience onboard M/T Vulcanus, the frequency and duration of sampling for combustion efficiency could be reduced to three two-hour test periods in a 24-hour day, each test period randomly selected during one 8-hour shift operation.

10) In case of equipment breakdown, the minimum monitoring requirement to ensure protection of the marine environment during equipment repair is considered to be the incinerator temperature and O_2 measurement.

11) Post-test inspections of the analyzers, conditioners and flowmeters revealed the following:

(a) Malfunction of electronic packages in two analyzers, which were replaced with spares

(b) Evidence of wear on some conditioner valves

(c) Minor corrosion in some analyzer and conditioner fittings

(d) Indication of gradual waste build-up in the vortex flowmeter, which was easily cleaned

(e) No waste build-up in the piping of ultrasonic flowmeter systems

Use of spare instruments ensured continued acquisition of combustion efficiency data throughout the burns.

2. DESCRIPTION OF THE M/T VULCANUS

2.1 GENERAL DESCRIPTION OF VESSEL AND INCINERATION EQUIPMENT

The M/T Vulcanus, originally a cargo ship, was converted in 1972 to a chemical tanker fitted with two large incinerators located at the stern. The vessel meets all applicable requirements of the Intergovernmental Maritime Consultative Organization (IMCO) concerning transport of dangerous cargo by tanker. Figure 1 is a picture of the vessel. Specifications and a detailed description of the ship's equipment have been previously presented in "At-Sea Incineration of Organochlorine Wastes Onboard the M/T Vulcanus" (Reference 1). The following description is intended to briefly review the ship's equipment noting any new changes or new information.

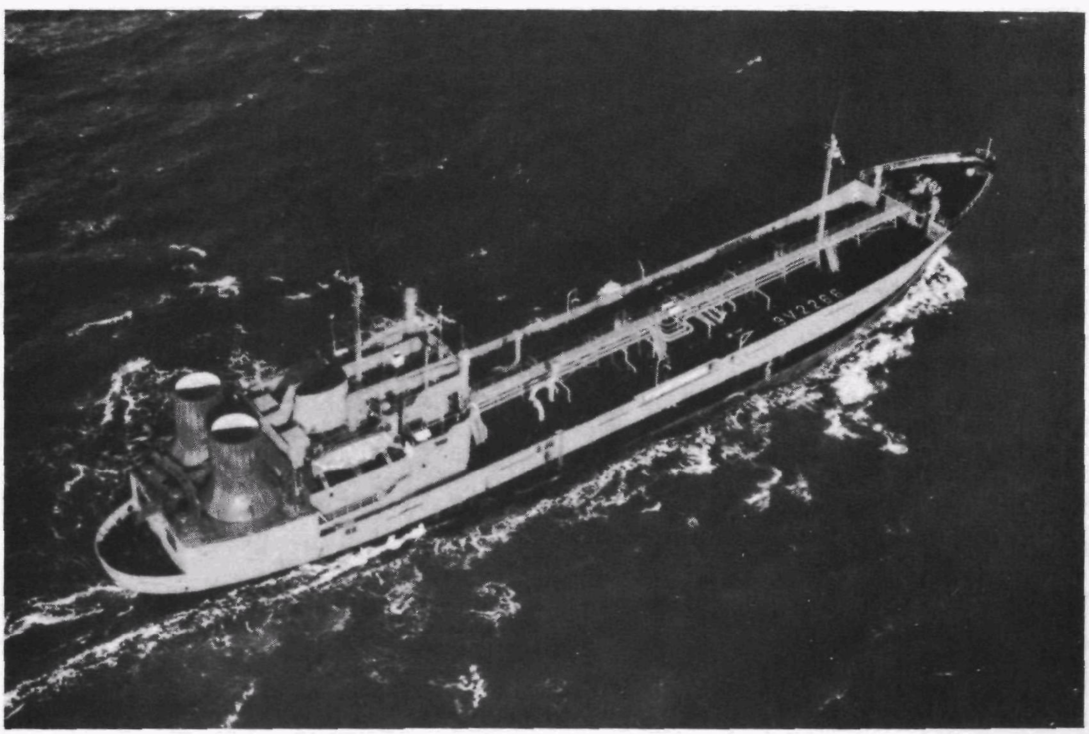

Figure 1. M/T Vulcanus-incinerator vessel

Waste is carried in 15 cargo tanks which range in size from 115 to 574 cubic meters (m^3) with an overall capacity of 3503 m^3. During normal operation the waste tanks can be discharged only through the incinerator feed system. There is, however, provision for discharging the cargo into the ocean if an emergency arises. Piping system construction makes it possible for any tank to be connected to either incinerator and for cargo to be transferred from one tank to another.

Waste is burned in two identical refractory-lined furnaces located at the stern. Each incinerator consists of two main sections, a combustion chamber and a stack, through which the combusting gases pass sequentially. This dual chamber configuration uses the first chamber for internal mixing and the second for adequate residence time.

Combustion air is supplied by large fixed speed blowers with a rated maximum capacity of 90,000 cubic meters per hour for each incinerator. Although no instrumentation is installed to monitor air flowrate, normal operation stated by the ship's engineer is about 80,000 cubic meters per hour.

Liquid wastes are fed to the combustion system by means of electrically driven pumps. The normal flowrate of waste is 2 to 3 cubic meters per hour per burner. Three vortex type burners are located at the same level on the periphery and near the base of each incinerator. Three-way valves are utilized on each burner to provide either waste feed, fuel oil feed, or a shutoff condition. Figure 2 is a schematic of the incinerator feed system, showing the piping and instrumentation at one incinerator, with the other incinerator being identical.

Periodically during the incineration process the burners require cleaning. Normally, each incinerator is shut down and the three burners are cleaned sequentially. Sometimes single burner cleaning is performed (should only one burner become plugged) while the remaining two burners fire waste. Cleaning is easily accomplished, and the normal period of time to clean three burners is less than one-half hour. During this time, incinerator temperature drop was insufficient to warrant use of fuel oil for reheating the incinerator prior to restart.

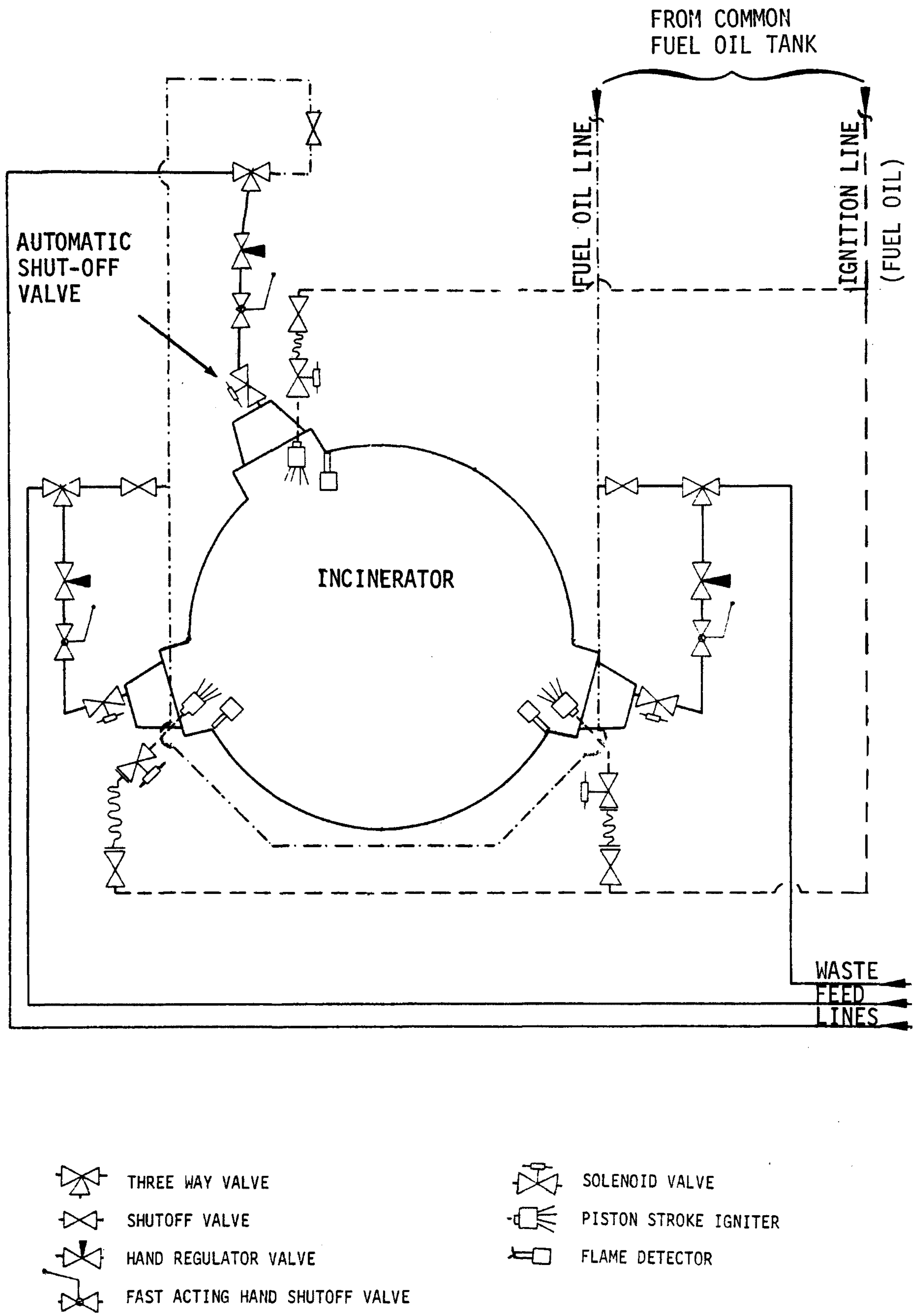

Figure 2. Incinerator feed line schematic

2.2 OPERATIONAL EQUIPMENT

Control of the incineration process is achieved by sounding of the waste liquid level in the tanks currently feeding the incinerators and by measurement of the wall temperature of the incinerator. An emergency automatic shutoff system, which monitors various components of the incineration system for failure, is also utilized.

2.2.1 Manual Sounding of Waste Tanks

Sounding of the liquid level in the tank is performed for two reasons. One is to estimate the approximate time the tank will become empty, the second is to monitor the liquid level as the level approaches the bottom of the tank. This ensures that switching to a new tank is accomplished before a flame out condition occurs. Normally, the center tanks on the ship are sounded when the liquid level in the tanks is visually low. The wing tanks, however, are sounded every hour because of their small capacity.

2.2.2 Measurement of the Incinerator Wall Temperature

Temperatures during operation of the incinerators are measured by two platinum-platinum/10% rhodium thermocouples in each incinerator. Each pair is located in the wall opposite one of the burners. One thermocouple provides temperature information to the automatic waste shutoff system and is called the controller thermocouple. A second thermocouple is referred to as the "indicator" because it provides temperature information to a panel located in the incinerator control room and to a panel ("black box") located on the bridge.

2.2.3 Emergency Automatic Waste Shutoff System

The following description of the automatic waste shutoff system utilized by the M/T Vulcanus is based upon verbal description of the system given to the contractor by the ship's crew.

The waste shutoff system consists of a number of different components which can effect the closing of spring loaded solenoid valves which shut off waste flow to each burner and simultaneously shut off power to the waste pumps. These spring loaded solenoid valves are normally closed. During incineration, the valves are held open by an electrically induced magnetic field. The waste flows through the solenoid valves until the electrical current is interrupted

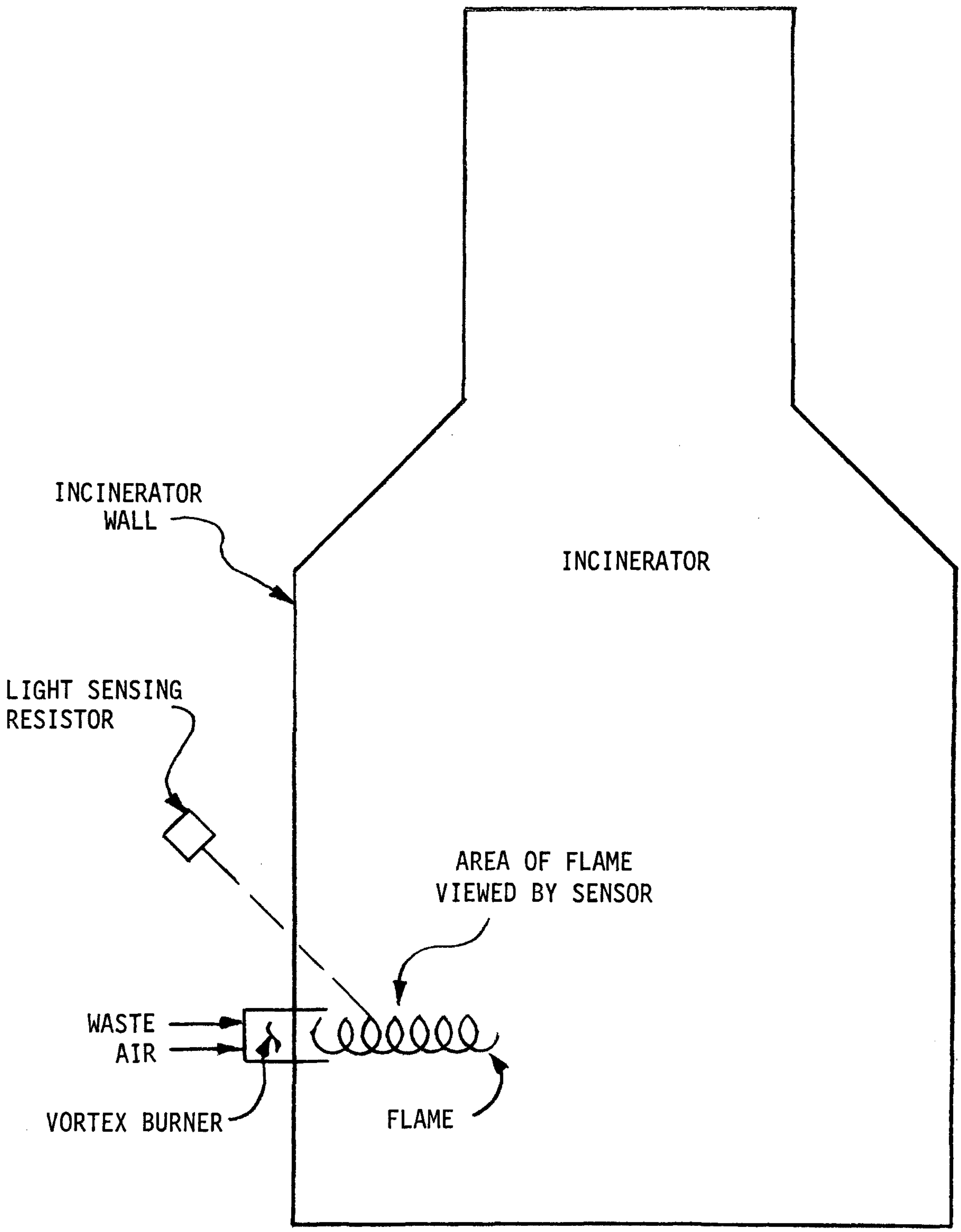

Figure 3. Optical flameout detector (light sensing resistor)

by a malfunction in the incineration system. Once interrupted, the malfunction must be repaired and restart procedures implemented before incineration can continue. These restart procedures require fuel oil startup if the incinerator temperature has dropped below a specified minimum temperature.

The automatic waste shutoff system will stop waste flow (or fuel oil flow) to the affected burner(s) and shut off power to the waste pumps when any one of the following malfunctions occur:

- Waste pump overload
- Combustion air fan motor overload
- Burner pump overload
- Steering air (directs and shapes burner flame) or combustion air failure to reach an incinerator burner

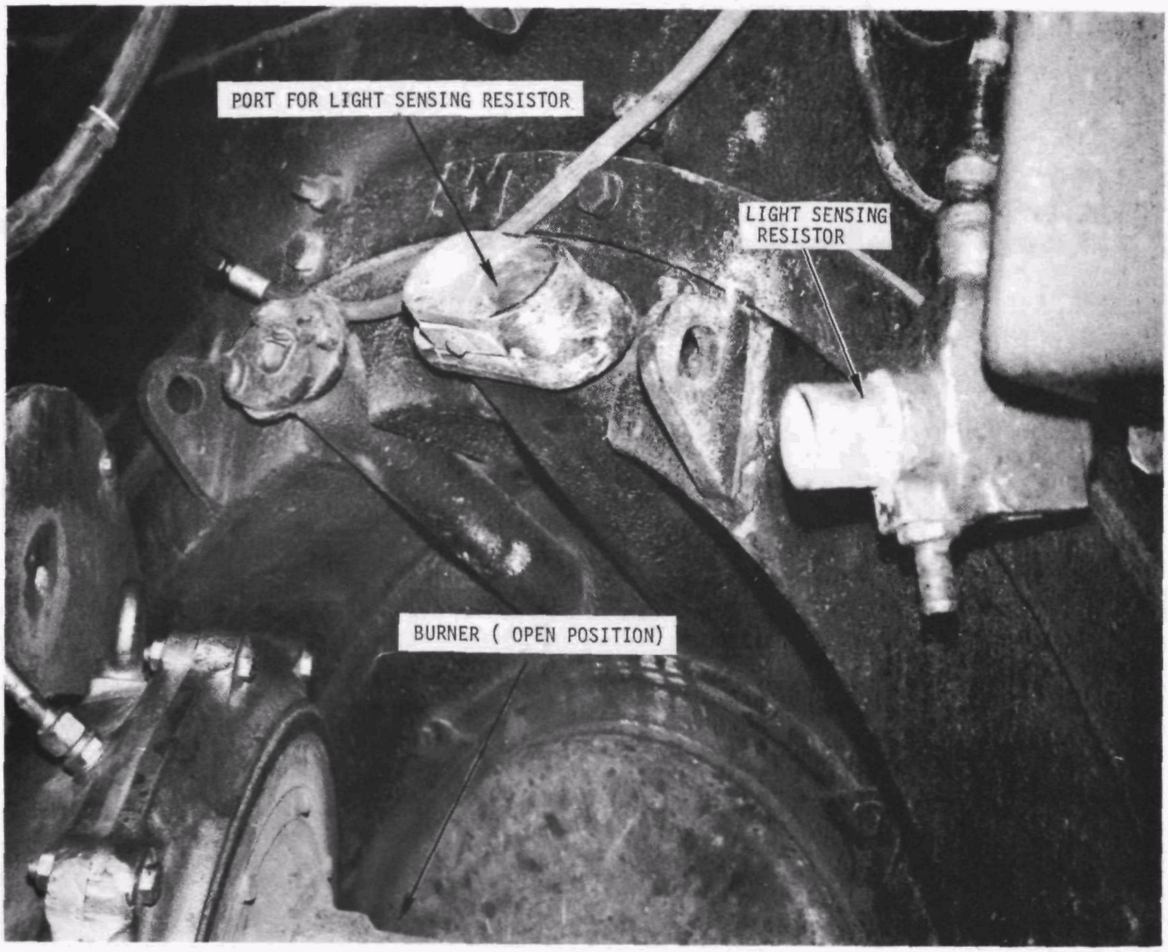

Figure 4. Location of flameout detector

- Open burner: A mechanical switch interrupts the electrical current when the burner swings open away from the incinerator wall (usually opened to remove residue during burner cleaning).
- Flame out: A light sensing resistor is located directly above each burner to monitor the flame. This resistor operates by viewing the flame and amplifying and conditioning the signal (see Figures 2, 3, and 4). Output of the sensor opens and closes several sets of contacts, half of which are normally closed and half normally open (under no flame condition). The normally closed contacts are not used in this system. Wires which conduct the electrical current used to induce the magnetic field for the waste shutoff valve are connected to the normally open position. During stable incineration the contacts are closed, and the electrical current flows through the contacts, completing the circuit which produces the magnetic field holding the waste shutoff valve open. Upon flame blockage or electrical failure, the contacts connected will return to normally open position, breaking the electrical current and removing the magnetic field from the waste valve, which in turn shuts by spring action.
- Temperature drops below minimum acceptable temperature: A thermocouple controlled sensor interrupts the waste shutoff valve electrical current when the incinerator temperature drops below a preselected minimum temperature. The system used is the Plastomatic 2000 (supplied by Withoff-Philips, Bremen, West Germany), previously discussed in Reference 1.

Once flow has been stopped by the automatic shutoff system, any malfunctions are repaired, and the following restart procedures are implemented:

- Manually restart waste pumps (or start fuel oil pumps if incinerator temperatures are low enough to require fuel oil startup).
- Depress ignitor button to provide ignition flame.
- Manually open emergency shutoff valve to initiate waste (or fuel oil) flow to burner.
- After stable combustion is attained, deactivate manual override of the emergency shutoff valves to return to automatic shutoff control condition.

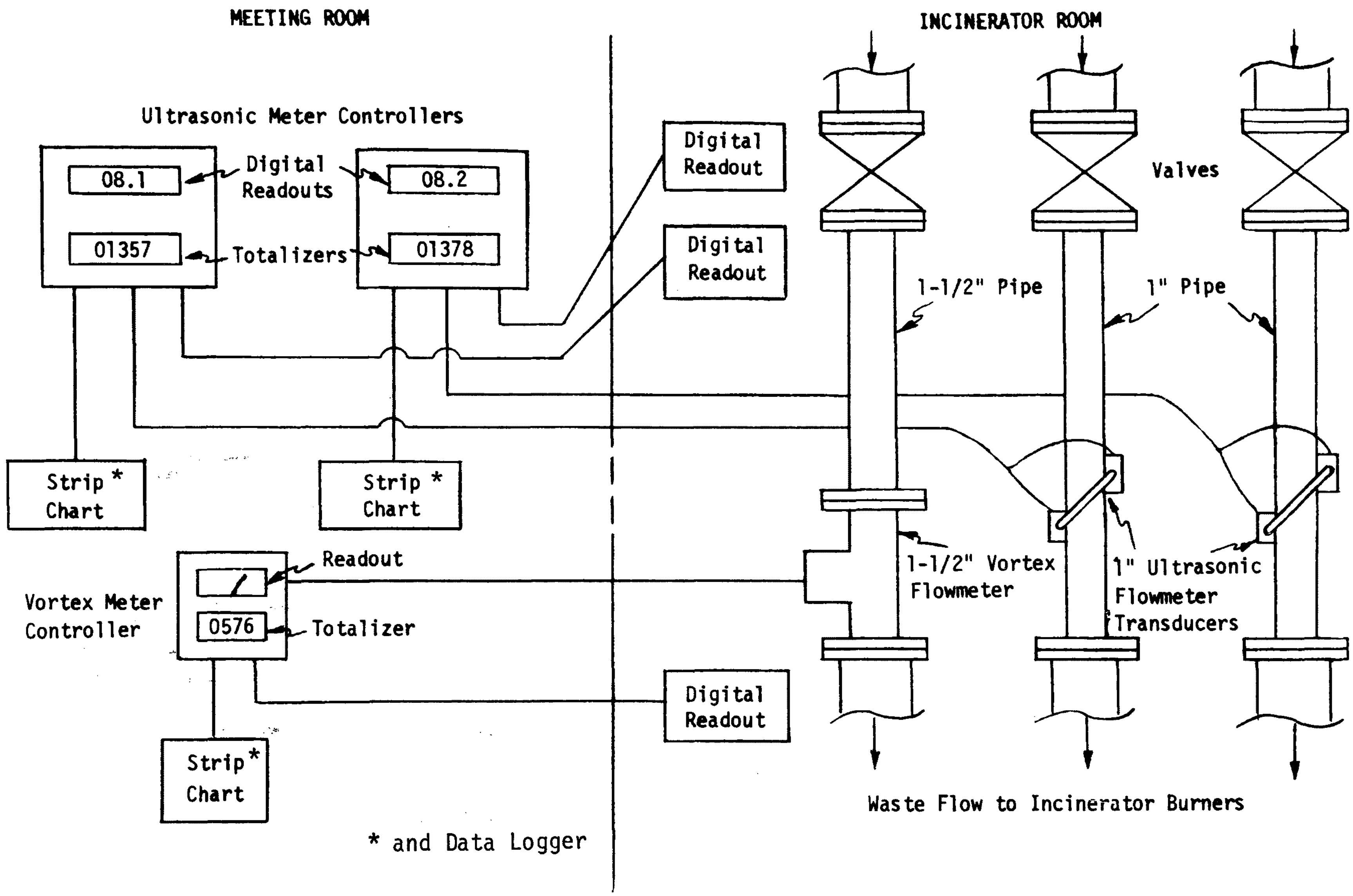

Figure 5. Flowmeter installation schematic

3. TEST INSTRUMENTATION

Test instrumentation evaluated onboard the M/T Vulcanus included two types of waste flow measurement devices and an on-line analyzer system for monitoring CO, CO_2, and O_2 in the incinerator combustion gas. The following sections describe each measurement system and its installation and operation.

