# Is your tank inert?

## A study into the challenges of ensuring inert atmospheres

**Dr Alan Collier**

HAZARDS 31 16 November 2021

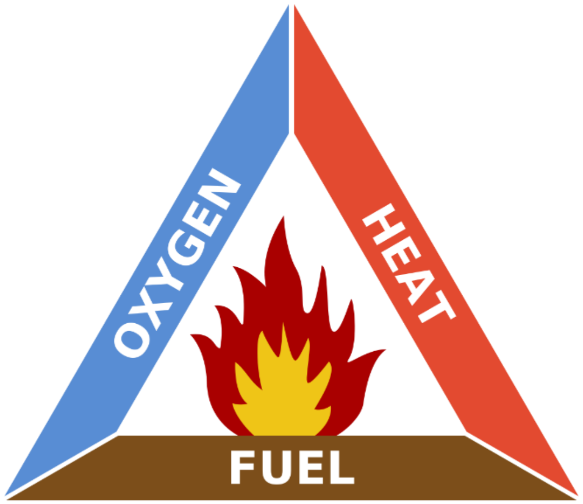
Classification: EXTERNAL USE

# Vessel inerting – the basics

- Why do it?

# Vessel inerting – the basics

- 3 things are required to have a fire or explosion



- Reaction and storage vessels with flammable liquids will always have fuel present
- It’s not always possible to remove all heat or ignition sources

- We can remove the oxygen by purging with nitrogen (or another inert gas)

# How do we remove the oxygen?

- Is there any guidance for this?
  - Yes!
    - e.g. CEN TR 15281, “Guidance on inerting for the prevention of explosions” (2006)

- For pressure / vacuum vessels we can use pressure or vacuum swing inerting

- This isn’t suitable for most storage tanks
  - Use flow-through inerting instead
  - Guidance provides a model for the time required to purge a vessel

# Purging time model

- The guidance assumes that the incoming purge gas is of “similar density” to the air in the tank
  - Exponential model assumes tank and purge gases are fully mixed

$$t = F\frac{V}{Q} ln \frac{(C_i - C_0)}{(C_i - C_f)} \qquad or \qquad \frac{C_f}{C_0} = \exp\left(-\frac{t\,Q}{F\,V}\right)\ if\ \ C_i = 0$$

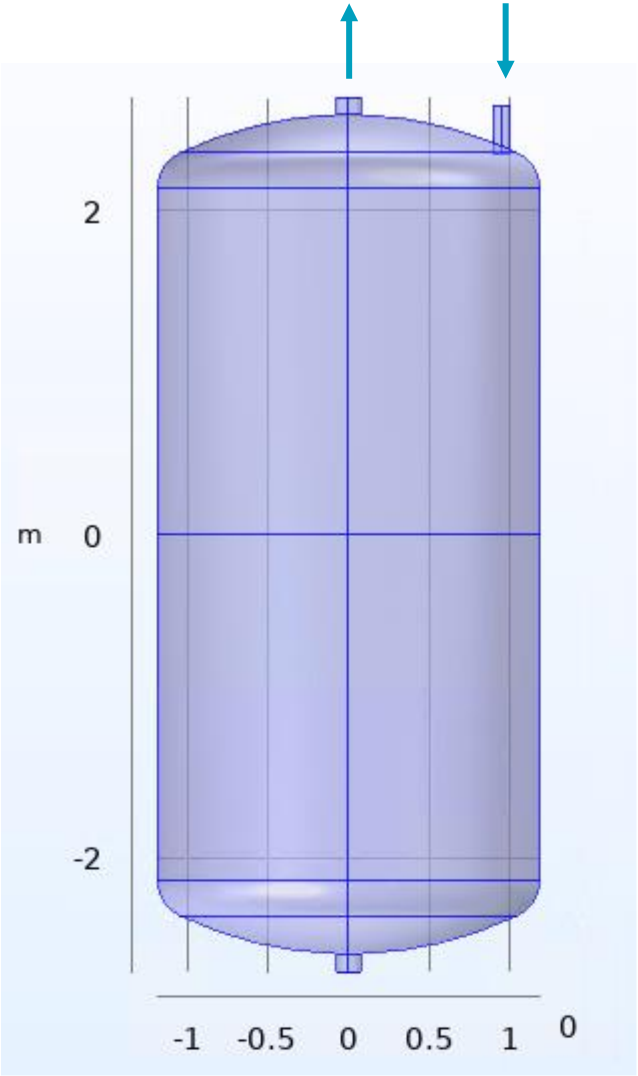
- t = time required for purging
- V = system volume
- Q = inert gas flow
- $C_f$ = required final oxygen concentration after purging
- $C_i$ = oxygen concentration of inert purge gas (commonly set as zero)
- $C_0$ = initial oxygen concentration in vessel (typically 21%)
- F = safety factor of “between 2 & 5 *depending whether the inlet and outlet are diametrically opposite*”

