



TECHNOLOGIES

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MODEL S-3A

OXYGEN ANALYZER

INSTRUCTION MANUAL
FOR THE
S-3A OXYGEN ANALYZER

MODEL:

S-3A/I _____ S-3A/II _____

SERIAL NUMBERS

READOUT/CONTROL
SENSOR (N-22M / N-37M)

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Warranty and Claims

We warrant that any equipment of our own manufacture or manufactured for us pursuant to our specifications which shall not be, at the time of shipment thereof by or for us, free from defects in material or workmanship under normal use and service will be repaired or replaced (at our option) by us free of charge, provided that written notice of such defect is received by us within eighteen (18) months from date of shipment. All equipment requiring repair or replacement under this warranty shall be returned to us at our factory, or at such other location as we may designate, transportation prepaid. We shall examine such returned equipment and if it is found to be defective as a result of defective materials or workmanship, it shall be repaired or replaced as aforesaid. Our obligation does not include the cost of furnishing any labor in connection with the installation of such repaired or replaced equipment or parts thereof, nor does it include the responsibility or cost of transportation. In addition, instead of repairing or replacing the equipment returned to us as aforesaid, we may, at our option, take back the defective equipment and refund in full settlement the purchase price thereof paid to Buyer. If you are returning equipment from outside the United States, a statement should appear on the documentation accompanying the equipment being returned declaring that the goods being returned for repair are American goods, the name of the firm who purchased the goods, and the shipment date.

This warranty shall not apply to any equipment (or part thereof) which has been tampered with or altered after leaving our control, or which has been repaired by anyone except us, or which has been subject to misuse, neglect, abuse, or improper use. Misuse or abuse of the equipment, or any part thereof, shall be construed to include, but shall not be limited to, damage by negligence, accident, fire, or force of the elements. Improper use or misapplication shall be construed to include improper or inadequate protection against shock, vibration, high or low temperature, overpressure, excess voltage and the like, or operating the equipment with or in a corrosive, explosive or combustible medium unless the equipment is specifically designed for such service, or exposure to any other service or environment of greater severity than that for which the equipment was designed.

This warranty does not apply to used or second-hand equipment, nor extend to anyone other than the original purchaser from us.

THIS WARRANTY IS GIVEN AND ACCEPTED IN LIEU OF ALL OTHER WARRANTIES, WHETHER EXPRESS OR IMPLIED, INCLUDING WITHOUT LIMITATION ANY WARRANTIES OF FITNESS OR OF MERCHANTABILITY OTHER THAN AS EXPRESSLY SET FORTH HEREIN, AND OF ALL OTHER OBLIGATIONS OR LIABILITIES ON OUR PART. IN NO EVENT SHALL WE BE LIABLE UNDER THIS WARRANTY OR ANY OTHER PROVISION OF THIS AGREEMENT FOR ANY ANTICIPATED OR LOST PROFITS, INCIDENTAL DAMAGES, CONSEQUENTIAL DAMAGES, TIME CHARGES, OR ANY OTHER LOSSES INCURRED BY THE ORIGINAL PURCHASER OR ANY THIRD PARTY IN CONNECTION WITH THE PURCHASE, INSTALLATION, REPAIR, OR OPERATION OF EQUIPMENT, OR ANY PART THEREOF, COVERED BY THIS WARRANTY OR OTHERWISE, WE MAKE NO WARRANTY, EXPRESS, OR IMPLIED, INCLUDING WITHOUT LIMITATION ANY WARRANTIES OF FITNESS OR OF MERCHANTABILITY, AS TO ANY OTHER MANUFACTURER'S EQUIPMENT, WHETHER SOLD SEPARATELY OR IN CONJUNCTION WITH THE EQUIPMENT OF OUR MANUFACTURE. WE DO NOT AUTHORIZE ANY REPRESENTATIVE OR OTHER PERSON TO ASSUME FOR US ANY OTHER LIABILITY IN CONNECTION WITH EQUIPMENT, OR ANY PART THEREOF, COVERED BY THIS WARRANTY.

*****CAUTION*****

DO NOT USE THIS INSTRUMENT IN THE PRESENCE OF FLAMMABLE ANESTHETICS OR FLUORINATED GASES.

DO NOT PASS ANY EXPLOSIVE OR COMBUSTIBLE GAS MIXTURES THROUGH THE HOT CELL. THE HIGH TEMPERATURE MAY CAUSE EXPLOSION AND DAMAGE TO THE INSTRUMENT.

NOT FOR USE WITH ANESTHETIC GAS MIXTURES.

THIS INSTRUMENT MUST BE ELECTRICALLY GROUNDED.
DO NOT USE AN UNGROUNDED CONNECTOR OF ANY KIND.

DO NOT OPEN SENSOR CABINET WITHOUT PRIOR FACTORY AUTHORIZATION AS THIS MAY DAMAGE THE CELL. DO NOT OPEN CONTROL UNIT CABINET WITHOUT PRIOR FACTORY AUTHORIZATION.

FOR HIGHEST ACCURACY, TOP COVER MUST REMAIN ON INSTRUMENT.

I

GENERAL INFORMATION

1.1 INTRODUCTION

The S-3A Oxygen Analyzer system provides continuous and accurate measurement of oxygen concentrations from 0-100%. The S-3A/I has a single oxygen channel; the S-3A/II has 2 oxygen channels. The Analyzer consists of a Readout/Control unit with a connecting cable to the Sensor. The single cell Model N-22M Sensor and double cell Model N-37M Sensor use a durable solid oxide (stabilized zirconia) cell that has an inherently rapid response to changes in oxygen concentration and is maintenance free. Double cell sensors (Model N-37M) permit differential oxygen measurement over all concentration ranges.

The Model R-1 or R-2 Flow Control is frequently used in conjunction with the S-3A Oxygen Analyzer; although separate equipment can certainly be used for gas handling if desired. The Model R-1 Flow Control contains the flow meter, pump, and needle valve in a single cabinet. The Model R-2 Flow Control contains 2 flow meters, pump, and 2 needle valves in a single cabinet.

