Granier sensors

Construction and installation

General principle:

These instructions refer to the constant heat sap flow gauge design developed by Granier (1985, 1987). A sap flow "gauge" consists of a paired heated and unheated sensor 20 mm in length inserted radially into the xylem of a tree with > 40 mm diameter. The temperature difference between the heated and unheated sensor is empirically related to sap flow with a relationship determined by Granier. This method is best for moderate to high rates of sap flux (but be cautious when exceeding the range of the original calibration which reached about 160 g $m^{-2}s^{-1}$). A correction factor is necessary if part of the sensor is in inactive xylem (heartwood) according to Clearwater et al. (1999).

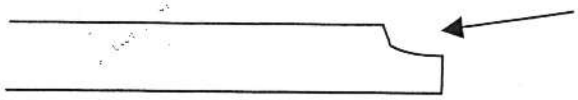
An advantage to this method over other thermal sap flow methods is that: 1) the sensors are inexpensive and straightforward to manufacture, 2) only one voltage measurement and therefore datalogger channel is required per sensor pair, and 3) other supporting parameters such as stem water content, wood heat capacity, and wounding do not need to be accounted for. A large number of replicates are possible to scale sap flow measurements to the stand and ecosystem level.

Sensor parts list:

Becton Dickinson19 gauge, 1.5 in hypodermic needles (14-821-14H from Fisher)
Dremmel tool with cutting disk
TT-T-36-1000 copper constantan wire from Omega, Inc.
TFCC-005-500 constantan heating wire from Omega, Inc.
crazy glue
carpenters glue
tool dip
solder and soldering iron
voltmeter
3/32" OD, 0.14" wall aluminum tubing (TTRA-2-36 from Small Parts, Inc.)

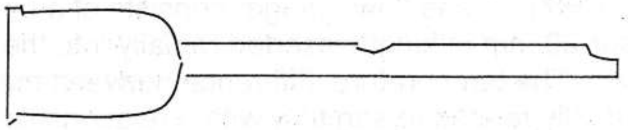
Needles:

1. Cut needles to 21 mm length with the Dremmel tool. Wear safety glasses when cutting metal with the Dremmel tool as pieces may come flying.
2. For heated sensors only: cut a ~0.5 mm notch in the cut tip of the needle. This will be helpful in wrapping the heating coil later. Also, poke a hole in the plastic base of the needle with uncut (sharp) hypodermic needle.



0.5 mm notch

3. For both heated and unheated sensors, cut a small hole in the center of the needle. Don't cut in too deeply or the sensor will be weakened. Ideally, cut until just film of metal remains that can be removed with a sharp needle.



4. Clean out the needles by running a small metal wire through the sensor repeatedly, removing any burrs or sharp points.

Thermocouples:

1. Cut ~ 15cm long pieces of copper-constantan thermocouple wire.
2. If the wire has a clear outer sheath surrounding the red and blue wires, remove it by gently running a razor blade down the center. Be careful not to nick the blue or red wires.
3. Strip off about 3 mm of insulation from both the copper (blue) and constantan (red) wires, exposing the bare metal. Be very careful not to nick the metal wire or it will later break off. After some practice, this can be done with wire strippers or by very lightly cutting the plastic with a razor blade and stripping the insulation off with your fingers.
4. Make 2-3 symmetric twists of the copper and constantan bare metal.
5. Solder the twists with a very thin, complete coat of solder. Do not heat solder directly with the soldering iron – heat the wires and gently touch them to the solder.
6. Cut off any remaining untwisted ends at the tip, leaving a 1 – 1.5 mm thermojunction.
7. Use a voltmeter to check the resistance between the two leads. It should be between 3 and 50 ohms. Out of range resistance means a junction has not been made and should be re-soldered.
8. Dip the thermojunction briefly in tool dip to insulate it. Make sure it has only a light, but complete coating.