3.1 FLOW MEASUREMENT SYSTEM

The flow measurement system consisted of flow sensors installed in the ship's waste feed piping and flow readout and recording devices, as shown schematically in Figure 5. Two basic types of flowmeters were selected for shipboard evaluation: 1) vortex shedding, and 2) ultrasonic. Installation of the flowmeters is shown in Figure 6. Location of the flowmeter controllers and

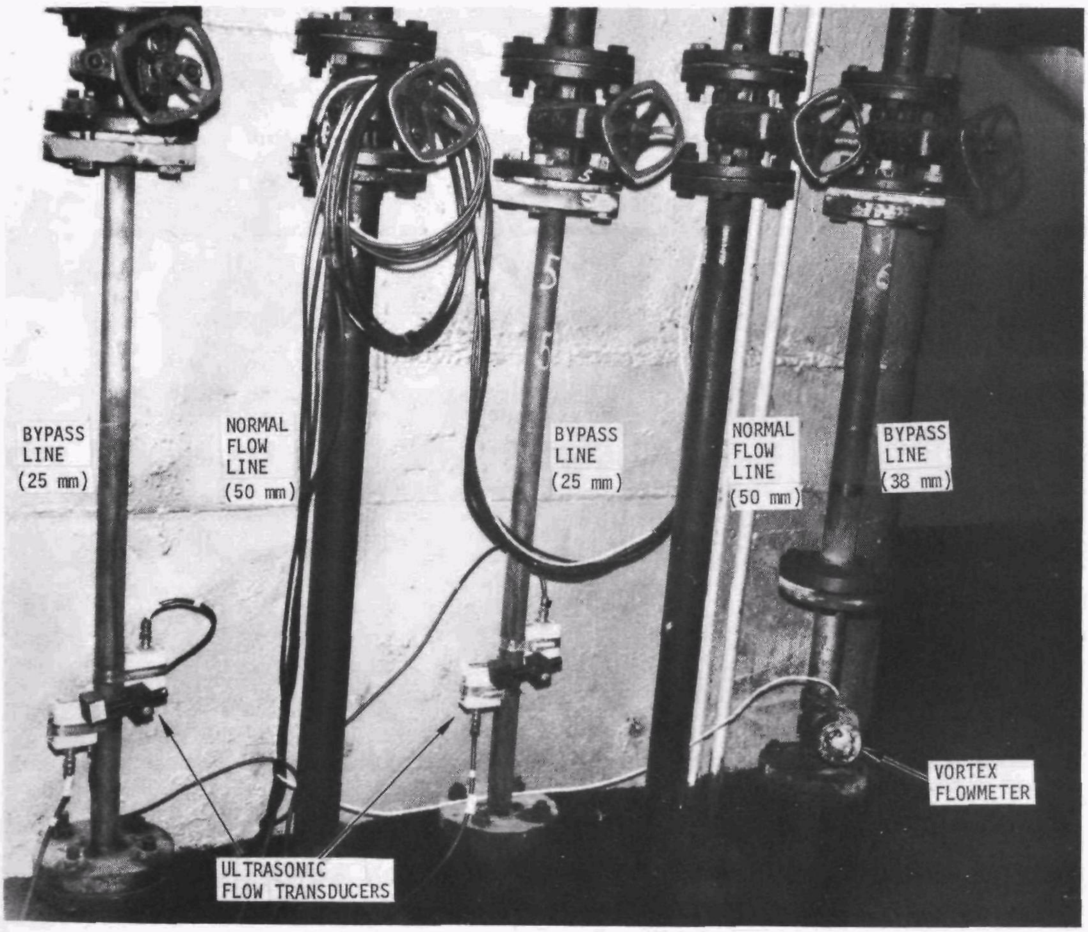

Figure 6. Flowmeters and waste piping in incineration control room

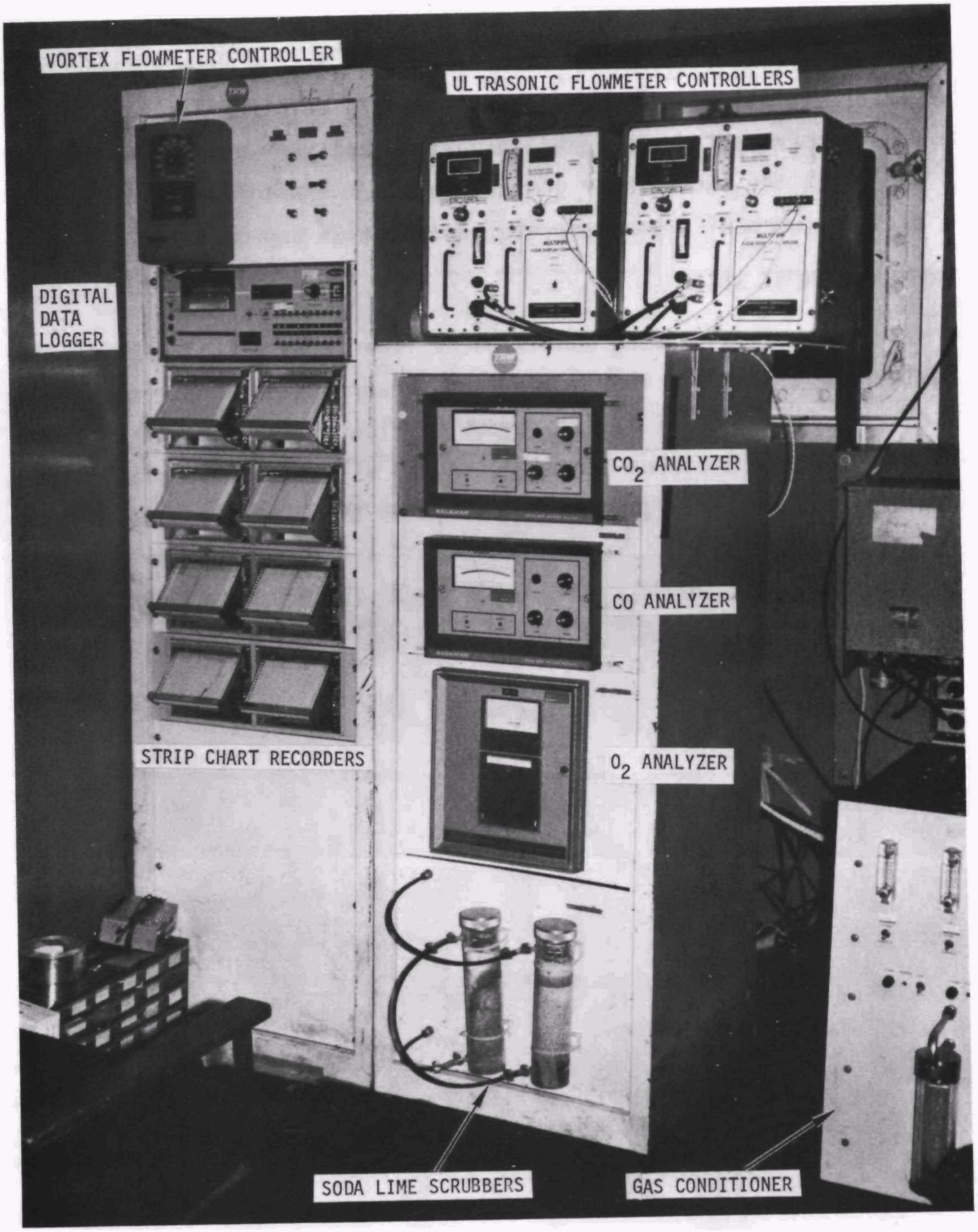

Figure 7. Test instrumentation installed in ship's meeting room

recorders is illustrated in Figure 7.

3.1.1 Vortex Shedding Meter

Vortex shedding meters are relatively new in the flow measurement field but have become highly developed in a short time period. The basic principle (Figure 8) is a well-known hydrodynamic phenomenon: flow past an unstreamlined obstruction cannot follow the obstacle contours on the downstream side, and separated layers become detached and roll into vortices in the low pressure area behind the body. Vortices are shed periodically from alternate sides of the body at a frequency proportional to flow velocity. A minimum pipe Reynolds number of at least 10,000 is required to sustain formation of vortices. At higher Reynolds numbers, the shedding frequency becomes independent of Reynolds number and the following relationship applies:

$$f = k \frac{V}{h} \qquad (1)$$

where

f = shedding frequency
k = constant
V = fluid velocity
h = cylinder height

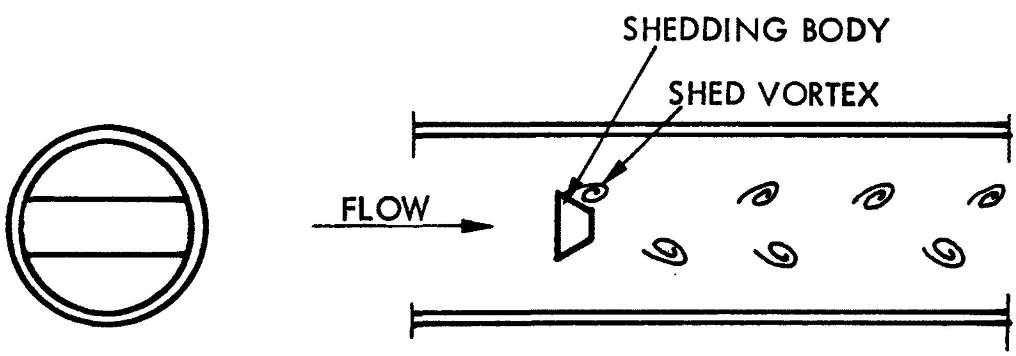

Figure 8. Vortex shedding meter schematic

Flow velocity is therefore directly proportional to shedding frequency. A number of methods have been developed to detect shedding frequency:

- Thermistors to detect changing direction of fluid path around obstruction

- Strain gage on tail of obstruction to detect deflection
- Ultrasonic sensing of vortices downstream of obstruction

Fischer and Porter's Series 10LV2000 liquid vortex flowmeter (Figure 6), selected for this evaluation, utilizes a strain gage on the obstruction for detection of shedding frequency. The meter output signal (m^3/hr) was displayed on the vortex meter controller and recorded on the digital data logger and a strip chart in the ship's meeting room (Figure 7). Flow readings (m^3/hr) were also displayed on digital readouts in the incinerator room, as shown in Figure 9. Totalizers for each meter also indicated accumulated total flow (m^3) on displays in the meeting room.

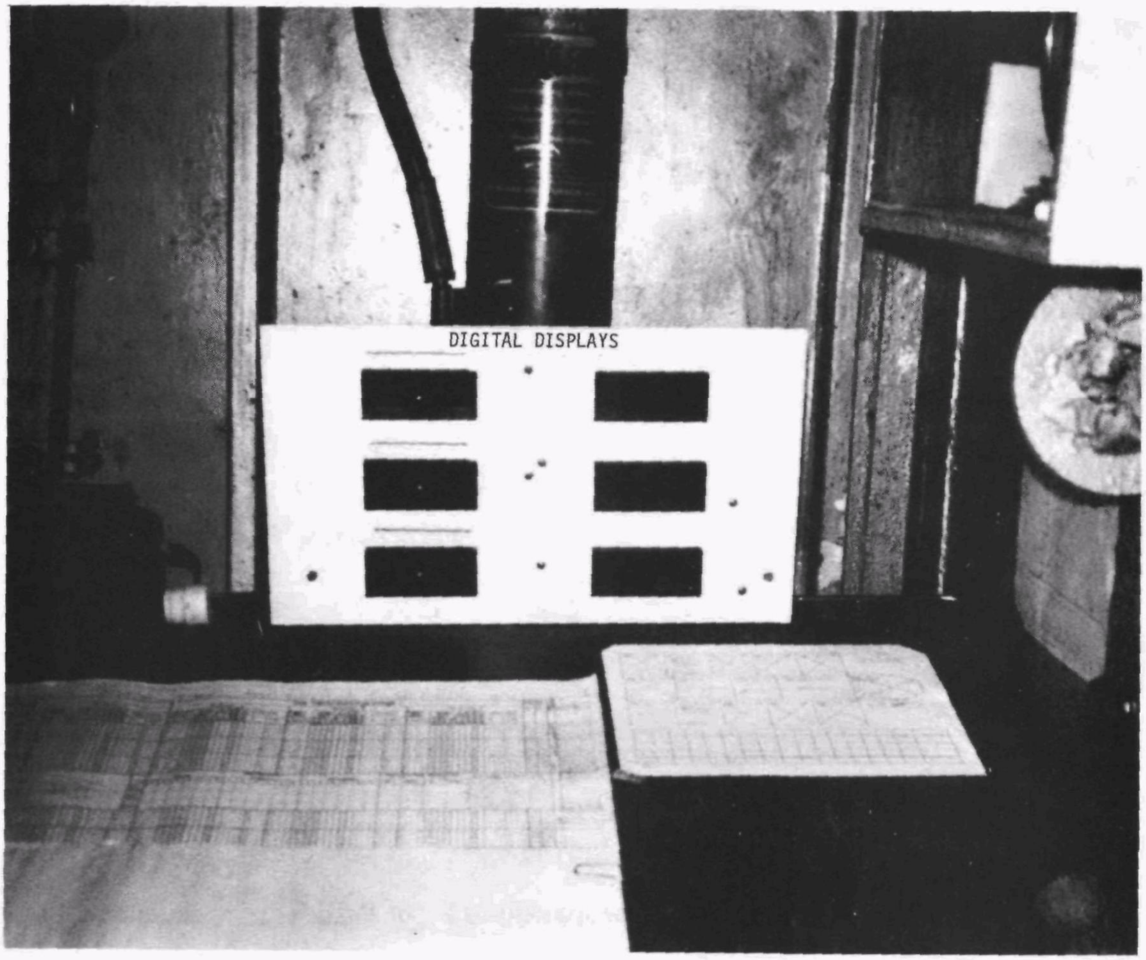

Figure 9. Remote flowmeter digital readouts located in incineration control room

3.1.2 Ultrasonic Meter

The Controlotron Series 240 ultrasonic flowmeter utilizes high frequency sound waves to measure flow velocity by the following basic principle: the resultant velocity of sound waves in a moving fluid is the vector sum of the fluid velocity and the sound velocity in the fluid at rest.

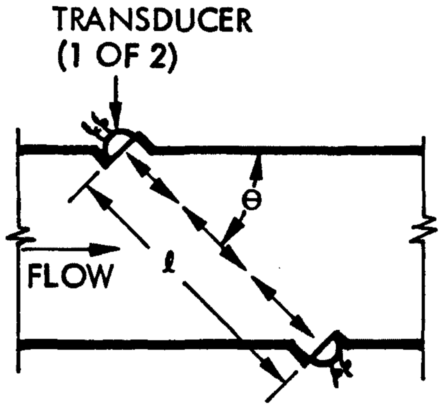

Figure 10. Ultrasonic meter schematic

As shown in Figure 10, two transducers, each capable of both sending and receiving, alternately transmit ultrasonic pressure pulses against and then with the direction of flow. The resultant pulse transit times can be expressed as:

$$t_d = \frac{\ell}{C + V\cos\theta} \quad \text{and} \quad t_u = \frac{\ell}{C - V\cos\theta} \qquad (2)$$

where:

t_d = pulse transit time downstream
t_u = pulse transit time upstream
ℓ = distance between transducers
C = speed of sound in fluid
V = fluid velocity
θ = angle between pipe axis and the acoustic path between transducers

Since frequency is the reciprocal of time period:

$$f_d = \frac{C + V\cos\theta}{\ell} \quad \text{and} \quad f_u = \frac{C - V\cos\theta}{\ell} \qquad (3)$$

$$\text{and} \quad f_d = f_u = \frac{2V\cos\theta}{\ell} \qquad (4)$$

where:

f_d = frequency of downstream pulses

f_u = frequency of upstream pulses

Difference in transit time, or frequency of pulses, with and against flow is proportional to fluid velocity and can be measured to determine flow velocity.

Installation of Controlotron flow transducers on two of the ship's waste feed lines is shown in Figure 6. Meter controller displays, digital data logger, and strip chart recorders are shown in Figure 7. Flow readings were also displayed in the incinerator room for the convenience of the ship's crew (Figure 9).

3.1.3 Equipment Costs

Costs of flowmeters and associated control and recording equipment installed on the M/T Vulcanus were:

- Ultrasonic flowmeter controller, flow transducer cable, strip chart recorder, mounting panels, remote flow indicator - approximately $6,000 for each meter, plus 2 - 4 manhours installation time
- Vortex flowmeter controller, flow sensor, cable, strip chart recorder, mounting panels, remote flow indicator - approximately $3,000 for each meter, plus 2 - 4 manhours installation time

3.2 CO, CO_2, O_2 MEASUREMENT SYSTEM

The on-line CO, CO_2, O_2 measurement system consisted of sample probes and lines, gas conditioner, calibration gases (CO, CO_2, O_2, and zero air), purge air line, and CO, CO_2, and O_2 analyzers all schematically shown in Figure 11. Figure 7 shows the system as it was installed in the meeting room onboard ship. A soda lime scrubber was used to protect the O_2 analyzer from hydrogen chloride in the sample gas.

3.2.1 Sample Probes and Lines

The probes used for the on-line monitoring system were 1.27 cm OD (0.5 in.) high temperature alumina tubes with a wall thickness of 1.6 mm. The alumina material was inert and had been shown to operate well in similar environments. One probe was installed in each incinerator. Teflon® lines connected the

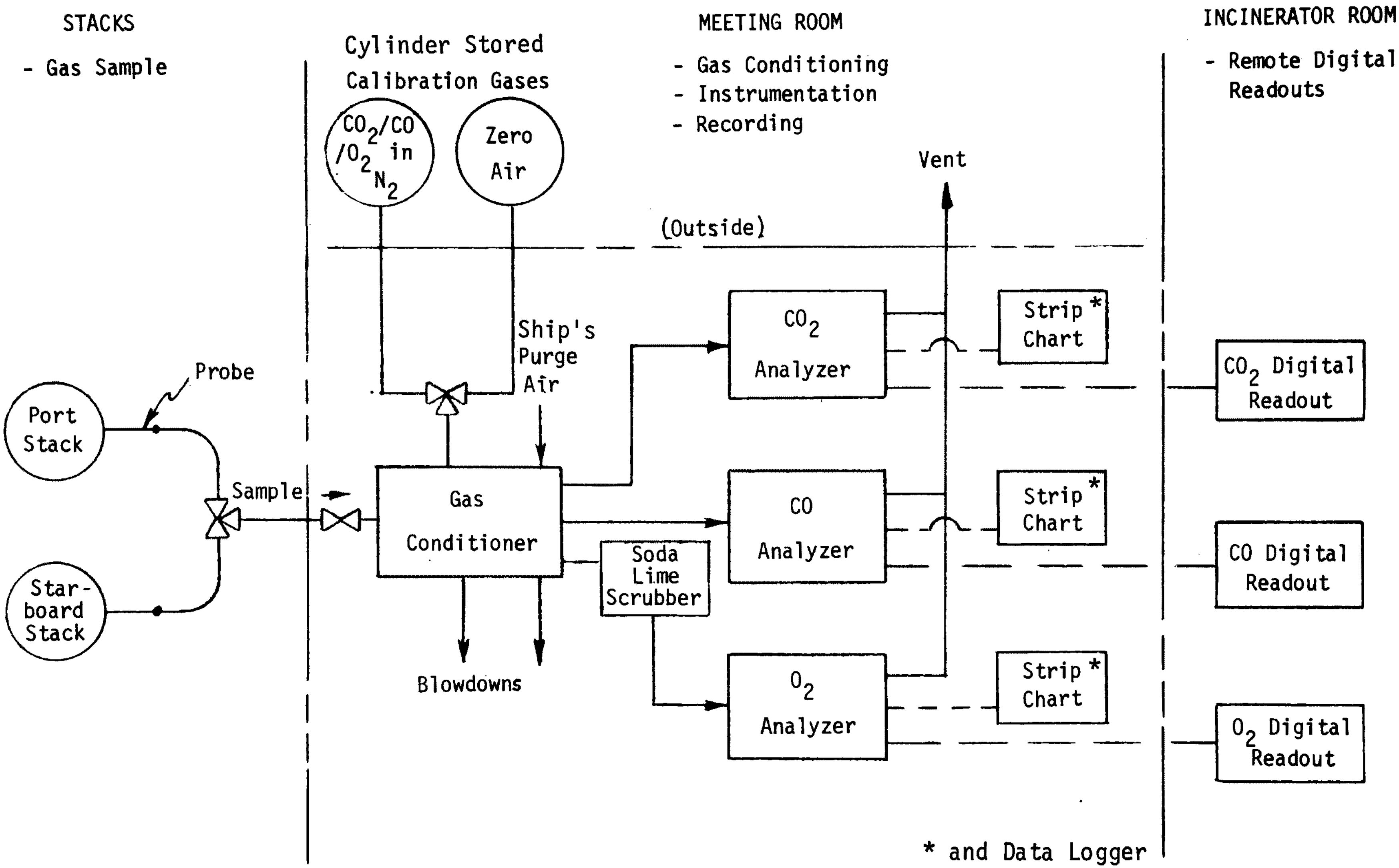

Figure 11. $CO/CO_2/O_2$ monitoring system installation schematic

probes to a three-way valve which was used to select either incinerator for gas analysis. A Teflon[R] line from the three-way valve was connected to the gas conditioner. This system made it possible to monitor either incinerator, although not both simultaneously. Figure 12 shows a probe installed onboard ship.

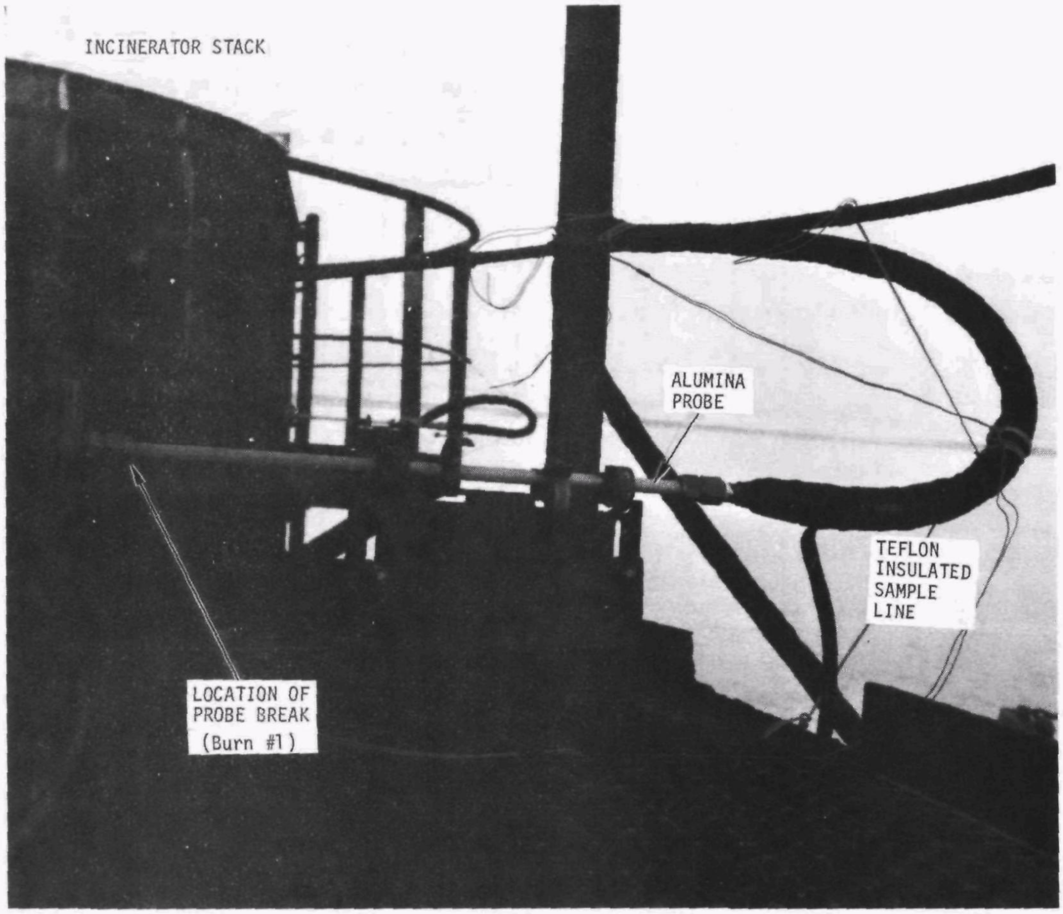

Figure 12. Sampling probe assembly installed onboard ship

3.2.2 Gas Conditioner

The gas conditioner was a Thermo Electron Corporation Model 600 sample conditioning system which utilized a refrigeration system to remove condensate and particulates from a continuous gas stream. This system was specifically designed to handle high concentrations of corrosive gases such as the high hydrogen chloride content of the combustion gas sampled. The model 600 gas conditioner supplied sufficient conditioned sample to operate all three (CO, CO_2, and O_2) analyzers in parallel. The dew point of the gas at the exit of the gas conditioner is reduced to approximately 4°C (40°F).

