A Study of Transient Two-phase Flows in CO_2 Pipelines

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Background

By 2050 200,000-360,000 km of pipeline will be required for transportation of CO_2 captured from fossil fuel power plant for subsequent sequestration (IEA, 2009).

IEA, Energy technology perspectives 2012: Pathways to a clean energy system.

CO_2 pipeline transportation – hazards

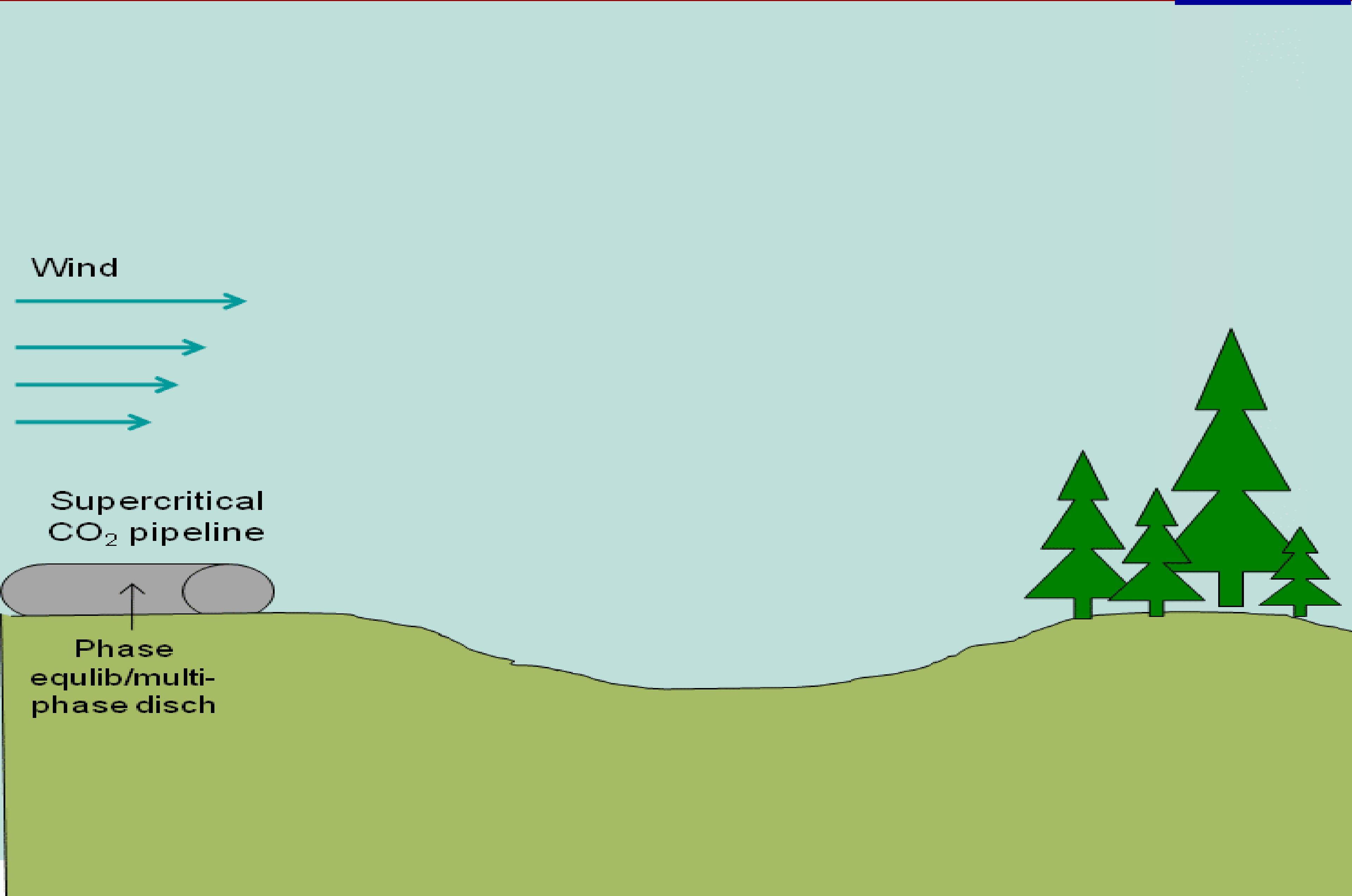
At concentrations higher than 10%, CO_2 gas can cause severe injury or death due to asphyxiation.