# Modelling a real system

- I was asked to confirm that the well-mixed model would work for a real system

- Diameter = 2.4 m
- Height = 5.2 m overall
- Torispherical ends
- Volume ~21 $m^3$

- 3”  inlet nozzle at r = 0.945 m on top head
- 6” vent nozzle central on top head
- Additional ports & access not modelled for simplicity



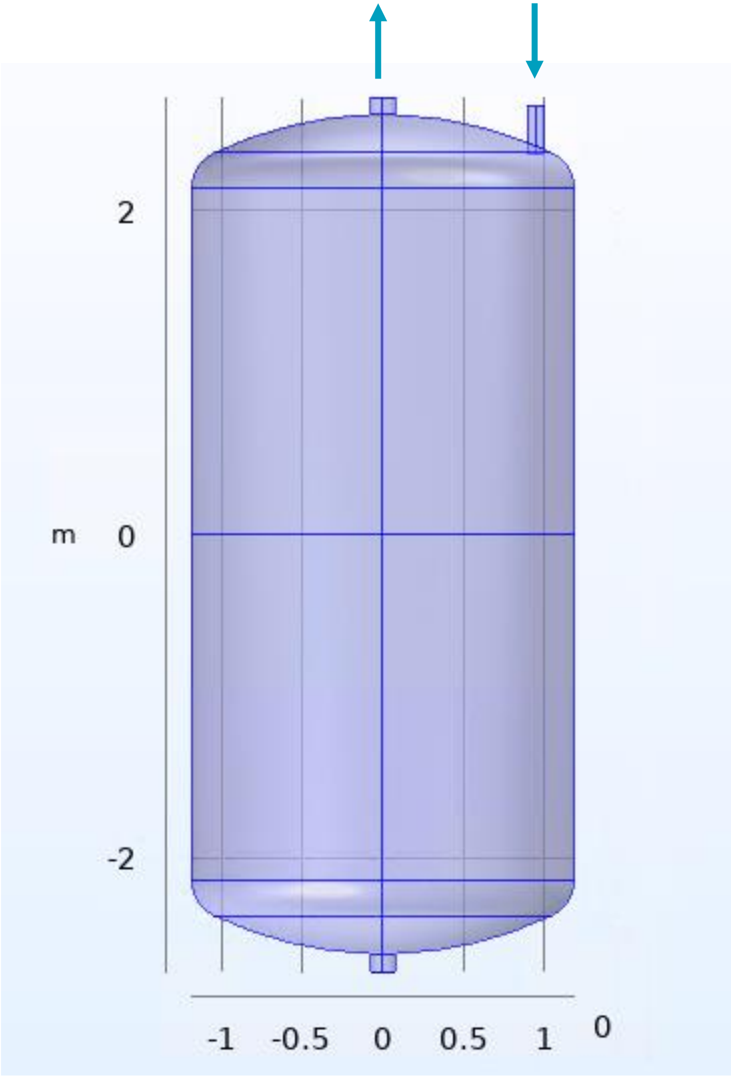
# Model parameters

- Determine mean and maximum $O_2$ concentration during purging.