1.2 FLOW DIAGRAM

The gas sample to be analyzed is flowed through an electrochemical cell in the sensor cabinet. The preferred flow arrangement is to draw the gas through the cell with the pump and then vent it to the room or into a hood. A difference in oxygen partial pressure across the cell generates a DC voltage which is fed to the S-3A Readout/Control unit where it is processed. The oxygen concentration of the sample is then displayed on the Display contained in the S-3A and can be recorded simultaneously via the Analog Output.

1.3 MODEL S-3A READOUT/CONTROL

The readout/control unit performs the following major functions:

- Provides convenient digital readout of the unknown oxygen concentration in percent or PPM. provides cell zero adjustment and rapid single- point calibration.
- Provides Analog Output for %O₂.
-
- Provides for semi-automatic periodic maintenance of the sensor to retain its high speed of response.
- Provides DC power to the sensor furnace and controls furnace temperature.
- Provides DC power for active thermocouple compensation.
- Displays sensor cell temperature digitally as thermocouple voltage.

The front panel controls/indicators are:

CELL RESTORE: Button permits periodic maintenance of sensor.

CELL RESTORE INDICATOR: Variable intensity lamp indicates instrument is in the 10-minute

cell restore mode.

NOTE: The FURNACE POTENTIOMETER is no longer needed because the electronics maintains the correct furnace temperature automatically.

FURNACE INDICATOR: Variable intensity lamp indicates power to the furnace.

CALIBRATE/SAMPLE SWITCH: Switches instrument between the CALIBRATE position and SAMPLE position.

CELL ZERO POTENTIOMETER: Sets instrument for the calibration gas chosen.

RANGE SWITCH: Selects concentration range for each channel to be displayed on Display.

NOTE: The minimum resolution is 10 ppm and the rightmost digit on the display is always 0.

DISPLAY: Displays readings as determined by range switch selection.

The rear panel controls/indicators are:

ON/OFF SWITCH: All power to unit switched on and off.

MAIN FUSE, F1: 2.5 Amp slo-blo for entire unit. (1.5 Amp for 230 Volt units).

POWER SUPPLY FUSE, P2: 0.5 Amp slo-blo for +/-15V DC power supply. (0.25 Amp for 230 Volt units).

HIGH/LOW HEAT SWITCH: Speed of furnace heat-up controlled.

FURNACE FUSE, F3: 5.0 Amp fuse for furnace circuit.

CONNECTOR: 17-pin connector for sensor cable.

ANALOG OUTPUTS CH1: %O₂ 0-10V on S-3A/I; % O₂ channel 1, 0-10V on S-3A/II.

CH2: % O₂ channel 2, 0-10V, S-3A/II only.

DELTA: % O₂ +/- 10V, S-3A/II only.

1.4 SENSOR

The insulated sensor cabinet contains one or two (in the case of the S-3A/II) solid oxide (stabilized zirconia) electrochemical cells, a furnace, and temperature sensing circuitry.

1.5 INSPECTION AND INSTALLATION

1.5.1 Inspection

The S-3A Oxygen Analyzer has been thoroughly inspected and carefully packed prior to shipment. When the instrument is received, it should be examined both before and after unpacking for any physical damage that may have occurred in transit. Install and operate the instrument as soon as possible to check for any internal damage. Save all packing materials until this inspection is complete. If damage is found, a claim should be filed promptly with the carrier and AEI Technologies should be notified so that we can arrange for any repair or replacement necessary.

1.5.2 Installation

Connect the Sensor Cable to the Sensor and the Control Unit. As shipped, the sensor inputs are protected by flexible tubing that should be removed. Also see Start-Up Section 2.4 and Calibration Section 2.5.

II

OPERATING INSTRUCTIONS

2.1 INTRODUCTION

The following sections provide much of the information necessary to Start-up, Calibrate, Operate, and use the S-3A.

2.2 GAS CONNECTIONS

2.2.1 General

The sample gas must flow through the sensor. The tubing for the Model N-22M Sensor is 1/8 inch O.D. while that for the N-37M is 0.071 inch O.D. For normal use, connect the sample gas to the IN port of the sensor. As shipped, the sensor inputs are protected by flexible tubing that should be removed. The gas supply system must be free of leaks, water, and sources of contamination. For typical respirometry applications 1/8 inch I.D. flexible PVC tubing should be used. 1/16 inch I.D. may be adapted for use in applications requiring the fastest response times or minimal dead space. However, at ppm level concentrations and for permanent laboratory installations, metal tubing is recommended to minimize contamination. Applications involving low oxygen concentrations are discussed further in Section 2.2.5.

When certain that the sample tubing connections are correctly connected, secure them onto the sensor IN - OUT port tubes using the cable ties provided. Use 3 cable ties rotated 120 degrees from each other on each sensor port tube.

The effect of a contaminant will depend on its chemical composition. A combustible contaminant will burn and consume oxygen, resulting in a lowered reading. An inert contaminant will dilute the gas stream, decreasing the oxygen concentration accordingly. Any adsorbed oxygen present may desorb and result in a higher reading.

CAUTION: **Do not pass any gas mixture that exceeds the explosive limits through the hot cell. The high temperature may cause explosion and damage to the sensor. Some gases (e.g., H₂, CO) will form explosive mixtures with air. In these cases, purge sensor with an inert gas before introducing sample or re-introducing air.**

Some further precautions should be observed to prevent damage to the sensor. Care must be taken not to introduce gas into the sensor at high pressures (or at very high flow rates). (If necessary, the cell can be protected from strong pressure surges by installation of a rupture disk.) A slug of liquid that is accidentally swept through the hot sensor will vaporize and may crack the cell. If the possibility of drawing liquid through the sensor exists, either because the sample contains liquid or as a result of condensation in the gas line, a filter or trap should be installed in the line before the sensor. A filter should also be used if any particulate matter is present which could clog the cell. For

fast response applications, where a filter may not be advisable, see Section 2.2.4.

