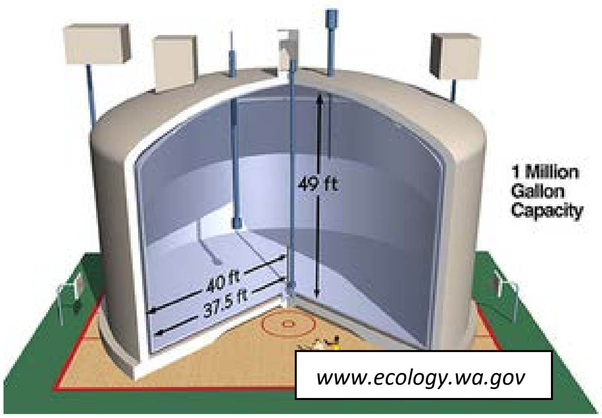
Introduction

GOTHIC is a versatile, general purpose thermal-hydraulics software package that includes a graphical user interface for constructing analysis models, a numerical solver that includes parallel processing capabilities and a post-processor for evaluating simulation results. It solves the conservation equations for mass, momentum and energy for multicomponent, multi-phase flow in lumped parameter and multi-dimensional geometries (1, 2, or full 3D), including the effects of turbulence, diffusion and buoyancy. The diverse equation set allows GOTHIC to solve multi-physics problems and the flexible nodalization options allows GOTHIC to provide computationally efficient solutions for multi-scale applications.

GOTHIC is an industry trusted tool for providing engineering solutions for a variety of applications to support the design, licensing, safety and operating analysis of nuclear power plant systems, containments and confinement buildings as well as spent fuel pools, spent fuel casks and waste storage tanks. GOTHIC has been used for design, licensing and safety analysis of existing plants, small modular reactors (SMR) and next generation plant designs. It has an established pedigree with verification and validation (V&V) covering a wide range of single and two-phase flow situations, which is documented and updated in the Qualification Report released with each version of the software. GOTHIC has been developed within a nuclear quality assurance (NQA) program that complies with 10CFR50, Appendix B and applicable parts of ASME NQA-1. Ongoing support and error reporting complies with 10CFR Part 21 requirements.

GOTHIC's lineage traces back to FATHOMS, COBRA-NC and COBRA-TF, but many enhancements and capabilities have been added over 30+ years of development that expand the code's applicability. GOTHIC has become a hybrid tool that bridges the gap between traditional system level thermal hydraulics analysis tools and computational fluid dynamics (CFD) analysis tools. GOTHIC's full treatment of the fluid-fluid shear as well as molecular and turbulent diffusion is consistent with that found in a CFD type code, except that GOTHIC relies on wall functions (*e.g.*, correlations for heat transfer coefficients and friction factors) rather than trying to resolve the boundary layer. As a result, GOTHIC can apply much larger computational cells than CFD type codes. The significant reduction in mesh density is one reason that GOTHIC is generally much more computationally efficient than CFD.



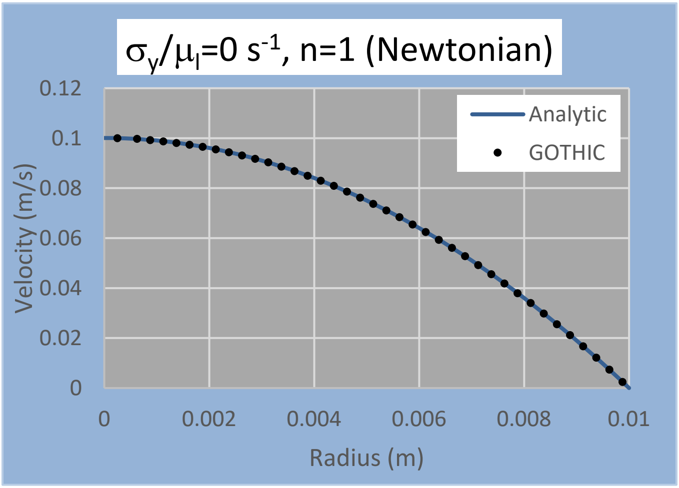
The capabilities of GOTHIC can be extended and customized by attaching Add-on modules. These Add-ons can be used to include additional source and sink terms for any of the balance equations and to make fundamental changes to GOTHIC models and assumptions. Add-on modules have been used, for example, to calculate chemistry in a fluid system. GOTHIC tracer were used to model the chemical constituents and the Add-on provided the source and sink rates for the tracers and the heat of reaction.

