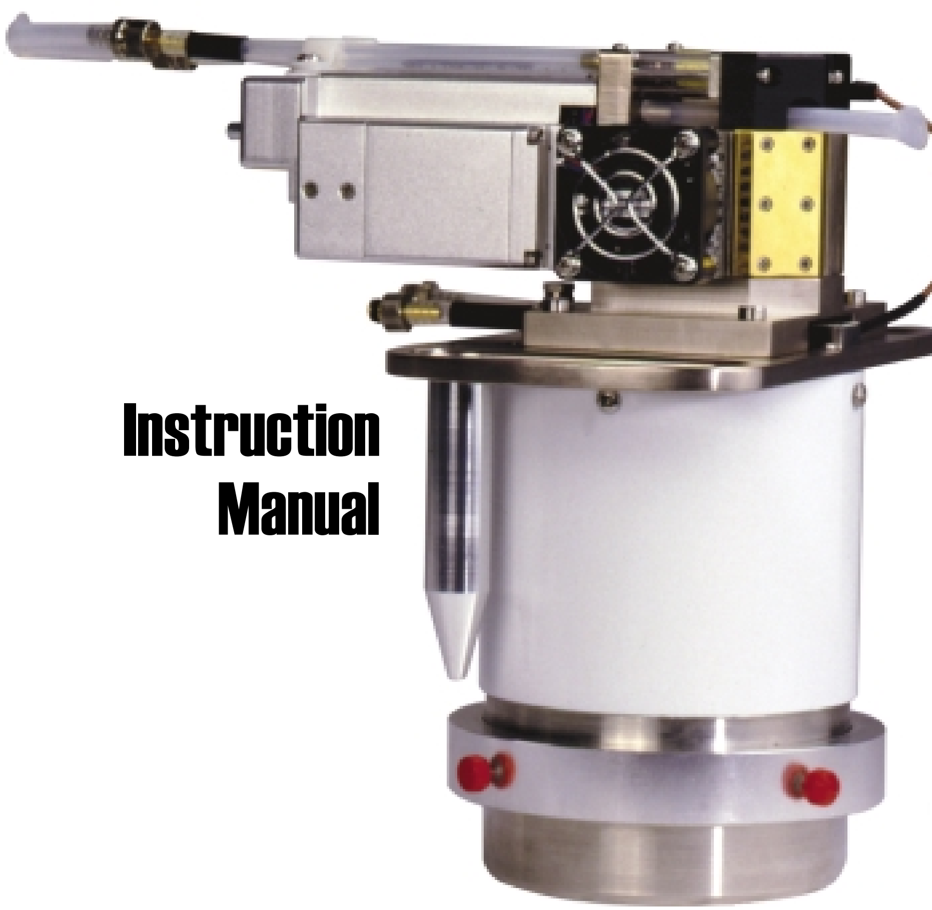
6400-09

Soil CO_2 Flux Chamber



Instruction Manual

LI-COR®

Biosciences

6400-09

Soil CO_2 Flux Chamber

Instruction Manual

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1 General Information

Considerations

Soil carbon dioxide is primarily produced by root respiration, decay of organic matter, and activity of microbes. Rainwater can have direct effects as well, by displacing gas in soil pore spaces (enhancing CO_2 flux at the surface), and by interacting with limestone soils. Also, rainwater itself carries some dissolved CO_2 that can be released in the soil.

Thus, soil CO_2 flux is dependent on soil temperature, organic content, moisture content and precipitation, and has a great deal of spatial variability. Soil CO_2 flux is also extremely sensitive to pressure fluctuations. An unvented chamber will induce significant pressure increases just by pushing the chamber down over a sealed volume. Soil water evaporation and heating of the air in the chamber head space also induces pressure increases in an unvented chamber. The 6400-09 Soil CO_2 Flux Chamber is vented so that pressures inside and outside the chamber are in a dynamic equilibrium.

Soil CO_2 flux measured using a chamber system is dependent on the CO_2 concentration in the measurement chamber. This is illustrated in Figure 1-1, which shows typical variations in measured soil CO_2 flux when the chamber headspace CO_2 concentration was allowed to rise. Healy et. al. (1996) used analytical and numerical models of gas diffusion to evaluate chamber headspace concentration influence on estimates of soil CO_2 flux. They found that chamber-induced perturbations of soil-gas concentration gradients could result in substantial underestimate of soil CO_2 flux (6 to 34% for a 30 minute measurement).

The LI-6400 Soil CO_2 Flux System has been designed to minimize perturbation in the soil-gas concentration gradient. Before starting the measurement, ambient CO_2 concentration at the soil surface is measured. Once the chamber is installed, the CO_2 scrubber is used to draw the CO_2 in the closed system down below the ambient concentration. The scrubber is turned off, and soil CO_2 flux causes the CO_2 concentration in the chamber headspace to rise (Figure 1-2). Data are logged while the CO_2 concentration rises through the ambient level. The software then computes the flux appropriate for the ambient concentration. This measurement cycle repeats for as many iterations as you select (Figure 1-3).

