CO_2QUEST

Optimal Valve Spacing for Next Generation CO_2 Pipelines

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http://www.co2quest.eu

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Introduction

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).

CO_2 pipeline transportation – hazards

At concentrations higher than 10%, CO_2 gas is toxic and can even be fatal.

In the event of the 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

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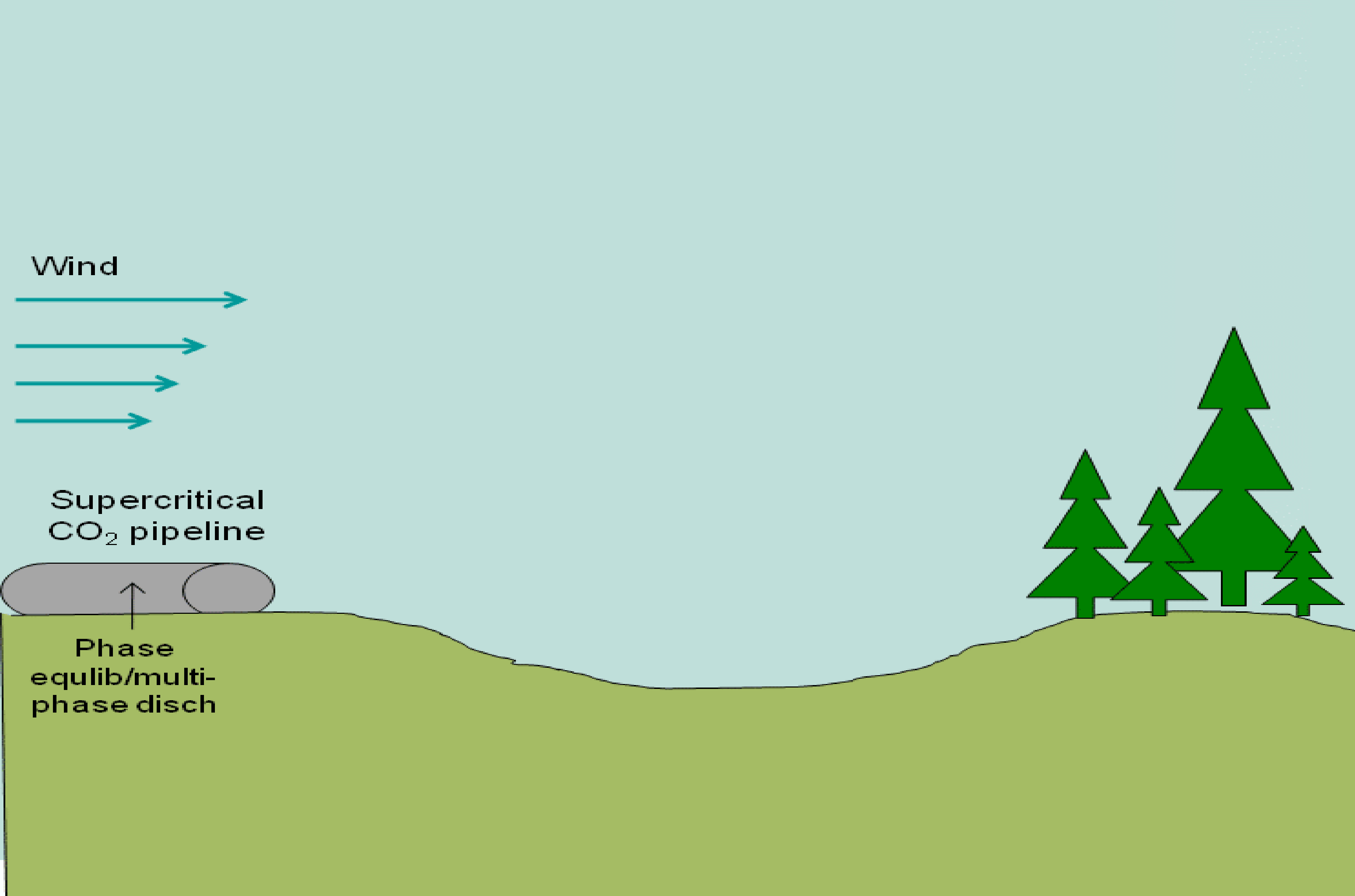
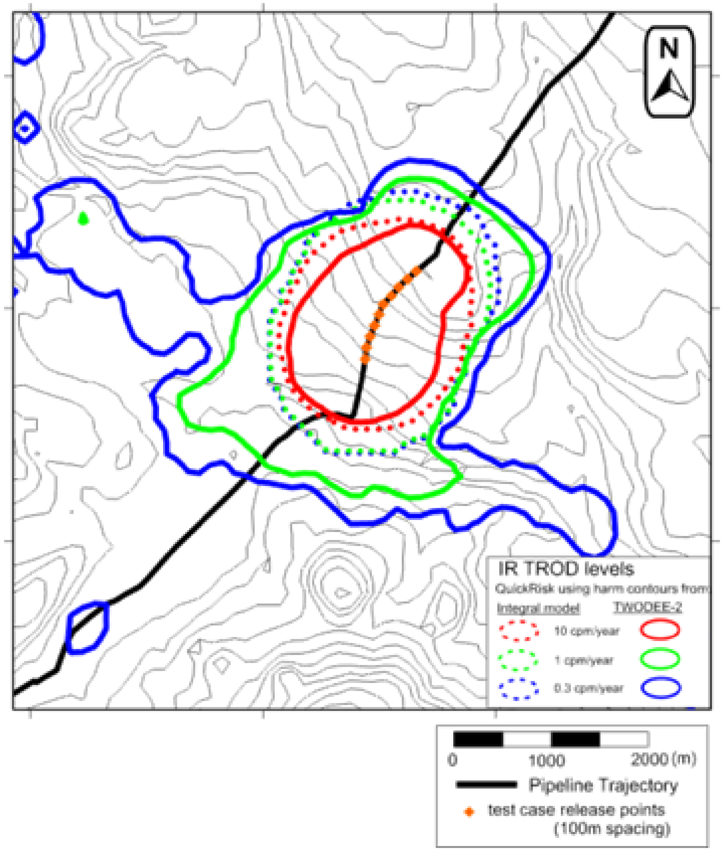
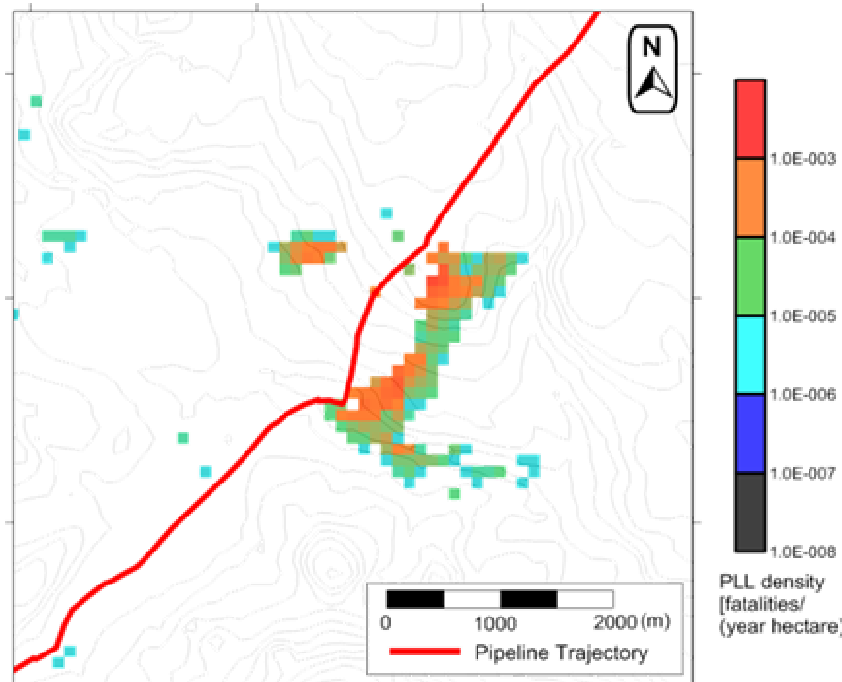
CO_2 pipeline transportation – hazards cont.