Constantan heating wire:

1. Cut about 50 cm of wire for each heated sensor.

Assembling heated sensors:

1. Insert the heating wire through the cut end of the needle until it comes out the base. Pull the wire through until there is about 5 cm at the base. Leave the remaining ~40 cm hanging at the cut end.
2. Insert both the blue and red thermocouple wires from a completed thermojunction through the cut end of the needle and gently push the wires through the needle until the come of out the needle base. This a difficult step and takes some practice. Burrs in the needle or thermojunctions that are too large will prevent insertion so make sure the needle is clean and the thermojunction is sufficiently small.
3. Pull the thermocouple wire through the needle until you see the junction (insulated with tool tip) in the hole in the middle of the needle. This can be difficult if the heating wire is in the way - sometimes a hand lends or low power microscope helps.
4. Apply superglue into the hole in the needle in small drops and wait until they are pulled in by capillary action. Repeat this step until the needle is full and glue is no longer taken in. If the glue is allowed to dry before continuing on to the next step, make sure it does not bulge out of the needle when dry.
5. Begin wrapping the long end of the heating wire around the cut end of the needle, using the notch to catch the first coil. Keep a steady but relatively light tension on the wire as you wrap, making sure the coils are as close together as possible without overlapping. When you come to the hole in the center of the needle the coils will depress into the hole, which is okay. Wrap all the way to the end of the needle where it meets the plastic base (ignore the white coating). Hold the coil steady with one hand and insert the loose end into the small hole you punched in the plastic base. Give the wire a little tug and bend it towards the outside of the needle to hold the coil in place.
6. Fill in the needle base with carpenter's glue to hold the wires in place and let it dry for several hours.
7. Cut off the excess heating wire so that both leads extend about 5 cm out of the needle base. Strip off about 1 cm of insulation from the two thermocouple leads and the heating wire leads.

Assembling reference sensors:

1. Proceed with steps 2 – 4 above; the process is the same as for heated sensors but without the heating wire and coils. After step 4 skip to step 6.

Testing the sensors and determining their resistance:

1. Use a voltmeter with a continuity tester to check the continuity between the thermocouple and the needle. **They should not be touching**. If they have continuity you must discard the sensor.

2. Use a voltmeter to measure the resistance across the heating wires for heated sensors. This should be < appox. 20 ohms. Record this value as R-total.
3. Measure the length of the heating wire that is not part of the coil or inside of the needle shaft. Multiply this value 0.4 ohms/cm to estimate R-leads.
4. R-coil = R-total – R-leads. Write this number with a sharp permanent marker or paint pen on the plastic base of the needle.

Aluminum sleeves:

1. Score the aluminum tubing with a sharp razor blade at 21 mm length by rolling back forth across the tubing. It should snap off easily. Remove any sharp burrs and ream out the end with a sharp needle or small pick that fits inside the tubing.

Sensor Installation in the field

You will need:
Battery powered drill
Butane powered soldering iron, solder
Heat conducting paste
Electrical tape
Aluminum shielding
Silicon sealant
Four stranded, shielded cable with copper wires, 22 gauge or lower
Wire cutters
Small paint scraper
Small pick to insert aluminum sleeves

1. Position the location for sap flow measurement as described below. Use the paint scraper to scrape off the bark carefully in a ~3 cm diameter area until the cork cambium is reached – the spongy layer under the bark. Do not disturb the xylem. Do the same in a second location 10 – 15 cm below the first.
2. Using a 3/32 size drill bit, drill a hole 2.5 mm in diameter and 22 mm long into the 1st area of scraped bark. Drill straight in towards the center of the trunk. Using a 3/64 size drill bit, drill a second hole 2 mm in diameter and 22 mm long into the lower area of scraped bark.
3. Insert the aluminum sleeve into the upper hole with a small pick or very small screwdriver that fits into the sleeve. The sleeve should go in all the way until the end is flush with the outer xylem.
4. Dip a heated sensor in heat conducting paste and insert it very slowly into the sleeve all the way. Be very careful in this step as it is easy to scrape the heater coil and damage the sensor. Wipe off excess paste.
5. Insert a reference sensor directly into the lower drill hole.

