EMULSION TANKER TRUCK HEATING MODELLNG

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Acknowledgement:

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TOPICS

- Background
  - Koenen and Vented Pipe Tests
  - Introduction of MBP for certain ANEs
- Modelling basis
- Results
- Proposal

ANE V2P: HIGH BOILING POINT PARAFFIN OIL

CONTEXT (CONT'D)

Figure 18.6.1.3: Examples of effect types D, E and F

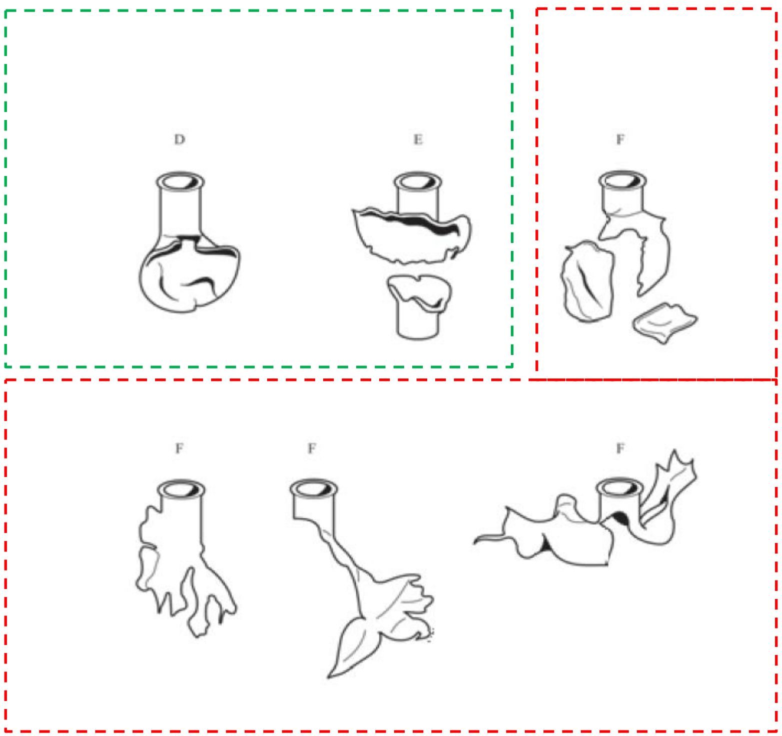
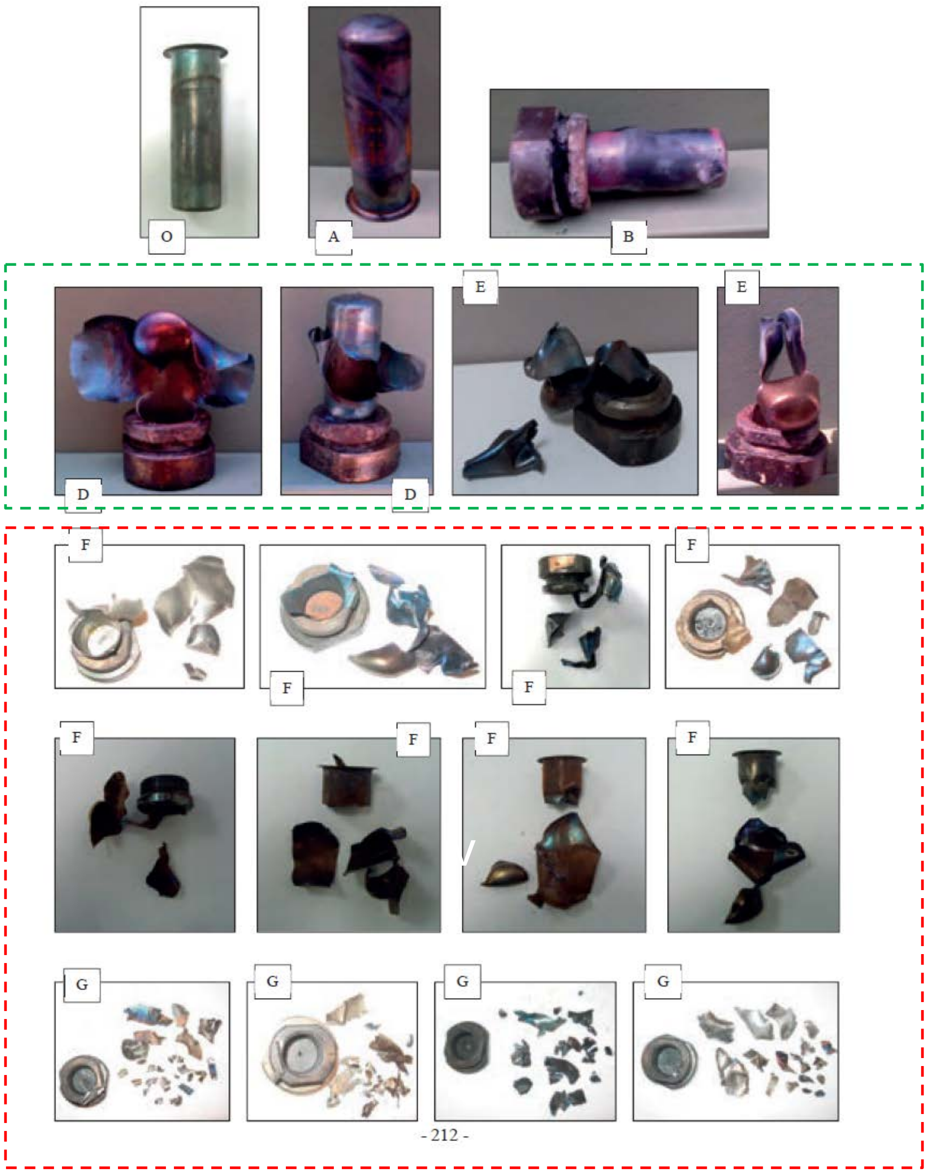


