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Coupling Finite Element and Finite Volume Simulation Within MOOSE

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Changing the World's Energy Future

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Coupling Finite Element and Finite Volume Simulation Within MOOSE

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This work focuses on adding capability to couple finite element (FE) variables into finite volume (FV) physics within INL's Multiphysics Object-Oriented Simulation Environment (MOOSE). This coupling can allow for improvement of multiphysics simulations where one set of physics is best suited for an FE discretization, while another set is best suited for an FV discretization. Electrohydrodynamics, which govern liquid metal reactor concepts and plasma dynamics, is a fitting example where the electromagnetic field equations are solved with FE and the fluid flow is solved with FV. The new FE to FV coupling method can be summarized as taking the element or face average of the FE variable value or gradient and applying that quantity directly in the FV equation objects.

A common way to validate code is the uses of the method of manufactured solutions (MMS). With MMS, the user picks a known solution and derives a set of initial conditions and source terms. These initial conditions and source terms are then supplied to the user's code. Those results are then compared to the manufactured solution to assure reasonable errors.

One can further verify their code by conducting a convergence study. Within a convergence study, one increases the mesh size of the problem and tracks the error run. For a given variable order, there is a predicted slope between mesh size and error.

The first set of MMS studies focused on coupling FE variable into FV equations. For FV problems, there are two sets of terms: terms focused on the centroid of the element (FVElementalKernel) and terms focused on the boundary of elements (FVFluxKernel). The user might want to couple a FE value in either a FVElementalKernel / FVFluxKernel, or couple a FE gradient in FVFluxKernel. This leads to the following cases where is the FV variable and is the FE variable:

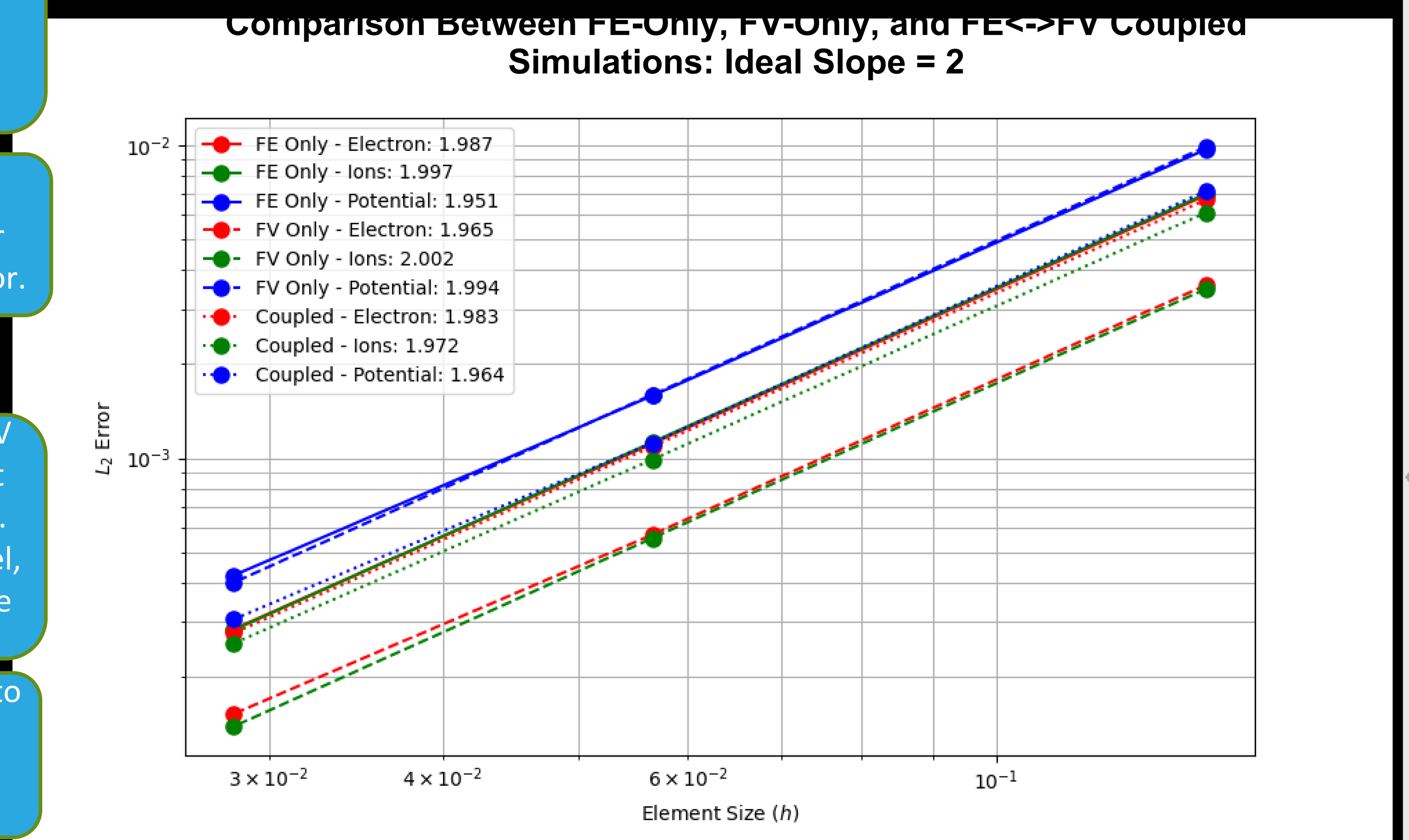
Case 1: FE value to a FVElementalKernel

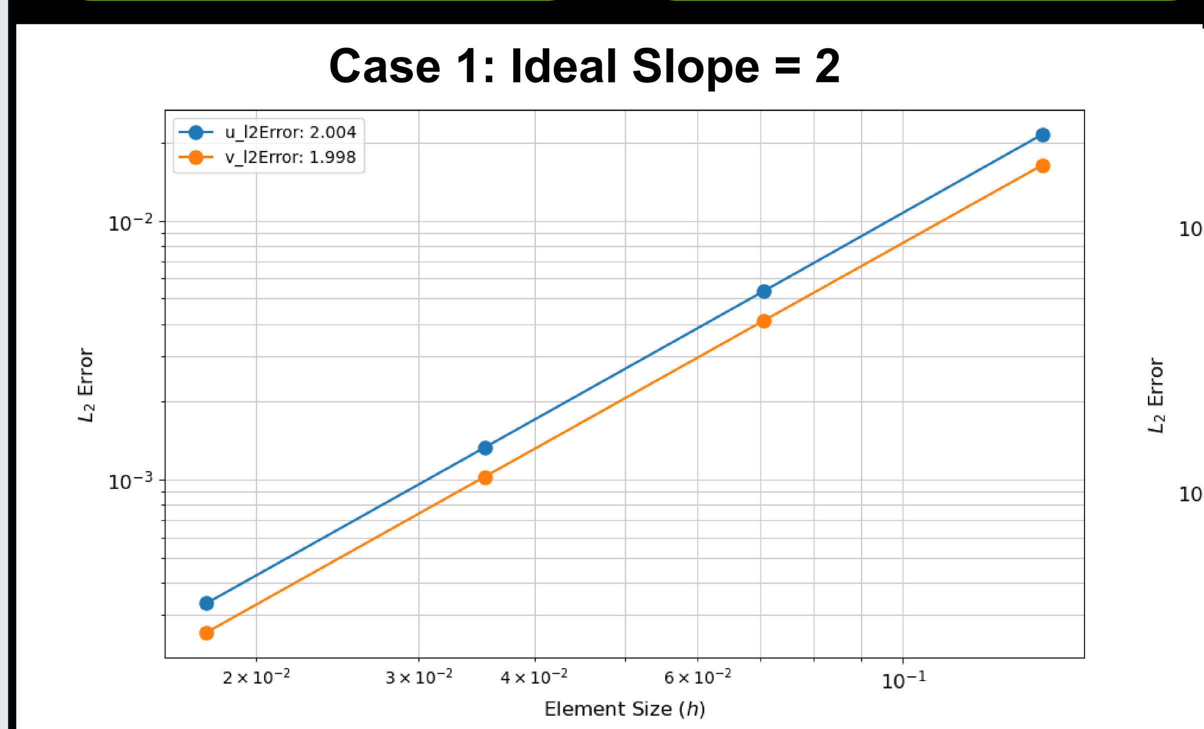
Case 2: FE value to a FVFluxKernel

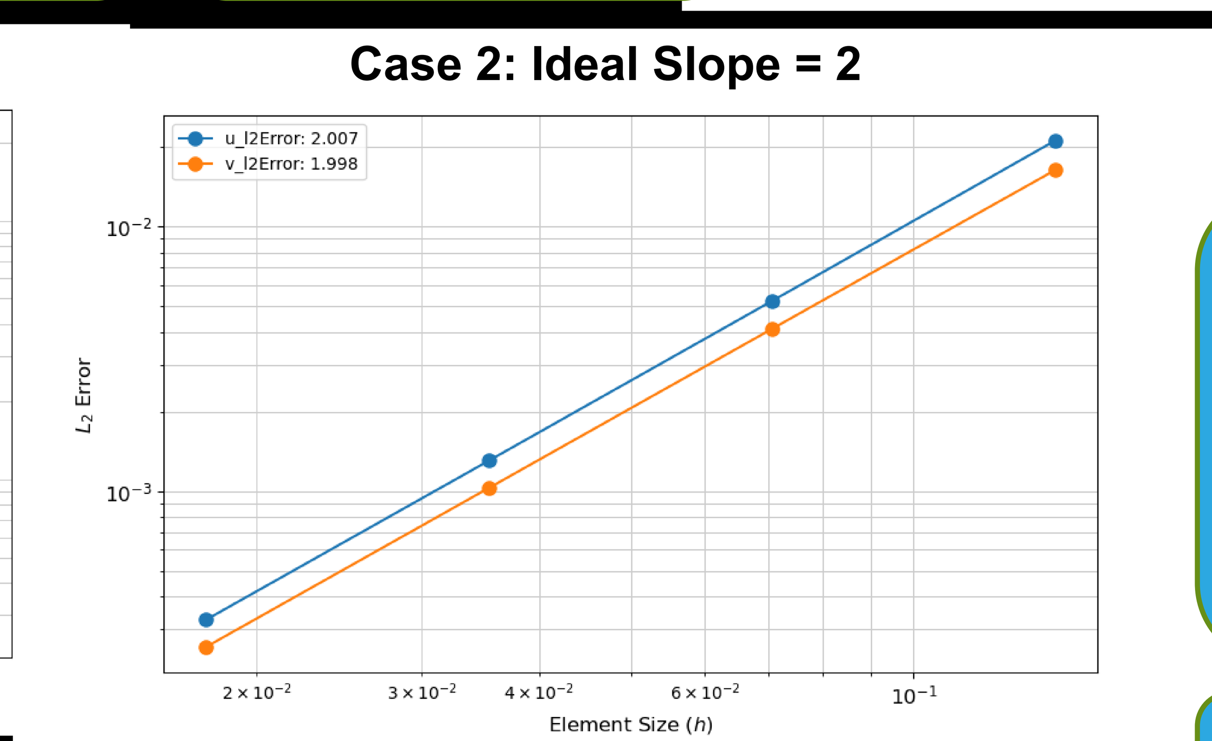
Case 3: FE gradient to a FVFluxKernel

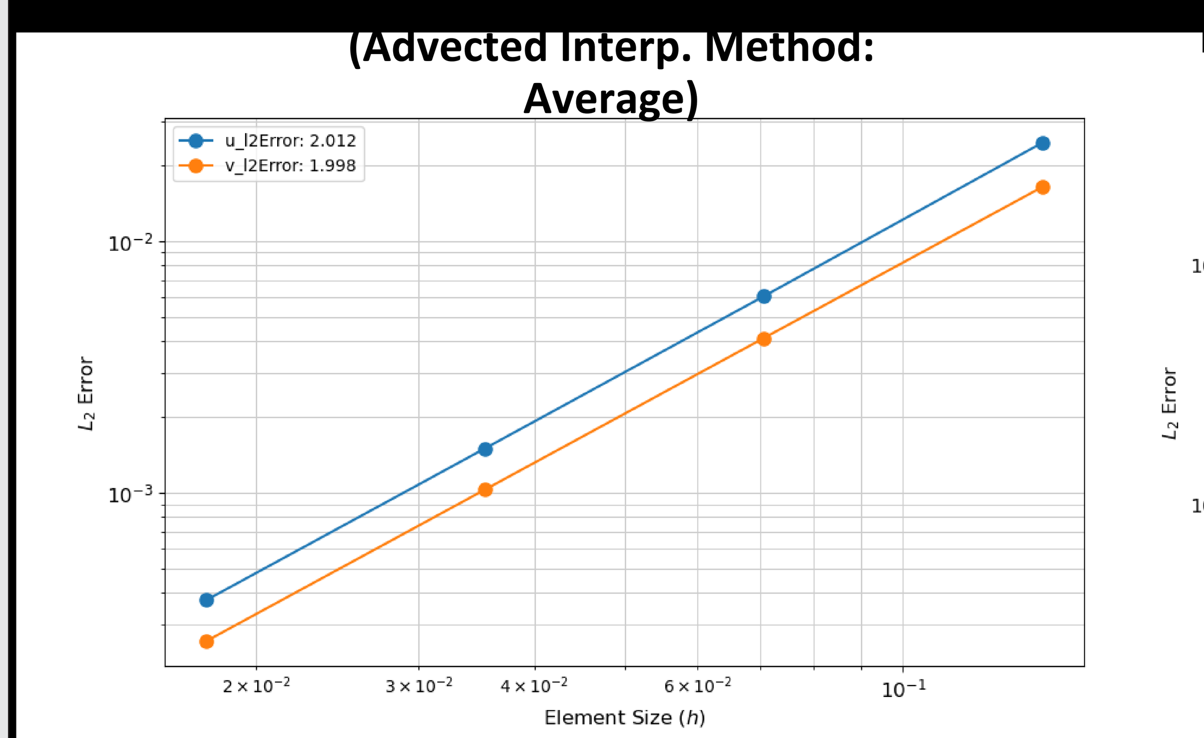
Electrohydrodynamic physics can be summarized as the physics that govern the flow of charged flows, where the advection term of the fluid flow is often determined by an electromagnetic force. These MMS equations are based on a simplified electrohydrodynamic equation (commonly known as the Drift-Diffusion equation) with an advection term using the electrostatic approximation:

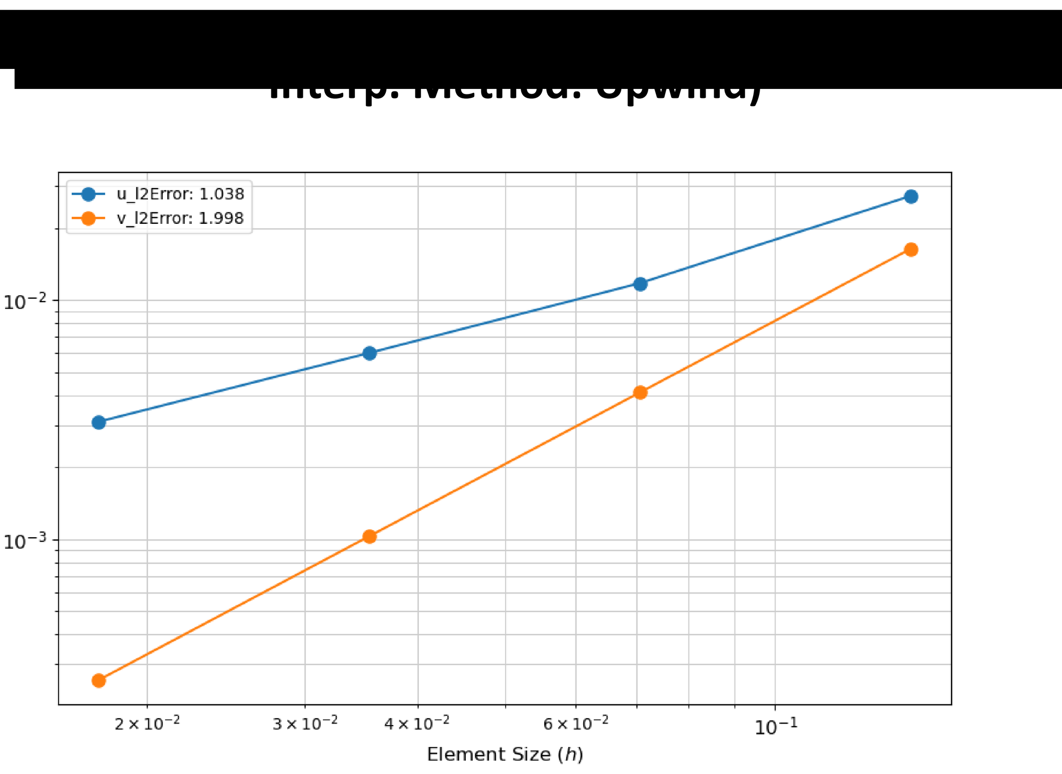
Where and are the FV variables, is the FE variable, and are the source terms calculated using MMS, and all other variable are constant coefficients that were determined to ensure that no terms are neglectable.











The capability to couple FE variables into FV equations has been added to MOOSE. This was done by taking the element or face average of the FE variable value or gradient and applying that quantity directly in the FV equation objects. The MMS convergence studies results show reasonable errors and slopes for one way coupling of FE to FV (cases 1 - 3), and two way coupling between FE and FV (the electrohydrodynamic equations).

Current work is now underway for experiential validation of the coupling. This will also focus on the electrohydrodynamic set of equations.

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