A flow rate of 50-500 ml/mm. may be used. 100 - 250 ml/mm. is recommended for most applications. 300-500 ml/mm. should be used for breath-by-breath analysis. The Model R-1 Flow Control provides a convenient means of maintaining suitable constant flow rates and the flow arrangements discussed below. Other flow control equipment can be used if preferred. **IMPORTANT: The Sample (unknown) and Calibration gases should be flowed at the same rate so that the total gas pressure in the cell remains the same.** Some variation in flow rate is permissible if the total cell pressure is not altered within the accuracy required. If separate lines are used for the calibration and unknown gases, the lengths and diameters of the tubing should be the same to insure equal pressure drops. The same mode of flow (i.e., forcing or drawing the gas through the cell) must be used for both calibration and unknown gases.

2.2.2 Preferred Gas Flow Arrangement

SAMPLE / CALIBRATION GAS → PARTICULATE FILTER → DRYER → MASS FLOWMETER [if needed] → S-3A INPUT → R-1(2) FLOW CONTROL INPUT

The arrangement shown above is recommended for most applications and is required for fast response. It permits maximum sensitivity to changes in sample oxygen concentration and avoids any possible contamination from the neoprene pump. The sample gas is drawn through the sensor by the pump and the rate of flow is controlled by the flow meter needle valve on the Flow Control. A flow rate of 100 - 250 ml/min is suitable for most applications. In some instances, for example, respiratory measurements with very small animals, the sample available for analysis may be limited and smaller flow rates should be chosen.

To adjust the sample flow rate partially close the flow meter needle valve by turning it clockwise but do not over tighten. Connect the calibration gas to the same Dryer input using approximately the same length and diameter tubing to be used for the unknown sample. Adjust the flow rate to the same value for both calibration and sampling using the needle valve.

The AEI Technologies Dryer Kit is ideal for drying of the sample gas.

2.2.3 Special Flow Arrangements

If the source of the gas is at high pressure (e.g., calibration gas in a tank), the pressure should first be reduced to atmospheric pressure. The gas may be collected in a sample bag and the sample bag can then be connected to the system. Alternately, the gas may be vented through a large syringe barrel to the atmosphere and sampled by placing a piece of small diameter tubing halfway down the barrel. The gas will be near room pressure at the point of sampling. Be sure to flow both the calibration and unknown gases through tubing of the same length and diameter and at the same flow rate so that the pressure drop will be the same.

2.2.4 Other Applications

The instrument responds extremely rapidly to changes in oxygen content in the sensor itself. There

is a delay in response due to the time necessary to transport the sample from its source to the sensor. This transport time can be minimized by use of a high flow rate (300—500 ml/min) and as short a length of small diameter tubing, 1/16" ID, as is practical.

To insure accurate response, mixing of the sample must be avoided. For optimum response, when the sample gas is clean and dry, no filter should be placed in the line as this may cause mixing and increase the transport time. For online pulmonary monitoring where large flow rates (500 ml/min) are used, special filter traps may be used to remove mucous and dust particles without significantly increasing the response time. If possible, the same plumbing should be used for calibration and measurement to maintain the same total pressure in the sensor.

If the sample size is limited, smaller diameter tubing may be used. For example, 15mm ID catheter tubing can be used for infant respiratory measurements. Alternately, a restrictive orifice may be placed in the line immediately following the sample, i.e., for respiratory measurements, at the mouthpiece. The pressure in the line and sensor will be decreased below 1 atmosphere, allowing a high flow rate to be maintained while decreasing mass flow. Be sure that the calibration gas is also passed through the orifice. It may be necessary to clean the line more frequently to prevent clogging or to use a special filter trap.

In breath-by-breath analysis, the exhaled breath is saturated with water vapor. The effect of the water vapor is to dilute the oxygen content of the sample; it does not interfere with the accuracy or response of the instrument. Condensation of moisture can occur when the sample is cooled from body temperature to that of the room. Accumulation of water in the line may damage the sensor and can be avoided by use of a Dryer.

The AEI Technologies Dryer Kit is ideal for drying of the sample gas.

2.2.5 Low Oxygen Concentrations

The PPM concentration range is displayed in ppm (parts per million). The minimum resolution is 1 ppm. For measurements at low oxygen concentrations, especially in the part-per-million range, greater attention must be paid to possible sources of leaks and contamination. Metal tubing, preferably stainless steel, is recommended wherever possible. Most plastic and rubber tubing is permeable to oxygen or water and should not be used. Teflon may be used if required for certain applications, but cannot be heated to bake out the system as can metal.

All surfaces exposed to the gas should be smooth and impervious. The number of fittings should be minimized in order to reduce dead space. Compression fittings are recommended. Volatile pipe dope or flux, or fittings that use sealants containing plasticizers should be avoided.

Leakage into the system can be reduced by using a high flow rate of sample gas. However, the flow rate through the cell itself should be limited to 300 ml/min. This combination can be achieved by using a cell bypass line, which also permits rapid flushing of the system. Once the system has been cleaned and degassed, it should be exposed to room air as infrequently as possible. If the sample gas is one which, when mixed with air, would form an explosive mixture, e.g., H₂, care must be taken to purge the system with inert gas before admitting the sample or reintroducing air. The explosive

limit of H₂ in air is 4 to 75% by volume. The lower explosive limit for CO in air is 12.5% by volume.

2.2.6 Flow Dependence

The readings obtained may vary somewhat with flow rate. For this reason, the rate of sample gas flow through the sensor should be carefully controlled using the R-1 or R-2, or other suitable flow control equipment.

At flow rates of less than 10 ml/min, or under no flow conditions, the reading will drift initially until a steady state is reached. This may take from a few minutes to several hours. Once equilibrium is established, further measurements may be made with a high degree of accuracy provided that a continuous gas flow at a constant flow rate is maintained. If the unknown gas flow must be interrupted, as is the case when discrete samples are being analyzed, airflow at the same rate should be substituted between samples to maintain steady state conditions. In this way, a motor-driven syringe can be used to inject 5-10 ml samples at a constant flow rate.

2.2.7 Pump Fluctuations

For some users, slight pump fluctuations have interfered with very accurate measurements. If this is a problem, insert a surge tank (bottle) in the line between the flowmeter and the pump. A bottle volume of 1000 ml is suitable.