In case the of accidental leakage/ release of CO_2 from a pipeline:

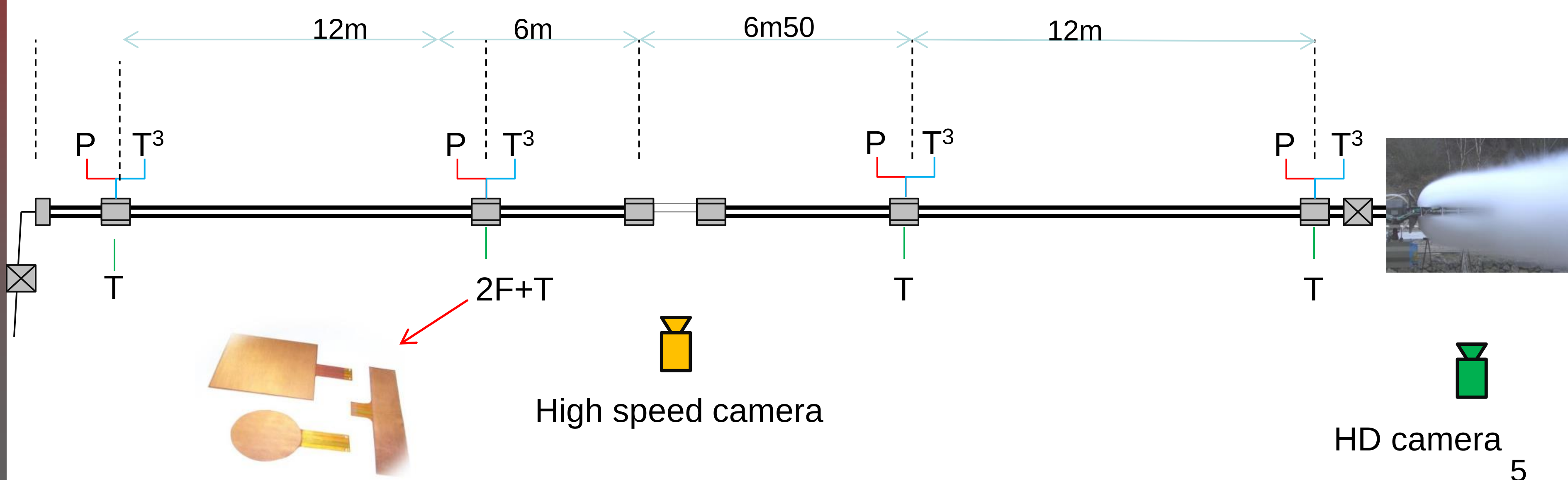
- the CO_2 gas can accumulate to potentially dangerous concentrations in low-lying areas,
- the released cloud could cover an area of several square kilometres.

Courtesy of Laurence Cusco, HSL

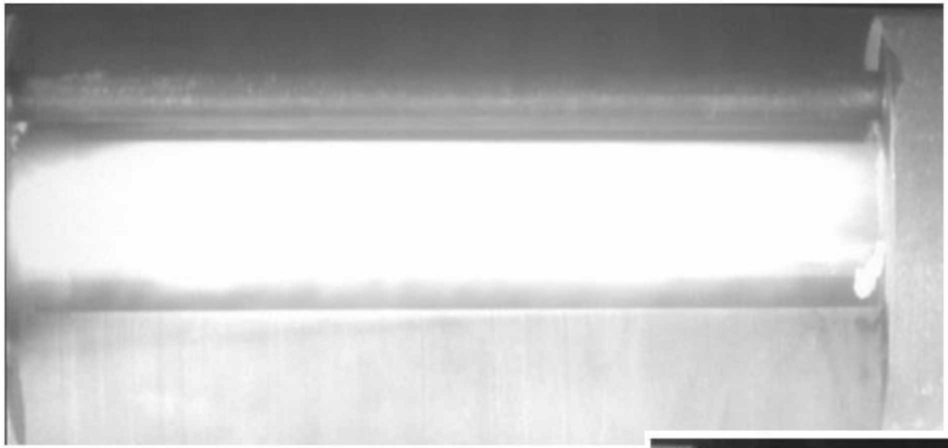
CO_2 pipeline transportation – hazards cont.