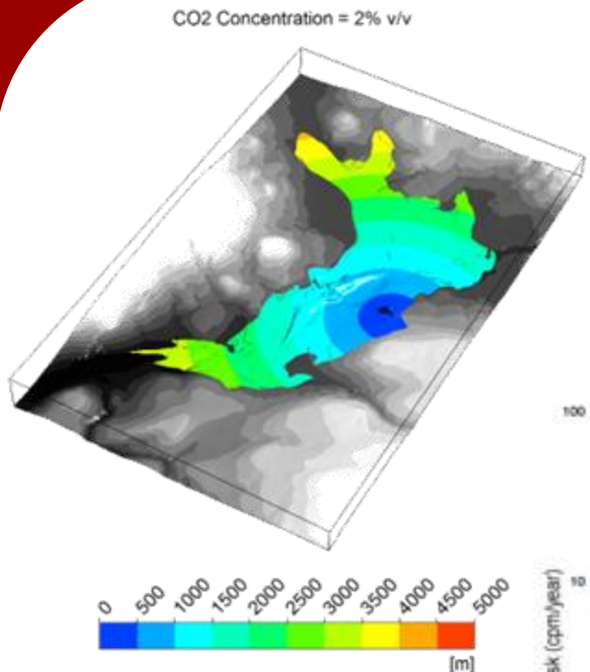




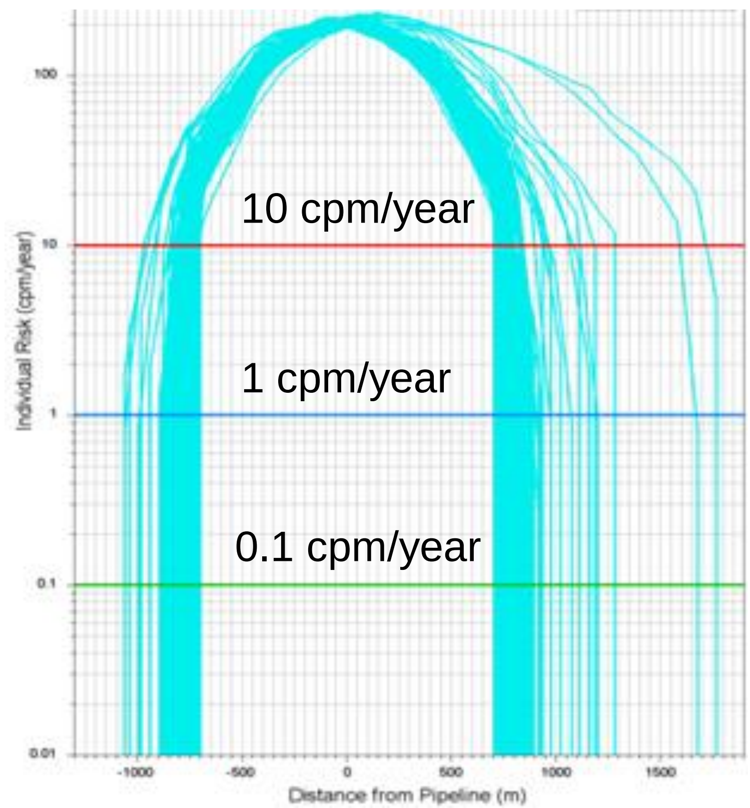
Individual risk contours (10 cpm/year, 1 cpm/year and 0.3 cpm/year) using TWODEE-2 dose results

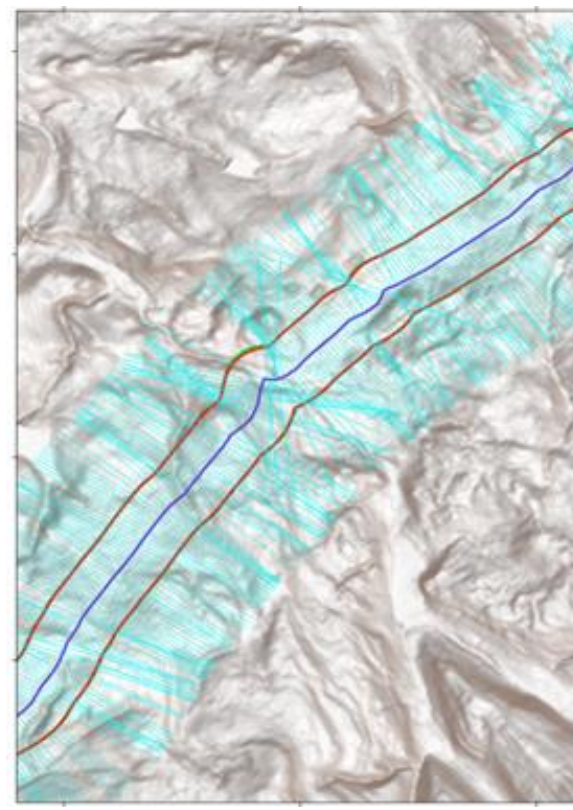


Geographical distribution of the *Potential loss-of-life* (PLL) or EV density map



Risk transects at regularly spaced points along the pipeline route





Presentation headlines

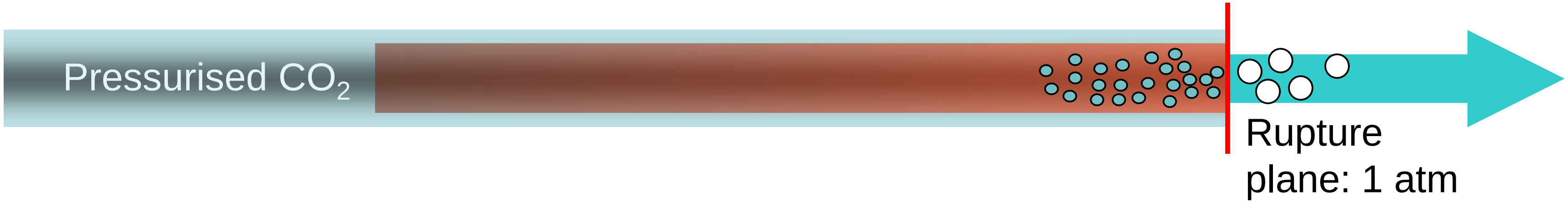
- A rigorous mathematical model for dynamic valve closure during pipeline decompression is developed
- Methodology is developed for a hazard-based optimisation of valve spacing
- Optimal valve spacing for a realistic Case Study is found to be ca. 15 km
- This is remarkably similar to current industrial standards for gas pipelines in the UK