2.3 ELECTRICAL CONNECTIONS

The sensor is connected via cable to the 17-pin circular connector on the rear of the S-3A. It is most important that the connectors be securely mated to ensure good electrical contact. Carefully push the connectors together as far as they will go and then turn the threaded sleeve until it feels tight. Repeat each of these steps in turn until about two threads remain visible or until the sleeve will not tighten further. The readout/control should be plugged into a 117VAC (230VAC for Model SOV) grounded three-terminal receptacle. The flow control can be plugged into a similar receptacle.

CAUTION: **This instrument must be electrically grounded. Do not use an ungrounded adaptor of any kind.**

2.4 START-UP

Make the necessary gas and electrical connections as described in the preceding two sections. Turn the power switch ON. The sensor furnace will begin to heat up. This is indicated by the red FURNACE indicator light on the front panel. The intensity of this light increases with increase in furnace power. The instrument is adjusted to operate at 750°C that has been preset at the factory. Turn the RANGE switch to the T.C. position. This position displays the output from the thermocouple that is used to monitor the sensor furnace temperature. A typical thermocouple output of 6.790 is equivalent to a furnace temperature of 750°C. The S-3A is considered completely warmed up when this thermocouple output fluctuates within +/-0.003 of 6.790 when observed over a period of at least 15 minutes. NOTE: This complete warm up period may take up to 16 hours.

The HI/LOW switch should remain in the LOW position.

2.5 CALIBRATION, CELL RESTORE AND LEAK TEST

2.5.1 Calibration Gas

There are a variety of grades of bottled calibration gases available on the market today. We strongly recommend that only Primary Laboratory Standard gases, certified gravimetrically, be used to calibrate the AEI Technologies gas analyzers. This grade of gas is normally delivered either with a very specific label or an attached certificate stating its contents out to two decimal places. Specified accuracy should be +/- 0.02% absolute or better for concentrations over 2%, +/- 10% of component for lower concentrations. Naturally, utilization of the most precise calibration gases assures you of the most accurate calibration possible for your AEI Metabolic Systems gas analyzers. Typically 16.00% O₂, 4.00% CO₂, Balance N₂ is used.

The AEI Technologies Calibration Gas Module is designed to meet these stringent requirements.

Room air is a suitable and convenient choice for some non-critical applications. It must be dried, free of contaminants, and well ventilated with fresh outside air.

2.5.2 Procedure

- 1). Turn the Range Switch to the desired channel and range to be calibrated.
- 2). Set the CELL ZERO POT to mid-range ("5" on the vernier counter).
- 3). Turn the CALIBRATE/SAMPLE SWITCH to the CALIBRATE position.
- 4). Flow calibration gas through the cell in the same manner that the unknown gas will be sampled. (Allow ample time for reading to stabilize).
- 5). Adjust the CELL ZERO POT to obtain the exact calibration gas value on the Display.

NOTE: If you run out of range on the ZERO POT: set the CALIBRATE/SAMPLE SWITCH in the SAMPLE position; turn the ZERO POT all the way back in the opposite direction; set the CALIBRATE/SAMPLE SWITCH in the CALIBRATE position; adjust the ZERO POT. Repeat until the display reads correctly.

- 6). Turn the CALIBRATE/SAMPLE SWITCH back to the SAMPLE position. The unit is now calibrated and ready for operation.

NOTE: The single-point calibration insures accurate instrument response over the entire range on all scales. No further calibration is required. It is not necessary to know either the exact composition of the ambient air in the sensor or the barometric pressure. It is only necessary that these remain constant during the period of calibration and measurement.

2.5.3 Cell Restore

Approximately once a week, activate the CELL RESTORE CYCLE by pushing the button on the front panel. A 12-minute maintenance cycle is initiated, during which the red light remains on. The button should be pressed only when the sensor has air or oxygen flowing through it and is at its operating temperature.

NOTE: The CELL RESTORE CYCLE will cause the cell temperature to change slightly. The S-3A should be allowed to stabilize again before measurements are taken. Therefore, pressing the Cell Restore button after tests are completed for the day is suggested. If the button is pressed accidentally, turning the Power ON/OFF switch to the OFF position momentarily can terminate the cycle. The S-3A should be allowed to stabilize before measurements are taken.

Zirconia oxygen sensors may slow down in response over a period of months in operation due to an aging effect. This maintenance cycle prevents this aging effect and permits the time constant of the sensor to be maintained for rapid response.

2.5.4 Leak Test

This test should be performed before any measurements are taken on the initial setup of the system and frequently thereafter. Gas leaks are one of the most common sources of error in gas measurement. The simplest method to test for leaks in the system is as follows:

- Turn on the R-1 Flow Control.
- Block the sample gas input using a clamp or your finger. It should initially be blocked at the farthest point in the sample gas tubing path from the R-1. In other words, blocked as close to the source of the sample as possible.
- Observe the balls on the R-1 flowmeter. Both balls will slowly drop to “0” and stay there without any bouncing if there is no leak. Even a slight movement of the balls indicates a leak.
- If the balls do not drop or they are bouncing, there is a leak in the system. The source of the leak can be further located by blocking the sample gas flow at other locations in the sample gas tubing path.

2.6 ANALOG SIGNAL OUTPUT FOR RECORDING

The analog output provides 0-10 Volts for 0-100% oxygen (+/- 10V for +/-100,000ppm oxygen on the Delta channel). Connect to the appropriate BNC Coax connector on the back panel of the S-3A labeled ANALYZER OUTPUTS – CH1 – CH2 – ‘Delta’. A shielded cable should be used. The shield of the cable should be connected to the low input of the recording device. It is recommended that the recording device have a differential input. This will avoid ‘ground loops’ that result in increased noise.

2.7 HIGH ACCURACY MEASUREMENTS

The S-3A Oxygen Analyzer can be used for high accuracy measurements. For measurements to

0.01%, the oxygen content of the gas used for calibration must be known to at least the same accuracy. A tank of Primary Laboratory Standard gas, certified gravimetrically, is recommended for highest accuracy.