Non-Newtonian Fluids

GOTHIC uses an effective eddy viscosity, including the effects of molecular (laminar) and turbulent viscosity. The built-in shear stress versus strain rate model assumes that the shear stress is a linearly related to the strain rate and that the fluid has no yield strength (Newtonian assumption). A GOTHIC Add-on has been developed that makes GOTHIC applicable to yield-pseudoplastic materials with a general shear/strain relationship of the form

$$\sigma_{ij} = \sigma_{ij}^{yield}(t, \gamma) + KS_{ij}^{n}$$

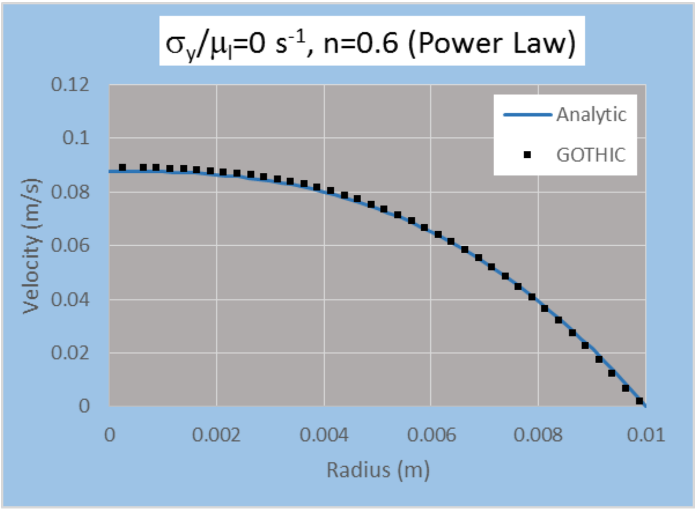
where σ_{ij} and S_{ij} are the stress and strain rate 2nd order tensors, σ^{yield} is the yield strength that may be a function of time and other parameters (γ) and K is the stiffness coefficient.

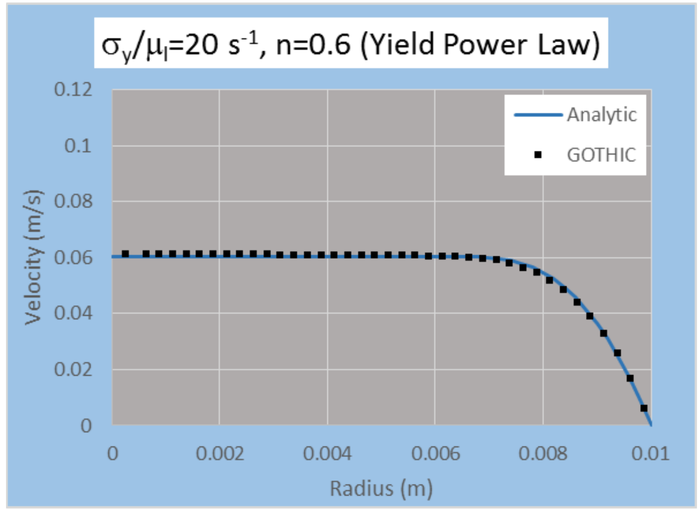


This general formulation allows the modeling of power law ($\sigma_{ij}^{yield} = 0$), Bingham ($n = 1$) as well as Newtonian ($\sigma_{ij}^{yield} =$

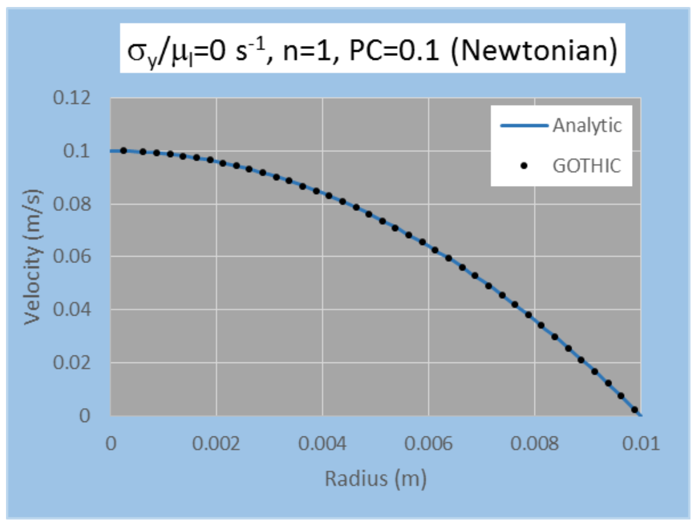
$0, n = 1$) fluids. Non Newtonian effects are approximated by calculating an effective viscosity from the generalized function and the magnitude of the calculated strain rate tensor.

Shown here are the GOTHIC calculated fully developed velocity profiles in a tube with comparison to analytic solutions. The specified inlet flow is the same for all cases. The calculated axial pressure gradient is within 5% of the theoretical value for all cases.



