

Boundary layer resistance (r_b) values for PP Systems PLC cuvettes

Background

Gas mixing efficiency in leaf cuvettes is tested in the factory by measuring the boundary layer resistance (r_b) over an area of exposed wet filter paper, which simulates a leaf. This is based on the method of Parkinson (1985)¹ and Parkinson & Day (1990)².

A close approximation of r_b is needed for three important gas exchange calculations used in CIRAS firmware: leaf temperature derived from the Energy Balance method, stomatal conductance (g_s) and sub-stomatal CO_2 concentration (C_i). Energy Balance is perhaps less important in the PLC6(U) cuvette, due to its built-in IR sensor used for determining leaf temperature. It is always needed for the calculation of g_s , the inverse of stomatal resistance (r_s):

$$r_s (\text{m}^2 \text{ s mol}^{-1}) = \left[\frac{(e_{leaf} - e_{out})}{(E \times P)} \right] - r_b$$

This is essentially the total leaf resistance less r_b , with a correction for the proportion of stomata distributed between the adaxial and abaxial leaf surfaces. Boundary layer resistance is relatively weak as compared to the resistance of the stomata to transfer of gas molecules. For a thorough discussion of leaf external and internal resistances see e.g. P. S. Nobel, 2009, *Physicochemical and Environmental Plant Physiology*, 4th Edition. Boundary layer resistance is also a factor in the von Caemmerer and Farquhar (1981)³ equation determining leaf conductance for CO_2 transport (g_c), where r_s and r_b are associated with different $H_2O:CO_2$ diffusion coefficients in air and in the leaf boundary layer, and subsequently used in the calculation of C_i :

$$g_c (\text{mmol m}^{-2} \text{ s}^{-1}) = \left[\frac{1}{(1.585 \times r_s) + (1.37 \times r_b)} \right] \times 10^3$$

For a PLC6(U) cuvette with the circular insert, the area of filter paper is 18 mm diameter (2.5 cm² projected area), exposed on both surfaces. For a PLC5 (N/C/P) the filter paper area is 3 cm x 1 cm (3 cm² projected area), forming the center part of a 1 cm wide simulated polythene leaf which is suspended across the entire width of the cuvette, exposed on both surfaces.

The resulting calculated r_b value is recorded on the "Tested" label, which is attached to each cuvette, and included with the instrument Packing Note. The r_b value should be recalculated if it is lost and periodically checked as the cuvette is used. An appropriate typical value can be used temporarily, with the understanding that any data must be recalculated using the correct r_b value.

Typical r_b values for the following cuvette types are:

PLC Type	r_b (m ² s mol ⁻¹)
Universal Cuvette - PLC6 (U)	0.30
Narrow Cuvette –PLC5(N)	0.15
Conifer Cuvette –PLC5(C)	0.15

¹ Parkinson, K.J. 1985. A simple method for determining the boundary layer resistance in leaf cuvettes. *Plant, Cell and Environment* **8**:223-226.

² Parkinson, K.J. and W. Day. 1990. Design and testing of leaf cuvettes for use in measuring photosynthesis and transpiration. pp. 207-229 in *Measurement Techniques in Plant Science* (Eds. Hasimoto, Y., Kramer, P.J., Nonanic, H. and Strain, B.R.). Academic Press, USA.

³ von Caemmerer, S. and G.D. Farquhar 1981. Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. *Planta* **153**:376-387.

Requirements for construction of the pseudo-leaf envelope

The pseudo-leaf consists of a simple water-resistant envelope with an 18 mm circular opening. The envelope may be constructed of plastic sheet or thin aluminum foil, closed on 3 sides, allowing new filter paper to be exchanged with older, dirty filter paper. The area dimensions of the sample plastic envelope shown below are 45 x 75 mm.

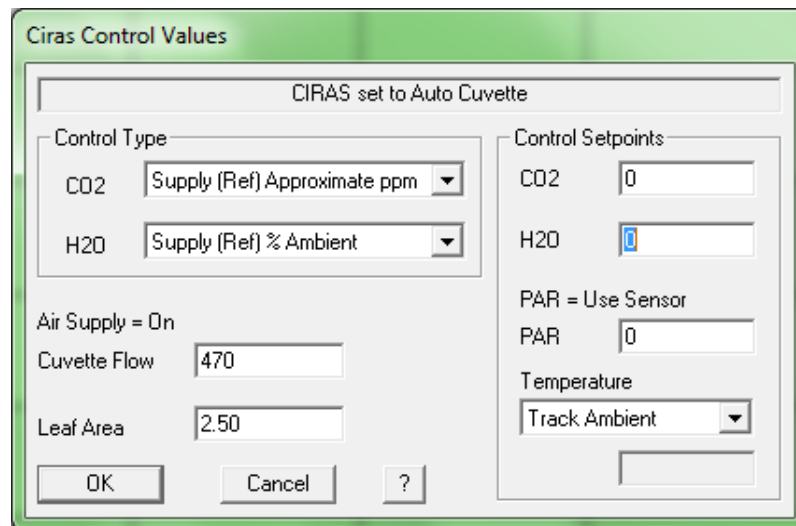


The cuvette upper and lower foam rubber gaskets must not come into contact with the filter paper once it is placed in the cuvette, as seen above, right.