3.2.3 Gas Analyzers

On-line monitoring of the concentrations of CO, CO_2, and O_2 was accomplished by the use of two sets of gas analyzers. One set of analyzers was installed in the system (primary analyzers), and one spare set was stored onboard ship in case a primary analyzer malfunctioned and could not be repaired. Besides the spare analyzers, spare parts were also carried onboard. The analyzers and their calibration ranges are shown in Table 1. Output signals from each analyzer are displayed on strip charts and recorded by a digital data logger (Figure 7).

Table 1. ON-LINE GAS ANALYZERS AND CONDITIONERS

Species Analyzed Analyzed	Mfg. and Model	Analyzer Type	Analyzer Range
Carbon monoxide (CO) (primary and spare)	Beckman 865	NDIR*	0-200 ppm 0-2000 ppm 0-2%
Carbon Dioxide (CO_2) (primary)	Infrared Industries 703	NDIR*	0-10%, 0-30%
Carbon Dioxide (spare)	Beckman 864	NDIR*	0-4%, 0-8% 0-15%
Oxygen (O_2) (primary)	Beckman 742	Electro-chemical	0-5%
Oxygen (spare)	Taylor 0247A	Paramagnetic	0-5%, 0-10% 0-25%

Gas Conditioner	Thermoelectron 600
Gas Conditioner (spare)	Thermoelectron 600

*Non-Dispersive Infra-red

3.2.4 Equipment Costs

Costs of combustion gas analyzers and associated recording equipment installed on the M/T Vulcanus were:

- CO, CO_2, O_2 analyzers and sample gas conditioners (including 100% spares), sample probes, and heat trace lines, transformer, instrument rack, strip chart recorders (3 plus 1 spare), remote indicators - approximately $40,000
- Installation time - 48 manhours

4. TEST OPERATIONS

The Vulcanus arrived at the Pan Ocean, B.V., dock located at Antwerp, Belgium, on November 21, 1978. During the next two days, as waste was taken onboard, the equipment for waste flowrate and combustion gas measurement was loaded and most of it installed.

On November 23 the Vulcanus left port for the burn zone (burn zone #1, as shown in Figure 13) and arrived early the morning of November 24. During the travel period to the burn zone, equipment installation and final system

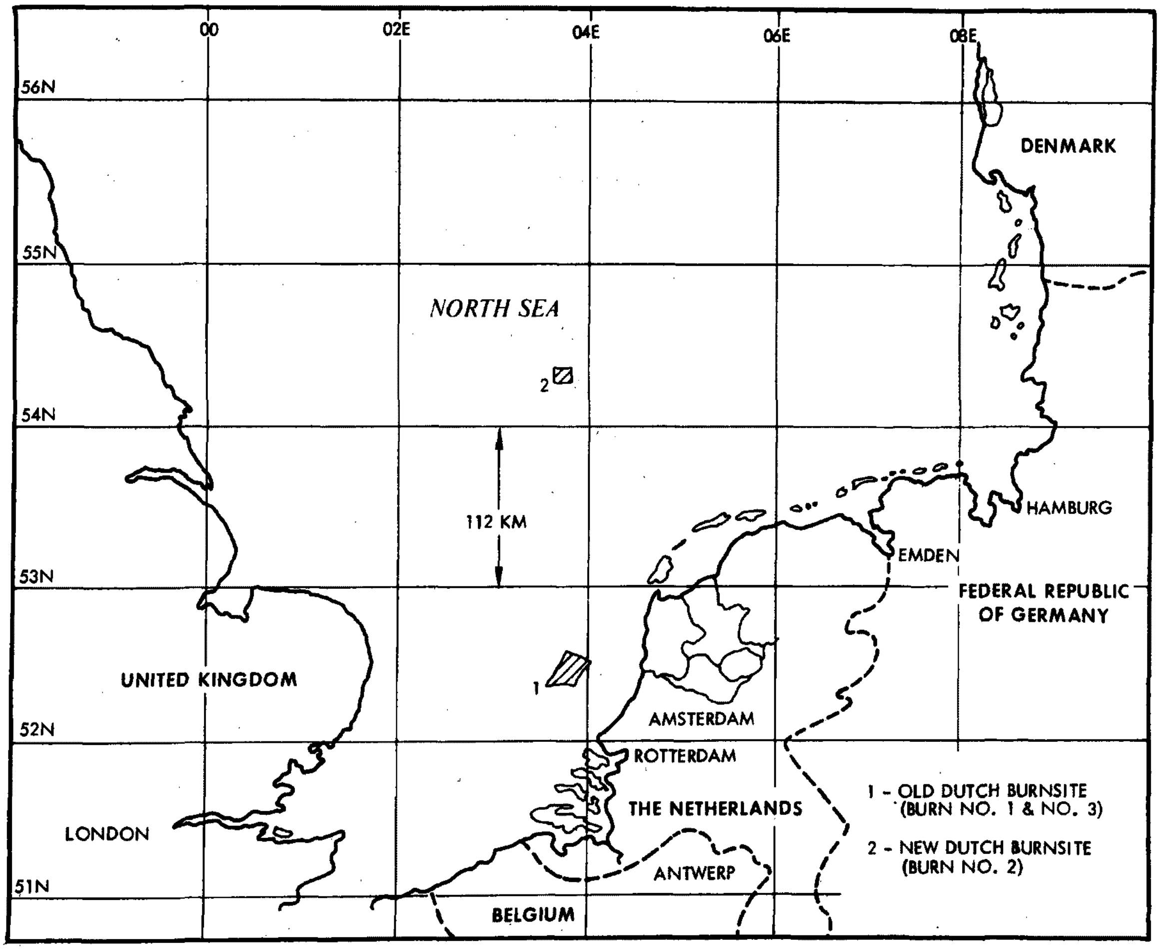

Figure 13. Incineration site locations

checkout and calibration were completed. Weather during the first burn was cold and the seas were reasonably calm. The plume from the incinerator was visible most of the time varying from a white-gray color to a slightly brown tinted gray color. Burn #1 lasted from November 24 to December 1. The Vulcanus arrived in port on December 4.

After loading waste for two days, the ship set out for the new burn zone (burn zone #2, Figure 13) on December 6. Because of rough seas on the way to the burn zone, sea water entered the lube oil and diesel fuel tanks. The ship had to stop dead in the water to remove the seawater contaminated lube oil from the engine. After replenishing with clean lube oil, the ship proceeded to the burn zone. Incineration of the wastes (Burn #2) began on December 8 and finished on December 16. The ship arrived in port on December 17.

For the third burn monitored by EPA, the ship completed waste loading operations and left port for burn zone #1, arriving on February 3, 1979. Waste incineration began on February 3 and was completed on February 10. Additional data acquisition and durability evaluations were performed with both the flowmeter and on-line gas analysis equipment. Stack emission data were also acquired by a team from the French Atomic Energy Commission onboard for this burn. After return to port, all of the flow measurement and combustion gas analysis equipment was removed and shipped back to Redondo Beach, California, for inspection, arriving on March 29, 1979.

4.1 FLOW MEASUREMENT

4.1.1 First Burn Commentary

The flowmeter system was not operational during the first burn. The problem was found during initial startup of the flowmeters. When the valves were opened to let waste pass through the flowmeters (see Figure 6), waste would not flow. Pipes in the bypass system, where the flowmeters were installed, had not been used for a long period and had become clogged. This precluded use of the flowmeters during the first burn because the pipes could not be cleaned during incineration. Between the first and second burn the pipes were thoroughly cleaned.

4.1.2 Second Burn Commentary

During the second burn the flowmeters operated without difficulty. Once in operation, the meters required no maintenance and were very reliable. The following account of minor problems associated with the flowmeters is presented. All of the problems encountered can be eliminated for future waste flow measurement onboard an incineration vessel.

Two problems associated with the accuracy of the ultrasonic flowmeters were found. The first relates to the inaccuracy of zeroing the flowmeter onboard ship. There are two methods of zeroing the ultrasonic flowmeters. The first involves zeroing under a no flow and full pipe condition. This could not be accomplished because at no time were the waste pipes full and not flowing. Pipes where the transducers were located are vertical, and they drain when flow stops. A solution would be to put a valve on each end of the flowmeter pipes so that waste could be trapped in the pipe to zero the instrument. It might also be possible to zero the ultrasonic flowmeters if another section of identical pipe could be filled with waste. Transducers could be placed on this pipe, zeroed, and then transferred to the pipe in the incineration system. However, tests would have to be performed to determine how accurate the transfer procedure would be.

The second procedure for zeroing these flowmeters is to determine the zero setting during normal flow conditions. This requires reversing the position of the transducers on the pipe being measured. During this procedure two signals (positive and negative) are produced which are displayed on the digital readout of the flowmeter controller. Under normal conditions, zero is set equal to the algebraic sum of these two signals. However, because of the ship's pitching and rolling, an oscillating signal such as the one shown in Figure 14 is produced on all three meters. This oscillation makes visual averaging of the flows extremely difficult and inaccurate.

The other problem associated with the ultrasonic flowmeters is the inaccuracy of adjusting the ultrasonic analog output (to recorders or remote digital readouts) to match actual flow. The procedure is to set the analog output for recording or remote digital display by adjusting the analog output to represent a predetermined flow range as shown by the digital readout on the

Vortex Meter

Ultrasonic Meter 'A'
(25 mm)

Ultrasonic Meter 'B'
(25 mm)

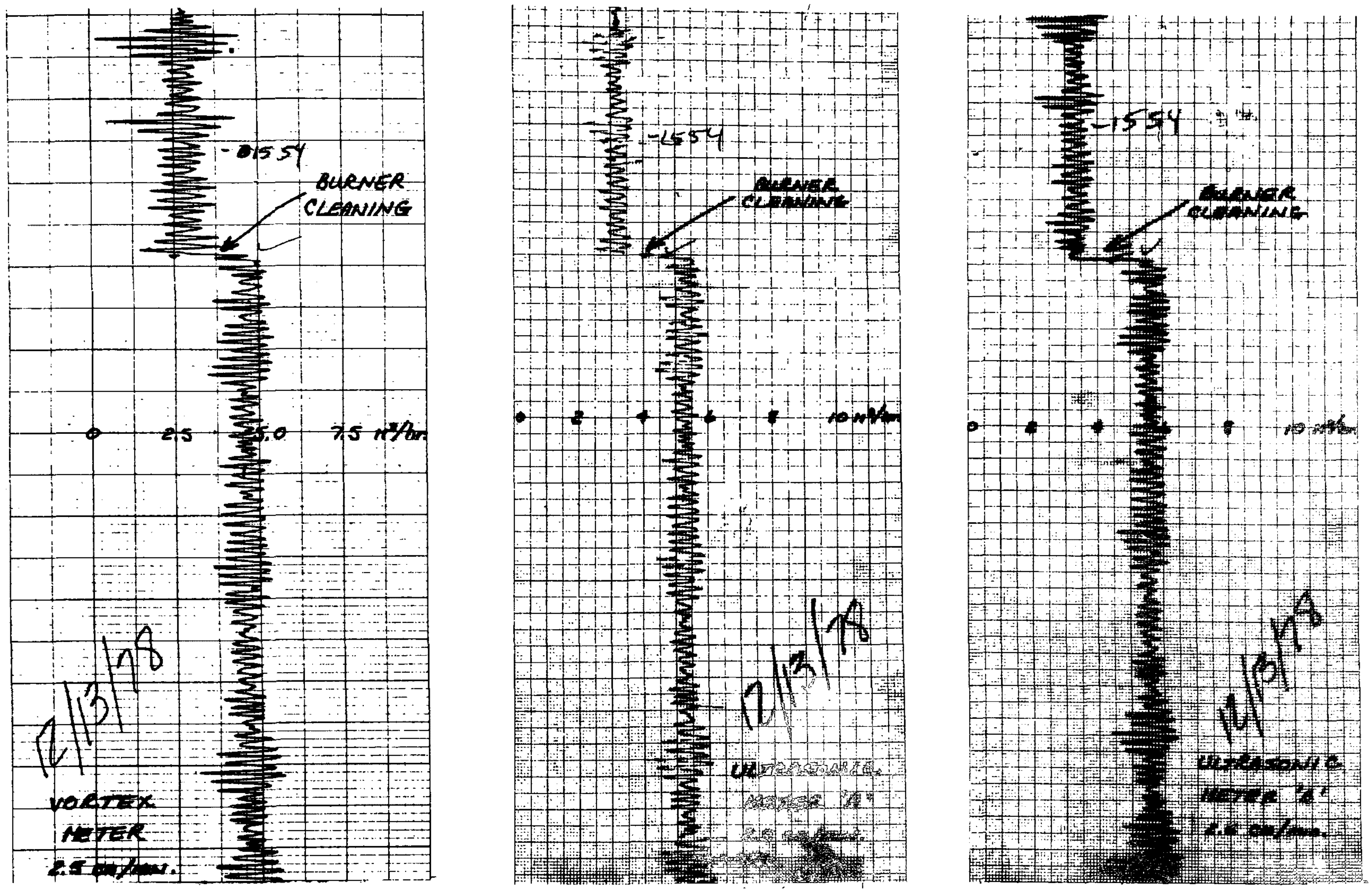

Figure 14. Sample strip chart records of flowmeter outputs

face of the controller. It was decided that a full scale setting of 0-10 m^3/hr would be ideal. Normally, with stable flow conditions, adjustment is easily made. However, oscillating flow causes inaccuracy of setting the analog scale. The adjustment difficulty is compounded because the computer digital readout displays the flow every three seconds. The value presented may be at any point on the oscillating data line (Figure 14), making visual averaging of the maximum and minimum points very inaccurate. In the future, the analog output could be adjusted prior to use onboard ship. In a laboratory under stable conditions, the analog output could be adjusted with a high level of accuracy.

Between the first and second burns when the ship was in port, two new components for the ultrasonic flowmeters arrived and were installed. The new components were two 50 mm (2") transducers and two matching plug-in signal conditioning units. These components were supplied because there was a possibility that the 25 mm (1") pipes installed previously (for 25 mm transducers and conditioning units) may have caused excessive pressure drop, resulting in too low a flowrate for the incinerators to function properly.

During the second burn, the 50 mm transducers were installed on the ship's own 50 mm pipes. The 25 mm transducers had been placed on 25 mm standard Schedule 40 carbon steel pipe specified by the flowmeter manufacturer and supplied by the contractor. Operation of the 50 mm flowmeters (used only during 2 days of Burn #2) produced data that was inaccurate when compared with the 25 mm transducer data and estimation of the flow by the ship's Chief Engineer. This inaccuracy was possibly because the ship's piping was not Schedule 40 carbon steel pipe. Inaccuracy could also have been caused by corrosion or scaling of the inside of the pipe surface. Future tests could eliminate this problem by supplying short sections of the proper type of pipes and inspecting these pipes for corrosion or scaling on a periodic basis.

A comparison was made of flowrates measured by flowmeter readings and tank depletion. This was accomplished by comparing flowmeter and tank sounding data over a three hour test period. On December 15 the waste from tank 5 starboard (stb) passed through pipes 5 and 6 only which were monitored by the ultrasonic flowmeter A (with 25 mm pipe transducer) and the vortex flowmeter, respectively. From 1600 to 1900 hours flowmeter data and hourly tank soundings were taken. Table 2 presents the data obtained during this test period. The accuracy of the tank sounding data was about ± 1.0 m^3 because of the ship's rolling and pitching. Also, during the test period the ship's list changed because of the waste removed from tank 5 stb. This added to the inaccuracy of the tank sounding. As can be seen from Table 2, the flowrates obtained from the flowmeters and tank sounding are within 1.0 m^3. It can be concluded that there is a reasonable correlation between the flowmeter measurements and the tank sounding data.

TABLE 2. COMPARISON OF FLOWMETER VS. SOUNDING TANK #5

Time of Measurement / Waste Flow Measurement (m^3)	1600	1700	1800	1900	Total Flow (m^3) 1600-1900	Flow Rate m^3/HR
Ultrasonic Flowmeter (25 mm)	0	3.782	6.950	10.720	10.720	--
Vortex Flowmeter (38 mm)	0**	4.40	8.41	12.86	12.86	--
Ultrasonic and Vortex	--	--	--	--	23.58	7.86
Tank Sounding*	0**	8	16	26	26.0	8.6

*Tank sounding data has an approximate error of ± 1.0 m^3 due to ship rolling and pitching.
** Normalized to 0 at 1600 hrs.

4.1.3 Third Burn Commentary

Both the vortex and ultrasonic flowmeters operated satisfactorily during the third burn period. No maintenance had been performed on these meters since their installation on November 22, 1978, prior to the first test burn.

It was observed that the flowmeter locations utilized onboard the M/T Vulcanus were not optimum for waste flow measurement for two reasons:

- Flow to more than one burner was usually fed through a single flowmeter line; therefore, separate flow to each burner could not be directly measured.
- Some of the flowmeter lines were bypassed at times, and no flow passed through these meters.

These conditions can be corrected by installing a flowmeter immediately upstream of each of the six burners. Because the flowmeter measurements are volumetric, both waste and oil mass flowrates can be measured, given the specific gravity of the fluid. This installation would provide the following:

- Flow would be measured individually for each burner.
- Individual meter readings could be summarized to determine total waste feedrate or for comparison with tank depletion rates.
- Zero flow readings would indicate when each burner was shut down for cleaning or at termination of incineration.

At the end of the third burn, the vortex flowmeter was removed from the waste feed system. A buildup of solid residue was observed on the upstream side of the blunt (non-streamlined) body within the vortex meter. Operation of the vortex meter was not apparently affected by the amount of solid buildup, but eventually inaccuracies or plugging might be expected as buildup increased. This condition can be avoided by inspection of the meter on a monthly basis and cleaning when necessary.

The 25 mm (1 inch) waste feed pipes used with the ultrasonic flowmeters were also removed after completion of this burn. Neither solids buildup nor any significant corrosion of the pipe interior were observed in either of the two pipe sections. It is recommended that measurements of the pipe I.D. be made to assure accuracy of the flow measurement.

4.2 CO, CO_2, O_2 MEASUREMENT

4.2.1 First Burn Commentary

On-line gas sampling proceeded smoothly with only a few minor problems, mostly associated with the new gas conditioning unit. Particulates in the gas stream caused some internal plugging of sample tubing and rapid build-up of particles on the gas conditioner filter, which required frequent maintenance, but did not present a real operational problem. Elimination of this problem can be accomplished for future testing by addition of a particulate filter upstream of the gas conditioner.

During operation the gas conditioner was found to contain a few nylon tube fittings which eventually failed when exposed to high pressure corrosive acid condensate. These fittings were replaced with stainless steel fittings onboard ship. The stainless steel fittings were adequate for the length of the sampling trips performed on this program, however, in the future, Teflon® fittings or stainless steel fittings with Teflon® inserts should be used to prevent corrosion problems during long continuous operating periods.

The ship's compressed air supply was inadequate for use in the gas conditioner. The gas conditioner requires a continuous 90 psi air supply for one minute to blow condensate from the condensate traps and to back purge the sample line. The ship's air supply has too small a capacity and can deliver up to about 130 psi for only a few seconds. For this reason, only condensate blowdown was possible because there was not enough air for both condensate blowdown and purging of the sample line. Compressed air bottles could be supplied for this purpose, or a large capacity tank could be added to the system.

The primary carbon dioxide analyzer supplied by Infrared Industries, Inc performed satisfactorily during the first day of sampling. During initial start-up on the second day of testing, the analyzer would not span correctly. After a period of troubleshooting, it was found that the instrument could not be repaired onboard the ship. This analyzer was removed and the spare carbon dioxide analyzer installed, a Beckman model 864.

On November 28, sampling of the port stack showed only ambient air was entering the sampling system. Sampling was switched to the starboard incinerator stack for the remainder of the burn. Further investigation established that the malfunction was located at either the probe, the connection of the probe to the Teflon® sample line, or the Teflon® sample line itself. Because of the high temperature near the incinerator, it was not possible to check those areas during the burn. After the end of the burn when the incinerator was cool, inspection showed that the probe had ruptured at the external wall of the port incinerator (see Figure 12).

One of the purposes of this program was to train ship's personnel to operate the equipment. During this burn, no one was available for training because of a shortage of engineers.

4.2.2 Second Burn Commentary

During the second burn, the Chief Engineer was available for training in instrument operation. Three hours a day were spent in instructing how to operate the instruments. After four days, the Chief Engineer understood how to operate all of the equipment. If he had been available for subsequent burns, he would have acquired enough experience to operate the instruments, however, it is not known if he would have had enough time to operate instruments along with his regular duty. In order to reduce the amount of operator time required, automatic calibration capability could be readily incorporated into each of the combustion gas analyzers. This could be accomplished by adding three-way solenoid valves which would flow calibration gases through each analyzer at selected intervals. Additional training would have been required to be able to solve any malfunctions in the combustion gas monitoring system other than the routine maintenance required. Members of the M/T Vulcanus crew considered to be candidates for training and operation of the instruments are listed below, along with a description of their present duties:

- Chief Engineer: 1) operation of incinerators, 2)operation of ship; stands 12-hour incinerator watch
- Second Engineer: operation of engines, 6- or 12-hour watches
- Third Engineer: operation of engines, 6- or 12-hour watches
- Fourth Engineer: operation of incinerators; stands 12-hour incinerator watch
- Assistant Engineers (4): 1) operation of incinerator, (2) operation of ship; stands 4-hour incinerator watch and 4-hour engine room watch

- Electrician: 1) operation of generators for incinerators,
  2) maintenance of all electrical equipment.

Between burns, the broken probe in the port stack was replaced. The first two days of CO, CO_2, and O_2 measurements appeared normal (port stack only). During the third sampling day, O_2 readings were abnormally high and CO_2 readings low, indicating an air leak in the sample acquisition system. Switching to the starboard incinerator also detected high O_2 levels, again indicating a definite leak in that system as well. Investigation of the system revealed that a leak was located at either the probes, sample lines, or connection of sample line and probe. The leak was subsequently found to be at the sample line/probe connection. The malfunction could not be corrected during incineration due to the high temperatures near the probable location of the malfunction. This problem may be resolved in the future by equipping personnel with a heat protection suit.

The on-line monitoring system could be operated continuously without any significant operating problems. The CO analyzer was replaced with the spare unit at the beginning of the second burn due to excessive drift. Calibration and maintenance could be performed on a preselected schedule when on-line monitoring would be shut down for a maximum of two hours daily (four half hour calibration and maintenance periods). Other requirements would be the availability of personnel to monitor the instruments and perform any required maintenance. This requires a visual inspection at least every two hours. If a failure should occur, longer periods of ship personnel involvement would be required to repair or remedy the failure.

4.2.3 Third Burn Commentary

Inspection of the incinerator stack sampling probes prior to the start of the third burn revealed that both the port and starboard probes were either broken off or burned off at the inner surface of the incinerator wall. This could have occurred at any time between the second and third burns because the probes were left in place during incineration while no contractor personnel were onboard. The holes through the firebrick were plugged and had to be tapped open with a rod or drilled out before new probes could be inserted in the incinerators.

Calibration checks of the on-line gas analyzers were performed prior to the third burn. During this checkout it was noted that two of the gas conditioner valves were noisy and were very hot after a ten-minute calibration period. To avoid potential problems at sea, the spare gas conditioner was installed prior to departure for the burn site. Nylon fittings were also replaced by stainless steel fittings. This gas conditioner operated satisfactorily during the burn period, requiring no maintenance other than periodic filter changes and manual purges to remove condensate.

