Improved Understanding on Collection of Airborne Particles by Permanent Magnetic Assembly

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Introduction

Introduction - Environmental monitoring and sample collection using magnetic force is gaining popularity in recent years. The collection applications span a wide range from microbial samples, medical treatment and air pollution particles. Most if not all the magnetic collection methods are electromagnetic-based collectors; we had developed a collector based on the permanent magnetic separation principle using fabricated permanent magnets. The initial performance of the magnetic collector was evaluated experimentally using laboratory-generated particles of varying magnetic susceptibility (Cheng et al., 2014, 2016) without knowing *a priori* the magnet performance and particle removal behavior within the system. To improve understanding of the magnetic collection mechanisms, the COMSOL® multiphysics software was used. The model results were also validated by the the experimental data. Maximum field density was theoretically and experimentally identified at the nodes of opposing polarity. Flux vector conformed to the configuration of collection matrix. The collector was found to have high collection efficiency for ferromagnetic particles greater than 40nm of the electrical mobility diameter.

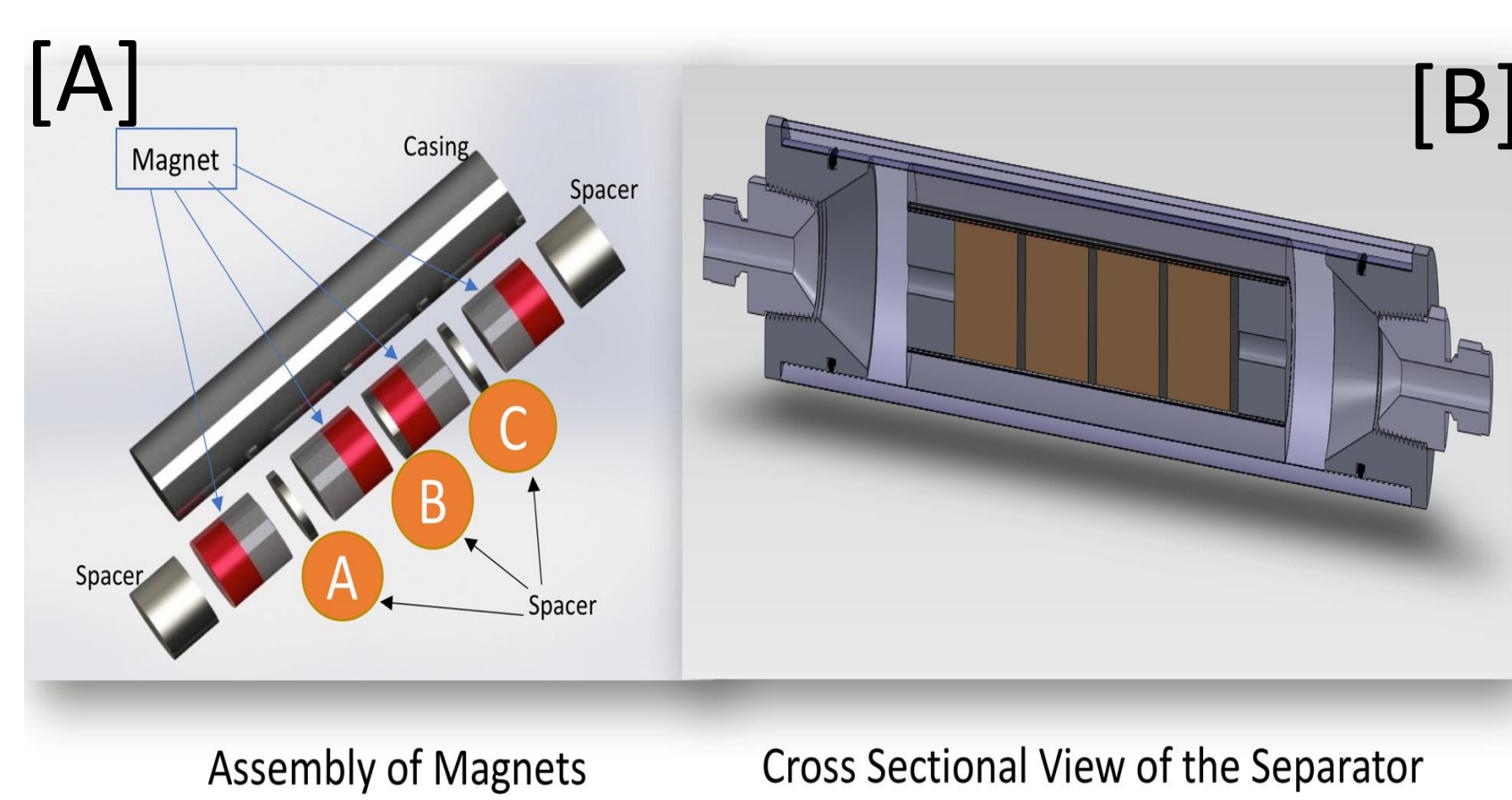## Assembly of Permanent Magnetic Collector (PMC)

