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MODEL 49 SERIES

INSTRUCTION MANUAL

(INCLUDING)

MODEL 49
U.V. PHOTOMETRIC AMBIENT OZONE ANALYZER

MODEL 49-003
U.V. PHOTOMETRIC AMBIENT OZONE ANALYZER
WITH INTERNAL OZONATOR

MODEL 49PS
U.V. PHOTOMETRIC AMBIENT OZONE CALIBRATOR

THERMO ENVIRONMENTAL INSTRUMENTS, INC.
8 WEST FORGE PARKWAY
FRANKLIN, MA 02038
TELEPHONE: (508) 520-0430
FAX: (508) 520-1460

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TABLE OF CONTENTS

I. INTRODUCTION

Thermo Environmental Instruments' Model 49, time-shared dual cell U.V. Photometric Ambient Ozone Instruments (Figure I-1) are capable of measuring ambient level ozone concentration on a continuous, real-time basis.

Compared to other ambient ozone measurement techniques, the Model 49 Instruments offer the following significant advantages:

- Balanced Optical System
- Balanced Flow System
- Simultaneous Zero and Sample Measurement Leading to Increased Specificity through Real-time Cancellation of Potential Interference Species
- Automatic Microcomputer Compensation for Changes in Temperature and Pressure
- Fast Response Time
- No Consumables Required
- Internal Diagnostics

Thermo Environmental Instruments Inc. is pleased to have supplied you with a Model 49. We are committed to the manufacture of instruments exhibiting high standards of quality, performance, and workmanship. We are prepared and eager to be of service to you in the use of this instrument.

There are three basic configurations of the Model 49 Series of Instruments:

1. MODEL 49 (Figure I-1)

   A Model 49 configured so as to determine the level of ozone in ambient air. The Model 49 has been accepted by the U.S. EPA as an equivalent method (EQOA-0880-047).

2. MODEL 49-003 (Figure I-1)

   A Model 49 with the addition of an internal ozonator with remote actuation capability to allow easy determination of zero, precision, and level 1 span checks. The Model 49-003 has been accepted by the U.S. EPA as an equivalent method (EQOA-0880-047). An external source of "zero-air" must be used with this option.

3. MODEL 49PS (Figure I-2)

   A Model 49 configured as an ozone primary standard calibration photometer in accordance with the latest EPA regulations. The Model 49PS also includes an internal ozonator.

