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News

Fundamental Research

Transfer and transport physics | Thermodynamics/Molecular modeling | Fluid mechanics

The Real-Fluid Model (RFM), developed at IFP Energies nouvelles (IFPEN), is an approach employed in compressible fluid mechanics to describe real fluid flows under complex thermodynamic conditions: high pressures, subcritical, supercritical[1] and transcritical[2] conditions, as well as phase changes. The advantage of the approach lies in the integration of a compressible, multicomponent description of the flow, a real-fluid equation of state (EoS)[3], and a vapor–liquid equilibrium (VLE) calculation.

History and development of the RFM

RFM was initially developed (Figure 1) in the context of **high-pressure and transcritical injection** modeling, particularly for applications in internal combustion engines. A key step was the development of a fully compressible two-phase model based on four equations (mass, momentum, energy, and species balances), under assumptions of mechanical, thermal, and thermodynamic equilibrium. In addition, thermodynamic closure, a VLE calculation procedure used to determine thermodynamic properties and phase composition, is based on a real-fluid EoS [1].
This approach was subsequently streamlined via a **tabulated RFM**. The thermodynamic and transport properties are pre-calculated in tables and then interpolated during the CFD[4]calculation. This strategy

makes it possible to maintain a realistic description of fluids while significantly reducing the cost associated with repeated thermodynamic equilibrium calculations. In particular, it has made it possible to extend the RFM to multicomponent mixtures and “Large-Eddy Simulation”[5] in the CONVERGE CFD code [2, 3].

From engines to CCUS

The thermodynamic properties of CO_2 become particularly important in **Carbon Capture, Utilization, and Storage (CCUS)** processes, during which CO2 is transported via pipelines in dense or supercritical form. The presence of impurities and depressurization phenomena are critical factors in that they can alter phase equilibria and flow dynamics. The RFM **thus** provides a suitable framework for coupling the phenomena of compressible dynamics and real fluid thermodynamics.
In the first study on this theme, Bhatia and Habchi [4] applied the RFM to the study of **CO? condensation in a nozzle** subjected to shock-wave expansion, taking into account the effect of impurities. The study demonstrates the value of this approach for simultaneously describing the dynamics of a fully compressible fluid, phase changes, and the influence of fluid composition.
The second study extends this approach to supercritical **CO_2 leaks in CCUS transport pipelines** [5]. The tabulated RFM, implemented in CONVERGE, is used to study transient depressurization and the propagation of decompression waves, focusing specifically on the influence of the choice of **equation of state**, **impurities**, and the **diameter of the leak outlet**. The simulations take into account impurities such as N_2, CH_4 and Ar, and are compared with available experimental data. A larger-scale pipeline configuration, representative of industrial conditions, is also being studied.

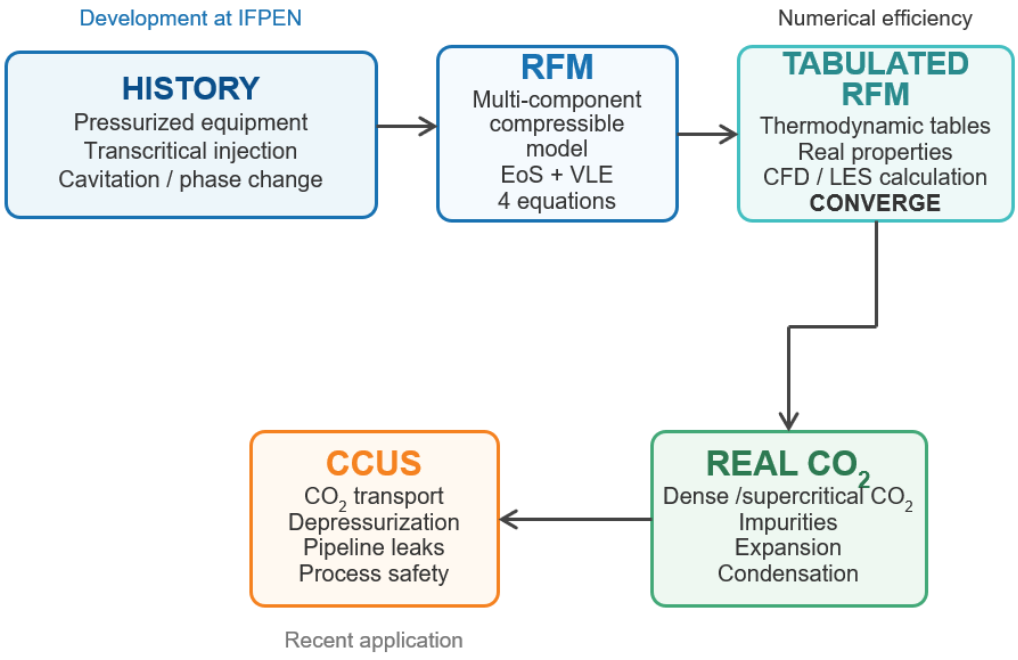

Figure 1 : Conceptual evolution of the Real-Fluid Model (RFM), from its development for high-pressure and transcritical flows through to its application to CO2 in carbon capture, utilization, and storage (CCUS) processes.

Conclusion and outlook

This research illustrates the evolution of the RFM, from a model designed for complex flows of real fluids at high pressure to a **simulation methodology applicable to CCUS infrastructure**. The combination of realistic thermodynamics, compressibility, phase changes, and the consideration of impurities provides a powerful tool for analyzing the transient phenomena encountered in CO_2 transport and is useful when studying the design and safety of these infrastructures.

[1] The state of a substance when its pressure or temperature exceeds that of the critical point (point on the temperature pressure diagram where the liquid gas equilibrum cruve ends). In the opposite case, it is in a subcritical state
[2] Condition generated when a subcritical fluid is injected into a supercritical fluid.
[3] At thermodynamic equilibrum, the Eo Sis a relationship between various physical parameters (pressure, volume, temperature) that determine its state.
[4] Computational Fluid Dynamics
[5] Method used in tubulence modeling

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Scientific contacts: Chaouki Habchi, Jean-Charles de Hemptinne

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