Figure 1. Drawing in the panel [A] shows a 3-stage reversed polarity magnetic core using commercially available permanent magnets and the panel [B] shows the cross-sectional view of the ORNL PMC consisting of the magnetic assembly.

A.1. Computing Magnetic Field of PMC:

- Materials: NdFeB magnets (N52 class)
- Overall assembly: 6" length, 1" diameter, cylindrical geometry

- COMSOL 5.3 MFNC/ACDC module
- Solving $-\nabla \bullet (\mu_0 \nabla V_m - \mu_0 M_0) = 0$ using fine physics-based mesh
- V_m = magnetic scalar potential
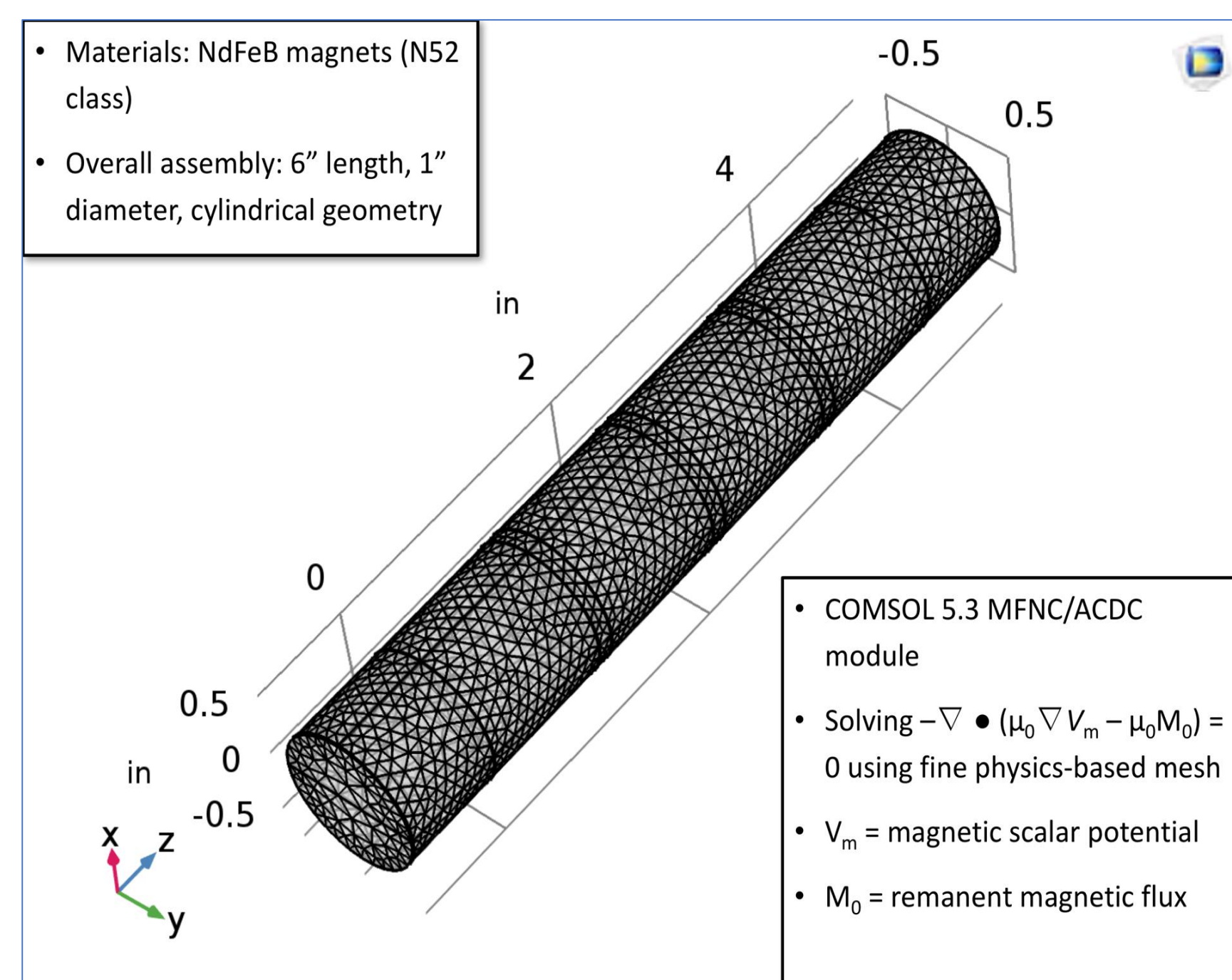- M_0 = remanent magnetic flux