- Initial T = 15 °
- $N_2$ temperature: 5, 10, 15 °C
- $N_2$ flow 20, 50, 75, 100 $m^3$/hour

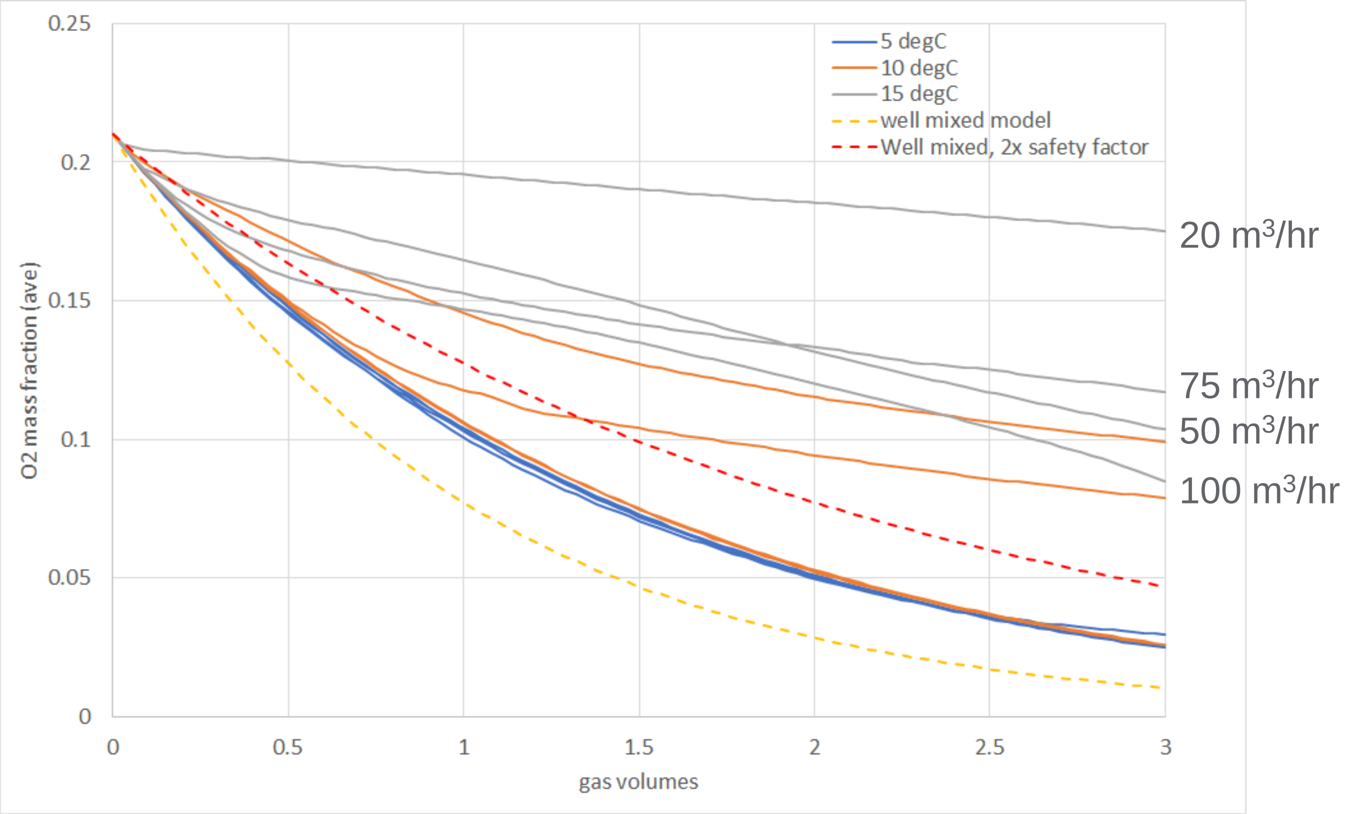
- Simulation time: equivalent to 3 tank volumes (63 $m^3$ $N_2$)