COOLTRANS Experimental release tests

Smaller scale venting tests, primarily of interest for maintenance

Large scale release tests and fracture

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

Emergency Shutdown Valves

Valve stations are placed along the pipeline for use in routine maintenance

Emergency Shutdown Valves (ESDVs) valves also play an important role in the event of a pipeline failure:

- Isolation of pipe sections for venting
- most importantly to limit the amount of inventory released

But installation and operation of these sites represents a significant financial cost.

Experimental setup

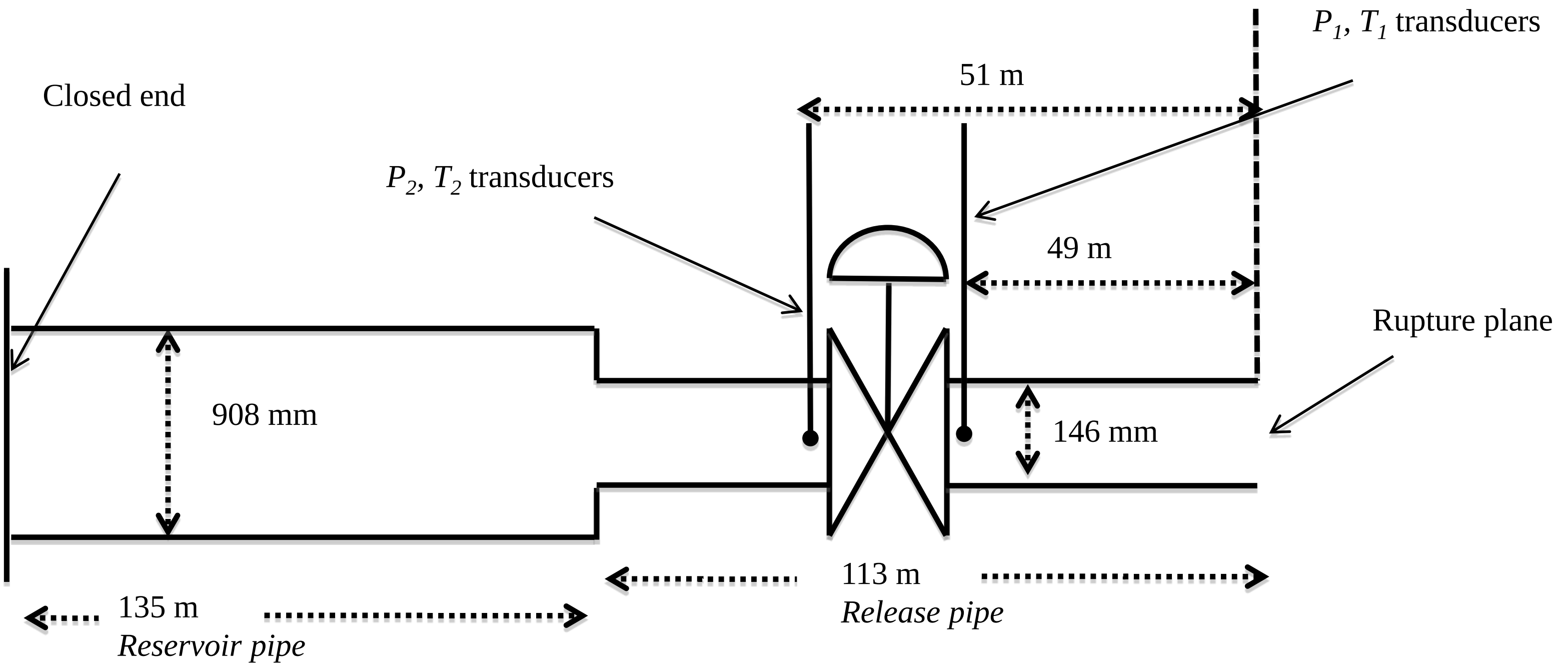


Figure 1: Schematic of the experimental set-up employed for the CO_2 FBR tests

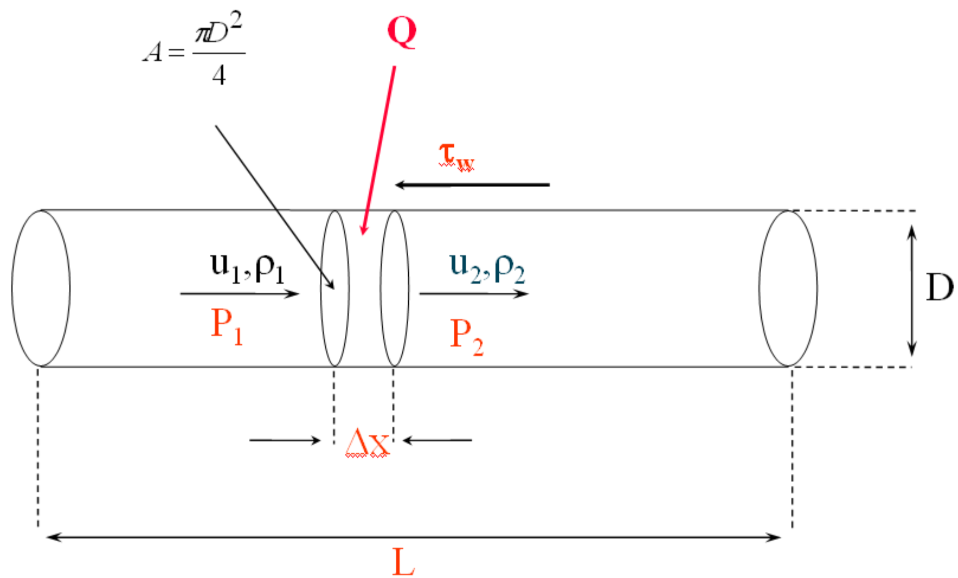
Release behaviour- rigorous outflow model

Governing Equations:

$$\frac{d\rho}{dt} + \rho \frac{\partial u}{\partial x} = 0$$

$$\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} + \frac{\partial P}{\partial x} = \alpha$$

$$\rho \frac{dh}{dt} - \frac{dP}{dt} - \left(q_h - u\beta_y \right) = 0$$



Where *ρ*, *u*, *P* and *h* are the density, velocity, pressure and specific enthalpy of the homogeneous fluid as function of time, *t*, and space, *x*. q_h is the heat transferred through the pipe wall to the fluid.