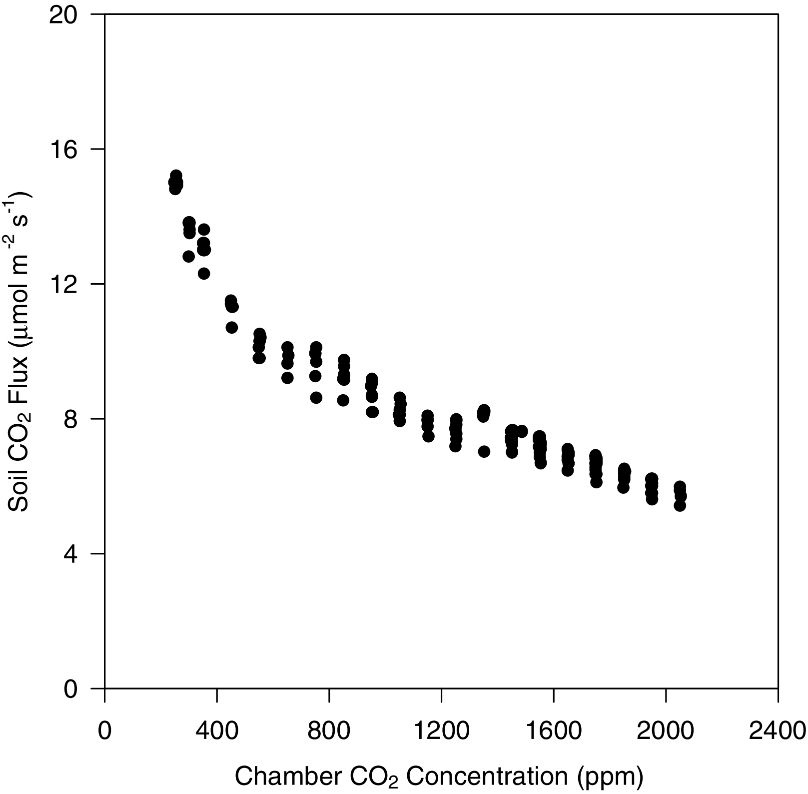


Figure 1-1. *Soil CO_2 flux rates depend on the chamber CO_2 concentration.*

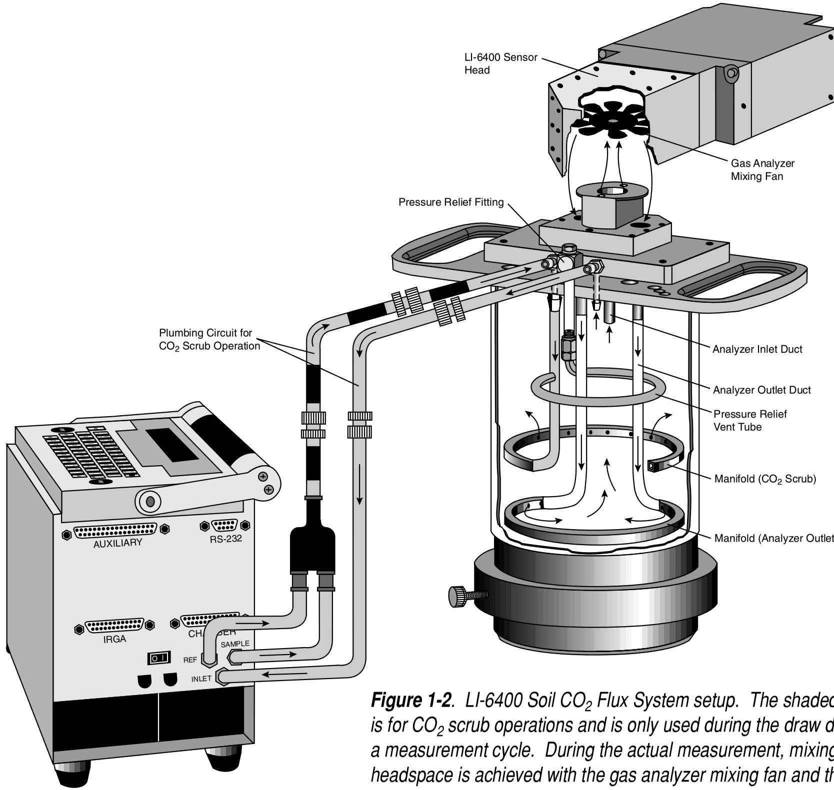
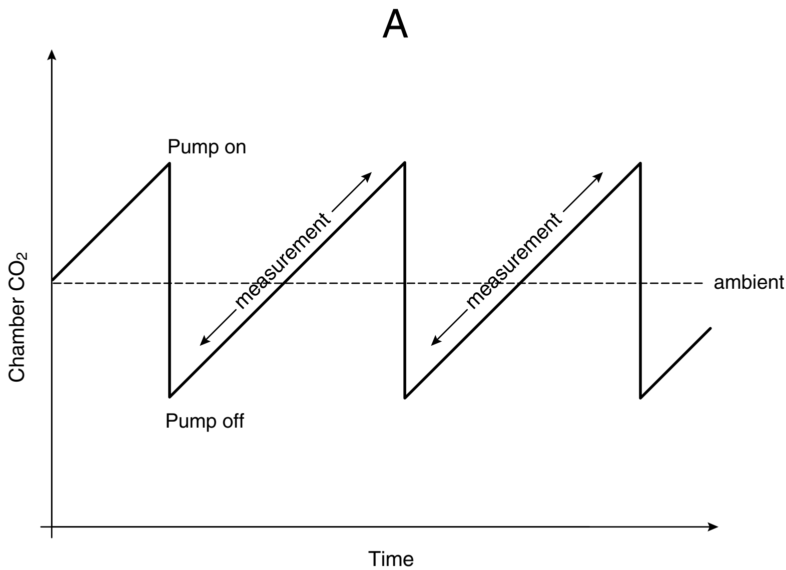


***Figure 1-2**. LI-6400 Soil CO_2 Flux System setup. The shaded plumbing circuit is for CO_2 scrub operations and is only used during the draw down portion of a measurement cycle. During the actual measurement, mixing in the chamber headspace is achieved with the gas analyzer mixing fan and the associated plumbing.*



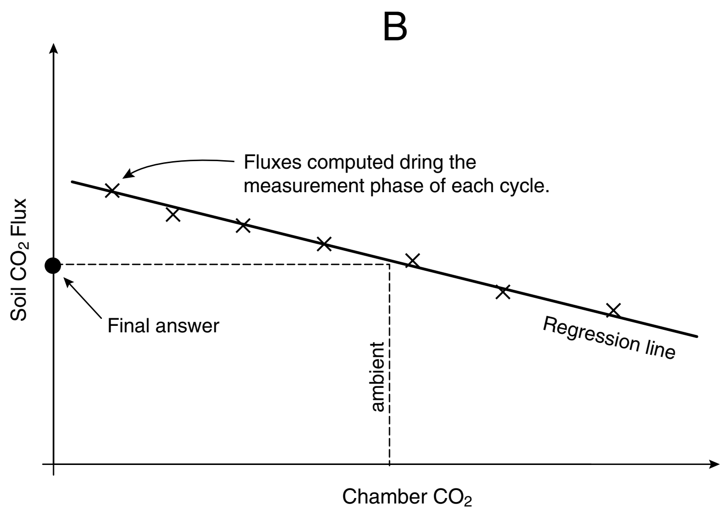


Figure 1-3. *(A). Time series of a measurement cycle. Pumping reduced CO_2 air into the chamber brings the CO_2 below ambient. After the pump turns off, CO_2 rises due to soil CO_2 efflux. During this phase, soil CO_2 flux is computed, and data for regressing flux as a function of CO_2 is generated. (B). At the end of the measurement cycle, the final flux value is computed by regressing flux vs CO_2, and computing the flux that corresponds to the target (ambient) concentration value.*

Precautions

- Keep the soil chamber shaded to avoid heating.

- If measurements are made on bare soil with no canopy, variation in the measured flux can occur due to dynamic pressure fluctuations at the pressure vent outlet caused by wind effects. The vent on the 6400-09 is shielded to minimize direct wind effects, but you may wish to shield the entire chamber from the wind.

- If a thin upper layer of soil becomes saturated from short intense rainfall, a surface gas seal can form that causes CO_2 concentration to increase below the saturated layer. A burst of CO_2 may be released when the sharp edge of the chamber is inserted, causing excessively high flux measurements when in actuality the undisturbed flux is very small. The initial flux from the burst of CO_2 can be two or more times larger than the actual flux that would be measured if the chamber were left installed for several hours without disturbing it. Collars usually provide better measurements under these conditions because of minimal disturbance; great care must be taken not to disturb the collars when putting the chamber onto them, however.

Reference

Healy, Richard W., R.G. Striegl, T.F. Russell, G.L. Hutchinson, and G.P. Livingston, 1996. Numerical Evaluation of Static-Chamber Measurements of Soil-Atmosphere Gas Exchange: Identification of Physical Processes. *Soil Sci. Soc. Am. J.* 60:740-747.

2 Attaching the Soil Chamber

General Description

Figure 2-1 shows an assembled 6400-09, and Figure 2-2 is an exploded diagram showing the parts of the 6400-09 CO_2 Flux Chamber. Some of the individual parts are described in more detail in Section 5. Figure 2-2 also contains a detailed parts list should you need to order individual parts.

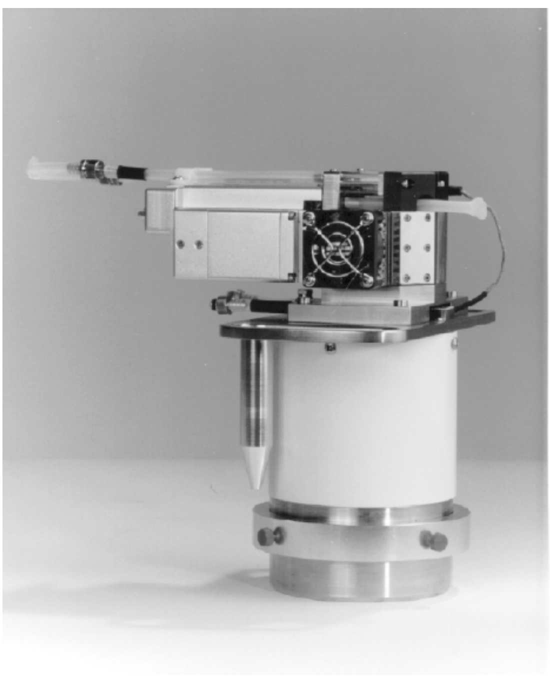
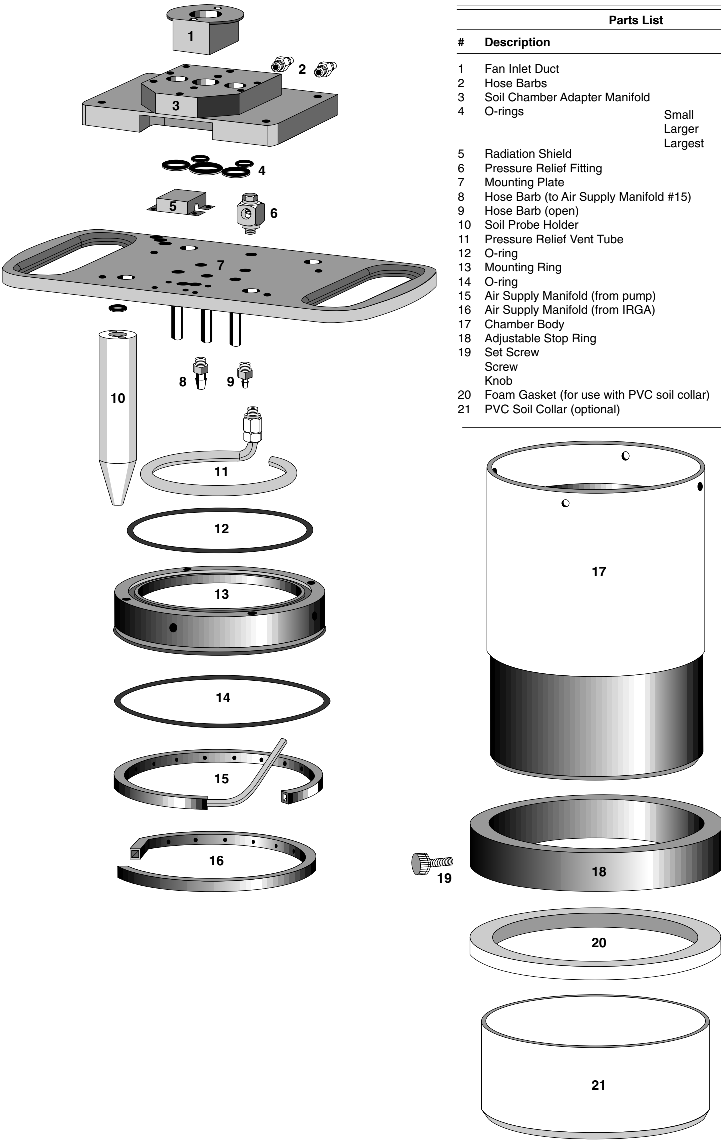