- Simulation environment: COMSOL Multiphysics®
  - Turbulent flow (k-ε model)
  - Heat transfer
  - Transport of concentrated species



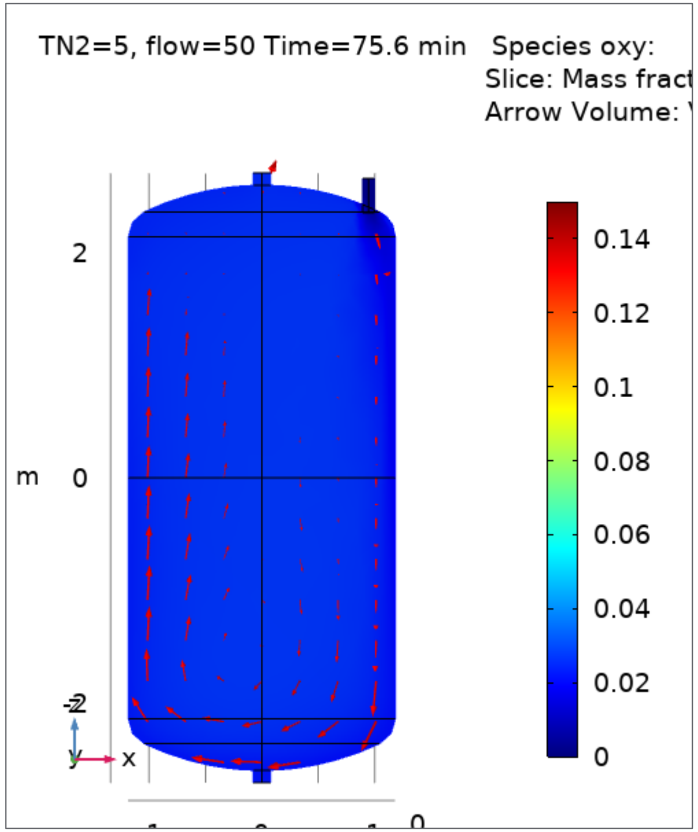
# Simulation Results

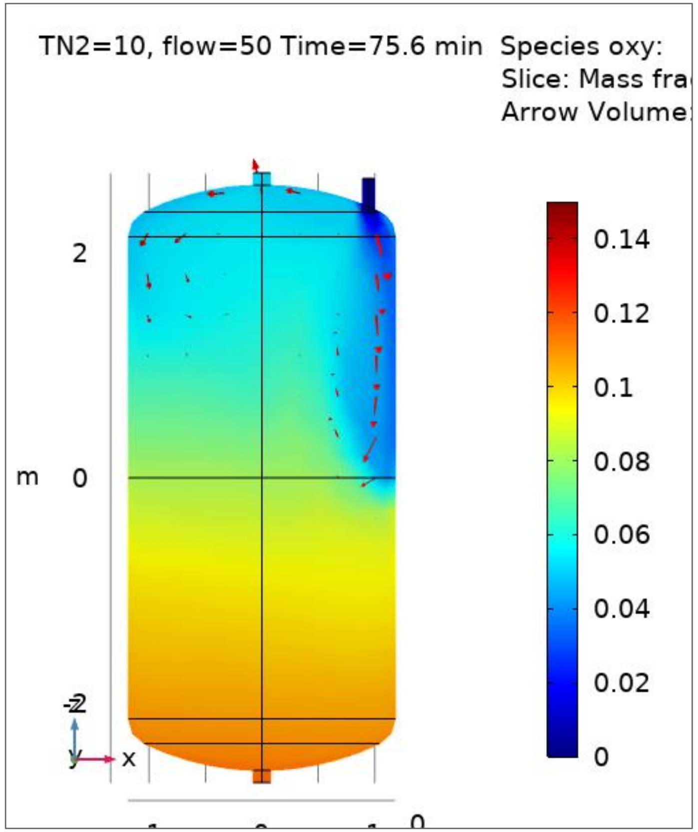
- The model shows the $N_2$ temperature has a significant effect on purging efficiency
- Purging is not effective if the inlet temperature is the same as the tank temperature
  - Nitrogen is lighter than air
- At 10 °C, a high inlet velocity is required to give good purging
  - Mixing is required
- At 5 °C, the gas velocity has no effect
  - The gases have the same density