The CO, CO_2, and O_2 analyzers all performed well with only minor adjustments during calibrations. Recorders operated satisfactorily and required no maintenance other than cleaning pen tips on three or four occasions during the entire burn.

On the sixth day of incineration, the stack sampling probes began plugging. Purging the starboard probe with high pressure air did not unplug the probe, but resulted in separation of the sample line from the probe. The port probe also could not be unplugged by purging, although the sample line remained attached. An air leak resulted in the port probe after purging which invalidated data acquired on the seventh day of the burn. After completion of burning and cooldown of the incinerators, it was observed that both probes were again broken or burned off at the inner wall of the firebrick. It is more likely that the probe had broken off because of vibration of the incinerators and had become plugged by particles of firebrick from the incinerator wall. This problem could be corrected by reducing the length of the probe inserted into the incinerator, which was 38 cm (15 inches) for these tests. Previous sampling tests (References 1 and 2) have indicated that representative samples can be obtained at 10 to 15 cm (4 to 6 inches) from the incinerator wall.

Replacement of broken probes currently is not possible during incinerator operation due to the high temperature near the incinerator. Replacement of broken probes or correction of probe seal leaks could be accomplished at sea by incorporating a retractable probe rather than a fixed probe. Mounting the probe on a retracting mechanism, such as used for the water-cooled probes in previous shipboard tests (References 1 and 2), would enable repairs or replacement of the probe without requiring cooldown of the incinerator. Another approach would be to redesign the probe to provide improved load-bearing capability and increase the fracture resistance of the probe.

4.2.4 Support of French Experiments

During the third burn, EPA supported the experiments performed by members of the French Atomic Energy Commission team during the period of March 2 to March 5. During this time the EPA gas sampling line and gas conditioners were used to provide gas samples to the French instruments. A written procedure was not provided by the French team, therefore the following description of the experiments which they conducted is based upon verbal information received by the contractor. A report will be available from the French, Centre D'Etudes Nucleaires, Fontenay-Aux-Roses, Republique Francaise.

Five (5) experiments were conducted as follows:

1) Shielded thermocouple was used to measure stack gas temperatures for calibration of the "Pyro IV" unit (see Experiment #5).

2) Video recordings (color television camera and magnetoscope) were made of the characteristic phases of incineration in order to obtain a better correlation between visually observed phenomena (presence of flame, smoke, or turbulence) and the measurement results. In addition, gas velocities were estimated by obtaining convection currents and particulate movement.

3) Helium was injected into the stack to obtain total gas flow by measurement of the helium concentration in exit gas by means of a spectrograph. Another objective of the helium trace experiment was to determine the homogeneity of gases at the stack exit plane.

The objective of the above three experiments was to correlate the data so that, having measurements from two of the three experiments, the results of the third experiment could be predicted.

4) A saturated sodium chloride solution was injected into the furnace port and the color of the exit gases recorded on video tape to obtain residence time in the furnace. Another objective was to

obtain gas velocity by the use of a spectrometer and by contrasting the video tape during injection with normal burning.

5) A "Pyro IV" unit was utilized during the test sequence. "Pyro IV" is an apparatus designed to measure at a distance, by optical means, the infrared radiation of a combustion gas at the stack exit. These measurements allow a continuous determination of the gas temperature and the concentration of CO and CO_2. The basic principle of the device is the use of selective narrow band pass filters and low pass filters to isolate the emissions from gases such as CO (4.7 μ) and CO_2 (4.2 μ). The unit is first calibrated against a black body and the concentrations of CO and CO_2 estimated based on the intensity of their emissions in these regions. The gas temperature is estimated by observing the appearance (or relative brightness) of particulates in the stack exit gases and by correcting for ambient effects and calibration factors. The contractor provided the French with the CO and CO_2 data taken during the same period for correlation with the Pyro IV results.

5. TEST RESULTS

This section presents the results of monitoring waste flowrates and combustion gas composition during at-sea incineration. Flowmeter and CO, CO_2, O_2 measurement data are summarized and discussed, and the post-test condition of the equipment is described.

5.1 FLOW MEASUREMENT

Signal outputs from one vortex flowmeter and two ultrasonic flowmeters were displayed visually and recorded on strip charts and an Esterline-Angus digital data logging device (typical strip chart records of flowmeter outputs are shown in Figure 14). Flowmeters and recording instruments used were previously described in Section 3.1. All of the flowmeter data are summarized in Table 3. No data were obtained during the first burn period because the ship's by-pass lines were plugged (see Section 4.1.1).

Flowmeter readings were obtained with all meters during the second burn. Each of the three lines being metered supplied waste to two of the ship's six burners, as listed in the footnotes of Table 3. All meters operated continually whenever waste was flowing through the pipes, and strip chart and digital data were acquired for 1 to 5 hour periods each day. Flow ranges and average values for the three meters are listed in the table for each test day. Normally, 25 mm (1") pipe size transducers were used with both ultrasonic meters (A and B). The 50 mm (2") pipe size transducers were used with ultrasonic meter B as noted.

Burning rates were varied by ship personnel to compensate for changes in the heat content of the waste being incinerated. Flowrates were increased when a waste of lower heating value was burned, as occurred during the seventh day of the second burn period. Waste flowrates to different burners are not intended to be identical; each burner feed rate is individually adjusted by the incinerator operator while observing the burner flame. Flowrates measured

TABLE 3. FLOWMETER DATA SUMMARY

Burn No.	Day No.	Date		Vortex Meter (1) m³/hr [data pts] (4)	Ultrasonic Meter A (2) m³/hr [data pts]	Ultrasonic Meter B (3) m³/hr [data pts]
1	1-7	11/25-12/1		No data - waste pipes to flowmeters plugged		
2	3	12/10	Range	3.0-3.5 [17]	4.5-4.6 [14]	(6) 4.5-4.6 [14]
			Mean	3.3	4.58	4.58
			Std. Dev. (5)	± 0.16	± 0.04	± 0.04
2	3	12/10	Range	-	-	(7) 1.9-2.1 [12]
			Mean			2.0
			Std. Dev.			± 0.08
2	4	12/11	Range	5.9-7.0 [27]		(7) 2.4-2.6 [8]
			Mean	6.4	5.8 [1]	2.5
			Std. Dev.	± 0.27		± 0.06
2	5	12/12	Range	3.5-5.1 [5]	3.3-4.1 [5]	(6) 4.5-4.9 [5]
			Mean	4.4	3.7	4.7
			Std. Dev.	± 0.68	± 0.36	± 0.14
2	6	12/13	Range	4.0-4.6 [6]	4.9-5.4 [6]	(6) 5.6-5.9 [6]
			Mean	4.4	5.2	5.7
			Std. Dev.	± 0.23	± 0.18	± 0.10
2	7	12/14	Range	(8)	(8)	(6) 6.5-6.7 [5]
			Mean			6.6
			Std. Dev.			± 0.08
2	8	12/15	Range	3.6-4.8 [23]	3.3-4.3 [23]	(6) 5.3-5.7 [8]
			Mean	4.2	3.7	5.5
			Std. Dev.	± 0.33	± 0.41	± 0.13
3	1	2/3	Range	4.0-5.4 [8]	7.8-8.0 [3]	(6) 2.4-62. [55]
			Mean	4.7	7.9	3.9
			Std. Dev.	± 0.53	± 0.12	± 1.25
3	2	2/4	Range	3.6-5.0 [45]	4.0-6.6 [52]	(8)
			Mean	4.4	5.5	
			Std. Dev.	± 0.36	± 0.80	
3	4	2/6	Range	2.6-7.1 [89]	2.5-7.0 [108]	(8)
			Mean	4.3	4.6	
			Std. Dev.	± 0.98	± 0.83	
3	5	2/7	Range	5.5-8.4 [120]	(8)	4.0-8.8 [54]
			Mean	7.0		7.2
			Std. Dev.	± 0.66		± 0.97
3	6	2/8	Range	4.8-10.6 [52]	(8)	7.1-7.4 [4]
			Mean	7.7		7.2
			Std. Dev.	± 1.43		± 0.13
3	7	2/9	Range	2.4-9.4 [42]	(8)	(8)
			Mean	5.7		
			Std. Dev.	± 1.78		

(1) Fischer & Porter series 10 LV 2000 liquid vortex flowmeter, 38 mm (1 1/2") pipe size, in line #6 feeding burners #1 and #6.
(2) Controlotron Series 240 ultrasonic flowmeter, 25 mm (1") pipe size transducer, on line #5 feeding burners #2 and #5.
(3) Controlotron Series 240 ultrasonic flowmeter, used on either 24 mm (1") or 50 mm (2") pipe sizes, on line #4 or #3, respectively, feeding burners #3 and #4.
(4) Data points taken at 10 minute intervals [in brackets] from a continuous strip chart.,
(5) Standard Deviation
(6) Ultrasonic flow transducer on 25 mm pipe provided by TRW.
(7) Ultrasonic flow transducer on 50 mm ship's waste pipe.
(8) Waste was not flowing in these pipes at this time.

by both ultrasonic meters on the third day of the second burn are identical because both meters were installed on the same line for comparison during this period only.

Readings taken with the 50 mm (2") ultrasonic flow transducers (Burn #2, days 3 and 4) were approximately one-half of the values expected. These transducers were installed on the ship's piping, which was not standard Schedule 40 carbon steel pipe as specified by the flowmeter manufacturer, or the pipe may have been eroded or corroded internally (see Section 4.1.2), causing an error in the calculated flowrates.

Flowmeter data obtained during the third burn are also listed in Table 3. The vortex and ultrasonic meters operated continually whenever waste was flowing through the pipes. Data were recorded for periods from 1 to 20 hours daily. Waste flow was increased by ship personnel whenever a lower heating value waste was incinerated, as during days 5 and 6 as shown in Table 3. The ultrasonic meters registered zero flow on numerous occasions when flow was redirected through other feed lines where meters were not installed (see Section 4.1.3).

5.2 CO, CO_2, O_2 MEASUREMENT

Table 4 summarizes the combustion gas composition data acquired with the on-line analyzers described in Section 3.2. Typical strip chart records of analyzer outputs are shown in Figure 15. CO, CO_2, and O_2 ranges and mean values for each test day are listed in Table 4, along with the corresponding calculated combustion efficiencies. Combining all of the first burn data results in a mean combustion efficiency of 99.983% with a 90% confidence level that 99% of the data will fall above 99.960%.

The total variance inherent in the measurement of a combustion gas constituent, σ_T^2, can be expressed as the sum of several variances:

σ_s^2 = variance due to changes in sample composition

$\sigma_{instrument}^2$ = variance due to calibration errors, drift, etc.

$\sigma_{reading}^2$ = variance due to reading data from charts, potentiometer lags, parallex, etc.

or, $\sigma_T^2 = \sigma_s^2 + \sigma_{instruments}^2 + \sigma_{reading}^2$.

TABLE 4. GAS COMPOSITION DATA SUMMARY

Burn No.	Day No.	Date	Data Points[1]		O_2 (percent)	CO_2 (percent)	CO (ppm)	Combustion Efficiency (%)[2]
1	1	11/25	5	Range	8.4 - 8.9	9.0 - 9.3	11 - 17	99.981-99.988
				Mean	8.6	9.2	14	99.985
1	2	11/26	13	Range	6.3 - 9.0	8.2 - 12.5	12 - 22	99.981-99.988
				Mean	7.6	10.5	16	99.985
1	3	11/27	28	Range	7.6 - 11.8	4.9 - 9.6	4 - 18	99.966-99.995
				Mean	9.2	7.3	10	99.986
1	4	11/28	18	Range	8.0 - 11.8	7.4 - 10.7	7 - 17	99.982-99.993
				Mean	9.9	9.1	10	99.989
1	5	11/29	24	Range	9.0 - 15.6	3.3 - 10.4	4 - 17.4	99.958-99.995
				Mean	11.5	6.9	11	99.984
1	6	11/30	30	Range	11.0 - 16.3	3.6 - 8.0	10 - 25	99.950-99.984
				Mean	13.6	5.7	14	99.974
1	7	12/1	38	Range	5.5 - 16.5	1.7 - 15.2	5 - 16	99.963-99.994
				Mean	10.8	7.7	10	99.985
1	1-7 (combined)	11/25-12/1	156	Range	5.5 - 16.5	1.7 - 15.2	4 - 25	99.950-99.995
				Mean	10.7	7.5	11	99.983
				Std. Dev.[3]	± 2.6	± 2.5	± 4	± 0.008
				Tolerance[4] Band	± 7.2	± 7.0	± 11	± 0.023
2	1	12/8	13	Range	9.0 - 12.0	8.7 - 10.1	2 - 10	99.989-99.998
				Mean	10.4	9.2	6	99.993
2	3	12/10	12	Range	14.1 - 15.3	2.9 - 3.7	8 - 14	99.958-99.974
				Mean	14.6	3.2	11	99.966
2	4-7	12/11-14	Data invalid - air leak into sampling system					
3	1	2/3	4	Range	5.4 - 9.8	4.6 - 13.9	18 - 28	99.953-99.984
				Mean	7.3	8.9	22	99.971
3	2	2/4	54	Range	3.8 - 10.2	6.0 - 14.6	8 - 37	99.963-99.988
				Mean	7.1	9.7	19	99.981
3	4	2/6	11	Range	10.4 -16.8	7.8 - 10.7	9 - 16	99.982-99.990
				Mean	12.2	8.2	12	99.986
3	5	2/7	10	Range	8.0 - 10.7	7.6 - 11.0	8 - 14	99.984-99.989
				Mean	9.7	8.7	12	99.987
3	6	2/8	25	Range	4.3 - 18.1	8.1 - 14.6	17	99.987-99.991
				Mean	8.6	11.0	12	99.989
3	7	2/9	Data invalid - air leak into sampling system					
3	1-6 (combined)	2/3-8	104	Range	3.8 - 18.9	4.6 - 14.6	7 - 37	99.953-99.991
				Mean	8.3	9.8	16	99.983
				Std. Dev.[3]	± 2.5	± 2.3	± 7	± 0.006
				Tolerance[4] Band	± 7.3	± 6.5	± 19	± 0.017

(1) Data points taken at 10 minute intervals

(2) $C.E. = \frac{\%\ CO_2 - \%\ CO}{\%\ CO_2} \times 100$ from a continuous strip chart.

(3) Standard Deviation

(4) There is 90% confidence that 99% of the data points fall within this range.

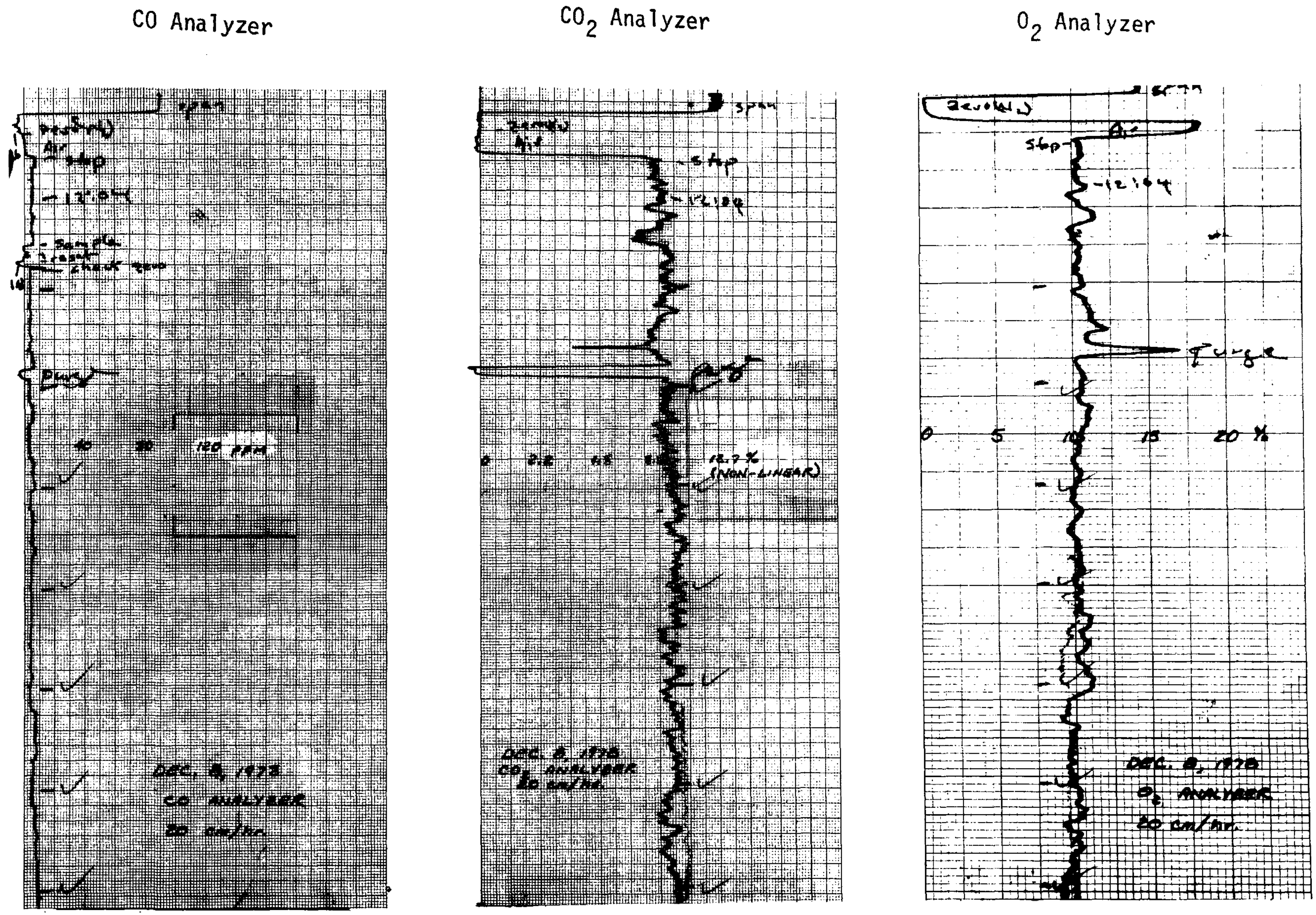

Figure 15. Sample strip chart records of CO, CO_2,O_2 analyzer outputs

The calculation of variation of CO, CO_2, and O_2 readings was made on an overall basis, (i.e., σ_T^2), therefore, errors due to instruments, etc., have already been included. This means that the true variation in CO, CO_2, and O_2 (i.e., σ_S^2) will be less than σ_T^2. Therefore, the use of σ_T^2 to represent the variance in combustion efficiency is conservative with respect to meeting IMCO incineration regulations and guidelines.

Data are listed for only two sampling days during the second burn period. After the third day it become evident that ambient air was leaking into the system and subsequent data was invalid. The leak was isolated to an area near the stack and could not be corrected while the incinerators were operating (see Section 4.2.2).

Third burn data are also listed in Table 4. Gas composition data were recorded for periods of up to 12 hours duration. Combined data from the third burn indicate a mean combustion efficiency of 99.983% with a 90% confidence level that 99% of the data will fall above 99.966%. These results are essentially the same as the combined data from the first burn, performed over two months previously, and effectively demonstrate the consistency of the combustion gas composition and measurement instrumentation over that time period.

5.3 DISCUSSION OF RESULTS

5.3.1 Flow Measurement

Results of this evaluation indicate that both the vortex and ultrasonic flowmeters tested are capable of accurately measuring waste flowrates during at-sea incineration. All of the meters tested performed satisfactorily, indicating a good agreement in flow readings and requiring no maintenance during the test burn. Operation of either flowmeter type, once installed, could be performed by ship's personnel after only 3 to 4 hours training.

The vortex shedding flowmeter installed in the waste piping operated continuously while internally exposed to the waste flow during the entire burn period. This flowmeter does not require a "no flow" condition for setting zero, and the meter controller has a built in calibration signal for adjusting the analog output to recorders or remote readouts. Periodic inspections (i.e., monthly) should be made of the internal components of the flow sensor which are in contact with the waste.

Ultrasonic flow transducers are externally clamped to the waste pipes and do not contact the waste itself. A no-flow/full pipe condition for zeroing these meters could be attained by the use of waste shutoff valves both upstream and downstream of the transducer location. Because the accuracy of these meters is affected by internal erosion or corrosion of the waste pipe, these pipes should be inspected periodically, particularly after incineration of very corrosive or particulate laden wastes. A short spool section of pipe installed in the waste feed system would facilitate cleaning or replacement of the pipe where the flow transducer is clamped.

5.3.2 CO, CO_2, O_2 Measurement

The on-line combustion gas analyzers provided accurate and reproducible CO, CO_2, and O_2 readings during the test burns. Average combustion efficiency calculated from CO and CO_2 data acquired during the first burn was 99.983 $\pm$ 0.023%, well within the 99.95 $\pm$ 0.05% range required by IMCO for at-sea incineration of these wastes. Measurements during the latter part of the second burn period were precluded by a leak in the sampling system near the stack which could not be corrected while the incinerator was at operating temperature. Third burn average combustion efficiency was 99.983 $\pm$ .017, essentially identical to the first burn average and indicating the reproducibility of the combustion gas composition and measurement instrumentation.

Providing spares for each of the gas analyzers proved to be a satisfactory means of assuring continuation of data acquisition without requiring extensive instrument repairs at sea. If both primary and backup analyzers should fail and are not readily repairable, from a technical standpoint waste incineration could continue only if O_2 measurements and incineration temperatures, at a minimum, were available (assuming that CO, CO_2 readings and combustion efficiency were satisfactory prior to backup instrument failure and that no changes in wastes or incineration conditions were initiated).

CO, CO_2, O_2 monitoring equipment was operated continuously for periods up to 12 hours duration without degradation of performance. It is estimated, on this basis, that continuous 24-hour operation can be achieved. Based upon results obtained onboard the M/T Vulcanus, adequate data for combustion efficiency verification could be acquired by three sampling periods, each two hours long, during a 24-hour day. Each test period can be randomly selected during a 8-hour shift period. This recommendation is supported by statistical analysis of the data acquired during this program. The continuous strip charts of each analyzer during each day were reviewed and the degree of drift estimated. The maximum rate of drift observed was then converted to a maximum change of combustion efficiency, calculated to be $9.3 \times 10^{-4}\%$ per hour maximum during one operating day. Results of this analysis indicated that the recommended sampling frequency (once every shift or a maximum of 12 hours between sampling periods) will provide adequate assurance that the combustion efficiency will meet the IMCO requirement (99.95% ± 0.05).

5.4 POST-TEST CONDITION OF EQUIPMENT

5.4.1 Flow Measurement Equipment

The vortex meter and the two ultrasonic meters tested were all operating satisfactorily at the end of the third burn period. Flow readings were within the expected range for both meter types. Meter controllers and recording devices functioned properly at all times and provided continuous flow data availability.

Post-test inspection of the vortex meter after nearly three months of operation revealed a buildup of solid waste residue on the upstream side and adjacent to the blunt sensing body. Inspection and cleaning of the vortex meter on a monthly schedule would avoid extensive solids buildup.

The ultrasonic meter transducers were mounted externally on 25 cm (1 inch) standard pipes, and remained in excellent condition. Inspection of the inside of these pipes showed no solids buildup or significant corrosion. Without any obstruction within the pipe, as with the vortex meter, there is no tendency for waste buildup on the smooth pipe walls.

5.4.2 CO, CO_2, O_2 Measurement Equipment

After the return of the on-line analyzers and conditioners to the contractor, all equipment was inspected and some units refurbished as required. The summary of the post-test condition of each instrument is presented in Table 5.