Figure 2. The geometric setup of the PMC model and mesh of the modeled geometry for simulation. The magnetic field was simulated using the COMSOL ACDC no current module and the governing equation was solved by the finite-element approach.

A.2. Computational Results:

- Magnetic field strength max at the opposing poles
- Flux favors use of collection matrix positioned outside of the magnet assembly
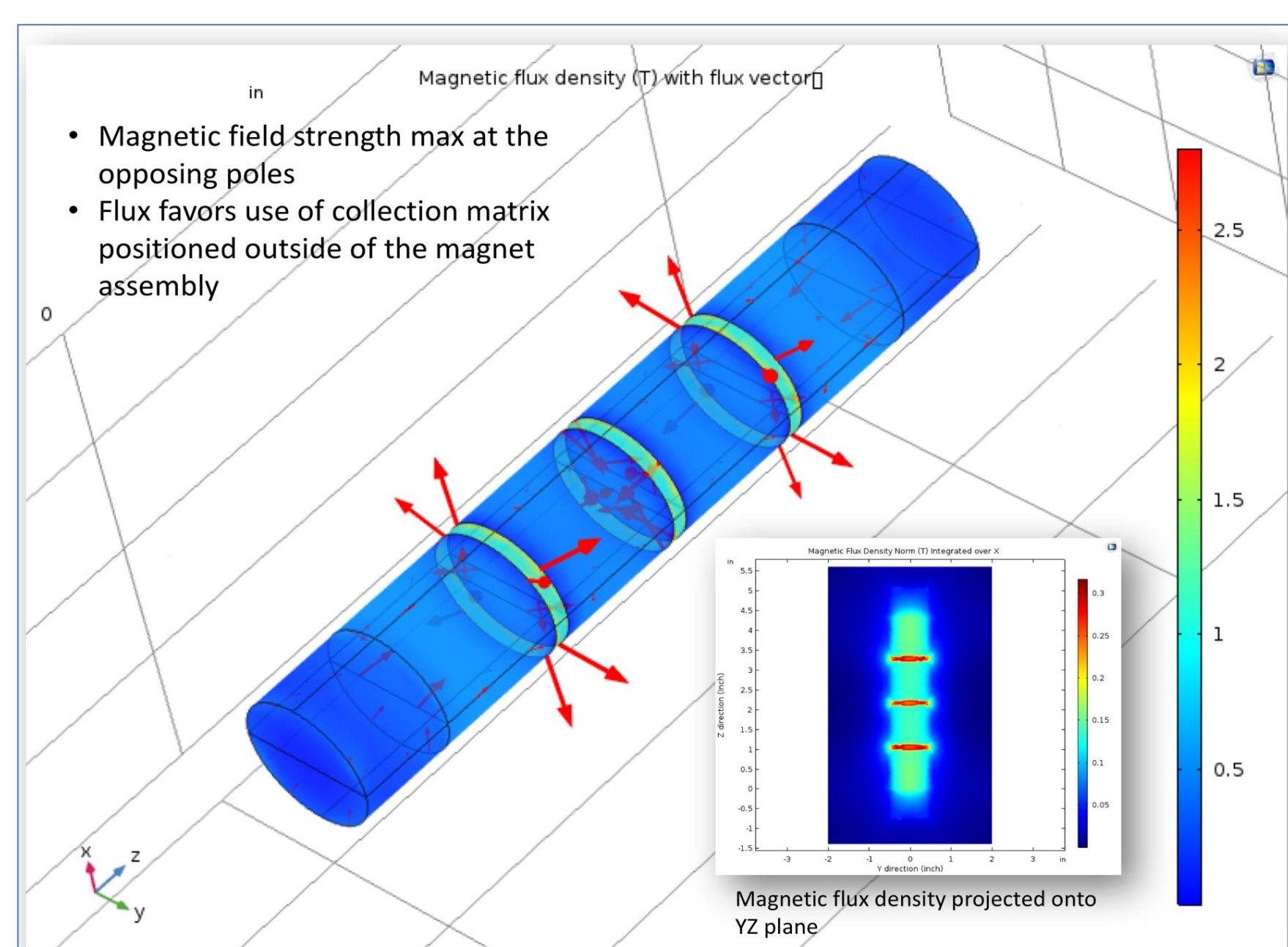
Magnetic flux projected onto YZ plane