Fig. 2-1. *6400-09 Soil CO_2 Flux Chamber.*



Parts List

#	Description		Part #
1	Fan Inlet Duct		
2	Hose Barbs		300-02547
3	Soil Chamber Adapter Manifold		
4	O-rings	Small	192-02597 (2)
		Larger	192-00225 (2)
		Largest	192-02889 (1)
5	Radiation Shield		6564-171
6	Pressure Relief Fitting		300-02561
7	Mounting Plate		
8	Hose Barb (to Air Supply Manifold #15)		300-02547
9	Hose Barb (open)		300-00567
10	Soil Probe Holder		9860-223
11	Pressure Relief Vent Tube		6560-232
12	O-ring		192-04095
13	Mounting Ring		9860-225
14	O-ring		192-04096
15	Air Supply Manifold (from pump)		
16	Air Supply Manifold (from IRGA)		
17	Chamber Body		9860-226
18	Adjustable Stop Ring		9860-227
19	Set Screw		
	Screw		140-04103
	Knob		236-03742
20	Foam Gasket (for use with PVC soil collar)		6560-229
21	PVC Soil Collar (optional)		6560-228

Figure 2-2. *Exploded view of soil CO_2 flux chamber.*

Attaching the Sensor Head to the 6400-09

To attach the sensor head, follow these steps:

The sensor head handle must be removed to accomodate the 6400-09.

1. Remove the male end of the leaf temperature thermocouple connector by pulling straight out, and pull the air hose from the underside of the leaf chamber. Pull the other end of the air hose from the match valve and replace with the short exhaust tube plug (in the replacement parts kit).

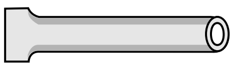


Figure 2-3. *Exhaust tube plug.*

2. Unplug the log switch (not used with the soil chamber). If the log switch wires are threaded underneath the bottom cover of the sensor head, this cover must be removed to free the log switch.

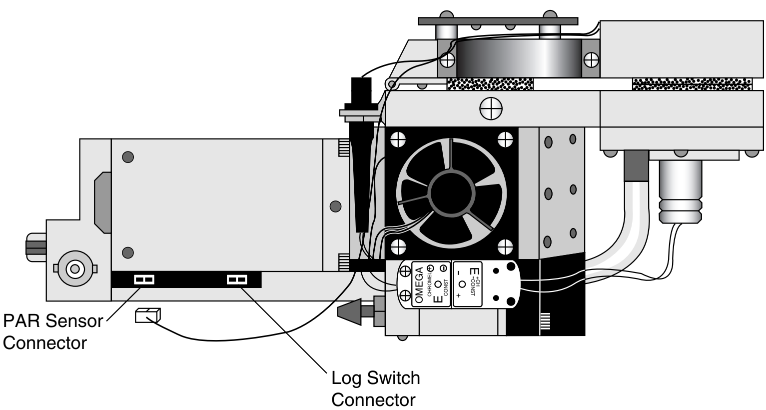


Figure 2-4. *Unplug the log switch.*

■ **To remove the bottom cover (if necessary):**

a. Turn the sensor head over and remove the 3 Phillips head screws as shown in Figure 2-5.

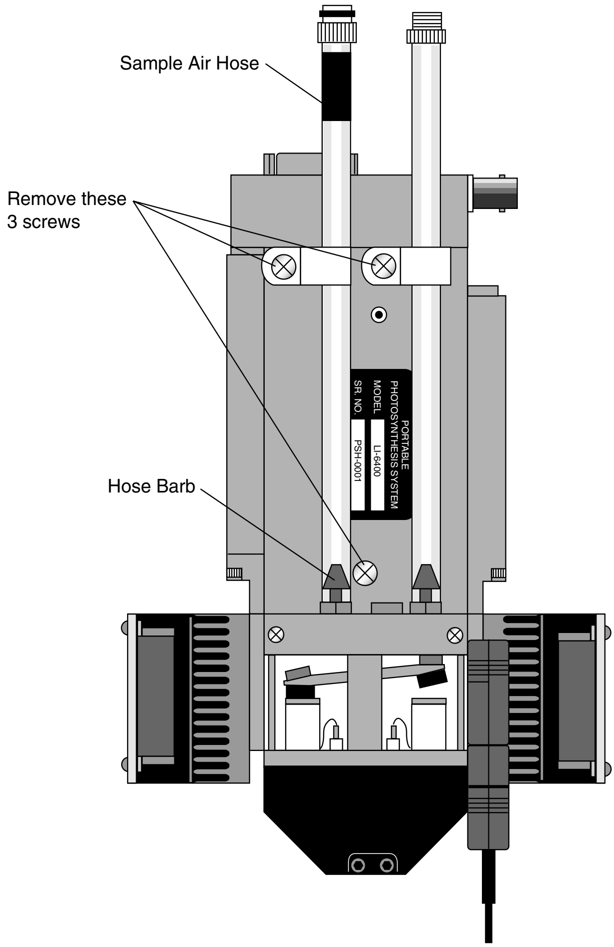


Figure 2-5. *Remove the 3 Phillips head screws from the bottom of the sensor head.*

b. Remove the hose barbs, if necessary. You may be able to slide the cover out from underneath the hose barbs; be careful not to damage the PC board under the cover. If you remove the hose barbs, note the position of the sample and reference air hoses; the sample hose is wrapped with a piece of black shrink wrap.

c. Free the wires.

d. Re-assemble the sensor head bottom cover. Be very careful not to pinch any wires when replacing the cover.

3. Remove the handle assembly:

a. Unlatch the handle, and unscrew the knurled leaf chamber adjustment nut (turn clockwise) until it is free of the handle (Figure 2-6).

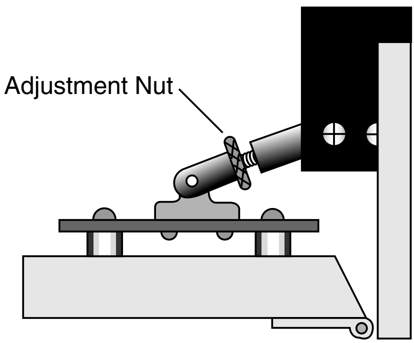


Figure 2-6. *Turn the adjustment nut clockwise to remove.*

b. With the handle latching mechanism in the closed position, wrap tape or string around the handle (where your hand would normally be) so that it will stay together. Failure to do so may result in the rear spring coming out. Leave the handle secured in this manner.

c. Remove the 2 screws (3 on some instruments) on the back side of the handle, as shown in Figure 2-7, using a #1 Phillips head screwdriver. Be careful not to lose the spacer that is between the handle mounting plate and the hinge.