More advanced models:

Brown et al. (2013) *Int. J. Greenh. Gas Control*

Brown et al. (2014) *Int. J. Greenh. Gas Control*

Experimental setup

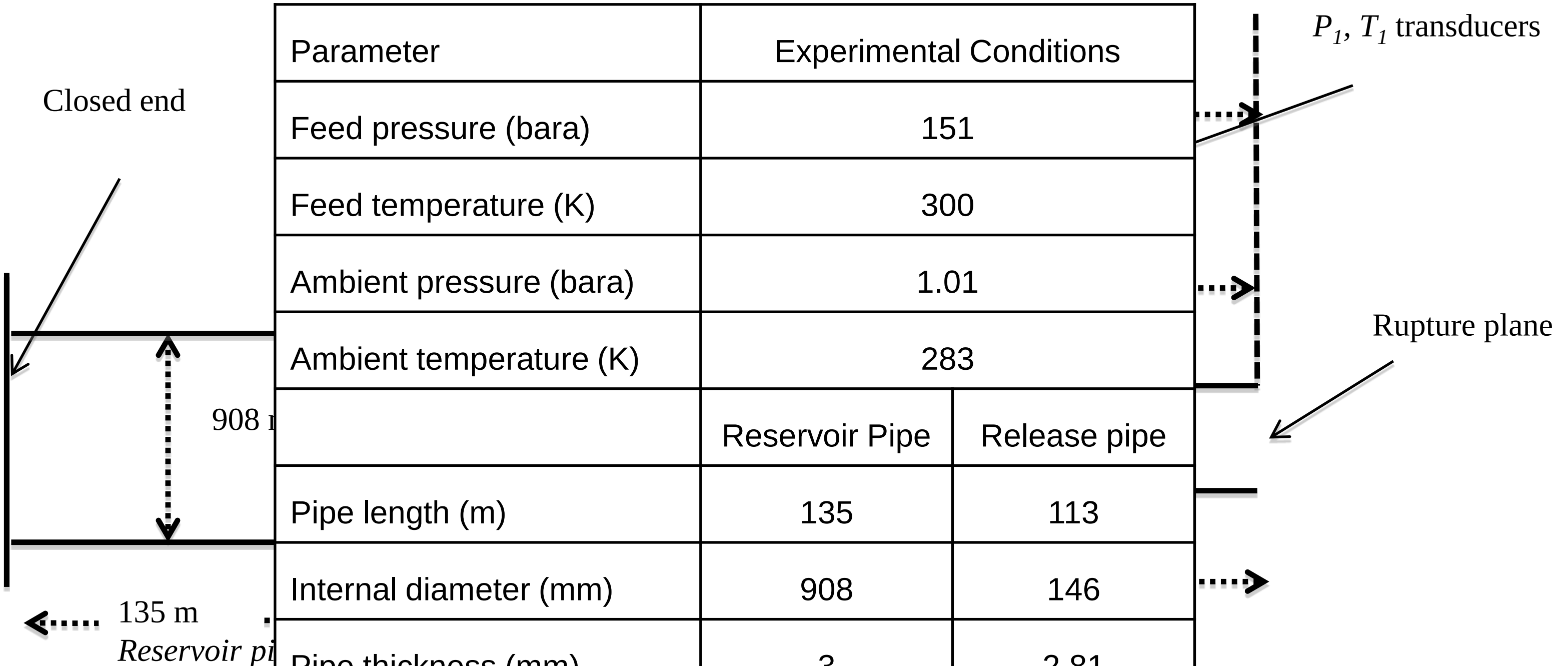
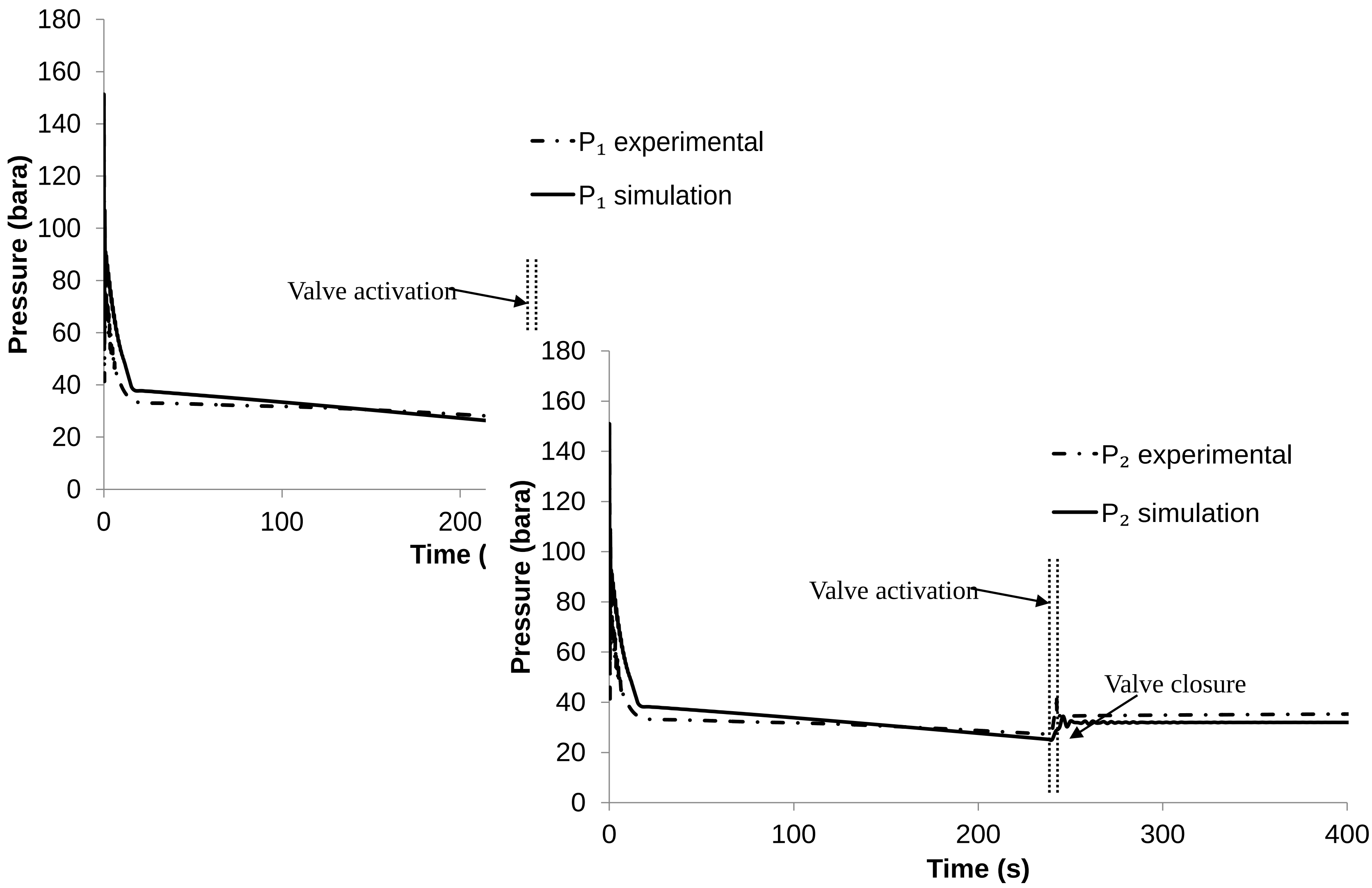