Table 5. POST TEST CONDITION OF ON-LINE GAS ANALYZERS AND CONDITIONERS

Species Analyzed	Mfg., Model & (S/N)	Utilization Burn No. 1	2	3	Post-Test Performance	Post-Test Condition	Comments
Carbon Monoxide							
Primary	Beckman 865 (0107963)	X	X (1st day)		Excessive drift	No evidence of corrosion	Refurbishment required for electronic package.
Spare	Beckman 864		X	X	Good	Slight corrosion on inlet and outlet fittings	Corrosion removed by wire brushing
Carbon Dioxide							
Primary	I R-703 (369)	X (1st day)			Incorrect Span	No evidence of corrosion	Refurbishment required for electronic package
Spare	Beckman 864 (0101447)	X	X	X	Good	Slight corrosion on inlet and outlet fittings	Corrosion removed by wire brushing
Oxygen							
Primary	Beckman 742 (0100222)	X	X	X	Good	Same as above	Same as above
Spare	Taylor 0247A (272/498)	-	-	-	N/A	N/A	Not used
Conditioners							
Primary	Thermoelectron 600 (GCU-7794-95)	X	X		Two noisy valves but operable one corroded valve but operable	Replacement of three valves and some fittings required	Nylon fittings replaced by S/S during test
Spare	Thermoelectron 600 (GCU-7795-95)			X	One noisy valve but operable	Replacement of one valve and some fittings required.	Same as above

Generally, only some of the analyzers showed slight evidence of corrosion due to exposure to the sampled gases, which is an indication that the gas conditioners performed their function well. The problems associated with analyzer malfunction were located primarily in the electronic package. This again re-emphasizes the need for spare instruments on board an incinerator ship because the operator of the instruments would not be able to repair these kinds of problems while on the ship. The conditioners showed the greatest extent of wear and, therefore, a spare unit needs to be provided.

6. REFERENCES

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APPENDIX A

OPERATING AND MAINTENANCE MANUAL

31497-6019-RU-00

At-Sea Incineration
Shipboard Instrumentation Evaluation

EPA Contract No. 68-02-2660

Operating and Maintenance Manual

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PREFACE

The Operating and Maintenance Manual was prepared to describe the CO, CO_2, and O_2 and the flowmeter measurement systems, including sections on installation, operation, sampling, data recording, data analysis, maintenance and troubleshooting. The manual was intended for use by the contractor during the initial phases of the program and later by the ship's crew during a training period and after departure of the contractor personnel.

An initial draft of the manual was used by the contractor during the first two test burns, and was marked up based upon onboard experience. In order to facilitate the use of the manual by the ship's crew, a German translation was prepared and provided to the M/T Vulcanus personnel along with copies of the equipment Manufacturer's Operating Manuals listed in Appendix B.

Additional updates of the Operating and Maintenance Manual were accomplished during the third test burn, and all corrections were incorporated into the final version presented in the attached Appendix A.

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CONTENTS (Cont'd.)

CONTENTS (Cont'd.)

FIGURES

TABLES

1. INTRODUCTION

This document presents the operating and maintenance procedures for instruments to measure waste flowrate and combustion gas composition during incineration of industrial chemical wastes onboard the M/T Vulcanus. Two different types of waste flowmeters, operating on ultrasonic and vortex shedding principles, will be evaluated as a more reliable and accurate method of monitoring waste flows than previous techniques. Evaluation will also be made of a $CO/CO_2/O_2$ monitoring system as compliance determination instrumentation to provide routine monitoring of combustion efficiency during waste incineration.

1.1 PURPOSE OF SHIPBOARD MEASUREMENTS

The general purpose of shipboard measurement of waste flowrate and combustion gas composition is described in the following paragraphs.

1.1.1 Flow Measurement

During at-sea incineration onboard the M/T Vulcanus, the total amount of waste burned is determined by manually sounding (measuring with a tape) the liquid level in each of 15 cargo tanks of known volumetric capacity. A relatively accurate sounding of the tanks is accomplished at dockside before and after each burn period. Accuracy of at-sea measurements is questionable because the ship is subject to roll and pitch conditions. Also, as wing tanks deplete, the ship's list changes and therefore causes inaccurate soundings. If sea conditions become sufficiently rough, tank sounding becomes impractical and at times unsafe. Another inaccuracy inherent in determining flow rates through tank depletion is the fact that a residual quantity of waste is present in each tank following a burn. This volume is increased during rough sea conditions due to sloshing and periodic movement of the waste away from the drainage line in the tank bottom.

For these reasons, a more reliable, direct, and accurate method of establishing and monitoring waste feed rates is desirable. An evaluation of commercially available flow measurement devices was conducted as part of this overall program. As a result of this study (Reference 1), two different types of flowmeters, ultrasonic and vortex shedding meters, have been selected for evaluation onboard the M/T Vulcanus. The objective of this evaluation is to determine the capability of each of these meters to withstand the at-sea environment and accurately and continuously measure flowrate of wastes during incineration.

1.1.2 $CO/CO_2/O_2$ Measurement

Experience in the Vulcanus Shell Chemical Waste Incineration (Reference 2) and the Herbicide Orange Incineration (Reference 3) Programs has shown that combustion efficiency is a good indication of waste destruction efficiency. Combustion efficiency may become one of the regulatory criteria for governing future waste incineration at sea. CO and CO_2 are the critical species to be determined in order to calculate combustion efficiency. Effluent O_2 concentration is also an indication of combustion efficiency. The objective of this task is to evaluate a CO, CO_2, and O_2 monitoring system for incineration effluents from at-sea incineration. This system will be evaluated from the standpoint that the monitoring system would ideally be a standard piece of equipment onboard the ship, and operation would be accomplished by regular shipbased personnel.

1.2 TEST STRATEGY AND OVERALL PROCEDURES

Test monitoring of waste feed rates and incinerator combustion products will be conducted by TRW personnel during incineration of one shipload of wastes, followed by further test monitoring by Vulcanus personnel during subsequent burn periods for an estimated two months. During the initial burn period, TRW personnel will instruct the ship's personnel in operation and maintenance of all flow measurement and gas composition monitoring and recording instruments.

The overall goal is to monitor and record effluent gas composition and waste flowrates for six hours each day during incineration.

1.2.1 Flow Measurement

Outputs of each flowmeter will be monitored by TRW or Vulcanus personnel for up to six hours daily. The objective of this task is not to determine the ship waste flow, but to evaluate the use of flowmeters under shipboard operating conditions. However, each flowmeter will be in continuous operation during incineration and is equipped with a digital totalizer, allowing cumulative flow readings to be checked against tank depletion times. Flow readings will be recorded in the Vulcanus meeting room and also displayed in the incinerator room for observation by ship's personnel.

1.2.2 $CO/CO_2/O_2$ Measurement

Combustion gas composition from either of the two incinerator stacks will be monitored for up to six hours daily. However, the major objective of these measurements is not to monitor incineration efficiency but to evaluate the capability of the CO, CO_2, and O_2 instruments to function effectively during extended shipboard operational conditions.

2. FLOW MEASUREMENT SYSTEM

The following sections describe the waste flow measurement system, its installation and operation, flowrate calculations, and general maintenance and troubleshooting procedures.

2.1 DESCRIPTION OF SYSTEM

The flow measurement system consists of flow sensors installed in the waste feed piping, and flow readout and recording devices. Two basic types of flowmeters were selected for shipboard evaluation: 1) ultrasonic and 2) vortex shedding. Detailed descriptions and photographs of the specific flowmeters to be used are contained in the manufacturer's operating manuals included in Appendix B.

2.1.1 Vortex Meter

Fischer and Porter's Series 10LV2000 liquid vortex flowmeter operates by a well-known hydrodynamic phenomenon: flow past a blunt body cannot follow contours on the downstream side, and separated layers become detached and roll into vortices in the low pressure area behind the body. Vortices are shed periodically from alternate sides of the body at a frequency proportional to flow velocity.

2.1.2 Ultrasonic Meter

The Controlotron Series 240 ultrasonic flowmeter utilizes high frequency sound waves to measure flow velocity. Two transducers, each capable of both sending and receiving, alternately transmit ultrasonic pressure pulses with and then against the direction of flow. Difference in transit time results in a frequency shift which is directly proportional to fluid velocity. Flow transducers clamp on externally to piping.

2.2 INSTALLATION OF SYSTEM

This section describes the installation of the flow measurement system components onboard the M/T Vulcanus. Installation of all equipment must occur while the ship is in port for waste loading. Figure 2.1 is a schematic of the flowmeter and instrumentation installation. Shown in this figure are the waste feed lines to the three burners of either incinerator.

2.2.1 Vortex Meter

A 1-1/2 inch vortex flowmeter is to be installed in one of the two-inch burner feed lines (Figure 2.1) in the incinerator room. Direction of flow is marked on the flowmeter body. A spacer section of 1-1/2 inch pipe, provided by TRW, is required between the upper flowmeter flange and the ship's flow valve, as shown in Figure 2.1. The upper flange of this spacer is left blank to be match drilled onboard ship. Gaskets and bolts are to be provided by the ship's crew. Electrical wiring to connect the meter to the controller is provided by TRW. The flowmeter body must be grounded.

The vortex meter controller is to be installed in the ship's meeting room near the top of the instrument rack, as shown in Figure 3.1. Connections to 120 volt AC power, vortex meter input signal, and 4-20 milliamp output signal are to be made to the controller as shown in Figure 12, page 19 of the Fischer and Porter Instruction Bulletin included in the Appendix of this document. Installation of the strip chart recorders and remote readouts used with the flowmeters is described in Section 4.

2.2.2 Ultrasonic Meter

Two one-inch ultrasonic flowmeters are to be installed in the remaining two burner lines to the same incinerator as the vortex meter. It was originally intended to install both a vortex and an ultrasonic meter in the same burner feed line for comparison of flow readings, but a 1-1/2 inch vortex meter had to be substituted for the 1-inch meter originally ordered because of production problems. Therefore, it was decided to install one vortex and two ultrasonic meters in the three burner lines to a single incinerator. This enables measurement of the total flow to one incinerator, which may be compared to flow rate as estimated from tank depletion times (if the tank is only feeding one incinerator, not both, which can be done by option of the ship's crew).

Installation of the ultrasonic meters is shown in Figure 2.1. The meters

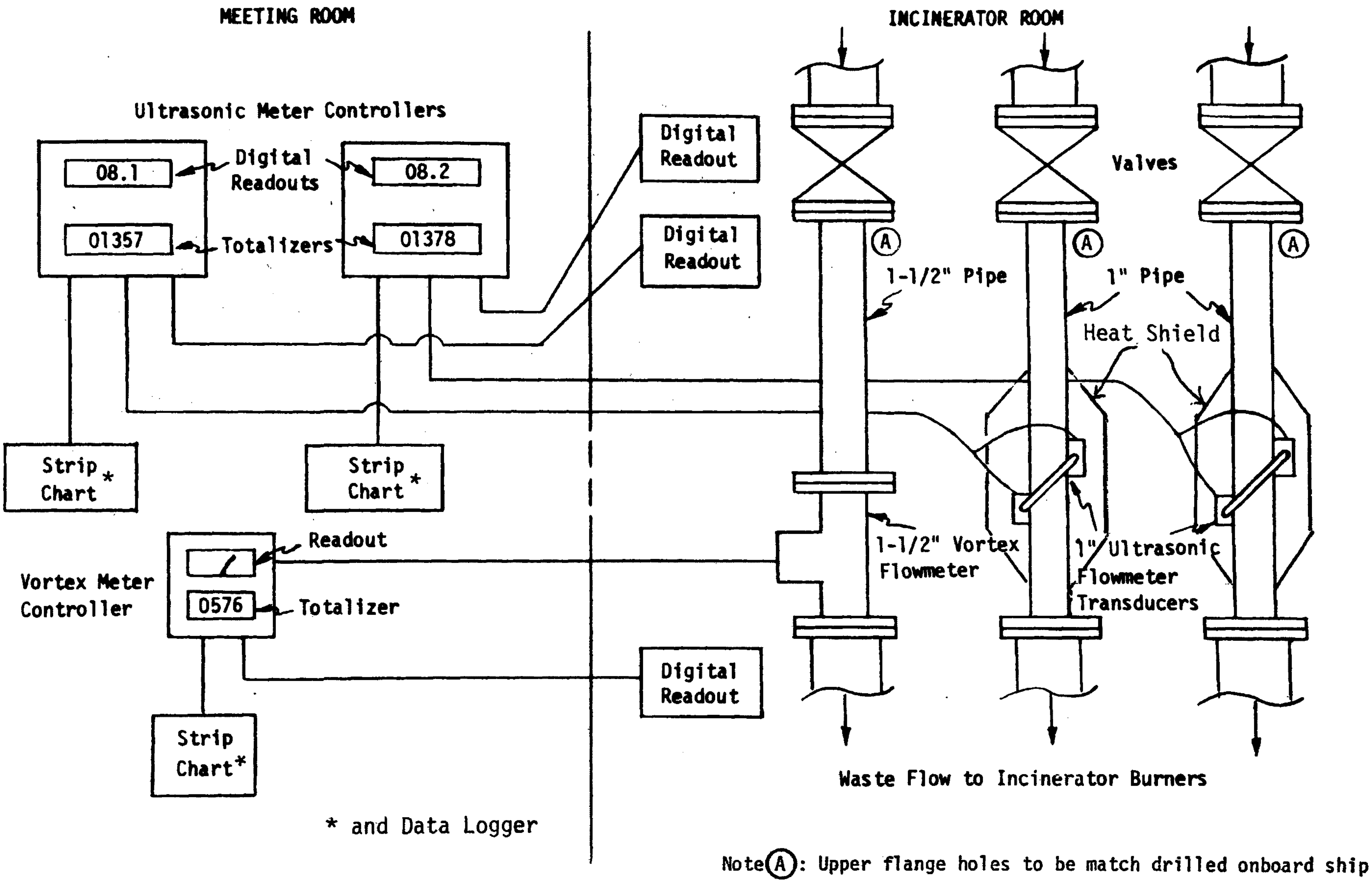


Figure 2.1 FLOWMETER INSTALLATION SCHEMATIC

are clamped to sections of 1-inch pipe. These pipe sections, provided by TRW, have a drilled flange on one end and a blank flange on the other end. These blank flanges are to be match drilled onboard ship. As with the vortex meter, the gaskets and bolts are to be provided by the ship's crew.

Installation of the flow transducers is described in detail starting with page 3-8 of the Clampitron Flowmeter Installation Manual included in the Appendix. Setting of the spacer bar to match the sonic velocity of the waste is performed as described in the manual. A sonic coupling compound, General Electric RTV-118, is provided by the flowmeter manufacturer and recommended for this application. Matched pairs of shielded cables, provided by TRW, must be used to connect the flow transducers to the controllers.

The ultrasonic meter controllers are to be installed in the ship's meeting room, as shown in Figure 3.1. Each controller has its own 120 volt AC power plug, which is to be plugged into the transformer output. Cables from the flow transducers are to be connected to the controller as marked ("upstream" cable to "up" connector, etc.). Controller outputs to the recorders and remote readouts are to be connected to the proper pins as listed in Table 3-3 of the Clampitron Installation Manual. Recorder and remote readout installation is described in Section 4.

2.3 OPERATION

This section describes the operation of the vortex and ultrasonic flowmeters. Operation of the recorders and remote readouts used with the meters is discussed in Section 4.2.

2.3.1 Vortex Meter

The vortex meter signal conditioner is factory preset according to the input signal, output signal, and power source selected. After the 120 volts AC power supply is energized, flow measurement will commence with flow through the meter. Generally, the piping system will be purged of entrapped air after several minutes of flow. During any period when there is flow through the meter, the flowrate will be displayed on the "% of Full Scale" indicator, the 7-digit counter will register the cumulative volume, and the analog output will be available for recording and remote display.

No calibration is required for normal operation if the signal conditioner is used with the flowmeter body for which it was programmed at the factory. Therefore, signal conditioners should be used with the proper meter body (as identified by serial numbers) for maximum accuracy. For this evaluation program, a different signal conditioner may be used only if it is not practical to change the flowmeter body during a burn period.

Prior to operation of the meter and as a checkout after installation, an internal check of the signal conditioner should be conducted. This procedure is performed by moving the option screw from position 1 to position 2, as described on page 22-23 of the Fischer and Porter Instruction Bulletin in the Appendix. (Note: always de-energize the signal conditioner power supply before changing programming screw options.) An internal test signal of 58.6 Hz will thus be generated for verification of proper function of the "% of Full Scale" indicator, the cumulative flow counter, and the analog output.

The two vortex flowmeters are originally set at 20 milliamps output (full scale or 100% flow) at .167 m^3/min or 10.0 m^3/hr. Nominal flow expected for each burner onboard the M/T Vulcanus is approximately 2 to 3 m^3/hr, which would give a reading of 60-90% of full scale because each flowmeter measures the flow to two burners, one on each incinerator. If it is desired to change the full scale span setting (within 33% to 115% of maximum meter capacity), this may be accomplished by simply altering the numerical span factor screw positions within the signal conditioner, as described in detail on page 25 of the Fischer and Porter Instruction Bulletin.

2.3.2 Ultrasonic Meter

The ultrasonic meter flow display computer is factory programmed for the specific pipe size and material provided: 1" carbon steel schedule 40 standard pipe. Installation of the flow transducer on the pipe was previously described in Section 2.2.2.

After the transducer and flow display computer are installed, and before first turning power on, check the following:

1. On the control panel, located at the upper right corner of the flow display computer, check that:
   a. SCALE switch set to INT.

b. STAB switch set to INT.

c. AUT-HI switch set to AUT.

d. N_R module in position and marked with appropriate Reynold's Number range.

e. EMPTY potentiometer in counterclockwise position.

2. Check that all modules are fully inserted and all cable connectors are engaged.

3. Ensure that the pipe is full and that the transducers are mounted using proper coupling compound.

After a warm up period of at least three minutes, a check of the transducer spacing should be performed to compensate for the sonic velocity of the specific waste fluid to be incinerated. The spacer bar is to be initially set at the index marking 7. If the voltmeter reading on the display coputer panel reads different from 7, loosen the spacer bar clamp and one transducer mounting strap. Slide the loose transducer (held tightly against the pipe) until the spacer bar marking and the voltmeter reading are the same, then tighten the spacer bar and transducer clamp.

Operation of the flowmeters is described in detail starting on page 4-1 of the Clampitron Instruction Manual. Particular attention should be made of pages 4-7 and 4-8 for a step-by-step listing of the operating procedures.

2.4 FLOWRATE CALCULATION

2.4.1 Sample Calculations

Waste flowrates are either read directly from the meter display or calculated for each flowmeter type as described below.

Vortex Meter

Flowrate at full scale (100% flow) and the flow volume for each totalizer count are noted on the face of each vortex meter signal conditioner. Initial setting of each meter is .167 m^3/min (or 10 m^3/hr) at full scale and .01 m^3 for each totalizer count. If the % of full scale reading during testing is 40%, then the flowrate is calculated as follows:

40% of full scale X 10 m^3/hr, or 4 m^3/hr.

Average flowrate may be calculated from the totalizer count change over a known period of time. If the totalizer count change is 1500 over a six-hour interval, for example, the average flow rate for that period is calculated as follows:

$$\frac{1500 \text{ counts X } .01 \text{ m}^3/\text{count}}{6 \text{ hours}} = 2.50 \text{ m}^3/\text{hr}.$$

If the specific gravity (S.G.) of the waste is known, the mass flowrate may be calculated from the volumetric flowrate:

$$2.50 \frac{\text{m}^3}{\text{hr}} \text{ X } 1.2 \text{ S.G.} = 3.00 \text{ tonnes/hr.} \qquad (1.2 \text{ S.G. assumed})$$

Ultrasonic Meter

Flowrate is displayed directly in either liters/minute or m^3/hr by the ultrasonic meter flow computer. The range switch may be left on liters/minute to obtain more significant digits, and converted to m^3/hour:

$$40.6 \frac{\text{liters}}{\text{min}} \text{ X } \frac{1 \text{ meter}}{1000 \text{ liter}} \text{ X } \frac{60 \text{ min}}{\text{hr}} = 2.436 \text{ m}^3/\text{hr}.$$

Average flowrate over extended time periods may be calculated from the totalizer count change. Each count on the ultrasonic meters represents one liter, or .001 m^3,

$$\frac{16000 \text{ counts X } .001 \text{ m}^3/\text{count}}{6 \text{ hours}} = 2.67 \text{ m}^3/\text{hr}.$$

The counter may also be set at "FASTOT," or one count = .0001 m^3/hr.

Mass flowrate may be calculated from volumetric flowrate, knowing the specific gravity (S.G.) of the waste =

$$2.67 \text{ m}^3/\text{hr X } 1.2 \text{ S.G.} = 3.20 \text{ tonnes/hr.}$$

2.4.2 Sample Data Sheet

Table 2.1 is a sample of the data sheets provided for recording flowmeter readings. At the bottom of the data sheets are the equations for calculating m^3/hr for the vortex meters, and the average volumetric and mass flow rate for both meter types.

2.5 MAINTENANCE AND TROUBLESHOOTING

2.5.1 Routine Maintenance

Both of the meter types tested have no moving parts, and the ultrasonic

Table 2.1

VULCANUS TESTS - FLOWMETER DATA

DATE ____________ WASTE SPECIFIC GRAVITY ______

TIME	VORTEX METER # ______ METER FACTOR ______ BURNER # ___			ULTRASONIC METER # ______ METER FACTOR ______ BURNER # ___			ULTRASONIC METER # ______ METER FACTOR ______ BURNER # ___		
	% FULL SCALE	M^3/HR (a)	TOTALIZER READING	% FULL SCALE	M^3/HR	TOTALIZER READING	% FULL SCALE	M^3/HR	TOTALIZER READING
AVERAGE FLOWRATE	M^3/HR (b) ______ TONNES/HR (c) ______			M^3/HR (b) ______ TONNES/HR (c) ______			M^3/HR (b) ______ TONNES/HR (c) ______		

(a) % FULL SCALE x M^3/HR FULL SCALE

(b) $\frac{\text{TOTALIZER COUNTS x METER FACTOR}}{\text{TOTAL TIME}}$

(c) M^3/HR x SPECIFIC GRAVITY

meter has no parts in contact with the waste fluid (ultrasonic transducers clamp externally to the flow pipe). Maintenance is therefore minimal and consists mainly of routine checks for loose connections or worn wiring between the flowmeters and the flow controllers. Internal surfaces of the vortex meter should be checked for buildup of solids or corrosion every month or two.

A spare vortex meter and controller are provided if one becomes inoperable. As mentioned previously in Section 2.3.1, the vortex meter should be operated with its matched controller; however, only slight accuracy is lost if a different controller is substituted. This would be acceptable during a test burn rather than attempt to change meter bodies in the waste piping, which should be done only in port between burns.

Although both ultrasonic meters are intended to be used, operation of only one would satisfy the objectives of this evaluation program. If one transducer or flow display computer becomes inoperable, the other transducer or plug in panels from the second unit may be substituted, as long as one ultrasonic system is functioning.

2.5.2 Troubleshooting and Repairs

In order to identify causes of malfunctions and perform repairs of either flowmeter type, a thorough understanding of the theory of operation is required. A technical discussion of this type and a troubleshooting guide can be found in the meter instruction manuals located in the appendix. The intention of this section is to present some of the problems that may be encountered during operation of the total system and solutions to these problems.

Vortex Flowmeter

No problems were encountered.

Ultrasonic Flowmeter

During initial startup of system, ensure that the transducers have been placed on a clean and rust-free section of pipe. If the empty signal continues after following the steps outlined in the Clampitron Manual, pull the power supply board out and switch the signal power switch to the "Hi" position, then proceed as described in the manual.

3. CO, CO_2, AND O_2 MEASUREMENT SYSTEM

The following sections describe the CO, CO_2, and O_2 measurement system and the installation, operation, maintenance, and troubleshooting of the system. Also, examples of combustion efficiency calculations are included.

3.1 DESCRIPTION OF SYSTEM

The CO, CO_2, and O_2 measurement system consists of sample probes and lines; gas conditioner; calibration gas and purge air system; and CO, CO_2, and O_2 analyzers.

3.1.1 Sample Probes and Lines

The probe to be used is a 1.27 cm OD high temperature alumina tube with wall thickness of 1.6 mm. This ceramic material is inert and has been shown to operate well in similar environments on previous programs. One of these probes is to be installed in each incinerator stack. Insulated Teflon lines connect these two probes to a three way stack gas select valve. This valve is connected to the gas sample shut-off valve on the valve panel inside the meeting room via a short piece of insulated Teflon line. The sample then flows through a short piece of Teflon line to the gas conditioner.

3.1.2 Gas Conditioner

Thermo Electrons Model 600 input sample gas conditioning system is designed to remove condensate and particulates from a continuous gas stream. This system is specifically designed to handle high concentrations of corrosive gases such as the high chloride content of the combustion gas to be sampled. The model 600 gas conditioner can supply sufficient conditioned sample to operate all three (CO, CO_2, and O_2) analyzers in parallel. The dew point of the gas at the exit of the gas conditioner is reduced to 4°C (40°F).

