Pulsating flame spread over a n-propanol pool at sub-flash temperatures

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Introduction

Courtesy of Prof. Jie Ji, SKLFSS, USTC

Numerical framework based on OpenFOAM

- Gas phase (flame spread)
  - Compressible solver with buoyancy effect used for directly solving flame dynamics;
- Liquid phase
  - Incompressible solver with buoyancy effect and viable properties developed in [1]
- A finite-rate one-step chemical reaction for combustion.

1. Xu, Baopeng and Wen, Jennifer X. (2020) The effect of convective motion within liquid fuel on the mass burning rates of pool fires – a numerical study. Proc. Combust Inst. Vol. 38. (In press)

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The 'film theory' based evaporation model [2]

Used in [1] and by many others, neglecting effect of liquid motion on evaporation.

The evaporation rate:

$$\dot{m}'' = h_m \frac{p}{R_f T_g} \ln\left(\frac{X_{f,g}-1}{X_{f,l}-1}\right)$$

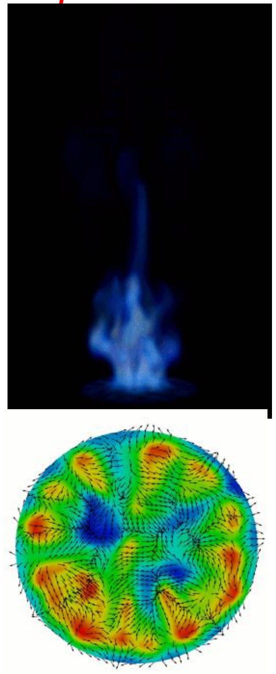
The fuel vapor equilibrium pressure at the surface temperature T_s

$$X_{f,l} = exp\left[\frac{\Delta H_v}{R_f}\left(\frac{1}{T_s} - \frac{1}{T_b}\right)\right]$$

The mass transfer coefficient:

$$h_m = \frac{Sh \cdot \mu_f}{L \cdot Sc \cdot \rho}$$

2. T. Sikanen, S. Hostikka, Fire Saf. J. 80 (2016) 95–109.



Predicted pool surface flow and pulsating pool fires [1]

1. Xu, Baopeng and Wen, Jennifer X. (2020) The effect of convective motion within liquid fuel on the mass burning rates of pool fires – a numerical study. Proc. Combust Inst. Vol. 38. (In press)

Interface

- **Mass exchange** (*newly implemented in in-house OpenFOAM*)
  - A diffusion evaporation model based on equilibrium assumption used for at the interface

- Momentum exchange
  - A thermocapillary model
- Energy exchange
  - A conjugate heat transfer model with in-depth radiation and evaporation sink

Computational conditions

Fuel region (n-propanol)

Pressure 0.1 MPa

Temperature 287, 290, 293 K

Width 20 mm

Fuel depth 2, 5, 10 mm

Walls adiabatic

Gas region (Ambient air)

Pressure 0.1 MPa

Temperature 293K

Width 40 mm

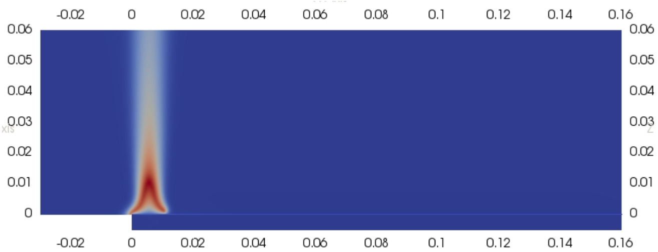
Mesh

3 million (20 microns at the interface)

