Recovery and Purification of ^{3}He Gas from Pulmonary MRI

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Introduction

Hyperpolarized ^{3}He has become the gold standard for characterizing emphysema and provides valuable information about ventilation uniformity and oxygen distribution [1-3]. Due to a recent shortage, ^{3}He gas has increased in price over four-fold and is often unavailable. The price of ^{3}He is now a primary contributor to the overall cost of performing lung MR experiments. In order to reduce this cost, and allow for continued scientific progress in the field, it has been proposed that ^{3}He be widely recaptured and purified, so that it can be reused for future lung MR experiments [4]. It has been shown that recycled ^{3}He, purified by methods similar to those described here, provides magnetization equivalent to ^{3}He purchased from gas providers [5,6]. Helium can be recaptured by diverting the exhaled gas into a flexible capture bag, recompressing for temporary storage if needed, and transporting to the purification site. N_2 and O_2, in addition to other atmospheric and exhaled contaminants, can be removed by exposing the gas to a highly adsorbent material at cryogenic temperatures. Here we describe a simple device for recovering and purifying the ^{3}He gas, using cryostatic separation and gas adsorption at 77K, with subsequent cryostatic recompression. Such a device can easily be used to provide ^{3}He for animal experiments.

Materials and Methods

Recapture: For small animal lung imaging, instead of releasing the exhaled gas to atmosphere, the exhale port is connected to a 60 L impermeable bag (Hans Rudolph, Kansas City, MO). As long as the volume of gas is significantly less than the capacity of the bag, the backpressure has insignificant effects on breathing patterns. For human lung imaging, the patient exhales through the same mouthpiece through which the ^{3}He was inhaled; a series of one-way valves redirects the exhaled gas through a bacterial filter and into a collection bag of approximately 60 L, allowing for multiple exhales to be captured after each imaging experiment.

Purification: In order to separate the ^{3}He from the much larger quantity of other exhaled gases, 0.4 kg of activated carbon were placed in stainless steel tubing (the charcoal trap), which was submerged in a 4 L flask of liquid nitrogen. The recaptured gas first passes through a cold trap so the H_2O and CO_2 are frozen out at 77 K. The gas then flows into the charcoal trap, where the N_2, O_2, and Ar are adsorbed, resulting in purified ^{3}He. The gas is pulled through the traps with a scroll pump and collected in a low-pressure (10 atm max) cylinder. Once the helium has been collected, the adsorbed gases are removed to atmosphere by evacuating the charcoal trap as it is heated to room temperature. If necessary, this purification process can be repeated to further increase the purity of the helium.

Recompression: After enough purified ^{3}He has been collected, its density can be greatly increased by being pumped into a small volume immersed in liquid ^{4}He, and then allowed to expand into a 440 cc lecture bottle as it returns to room temperature, providing room-temperature pressures of 50 to 100 atm. With the addition of a small amount of nitrogen buffer gas, the cylinder will be ready to refill Rb-glass cells used for hyperpolarization.

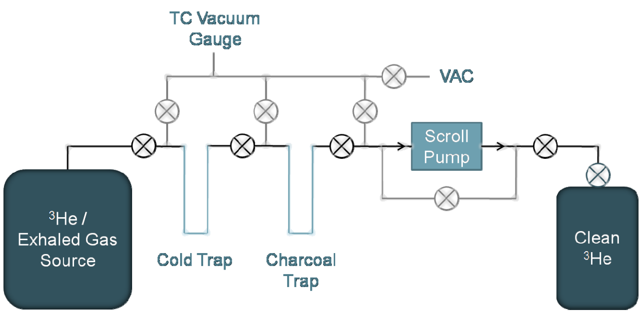

Figure 1: The system begins evacuated. The unpurified gas is exposed to the cold trap followed by the charcoal trap. The scroll pump pulls the gas through the traps and into the collection cylinder containing purified ^{3}He. After purification, the vacuum pump removes the evaporating impurities as the traps are heated.

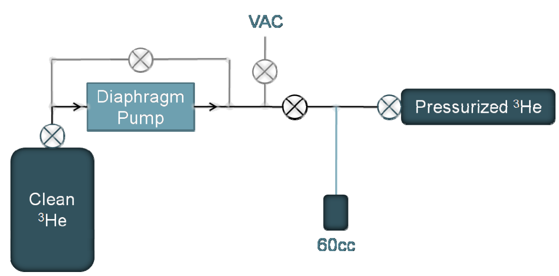

Figure 2: The system begins evacuated. The 60 cc vessel is cooled to 4 K with liquid helium. The diaphragm pump compresses the ^{3}He up to 7 atm into the vessel, where it becomes a dense supercritical fluid. The vessel is then valved off from the diaphragm pump and opened to the 440 cc pressurized ^{3}He cylinder. The vessel is then slowly heated to room temperature, causing the ^{3}He to fill the 440 cc cylinder.

Results

We tested the device with ^{4}He / exhaled gas mixtures (e.g. 0.5 L ^{4}He, 35 L exhaled gas). In all cases, the quantity of purified gas obtained was found to equal the amount of helium present in the original mixture, indicating that virtually all of the helium passes through the purification stage, with at most small levels of remaining impurities. Approximately 5 L of purified ^{3}He have been collected from exhaled gas used in lung imaging experiments, to date.

Conclusions

The recycling of ^{3}He is very feasible, even with the prototype home-built apparatus demonstrated here at 77K. A similar apparatus operating at liquid ^{4}He temperature (4K) could be more efficient. Widespread recycling of ^{3}He gas by all research groups will permit pulmonary gas imaging research to continue unhindered, and will significantly reduce the cost of performing lung MR experiments and future therapeutic, clinical drug, or device trials.

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References

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