"Weighing" a Gas with Microwaves and Sound, I. Measuring the Volume with Microwaves

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NIST calibrates gas flow meters with ranges up to 2000 L/min by generating a steady flow through the meter under test and then diverting the downstream flow into a carefully thermostatted, 0.677 m^3 collection tank for a measured time. The quantity of gas collected is measured with an uncertainty of 0.013 % using the gas's equation of state, measurements of the temperature and pressure, and the volume of the thermostatted tank. For larger range flow meters it would be simpler and faster to calibrate them by using a larger thermostatted, collection tank (for example, 10 m^3). However thermostatting such a tank is expensive. The present work shows that we can accurately determine the volume of gas within a large, off-the-shelf, commercially manufactured, un-thermostatted tank. Using microwave techniques that are scalable to very large volumes, we measured the interior volume of a 0.3 m^3, commercially manufactured pressure vessel with a relative uncertainty of 0.06 %, as confirmed by independent, more-accurate gas-expansion measurements. This pressure vessel (or a much larger one of a similar design) could be used as either a calibrated volume standard or as a gas source and/or a gas collector for the calibration of gas-flow meters. In addition, we determined the expansion of the vessel with temperature $(\partial V/\partial T)_p/V = (35.3 \pm 1.9)10^{-6}\ K^{-1}$, and we estimated the pressure expansion $(\partial V/\partial p)_T/V = 0.9 \cdot 10^{-3}\ MPa^{-1}$. The volume measurement did not require careful thermostatting; its uncertainty was dominated by imperfect modeling of the volume's shape.