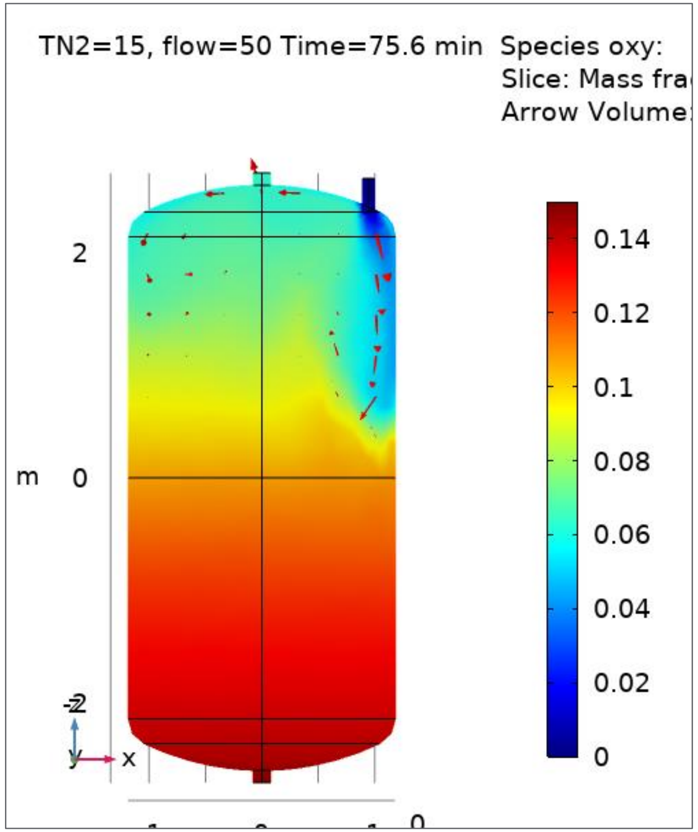


# Can we see what is happening?

- At moderate inlet velocity (2.7 m/s → 50 $m^3$/hour) the gas momentum is insufficient to overcome the difference in density between air and nitrogen unless the nitrogen is cold (5 °C)
- At 15 °C the nitrogen floats to the top and is vented with little mixing