Measurements of this accuracy will be sensitive to small changes with time in the composition of the reference air in the sensor cabinet. More frequent calibration checks may be necessary. It may be preferable to use the Dual Channel S-3A/II Oxygen analyzer that eliminates the effect of changes in cabinet air.

2.8 OVERRANGE

The Display overranges at 99.98%.

III

PRINCIPLES OF OPERATION

3.1 SENSOR

3.1.1 Description

The sensor contains a high-temperature galvanic cell for measuring the oxygen partial pressure, a furnace to maintain the cell at 750C, and temperature sensing circuitry. The N-22M Sensor contains one closed-end cylinder of calcia— stabilized zirconia which, at elevated temperatures, becomes an electrolytic conductor of oxide ions. The inside and outside of the cylinder bottom are coated with porous platinum electrodes to which platinum lead wires are attached. The cylinder is gas—tight to prevent mixing of the gases between the inside and the outside of the cell.

3.1.2 Electrolyte

Addition of oxides such as calcia or yttria to zirconia or thoria produces solid solutions with an imperfect fluorite lattice structure containing oxide ion vacancies. At high temperatures these solid solutions behave as ideal electrolytes. They exhibit high electrical conductivity with an oxide ion transference number of close to unity ($t_0 = 1$). No cations are transferred through the oxide ($t_{cation} = 0$). Over a large oxygen partial pressure range virtually no electronic conductivity is present ($t_e = 0$). Essentially all conductivity is due to oxide ion transfer. Electronic conductivity leads to a lowering of the cell voltage. If E_t is the theoretical cell voltage, the measured cell voltage would become $E = E_t(1 - t_e)$.

The concentration of oxide ion vacancies is fixed by the composition of the oxide system and is independent of oxygen partial pressure. The ionic contribution to electrical conductivity will not be pressure dependent. However, partial pressure changes may affect electronic conductivity due to excess electrons (-) or electron holes (+). Even though the concentration of electrons or holes may be small, their mobility is high. In a certain partial pressure regime they may make a substantial contribution to the conductivity,

total = ionic + $Fu - [(-)] \cdot Fu + [(+)]$, where F is Faraday's constant and u the nobility (cm^2/Sec volt). The total conductivity can be written in terms of the oxygen partial pressure as follows:

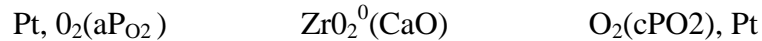
$$\text{total} = \text{ionic} + K'1 (\text{PO}_2)^{-1/4} + K''_2 (\text{PO}_2)^{1/4}.$$

For calcia-stabilized zirconia at 750C, the total conductivity is independent of oxygen partial pressure and $t_e = 0$ from 1 to 10^{-28} atmospheres oxygen. 10^{-28} atm. oxygen is equivalent to 100 ppm H_2O in H_2 ($\text{H}_2/\text{H}_2\text{O} = 10\text{exp}4$). At lower partial pressures, an increasingly great excess electron component participates in the transport process and a sensor containing a thoria cell should be used. A thoria sensor cannot be used above $P_{\text{O}_2} 10\text{exp}-10$ atm. because a considerable contribution from excess electron holes begins to occur with increasing partial pressure. An exact lower

limit for calcia-zirconia and upper limit for yttria- thoria cannot be given because of variations in impurity content from cell to cell.

3.1.3 Determination of Molecular or Free Oxygen in Inert Gases

The cell is specifically responsive to the oxygen partial pressure in the gas phase at both its electrodes and can therefore be described as an electrochemical concentration cell reversible to oxygen and represented by the notation.



where cPO₂ is the oxygen partial pressure at the cathode and is the oxygen partial pressure at the anode. The cell, in the Model N—22/N—22M Sensor, where p₀₂(unk) is the unknown oxygen pressure and P₀₂(ref) is the reference oxygen partial pressure. If P₀₂(ref) = P₀₂(unk), then P₀₂(ref) = cPO₂, P₀₂(unk) = aP₀₂ and the electrode on the reference side is positive with respect to that on the unknown side.

The open circuit cell voltage, E, follows the Nernst equation:

$$E = RT/nF \ln P_0(\text{ref})/P_0(\text{un}][c),$$

where R = 8.314 joules/mole—degree, F = 96,500 coulombs/Faraday, and n = 4 Faradays/mole.

If the cell voltage, E, is expressed in millivolts, the equation can be written:

$$E(\text{mV}) = 0.0496T \quad -\log P_{\text{O}_2}(\text{unk}) + \log P_0(\text{ref})$$

where T is the absolute temperature and P₀₂(ref) and P₀₂(unk) are in atmospheres. The air in the sensor cabinet serves as the reference gas. Then P₀₂(ref) = P₀₂(air). At an operating temperature of 750C (1023 deg. K) and for a reference oxygen concentration of 20.94% at 1 atmosphere total pressure, the equation reduces to:

$$E(\text{mV}) = 50.75 \quad -\log P_{\text{O}_2}(\text{unk}) - 0.6789$$

This is the form of the equation used for calculation of free oxygen concentration in an inert gas. An inert gas, in this instance, is one in which all species present are either fully oxidized or inert.

3.1.4 Measurements in Reducing Gases

In reducing gas mixtures, only a very small residual amount of oxygen is present. The oxygen concentration is determined by equilibria among the species present. Some examples are as follows:

WATER/HYDROGEN MIXTURES

$$E(\text{mV}) = RT/4F \ln PO_2(\text{ref}) + RT/2F \ln K_1 + RT/2F \ln PH_2/PH_2O = 955 + 101.5 \log PH_2/PH_2O$$

for a temperature of 750deg. C where $K_1 = 5.75 \times 10^{exp9}$ and a reference gas of dry air at 1 atmosphere. The equilibrium oxygen concentration is determined by the hydrogen/water ratio in this region.

CO/CO₂ MIXTURES

$$E(\text{mV}) = RT/4F \ln PO_2(\text{ref}) + RT/2F \ln K_2 + RT/2F \ln PC_2/PCO_2 = 966 + 101.5 \log PC_2/PCO_2$$

for a temperature of 750deg. C where $K_2 = 7.25 \times 10^{exp9}$ and a reference gas of dry air at 1 atmosphere.