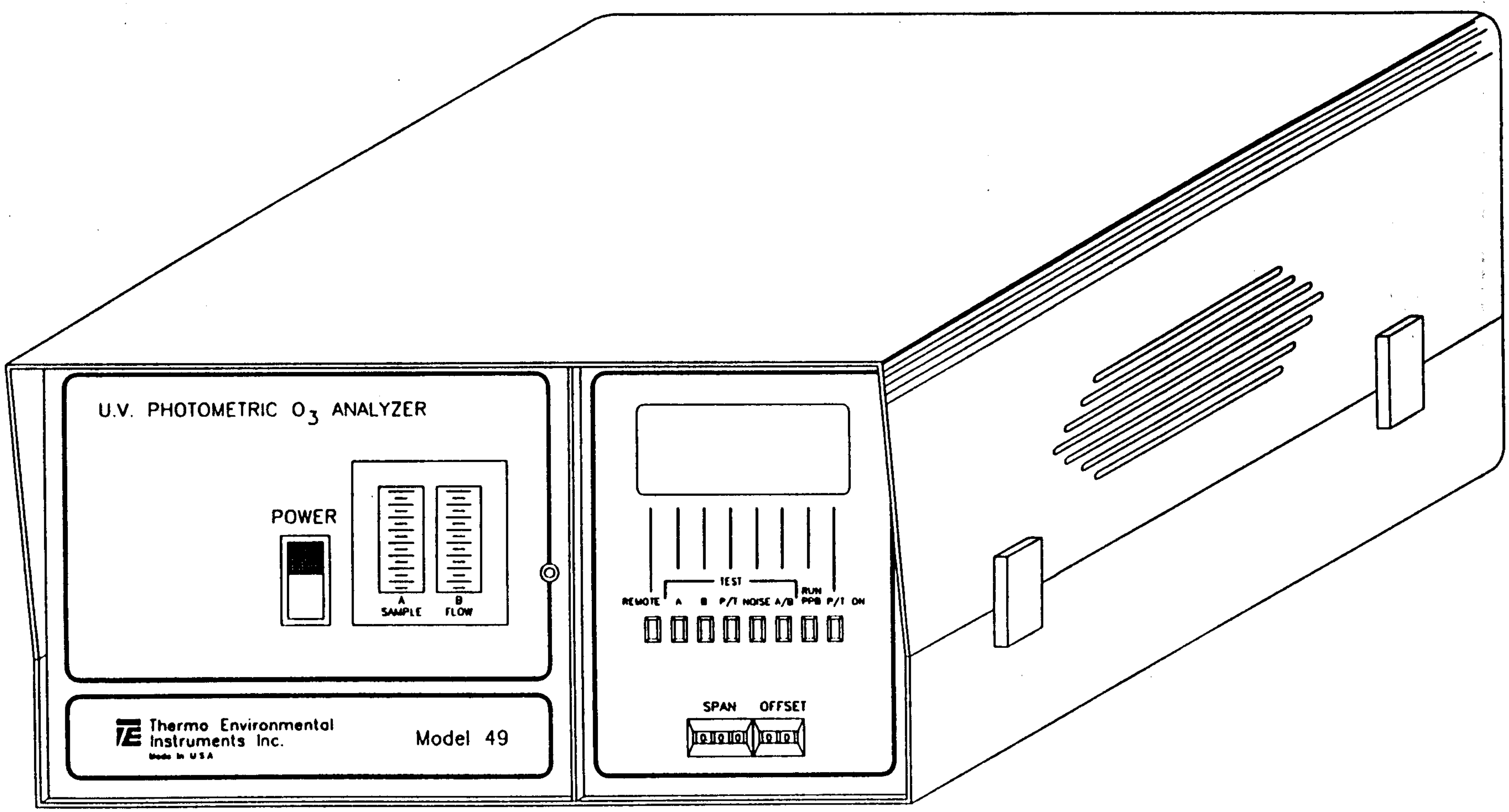

Figure I-1: Model 49 Front Panel Controls

The Models 49, 49-003, and 49PS all include the same basic optical bench, source detector, pressure transducer, and temperature transducer. The digital electronics are virtually the same. The main difference between the analyzer (Model 49 and 49-003) and calibrator (Model 49PS) is in the source of the reference gas used. In the analyzer (Model 49 and 49-003), the reference is formed by passing ambient air through the ozone removing catalytic converter. In the calibrator (Model 49PS), the reference measurement is performed on the same "zero-air" that feeds the internal ozonator.

The term Model 49 will be used in this manual when describing the components that are common to all three models. It should be noted that the Models 49 and 49-003 are those designated equivalent by the EPA. There is no formal certification program by the EPA for calibration methods that are applicable to the Model 49PS.

The rest of this chapter includes a general description of the Model 49 Series. If desired, the reader can go directly to Chapter II, "Installation," or Chapter III, "Operation."

PRINCIPLE OF OPERATION

General Theory Of Operation

Figure I-3 illustrates in simplified form the general principle of operation of an ultraviolet photometric ozone analyzer. The U.V. photometer determines ozone concentration by measuring the attenuation of light due to ozone in the absorption cell, at a wavelength of 254 nm. The concentration of ozone is related to the magnitude of the attenuation.

The reference gas passes into the absorption cell to establish a "zero" light intensity reading (I_o). The solenoid then switches, and the sample gas passes through the absorption cell to establish a "sample" light intensity reading (I). The ratio of these two readings (I/I_o) is a measure of the light absorbed by ozone in the sample at 254 nm. It is directly related to the concentration of ozone in the sample through the Beer-Lambert law (Appendix A).

$$\frac{I}{I_o} = e^{-KLC} \qquad (1)$$

where K = 308 cm^{-1} at 0°C, 1 atmosphere and at 254 nm

L = length of cell, in centimeters

C = concentration in parts per million (ppm)