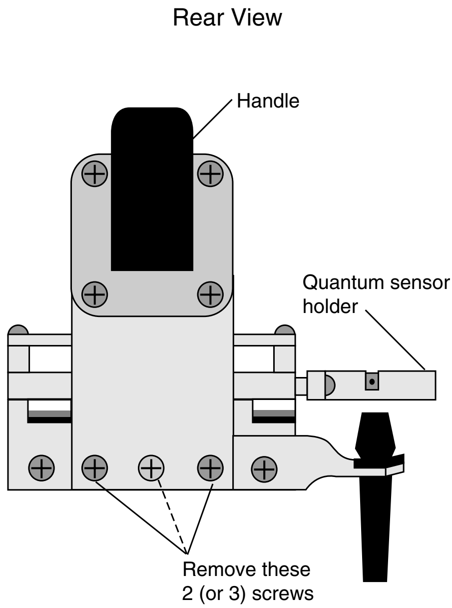


Figure 2-7. *Remove the screws on the back side of the handle.*

4. Remove the upper half of the leaf chamber.

a. Unhook the connector from the PAR sensor or LED light source, if necessary.

b. Remove the 2 screws from the hinge on the rear of the upper half of the leaf chamber (Figure 2-8).

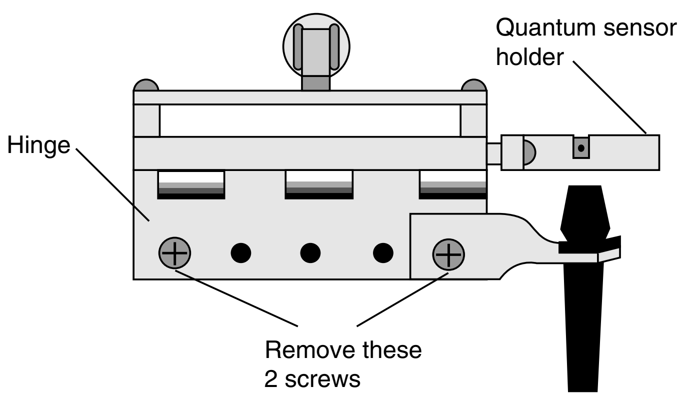


Figure 2-8. *Remove the 2 screws from the handle hinge.*

NOTE: When removing the soil chamber and reattaching the handle, the wires to the log switch need not be threaded beneath the sensor head cover.

c. Remove one fan shroud screw and attach the lamp connector (Figure 2-9).

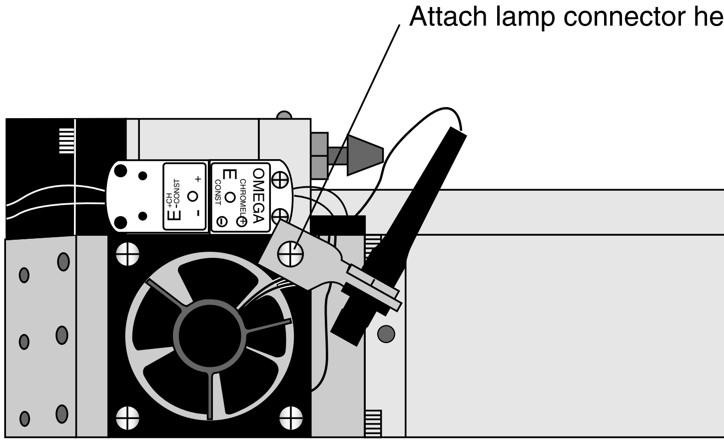


***Figure 2-9**. Attach the lamp connector to the fan shroud.*

5. Remove the lower half of the leaf chamber. There are 8 hex head cap screws on the optical bench cover, as shown in Figure 2-10. Remove the cap screws with a 5/64" hex key (in the spares kit). The lower half of the leaf chamber can now be removed.

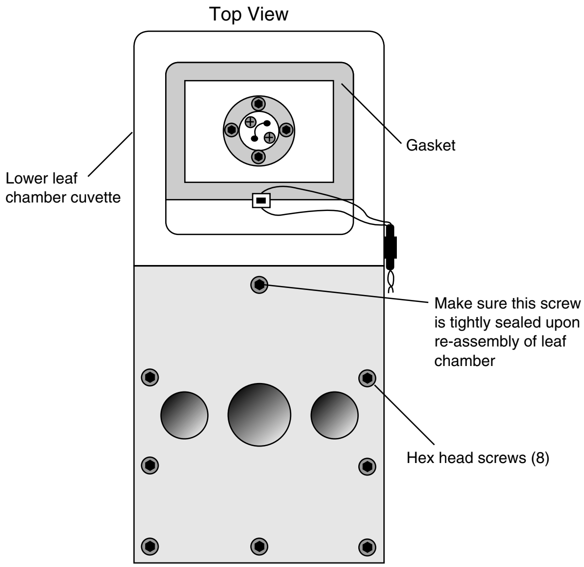


Figure 2-10. *Remove the 8 hex head cap screws.*

6. Attach the soil chamber mounting block with the 8 hex head cap screws from the previous step. The proper orientation of the mounting block is shown in Figure 2-11. Note the thin vinyl gasket on the top surface of the optical bench (Figure 2-11). This gasket is reusable; it should adhere to the optical bench, but if it becomes detached, be sure to reposition it before attaching the mounting block. Tighten the 8 screws carefully and evenly. *Note that the screw nearest the leaf chamber forms a metal-to-metal seal in the air pathway, and must be tight upon re-assembly of the standard leaf chamber.*

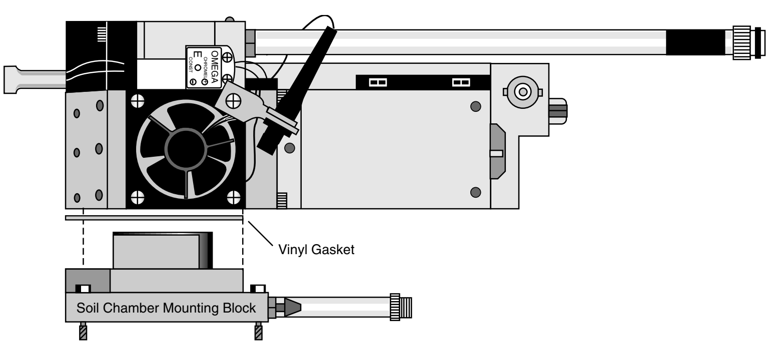


Figure 2-11. *Attach the mounting block to the sensor head.*

7. Make sure all O-rings are properly positioned, as shown in Figure 2-12.

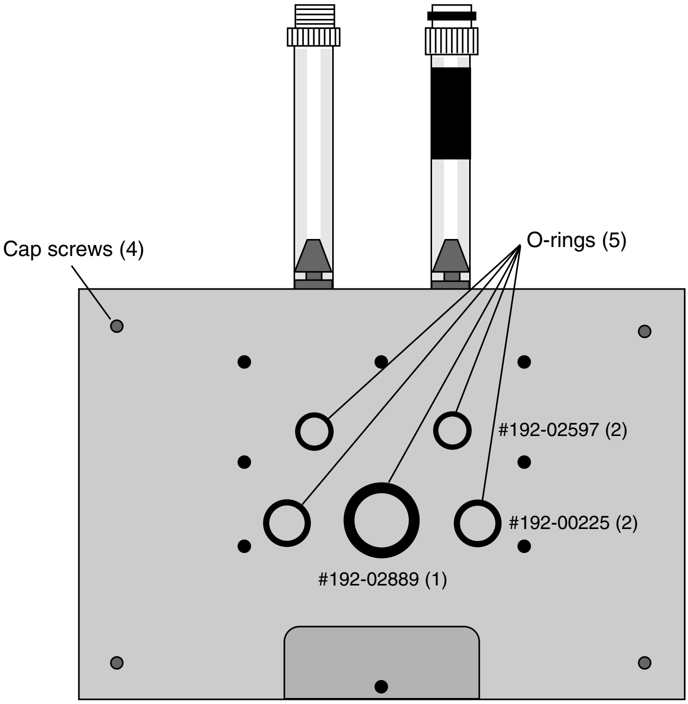


Figure 2-12. *Location of O-rings and cap screws.*

8. Attach the 6400-09 body to the sensor head/mounting block assembly using the 4 cap screws (use the 5/64" hex key included), located on each corner of the mounting block (Figure 2-13).