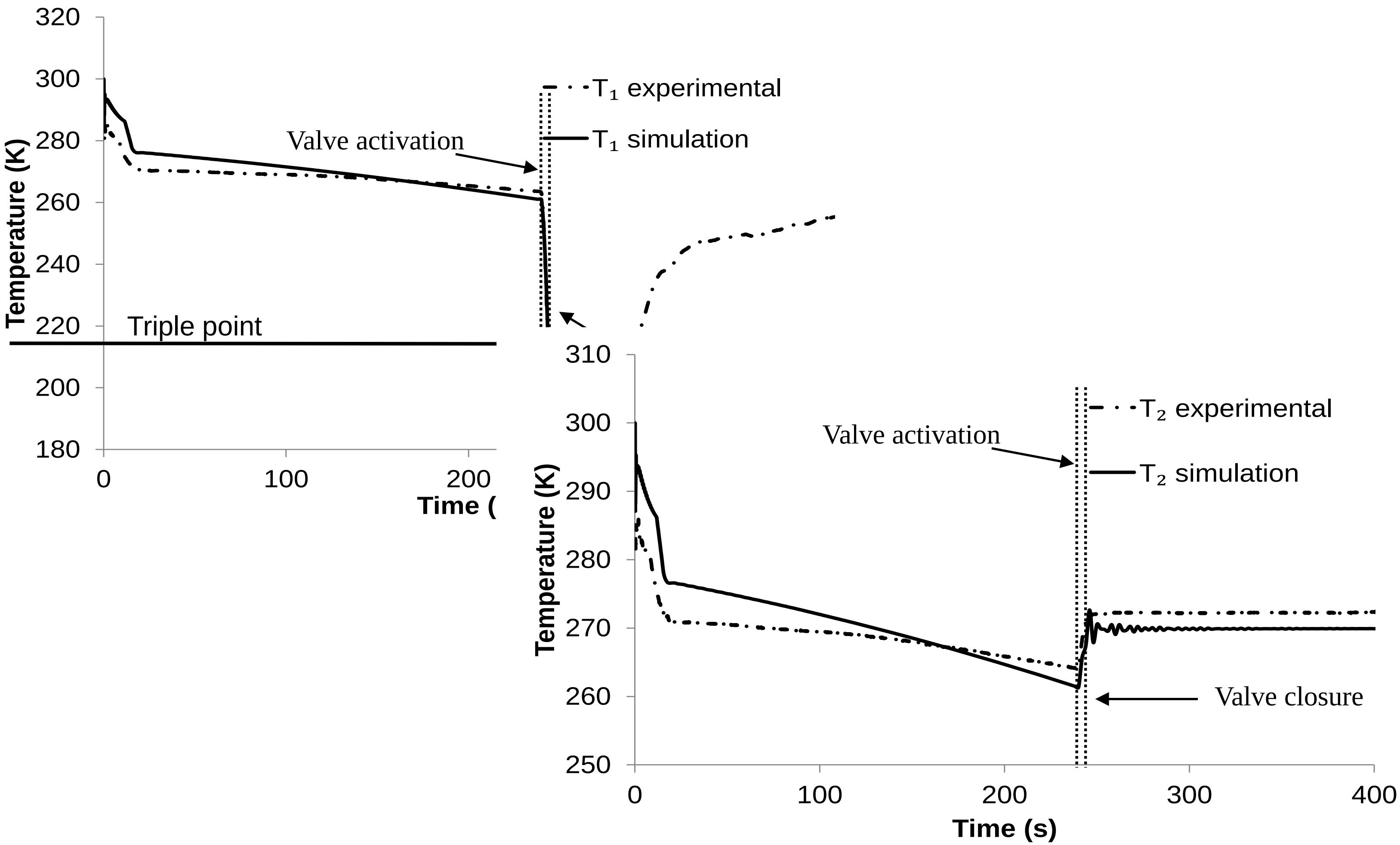
Figure 1: Schem … CO_2 FBR tests

Parameter	Experimental Conditions	
Feed pressure (bara)	151	
Feed temperature (K)	300	
Ambient pressure (bara)	1.01	
Ambient temperature (K)	283	
	Reservoir Pipe	Release pipe
Pipe length (m)	135	113
Internal diameter (mm)	908	146
Pipe thickness (mm)	3	2.81
Pipe roughness (mm)	0.05	
Valve closure rate (cm/s)	2.95	
Valve activation time (s)	240	

Comparison with predictions: Pressure



Comparison with predictions: Temperature



Can we calculate the optimal number of valves for a given pipeline to simultaneously reduce costs and hazard posed by potential failure?

Problem definition

The problem is posed as a simple trade-off between the reduction in the consequences of failure offered by the valve and the cost:

$$\min_{d \in D} J_1(d), J_2(d)$$

The total valve cost for installation, J_2 , is calculated using (Medina et al., 2012):

$$J_2(d) = \frac{V_{PN} r (1 + r)^n L}{\left((1 + r)^{n+1} - 1\right) d},$$

V_{PN} is the single valve cost (€)

r is the average life time of the equipment (y)

n is the discount rate

L is the overall length of the pipeline (km)

D is the distance between consecutive valves (km)

Problem definition cont.

The definition of J_1 problematic because must:

1. Incorporate the effect emergency shutdown on the release behaviour

2. Simulate the dispersion of the released CO_2 cloud
   - A detailed model for the dispersion is not practical for optimisation (typically this can require months of HPC resources)
   - Dense gas dispersion model SLAB utilised

