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Development of Low Cost Pressure Chamber Instrument for Leaf Water Potential

K. Mohan Kumar[1], V. Guru Lokesh[2], S. R. Daamodaran[3], S. Indhirajeeth[4], M. Deepan Christo[5]
[1]*Assistant Professor, Dept. of Mechanical Engg., Sri Shakthi Institute of Engg. and Tech., Coimbatore, India*
[2,3,4,5]*UG Student, Dept. of Mechanical Engg., Sri Shakthi Institute of Engg. and Tech., Coimbatore, India*

***Abstract*: The project aims in developing a low cost pressure chamber instrument for calculating the leaf water potential in plants. The leaf water measures are reference measures used for estimating the water status or content in the leaves. The pressure chamber instrument is a typical air tight container with minutes opening for the petiole of leaf to project out for water to ooze out. The apparatus is widely used in agricultural fields and laboratories to study water potential of the plants. The cost of the setup is around 2000-3000 USD (approx.). The outcomes of low cost pressure chamber instrument revise the cost of the instrument up to 25000 INR and providing stable use.**

***Keywords*: Leaf water potential, Pressure chamber instrument.**

1. Introduction

A relatively quick method for estimating the water potential of large pieces of tissues, such as leaves and small shoots, is by use of the pressure chamber. This method was pioneered by Henry Dixon at Trinity College, Dublin, at the beginning of the twentieth century, but it did not come into widespread use until P. Scholander at the Scripps Institution of Oceanography improved the instrument design and showed its practical use.
The organ to be measured is excised from the plant and is sealed in a pressure chamber with the cut edge (a petiole in the case of a broad-leaf) protruding out. Before excision, the water column in the xylem is under tension. When the water column is broken by excision of the organ, water is pulled rapidly from the xylem into the surrounding living cells under the gradient of water potential existing between cells and xylem. The chamber is then pressurizes with compressed gas until the distribution of water between the living cells and the xylem conduits is returned to its initial, pre-excision, state. This can be detected visually by observing when the water returns to the open ends of the xylem conduits that can be seen in the cut surface. The pressure needed to bring the water back to its initial distribution is called the balance pressure. It is equated with whole leaf water potential.

2. Early-models

A. Scholander pressure bomb

The early model devised by Scholander was known as pressure bomb or Scholander bomb, it is simple apparatus for measuring small section of leaves. The design was like Bi-cycle pump used in olden days. The leaves were mounted in a rectangular cross sectioned container with air tight seals. The air was compressed through a diaphragm type pump mounted with handles.

B. Pressure Chamber instrument versus other methods

The pressure chamber method is a relatively easiest and ergonomic method to determine water potential in plants. As, this method serves as error-free measurement. When compared with other methods this procedure doesn’t require temperature measurement for determining the leaf characteristics. The cost of the equipment is relatively low and involves a simple setup procedure.

3. Methodology

A. Working of Pressure Chamber Instrument

A pressure bomb or pressure chamber or ‘Scholander’ bomb is an instrument that can measure the approximate water potential of plant tissues. A leaf and petiole or stem segment is placed inside a sealed chamber. Pressurized gas (normally compressed nitrogen) is slowly added to the chamber. As the pressure increases at some point the liquid contents of the sample will be forced out of the xylem and will be visible at the cut end of the stem or petiole. The pressure that is required to do so is equal and opposite to the water potential of the sample (Ψ leaf or Ψ total). Pressure bombs are field portable and mechanically simple, which make them the predominant method for water potential measurements in the fields of plant physiology and ecophysiology. Several water potential variables can be determined using the pressure bomb analysis. The most common of which are predawn leaf water potential and midday leaf water potential.

In simplest terms, the pressure chamber can be thought of as measuring the "blood pressure" of a plant, except for plants it is water rather than blood, and the water is not pumped by a heart using pressure, but rather pulled with a suction force as water evaporates from the leaves. Water within the plant mainly moves through very small interconnected cells, collectively called xylem, which are essentially a network of pipes carrying water from the roots to the leaves. The current model of how this works is that the water in the xylem is under tension, and as the soil dries, or for some other reason the roots become unable to keep pace with evaporation from the leaves, then the tension increases. Under these conditions you could say that the plant begins to experience "high blood pressure."