MIXTURES CONTAINING H₂, H₂O, CO, and CO₂

$$E(\text{mV}) = RT/4F \ln PO_2(\text{ref}) + RT/2F \ln K_1 + RT/2F \ln PH_2/PH_2O \\ = RT/4F \ln PO_2(\text{ref}) + RT/2F \ln K_2 + RT/2F \ln PC_2/PCO_2$$

The oxygen analyzer can be used with a large number of systems involving oxygen equilibria.

3.1.5 Calibration

The oxygen content of a gas (% , ppm) can be written in terms of its oxygen partial pressure and the total pressure of the gas:

$$\%O_2 = 100 P_{O_2}/P_T$$

Thus the oxygen partial pressure, P_{O_2} , is a function of the total pressure, P_t .

The operating procedure provides for calibration of the instrument with a gas of known oxygen content. There are several reasons for this step.

- a) It is necessary for the total pressure on both the reference and the unknown sides to be the same in order for the partial pressure ratio to equal the concentration ratio. This may not be exactly true as the sample gas is flowed through the cell while the reference gas is static. Calibration corrects for this.
- b) In the calibration procedure described in Section 2.5, it is stressed that the same flow rate and plumbing arrangement be used for the unknown and calibration gases. This is to ensure that the total pressure in the cell is the same for both the calibration and unknown gases, i.e., $P_t(\text{cal}) = P_t(\text{unk})$.

The %O₂(unk)/%O₂(cal) ratio is independent of the barometric pressure. The effect of barometric pressure on P_{O₂}(ref)/P_{O₂}(unk) is therefore completely cancelled by the calibration procedure.

- c) The composition of the reference air in the sensor cabinet will vary slightly from day to day as the relative humidity and carbon dioxide content change. Calibration obviates determining its exact composition.
- d) Thermal and partial pressure effects may generate small electric potentials.

The above factors result in contributions to the cell output which can all be expressed in the form of a single additive constant, cell zero. The instrument is calibrated by flowing gas known oxygen content through the cell and offsetting the cell output so that the display displays the correct oxygen concentration.

$$E_{\text{theor}} = E_{\text{cell zero}} + \text{'Delta' cell zero} = 50.75[-1 \log P_0(\text{unk}) - 0.6789]$$

for 750C and 20.94% reference at 1 atmosphere. The cell zero correction, cell zero, will remain constant as long as the factors discussed above do not change. Their value need not be known.

IV

MAINTENANCE AND REPAIR

4.1 INTRODUCTION

This equipment has been designed for reliable long-term operation with a minimum of maintenance. With the exception of the CELL RESTORE function described in Section 2.5.3 of the operating instructions, no regular maintenance procedure is required. If difficulty is experienced, the gas handling system should be checked carefully as flow problems constitute the most probable source of error. It is recommended that AEI Technologies be contacted before any servicing or repair of the instrument itself is attempted.

4.2 FLOW SYSTEM

An unstable or malfunctioning pump is frequently the source of signal instability. This instability can easily be differentiated from that caused by electronic malfunction (which is much less likely) by simply disconnecting the sensor from the sample source and flow system. The oxygen concentration reading should be followed on the panel meter or analog output. If a smooth curve tending toward the oxygen content of room air is obtained, the problem is with the flow system, not the sensor or the electronics.

Leaks (see Section 2.5.4), contamination, or line blockage can result in error in oxygen measurement. These problems may be subtle and difficult to find. Factors involved in setting up the gas handling system are discussed in Section 2.2.1 through 2.2.4 of the operating instructions. These sections should be read if flow problems arise. For low oxygen concentration, leakage of air into the system will cause high instrument readings, while at high oxygen concentrations, air leakage will dilute the sample and lower readings.

Line blockage will decrease gas flow and can be detected by lowered flowmeter readings. If the gas lines become blocked on the input side of the cell and the sample is being drawn through the cell, the effect will be to partially evacuate the cell and lower the reading.

If the same node of flow (i.e., drawing or forcing the gas through the cell) is not used for calibration and unknown gases, erroneous readings may result. If the calibration gas is drawn through the cell and the unknown gas forced, high instrument readings may result. Forcing the calibration gas through the cell while drawing the unknown gas will cause low readings.

4.3 SENSOR

The sensor should require no maintenance other than that provided by the CELL RESTORE function. Erroneous readings which might be thought to result from sensor malfunction are usually caused by flow problems and this possibility should be considered first. However, if liquid droplets or explosive gas mixtures are allowed to enter the hot sensor, damage to the sensor cell can occur. If the cell cracks, the instrument oxygen readings may become random. This fault can be diagnosed by the Leak Test procedure in Section 2.5.4.

If the cell electrode leads become disconnected, the instrument reading will usually go off scale. Thus either 0 my or “overload” will be indicated on the CELL 0-100 my scale. The instrument will not respond to changes in oxygen concentration of the gas flowing through the sensor.

If the sensor is believed to be malfunctioning, do not attempt to dismantle it. Contact AEI Technologies for repair or replacement instructions.

The following instrument sensor problems are unlikely to occur but are included for completeness:

-Furnace winding opens — The thermocouple output, which can be read on the T.C. 0—10 my scale, will drop slowly as the sensor drops to room temperature, regardless of the FURNACE potentiometer setting. The FURNACE power light will be off.

-Thermocouple breaks — The furnace will go full on and the temperature will rise to approximately 1000C. At this temperature, if pure oxygen is flowed through the cell, the instrument will indicate an oxygen content of about 115%. The FURNACE power light will be on.

4.4 READOUT/CONTROL UNIT

The electronics of the S-3A have been designed for maximum stability and should not need maintenance. If you run out of range on the ZERO POT: set the CALIBRATE/SAMPLE SWITCH in the SAMPLE position; turn the ZERO POT all the way back in the opposite direction; set the CALIBRATE/SAMPLE SWITCH in the CALIBRATE position; adjust the ZERO POT. Repeat until the display reads correctly.