3. **<u>Define a meaningful metric for the hazard from the above</u>**

Disperion of cloud - SLAB

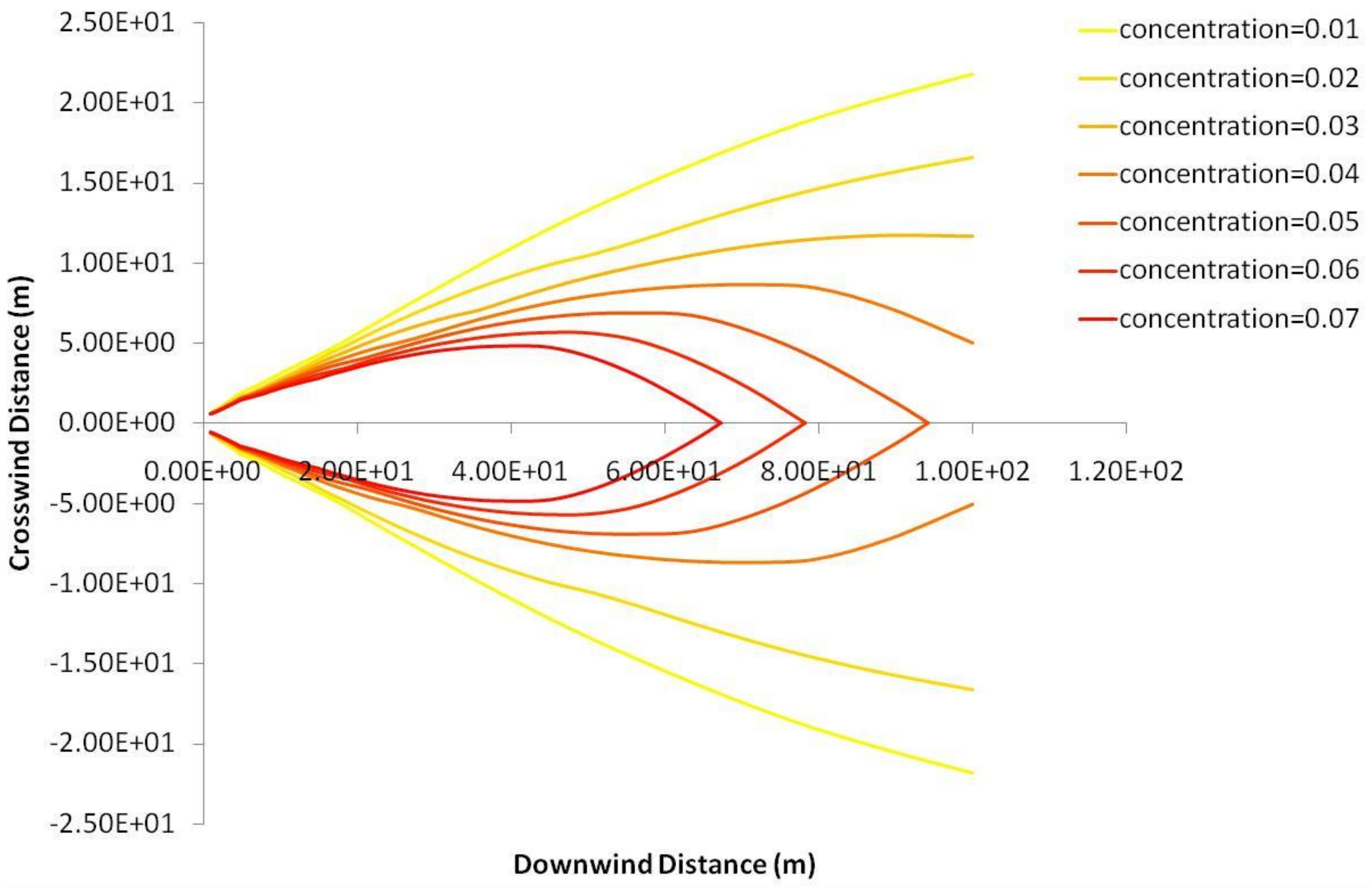


Figure 2: Variation of concentration contours for 4 sampling sets

Definition: J_1

From the cloud dispersion model could calculate Dangerous Toxic Loads given a population density with either the:

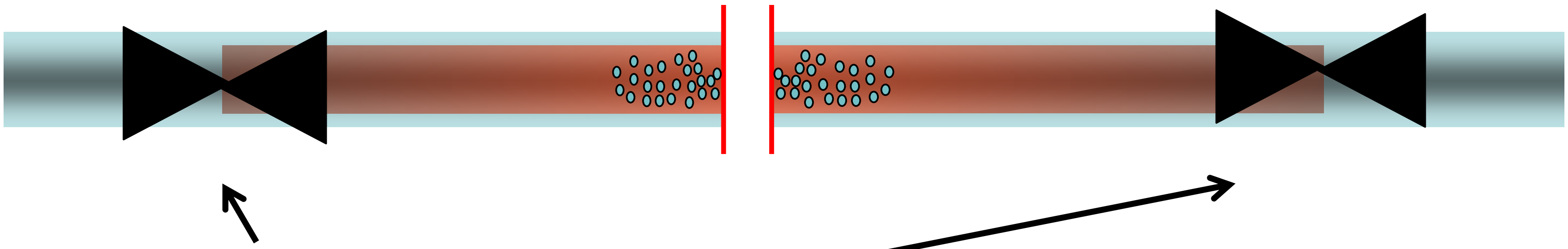
- SLOD (Significant Likelihood of Death)
- SLOT (Specified Level of Toxicity)

But for CO_2 these are contentious so we select a simple measure:

- Quasi-steady CO_2 concentration of contours calculated at given intervals
- Time averaged area bounded by the 7 % contour was calculated and used for J_1

Optimisation Case Study

Find the optimal valve spacing for a typical 96 km pipeline with a Full Bore Rupture at 48 km



Emergency valves placed upstream and downstream of failure

A parallel Monte Carlo simulation using 30 different randomly generated valve spacings was performed to generate the Pareto set.

Optimisation Case Study cont.

Table 1. Pipeline characteristics and fluid conditions for failure scenario.

Parameter	Value	Parameter	Value
Pipeline		*Boundary Conditions*	
Pipeline external diameter	610 mm	Upstream end	Constant pressure
Pipeline wall thickness	19.4 mm	Downstream	No back flow
Pipeline wall roughness	0.005 mm	*Initial Conditions*	
Pipeline length	96 km	Pressure in pipe	151 bara
Pipeline angle	Horizontal	Temperature in pipe	30 ° C
		Ambient temperature	10 ° C