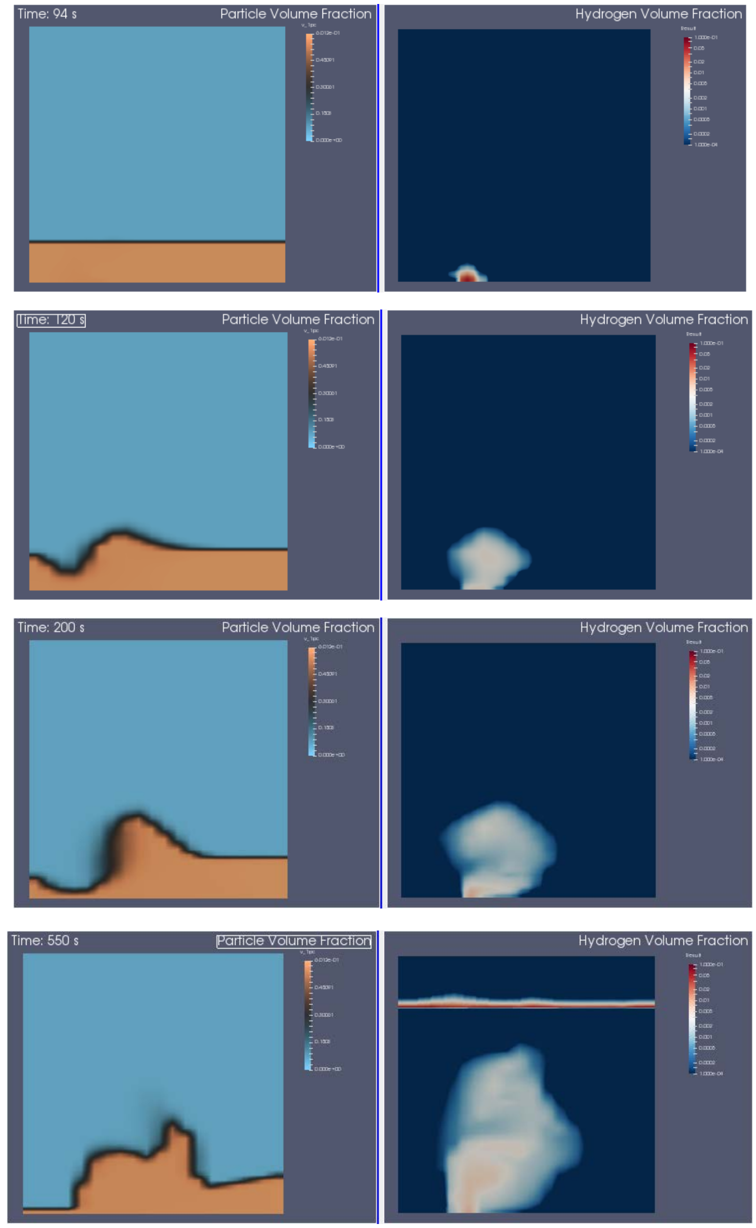


Many non-Newtonian fluids of interest are suspensions or settled beds of particles in a normally Newtonian fluid. GOTHIC can model any number of particle fields, including settling, heat capacity and diffusion effects. The effective viscosity and yield strength of the liquid phase depends on the concentration of the particles. With multiple particle fields of varying sizes, GOTHIC calculates the volume fraction occupied by a packed bed, including infiltration of smaller particles in a bed of large particles. The yield strength is typically a function of the particle concentrations relative to the maximum packing factor. The shear strength of a particle typically increases over time as the settling proceeds. These effects can be modeled by specifying a shear strength that is a function of time and the particle concentration relative to the maximum packing factor. The graph to the right shows the fully developed velocity profile in a tube with a particle volume fraction of 0.1. For this case the velocity profile is the same as the Newtonian profile for water but the axial pressure gradient is 30% higher.



Demonstration Model

The series of frames from a GOTHIC animation of a water filled tank with a settled sludge layer is shown here. The simulation includes a localized hydrogen source in the sludge that is left of center. In each frame, the view on the left shows contours for the particle concentration and the right view shows the volume fraction of the hydrogen bubbles. Early in the transient the hydrogen bubble is trapped in the sludge due to the high effective viscosity of the packed particle bed. Eventually, the buoyancy lift force due to the hydrogen bubbles is sufficient to begin moving the sludge layer, releasing the hydrogen to accumulate in the air space above the liquid in the tank.



Related Experience

GOTHIC was used to model the hydrogen release behavior of Tank SY-101 at Hanford where hydrogen generation in the sludge layer would periodically result in a release of significant quantities of hydrogen, similar to what is shown in the demonstration model. The code was used to investigate mitigating strategies that would release the hydrogen at a more constant rate to eliminate safety concerns.

Conclusions

GOTHIC is a computationally efficient thermal-hydraulic analysis tool that includes both system level and CFD-like attributes. The software provides an integrated analysis environment that allows for fast, flexible creation or modification of models. It is an industry trusted tool with an established QA pedigree. The built in capabilities to model multiphase flow and heat transfer in complex geometries, combined with the ability to extend and customize the code with Add-ons make it an effective tool for modeling a wide range situations, including non-Newtonian fluids.

Contact Information

Additional information can be obtained by contacting:

Jim Harrell, Senior Director	HarrellJR@zachrynuclear.com	(919) 465-7230 x227
Jeffrey Lane, PhD, GOTHIC PM	LaneJW@zachrynuclear.com	(919) 903-6763