3.1.3 Calibration Gas and Purge Air System

Two high pressure gas cylinders contain the gases needed to calibrate and zero the three analyzers. One gas cylinder contains zero grade nitrogen for zeroing all the analyzers. The other cylinder contains a mixture of gases: 100 parts per million (ppm) of CO, 12% CO_2, and 15% O_2 in nitrogen. The calibration gas mixture was ordered to calibrate the analyzers at the proper range for each measured constituent, based on previous knowledge of the approximate composition of the combustion gas.

The purge air needed by the gas conditioner is supplied by the ship's compressed air supply. The high pressure air from the ship is stepped down to 100 psig (used by the gas conditioner) by a regulator located in the meeting room. This regulator includes oil and water traps.

3.1.4 CO, CO_2, O_2 Analyzers

There are two analyzers to measure each constituent (CO, CO_2, and O_2) in the combustion gas. The analyzers are split into primary and spare analyzers. The primary analyzers consist of the Infrared Industries model 703 CO_2 analyzer, the Beckman model 865 CO analyzer, and the Beckman model 742 O_2 analyzer. The spare analyzers are Beckman model 864 CO_2 analyzer, another Beckman model 865 CO analyzer, and the Taylor model OA273 O_2 analyzer.

The CO and CO_2 analyzers operate under the principles of infrared absorption. During operation a portion of the infrared radiation is absorbed by the component of interest in the sample, with the percentage of infrared radiation absorbed being proportional to the component concentration. The amount of absorption can then be measured, amplified, and the reading displayed which is directly proportional to the amount of the component in the gas.

The Beckman model 742 O_2 analyzer consists of an amplifier unit and an amperometric oxygen sensor (located directly behind the amplifier). The sensor responds to the partial pressure of oxygen. The amplifier unit measures the magnitude of the sensor signals, which is amplified and the reading displayed.

The Taylor model OA273 O_2 analyzer operates on the paramagnetic properties of the oxygen. The analyzer measures the intensity of the paramagnetic properties of the gas stream which varies as the amount of oxygen varies in the gas stream. The intensity is amplified, and the reading is displayed.

3.2 INSTALLATION OF SYSTEMS

The installation of the CO, CO_2, and O_2 measurement system is discussed in the following subsections. Figures 3.1 through 3.5 are presented to show the location of sample probes and lines, gas conditioner, calibration gases, CO, CO_2, O_2 analyzers, and recorders. Procedures to be used during installation of this equipment are described.

3.2.1 Sample Probes and Lines

Sample probes (one in each stack) are held in place using the probe holders shown in Figure 3.2. The probe holders are secured by bolts to the stack. The ceramic probes are inserted through the probe holder and extend into the stack so that approximately 15" of probe extends into the stack (towards the center) beyond the inner wall.

The sample line connects to the ceramic probe with 1/2" stainless steel swage lock fittings using asbestos packing for a seal. This line is first tied securely to the railing surrounding the stack to minimize any movement of the line that could fracture the fragile ceramic probe. The sample line should be tied securely, but with no stress or pull upon the ceramic probe, as this might also fracture the probe. The line should be tied at various points along the path to the meeting room, and should be installed so that there are no low points along the pathway from sample probe to the meeting room. This is to ensure that liquid cannot remain in the line, freeze, and thereby obstruct the flow of sample. The three-way valve used to select port or starboard stack gases should be installed so that it is easily accessible from the bridge deck. A proposed pathway for the sample lines and location of the three-way valve is shown in Figures 3.3 and 3.4.

3.2.2 Gas Conditioner

The gas conditioner is to be installed in the meeting room next to the instrument racks as shown in Figure 3.1.

Connections to the gas conditioner can be seen in Figure 3.5 and consist of sample line, calibration gases, purge air, three separate outputs for analyzers (one for each analyzer), one by-pass, two blowdowns, and a power connection.

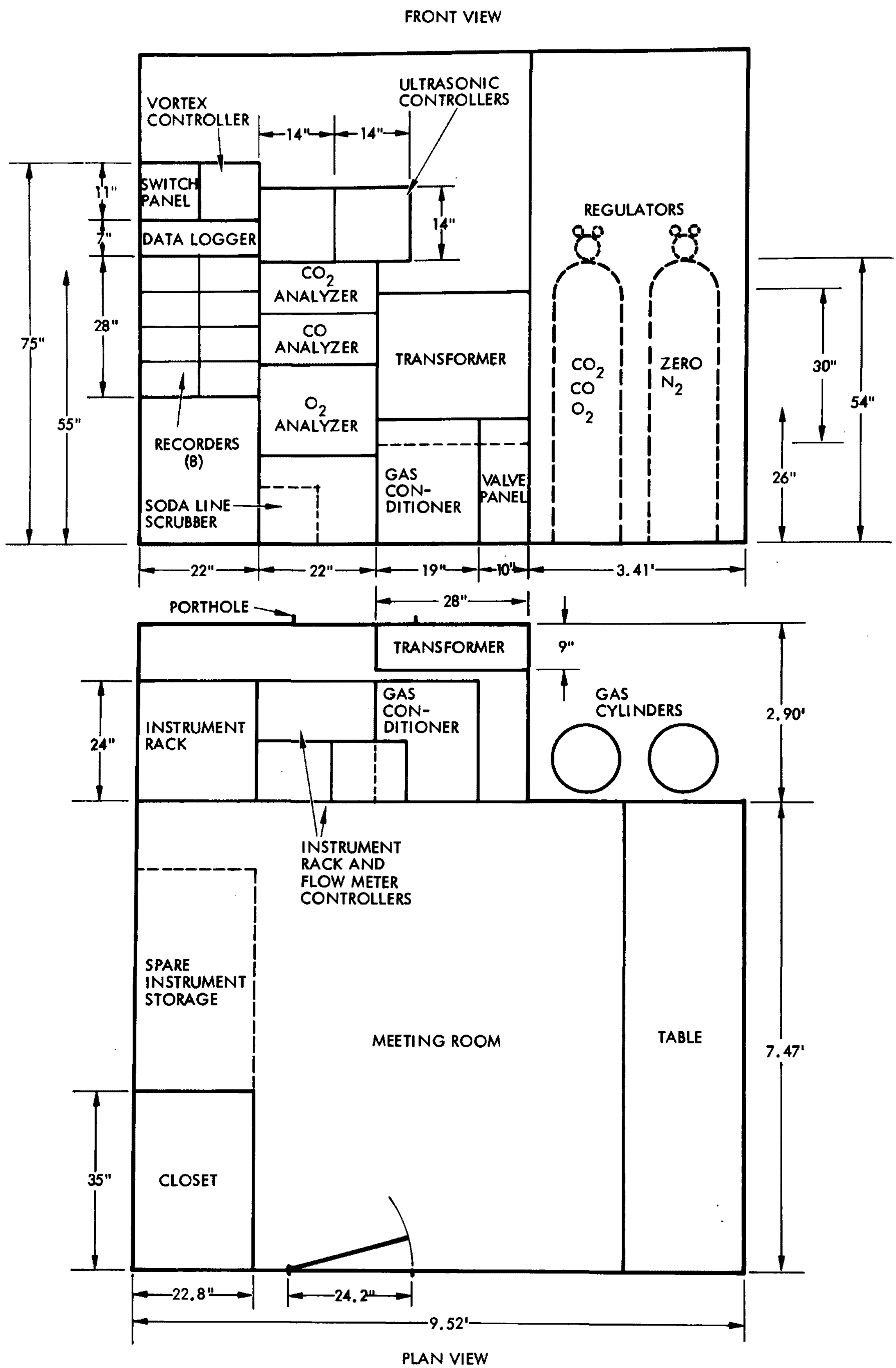


Figure 3.1. Physical layout of instrumentation in meeting room

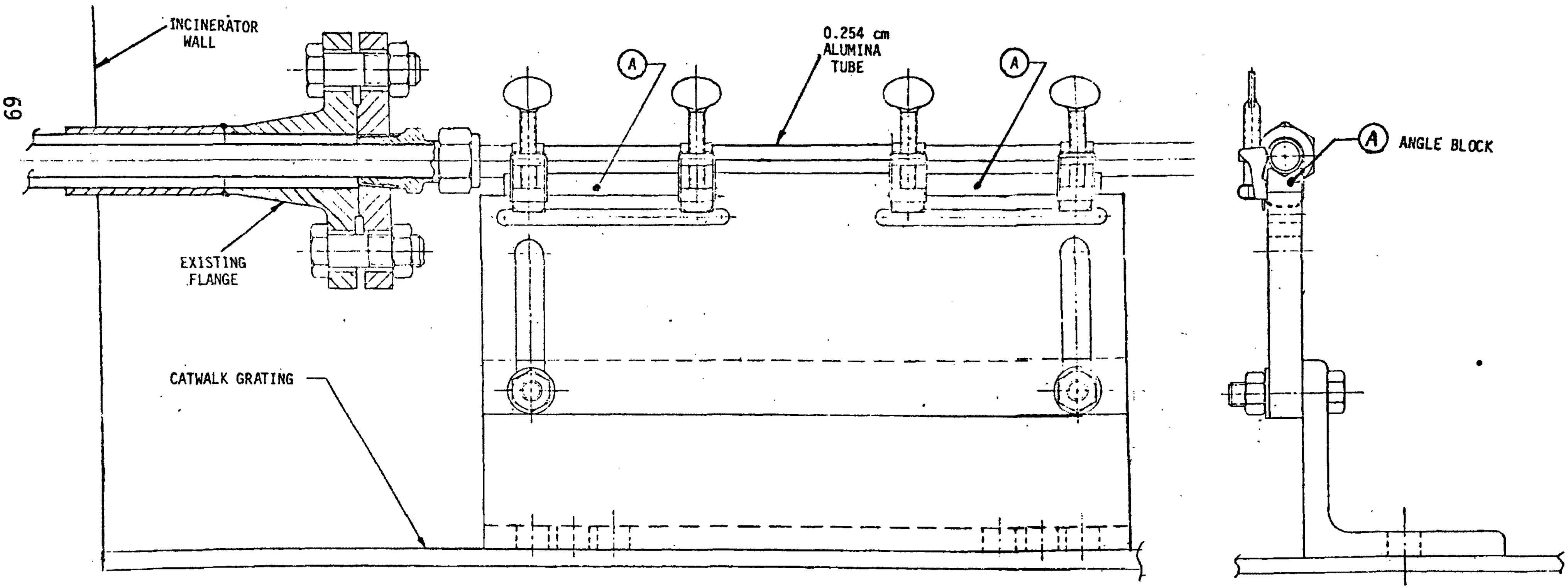


Figure 3.2 Probe Holder

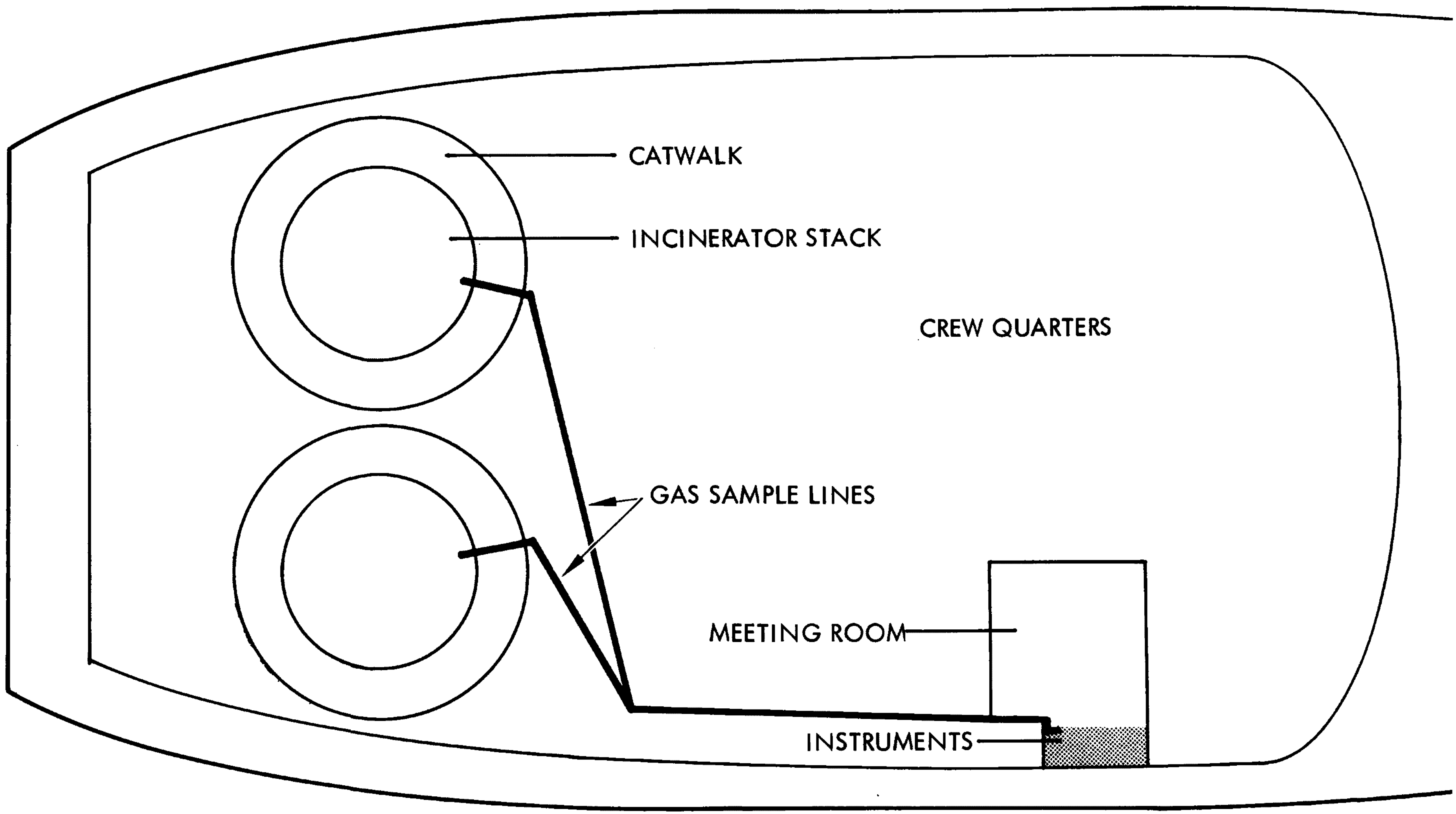


Figure 3.3. Gas sample line path

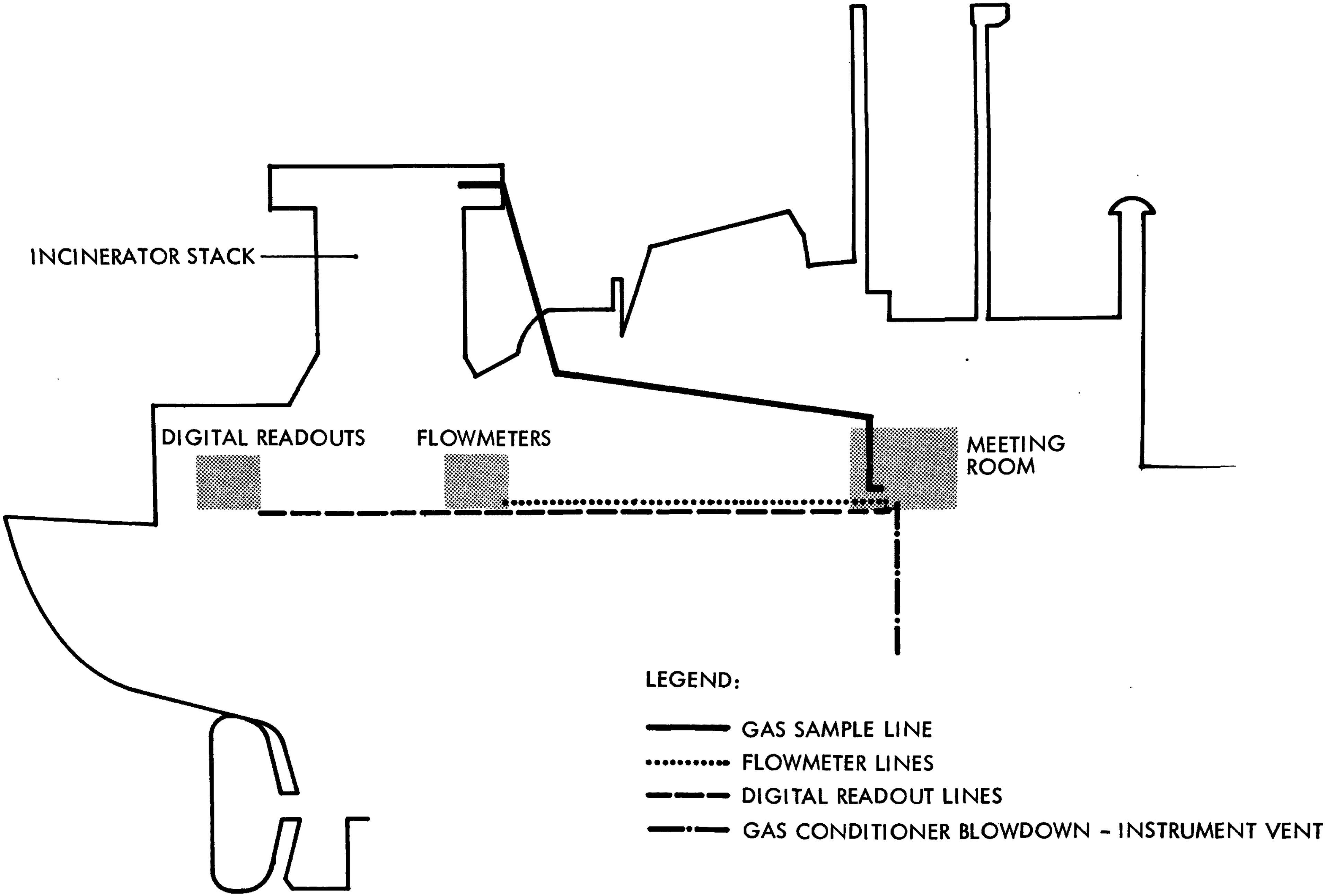


Figure 3.4. Pathway for Lines from meeting room

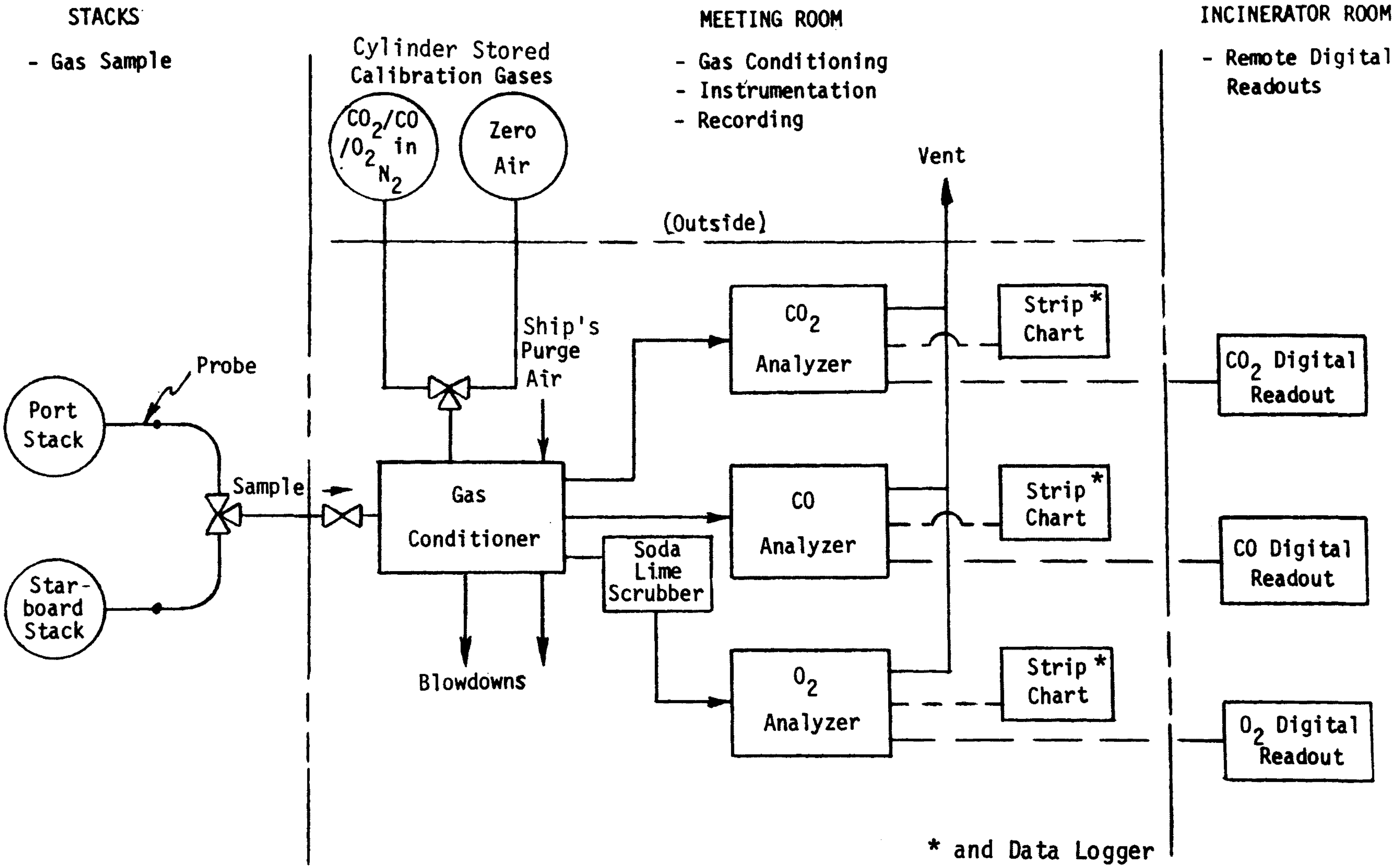


Figure 3.5. $CO/CO_2/O_2$ monitoring system installation schematic

Installation Procedure

1) Connect high pressure (100 psig) air from regulator to the fitting labeled "purge air" on the rear panel.

2) Connect unit to 115V power supply from power converter and turn on main power. Two to three hours of warm-up time is necessary (if bath has not been previously cooled) for the water bath to cool to 37° to 40°F (pump will not work until temperature of bath is below 45°F).

3) Plumb sample line from valve panel to fitting marked "sample inlet" on rear panel.

4) Plumb sample outlets marked 1, 2 and 3 to gas analyzers CO, CO_2, O_2 respectively.

5) Plumb calibration/zero gas line from valve panel through the 1/4" swagelock Tee to the three inlets marked "span inlets" on rear panel.

6) Plumb the by-pass to the instrument outlet manifold located on the lower rear side of the instrument rack nearest the gas conditioner.

7) Plumb both blowdowns to each drain line which exits via the stern wall.

   a) Condensate from trap nearest the front of the gas conditioner to line discharging directly from room.

   b) Condensate from rear trap to container behind gas conditioner with vent line exiting room. (This container must be emptied manually - once a burn).

8) Turn pump on and adjust the flowmeter valves for about 4 CFH flowrate.

   NOTE: Pump may not start unless flowmeter valves are open.

3.2.3 Calibration/Zero Gas and Purge Air System

Calibration gases which are used by the gas analyzers are located on the walkway outside the meeting room as shown in Figure 3.1. The following describes the connection of the calibration/zero gases in the gas cylinders to the gas conditioner via the valve panel. This panel includes the calibration gas shutoff valve, zero gas shutoff valve, and calibration/zero gas select valve.

Installation Procedure

1) Connect regulators to gas cylinders (using conversion fittings if necessary).

2) Connect 1/4" polypropylene (pp) tubing from regulator through stern wall of ship and connect to valve panel. Calibration gas and zero gas cylinders should be connected to the calibration gas shutoff valves.

3) Check to see that 1/4" pp tubing connects shutoff valves to calibration/zero gas select valve; if not, connect as shown in Figure 3.5.

4) Check to see that 1/4" pp tubing connects calibration/zero gas select valve to 1/4" SS Swagelock tee and from the tee to the three "span" inlets on the gas conditioner; if not, proceed to do so as shown in Figure 3.5.

3.2.4 CO, CO_2, O_2 Analyzers

Figure 3.1 shows the physical location of the three primary CO, CO_2, and O_2 analyzers. In the case of back-up instruments, the only difference in installation will be the Taylor O_2 analyzer (comments concerning differences in installation of the Taylor analyzer will be noted).