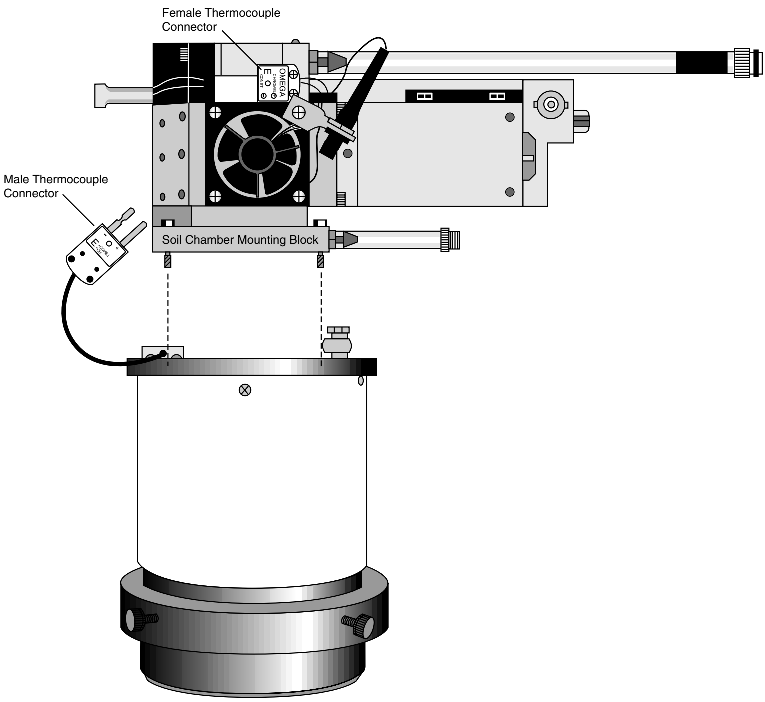


Figure 2-13. Attach the 6400-09 body to the mounting block.

9. Connect the male and female ends of the thermocouple connectors.

10. Join the sample and reference tubes on the sensor head with the "U" shaped piece of tubing, in the 6400-09 replacement parts kit (Figure 2-14).

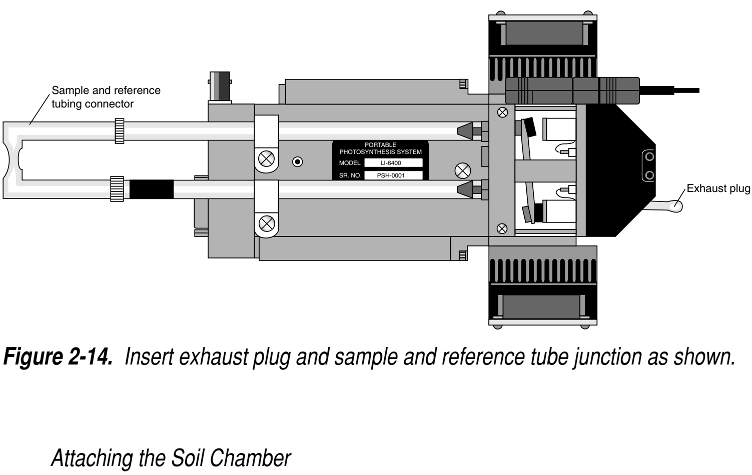


Figure 2-14. Insert exhaust plug and sample and reference tube junction as shown.

11. Connect the air supply tubes on the 6400-09 as described in Section 4, "Check Hose Connections". Attach the chamber and IRGA connectors.

12. Connect the soil temperature probe to the LI-6400 console using the 6400-13 thermocouple adapter assembly (in the spares kit). The adapter plugs into the auxiliary port on the LI-6400. Assembly is complete.

3 Software

Configuring OPEN for Soil Measurements

To make soil CO_2 flux measurements, OPEN 3.0 or above is required to create and implement an appropriate software configuration.

Creating a Soil Chamber Configuration

1. Access the Config Menu from OPEN's main screen.
2. Select "6400-09 Soil Chamber" on the Installation Menu.
3. When "Press <enter> to continue" is displayed, press **Enter**.
4. You will be shown a configuration file in a window entitled "The Config (press <esc>)". Press **Escape**.
5. When "Store this configuration ?" is displayed, press **Y**.
6. The Standard File Dialog is displayed, with the default file name "Soil Chamber" in the directory "/User/Configs/UserPrefs". Modify the name "Soil Chamber" if you like, and press **Enter**. Some files will then be copied, followed by a reminder of how to implement a new configuration (explained below). Press **Enter** and you are done creating a soil CO_2 flux configuration file.

Implementing the Soil Chamber Configuration

1. Access the Config Menu.
2. Select "Reset to User Configuration" in the Reset Menu.
3. When the menu of configuration choices is displayed, select "Soil Chamber" (or whatever it was named in Step 6 above).

Whenever you power the LI-6400 on with the soil chamber attached, select "Soil Chamber" when prompted to select a configuration.

The Soil Chamber Configuration

This section describes changes that the soil chamber configuration makes to the LI-6400 software.

OPEN's Main Screen

"LI-6400 Soil CO2 Efflux System" is displayed instead of "LI-6400 Photosynthesis System".

Calib Menu

The Calib Menu has only three entries:

"IRGA Zero (CO2S, H2OS)"
"IRGA Span"
"View, Store Zeros & Spans"

The first entry is a special zeroing routine for just the sample IRGAs. The second entry is for spanning the IRGAs. The third entry is the same as in the normal Calib Menu list.

If you wish to access an item that is in the normal calibration menu while the soil chamber configuration is in effect, enter the Filer, select the directory "/Sys/Open/Calib Menu", highlight the item to execute, and press **X**. This runs the selected program.

New Measurements Function Keys

The following keys are shut off by the soil chamber configuration:
"MATCH" (level 1, F5). Matching is not necessary, since only the sample IRGA's are used.
"<rspns> (level 2, F1)
"FLOW=" (level 2, F2)
"Mixer" (level 2, F3)
"Lamp" (level 2, f5)
"STOMRAT" (level 3, f2)

The following keys are new, or have different meanings in soil chamber mode:

"AUX OP Params" (level 3, f2). This prompts for four auxiliary operating parameters:

> **"Extra Draw Down (ppm)"** - Draw down beyond the window minimum. (See #315, page 3-5).
> **"Flow during Draw Down (µmol/s)"** - Enter flow during draw down.
> **"Dead Time (secs)"** - Measurements can't start for this time period following the end of the draw down. (#316, page 3-5).
> **"Min Measure Time (secs)"** - Measurement period must last for at least this time period. (#317, page 3-5).

"AREA=" (level 3, f1). Area defaults to 71.6 cm^2, and is the soil surface area within the chamber. When using soil collars, this area may be larger (typically 80 cm^2), depending upon the collar diameter.

"Prompt ALL" (level 3, f5). Prompts for all user constants presently in the prompt list. The default items are insertion depth and plot #, but this can be changed (Prompt Control in the Config Menu).

"Target=" (level7, f1). Sets the target concentration and the delta. The target is the CO_2 concentration at which you want the measurement taken, and the delta defines the operating window around that target. For example, if you specify a target of 360 and a delta of 20, the measurement will occur while the CO_2 rises from 340 to 380. Once above 380, the pump will pull the CO_2 back down to 340 (minus any extra draw down) for another cycle.

"Cycles=" (level 7, f2). Picks the number of repetitions to perform. The key labels show the current repetition number, and the maximum number of repetitions. One repetition, or cycle, consists of pumping the CO_2 down to the (target - delta) ppm, and measuring while the CO_2 rises to (target + delta).

"Start" (level 7, f3). Starts/stops the measurement cycles.

"Obs" (level 7, f4). Selects what is stored in the log file (if a log file is open) during a measurement. The choices are:

0) Off
1) Intermediate Obs Only
2) Final Results Only
3) Everything

During the measurement cycle, the LI-6400 computes an "observation" every 2.5 seconds. This observation includes a CO_2 efflux value based on a rate of change of CO_2 with time over the previous 7.5 seconds (10 measurements). At the end of the cycle, when CO_2 has reached (target + delta), a "Final Result" is computed by regressing CO_2 efflux against CO_2 concentration, and computing the CO_2 efflux rate appropriate for the target concentration. Typically, you only need to store the Final Result (option 2), but the other options are available.

"Depth=" (level 7, f5). Allows you to specify the chamber insertion depth. This is important because it affects the system volume. Insertion depth is the distance (cm) from the cutting edge of the chamber to the top of the soil. (#305, page 3-5)

Examples: If the chamber is pushed into the soil 3 cm, the insertion depth is 3. If the chamber is sitting on a soil collar, so that the cutting edge is 1 cm above the soil surface, the insertion depth would be -1.