Figure 18.6.1.4: Examples of Koenen test results



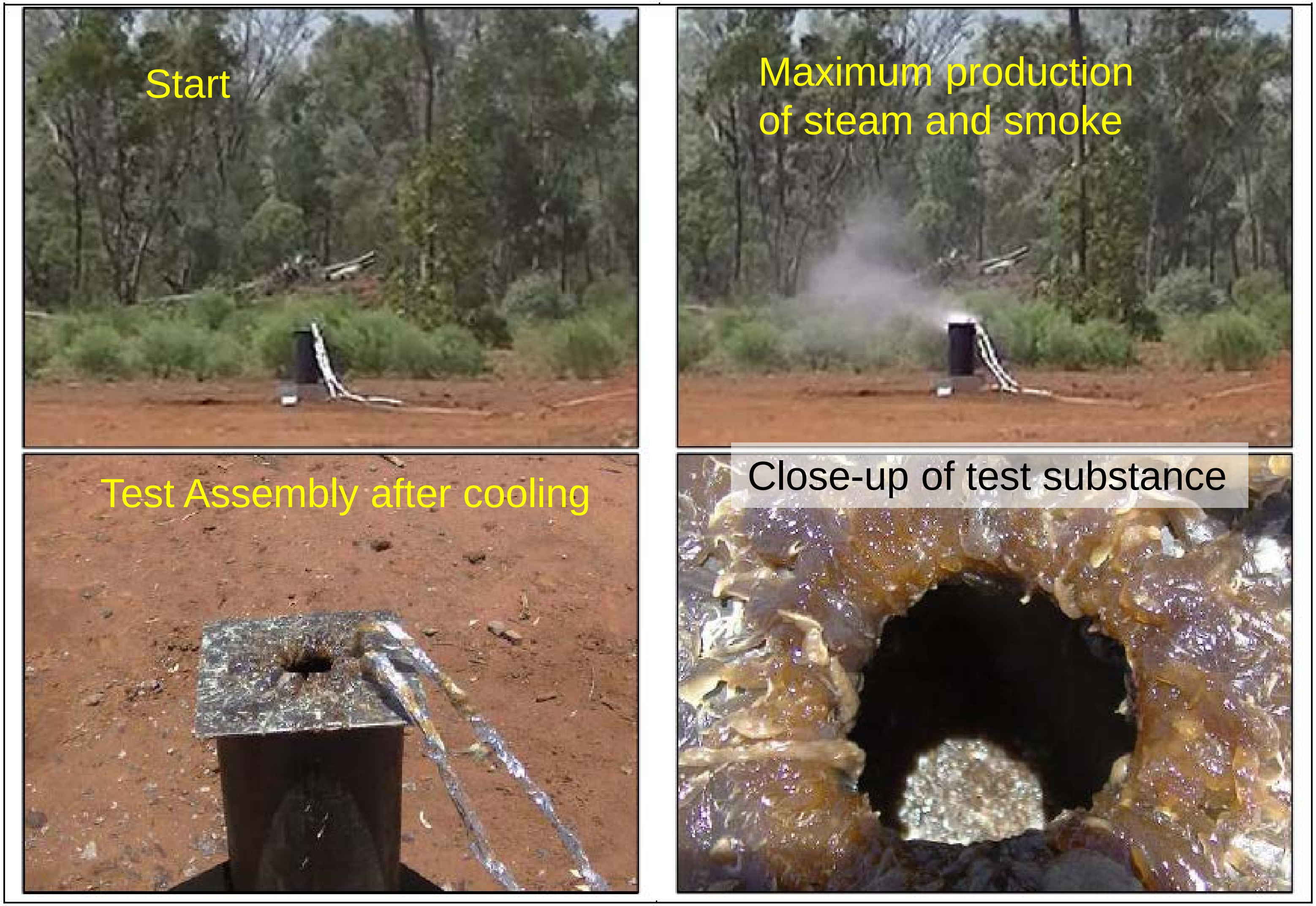
CONTEXT

- Certain ANEs were shown to give false positives in 8(c) Koenen Test
- The 8(e) Minimum Burning Pressure (MBP) Test was introduced.
  - Criteria are >60 seconds reaction time
  - Water content 14% or more
  - MBP > 5.6Mpa
- These ANEs must also pass 8(d) Vented Pipe Test to be transported in bulk in portable tanks
- The 8(d) is larger scale Koenen Test where effect of mass was to be determined

CONTEXT (CONT'D)

- Unlike Koenen Test, 8(e) does not measure an effect but property of substance, which is invariant with scale.

ANE in 8(d)(ii) Test



CONTEXT (CONT'D)

Modelling:

- A numerical model was developed for portable ANE tank
  - based on fundamental equations of physics
  - measured physical parameters or those based on correlations widely accepted within literature
  - no adjustable parameters
- Model was to answer two questions:
  - Can it reproduce what incidents in the field have reported?
  - Will it answer question of whether heat transfer can be attributed to scale, or physical properties alone?

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ANE TEST WITH AL TANK

Figures Referred to in this document

Figure 1. Figures taken from UN/SCETDG/21/INF.20 showing the aluminium tanker test with ANE, carried out in Kuosanen, 2002

The tank was made of aluminium (5 mm wall thickness) and equipped with four separate compartments. Only one compartment was used (5 m^3) in the test and it was the one above the four double tires, at the end of the tank (see Figure 1-1). The compartment was filled with 6 000 kg (4.3 m^3) of emulsion matrix.

Figure 1-2 shows the burning tanker and Figures 1-3 and 1-4, the tank after the fire.

Figure 1-1: The tank before the fire.