Ignition

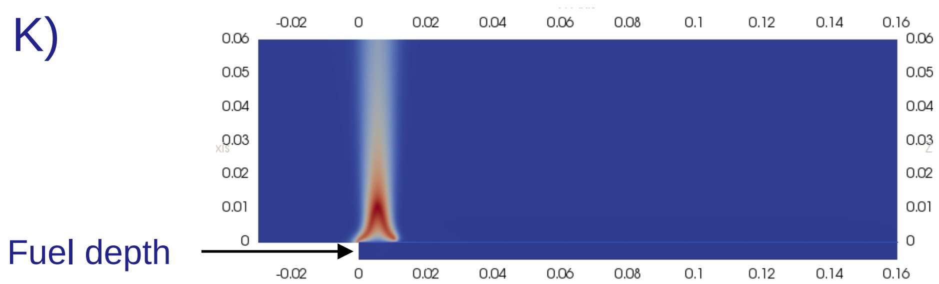
Pilot flame

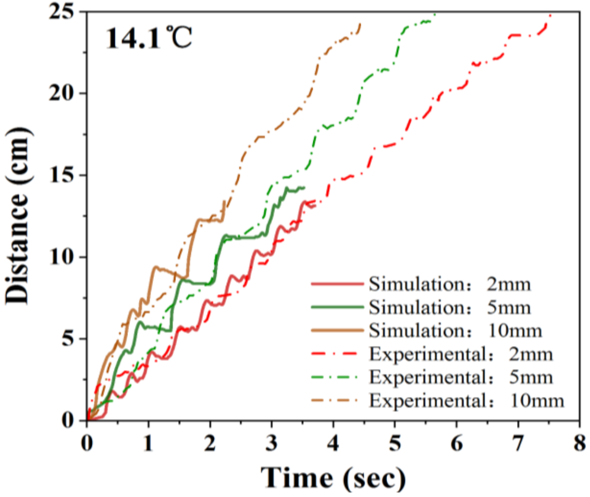
3. FJ Miller, HD Ross, Further observations of flame spread over laboratory-scale alcohol pools,, Symp. (Int) on Combus 24 (1), 1992.

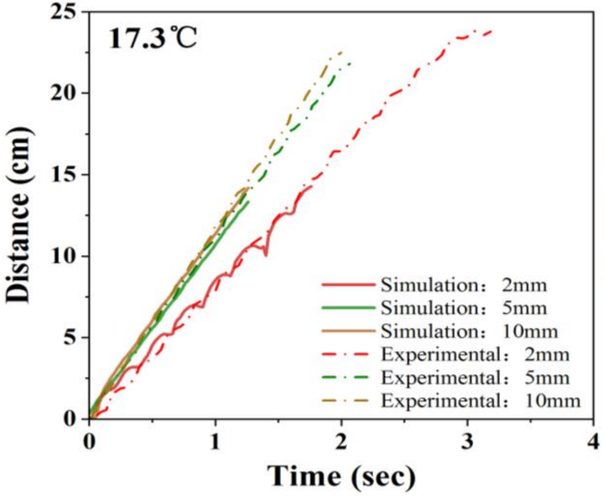


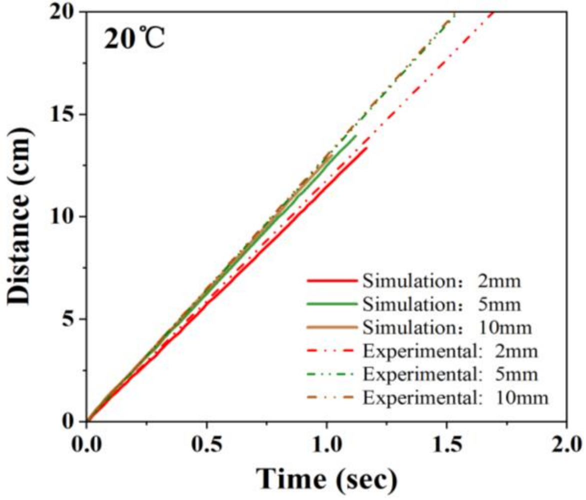
Predicted and measured flame edge location *vs* time for different fuel depths and initial temperatures

Flash point of n-propanol: 25 ^{0}C (298 K)