User Variables

The soil CO_2 flux configuration defines a number of user variables and constants.

ID #	Label	Description
300	dC/dt	Running average of dC/dt (µmol/mol/s) over the previous 7.5 seconds
301	dW/dt	Running average of dW/dt (mmol/mol/s) over the previous 7.5 seconds
302	C2avg	CO_2 appropriate for Rsoil (#320) Mode=3: Running average of CO_2 (µmol/mol) over previous 7.5 seconds Mode=4: Target CO_2
303	Wavg	Running average of H_2O (mmol/mol) over previous 7.5 seconds
304	Vtot	Actual system volume (cm^3), accounting for insertion depth

*305	InsDpth	Insertion depth (cm)
306	dc'/dt	Rate of change of CO_2 density corrected for evaporation (see Table 6-1, page 6-4)
*307	Vbase	Total volume (cm^3) at 0 insertion depth
310	Mode	Operating mode (0, 1, 2, 3, or 4) 0 - off 1 - drawing CO_2 down to (target - delta - extra) 2 - waiting to get up to (target - delta) and for dead time to expire 3 - measuring 4 - final result (just reached target + delta) and min. measure time has expired
311	Smpls	# obs of slopes or flux rates
312	Program Status	Shows Mode labels
313	Target	Target CO_2 µmol/mol
314	Delta	CO_2 Delta µmol/mol
*315	ddMargin	Extra draw down (ppm)
*316	Dead Time	Dead time after pump off
*317	MnMsrTme	Minimum measurement time
*318	NumCycles	Max # of cycles
320	EFFLUX	Soil CO_2 Efflux Rate µmol/m^2/s If Mode=3: Observation If Mode=4: Final result
321	RHcmbr%	RH in soil chamber %, based on Tsch_C
322	Tsoil_C	Soil Temp C, based on soil temp probe.
323	RHirga%	IRGA RH, based on Tair (in sample cell).
324	Tsch_C	Soil Chamber Air Temp C (measured with 'leaf temp' thermocouple)
330	R(C)m	Slope of dc'/dt vs CO_2 (valid when Mode=4)
331	R(C)b	Offset of dc'/dt vs CO_2 (valid when Mode=4)

AutoPrograms

The AutoProgram "Soil Efflux vs CO2" is added to the programs stored in /user/configs/AutoProgs" when the soil CO_2 flux configuration is first created. This autoprogram lets you specify a range of target values to be measured automatically.

* Indicates a constant that can be included in the prompt list (Prompt Control in the Config Menu). The prompt list can be triggered by "Prompt ALL" (level3, f5) and/or can be made to trigger at the start of a measurement.

4 Making Measurements

The procedure below lists the steps required to make a soil surface CO_2 flux measurement, and assumes that the LI-6400 sensor head has already been attached to the chamber, and that the system has been configured for use with the chamber. These topics are covered in Sections 2 and 3.

There are two different methods of making measurements. The 6400-09 can be inserted directly into the soil for measurements, or it can be used with "soil collars" that are inserted into the soil. There are some factors to consider when inserting the 6400-09 directly into the soil, including:

- Using the system without preinstalled collars can allow the user more extensive sampling.
- The disturbance caused by insertion of the chamber in the soil will generally cause air laden with CO_2 to be displaced. Therefore, you should plan to wait as long as 30 minutes after insertion of the chamber before making the measurement.
- Direct insertion will disturb the soil surface, making it a destructive technique.

Soil chamber collars have several advantages over direct insertion, including:

- The disturbance effect of insertion will not affect measurements conducted several hours or days later.
- It is possible to make repeated measurements at one location.

Measuring With Soil Collars

Soil collars should be installed several hours to one day before making a measurement. You can test to see if the flux has stabilized by making a measurement immediately after installing the collar, and then make subsequent measurements over time. Note, however, that the soil surface CO_2 flux depends on the time of day, and the diurnal cycle can be quite large.

Care must also be taken not to let the bottom edge of the chamber disturb the soil surface within the collar. However, the chamber edge should be as close to the soil surface as practical so that air flow within the chamber produces mixing near the soil surface. Adjust the stop ring to position the chamber near the soil surface. Use a foam gasket between the bottom of the stop ring and the top of the soil collar to minimize leaks between the collar and the chamber.

The soil area value should be set to 80 cm^2 (or whatever is appropriate based on the collar diameter).

Measuring Without Soil Collars

The chamber should be installed on the soil surface by pressing gently and firmly straight down on the mounting plate without rotation. Rotating the chamber may disturb the soil surface by creating a gap around the inside of the chamber, allowing CO_2 in the soil to escape. The soil surface should not be disturbed at all immediately before the measurement. If the surface must be cleared or smoothed before measurements can be made, it should be done prior to the measurement; preferably hours for minor alterations and a day for severe alteration.

Making Measurements

1. Position the Air Supply Manifold

Move the lower air supply manifold up or down inside the chamber body so that it is 1-2 cm above the soil surface, regardless of whether or not soil collars are being used for the measurement. This will ensure proper mixing of air coming from the IRGA.

2. Check Hose Connections

The general plumbing arrangement between the LI-6400 and the 6400-09 is shown in Fig. 4-1. Note that there is a piece of black shrink wrap on one of the hoses leading from the soil chamber; this hose is connected to a "Y" connector provided, so that air from both sample and reference ports flows back to the soil chamber. Attach the "Y" connector to the sample and reference inlets on the console, as shown below. The second hose leading from the soil chamber is connected to the Air Inlet port on the console with a second tubing connector provided.

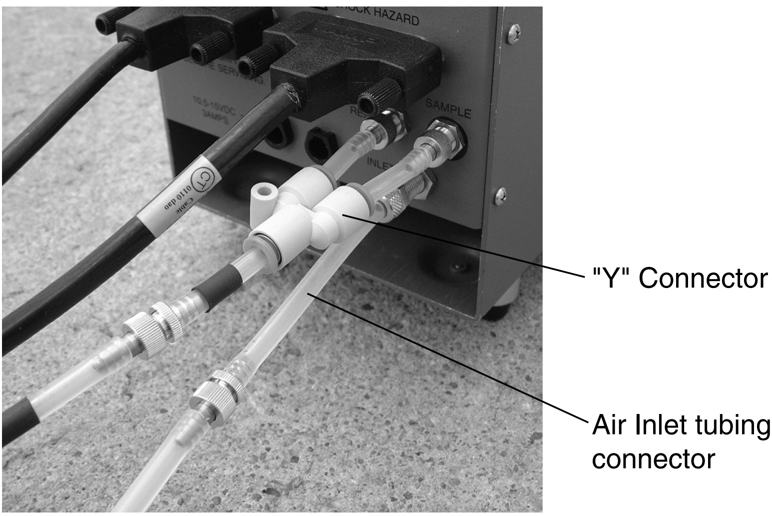


Figure 4-1. *Photo showing plumbing arrangement of 6400-09 and LI-6400.*

3. Measurement Procedure

The following measurement procedure assumes that you have already completed all necessary instrument preparations.

1. Determine the CO_2 concentration of the air near the soil surface. To do this, lay the chamber on its side and monitor soil chamber CO_2 concentration (CO2S).

2. Install the 6400-09 at the measurement location. Insert the soil temperature probe to an appropriate depth (typically 5 to 10 cm), near the Soil CO_2 Flux Chamber.

3. Go to the New Measurements window (f4) in the LI-6400. Set the CO_2 "Target" and "delta" (menu level 7, f1). Use the ambient CO_2 concentration determined in Step 1 as the "Target", and choose a delta appropriate for your site. For low rates, the delta should be 5 or 10 ppm. For higher rates, the delta will have to be increased.

4. Enter the insertion "depth" of the chamber, in cm (menu level 7, f5). This is measured from the bottom of the chamber. If inserting directly into the soil, this will vary between 1 and 3.2 cm, depending on the soil type and the Stop ring position (Figure 4-2a). If using soil collars, this will be entered as a negative number and will be equal to the distance in cm between the bottom edge of the soil chamber and the soil surface (Figure 4-2b).