Figure 1-2: The tank during fire. White smoke indicates decomposing emulsion matrix.

Figure 1-4: The tank after the fire (rear view)

Figure 1-3: The tank after the fire (side view).

ANE Transport Incident – Australia

March 12, 2018
Queensland

- Driver tried to extinguish fire using 8X9kg Dry Chemical Powder
- Another vehicle stopped to assist, but fire could not be contained
- Fire spread to all 12 tyres on trailer

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ANE Transport Incident – USA

- **Tractor pulling tanker trailer blew its front tire**
- **Driver lost control of vehicle crossing median striking three other vehicles en route.**
- **Cab caught on fire while crossing median.**

July 12, 2018
Highway I-85, South Carolina

TRANSPORT FIRE INCIDENT, SOUTH CAROLINA, USA, JULY 12, 2018

SAFEX IN18-08

- Tractor pulling tanker trailer blew its front tire
- Driver lost control of vehicle crossing median striking three other vehicles en route.
- Cab caught on fire while crossing median.

- Minor injuries to driver and struck vehicles' occupants.
- Residents evacuated to 1-mile radius.
- ANE transferred to another tanker once fire was put out.
- ANE had 18.26% water

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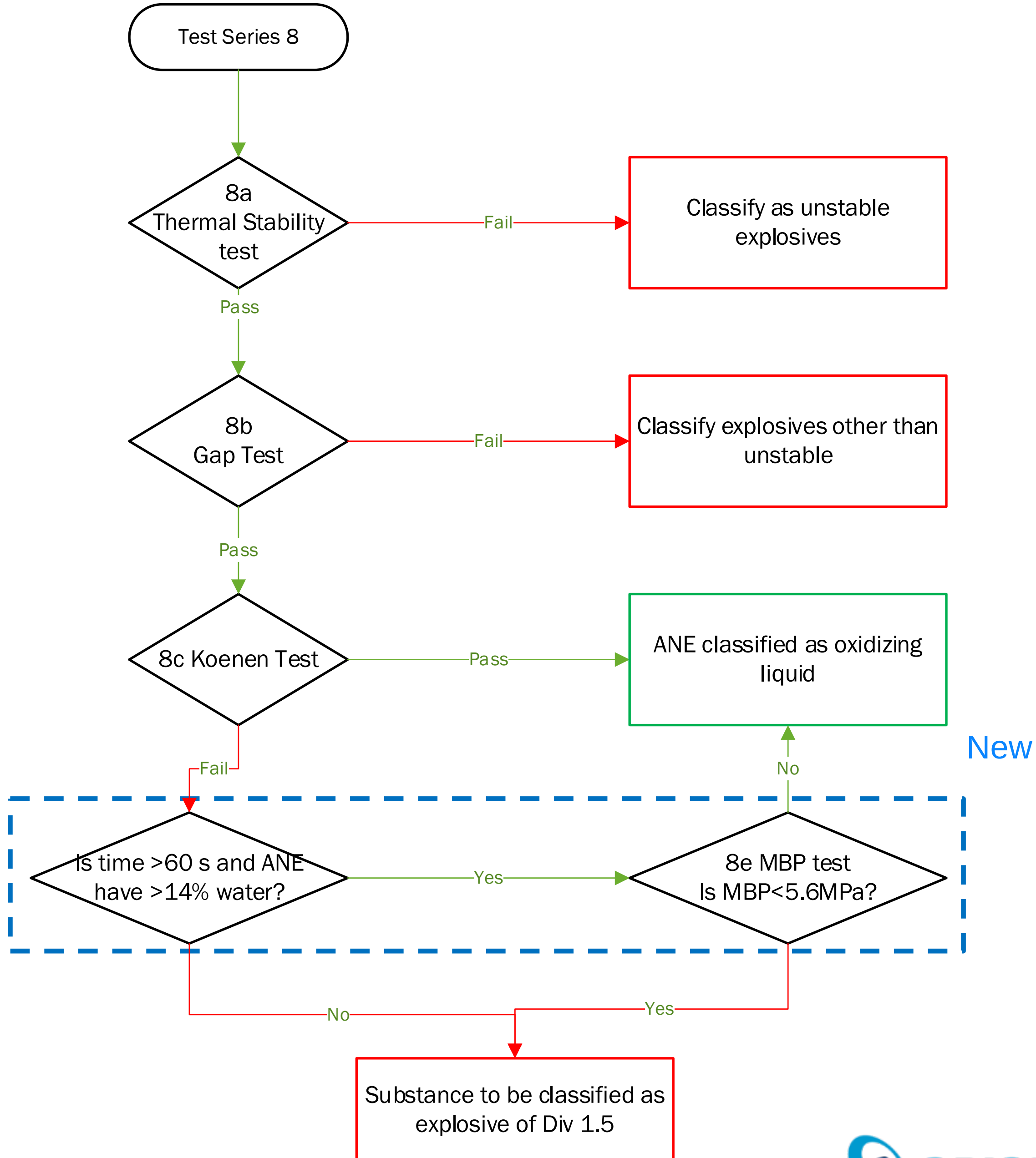
USA, DEC. 2005
SENSITISED AN EMULSION

- Fire began in the engine area
- 3 extinguishers were emptied
- Area Evacuated
- 4,000lb sensitized emulsion in truck
- Emulsion near heated area was crusted up. Rest was pumped out.