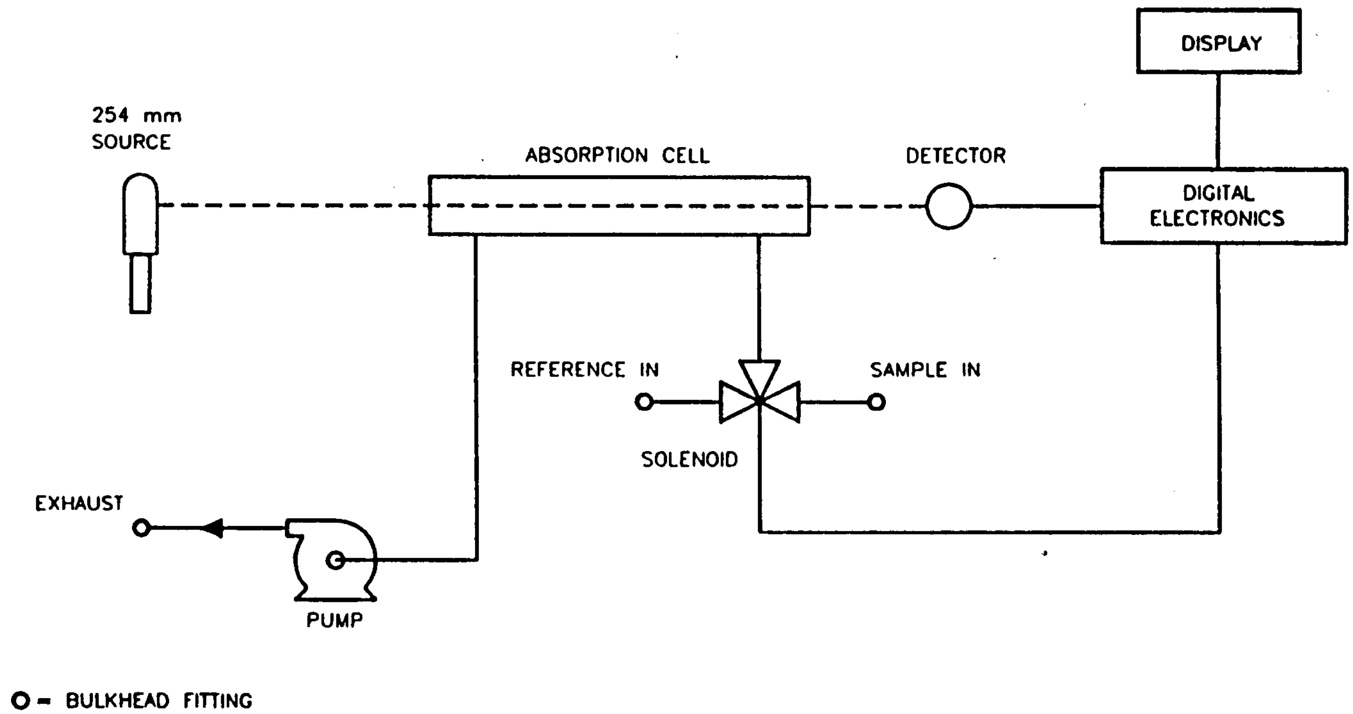

FIGURE I–3 SIMPLIFIED SCHEMATIC OF U.V. PHOTOMETER

A change in C of ± 1 ppb leads to a change in I/I_o of .002%. The source must be stable to better than .002% in the time frame it takes to measure I and I_o (typically around 10 seconds) in order for the photometer to have a sensitivity of ± 1 ppb. Since a well designed source and power supply comes close but still does not meet these stability criterion, a second detector is used to monitor the changes in light intensity and to correct for these changes. The Thermo Environmental Instruments Inc. Model 49 instruments are unique in how they treat the second detector. The scheme used is shown in Figures 1-4 & 1-5. This system is basically two photometers of the type shown in Figure 1-3, utilizing two separate but similar absorption cells and detector systems. The do however, share the same source. These two photometers operate 180° out of phase, but synchronously, i.e., when Cell A contains reference gas, Cell B contains sample gas and vice versa. The two detectors integrate the signals simultaneously, thus I in Cell B (I(B)) is determined at the identical time I_o in Cell A (I_o(A)) is determined. The solenoids then switch and after an appropriate flush time (approximately 7 seconds) I_o(B) and I(A) are determined. From the Beer-Lambert equation, the concentration in Cell A, C(A) can be determined from I(A)/I_o(A) and the same for C(B) from I(B)/I_o(B). It can be demonstrated[1] that the average value of these two readings factors out the fluctuation in lamp intensity, i.e.,

$$C = \frac{C(A) + C(B)}{2} \qquad (2)$$

Since the value of K in the Beer-Lambert equation is a function of temperature and pressure, the Model 49 contains a temperature and pressure transducer to correct for any ambient pressure and temperature changes. The microcomputer in the Model 49 solves the equation directly for each cell, corrects for temperature and pressure, and outputs the average concentration to both the front panel digital display and the recorder analog output.

INSTRUMENT DESCRIPTION

The instrument can be most conveniently discussed by separating it into the following operational components (Figure I-6):

- Optical Bench
- Lamp and Lamp Power Supply
- Detector and Detector Electronics
- Pressure and Temperature Transducer
- Microcomputer
- Flow Components (Pump, Valves, Flowmeter, and Plumbing)
- D.C. Power Supplies
- Ozonator and Output Manifold (Model 49PS or Model 49 with Option 003)
- Ozonator Power Supply

[1] Technical Paper - TP-49-01 available from Thermo Environmental Instruments Inc., 8 West Forge Parkway, Franklin, MA 02038.