CO_2Quest experimental facilities



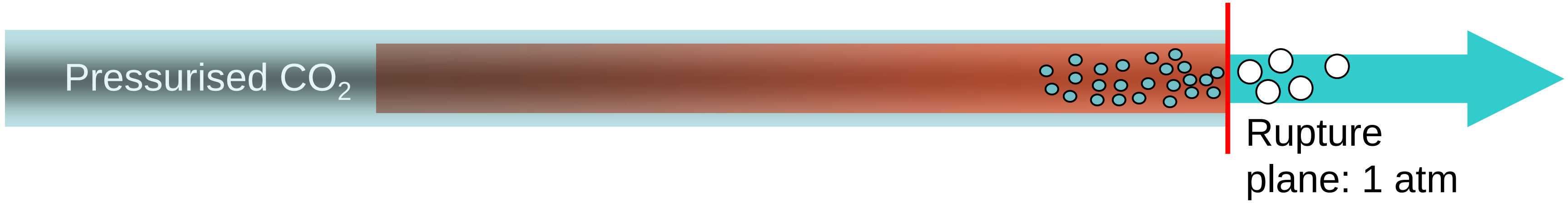
Video recording during release



Full bore rupture

Puncture release

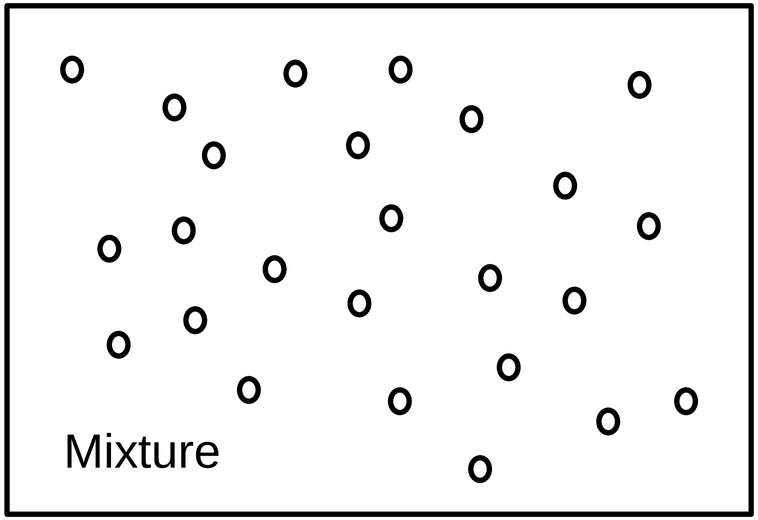
Physics of decompression



- At the rupture plane the fluid is exposed to ambient air
- Following the rupture, the rarefaction wave starts propagating along the pipe
- The vapour phase emerges in the expansion wave
- Due to rapid cooling of the fluid in the decompression wave, the solid phase may also be released from the pipe

Mathematical model -Pipeline discharge

Homogeneous Relaxation Model



Balance equations:

$$\frac{\partial \rho_{mix} z}{\partial t} + \frac{\partial \rho_{mix} u_{mix} z}{\partial x} = S_z$$

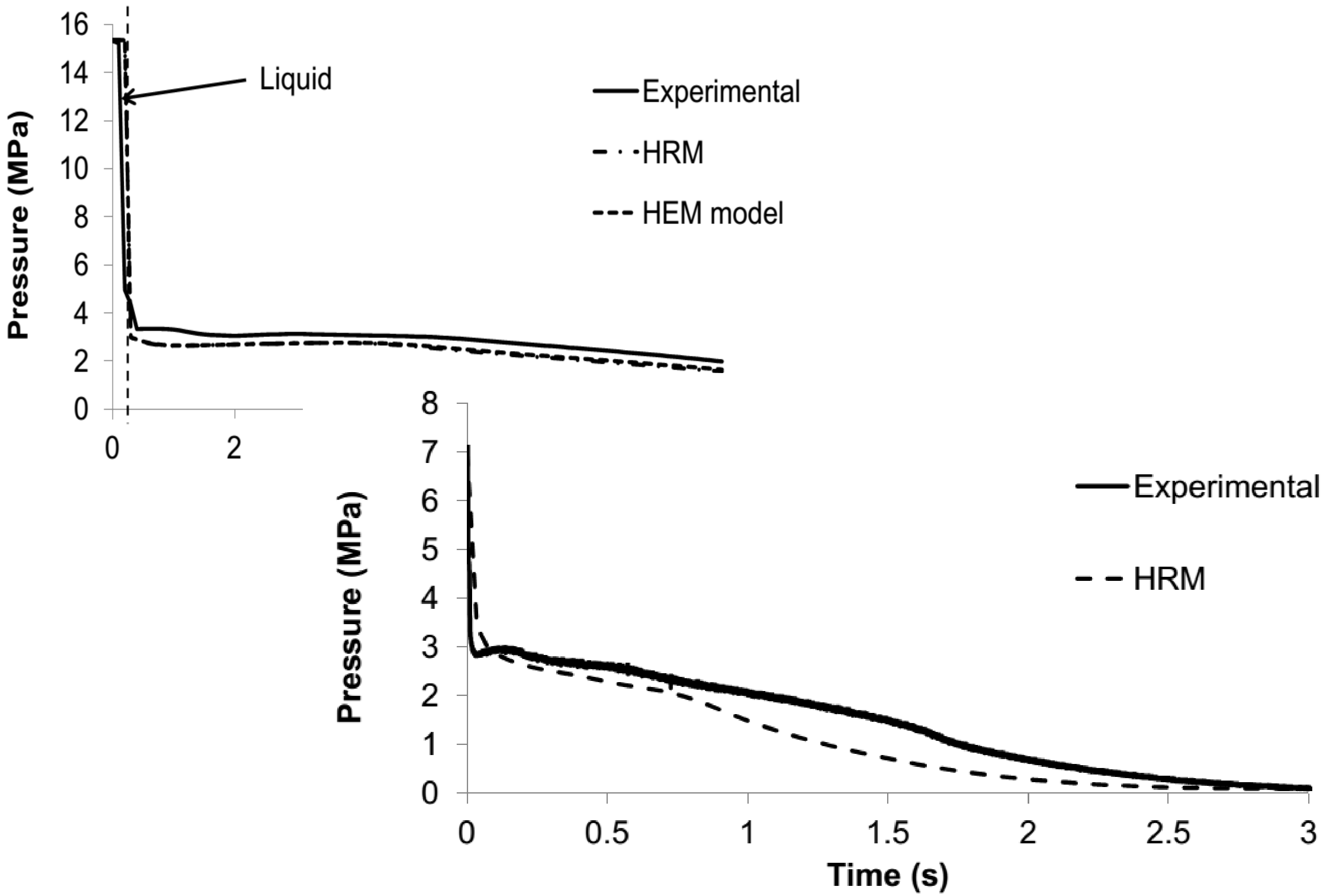
$$\frac{\partial \rho_{mix}}{\partial t} + \frac{\partial \rho_{mix} u_{mix}}{\partial x} = S_\rho$$