Test Series 8



MODELLING

- Group of representatives from the IME, DOT and DOT contractors along with Orica developed physics for model
  - Include ullage
    - Multiphase flow – level set method
    - One model presented here: 10% ullage (90% filled with emulsion)
  - Free convection
    - Turbulent flow – y-algebraic model
    - Non-Newtonian flow in emulsion phase – Carreau fluid
    - Boussinesq approximation for buoyant flow
    - Darcy Law source term for solidification – crust formation
  - Heat transfer
    - Convection and conduction
    - Reaction
    - Crust formation – vaporization of water using apparent heat capacity method
  - Mass transfer
    - Convection and diffusion
    - First order reaction kinetics
      - Separate kinetics for emulsion and crust phase
  - COMSOL Multiphysics used in modelling

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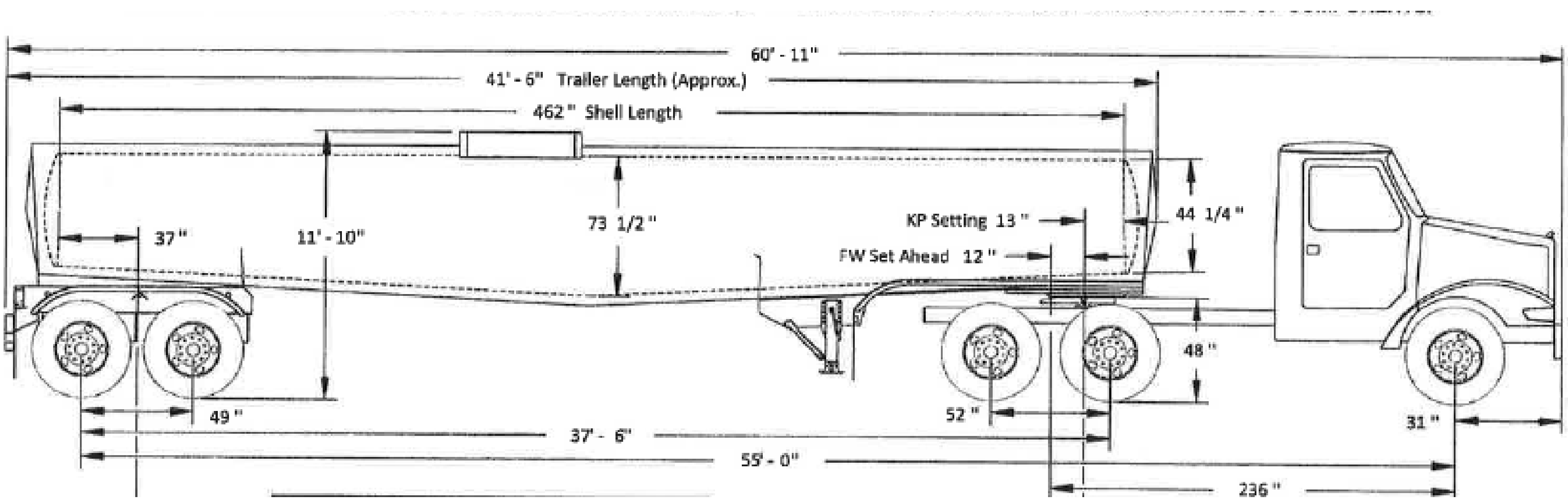
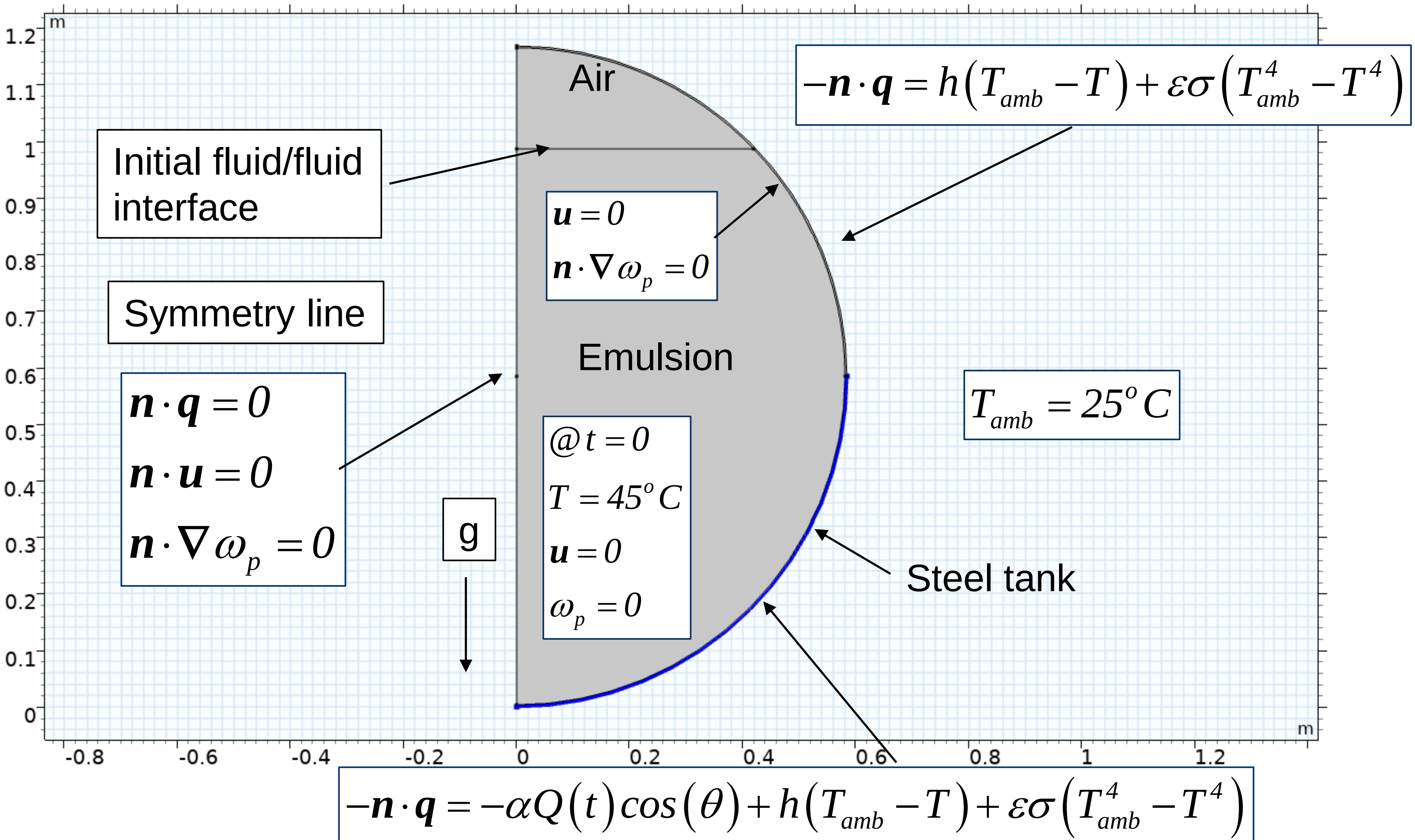
EMULSION TANKER TRUCK HEATING MODEL –GEOMETRY

