Highly Efficient Xe-129 DNP in the Frozen State via Pellet Formation

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Introduction: Recent advancements in hyperpolarized (HP) ^{129}Xe gas-MRI technologies have enabled new approaches to probe regional structure and function of the lung parenchyma to detect pulmonary disorders [1]. Dynamic Nuclear Polarization (DNP) of ^{129}Xe has the potential for higher production rates compared to conventional optical pumping method at lower costs since it is performed in solid state at densities much higher than the gas phase [3]. Yet, Several challenges, technical and otherwise, must be overcome in order for ^{129}Xe DNP to be useful as an investigative tool for clinical applications. Earlier we had implemented a method to produce solid xenon/1-propanol/radical mixtures with an aim to polarize solid mixtures of ^{129}Xe using DNP [4]. Previous work has shown that ^{129}Xe DNP efficiency may be improved by crushing the solid sample into millimeter-sized pellets [4]. Increasing the surface area between the solid sample and liquid helium lowers the samples' intrinsic temperature by limiting overheating effects introduced by the microwave source. Here, we present an improved method for producing highly polarized ^{129}Xe solid mixtures via pellet formation that is both quick and efficient. Used in conjunction with a newly constructed NMR/DNP probe that benefits from an efficient sample insertion/extraction and more accurate temperature control, such methods yield a 2-fold increase in our polarization levels.

Methods and Materials: The new probe has a large microwave chamber, which provides more room to accommodate large samples. The top section of the probe has a sample insertion/retrieval port with a vacuum cap, large enough to insert a PEEK sample cup similar to that of the Hypersense commercial DNP polarizer or a 5-mm NMR sample tube. The port is connected to the microwave chamber using a long G10 fiber-plastic tube providing a direct sample insertion and extraction route. This tube opens to a perforated G10 (12.7 mm ID, 1.6 mm wall thickness) sleeve of the same diameter mounted on a sample pedestal at the bottom of the microwave chamber to. An insulated copper two-turn saddle-shaped NMR coil, 20 mm in diameter is mounted outside this sleeve within the microwave chamber. Three non-magnetic field-invariant resistive temperature sensors (CernoxTM, Lakeshore) were installed at different heights (one below the NMR coil, one embedded into the top plate of the microwave chamber, and one 1 cm above the chamber) to measure the temperature and monitor temperature gradients.
The ^{129}Xe sample was prepared using our improved custom-built polarized in this probe to compare polarization before and after crushing it into pellets; the sample initially was polarized in a 5 mm NMR tube (Wilmad 504-PP or 524-PP, 0.77 mm wall) and subsequently crushed into small pellets and transferred into a custom-built PEEK sample cup and reinserted into the polarizer using the Hypersense sample insertion rod. The Sample composed of 3.1 mg of Finland-acid radical (3% w) dissolved in 104 mg of 1-propanol loaded with 8.8 cm^3 of enriched xenon gas. Samples were mixed at 195 K using an ethanol/dry ice bath at 4.2 atm of Xe overpressure using our improved custom-built, hermitically sealed sample preparation manifold [5].
The NMR tube containing the sample was then transferred to a Styrofoam box and immersed in liquid nitrogen. Sample was carefully crushed with a precooled plier into 2-5 mm frozen pellets of the solid mixture. The pellets were transferred into the custom-made PEEK sample cup **(Fig. 1)** immersed in the same pool of LN2 and then transferred to the magnet. Samples were polarized at 5T field at a temperature of 1.48K for over 500 minutes. Spectra were acquired using 5 μs hard RF pulses (5°< flip angle). Data was processed using a custom code in MATLAB. After baseline adjustment, FFT, and zero-phase correction, spectra were fitted to single Gaussian line shapes, and the individual peak integrals were computed by numerical integration of the fitted lineshape. Polarization was calculated by normalizing the peak integrals by the corresponding thermally-relaxed values measured without DNP at ~1.48K temperature using the theoretical Boltzmann polarization value of a spin-1/2, $P_{th} = \tanh(hf/(2k_BT))$, where h and k_B are the Planck and Boltzmann constants respectively, f is the NMR frequency, and T is the temperature.