Figure 3. The computational result for steady-state magnetic field shown above revealed the maximum flux density is located at the three nodes of reversing polarity as originally data from the Hall probe data. The field vector is oriented outward toward the collection matrix; i.e., the stainless steel wool. This conforms the initial configuration for optimal particle collection.

A.3. Validation of Computational Results:

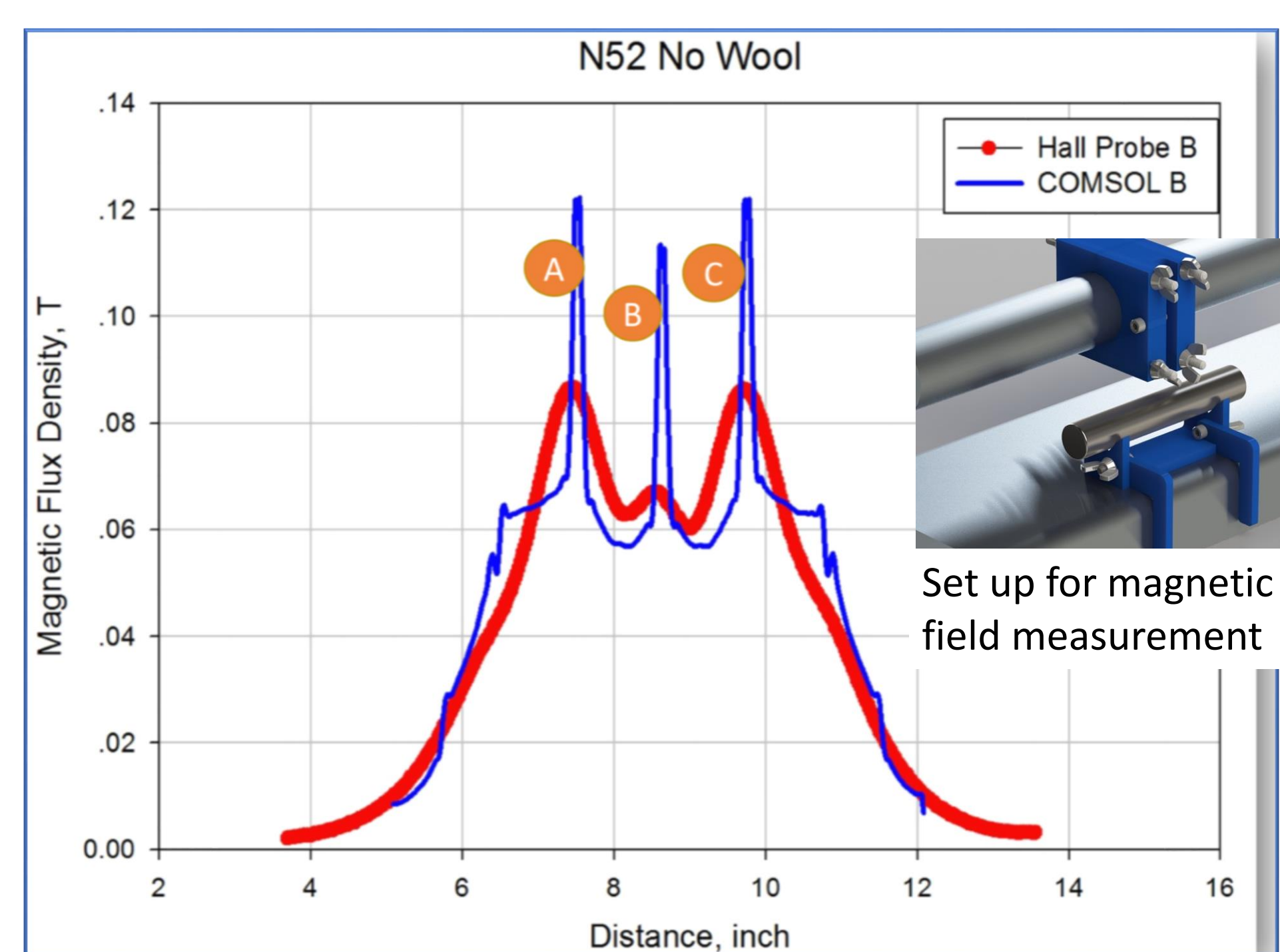Set up for magnetic field measurement

Figure 4. The above figure shows a comparison between the simulated magnetic flux density and measurements by the Hall probe (Metrolab 3-axis magnetometer THM1176). The model correctly predicted the locations of max magnetic flux density. Integrated flux density of the 3-stage assembly agreed reasonably well with the two areas under the curves different by only 5.68%. Finite precision in the probe translocation and rail movement averaged readings thereby generated spatially coarser data than the model yielded. The model predicted the max flux density at the 3 nodes were found to be 23% higher than the measurement. Since the results were for the no-wool (i.e., non-high-gradient magnetic field) condition, we expect the gradient setup would increase the flux density substantially, which is an ongoing calculation. The experimental data presented in the next section on particle capture had indirectly verified our prediction.