6. To wire the sensors, twist the upper and lower constantan (red) wires together. Tie a length of 4 stranded cable long enough to reach the datalogger to the trunk (so that if someone trips on the cable they will not pull directly on the connections). Connect the 4 stranded cable to the sensors as follows:

   Heater wire to red
   Heater wire to black
   Upper copper (blue) wire to green
   Lower copper (blue) wire to white

7. Solder all the joints and cover them in electrical tape to avoid shorts.
8. Shield the sensors as described below.

Notes on sensor placement and shielding:

- The best place to measure sap flow is just under the canopy but this is often not feasible. On tall canopies it is common to place all sensors at breast height (1.4 m from the ground). Do not place them closer to the ground due to problems with thermal gradients from the soil.
- Sap flow may vary both axially around the tree and radially within the xylem. If sapwood is very deep (4 cm or more) it is advisable to measure all of the relevant depths, for instance 0 - 2 cm and 2 - 4 cm. The instructions above are for the 0 – 2 cm depths only but they may be easily adapted for radial measurements.
- Axially, you must either account for differences in sensor placement, for instance the north vs. south side of the tree, by sampling both and testing for differences, or by randomly placing the sensors axially and averaging out these differences. If the goal is to scale sap flux to the stand level, don't place the sensors in only one axial direction, e.g. the north side of all trees, or the values will be biased.
- The sensors should be shielded from radiation with reflective material. Aluminum bubble wrap wrapped all the way around the tree can work well to minimize thermal gradients, but in humid areas this may create problems with fungal growth (and critters!). Disposable aluminum baking pans are an inexpensive solution that allows air flow – they must be sealed at the top with silicon sealant to prevent water from seeping onto the heated sensor during rain events, but otherwise they can remain unsealed.

Wiring the datalogger and power supplies:

- This is a constant heat method that requires that 0.2 W of power be delivered to the sensors. A circuit diagram and parts list for a power controller to do this is attached. This particular design controls 3 sensors on one circuit but this can modified. Be sure to group sensors of similar heater coil resistance, R_{coil} (the resistance you wrote on the base of the sensor) together on one power controller.

- On the datalogger end, the multiplexer should be set for differential measurements. Green is wired to H and white to L. The red and black wires are connected to the power controllers. Since you already know R_{coil} you can use Ohm's law to calculate the correct current that will deliver 0.2 W to the sensors:

  current = sqrt(0.2 W/R_{coil})

  Note: to adjust the current at the power controllers you need to account for the resistance of the cables going from the power controllers to the tree. Use the relationship voltage = current*resistance to set the correct voltage with the variable resistor on the power controller. In this case the resistance is the total resistance measured across the sensors + cables.
- Because the power is always on, you may program the datalogger to sample frequently and then average over some time interval. Sampling every 30 seconds and averaging over 30 minutes is common.
- To troubleshoot the system, refer to the attached trouble shooting guide
- To calculate sap flow from logged millivolt difference, a nice piece of software has been written by Yavor Parashkevov at Duke University. Currently, this program (called "Baseliner") runs only on PC's but a Mac version may eventually be available: contact Yavor at yavor@duke.edu. In the Ehleringer Lab a version of Baseliner is available on the PC in the Bellows room. Follows its help function to learn how to use it.

References

Clearwater MJ, Meinzer FC, Andrade JL, Goldstein G, Holbrook NM. 1999. Potential errors in measurement of nonuniform sap flow using heat dissipation probes. Tree Phys. 19:681-687.

Granier A. 1985. Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres. Ann. Sci. For. 42: 193-200.

Granier A. 1987. Evaluation of transpiration in a Douglas-fir stand by means of sap flow measurements. Tree Phys. 3: 309-320.