– 2-dimensional planar symmetric model developed
– Position directly over burning tires chosen

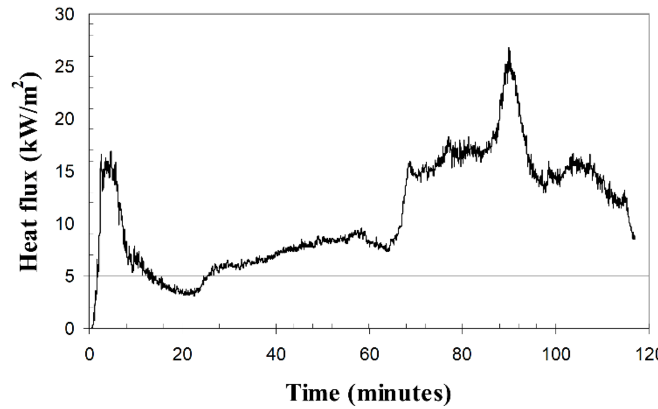


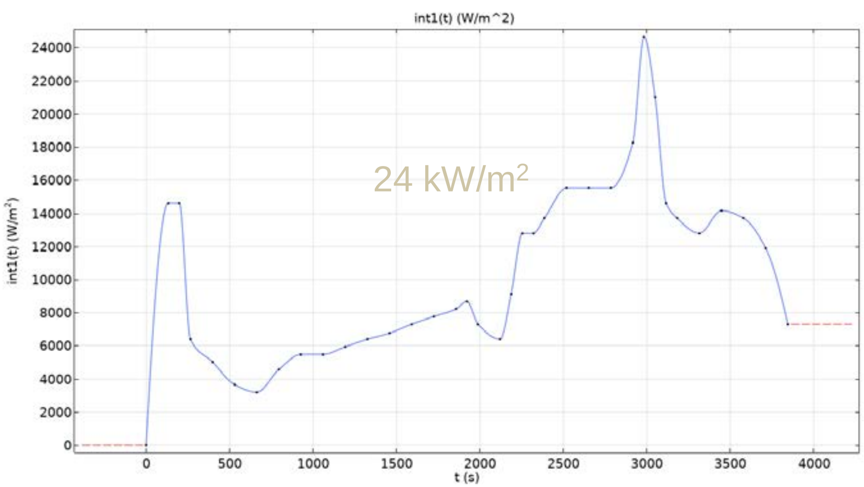
MODEL BOUNDARY AND INITIAL CONDITIONS

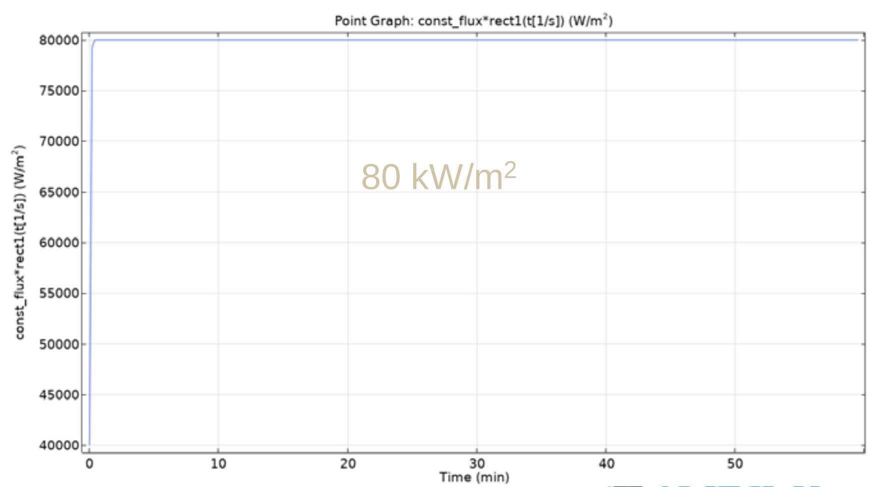


MODELLING HEAT FIRE HEAT FLUX

Figure 9 A photo taken after 4:16 minutes from ignition. The heat release rate is about 2 MW. The peak heat release rate was 2.3 MW, reached at 3 minutes after ignition.