Boundary Layer Test

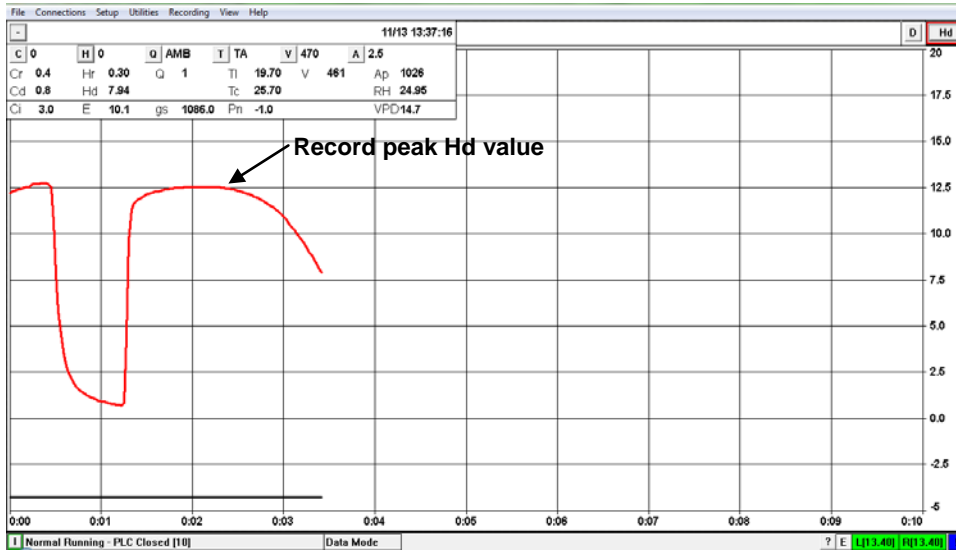
Remove the LED light unit. In the CIRAS-2 Controls menu set the following environmental controls:

Cr=0; Hr=0; cuvette flow rate (V)=470; temperature T=TA (Track Ambient). Perform a Zero and DiffBal cycle. Set up the graphical display to plot Hd (H₂O differential).

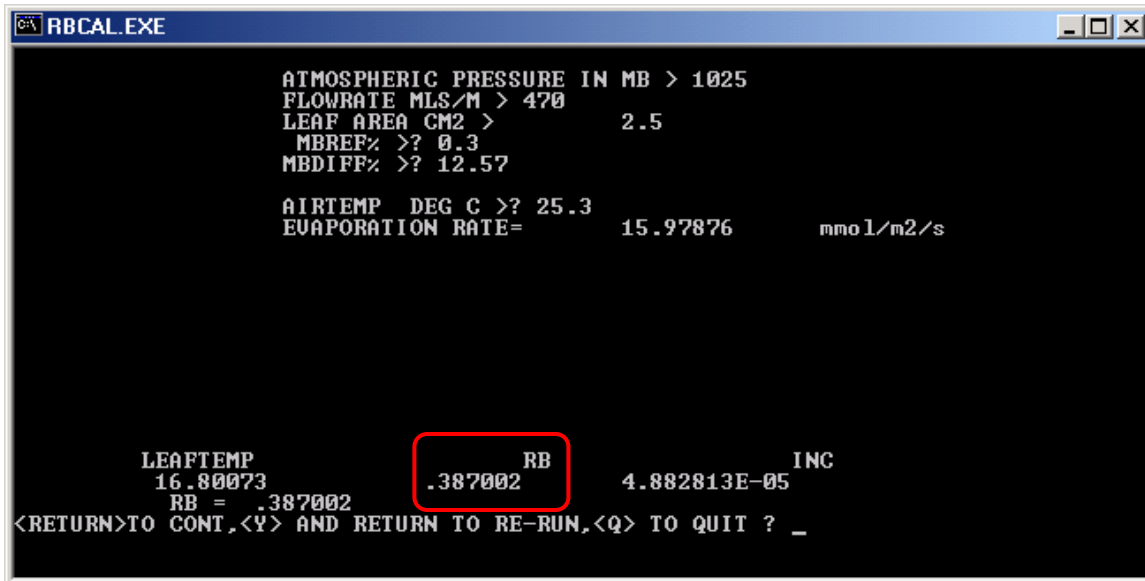


With a syringe or moist cotton swab, carefully wet the exposed 2.5 cm² filter paper area. Avoid water on the aluminum foil or plastic frame of the envelope. Do not wet the closed cell foam cuvette gasket - wetting the gasket will increase the leaf chamber humidity and result in a failed test. Open the cuvette and place the pseudo-leaf envelope in the cuvette. Align the filter paper area of the envelope with the 2.5 cm² circular opening. Close the cuvette and cover the leaf chamber with a dark cloth (PAR sensors read 0).

You should observe a rapid rise in the cuvette water vapor differential (Hd, mb) followed by a short stability phase of perhaps 1 minute duration, depending on the degree of wetness of the filter paper. *Note this average Hd value.* As the paper dries due to evaporation the positive differential will fall back towards zero.



The DOS boundary layer calculation software program *RBCAL.EXE* is provided to calculate boundary layer resistance. Open the program and enter the value of each parameter as prompted:



For AIRTEMP, enter the cuvette temperature °C (Tc). Note that the evaporation rate ($\text{mmol m}^{-2} \text{s}^{-1}$) will be much higher than typical leaf transpiration rates. Ensure that r_b is $\leq 0.5 \text{ m}^2 \text{ s mol}^{-1}$. Typical results range from 0.3-0.5. If not, rewet the filter paper (if dry) and rerun the test by entering “Y” in the *RBCAL.EXE* program. From the example above, enter 0.39 in the CIRAS-2 Settings dialog and in any necessary data recalculation. Enter “Q” to exit the DOS program.

Note that newer computer operating systems such as Windows Vista, 7, 8 do not support older DOS programs. The program can only be run on these computers by installing both Windows XP Mode and Windows Virtual PC (<http://www.microsoft.com/windows/virtual-pc/download.aspx>).

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