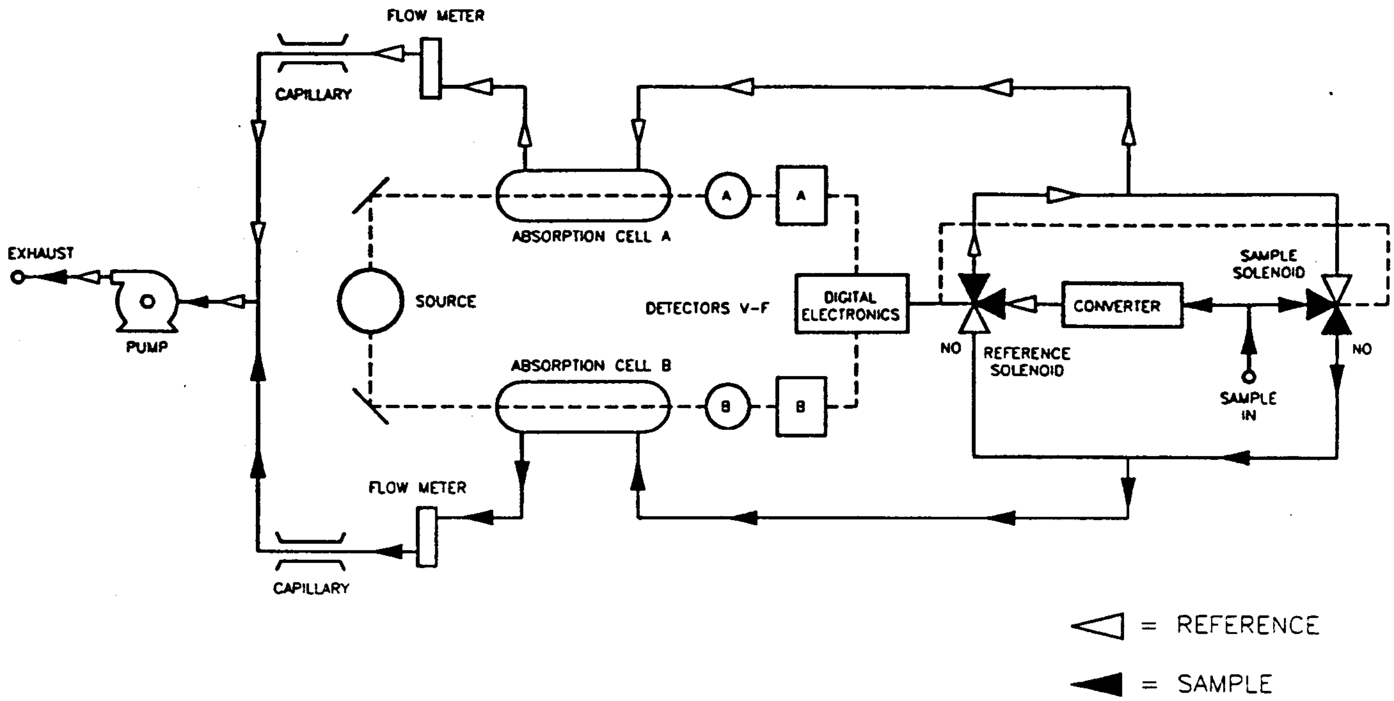

FIGURE I-4: FLOW SCHEMATIC OF MODEL 49
SAMPLE SOLENOID - NO; REFERENCE SOLENOID - NC

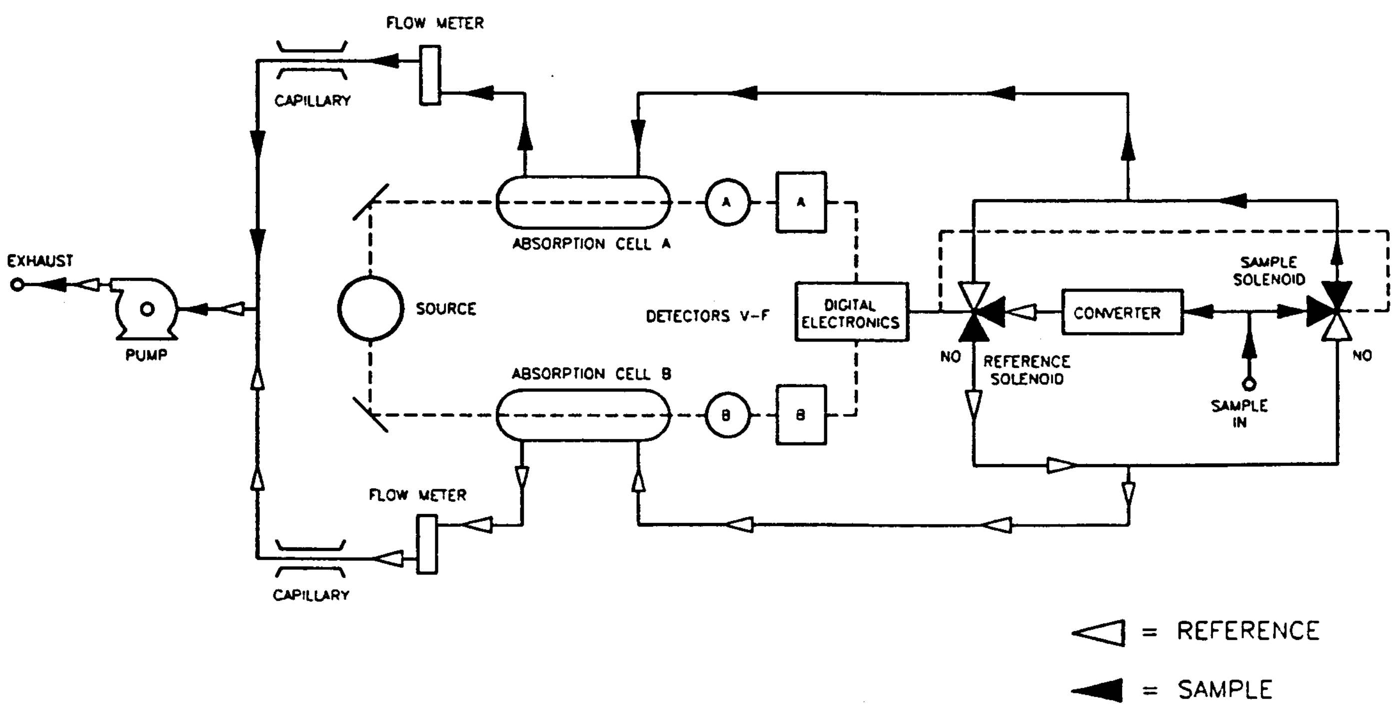

FIGURE I-5: FLOW SCHEMATIC OF MODEL 49
SAMPLE SOLENOID - NC; REFERENCE SOLENOID - NO

The computer will calculate, apply, and store a NO_x balance correction (b.F.) which will adjust the NO_x analog output to reflect the NO concentration, any NO_2 impurity in the NO working standard, and the NO_x zero offset. The NO_x recorder response will equal:

$$\text{Recorder Response (\% scale)} = \frac{[NO_x]_{OUT}}{URL} \times 100 + Z_{NOX}$$

Where:

URL = Nominal upper range limit of the NO_x channel, PPM

Record the NO_x concentration and the analyzer's NO_x response.