V

S-3A/II DUAL CHANNEL OPERATION

5.1 DUAL CHANNEL INSTRUMENT S-3A/II

The S-3A/II Dual Channel Readout/Control is used with an N-37M Sensor to monitor the oxygen content of two separate gas streams continuously and simultaneously, and to measure the difference in oxygen concentration between them to 10 ppm O₂ (0.001% O₂). The differential signal, (CH1 - CH2), can be recorded directly. All three signals can be recorded simultaneously and each can be displayed in turn on the Display. The instrument differs in operation from the S-3A/I as follows:

Analyzer Outputs

There are three ANALYZER OUTPUTS on the rear of the S-3A/II chassis labeled CH1, CH2, and "Delta". All are available continuously and simultaneously. ANALYZER OUTPUTS CH1 and CH2 provide a signal for recording from cell 1 and 2 respectively. These outputs are 0-10 V for 0-100% oxygen. The "Delta" output provides a signal for recording Cell 1 – Cell 2. This output is +/-10 V for 0-100,000ppm oxygen.

Delta Channel

The Delta channel has a slower response time than CH1 and CH2. Both the display and the Analyzer Output update about every 4 seconds. This is because of additional signal averaging on this channel.

Display

The Delta channel concentration is displayed in ppm (parts per million). The minimum resolution is 10 ppm and the least significant digit on the display is always 0.

Calibration

The Delta Channel cannot be calibrated as an independent channel simply because it is not independent. Select either CH1 or CH2, switch to CALIBRATE position, and make a very small adjustment in the CELL ZERO POT. Then select the Delta Channel again (or monitor the "Delta" Analyzer Output), wait at least 10 seconds, and see if further fine adjustment is desired. In this way the Delta Channel may be adjusted to 0% O₂ when both CH1 and CH2 have the same input concentration.

VI

R-1/R-2 FLOW CONTROL

1.1 INTRODUCTION

The Model R-1 (R-2) Flow Control is frequently used as an integral part of any gas measurement system. The Flow Control is frequently used in conjunction with the S-3A Oxygen analyzer and CD-3A Carbon Dioxide analyzer. The Model R-1 Flow Control contains the flow meter, pump, and needle valve in a single cabinet. The Model R-2 Flow Control contains 2 flow meters, pump, and 2 needle valves in a single cabinet.

1.2 FLOW DIAGRAM

The preferred flow arrangement is to draw the gas through the gas analyzer with the pump and then vent it to the room or into a hood. Flow meter calibration curves are shown below.

1.3 CONTROLS/INDICATORS

The front panel controls/indicators are:

ON/OFF SWITCH: All power to unit switched on and off.

FLOWMETER: Displays the flow rate. See Flow Rate Graph below for conversion to ml/min.

FLOW ADJUST: Adjusts the flow rate.

The rear panel controls/indicators are:

POWER SUPPLY FUSE: 0.25 Amp for 230 VAC units. No fuse on 117VAC units.