$$\frac{\partial \rho_{mix} u_{mix}}{\partial t} + \frac{\partial \rho_{mix} u_{mix}^2 + P}{\partial x} = S_u$$

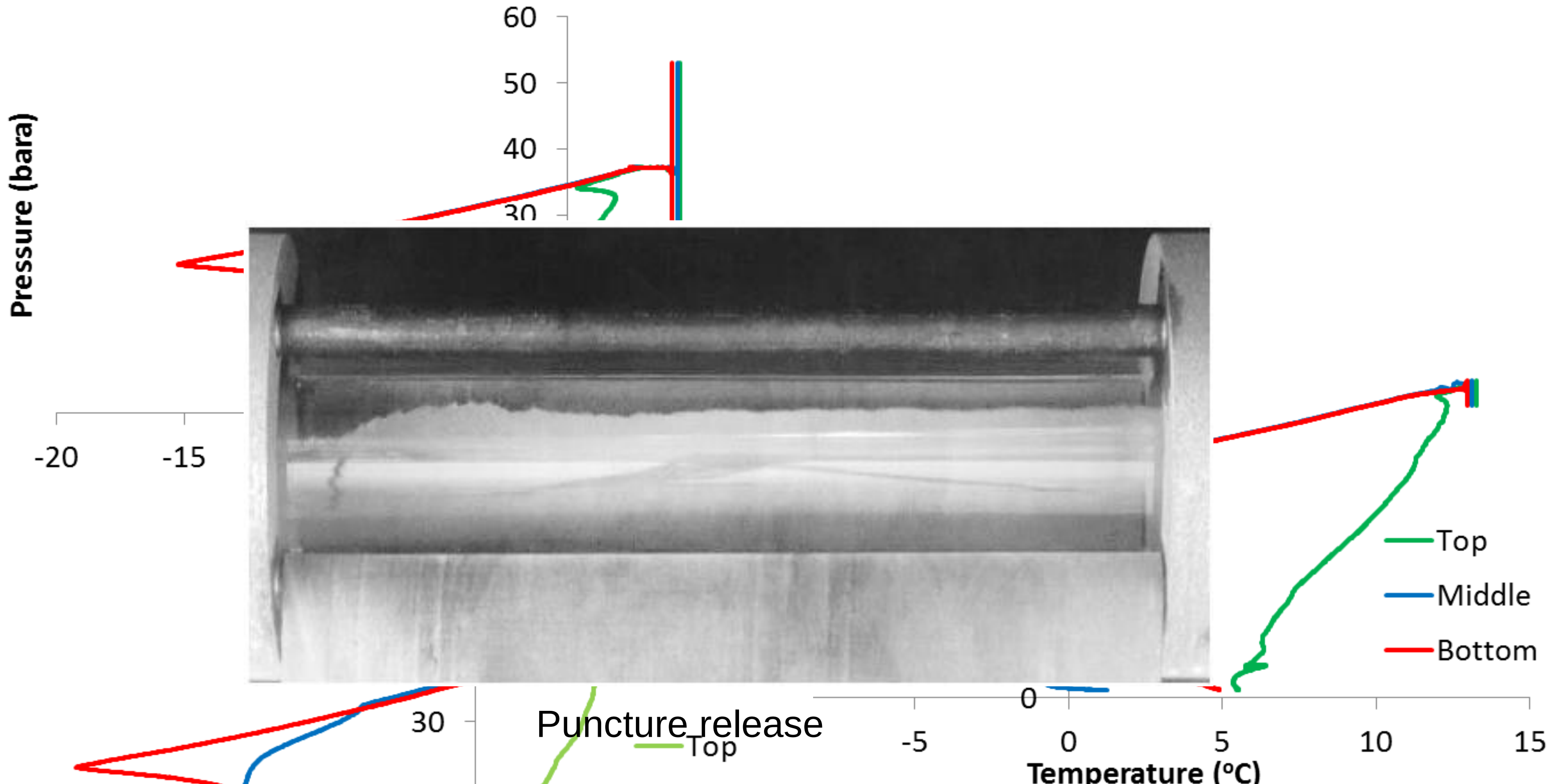
$$\frac{\partial \rho_{mix} E_{mix}}{\partial t} + \frac{\partial \rho_{mix} H_{mix}}{\partial x} = S_e$$

where *ρ*, *u*, *P*, *H, z* and *E* are the density, velocity, pressure, total enthalpy, vapour quality and total energy of a two-phase fluid mixture as function of time *t* and space *x.*