3) Preparation of NO, NO_2, and NO_x Calibration Curves

a) Generate several additional NO and NO_x concentrations by decreasing F_{NO} or increasing F_D. For each concentration generated, calculate the exact NO and NO_x concentrations using the above equations for $[NO]_{OUT}$ and $[NO_x]_{OUT}$. Record the NO and NO_x responses. Plot the Model 42 responses versus the respective calculated NO and NO_x concentrations and draw or calculate the respective calibration curves. For subsequent calibrations where linearity can be assumed, these curves may be checked with a three-point calibration consisting of a zero point, NO and NO_x concentrations of approximately 80% of the URL, and an intermediate concentration(s).

b) Adjust the GPT system to generate a NO concentration near 90% of the URL of the instrument range selected. Sample this NO concentration until the NO and NO_x responses have stabilized. Measure and record the NO concentration as $[NO]_{ORIG}$

c) Adjust the O_3 generator in the GPT system to generate sufficient O_3 to produce a decrease in the NO concentration equivalent to about 80% of the URL of the NO_2 range. The decrease must not exceed 90% of the NO concentration determined in step (b) above. After the analyzer responses have stabilized, record the resultant NO concentrations as $[NO]_{REM}$. Set the instrument display to read NO_2, push the CAL button, set the thumbwheel switches to reflect the sum of the following: the NO_2 concentration generated by GPT ($[NO]_{ORIG}$ - $[NO]_{REM}$) and any NO_2 impurity (note that if the Model 42 is in the PPB mode, the four thumbwheel switches are used without a decimal point position, e.g., 410 PPB is entered as 0410, 45 PPB entered as 0045, 3550 PPB entered as 3550.

Optical Bench (See Figure I-7)

The optical bench is a dual cell device, with each cell having a length of 37 cm. It has been designed for easy disassembly for cleaning. All internal surfaces have been coated with polyvinylidine fluoride to ensure that ozone undergoes no decomposition upon exposure to the internal surface of the bench. Both the source and detectors mount rigidly onto the bench. The optical bench is very rigid and needs no optical alignment.

Lamp and Lamp Power Supply

The lamp is a low pressure mercury vapor lamp with an expected lifetime in excess of one year. The lamp is driven by a precisely regulated power supply with a square wave at about 15 kHz to ensure a high level of stability. In order to achieve the highest level of stability of light output, the lamp itself is mounted in a temperature controlled, insulated aluminum block that provides the necessary thermal stability.

Detector and Detector Electronics

The detector and associated electronics are mounted together in a small, well-shielded can to ensure the highest levels of detector stability and lowest levels of noise. The detectors are small solar blind vacuum photo-diodes, which are followed by high quality electrometers, which in turn are followed by V-F (voltage-to-frequency) converters. All lines are well-shielded and held to an absolute minimum length. The frequency output of the detector system is directly proportional to the light intensity.

Pressure and Temperature Transducer

A strain gauge pressure transducer is used on the Model 49. In order to remove any temperature dependence, the transducer is thermostated at about 50 °C. The pressure transducer assembly contains all the driving electronics. The output of the pressure transducer assembly is a pulse train whose frequency is directly proportional to the pressure. A thermistor is used to measure the bench temperature. It has been demonstrated that the bench temperature is close to the sample gas[2] temperature.

Microcomputer

The microcomputer on the Thermo Environmental Instruments Inc. Ozone Photometer is based on the Motorola 6800 family. The pulse train outputs of the two detector systems and the pressure transducer feed directly into computer-controlled counters.

[2] Model 49 Equivalency Report submitted to the U.S. Environmental Protection Agency.

The software operates on this information to determine the ozone concentration, to control the valve timing, to output diagnostic data, and to output the computed ozone concentration to the front panel digital display and rear analog recorder jacks. Other outputs, such as RS232, etc., are available as options. The software contains sophisticated algorithms to minimize noise, to increase the sensitivity, and to check for malfunctions.

Flow Components

The Thermo Environmental Instruments Inc. Model 49 operates at nominal atmospheric pressure. Figures I-8, I-9 and I-10 summarize the flow schemes for the different models. A downstream pump and two capillaries control sample flow through the cells which is monitored by two rotameters. Total flows of less than 1 l/min (2 scfh) should be avoided since the flush time would be excessive. Total flows of greater than 3 l/min should also be avoided since there would not be enough residence time in the converter to ensure greater than 99% conversion of the ozone. The solenoid valves operating under computer control allow sample gas to pass through Cell A and reference gas through Cell B, or vise versa, depending upon which cycle the instrument is performing.

Power Supplies

The microcomputer electronics are powered by a ±5 VDC power supply, the detector electrometer by a ±15 VDC supply, the lamp power supply by an 18-volt supply, and the solenoid by a +24-volt supply. All D.C. voltages, with the exception of the +24-volt supply, are highly regulated.

Ozonator

The ozonator on the Model 49PS (and included in Option 003) operates on the photolytic principle. The ozone level produced is a function of light intensity at 185 nm and gas flow. The light intensity is varied by changing the current into the lamp. The gas flow is held constant by a pressure regulator followed by a capillary. The distribution manifold is all Teflon with three outputs; one to supply the Model 49PS or 49-003, one to supply the instrument being calibrated, and one for the atmospheric dump.

Ozonator Power Supply

The ozonator power supply for the Model 49PS is similar to the bench source lamp power supply. The current into the lamp is variable to change the ozone level. This level can be changed manually, in which case the ozone output cannot be determined before hand. However, the level is stable as well as reproducible. The level can also be controlled in an automatic mode, in which case the photometer measures the ozone output, compares it to the value being asked for, and changes the lamp current if necessary for these two values to agree. The ozonator lamp power supply also includes the ozonator heater circuitry. The Option 003 power supply is similar, except it only has a manual mode, and can be preset to two levels. The Option 003 power supply also includes the driver circuitry for the zero/precision/span solenoid.