Airborne Particle Separation
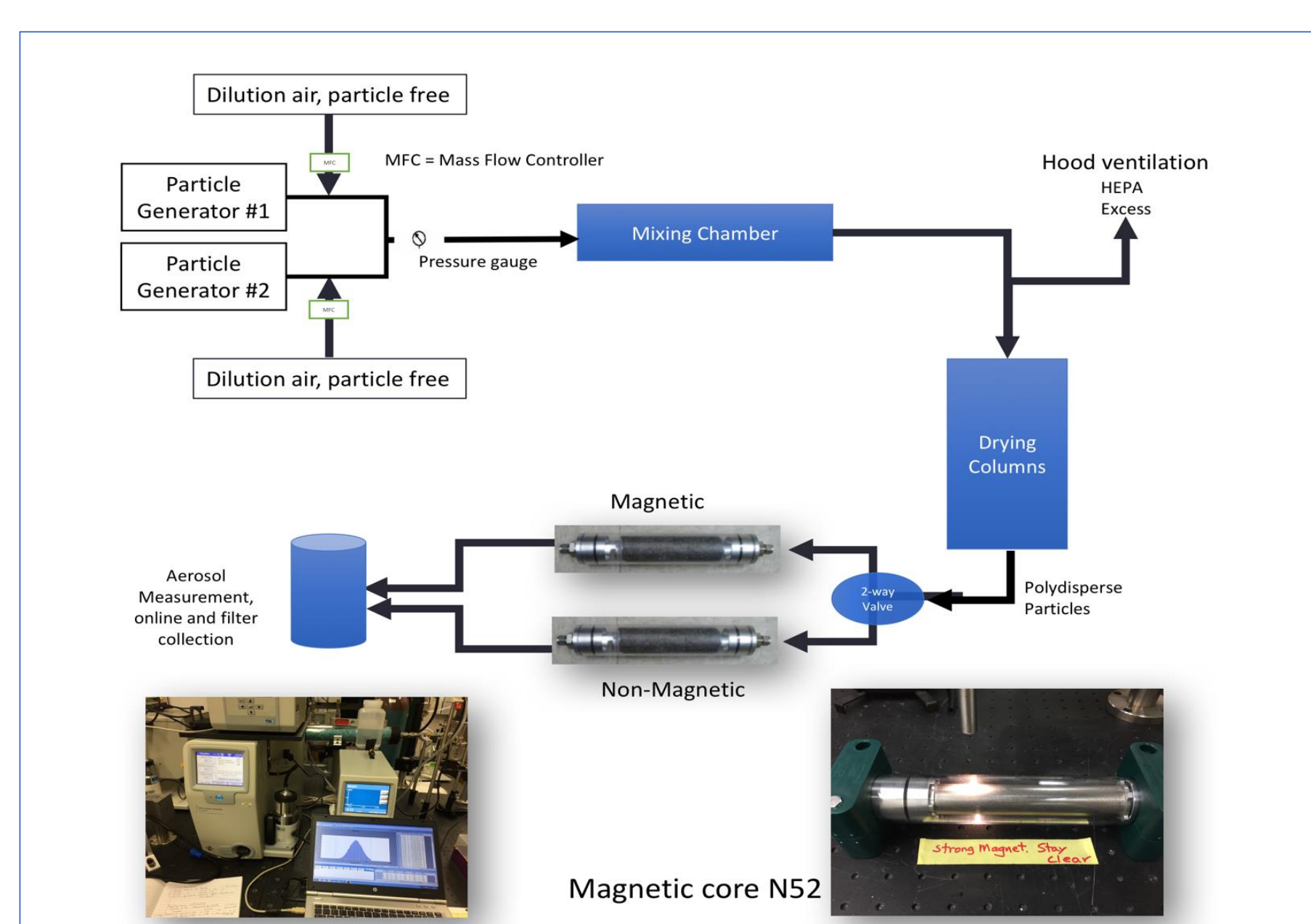## B.1. Experimental Setup:

Magnetic core N52

Figure 5. The schematic above shows the experimental setup for evaluating particle capture by the systems. Chemicals including NaCl, sucrose, Fe_3O_4, CuO, Arizona road dust and PSL were used singularly or in a mixture as the materials for generating the test particles. Not all the data were shown in this presentation due to space limitation. Depending on a run, atomization, ultrasonic vibration, electrospray, and fluidized-bed suspension were used as means for aerosol particle generator for the experiments.
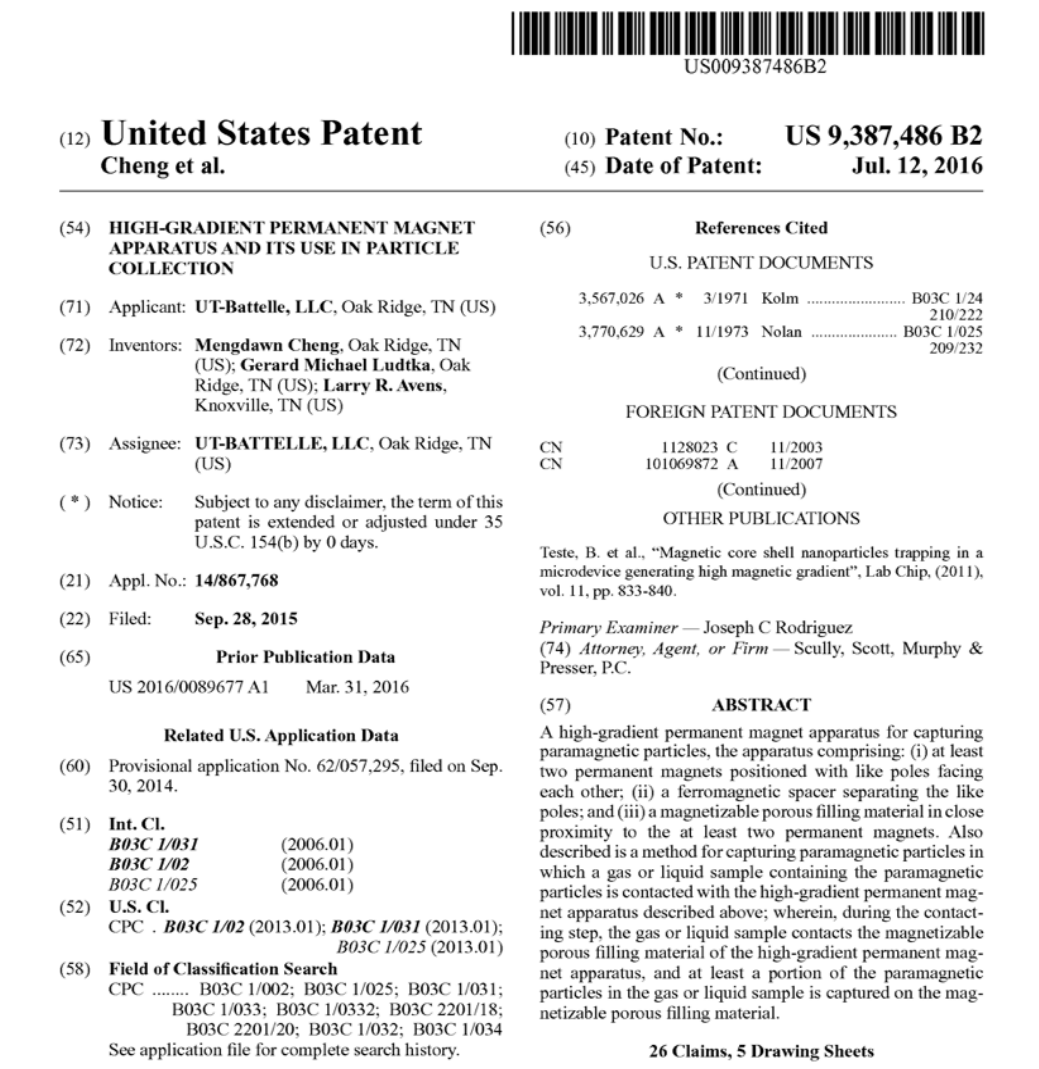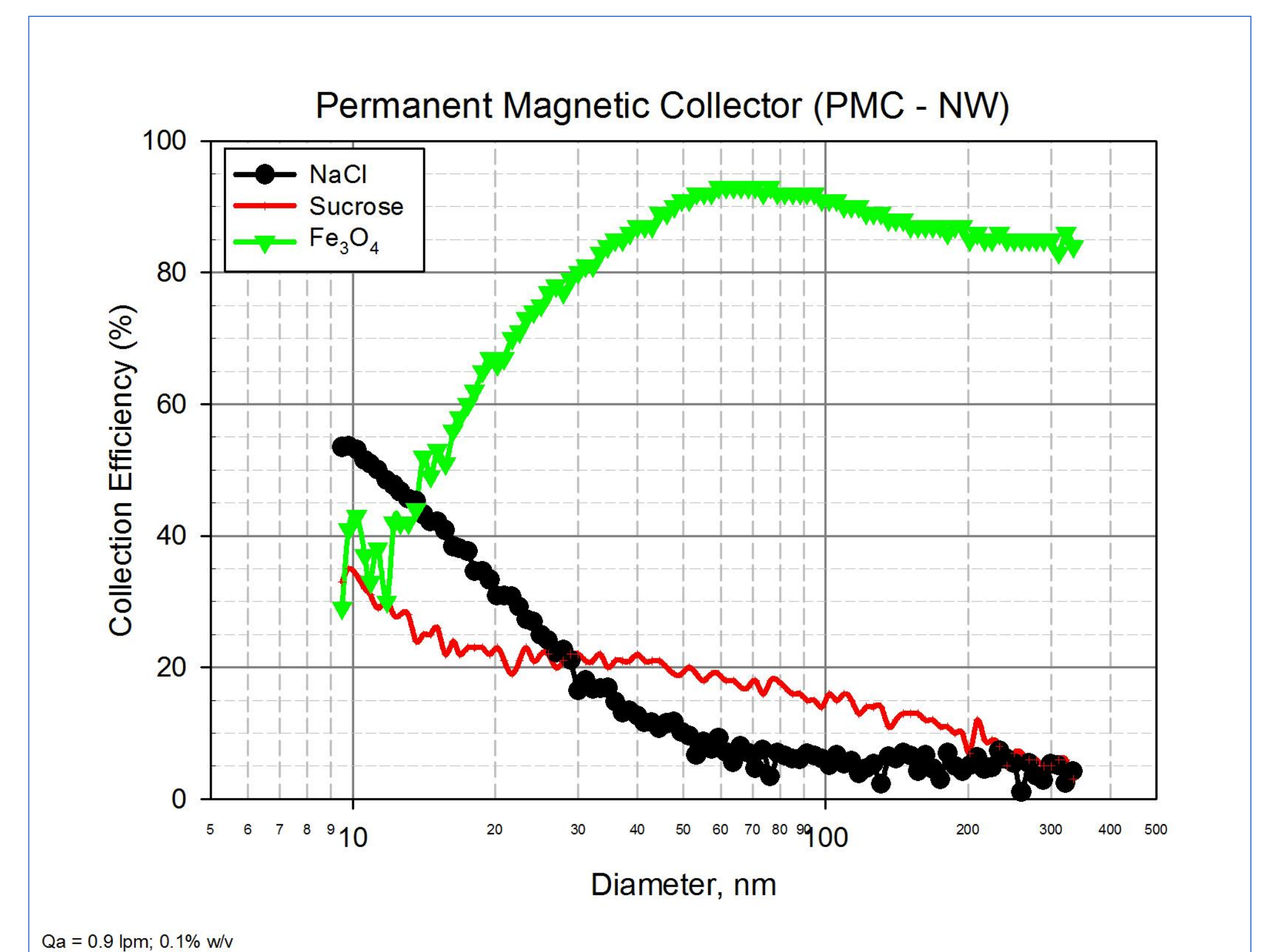
B.2. Experimental Results:

Figure 6. As expected, magnetic force showed little on the collection of weak diamagnetic (NaCl) or non-magnetic (sucrose) particles. The sucrose curve slightly decreased as the particle size increased, but the diamagnetic property of NaCl might have contributed to the enhanced collection at small size region (less than 20 nm). The ferromagnetic (Fe_3O_4) particles exhibits different collection behavior from the other two test particles. The collection efficiency increased as the Fe_3O_4 particle size increased and that efficiency reached a maximum at 50 nm then plateaued out beyond 50nm.

Conclusions:

- COMSOL ACDC (no current) module correctly predicted the location of the maximum field flux density that was at the opposing polarity nodes and verified by the Hall probe data.
- The magnitude of the field flux density integrated over the entire volume was about ±5% different from Hall probe data.
- The magnetic flux direction was identified pointing toward the collecting matrix.
- The PMC assembly was able to capture ferromagnetic particles with high efficiency.

References:

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- Cheng, M.-D., et al. (2016) US Patent #9,387,486
- ACDC user manual, COMSOL, Inc.
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