This works reasonably well…

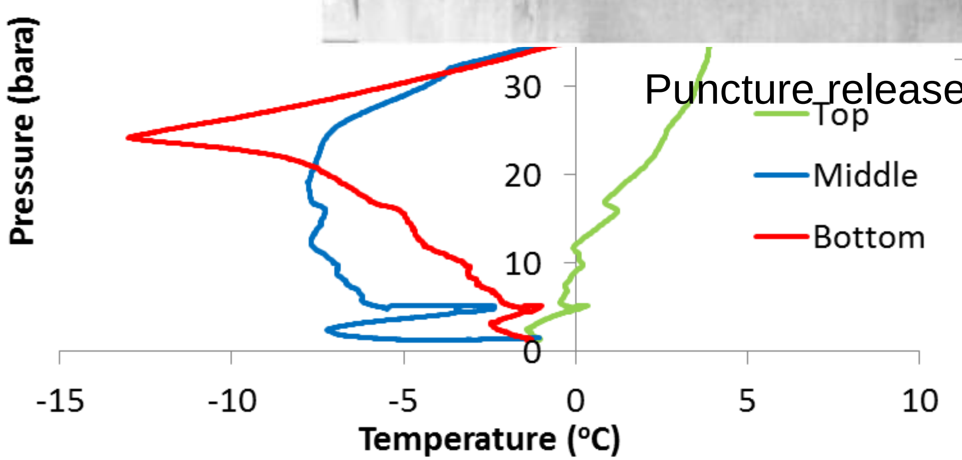


But…



Test 27

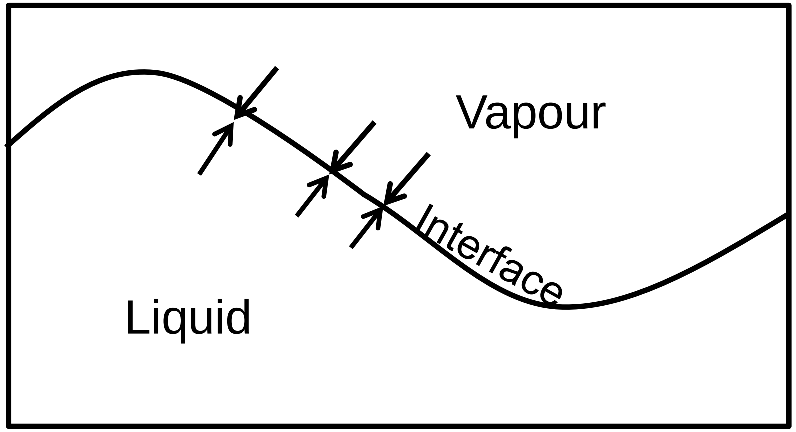
Puncture release



Test 28

Mathematical model -Pipeline discharge

Two-Fluid Model



Balance equations:

$$\frac{\partial \alpha_i \rho_i}{\partial t} + \frac{\partial \alpha_i \rho_i u_i}{\partial x} = S_\rho$$

$$\frac{\partial \alpha_i \rho_i u_i}{\partial t} + \frac{\partial \alpha_i \rho_i u_i^2 + \alpha_i P_i}{\partial x} = P_i \frac{\partial \alpha_i}{\partial x} + S_u$$

$$\frac{\partial \alpha_i \rho_i E_i}{\partial t} + \frac{\partial \alpha_i \rho_i H_i}{\partial x} = -P_i u_{int} \frac{\partial \alpha_i}{\partial x} + S_e$$

$$\frac{\partial \alpha_v}{\partial t} + u_{int} \frac{\partial \alpha_v}{\partial x} = S_i$$

Characterisation of these terms is difficult

where α is the volume fraction as function of time t and space x.

Inter-phase heat and mass transfer

Simple models for the heat and mass transfer are applied.

