Development of the Backpack Ratiometer for measuring CO_2 and O_2 in the field

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Climate models used to calculate how much carbon the landmasses can sequester each year are constantly getting better. However, a large amount of the research that has gone into creating these models has been conducted in a laboratory setting where the environment is well-controlled. This is great for data collection but hinders the ability to model the real world. Plants consume and produce both CO_2 and O_2, but the specific ratios for which they do so in nature, where conditions are unstable, is less well-known. Each plant at different ages and different times of year will consume and produce gases at different rates, and this information is crucial to develop better climate models.

To measure the O_2:CO_2 exchange ratio around a plant outdoors with the necessary precision, a mobile CO_2/O_2 analyzer must be carefully constructed. It must be light enough to carry around to remote areas, draw relatively little power to operate on batteries for hours, and control gas flow rates, analyzer cell pressure, and water content. The final system developed this summer is shown below.

Flows were matched by using the Alicat Mass Flow Controllers and pressures were passively controlled by making plumbing as symmetric as possible between the two sides of the system. The active flow control was deemed necessary after passive flow and pressure control failed in many tests. By controlling the flows, the pressures were balanced. To control the water content, there were two options. The first was to chemically dry the air using magnesium perchlorate traps shown below, which work almost as soon as the system is powered on. However, this chemical is reactive and consumable which places additional constraints on the operation and maintenance of the ratiometer and was used mainly out of convenience.

The other option is a special kind of tubing called Nafion, which allows for the unidirectional passage of water. In the most basic sense, the tubing is made of a tube within a tube, with the inner formed of Nafion allowing water to pass from the inner stream to the outer stream. The air is dried as it passes through the inner tube, then through the analyzers, and then is routed back through the outer tube where it is used to dry the inner air – a process known as reflux. As the process continues, the air passing through the cells grows drier which increases the gradient in the Nafion causing the extraction of water to happen faster until a critical value is reached. Much of the research earlier in the summer was focused on characterizing the Nafion's drying capabilities and impact on gas composition. During these trials, it became clear that the LI7000 needed internal maintenance and the Oxzilla required new fuel cells (the O_2 sensors) all of which had been impacting readings. The systems then needed recalibration and testing redone. Nafion has no significant impact on CO_2, and O_2 testing was inconclusive but promising. However, it takes about 3 hours before the water content reached a stable lower limit from 100% relative humidity. This means the mobile system will have roughly 3 hours of runtime before useful data can be collected, providing a convincing argument for chemical drying even with its limitations.

The fuel cells in the Oxzilla consume oxygen for analysis, so placing the LI7000 downstream of it could have posed a problem. To see how much oxygen the cells consume, extra parts had to be machined to seal the mounts where the cells attach into the Oxzilla, and dry gas was carefully split into two streams and passed through the Oxzilla into the LI7000 with one cell mounted and the other blocked off. If CO_2 was noticeably different, the LI7000 would have to be upstream of the Oxzilla, but it was not. The only reason this is done is to balance pressures between the cells in the machines. Matched flow rates and venting cells to the open air or through symmetrical plumbing means the pressure should theoretically be equal. The internal plumbing in the LI7000 is simpler than the Oxzilla, so it is best placed downstream.

With indoor testing complete and having produced promising results, outdoor testing began. During the day, it is expected that CO_2 levels are lower and O_2 levels are higher near a plant relative to ambient air. Testing showed an increase in both CO_2 and O_2 near grass and trees, which made little sense, so more indoor tests were conducted with a human in a closet as a makeshift respiration chamber and a leaf in a cuvette with a greenhouse lamp, both of which showed near perfect results. The Respiration Exchange Ratio of the respiration chamber was about 0.82, where 0.80 is considered average, and the RER for the leaf was about 1.13, which should be close to 1. The outdoor results were found to be due to poor water control.

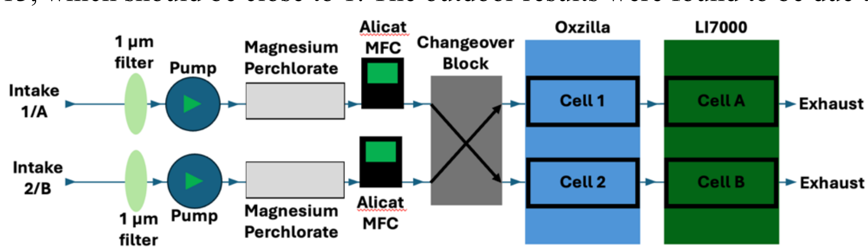

Figure 1: final ratiometer configuration.

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