7 % concentration contours

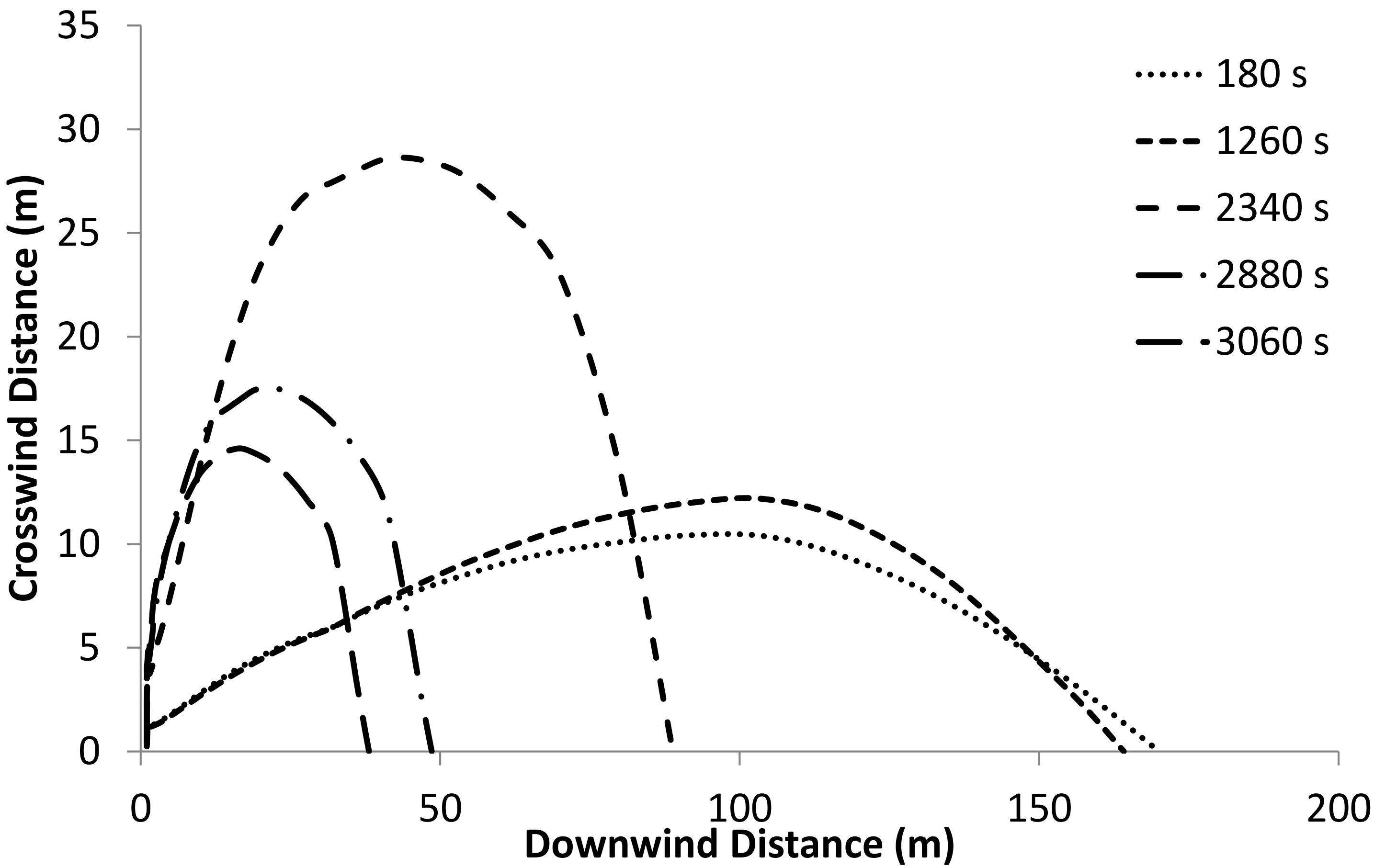


Figure 3: Variation of 7 % concentration half-contours with time

Objective curves

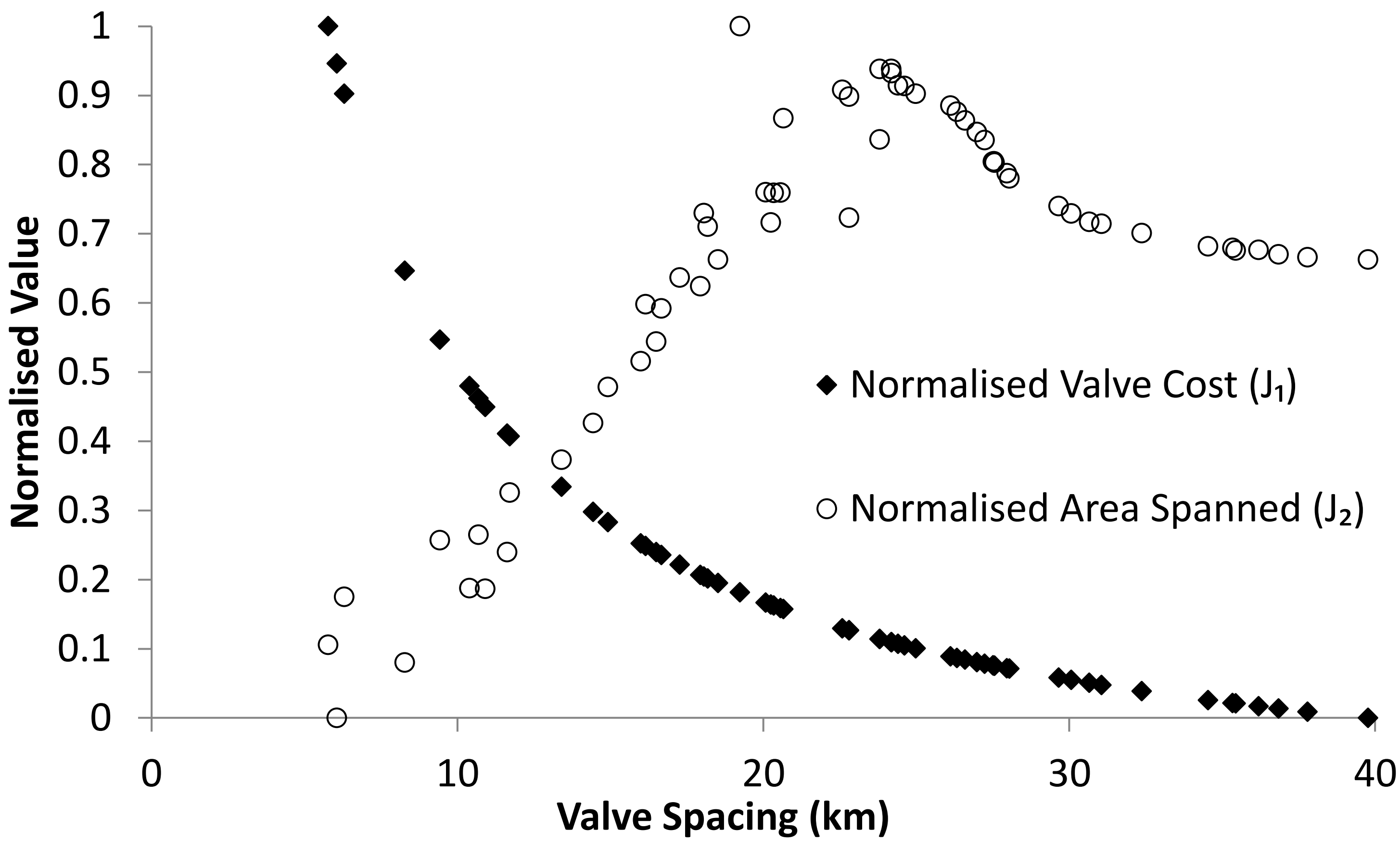


Figure 4: Normalised valve cost and area spanned by 7 % concentration

Pareto set

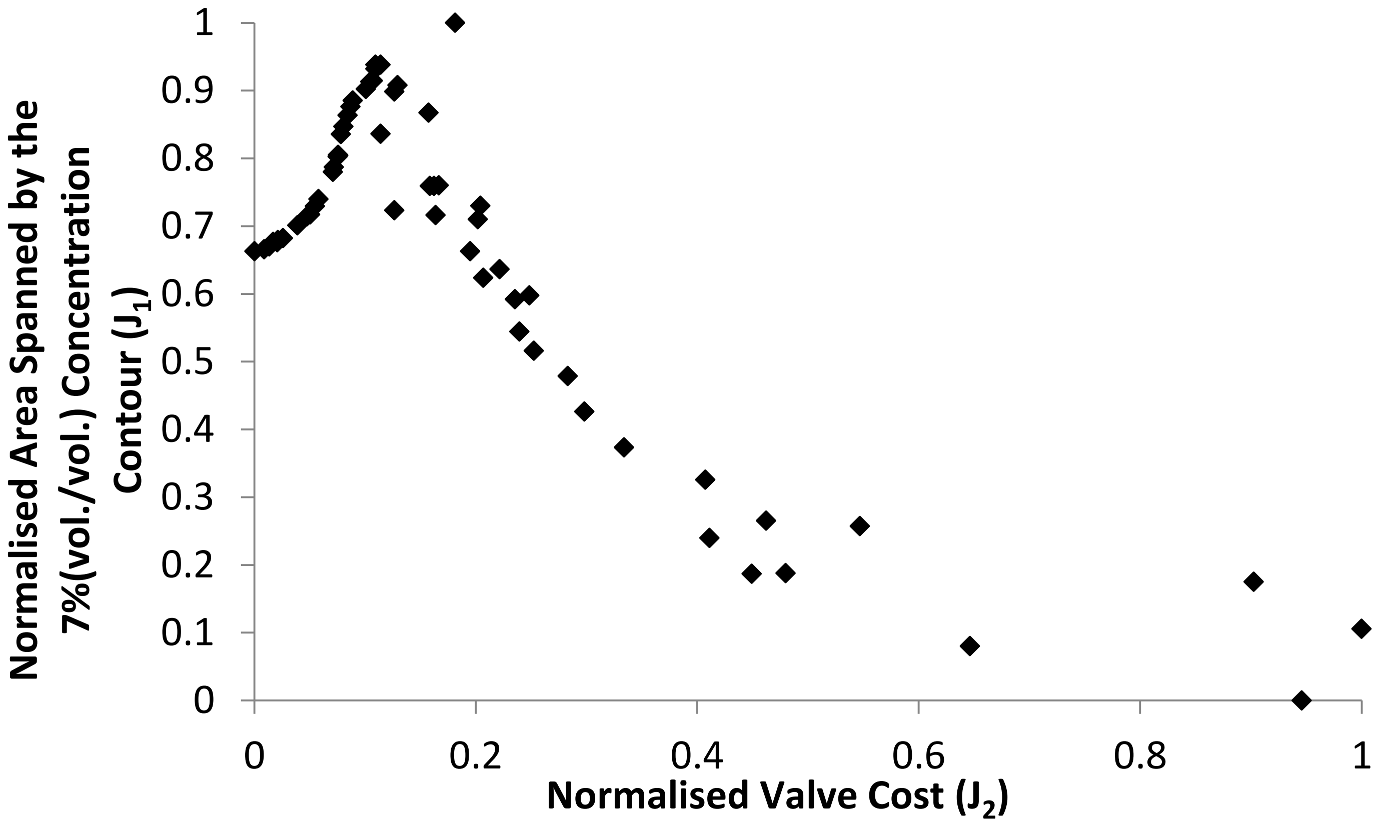


Figure 5: Normalised Pareto set

Comparison of trade-off curves