Inter-phase heat transfer model:

$$q_v^i = \frac{1}{\tau} A_{int}(T_{sat} - T_v)$$

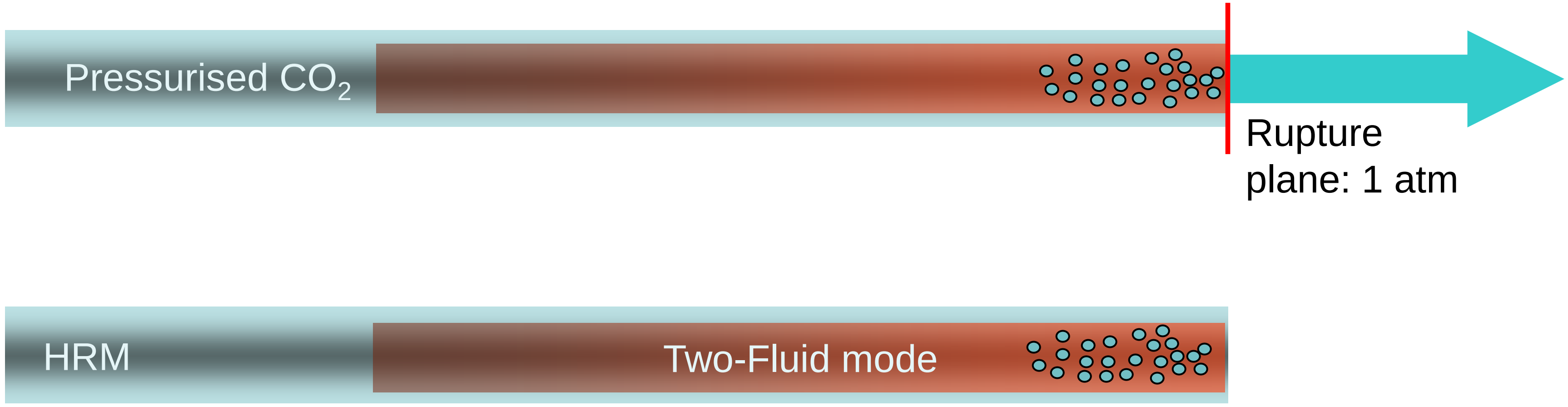
$$q_l^i = \frac{1}{\tau} A_{int}(T_{sat} - T_l)$$

Inter-phase mass transfer model:

$$\Gamma_v = -\Gamma_l = \frac{(q_l^i + q_v^i)}{h_{sat,v} - h_{sat,l}}$$

These are both governed by the relaxation time scale τ

Switching between the models



Pipeline discharge model

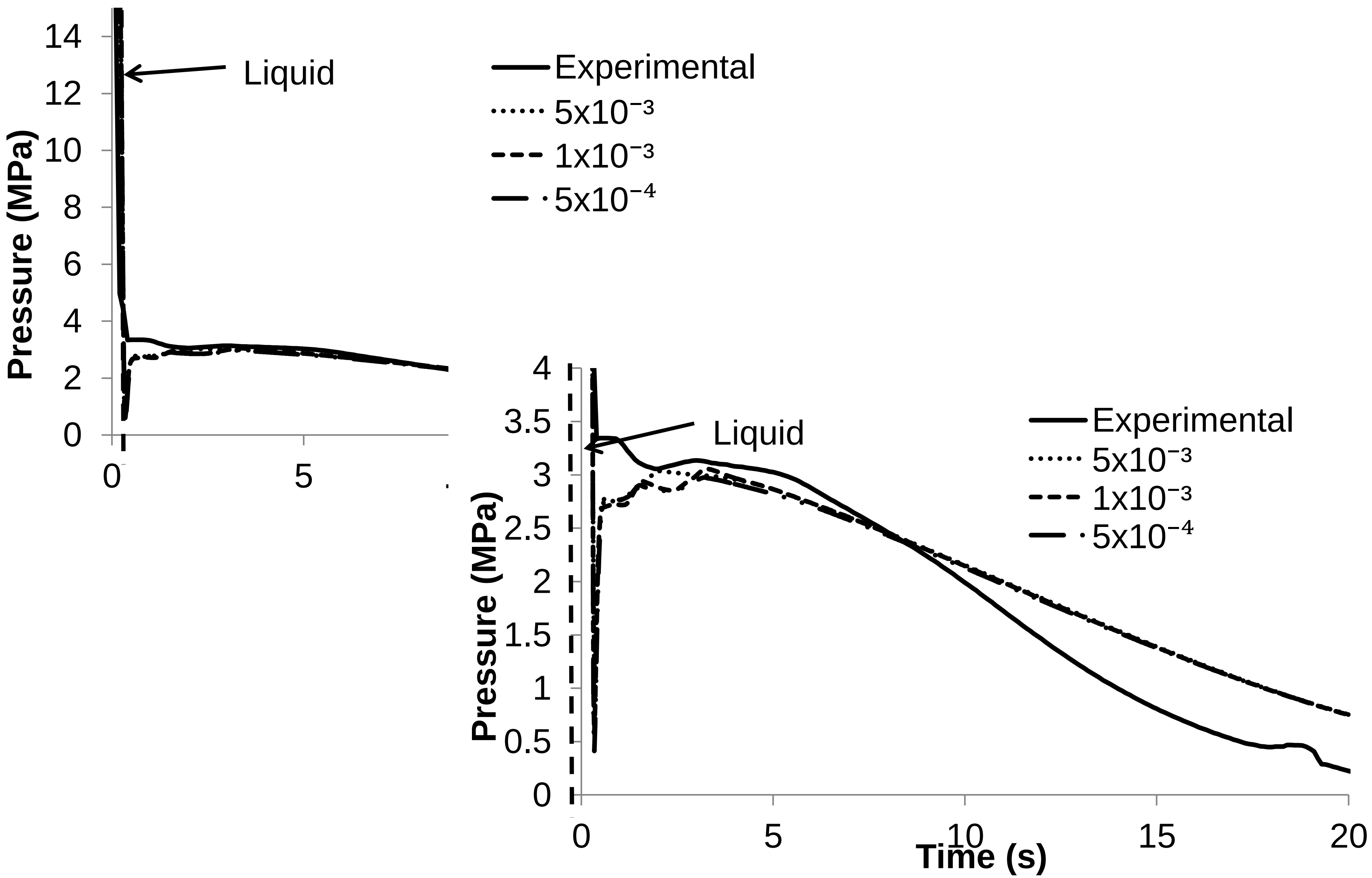
Peng-Robinson Equation of State for CO_2