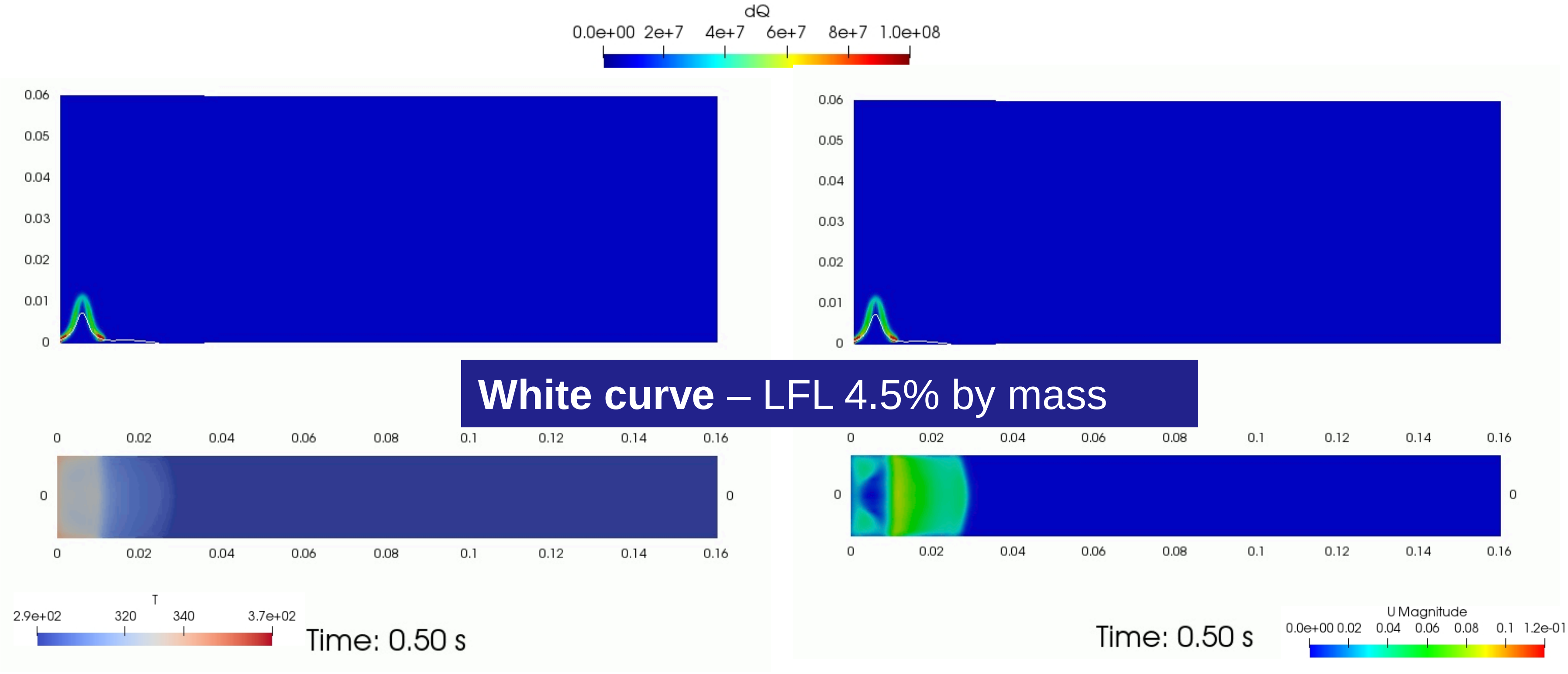






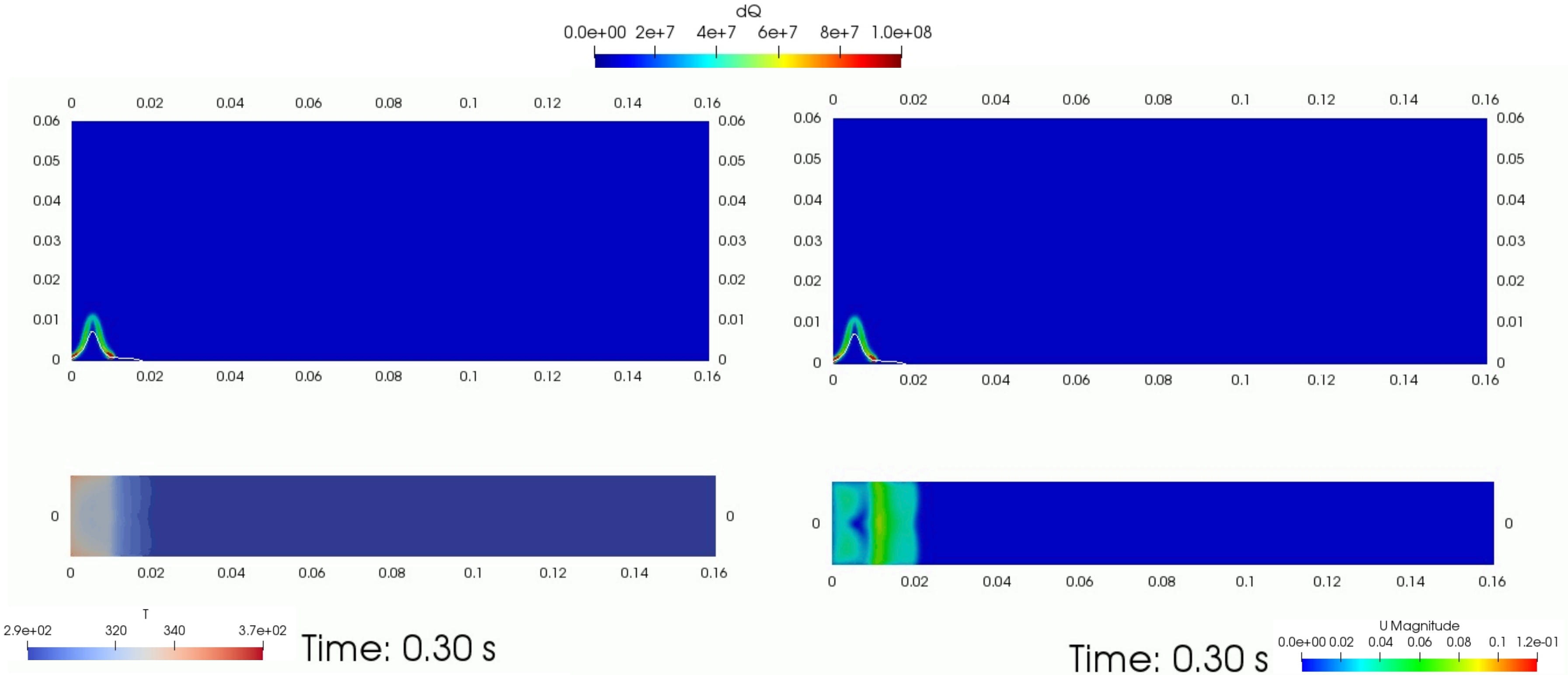


Pulsating spread (287 K)



White curve – LFL 4.5% by mass