# Flow and nozzle diameter effect

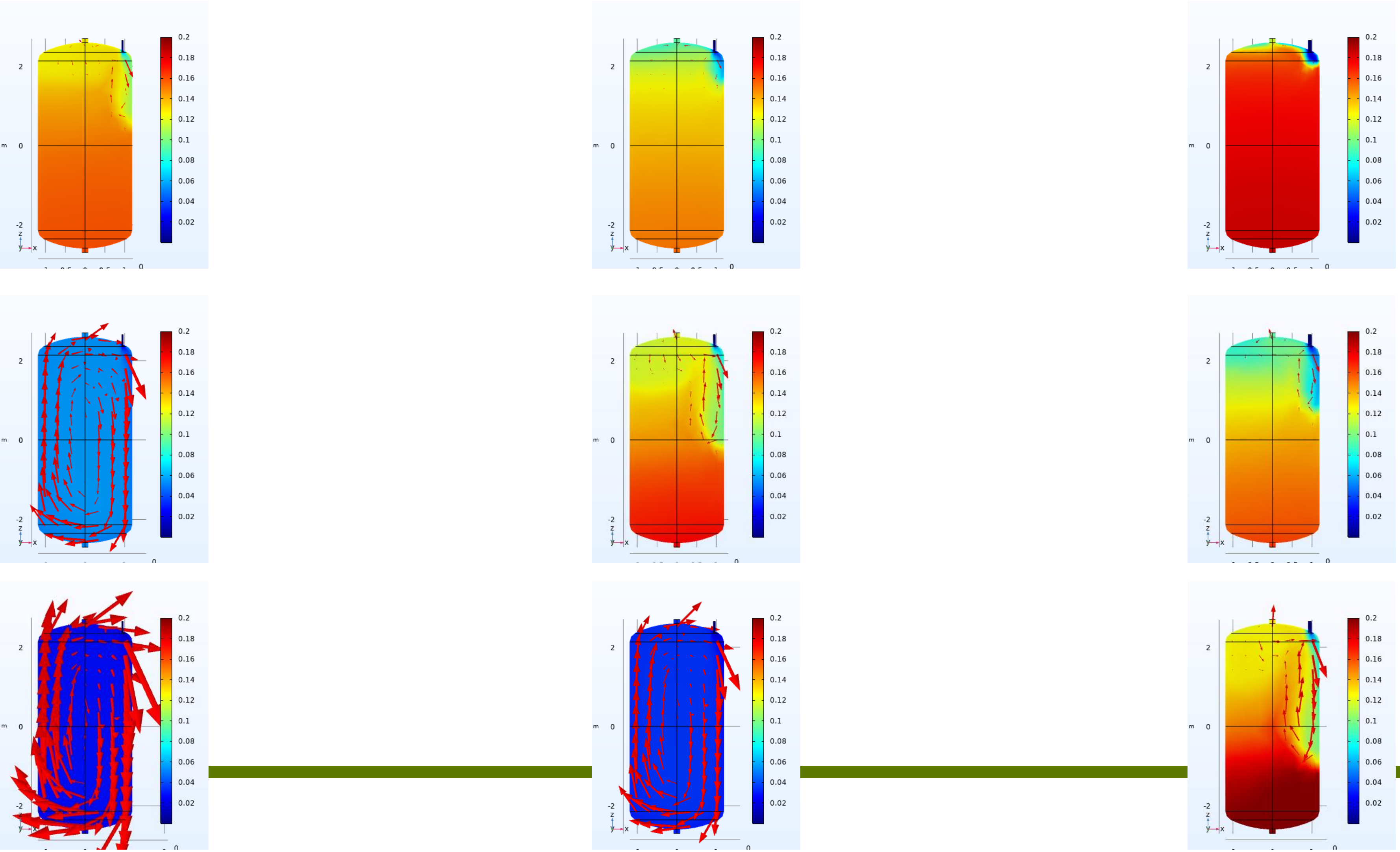
- Initial vessel T = 15 °C.  Inlet $N_2$ T = 20 °C (very buoyant)
  - Oxygen concentration and flow indicators after 63 $m^3$ $N_2$

35mm inlet  50mm inlet  75mm inlet

20 $m^3$/hr

50 $m^3$/hr

100 $m^3$/hr



# Can we put some engineering into this?

- 1966: Turner related plume height in clouds with momentum and buoyancy fluxes
- 2008: Williamson et al reformulated in terms of Froude & Reynolds numbers:

$$Fr = \frac{U_0}{\sqrt{R_0 \sigma}}$$

$$Re = \frac{U_0 R_0}{\nu_0},$$

- where $\sigma$ is a 'reduced gravity' $\sigma = g \frac{\rho_i - \rho_0}{\rho_0}$
- For 'forced turbulent fountains' (Re>~2000, Fr>~3):
  - penetration depth $Z_m$ scales as