$$P = \frac{RT}{v - b} - \frac{a}{v(v + b) + b(v - b)}$$

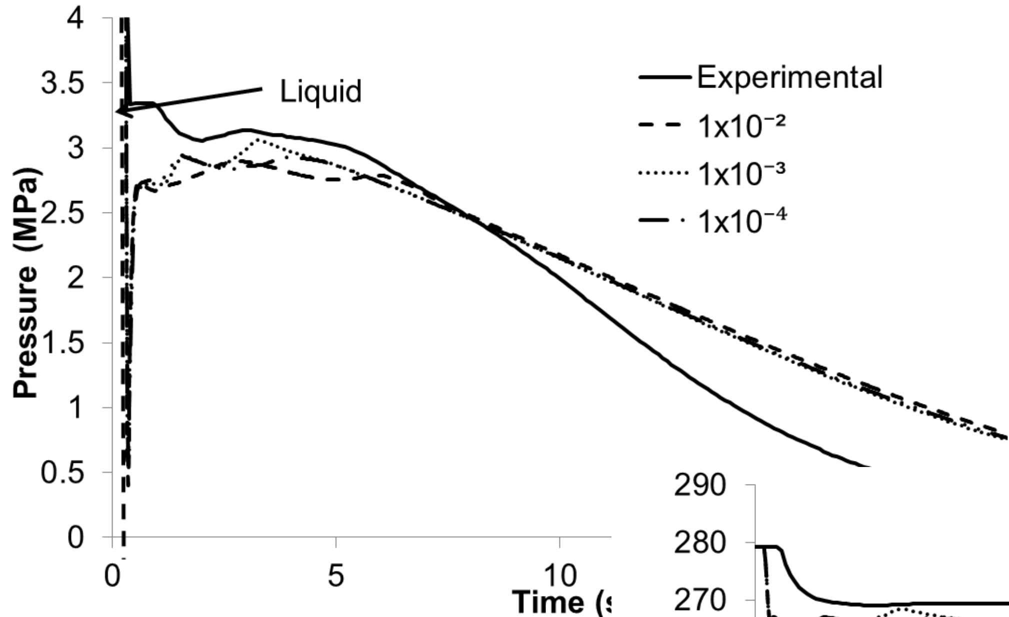
P, T, v – pressure, temperature and specific volume

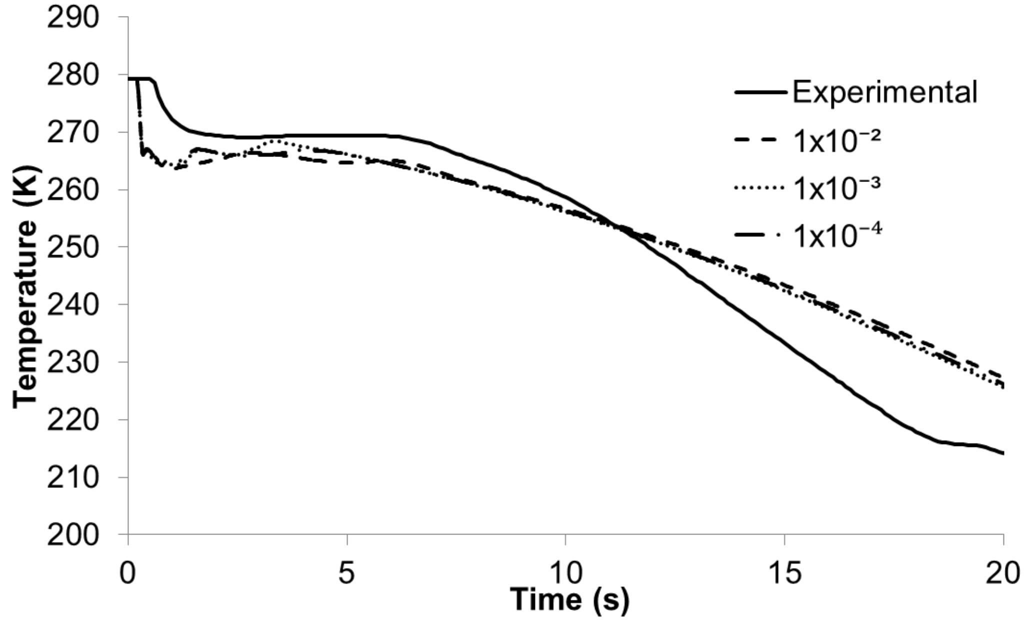
a and b – are empirical parameters accounting for the intermolecular attraction forces and the molecular volume respectively