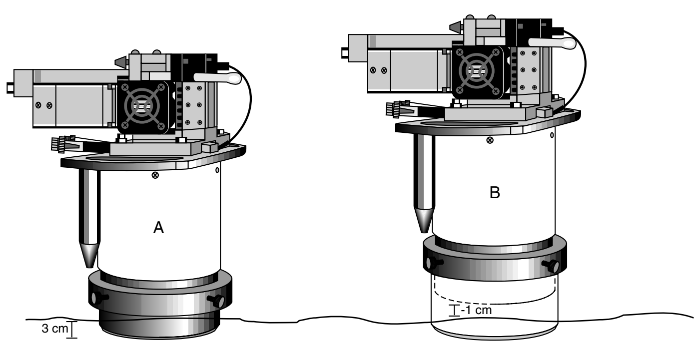


Figure 4-2. *Measure the insertion depth.*

5. Enter the number of cycles the instrument should perform at any given location (menu level 7, f2).

6. Select whether you want to save final computed values, intermediate instantaneous observations, or both (menu level 7, f4).

7. Press **Start** (menu level 7, f3). You will be prompted to enter a name for the log file if one is not already open. If you press <escape>, you can log to memory or to the comm port. If you press <escape> again, you will not be logging, *but the soil measurement will still proceed.*

You can also be automatically prompted for all of the items in the prompt list, by setting level 3, f4 to "Prompt ON Log".

8. Add any remarks. The measurement cycle will begin.

NOTE: You may want to graphically monitor your measurements using "Soil Efflux RTG" (Figure 4-3). This is the default strip chart configuration for the soil chamber configuration.

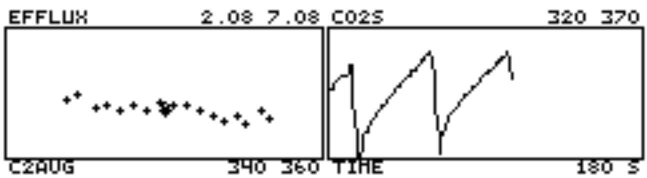


Figure 4-3. *The real time graphics display "Soil Efflux RTG" will display a strip chart of CO_2 in the sample cell, as well as a plot of soil CO_2 flux as a function of CO_2 for each measurement cycle.*

5 Maintenance

Spare Parts Kit

This kit contains some common replacement parts for the 6400-09. If you need to re-order any individual parts, please refer to the part numbers shown in Table 5-1 below. More part numbers are shown in Figure 2-2, page 2-2.

Table 5-1. Soil CO_2 Flux Chamber Spare Parts List

Part #	Description
6000-09TC	Soil probe thermocouple
6400-13	Thermocouple adapter assembly
9964-054	Replacement parts kit
6560-228	Soil collars*
9960-112	Gasket kit (foam gaskets and O-rings)

* Soil collars can be easily made from polyvinylchloride (PVC) tubing. Instructions are given later in this section.

Soil Temperature Probe

The soil temperature probe cable insulation may have a tendency to work loose from the thermocouple connector shell. If this happens, open the connector (remove 2 screws) and stretch the cable insulation back into the shell, and reassemble.

The soil temperature probe can be ordered from LI-COR under part #6000-09TC, or directly from Omega Engineering Inc. (Stamford, CT) under part #MHP-CXSS-316U-6-SMP-M-NP.

Making Soil Collars

Soil collars can be easily constructed from thin-walled polyvinyl chloride (PVC) pipe (i.e., sewer and drain pipe). The tubing must have an inside diameter of 3.930” (10 cm) or larger [maximum 4.65” (11.8 cm) O.D.]. Cut a section approximately 1.75” (4.4 cm) long or longer, depending on your soil type and experiment, and bevel one edge with a grinding wheel so that it can be pressed into the soil. Soil collars are also available from LI-COR at a nominal cost under part #6560-228 (1 each).

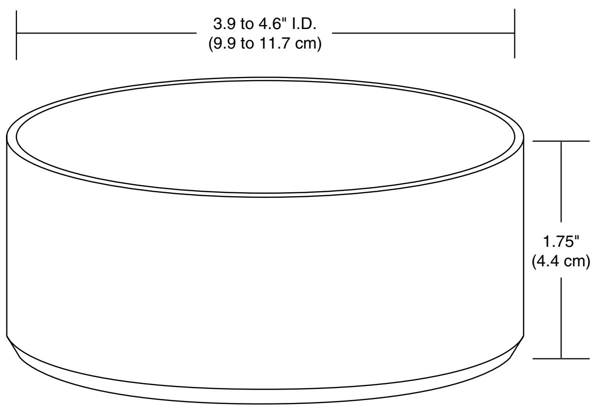


Figure 5-7. *Soil collar dimensions.*

Zeroing the IRGAs

In order to zero the sample analyzer, it is necessary to replumb the system.

Zeroing the IRGA While Attached to the Soil CO_2 Flux Chamber

1. Plumbing changes for zeroing the IRGA:

a. Disconnect the To-Sample tube (it has black heat shrink) from the jumper shown below (Figure 5-8).

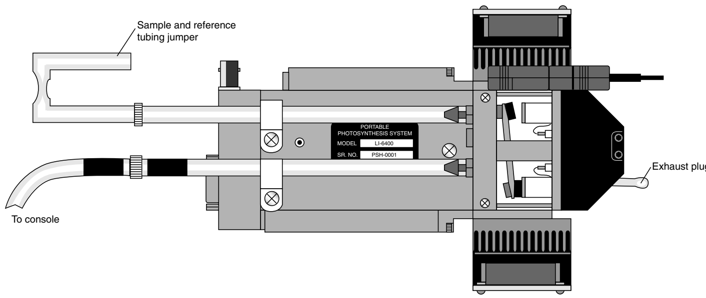


Figure 5-8. *Hose configuration after changing the tubing to zero the IRGA.*

b. There are two long hoses coming from the console. Find the end with the black heat shrink that is attached to the soil chamber. Disconnect it (on the soil chamber end), and re-connect it to the short To-Sample tube discussed in Step 'a' above.

2. You also need to cover the open end of the soil chamber. Either put the plastic cap back in place, or set it down on a smooth surface. The goal is to prevent large CO_2 concentrations (such as from your breath) from finding their way into the chamber, and diffusing into the IRGA.

During zeroing, the system will have the fan shut off, so air from the soil chamber will not be actively exchanged with air in the optical path of the sample analyzer. The system is now plumbed for zeroing.

3. Turn the soda lime tube on full scrub when zeroing for CO_2, and the desiccant tube on full scrub when zeroing for H_2O.

Setting the IRGA Span

1. Connect the span gas directly to the sample analyzer inlet. *Do not connect to the console*. **NOTE:** If you also want to check the span of the reference analyzer, connect the gas directly to it when you are ready. Do NOT connect via the sample cell with the match valve on.

2. Cover the open end of the soil chamber if checking the sample IRGA span. Either put the plastic cap back in place, or set the chamber down on a smooth surface to prevent large CO_2 concentrations from finding their way into the chamber, and diffusing into the IRGA.

   During spanning, the system will have the fan shut off (regardless of where you have the fan speed set), so air from the soil chamber will not be actively exchanged with the air in the optical path of the sample analyzer.

   The system is now ready for checking the span.

6 Equation Derivation

The mass balance of CO_2 for the 6400-09 soil flux chamber (Figure 6-1) is given by

CO_2 In = Storage + CO_2 Out

$$sf_c = \rho v \frac{\partial c}{\partial t} + uc \qquad 6\text{-}1$$

where s is the soil surface area (m^2) enclosed by the chamber, v is the volume (m^3) of the chamber and IRGA, f_c is the flux of CO_2 coming from the soil surface (mol CO_2 m^{-2} s^{-1}), ρ is the density of the air (mol m^{-3}), c is the CO_2 concentration (mol CO_2 mol^{-1}), and u is the flow rate (mol s^{-1}) of escaping air from the system, largely due to soil evaporation into the system.