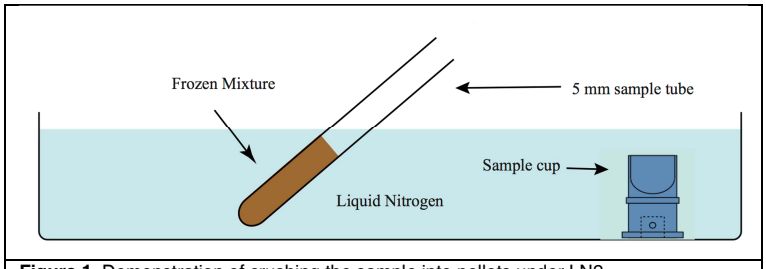

Figure 1. Demonstration of crushing the sample into pellets under LN2.

Results and Discussion: Fig 2.A shows examples of NMR hyperpolarized spectrum and magnified (5x) thermal spectrum at ~1.48K at 5T. Polarization build-up curves for the sample before and after crushing are depicted in **Fig 2.B**. Spin-up time constant increased from 131± 28 min to 161± 30 min upon crushing. A comparison between the polarization build-up curves in **Fig 2.B** indicates an increase in polarization by a factor of ~2 with pellet formation due to better liquid helium circulation around the sample as evidenced by longer spin-up times. Maximum polarizations of 10±1% and 20±3% are achieved for the 5mm and the crushed sample, respectively.

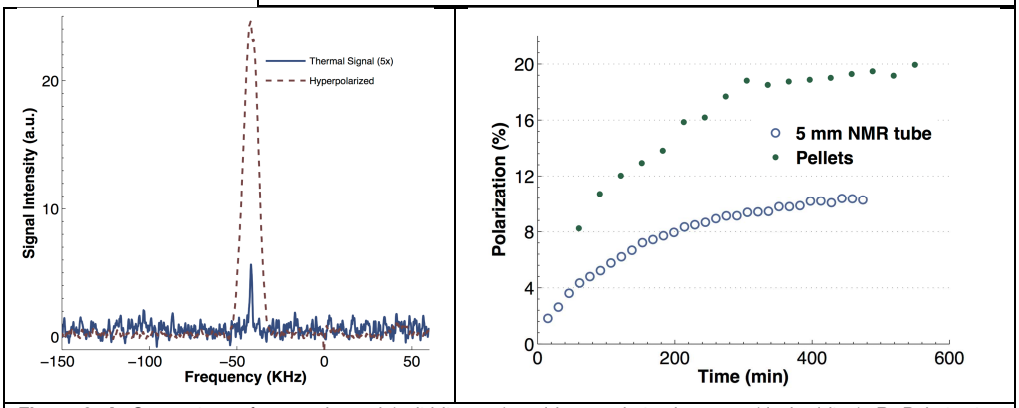

Figure 2. A. Comparison of xenon thermal (solid line, 5x) and hyperpolarized spectra (dashed line). **B.** Polarization build-up of the solid xenon mixture before (open circles) and after (filled circles) crushing.

Conclusion: Previously we demonstrated a basic method to prepare solid mixtures of gas and trityl (Finland acid) radical dissolved in 1-propanol for hyperpolarization using DNP technology. Building upon this method, we developed a technique to form sub-centimeter sized pellets of the solid mixture without loss of gas via sublimation. We have constructed a custom-made PEEK sample cup and we have simplified our sample insertion technique to insert this cup into the precooled probe in a matter of seconds. Our goal is to use the demonstrated technique and our improved probe to highly polarize larger quantities of solid ^{129}Xe and other biologically interesting gases to transport to nearby facilities without significant loss of polarization.

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References: [1] S. B. Fain, et al. *Journal of Magnetic Resonance Imaging,* vol. 25, pp. 910-923, 2007/05 2007, [2] F. W. Hersman, et al. *Academic Radiology,* vol. 15, pp. 683-692, 2008/06 2008. Z. I., [3] Cleveland, et al. *PLoS One,* vol. 5, p. e12192, 2010/08/16 2010. [4] Kuzma N.N. et al. Proc. Intl. Soc. Mag. Res. Med. 21, Utah, 2013, ID. 1925. [5] Keenan C.D. et al. Abstract No. 3596 (submitted to ISMRM 2014).