Connections to the instruments will include gas sample line from gas conditioner, vent line to manifold system, output to recording instruments and 115V power to the analyzer.

Installation Procedure

1) Mount analyzer on rack as shown in Figure 3.1. Each analyzer has its own type of front mounting plate (the Beckman Model 864 and 865, CO_2 and CO respectively, front plates are interchangeable) which is attached to the rack to help support the analyzer. The backup Taylor O_2 analyzer has no mounting plate but can be temporarily located on top of the gas conditioner (taped down if necessary). During mounting of the analyzers, the CO and O_2 analyzers must be supported by runners which support the length of the analyzer on each side. These runners can be adjusted vertically with a wrench (loosen and slide, then tighten).

2) After the instrument is mounted and secure, attach 1/4" pp sample line to sample inlet.

3) Attach 1/4" pp vent line to manifold at bottom rear of instrument rack.

4) Attach recorder output lead (usually white) to terminal strip #A (found near the top outside) on adjacent instrument rack.

5) Plug instrument into 115V power supply located on vertical strip attached inside rear of instrument rack.

3.3 CALIBRATION OF SYSTEM

This section describes calibration of the CO, CO_2, and O_2 analyzers. The section is divided into two main parts. The first part covers calibration of the primary analyzers which include the Infrared Industries (II) model 703 CO_2 analyzer, the Beckman model 865 CO analyzer, and the Beckman model 742 O_2 analyzer. Part two describes calibration of the spare analyzers which include the Beckman model 864 CO_2 analyzer and the Taylor model OA 272 analyzer. Both primary and spare CO analyzers are Beckman model 865 CO analyzers; therefore, description of calibration procedures for this analyzer are only discussed in Calibration of Primary Analyzers.

Prior to calibration of analyzers, turn on calibration gases. This is done by adjusting the regulators to 10 psi on the gas cylinders outside of the meeting room. (Note: these regulators can be left open until the end of each burn.) The gases can be shut off using the calibration/zero gas valves in the meeting room.

3.3.1 Calibration of Primary Analyzers

Included in this subsection is Table 3.1 which summarizes the frequency at which certain calibration procedures should be performed. Table 3.1 also denotes which instrument functions and control settings should be frequently checked and recorded.

O_2 Analyzer Calibration Procedure (Beckman 742)

Step # Procedure

1) Plug in analyzer and allow to equilibrate for 5 minutes.
2) Set on RANGE 0-25% (see Figure 3.6).
3) Set upscale calibration.
   a) Pass calibration gas (or air) through analyzer. This is accomplished by:

   Calibration gas:

   - turning calibration gas shut-off valve to on position
   - turn calibration/zero gas select valve to calibration gas
   - flip gas conditioner toggle switch #3 to span and adjust O_2 flowmeter to 1 liter/min (2 SCFH).

   Air:

   - leave Sample/Span switch to on sample
   - flip Sample/Air switch to Air. (Note: Pump must be running)

TABLE 3-1. FREQUENCY OF CALIBRATION

Analyzer	Step #	Task	Frequency of Execution*	Record in Log Book
O_2-Beckman**	1-3	Upscale calibration	B,A	
CO-Beckman	1	Mechanical meter zero	I	
	3	Oscilator tune	B	Record scale reading
	5	Check bias adjustments	C	
	6	Source balance	C	
	7	Set zero	B,A	
	8	Upscale calibration	B,A	Record gain control
CO_2-Infrared Industries**	1	Set zero	B,A	
	2	Upscale calibration	B,A	
O_2-Taylor	1	Set zero	B,A	
	2	Upscale calibration	B,A	
CO_2-Beckman	1	Mechanical meter zero	I	
	3	Oscilator tune	B	Record scale reading
	5	Check bias adjustments	C	
	6	Source balance	C	
	7	Set zero	B,A	
	8	Upscale calibration	B,A	Record gain control

*B-before each 6-hr sampling period, A-after each 6-hr sampling period, I-after installation only, C-after period of no use for a few days or loss of sensitivity of analyzer

**Primary analyzers

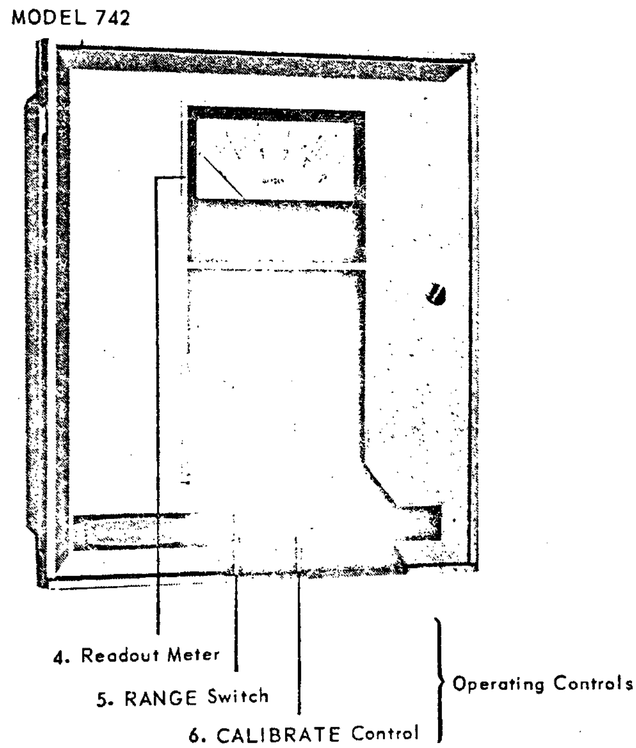
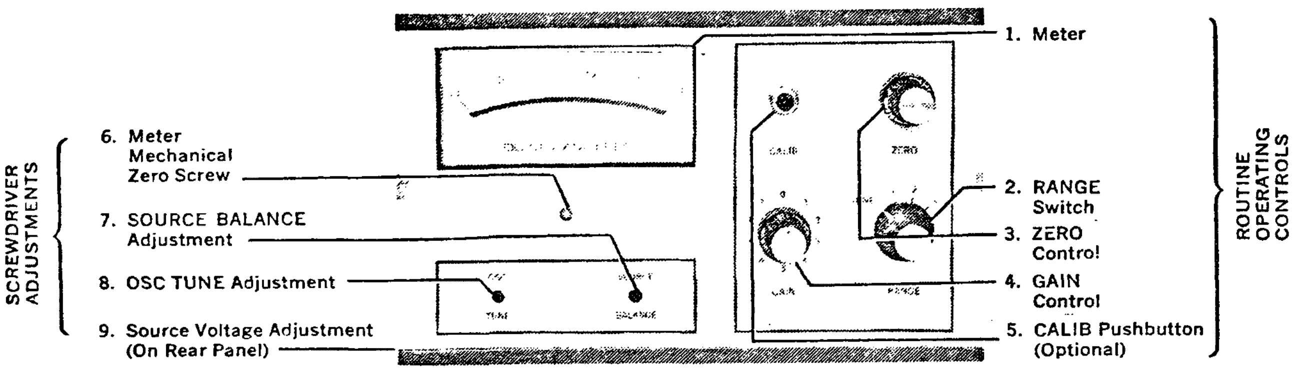


Figure 3.6. Beckman oxygen analyzer

A. EXTERNAL CONTROLS AND ADJUSTMENTS



CONTROL	FUNCTION(S)
1. Meter	Readout of sample data or oscillator tuning check, depending on position of RANGE Switch (item 2). During operation, a calibration curve is used to convert meter readings into concentration values. (Alternatively, linear readout of concentration values for a given operating range is obtainable through use of the optional 633756 Linearizer Board.)
2. RANGE Switch	TUNE: Test position, used periodically to verify proper oscillator tuning. In TUNE mode, meter should indicate the previously determined "Normal Tuning Value." If not, reset OSC TUNE Adjustment, item 8. Position "1": Selects lowest-sensitivity operating range for readout on meter and recorder. Position "2": Selects intermediate-sensitivity operating range. Position "3": Selects highest-sensitivity operating range.
3. ZERO Control	Used to set zero point on meter scale or recorder chart. With RANGE Switch and GAIN Control at appropriate settings and zero standard gas flowing through analyzer, the ZERO Control is adjusted for zero reading.
4. GAIN Control	Used to set fullscale or near-fullscale standard point on meter scale or recorder chart. With RANGE Switch at 1, and an upscale standard gas appropriate to Range 1 flowing through the analyzer, GAIN Control is set for correct reading. If analyzer incorporates optional calibration accessory, upscale gas may be simulated by depressing CALIB Pushbutton (item 5). With GAIN Control at counterclockwise limit, gain is zero. Clockwise rotation of 10.0 turns increases gain to maximum. Panel is marked at intervals of 1/10 turn to facilitate recording settings.
5. CALIB Pushbutton (Operative only if analyzer has optional calibration accessory)	When depressed, inserts a reflecting window into the sample beam, to simulate a specific concentration of the measured component. Simulated concentration value is valid only for operation at a particular ambient pressure. If barometric pressure changes significantly, calibration must be checked against upscale gas.
6. Meter Mechanical Zero Screw	With analyzer power cord disconnected, meter should read zero. If not, this screw is adjusted to zero the meter.
7. SOURCE BALANCE Adjustment	Used to obtain proper balance between intensities of sample and reference sources, and to bias the optical system into linearity. Procedures for initial adjustment and subsequent checkout of the SOURCE BALANCE are included in Startup Procedure of Paragraph 3.1.
8. OSC TUNE Adjustment	Used to tune oscillator circuit. To adjust tuning, insert a **thin-bladed** screwdriver through the front-panel hole, through the cardboard guide tube, and into the slot of the adjustment screw. During **initial startup,** RANGE Switch is placed at TUNE. The OSC TUNE Adjustment is set at counterclockwise limit, and then turned clockwise until a peak reading is obtained on the meter. Then, OSC TUNE Adjustment is rotated counterclockwise until meter reading decreases to between 70% and 75% of the peak reading previously obtained. The resultant meter reading, designated "Normal Meter Reading in TUNE Mode," is noted for future reference. During subsequent **operation,** oscillator tuning is checked periodically by turning RANGE Switch to TUNE. Meter should read within a few scale divisions of "Normal Meter Reading in TUNE Mode." If meter reading is outside the acceptable limit, repeat tuning procedure described above.
9. Source Voltage Adjustment (On Analyzer Rear Panel)	Used to set the voltage applied to the two sources. Nominal setting is 30 volts.

Figure 3.7. Analyzer controls and adjustments

b) After instrument has equilibrated, adjust the CALIBRATE control (see Figure 3.6) to concentration of oxygen in the certified calibration gas mixture (~ 15%), or to 21.9% for air as noted by the red line on the analyzer meter.

CO Analyzer Calibration Procedure (Beckman 865)

Step # Procedure

1) With power cord disconnected, verify that front-panel meter reads zero. If not, adjust Meter Mechanical Zero Screw for zero reading. (see Figure 3.7).

2) Turn on instrument.

3) Check oscillator tuning:

a) Turn RANGE Switch to TUNE.

b) If instrument has been in routine operation, compare present meter reading with previous readings obtained in TUNE mode. Present and past readings should agree to within a few of the smallest scale divisions; if so, oscillator is properly tuned; proceed directly to Step 4.

If analyzer has not yet been in operation, or if reading in TUNE mode is not within the acceptable limits, tune oscillator per instructions in instrument manual (Beckman 865).

4) Set Zero

a) Pass zero gas through instrument.
This is accomplished by:

- turning on zero gas shut-off valve.
- turning calibration zero gas select valve to zero gas.
- flip toggle switch #1 on gas conditioner to span and adjust to 1 liter/min (2 SCFH).

b) Verify zero control is fully clockwise.

c) Set RANGE switch to position 3.

d) With zero gas flowing, increase GAIN control setting until recorder reads 100% (or 10 large divisions). If 100% is not obtainable, set GAIN control at maximum setting.

e) After allowing instrument to come to equilibrium, turn zero control counterclockwise until meter reads exactly zero.

f) Tighten lock ring on zero control and turn off zero gas.

5) Setting Upscale Calibration

a) Set RANGE switch to position 3.

b) Pass calibration gas through analyzer. This is accomplished by:

- turning calibration gas shut-off valve to on position.

- turn calibration/zero gas select valve to calibration gas.
- flip gas conditioner toggle switch #1 to span and set flowmeter to 1 liter/min (2SCFH).

c) Adjust GAIN control to appropriate near-fullscale reading as dictated by the calibration curve (Figure 3.8).

d) Tighten lock ring on GAIN control knob and turn off calibration gas.

e) Pass zero gas through analyzer to verify zero has not shifted during calibration.

f) Record GAIN control setting.

CO_2 Analyzer Calibration Procedure (Infrared Industries 703)

Step # Procedure

1) Zero Procedure

a) Turn the instrument on by rotating function switch clockwise one position.

b) Allow zero gas to flow through cell at a flow rate of 2-4 SCFH.

This done by:

- turning zero gas shut-off valve to the on position
- turn calibration/zero gas select valve to zero gas
- flip CO_2 (#2) toggle switch on gas conditioner to span and adjust CO_2 flowmeter to 2-4 SCFH

c) Allow 15 minutes warmup time. Flip sensitivity switch to low position.

d) Rotate ZERO control until recorder reads zero.

2) Upscale Calibration with Internal Calibration Mechanism

a) Rotate function switch to span position.

b) Allow reading to stabilize and adjust the span control until recorder reads 100% (10 larger divisions).

NOTE: With RANGE toggle switch on low position, instrument at 100% assimilates 10% CO_2 and at the high position the 100% reading assimilates 30%.

3) Upscale Calibration with a Calibration Gas

a) After instrument has been zeroed as detailed in Step 1, introduce calibration gas. This performed by:

- turning calibration gas shut-off valve to the on position
- turn calibration/zero gas select valve to calibration gas
- flip toggle switch #2 (CO_2) to the span position and adjust CO_2 flowmeter to 2-4 SCFH.

b) Set RANGE toggle switch on high for calibration gas greater than 10% or on low if calibration gas is less than or equal to 10% and set span control until recorder reads the same as the certified concentration of CO_2 in calibration gas mixture.

3.3.2 Calibration of Spare Analyzers

Oxygen Analyzer Calibration Procedure - Taylor Model OA.272

Step # Procedure

1) Set Zero

   a) Pass zero gas through analyzer.

   b) Select 5% RANGE switch and wait for reading to stabilize.

   c) Stop sample flow and adjust left-hand calibration screw to obtain the correct zero reading on meter.

2) Upscale Calibration

   a) Pass calibration gas through analyzer (see Section 3.3.1 O_2 calibration, Step 3a for this procedure).

   b) Turn on and wait for reading to stabilize. Stop flow and adjust right-hand calibration screw to obtain the correct reading (15%).

CO_2 Analyzer Calibration Procedure (Beckman 864)

Step # Procedure

1) With power cord disconnected, verify that front-panel meter reads zero. If not, adjust Meter Mechanical Zero Screw for zero reading (see Figure 3.7).

2) Turn on instrument.

3) Check oscillator tuning:

   a) Turn RANGE switch to TUNE.

   b) If instrument has been in routine operation, compare present meter reading with previous readings obtained in TUNE mode. Present and past readings should agree to within a few of the smallest scale divisions; if so, oscillator is properly tuned; proceed directly to Step 4.

   If analyzer has not yet been in operation, or if reading in TUNE mode is not within the acceptable limits, tune oscillator per instructions in instrument manual found in Appendix.

4) Set Zero

   a) Pass zero gas through instrument.

This is accomplished by:

- turning on zero gas shut-off valve.
- turning calibration zero gas select valve to zero gas.
- flip toggle switch #2 on gas conditioner to span and adjust to 1 liter/min (2SCFH).

b) Verify zero control is fully clockwise.

c) With ZERO at clockwise limit, set RANGE switch to position 3.

d) With zero gas still flowing, increase GAIN control setting until recorder reads 100% (or 10 large divisions). If 100% is not obtainable, set GAIN control at maximum setting.

e) After allowing instrument to come to equilibrium, turn ZERO control counterclockwise until meter reads exactly zero.

f) Tighten lock ring on ZERO control and turn off zero gas.

5) Setting Upscale Calibration

a) Set RANGE switch to position 3.

b) Pass calibration gas through analyzer. This is accomplished by:

- turning calibration gas shut-off valve to on position.
- turn calibration/zero gas select valve to calibration gas.
- flip gas conditioner toggle switch #2 to span and set flowmeter to 1 liter/min (2 SCFH).

c) Adjust GAIN control to appropriate near-fullscale reading as dictated by the calibration curve (Figure 3.9).

d) Tighten lock ring on GAIN control knob and turn off upscale calibration gas.

e) Pass zero gas through analyzer to verify zero has not shifted during calibration.

f) Record GAIN control setting in log book.

3.4 SAMPLING

Sampling follows directly after calibration of the analyzers. Sampling is initiated only after calibration has been performed on the analyzers as described in Section 3.3. The flowrate of the sample gas to the analyzers should be at the same rate that each analyzer was calibrated at. All the analyzers are operated the same way when analyzing the sample, therefore, only one sampling procedure is presented.

FIGURE 3.8

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PROCESS INSTRUMENTS DIVISION
FULLERTON, CALIFORNIA • 92634

INFRARED ANALYZER CALIBRATION & DATA SHEET

Customer: TRW
Address: Redondo Beach, Calif.
Application:
Ranges: 1. 2. 3. 0-200 PPM

1. Uncalibrated Linearizer Range 1 [ ]
2. Calibrated Linearizer Range 1. [ ] 2. [ ] 3. [ ]
   Refer to switch chart on schematic
3. Gas Free Calibration Assy. [ ]
4. Calibration Curve [ ] Typical Curve [ ]
5. Current Output Board [ ]
6. Bench Mounting Kit [ ]
7. Stainless Steel Tubing [ ] Teflon Tubing [ ]
8. Air Purge Kit [ ]
9. Explosion Proof Case [ ]
10. Remote Range Switching [ ]
11. AC Power 50 HZ [ ] 60 HZ [ ]
12. Motor Source Assembly Replacement:
    633773 [ ] 638449 [ ]
    638450 [ ] 638451 [ ]
13. Calibration Pressure:
    Atmospheric [ ] Other [ ]

REMARKS:

S.O. No.: RAPID 7963
P.O. No.: H 25900 CH8C
Model No.: 865
Serial No.: RAPID 7963

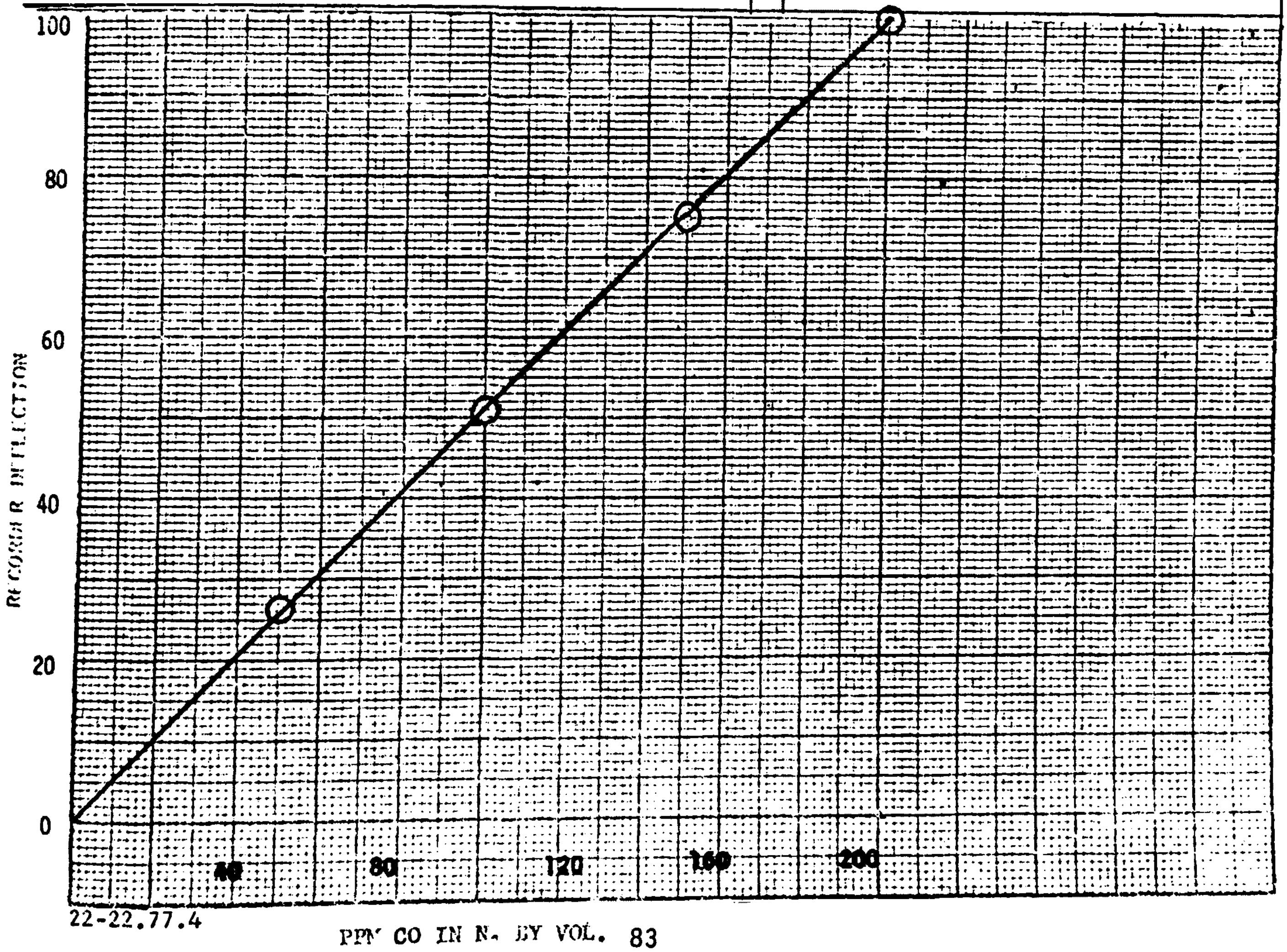
Detector Ser. No.: 6099F
Detector Part No.: 633943
Tag No.:
Configuration No.: 788916

Repeatability: (In % of F.S.)
Range 1: % Range 3: %
Range 2: % Range 4: %

Interference Gas	Mol %	Resp. Equiv.
1. CO_2	10%	
2.		
3.		

Engineer: J. Wilson

Date: 9-13-78



22-22.77.4

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FULLERTON CALIFORNIA • 92634

Figure 3.9

INFRARED ANALYZER CALIBRATION & DATA SHEET

Customer: TRW
Address: Manhattan Beach, California
Application: Carbon Dioxide
Ranges: 1. 2. 3.