MODELLING OUTPUT -10% ULLAGE; PEAK HEAT FLUX 24 KW/M^2

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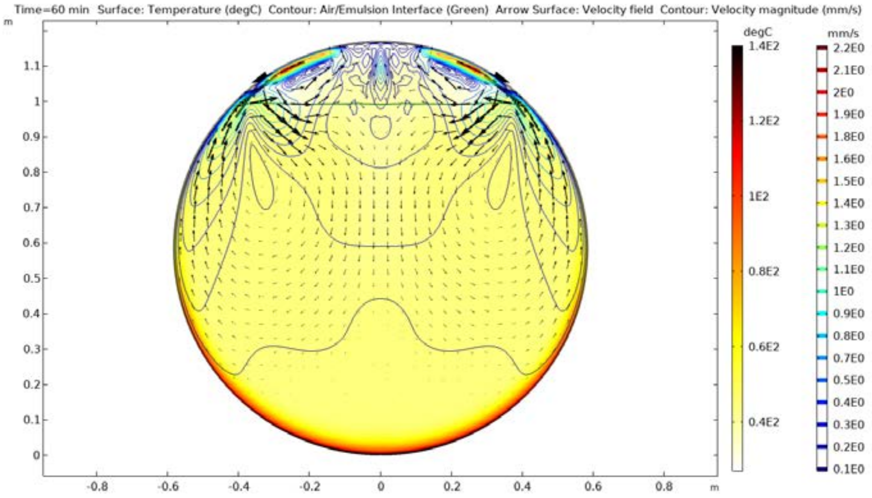
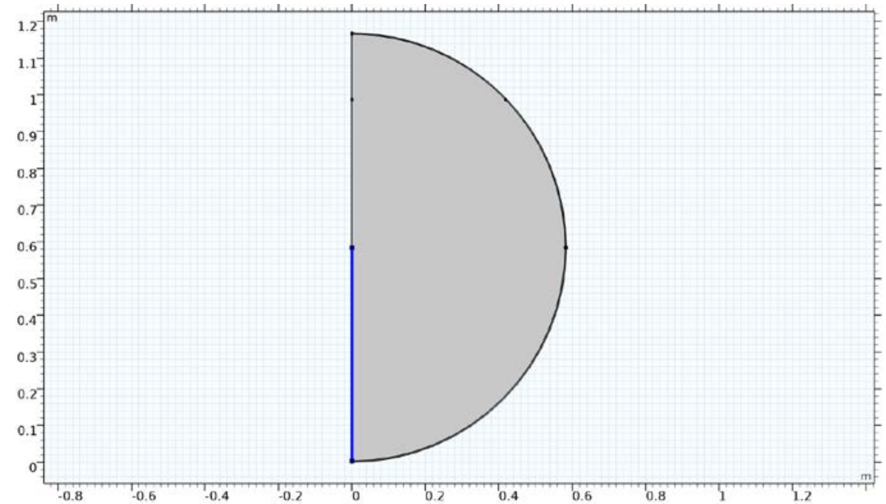
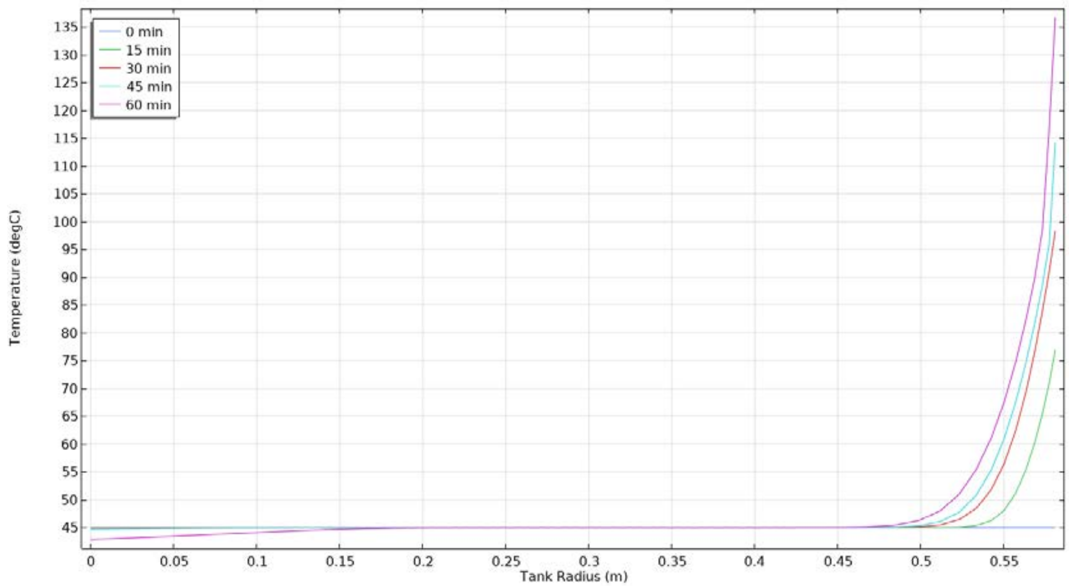
TEMPERATURE PROFILE FOR 10% ULLAGE AND PEAK HEAT FLUX OF 24KW/M^2