SPECIFICATIONS

Full scale Analog Range	0-.1, .2, .5, 1.0, 2.0, 5, 10, 20, 50, 100, 200, 500 ppm (0-.5 and 0-1.0 ppm for designated operation; converter is sized for concentrations below 1 ppm)
Zero Drift	Less than 1/2% per month
Precision	0.002 ppm
Linearity	±.001 ppm
Noise	±.001 ppm
Minimum Detectable Limit	0.002 ppm
Response Time (0 to 95%)	20 Seconds
Lag Time	10 Seconds
Span Drift	Less than 1% per month (including drift of transducer)
Automatic Correction for Temperature and Pressure	Better than ±1% per year
Flow Rate	1-3 liters per minute
Outputs	
Analog	0-10V Standard. Others available.
Digital (Optional)	RS232
Operating Temperature Range	0-45°C (20-30°C for EPA Designation)
Physical Dimensions	17"W x 8 3/4"H x 23"D (43cm W x 22cm H x 58cm D)
Weight	35 pounds

Ozonator Specifications

Output	.025 - 1.000 ppm at 6-8 liters per minute
Response	1 minute (to 99% of final value) in auto mode
Stability	±4 ppb or ±1%, whichever is greater

III. OPERATION

This chapter describes the operation of the Model 49 Ozone Instrument. It is assumed that the instrument has already been calibrated (see Chapter IV "Calibration," for calibration procedures). First a description of the individual controls is given. Then a step-by-step start-up and shutdown procedure is outlined.

DESCRIPTION OF CONTROLS (FIGURES I-1 AND I-2)

(Unless otherwise designated, the following comments refer to all instruments.)

Power Switch

Controls power to the electronic circuits, pumps, and solenoid valves. When turned on, the power ON light should be lit; there should also be an audible sound from the pump. The instrument automatically goes into the start-up mode.

Sample Flowmeters

The flowmeters show the flow rate. They should show approximately 1 liter per minute (2 scfh) ±30% per cell. The flow rate is set by the capillary. It can only be changed by using a different size capillary.

LED Display

Depending upon the mode of operation, the display will show concentration in ppb, detector frequencies, pressure in mm Hg, temperature in degrees Celsius, noise diagnostic, balance diagnostic and full scale analog range (analyzers only). Each time an update occurs, the decimal point blinks.

Sample A/B Solenoid Position LED

Indicates whether Cell A or Cell B is receiving the sample gas. In the Model 49-003, these LEDs will blink once a second anytime the analyzer is in the non-sample (i.e., zero/span solenoid actuated, and/or ozonator) mode, giving a visible indication to the user of this fact.

Pushbuttons

Allows the operator to change the mode of operation of the instrument. A LED (Light Emitting Diode) above the pushbutton indicates the active mode. There are eight (8) pushbuttons:

Remote Mode - This pushbutton is used to engage (LED above pushbutton on) or disengage (LED above pushbutton off) only if the remote options are installed. These options include the RS-232 interface and remote activation of the internal ozonator. For a Model 49 if neither the RS-232 nor 003 Option is installed (i.e., there is no board in position 6 of the microcomputer mother board), make sure that switch 4 on the dip switch of board 49-3 is in the on position.

Test A - Indicates the frequency output of Detector A in Hz (should be between 70 - 120 kHz). This frequency is directly proportional to the light intensity reaching Detector A. Upon initial entry into Test A mode, the solenoids are energized such that ozone-free sample continually flows through Cell A. Each successive energization of Test A pushbutton causes the solenoids to switch, allowing the user to operate the Model 49 Series Instruments in a purely manual mode. (See Chapter IV "Calibration," for complete instructions on how to do a check of the Ozone U-V calibration photometer). Note that the Sample A/B solenoid position LED will also switch.

Test B - Test B is identical to Test A, except for Cell B.

Test P/T - Initial, entry into this mode causes the pressure (in mm Hg) to be displayed. If the pushbutton is engaged a second time, the solenoids switch and the pressure is still displayed. The third and fourth engagement cause the temperature (in degrees Celsius) to be displayed. For Models 49 and 49-003, the fifth and sixth successive engagements of this pushbutton display elapsed time in minutes modulo 60. It is used to synchronize the output of the hour average, if this optional output is being used (see "Internal DIP Switch" and "Hour Average" in this chapter.

Test Noise - If the current mode is Test A or Test B, entry into this mode will cause the noise level of the previous mode (Test A or Test B) to be displayed. "Noise" is defined as the frequency fluctuations of the detector output averaged over the past 20 seconds. It should be below 4.0 Hz. Note that the noise diagnostic gives an indication of the noise level of the source. It is not equal to the level of noise obtained in the sample mode.

Test A/B - If the previous mode was Run, entry into this mode causes the calculated ozone concentration for each individual cell to be displayed simultaneously. The left three digits indicate the concentration calculated for Cell A and the right three digits indicate the concentration calculated for Cell B. If the Model 49 has stabilized, the average of ten successive readings should agree to within three (3%) percent if a constant ozone concentration is introduced. The analog output is the average of the two values (i.e., the same value as one would have in the Run mode). If the previous mode was Test A, Test B, Test P/T, or Test Noise, the program enters into the start-up ramp (see "Start-Up" below).