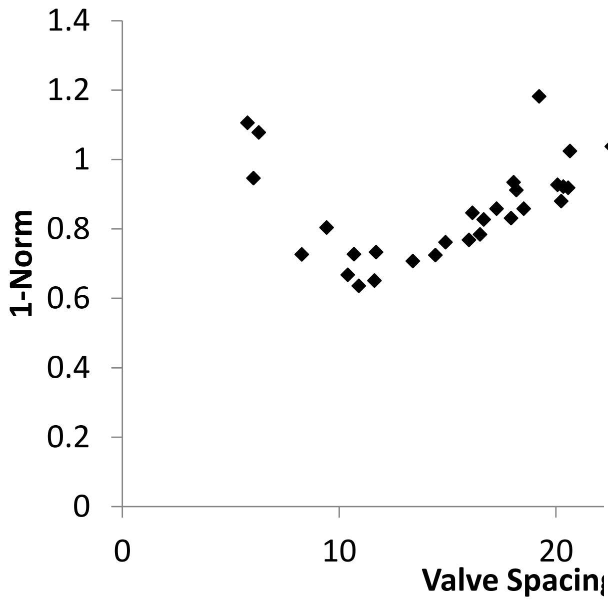


Figure 6: Results under 1-Norm

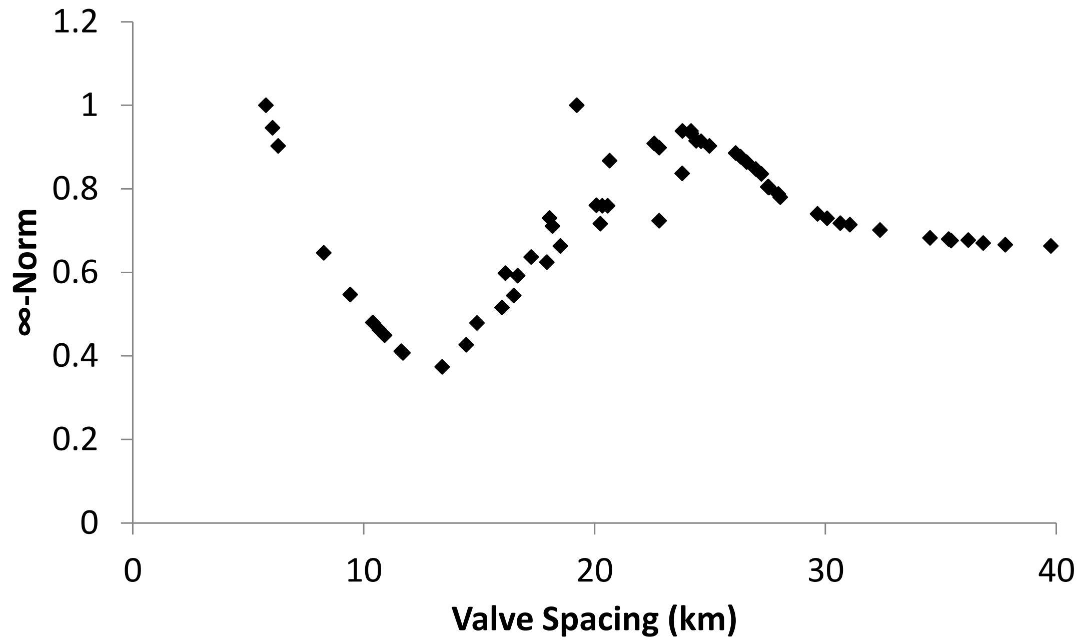


Figure 7: Results under ∞-Norm

Conclusions

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Project partners

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Thank you

Questions

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