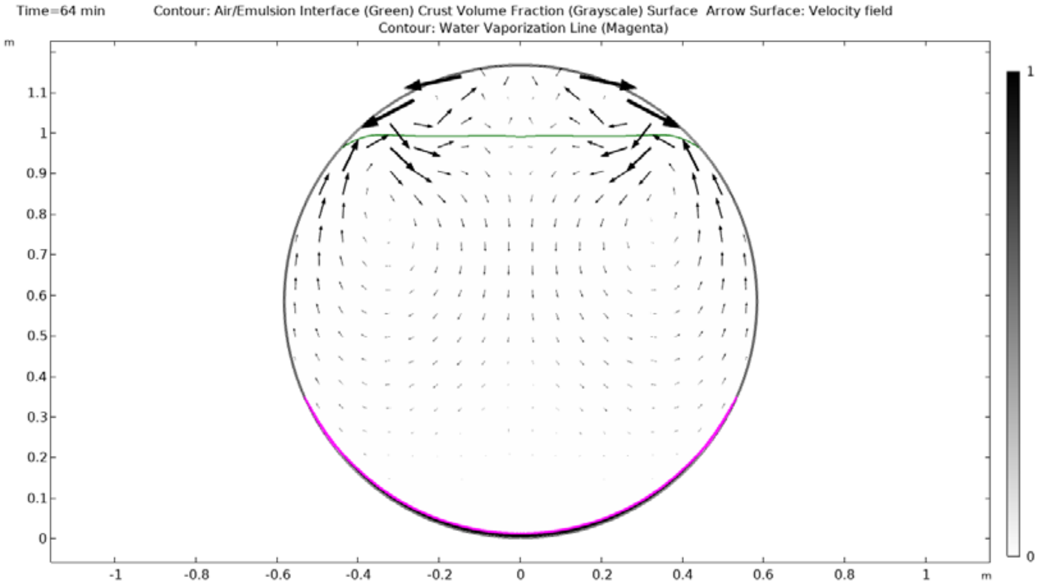




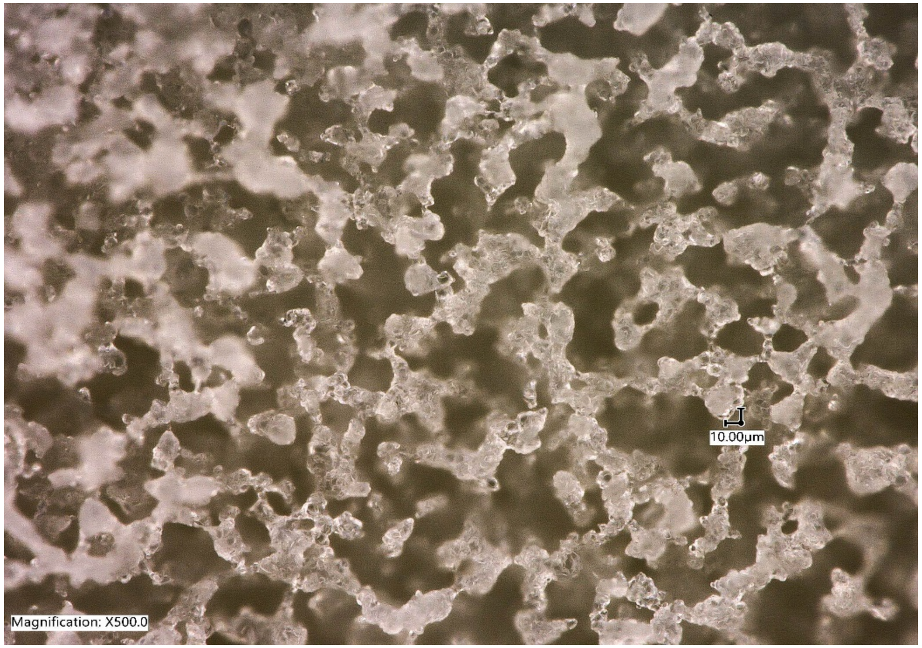


- Heat penetrates 10% of emulsion at most
- Temperature exceeds vaporization point of water after 30 minutes
- Convection plays negligible part in heat transfer due to viscous buoyant flow
- Ullage plays no place in heat transfer