1. Uncalibrated Linearizer Range 1 [ ]
2. Calibrated Linearizer Range 1. [ ] 2. [ ] 3. [ ]
   Refer to switch chart on schematic
3. Gas Free Calibration Assy. [ ]
4. Calibration Curve [xxx] Typical Curve [ ]
5. Current Output Board [ ]
6. Bench Mounting Kit [ ]
7. Stainless Steel Tubing [ ] Teflon Tubing [xxxx]
8. Air Purge Kit [ ]
9. Explosion Proof Case [ ]
10. Remote Range Switching [ ]
11. AC Power 50 HZ [ ] 60 HZ [xxxx]
12. Motor Source Assembly Replacement:
    633773 [xxx] 638449 [ ]
    638450 [ ] 638451 [ ]
13. Calibration Pressure:
    Atmospheric [xxx] Other [ ]

REMARKS:

S.O. No.: RAPID 7396
P.O. No.: G14892 CG7C
Model No.: 864
Serial No.: 101447

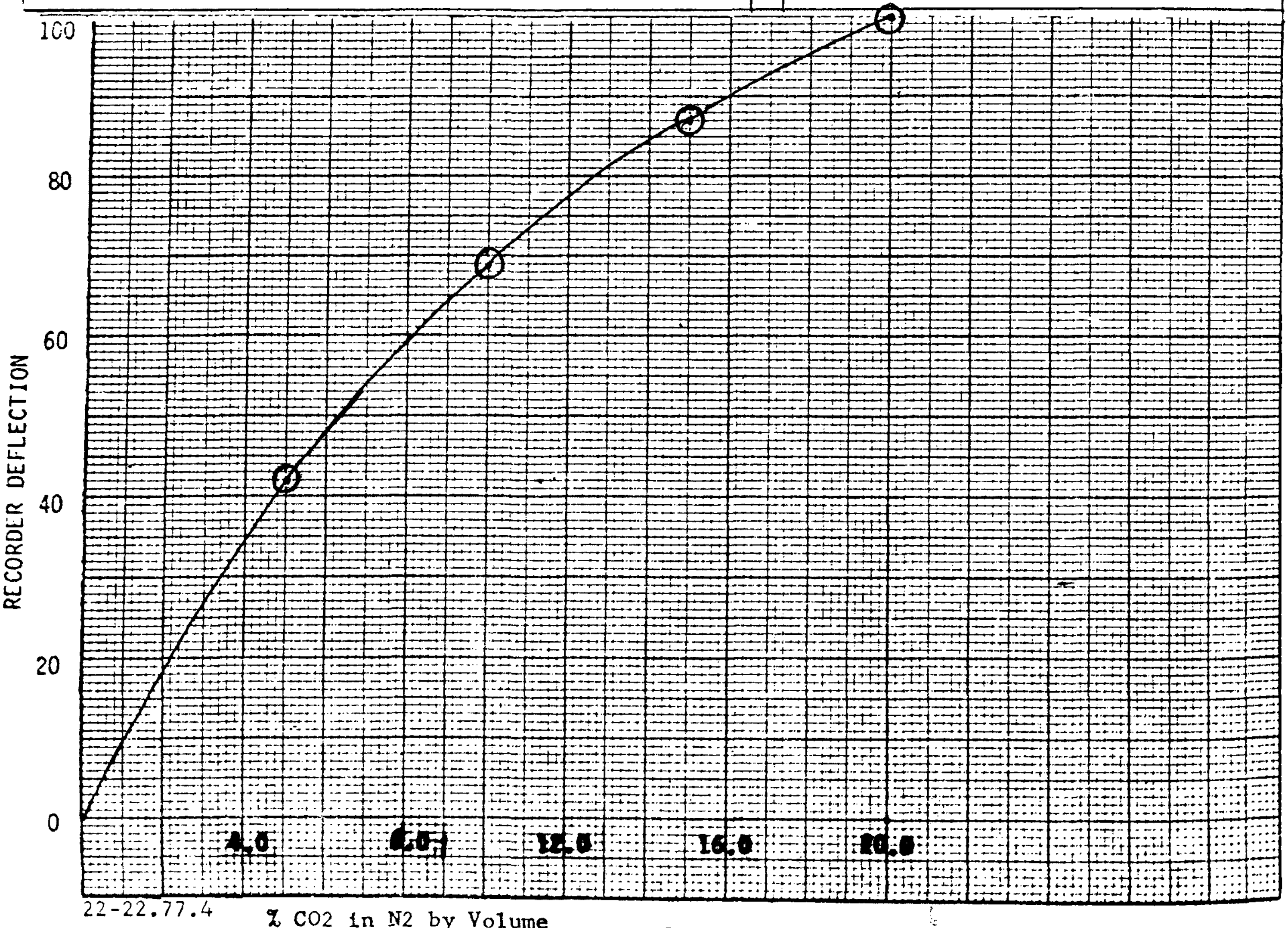
Detector Ser. No.: 3827F
Detector Part No.: 636857
Tag No.:
Configuration No.: 788923

Repeatability: (In % of F.S.)
Range 1: ±1 % Range 3: ±1 %
Range 2: % Range 4: %

Interference Gas	Mol %	Resp. Equiv.
1.		
2.		
3.		

Engineer: Jim Wilson

Date: 2/27/78



Sampling Procedure

1) Turn analyzers on to appropriate range as follows:

O_2 analyzers	0-25%
CO analyzers	Range 3
CO_2 analyzer (Infrared Industries)	High (0-30%)
CO_2 analyzer (Beckman)	Range 1

2) Pass sample gas through analyzer. This is accomplished by the following steps:
   - turn sample shut-off valve to sample position
   - turn on gas conditioner pump
   - flip gas conditioner sample/span toggle switches to sample position

3) Ensure that the data recorders are operating correctly as described in Section 4.2 (operation of data recording instruments).

   System should now continuously monitor the combustion gas. At the end of the measurement period the upscale calibration and zero should be checked to ensure no drift has caused an error in measurement. If there has been a drift, it should be noted in the instrument log book.

3.5 COMBUSTION EFFICIENCY CALCULATION

3.5.1 Sample Calculation

The following are the methods of defining and calculating combustion efficiency.

Combustion Efficiency

Combustion efficiency is defined as $\% \text{ CE} = 100 \times \frac{\% \text{ CO}_2 - \% \text{ CO}}{\% \text{ CO}_2}$

where % CO_2 is the percentage CO_2 composition of the combustion effluent measured by the CO_2 monitor, and % CO is the percentage CO composition of the combustion effluent calculated from measurements by the CO monitor.

Sample Calculation

Assume the CO_2 monitor indicates that CO_2 is 9% of the combustion effluent. Assume CO is 9 parts per million (ppm).

To convert parts per million to percent, multiply by 0.0001 (i.e., 1×10^{-4}). Therefore, 9 ppm is 0.0009%.

Combustion efficiency is

$$\% CE = \frac{\% CO_2 - \% CO}{\% CO_2} \times 100$$

$$\frac{9 - 0.0009}{9} = 99.99\%$$

3.5.2 Sample Data Sheet

The sample data sheet for recording combustion efficiency data is presented in Table 3.2.

3.6 MAINTENANCE AND TROUBLESHOOTING

3.6.1 Maintenance

Maintenance consists of those procedures which are performed routinely on all of the equipment. Table 3.3 shows the frequency that these maintenance procedures should be performed.

Sample Probes and Lines

- Visual inspection should be made to see if probe is in good condition.

Gas Conditioner

- Check water level of bath.
- Monitor internal components for leaks by removing top panel and visually inspect.
- Change filter - (signaled by dark gray or black appearance) Filter will probably be changed every day.

Filter change procedure is as follows:

1) Remove filter housing from gas conditioner.
2) Loosen nut at bottom of filter housing and slide filter from housing.
3) Insert new filter and attach to gas conditioner.

Calibration Gas and Purge Air System

- Visually inspect amount of gases in cylinders before each departure. The gas cylinder should not be used if cylinder pressure is below 300 psi.

Table 3.2

VULCANUS TESTS: ON-LINE MONITOR DATA

DATE: ____________________

INCINERATOR: ______________

TEST NO. TIME	% O_2 CH. NO.	% CO_2 CH. NO.	PPM CO CH. NO.	COMBUSTION[A] EFFICIENCY, %	REMARKS

[A] $\frac{\% CO_2 - \% CO}{\% CO_2} \times 100$

TABLE 3-3. FREQUENCY OF MAINTENANCE

Equipment	Procedure	Frequency
Probes and sample lines	-Visual inspection	After every burn
Gas conditioner	-Check water level of cold bath	Before each test period
	-Monitor in termal components for leaks	Before each test period
	-Charge filter	Every four weeks of operation
Calibration gas system	-Check cylinder pressure*	Every 2-3 days
CO, CO_2 and O_2 analyzers	-As per Table 3-1	As per Table 3-1
Strip chart recorders	-Check amount of strip chart left	After each test period
	-Check level of ink in cartridges	After each test period
Data logger	-Check amount of printer paper	After each test period

*If cylinder pressure is below 300 psi, do not use, replace with new cylinder

CO, CO_2, and O_2 Analyzers

Beckman models 864 and 865, CO_2 and CO analyzers respectively:

- Daily reading of oscillator. Tune and gain control setting as described in Section 3.3.
- Normally no maintenance will be required, however, should loss of sensitivity occur (cannot calibrate with gain control on maximum setting), the sensor should be recharged or replaced for recharging. See Section 6.1, page 26 in manual.

- Infrared Industries model 703 CO_2 analyzer
  - Requires no maintenance
- Taylor Industries model OA273 O_2 analyzer
  - See page 1009 for battery replacement and filter replacement.

3.6.2 Troubleshooting and Repairs

Due to the highly technical nature of the instruments used, it is impracticable to present a discussion of troubleshooting and repair for each individual instrument, and in most cases troubleshooting of each individual analyzer is covered by its own instrument manual found in the appendix. Only the gas conditioner is not covered thoroughly.

The following troubleshooting discussion is concerned with loss of flow of the gas sample, which includes plugging of sample lines and the gas conditioner.

If loss of flow is found (noted by a drop in by-pass flow or no flow condition), the following procedure is employed to repair the system:

1) Remove sample inlet to gas conditioner. If no change in flow condition, proceed to step two. If flow resumes normal flow, attach high pressure air to sample line and flush sample line with high pressure air. If this fails, search for plugged line or probe and replace. After clearing the line, reattach sample line and resume sampling.

2) Disconnect line at valve between first condensate trap and filter. If flow condition returns to normal, condensate trap or coil is plugged. To repair, attach high pressure air to 1/4" line from trap and purge trap and coil with high pressure air to remove plug. If flow condition does not return to normal, replace filter in housing on front of gas conditioner. If this does

not solve problem, check second condensate trap and coil for plugging. It is possible that the temperature bath which the trap and coil are in is too cold and water is frozen in the trap or coil lines. To correct, add warm water to melt ice in the lines.

4. DATA RECORDING SYSTEM

The data recording system consists of different types of instruments capable of recording and/or displaying the output from the flowmeters and CO, CO_2, and O_2 analyzers.

4.1 DESCRIPTION OF SYSTEM

The data recording system consists of three different types of instruments: strip chart recorders, a data logger, and remote digital readouts.

4.1.1 Strip Chart Recorders

There are eight strip chart recorders located in the meeting room as shown in Figure 3.1. They are used to continuously monitor the outputs from the instruments. Six of these recorders are to be used as primary recorders for monitoring the six instruments (three flowmeters and three combustion gas analyzers). Two recorders will be used as backups in case of primary recorder failure. Two types of Hewlett Packard recorders are used, the Model 680 and 680M.

4.1.2 Data Logger

The data logger, located as shown in Figure 3.1, is to be used for two functions: to log the output of the instruments at 20 minute intervals and to provide digital readout of the output from the instruments. The data logger accepts all the outputs from the instruments and will print out each input signal on demand or on a preset time interval. The instrument can also be switched manually from one input to another so that each input can be read out digitally.

4.1.3 Remote Digital Readouts

Six digital readouts have been installed in the recording system so that the output from each instrument (flowmeters or combustion analyzers) can be read at a remote location in the combustion room. These digital readouts will be proportional to the analog signal displayed on the front panel of each instrument.

4.2 OPERATION OF THE SYSTEM

When sampling begins, all three data recording and/or readout devices will be operating simultaneously.

4.2.1 Operation of Strip Chart Recorders

1) Set voltage selection to 0-5 volts.
2) Turn recorder on (flip toggle switch to on).
3) Flip pen up/down switch to down position.
4) Flip primary/spare toggle switch at top right of instrument rack to recorder being used as either primary or spare.
5) Set chart speed to 20 cm/hr (8 in/hr).
6) Calibration
   a) Zeroing
      - Apply zero signal to recorder - this can best be done at time of zeroing flowmeter or combustion analyzer during calibration (see Section 2.3 or 3.3).
      - With zero signal applied, adjust zero control to zero on chart output (simultaneously set zero on data logger-digital display).
   b) Upscale calibration
      - Check upscale calibration by applying an output from instrument being recorded (can be done during upscale calibration of instrument) and checking to see that the recorder reflects approximately the same value as the instrument's own analog or digital display readout (and exactly the same as data logger digital display). If reading does not correspond, see Section 5.23 in recorder manual.
7) Recorder can now be used to accurately monitor the output from an instrument.

4.2.2 Operation of Data Logger

Numbers in parenthesis refer to Figure 4.1.

1) Turn on power switch (#10).
2) Set frame rate switch (#2) at 20 minutes.
3) Set day (#9) - example: 28th day of month - 028.
4) Set time. Flip TIME/MEASURE switch (#6) to TIME and set the correct time: first press the SLOW/FAST switch (#7) to FAST to

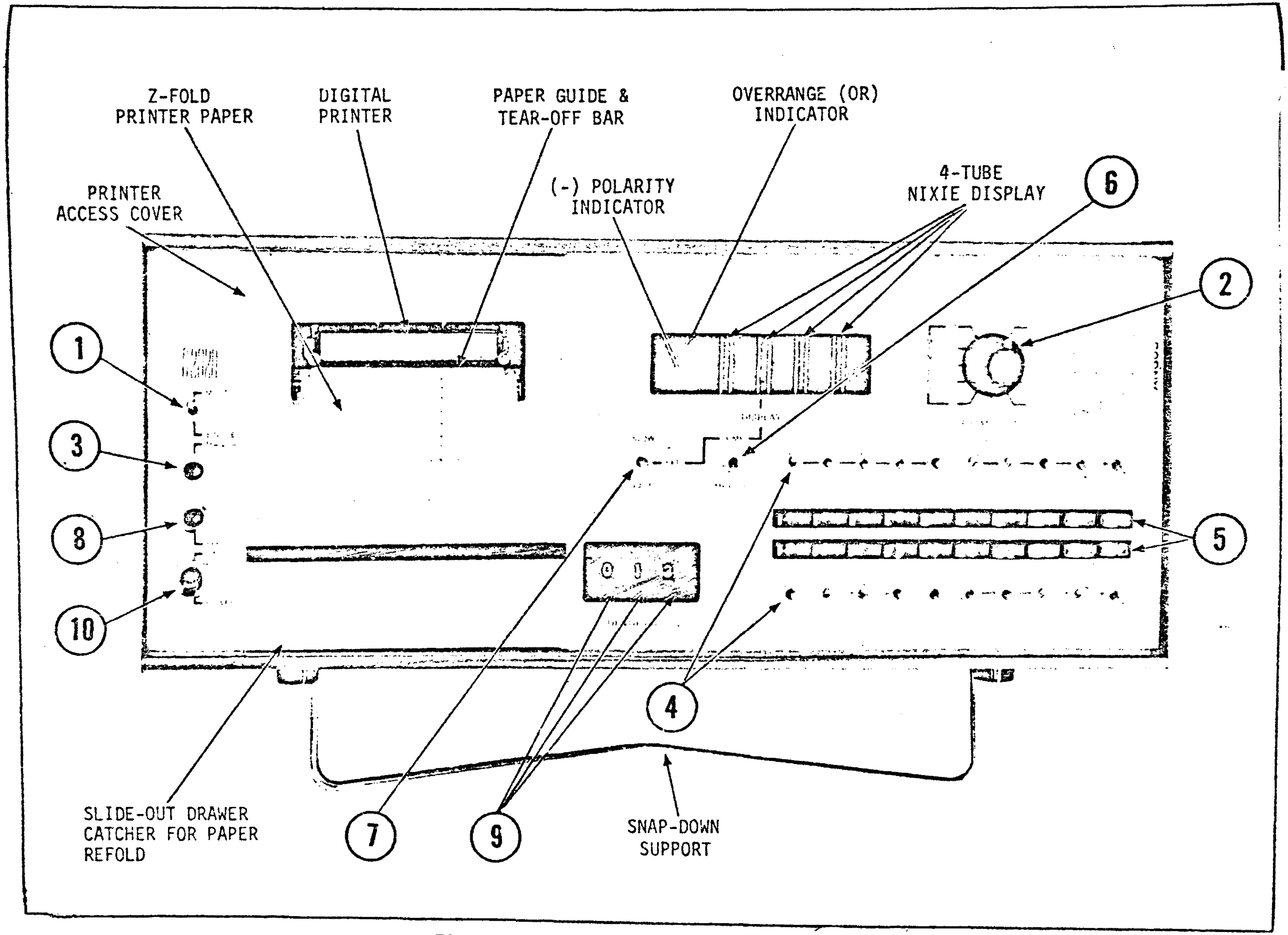


Figure 4.1. Front panel view of data logger.

set the approximate time, and then press the switch to SLOW to set the exact time. When setting up, check jumper location on the PC card to see that it conforms with the power line frequency being applied. (See Esterline-Angus instruction manual appendix.)

5) Ensure that voltage select switches (#4) are in 100 mV position.

6) Choose the desired readout and printouts by adjusting the channel select switches (#5). The digitally displayed value corresponds to the notation above the switch which is pressed in. All values up to the depressed switch will be printed out. Normally switch #5 should be depressed, so that all values will be printed out.

7) Instrument will now automatically printout the signals from the instruments every 20 minutes.

Explanation of other switches:

- manual switch (#3) can be used to trigger data printout. (System will printout to the channel select switch (#5 in our case) pushed in.
- feed button (#8) when pushed in will advance printout tape.

4.2.3 <u>Operation of Digital Readouts</u>

Readouts need no operating procedure. When instruments (flowmeters or combustion analyzers) put out a signal, the digital readouts will display a signal proportional to the instruments output.

Example:

CO instrument - Beckman model 865

0-5 volts fullscale. At 80% reading on analyzer analog display the digital readout will display 4 volts (or 80% of 5 volts).

4.3 MAINTENANCE

The strip chart recorders and the data logger require maintenance while the digital readout does not require any maintenance.

4.3.1 <u>Strip Chart Recorders</u>

<u>Chart Paper Loading</u>

Remove chart magazine as follows:

1) Depress the lever which is adjacent to the power switch at the bottom of the control panel.
2) Raise the chart magazine to a horizontal position.
3) Slide magazine from the recorder.

Install a roll of 6" width graph paper as follows: (Refer to Figure 4.2).

1) Position the empty chart magazine as indicated in Figure 4.2.
2) Insert the supply roll between the upper spring loaded hubs with the elongated drive holes of the paper to the right.
3) Thread paper from the new supply roll under the guide bar.
4) Bring the paper over the top of the sprocket drive drum and engage the sprockets.
5) Pull the paper down across the face of the chart magazine and feed through the slot at the bottom of the platen.
6) Rotate the drive gear so that the paper will feed through the slot.
7) The paper will now feed out through the bottom of the chart magazine and may be torn off as the operator desires. If this type of operation is desired, the chart paper magazine may be installed in the recorder. For operation with the chart stored on a take-up spool within the chart magazine, continue with steps 8 and 9.
8) Install an empty take-up spool (supplied) between the two lower hubs. Index the left end of the spool so the drive stud on the left hub mates with the slot on the take-up spool.
9. Attach the end of the chart paper on the take-up spool with adhesive tape. Rotate the drive gear until several turns of paper are on the take-up spool. Inspect for proper chart tracking without buckling and then install the chart magazine.

Install Ink Cartridge

Remove chart magazine as described in chart paper loading. Force the cartridge over the piercing tube of the corresponding pen and screw all the way on. The piercing tubes (up to two) are located in the same plane as the pen. Depressing the primer will force ink from the cartridge to the pen tip.

4.3.2 Data Logger

Replacement of Printer Paper

Detailed instructions for loading of printer paper are graphically illustrated on a decal affixed to the inside bottom surface of the slide-out drawer that is used to catch the refolded paper.

To load, refer to Figure 4.1 and proceed as follows (numbers in parenthesis refer to figure):

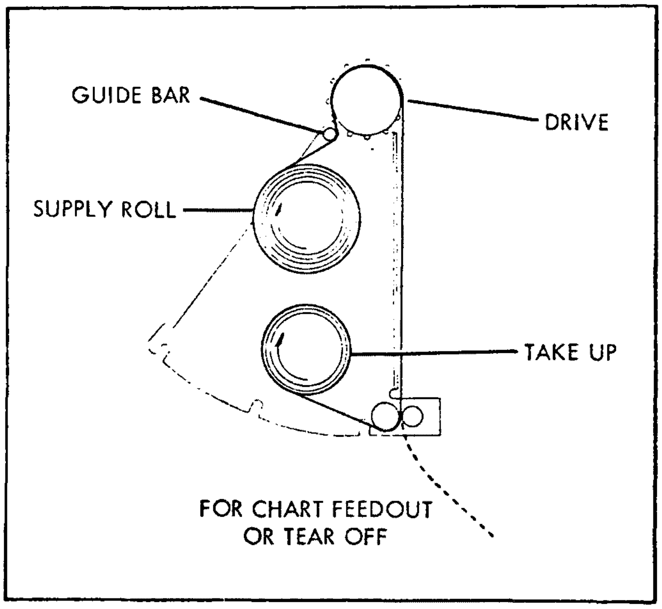


Figure 4.2 Chart loading diagram.

1) Place FRAME RATE switch (2) in one of the external triggering positions (either EXT. TRIG. or AUX.). Then, turn on instrument power (10).

   NOTE: Positioning of the FRAME RATE switch in this manner inhibits the printer (provided that there are no external incoming trigger pulses being applied) when either loading the paper or setting the time of the internal clock.

2) Snap out and remove the printer access cover.

3) Flip down the plastic paper guide/tear-off bar.

4) Perform the three steps as indicated by the loading instructions on the decal inside the slide-out drawer.

5) Keep FEED pushbutton (8) depressed until paper feeds out front of printer and beyond the plastic tear-off bar. Flip tear-off bar back into position, and tear off one or two folds of paper.

6) Snap the printer access cover back into place.

7) The paper is now loaded and ready for printout operations.

4.4 TROUBLESHOOTING

Pen tip clogging (recorder will not ink properly)

- Remove chart paper cartridge
- Remove ink cartridge
- Flush ink system with water*
- Dry ink system with air
- Add new ink cartridge
- Use syringe to suck ink to pen tip (if needed)
- If recorder still does not work, switch to spare recorder.

*Note: If system will not flush properly, use wire to unclog pen tip.

5. REFERENCES

1. TRW Report "Evaluation of Waste Flow and Temperature Measurement for Shipboard Incineration " dated May 1978

2. EPA-600/2-77-196 "At Sea Incineration of Organochlorine Wastes Onboard the M/T Vulcanus" dated September 1977

3. EPA-600/2-78-068 "At-Sea Incineration of Herbicide Orange Onboard the M/T Vulcanus" dated April 1978

APPENDIX B

Manufacturer's Operating Manuals

1.	Instruction Bulletin for Series 10 LV 2000 Liquid Vortex Flowmeter	Fischer & Porter
2.	Series 240 Clampitron Flowmeter Bulletin 240-IM Installation Manual	Controlotron Corporation
3.	Instruction Manual Model 600 Dual Input Sample Gas Conditioning System	Thermo Electron Corporation
4.	Beckman Model 865 (CO) Infrared Analyzers	Beckman Instruments, Inc.
5.	Beckman Model 864 (CO_2) Infrared Analyzers	Beckman Instruments, Inc.
6.	IR/702/703 Gas Analyzer (CO_2) Analog/Digital Operations Manual	Infrared Industries, Inc.
7.	Beckman Models 741 and 742 Oxygen Analyzers	Beckman Instruments, Inc.
8.	Taylor Servomex Instruction Manual Oxygen Analyzer Types OA 272/273	Taylor Servomex Limited
9.	Instruction Manual Model D-2020 Digital Data Acquisition System (DDAS)	Esterline Angus
10.	Operating and Service Manual Strip Chart Recorders (Includes Metrics) 680/681/682/683	Hewlett Packard
11.	Weston Line Operated DPM 2460 Series Operators Manual	Weston Instruments

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16. ABSTRACT The report describes the test operations and results of measuring organochlorine waste flowrate and CO, CO2, and O2 in the effluent gas during incineration of industrial chemical waste onboard the M/T Vulcanus. The data was obtained during shipboard test burns in the North Sea during November and December 1978 and February 1979. Program objectives were to gather data on durability and accuracy of both the waste flowmeters and the CO, CO2, and O2 monitoring system when used on a continuous routine basis. Combustion efficiency exceeded 99.95% in all cases, meeting IMCO requirements of 99.95 + or - 0.05%. The ultrasonic and vortex waste flowmeters and the CO, CO2, and O2 monitoring system performed satisfactorily during the burns. The CO, CO2, and O2 equipment was operated continuously for a maximum of 12 hours. The vortex flowmeters indicated gradual waste buildup, although buildup did not occur in the ultrasonic flowmeter piping. Monthly inspection and cleaning of the vortex meters would avoid extensive solids buildup. Use of spare instruments ensured continuous acquisition of combustion data throughout the burns. Post-test inspection of the analyzers indicated only minor corrosion and wear.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Combustion	Pollution Control	13B	21B
Chlorine Organic Compounds	Evaluation	Stationary Sources		14B
	Instruments	Organochlorine	07C	
Incinerators	Monitors	At-sea Incineration		
Oceans	Flowmeters	Chemical Waste	08F	
Waste Disposal	Carbon Dioxide			
Carbon Monoxide	Oxygen		07B	

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