Impact of model switching

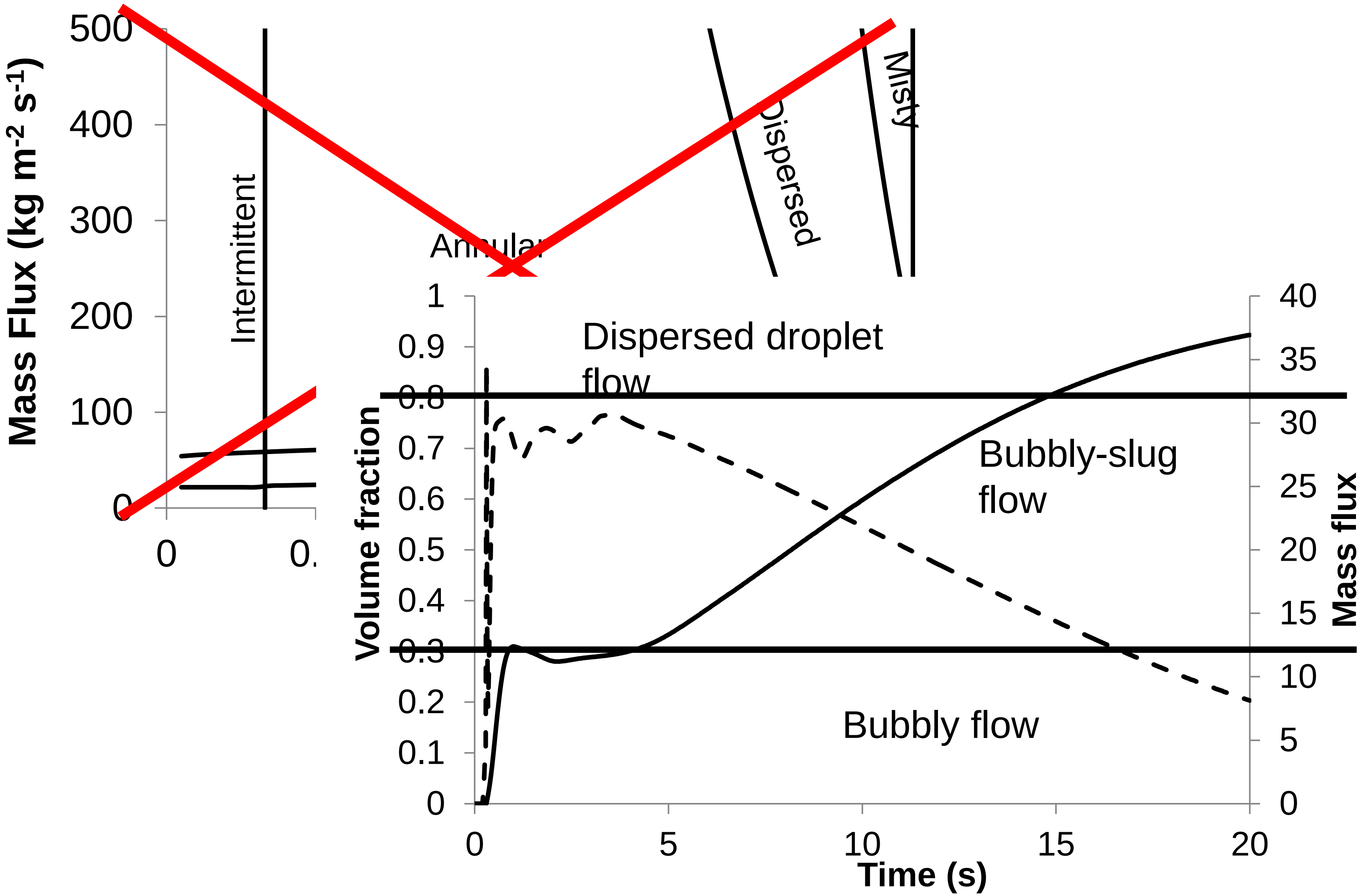


Impact of heat and mass transfer (τ)





Future work-What flow regime are we in?



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Thank you

Questions

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