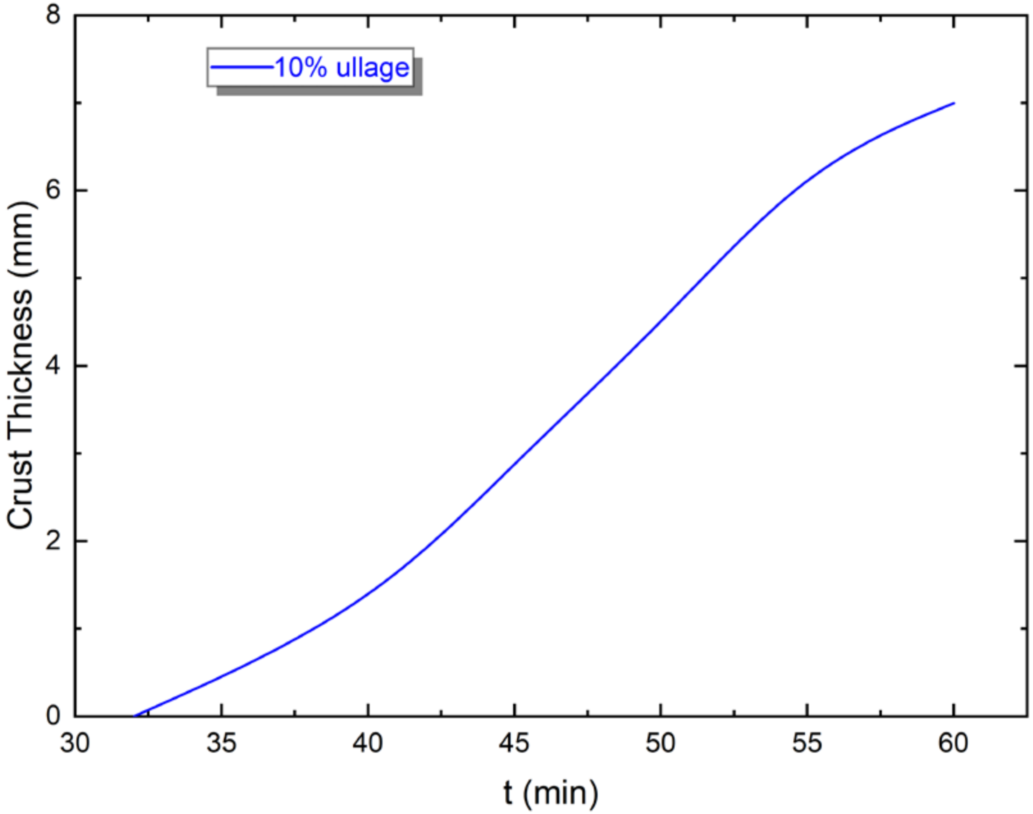
CRUST FORMATION FOR 10% ULLAGE AT PEAK HEAT FLUX OF 24KW/M^2



Laboratory crust sample optical micrograph with focus bracketing



CRUST FORMATION FOR 10% ULLAGE AT PEAK HEAT FLUX OF 24KW/M^2

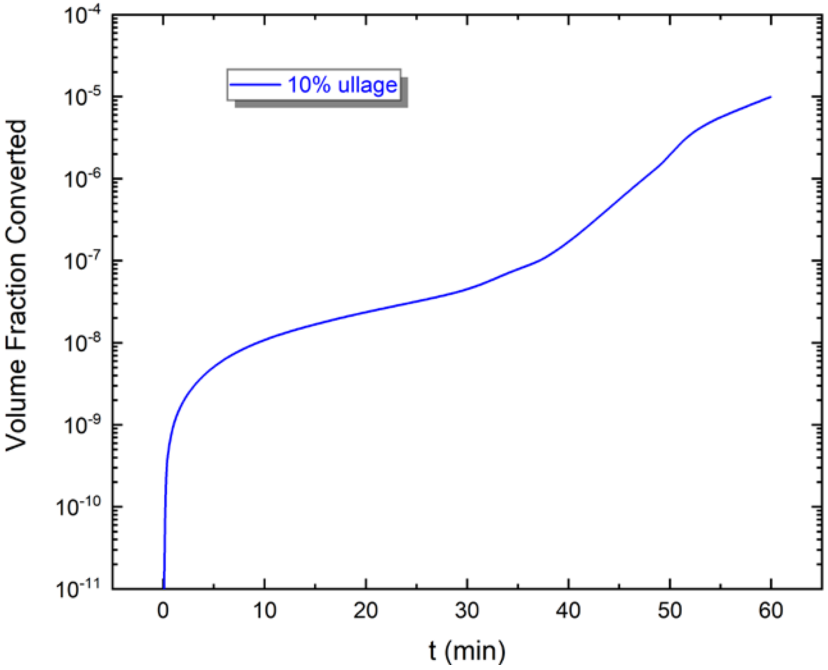


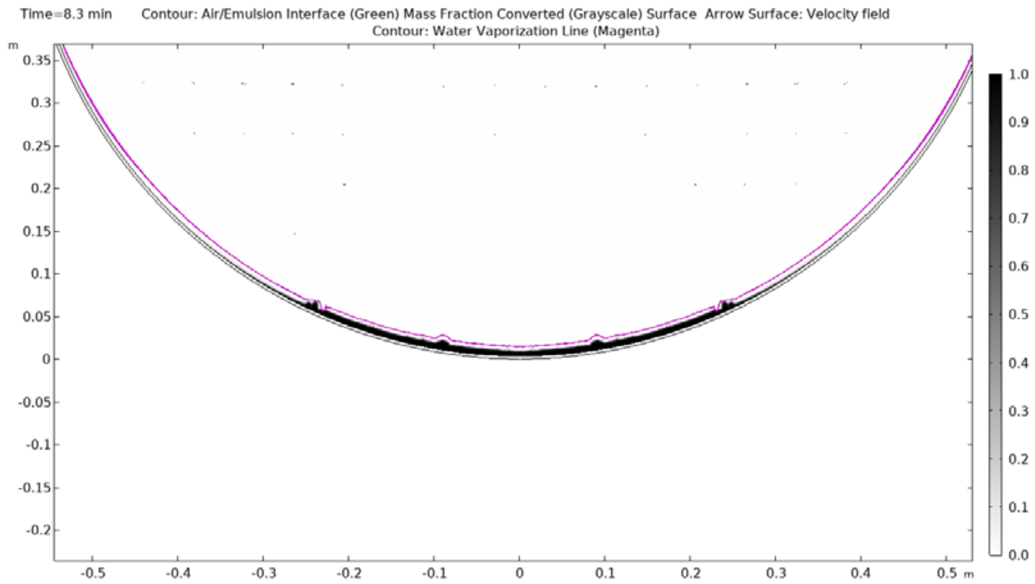
- Crust found in tanks is of order of single centimeters
- Model prediction consistent with thermal diffusion lengthscale

$$L_{Therm\ diff} = \sqrt{D_T t}$$
$$= 10\, mm$$

- This is consistent with that measured from incidents in the field

REACTION CONVERSION FOR THE 24 AND 80KW/M^2 HEAT BOUNDARY FLUX





- For 24kW/m^2 case, fraction converted is negligible
- For constant 80kW/m^2 case, reaction rates increase rapidly, and solver takes small timesteps at 8.3 min
  - Reactions are constrained to crust phase
  - Emulsion ignites not propagates - other models to predict these physics
  - This flux is an unrealistic condition, only appropriate for large diesel fires and experiments
- This indicates temperature profiles are dominated by formation of crust and reaction rates
- Since crust dimensions can be predicted by thermal diffusivity alone, the temperature profile is a function of physical properties, not scale and the MBP is the appropriate test

SUMMARY

- Modelling work show conformance to field observations of transport fires involving ANEs
- ANEs transported today typically have high water content which translates to high Minimum Burning Pressure
- Distribution of heat is suppressed in emulsions due to physical properties:
  - Emulsion solidifies before it reacts
    - crust thickness is two orders of magnitude smaller that tank radius
    - thermal diffusivity decreases by crust formation resulting in temperature of bulk mass almost unchanged, and hence its MBP is also unchanged.
- Work to complete
  - Complete simulations for aluminum tank melting
  - Publish the work in a peer reviewed journal

Thank you/Merci