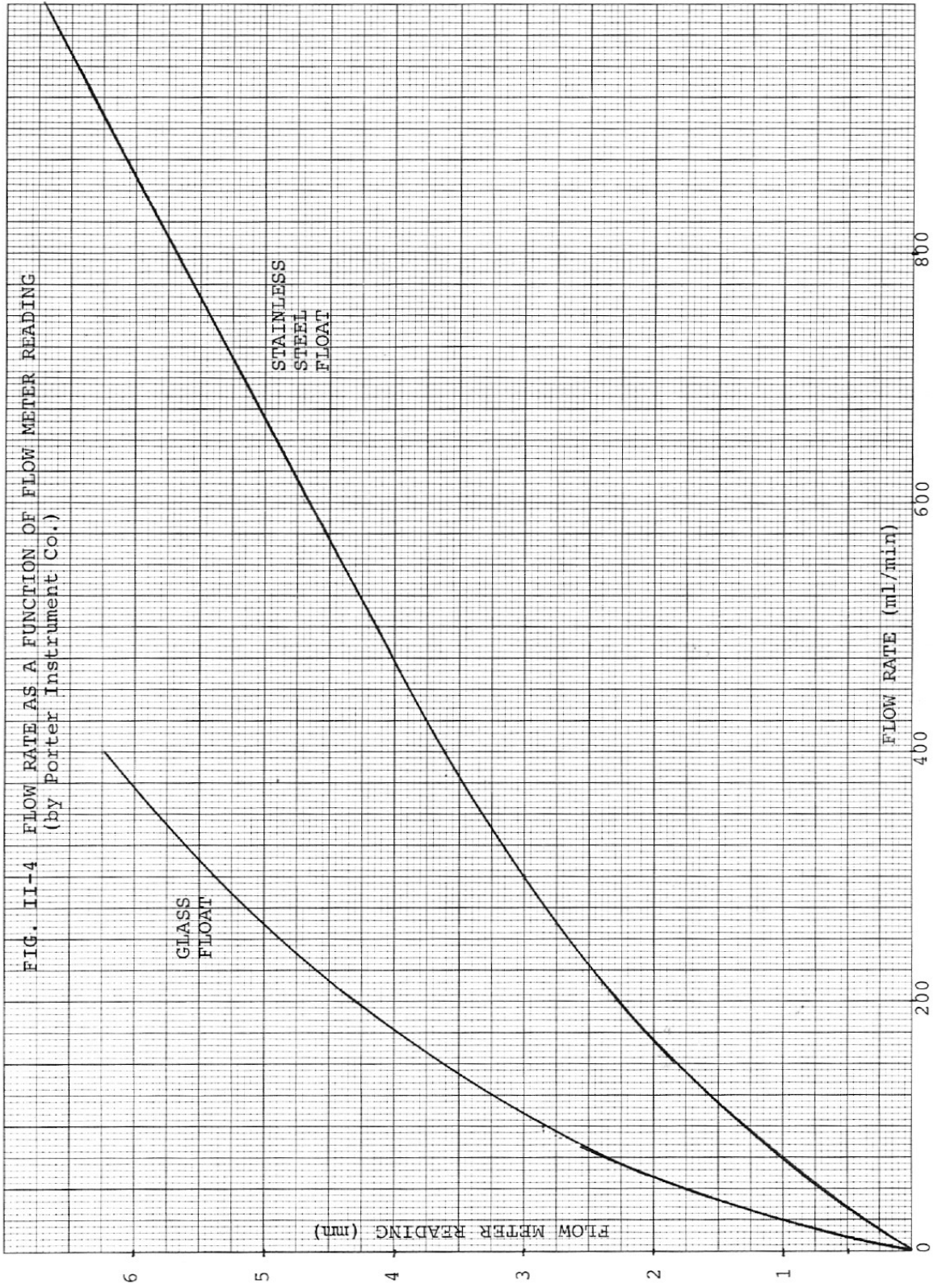
1.4 INSPECTION AND INSTALLATION

1.4.1 Inspection

The Model R-1 (R-2) Flow Control has been thoroughly inspected and carefully packed prior to shipment. When the instrument is received, it should be examined both before and after unpacking for any physical damage that may have occurred in transit. Install and operate the instrument as soon as possible to check for any internal damage. Save all packing materials until this inspection is complete. If damage is found, a claim should be filed promptly with the carrier and AEI Technologies should be notified so that we can arrange for any repair or replacement necessary.

1.4.2 Installation

The Flow Control is shipped ready for use.



R-1/R-2 OPERATING INSTRUCTIONS

2.1 INTRODUCTION

The following sections provide much of the information necessary to Connection and Use the R-1 (R-2) Flow Control.

2.2 GAS CONNECTIONS

2.2.1 General

The tubing on the Model R-1 (R-2) Flow Control is 1/8 inch O.D. For normal use connect the OUT port of the Sensor to the IN port of the R-1 (R-2) Flow Control using 1/8 inch I.D. soft PVC tubing. As shipped, the Flow Control inputs are protected by flexible tubing that should be removed. The gas supply system must be free of leaks, water, and sources of contamination.

Flow rates of 50—500 ml/min are typically used. The Model R-1 Flow Control provides a convenient means of maintaining suitable constant flow rates. **IMPORTANT: The Sample (unknown) and Calibration gases should be flowed at the same rate so that the total gas pressure in the system remains the same.** Some variation in flow rate is permissible if the total system pressure is not altered within the accuracy required. If separate lines are used for the calibration and unknown gases, the lengths and diameters of the tubing should be the same to insure equal pressure drops. The same mode of flow (i.e., forcing or drawing the gas through the system) must be used for both calibration and unknown gases.

2.2.2 Preferred Gas Flow Arrangement

To adjust the flow rate partially close the flow meter needle valve by turning it clockwise until the desired flow rate is achieved; but do not over tighten.

With the single-channel R-1, the inlet and outlet of the pump are independent of those of the needle valve and flow meter. This permits the flow control to be used in three modes of operation below. The R-1 is shipped as in Arrangement (A) below.

The Model R—2 Flow Control handles two independent gas streams (e.g., unknown and reference gases through a double-cell sensor, or two unknown gases). It contains two needle valves, two flow meters, and one pump. Only Arrangement (A) below can be used with the R-2. NOTE: The OUT port of the flowmeter has been connected at the factory to the IN port of the pump with a piece of tubing.

Arrangement (A) With the R-1, connect meter OUT to pump IN using the short piece of tubing provided). Turn the pump ON with the toggle switch and turn the needle valve(s) off to finger tightness (do not overtighten). Connect sensor(s) OUT to meter(s) IN and the sample gas(es) to sensor IN(S). Slowly open the needle valve(s) until the desired flow rate is achieved. (100 ml/min is suitable for most applications).

Arrangement (B) Disconnect the tubing between meter OUT and pump IN. Turn the pump on and the needle valve off (do not overtighten). Connect pressurized sample gas to meter IN and adjust gas flow rate to desired value with the needle valve. Again turn the needle valve off and connect meter OUT to sensor IN. Carefully turn the needle valve on until the flow meter reads the desired value.

Arrangement (C) Disconnect the tubing between meter OUT and pump IN. Turn the pump on and needle valve off (do not overtighten). Connect sample gas to pump IN and connect pump OUT to meter IN. Connect meter OUT to sensor IN. Open the needle valve until the desired flow rate is achieved.

2.2.3 Pump Fluctuations

For some users, slight pump fluctuations have interfered with very accurate measurements. If this is a problem, insert a surge tank (bottle) in the line between the flowmeter and the pump. A volume of 1000 ml is suitable.

2.3 ELECTRICAL CONNECTIONS

The Model R-1 (R-2) Flow Control should be plugged into a 117VAC (230VAC for Model R-1V) grounded three-terminal receptacle.

CAUTION: This instrument must be electrically grounded. Do not use an ungrounded adaptor of any kind.

R-1/R-2 MAINTENANCE AND REPAIR

4.1 INTRODUCTION

This equipment has been designed for reliable long-term operation with a minimum of maintenance. If difficulty is experienced, the gas handling system should be checked carefully as flow problems constitute the most probable source of error. It is recommended that AEI Technologies be contacted before any servicing or repair of the instrument itself is attempted.

4.2 FLOW SYSTEM

Leaks (see Section 4.3), contamination, or line blockage can result in error in measurement. These problems may be subtle and difficult to find. Line blockage will decrease gas flow and can be detected by lowered flowmeter readings. NOTE: Regularly check the system for leaks.

If the same mode of flow (i.e., drawing or forcing the gas through the cell) is not used for calibration and unknown gases, erroneous readings may result.

4.3 LEAK TEST

This test should be performed before any measurements are taken on the initial setup of the system and frequently thereafter. Gas leaks are one of the most common sources of error in gas measurement. The simplest method to test for leaks in the system is as follows:

- Turn on the R-1 Flow Control.
- Block the sample gas input using a clamp or your finger. It should initially be blocked at the farthest point in the sample gas tubing path from the R-1. In other words, blocked as close to the source of the sample as possible.
- Observe the balls on the R-1 flowmeter. Both balls will slowly drop to “0” and stay there without any bouncing if there is no leak. Even a slight movement of the balls indicates a leak.
- If the balls do not drop or they are bouncing, there is a leak in the system. The source of the leak can be further located by blocking the sample gas flow at other locations in the sample gas tubing path.



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