$$Z_m = 2.4\, R_0\, Fr$$

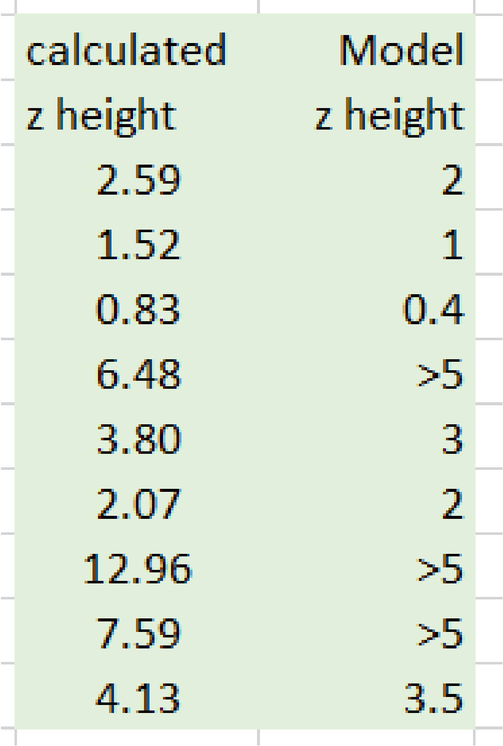
# Can we put some engineering into this?

- We can rewrite in terms of physical variables U (inlet velocity) and $R_0$ (inlet radius)

$$z = 2.4\, U \sqrt{\frac{R_0}{\sigma}} \qquad \text{where } \sigma = g\, \frac{\Delta\rho}{\rho}$$

- Compare calculation with simulations 2 slides ago

- Excellent agreement!
  - Provides some validation for the model
  - The fit is improved by reducing the constant to 1.95
- We can now put some numbers into the guidance



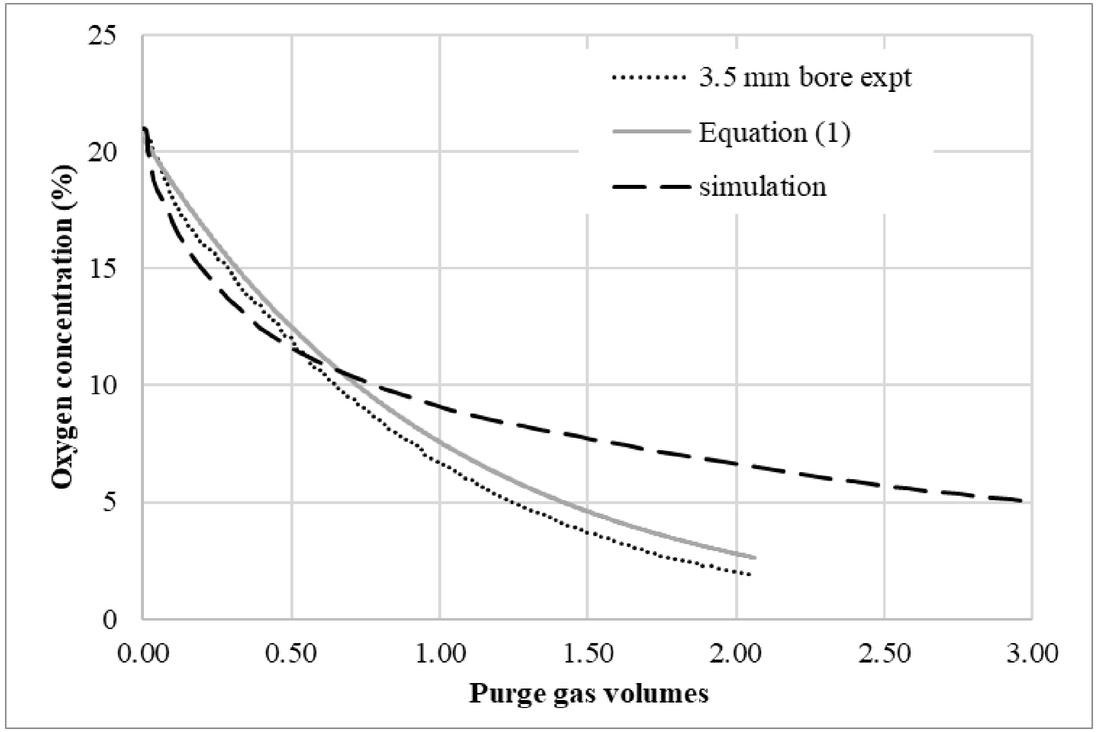
| calculated z height | Model z height |
|---|---|
| 2.59 | 2 |
| 1.52 | 1 |
| 0.83 | 0.4 |
| 6.48 | >5 |
| 3.80 | 3 |
| 2.07 | 2 |
| 12.96 | >5 |
| 7.59 | >5 |
| 4.13 | 3.5 |