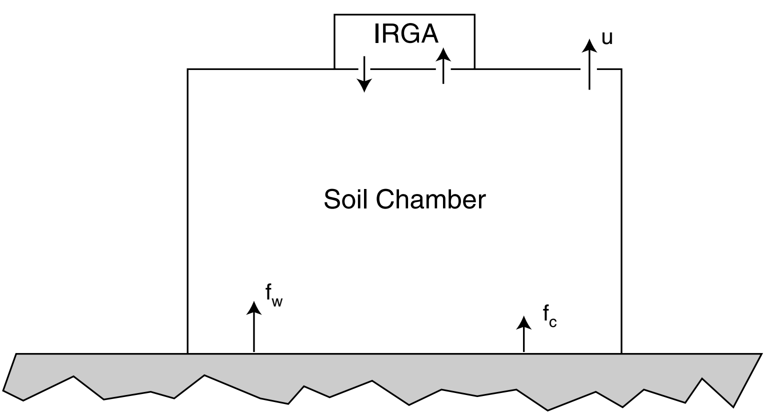


Figure 6-1. *Schematic of the soil chamber. Soil evaporation f_W and soil CO_2 flux f_C add mass to the chamber, which is balanced by a flow u of air, water, and CO_2 out of the chamber.*

The mass balance of water vapor is given by

Water In = Storage + Water Out

$$sf_w = \rho v \frac{\partial w}{\partial t} + uw \qquad 6\text{-}2$$

where f_w is the flux of H_2O coming from the soil surface (mol H_2O m^{-2} s^{-1}), and w is the water vapor concentration (mol H_2O mol^{-1}).

If we assume that evaporation is the sole cause of the leakage, then u = sf_w, and we can write

$$sf_w = \rho v \frac{\partial w}{\partial t} + sf_w w \qquad 6\text{-}3$$

$$= \frac{\rho v}{(1 - w)} \frac{\partial w}{\partial t}$$

Substituting this for u in (6-1) leads to

$$sf_c = \rho \mathrm{v} \frac{\partial \mathrm{c}}{\partial \mathrm{t}} + \frac{\rho v c}{(1 - w)} \frac{\partial \mathrm{w}}{\partial \mathrm{t}} \qquad 6\text{-}4$$

Collecting terms leads to

$$f_c = \frac{\rho v}{s} \left(\frac{\partial c}{\partial t} + \frac{c}{(1 - w)} \frac{\partial w}{\partial t} \right) \qquad 6\text{-}5$$

Equation (6-5) takes a slightly different form as implemented in the LI-6400, since the measured and entered parameters have different units, and density must be computed from temperature and pressure. The terms are defined in Table 6-1.

$$c\left(\frac{\text{mol CO}_2}{\text{mol air}} \right) = C\left(\frac{\mu\text{mol CO}_2}{\text{mol air}} \right) \times 10^{-6} \left(\frac{\text{mol}}{\mu\text{mol}} \right) \qquad 6\text{-}6$$

$$w\left(\frac{\text{mol H}_2\text{O}}{\text{mol air}}\right) = W\left(\frac{\text{mmol H}_2\text{O}}{\text{mol air}}\right)\times 10^{-3}\left(\frac{\text{mol}}{\text{mmol}}\right) \quad \text{6-7}$$

$$\rho\left(\frac{\text{mol}}{\text{m}^3}\right) = \frac{P(kPa)\times 10^3\left(\frac{N/m^2}{kPa}\right)}{8.314\left(\frac{Nm}{mol\ \text{K}}\right)\left(T_c + 273(K)\right)} \quad \text{6-8}$$

$$\frac{v}{s}\left(\frac{m^3}{m^2}\right) = \frac{V\left(cm^3\right)\times 10^{-6}\left(\frac{m^3}{cm^3}\right)}{S\left(cm^2\right)\times 10^{-4}\left(\frac{m^2}{cm^2}\right)} \quad \text{6-9}$$

Substituting Equations 6-6 through 6-9 into 6-5 yields

$$F_c = \frac{kPV}{S(T_c + 273)}\left(\frac{\partial C}{\partial t} + \frac{C}{(1000 - W)}\frac{\partial W}{\partial t}\right) \quad \text{6-10}$$

where k = 10/8.314 = 1.2028.

Table 6-1. The terms of the LI-6400's soil flux equation (6-10).

Symbol	Description	Units	Soil Config LABEL
F_c	Soil flux of CO_2	µmol CO_2 m^{-2} s^{-1}	EFFLUX
P	Atmospheric pressure	kPa	Press_kPa
V	Total system volume	cm^3	Vtot
S	Enclosed soil area	cm^2	Area
T_c	Air temperature in chamber	°C	Tsch_C
C	CO_2 concentration	µmol CO_2 mol^{-1}	CO2S_µml
W	H_2O concentration	mmol H_2O mol^{-1}	H2OS_mml
$\frac{kP}{(T_c + 273)}\left(\frac{\partial C}{\partial t} + \frac{C}{1000 - W}\frac{\partial W}{\partial t}\right)$			dc'/dt

A Specifications

System Volume (0 insertion depth): 991 cm^3
Soil Area Exposed: 71.6 cm^2 (11.1 $in.^2$)
80.0 cm^2 (12.4 $in.^2$) with supplied PVC soil collar
Diameter: 9.55 cm (3.76 in.)
Air Temperature Thermocouple:

Type E:	Range: ± 50 °C of reference junction
Reference Junction:	Optical housing block thermistor Accuracy: ± 10% of T difference between air and reference junctions with the amplifier zeroed

Soil Temperature Probe:

Type E:	Ambient Temperature Range: 0 to 50 °C Soil Temperature Range: ± 30 °C from ambient within the range of -20 °C to 60 °C.
Accuracy:	± 1.5 °C, 0 to 50 °C

Size: 16.50 H × 19.80 W × 10.20 D cm. (6.5 × 7.8 × 4.0")
Weight: 1.8 kg (3.75 lbs.)

*Specifications subject to change without notice.

Warranty

Each LI-COR, inc. instrument is warranted by LI-COR, inc. to be free from defects in material and workmanship; however, LI-COR, inc.'s sole obligation under this warranty shall be to repair or replace any part of the instrument which LI-COR, inc.'s examination discloses to have been defective in material or workmanship without charge and only under the following conditions, which are:

1. The defects are called to the attention of LI-COR, inc. in Lincoln, Nebraska, in writing within one year after the shipping date of the instrument.
2. The instrument has not been maintained, repaired, or altered by anyone who was not approved by LI-COR, inc.
3. The instrument was used in the normal, proper, and ordinary manner and has not been abused, altered, misused, neglected, involved in and accident or damaged by act of God or other casualty.
4. The purchaser, whether it is a DISTRIBUTOR or direct customer of LI-COR or a DISTRIBUTOR'S customer, packs and ships or delivers the instrument to LI-COR, inc. at LI-COR inc.'s factory in Lincoln, Nebraska, U.S.A. within 30 days after LI-COR, inc. has received written notice of the defect. Unless other arrangements have been made in writing, transportation to LI-COR, inc. (by air unless otherwise authorized by LI-COR, inc.) is at customer expense.
5. No-charge repair parts may be sent at LI-COR, inc.'s sole discretion to the purchaser for installation by purchaser.
6. LI-COR, inc.'s liability is limited to repair or replace any part of the instrument without charge if LI-COR, inc.'s examination disclosed that part to have been defective in material or workmanship.

There are no warranties, express or implied, including but not limited to any implied warranty of merchantability of fitness for a particular purpose on underwater cables or on expendables such as batteries, lamps, thermocouples, and calibrations.

Other than the obligation of LI-COR, inc. expressly set forth herein, LI-COR, inc. disclaims all warranties of merchantability or fitness for a particular purpose. The foregoing constitutes LI-COR, inc.'s sole obligation and liability with respect to damages resulting from the use or performance of the instrument and in no event shall LI-COR, inc. or

its representatives be liable for damages beyond the price paid for the instrument, or for direct, incidental or consequential damages.

The laws of some locations may not allow the exclusion or limitation on implied warranties or on incidental or consequential damages, so the limitations herein may not apply directly. This warranty gives you specific legal rights, and you may already have other rights which vary from state to state. All warranties that apply, whether included by this contract or by law, are limited to the time period of this warranty which is a twelve-month period commencing from the date the instrument is shipped to a user who is a customer or eighteen months from the date of shipment to LI-COR, inc.'s authorized distributor, whichever is earlier.

This warranty supersedes all warranties for products purchased prior to June 1, 1984, unless this warranty is later superseded.

DISTRIBUTOR or the DISTRIBUTOR'S customers may ship the instruments directly to LI-COR if they are unable to repair the instrument themselves even though the DISTRIBUTOR has been approved for making such repairs and has agreed with the customer to make such repairs as covered by this limited warranty.

Further information concerning this warranty may be obtained by writing or telephoning Warranty manager at LI-COR, inc.

IMPORTANT: Please return the User Registration Card enclosed with your shipment so that we have an accurate record of your address. Thank you.

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