Run - This is the normal operating mode. Upon entry into this mode from any other mode except Test A/B, the program enters a 20-second waiting period. During this period the digit display increases from 1000 to 1050 for the Model 49PS, and indicates the full scale analog output in ppb for the Models 49 and 49-003. The analog output is full scale volts during the waiting period and follows the digital output during the monitoring mode. The digital display output is in ppb. Note that the Run mode is the default mode. This means that the Model 49 automatically goes into the Run mode after being turned on. It also automatically reverts to the Run mode one hour after the last diagnostic pushbutton (i.e., Test A, Test B, P/T, Noise, and A/B) has been engaged.

P/T On - This is a bistable (on/off) switch. If energized, the Model 49 automatically corrects for changes in gas temperature and pressure. Automatic correction for temperature and pressure is only performed if the LED above the P/T or pushbuttons is lit. If the P/T correction is disengaged, a temperature of 0 °C and pressure of 760 mm Hg is assumed.[1]

Thumbwheel Switches

Span (Model 49 and 49-003) (Figure I-1) - The span thumbwheel sets the effective span on the Model 49. The nominal value should be 500 (see Chapter VI, "Electronics and Software," for more information about Software). Each change of one digit changes the span by 0.2%.

Offset (Model 49 and 49-003) (Figure I-1) - The offset thumbwheels change the zero reading of the Model 49. The nominal value for a zero reading is 50 (see Chapter VI, "Electronics and Software," for information about Software. Each change of one digit adds or subtracts 1 ppb from the digital and analog output. Note that the Model 49 is capable of negative readings. Note that also that the span and offset adjustments are completely independent.

Gain (Model 49PS) (Figure I-2) - If the gain thumbwheel is set at zero, the internal ozonator operates in the manual mode. If the gain thumbwheel is set for 1-9, the ozonator is operated in the automatic mode. There is an optimum gain setting; its value is a function of gas flow and lamp condition. Its value is independent of the ozone level desired. If the gain is too low, it will take a long time for the ozonator output to reach the desired value. If too large, the ozonator output will oscillate around the desired value. See "Start-Up" section below for determination of optimum gain setting.

Ozone Level (Model 49PS) - In the automatic mode, the value set by these thumbwheels sets the desired ozone output level in ppb. In the manual mode, increasing the setting increases the ozone output; decreasing the setting decreases the ozone output. While in the manual mode, the value set is stable, however there is no way of knowing before hand the ozone level.

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[1] In order to avoid confusion, note that the U.S. EPA uses a standard condition of 0 °C and 760 mm Hg as the standard to define the ozone absorption coefficient (see Appendix B) and a different standard condition when referring to flow measurements, i.e., 25 °C and 760 mm Hg pressure.

Offset (Model 49PS) - The offset thumbwheels change the zero reading of the Model 49PS. The nominal value for a zero reading is 5. Each change of one digit adds or subtracts 1 or 10 ppb from the digital and analog output if Switch 2 on board 49-3 is off or on respectively. Note that the Model 49 PS is capable of negative readings. Note also that earlier versions of the Model 49PS do not contain the offset capability.

START-UP

Turn the power switch on. The Model 49 automatically enters the start-up mode during which time the following occurs:

1. The lamp block heater starts heating the lamp block. In order to increase the lamp life expectancy, the lamp does not ignite until the lamp block reaches the operating temperature (approximately 50 °C). If the instrument contains an internal ozonator, the ozonator lamp will not ignite until the ozonator block also reaches operating temperature.

2. During the waiting period for the lamp to warm-up, the following should be noted in a properly operating instrument:

   When the power switch is energized, the LED display displays the word "HELLO" for four seconds, followed by a one-second blank period.

Start-Up for the Models 49 and 49-003

The LED display increments once every 0.4 seconds from -23 to 0. The analog output follows the digital display going from -2.3% of fullscale to zero. Zero is displayed on the LED display for 30 seconds. The analog output is zero. The LED display then increments from 0 to 1000, during which time the analog output follows the digital display incrementing from zero to full scale voltage. The LED display then displays the full scale analog range of the Model 49 for 20 seconds. The analog output is full scale. If a recorder is connected, a ramp as shown in Figure III-1 is generated.

Start-Up for the Model 49PS

The LED display increments every 0.4 seconds going from -100 to +1050. This takes 7.3 minutes. The analog output tracks the digital display in the following manner. For a digital display of -100 to -23, -2.3% of the full scale voltage is present on the analog output. From -23 to +1000, the analog output increases from -2.3% of full scale to full scale, following the digital display. From 1000 to 1050, full scale voltage is present on the analog output. If a recorder is connected, a ramp as shown in Figure III-3 is generated.

During the generation of the ramp as described above, the solenoids should be switching every 10 seconds, with the solenoids position LED changing position every 10 seconds. Upon completion of the ramp, the Model 49 automatically goes into the Run mode,