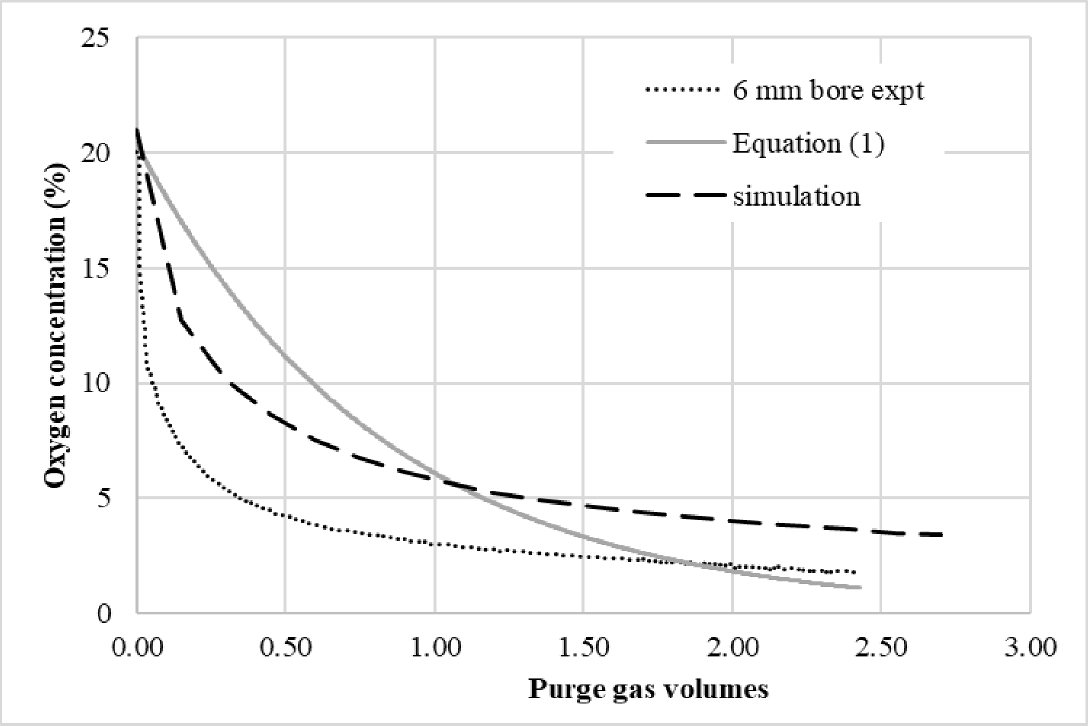
# Back to the real world

- Validating the simulations against manufacturing assets is challenging!
  - Inerting is only performed occasionally
  - Understanding of $N_2$ flows and inlet geometries is often poor

- Initial work completed using 20L lab vessel
  - 1:10 linear scale-down of simulated vessel
  - 3.5 and 6.0mm inlet diameters used
  - Oxygen concentration measured at outlet

# Validation of the model and correlation





- Narrow inlet tube, 1 L/min
- Experiment follows 'well mixed' curve
- Calculated plume depth only half vessel height

- Wide inlet tube, 1 L/min
- Experiment shows extensive bypassing
  - Vessel is poorly inerted

# Summary

- It can be difficult to purge tall vessels if the inlet and vent are both at the top
  - Venting through the bottom runoff valve gives better ‘flow-through’ in this case

- An inlet jet with sufficient momentum is required to ensure good mixing with the air in the vessel

- We can calculate the plume depth
  - Must be greater than the vessel height to prevent stratification and poor inerting

- Knowledge of the purge gas flowrate and inlet geometry are essential
  - A temperature measurement would also be useful

- Better process knowledge leads to improved safety!