Simply put, the pressure chamber is just a device for applying air pressure to a leaf (or small shoot), where most of the leaf is inside the chamber but a small part of the leaf stem (the petiole) is exposed to the outside of the chamber through a seal. The amount of pressure that it takes to cause water to appear at the petiole tells you how much tension the leaf is experiencing on its water: a high value of pressure means a high value of tension and a high degree of water stress. The units of pressure most commonly used are the Bar and the Mega Pascal. Because tension is measured, negative values are typically reported. An easy way to remember this is to think of water stress as a "deficit:" the more the stress, the more the plant is experiencing a deficit of water. The scientific name given to this deficit is the "water potential" of the plant. The actual physics of how the water moves from the leaf within the pressure chamber to the cut surface just outside the chamber is more complex than just "squeezing" water out of a leaf, or just bringing water back to where it was when the leaf was cut. In practice, however, the only important factor is for the operator to recognize when water just begins to appear at the cut end of the petiole.

4. Design

A. Parameters considered for design

- Average length of leaves in Southern Indian Regions.
- Measurement reading ranges (minimum to maximum) for designing the chamber capacity.
- Aesthetics and portability for field carriage and use at site.

B. Dimensions of the Pressure vessel.

The average size of the leaves ranges between 70mm to 160mm, the chamber was designed on the leaf enclosure capacity. Use of circular type chamber ensures easy air sealing and fixing for leaves and also eliminates the use of grooves to lock.

Length - 170mm
Diameter – 85mm
Wall thickness – 15mm
Leaf nut length- 45mm
Leaf nut diameter – 55mm
Petiole projection hole – 3mm.

C. Capacity characteristics of pressure chamber

Maximum pressure capacity – 42 bar.
Maximum length leaf (including petiole size) - 210 mm.

5. Materials and manufacturing methods

A. List of components used.

- Aluminium 6061 cylindrical workpiece
- Circular O- rings.
- Rubber gland gaskets
- 1/4 inch diameter rubber hose
- Air flow regulator
- Pressure gauge
- Nitrogen gas tank.
- Magnifying glass
- Aluminium foil bags

B. Properties of materials

1) Aluminium 6061

6061 is a precipitation- hardened alloy with contents of magnesium and silicon.

Density ρ – 2.70 g/cm$^{3.}$
Young's Modulus – 68.9 GPa
Tensile strength – 124-290 MPa
Melting temperature T_m – 585^o C
Thermal Conductivity k – 151-202 W/m.K
Specific heat capacity – 897 J/kg.K

2) Dry nitrogen gas N2

State – gaseous at 20^o C
Colour – colourless
Density – 0.001165 gm/cc
Melting point – -209.86^o C
Boiling point – -195.8^o C
Specific heat – 1.040 J/g/ ^{o}C
Vapour pressure – 101.325kPa

Since, the nitrogen gas is inert in nature and does not affect the leaf characteristics nitrogen gas is widely preferred over other gases.

Table 1
A. Bill of materials for pressure chamber instrument

No.	Components	Size	Quantity No.
1	Pressure chamber	Dia=85mm Length=170mm Thickness=15mm	01
2	Nitrogen gas tank	2.24kg, 130 bar	01
3	Pressure gauge	0-70 bar	01
4	Pressure regulator	$^1/_4$ inch hose fit	01
5	Control valve	$^1/_4$ inch hose fit	01
6	Rubber gland gaskets	1mm, 2mm, 3mm	03
7	Circular O- rings	85mm diametric	02
8	Aluminum foil bags		05
9	Magnifying glass		01

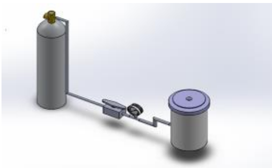

Fig. 1. CAD model of pressure chamber instrument in Solid works

Fig. 2. Pressure chamber instrument with leaf mounted.

Table 2
Cost estimation data

S. No.	Specification	Cost/ Size	Quantity (No's)	Cost (Rs.)
1	Aluminium 6061 cylinder rod	200/kg	11	2200
2	Pressure gauge		1	450
3	Nitrogen tank	2.24 kgs	1	9800
4	Valve fittings	Cga 580	1	800
5	Hose	1 meter	1	200
6	Rubber O-rings	85mm	2	110
7	Leaf gland gaskets	42mm dia	1	30
8	Teflon windings	100roll tapes	2	100
9	Silica gel		1	210
10	Labour charges	150/hour	12 hours(appr)	1800
11	Machining charges	$^1/_4$ ISO drill bits, 3mm drill	2	80
12	Magnifying glass		1	30
13	Nitrogen gas filling	180/kg	2.24	403
	Total			**16,213 INR**

Fig. 3. Fully assembled apparatus

6. Conclusion

Thus the concept of low cost pressure chamber instrument to find the leaf water potential in plants was manufactured with optimum available resources using the conventional machining processes and was validated with Tamilnadu Agricultural University (TNAU), Coimbatore.

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