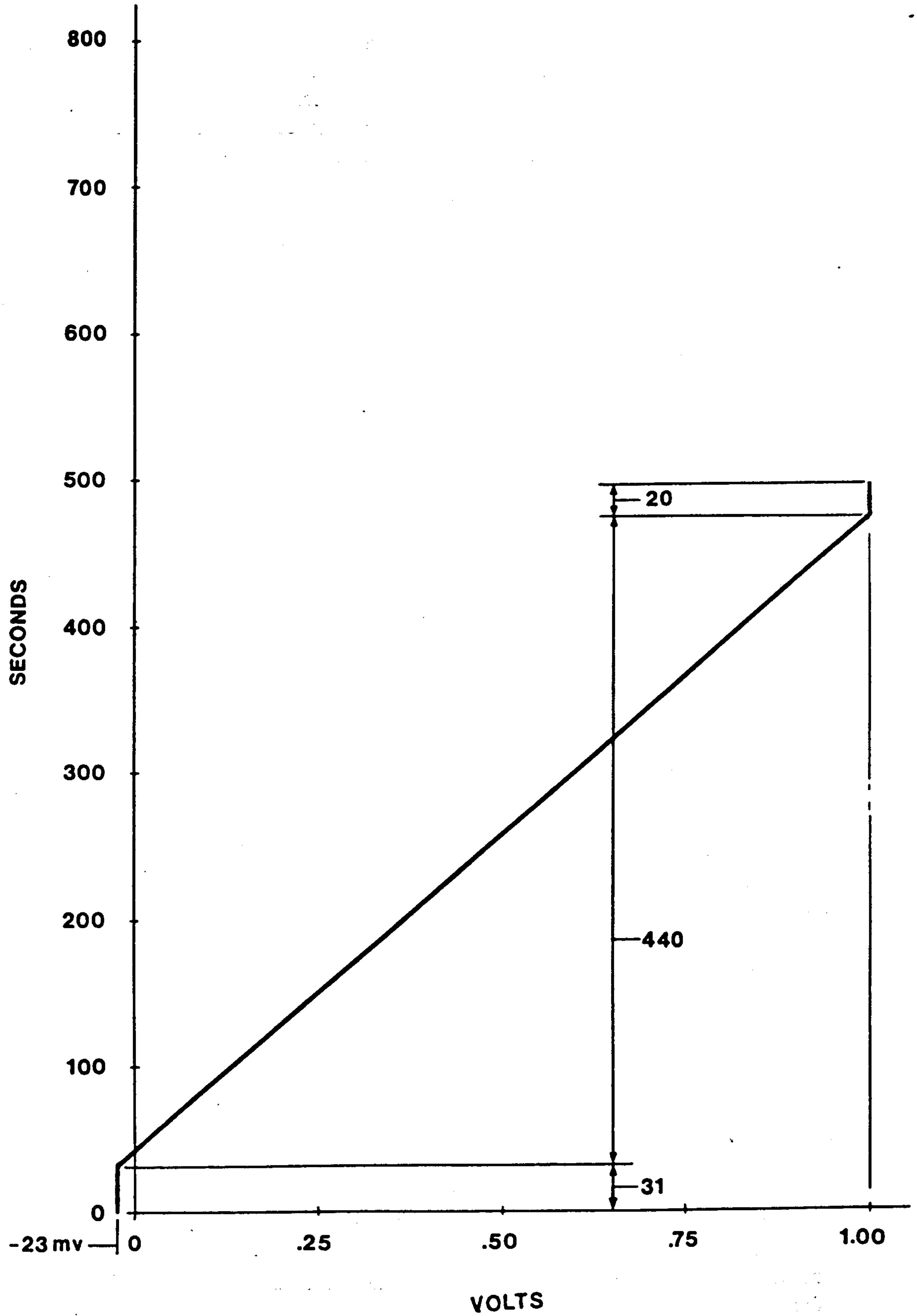

Figure III-1: Start-up Ramp

displaying the concentration in ppb. If the lamp has not ignited by the time the ramp is completed, the message "ERROR" will be displayed. The "ERROR" message will extinguish as soon as the lamp ignites. Since it typically takes from 7 to 12 minutes for the lamp to ignite from the time the power was first turned on, it is not uncommon to observe the "ERROR" message for a few minutes after the ramp is completed. The analog output is full scale whenever "ERROR" is displayed.

If the Model 49 was turned off momentarily and then restarted, it will automatically revert to the start-up mode. If it is desired to eliminate the ramp waiting period, energize the Test A, Test B, or Test P/T pushbutton, then energize the Run pushbutton. The program will revert to the 20-second waiting period and then start to monitor ozone.

SHUTDOWN

De-energize the power switch on the front panel. The Model 49 is now powered down.

LOSS OF POWER

If a power failure occurs, the Model 49 automatically restarts in the start-up mode upon resumption of power. The ramp will be generated on any recording device that is connected to the analog output, giving a visual indication that a power failure has occurred.

INTERNAL OZONATOR CONTROLS (OPTIONS 003) FIGURE III-2

Zero/Span Switch

This switch energizes the zero/span solenoid to enable the user to check zero, precision, and span of the Model 49-003. When the switch is in the sample position, sample gas from the sample input bulkhead flows into the photometer. <u>This switch is only active if the Model 49-003 is not in the remote mode.</u> When the solenoid is engaged, the solenoid position LEDs blink every second giving a visual indication of the status.

Adjust Level A

This potentiometer allows the user to adjust the output of the ozonator for Level A. A similar potentiometer (R 1425 on Board 49-14) is on the ozonator power supply board to allow the user to adjust Level B.

Level A, Zero, Level B Switches

This is a three-position switch. In the center position (zero), the ozonator lamp is not powered and thus zero air is present in the manifold. In Level A position, the ozone output is a adjusted by Level A potentiometer. In Level B, the output is as adjusted by Level B potentiometer. <u>This switch is only active if the Model 49-003 is not in the remote mode.</u> When the ozone generator is on, the solenoid position LEDs blink every second giving a visual indication of the status.