Pulsating spread (290 K)



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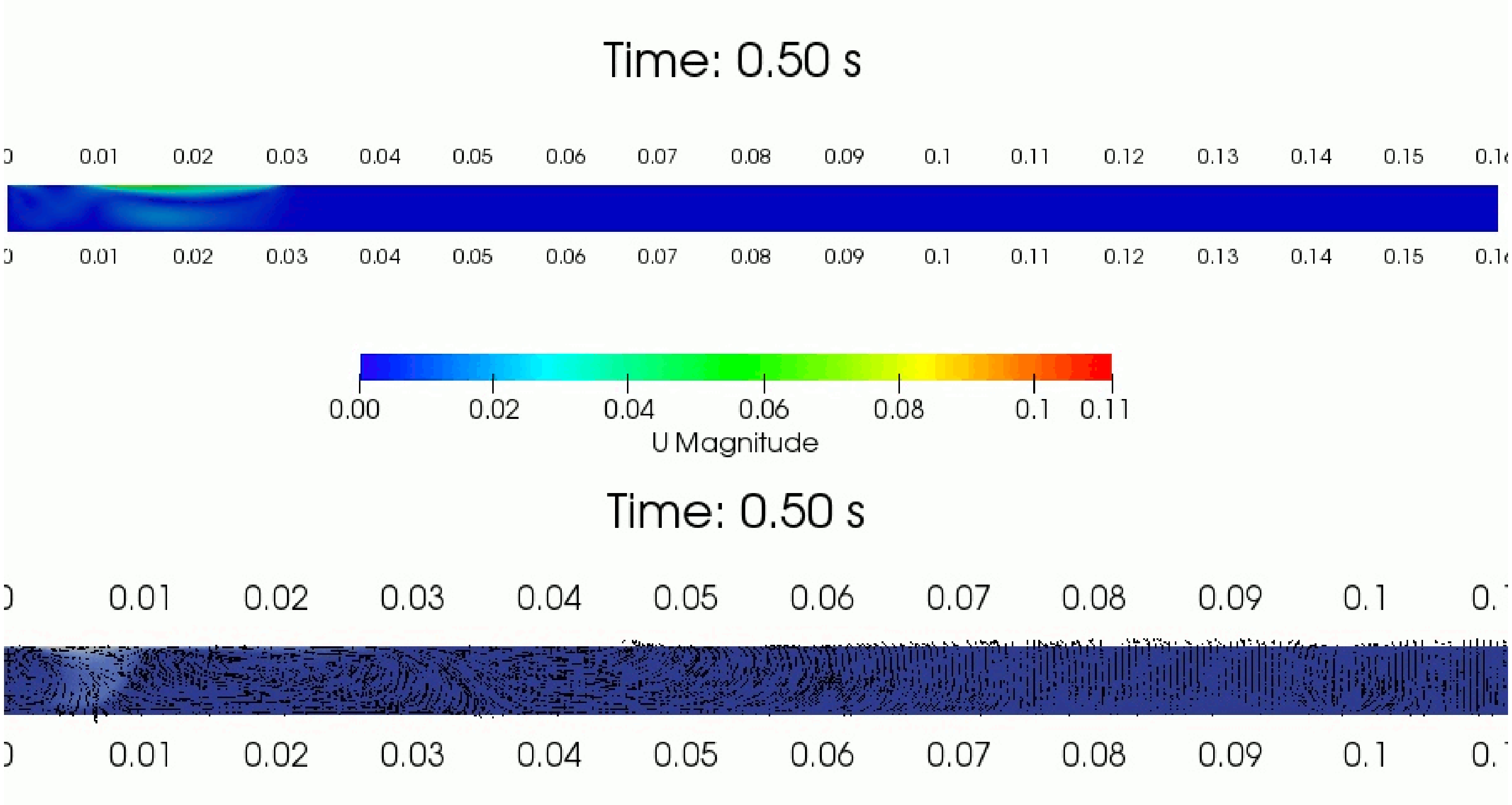
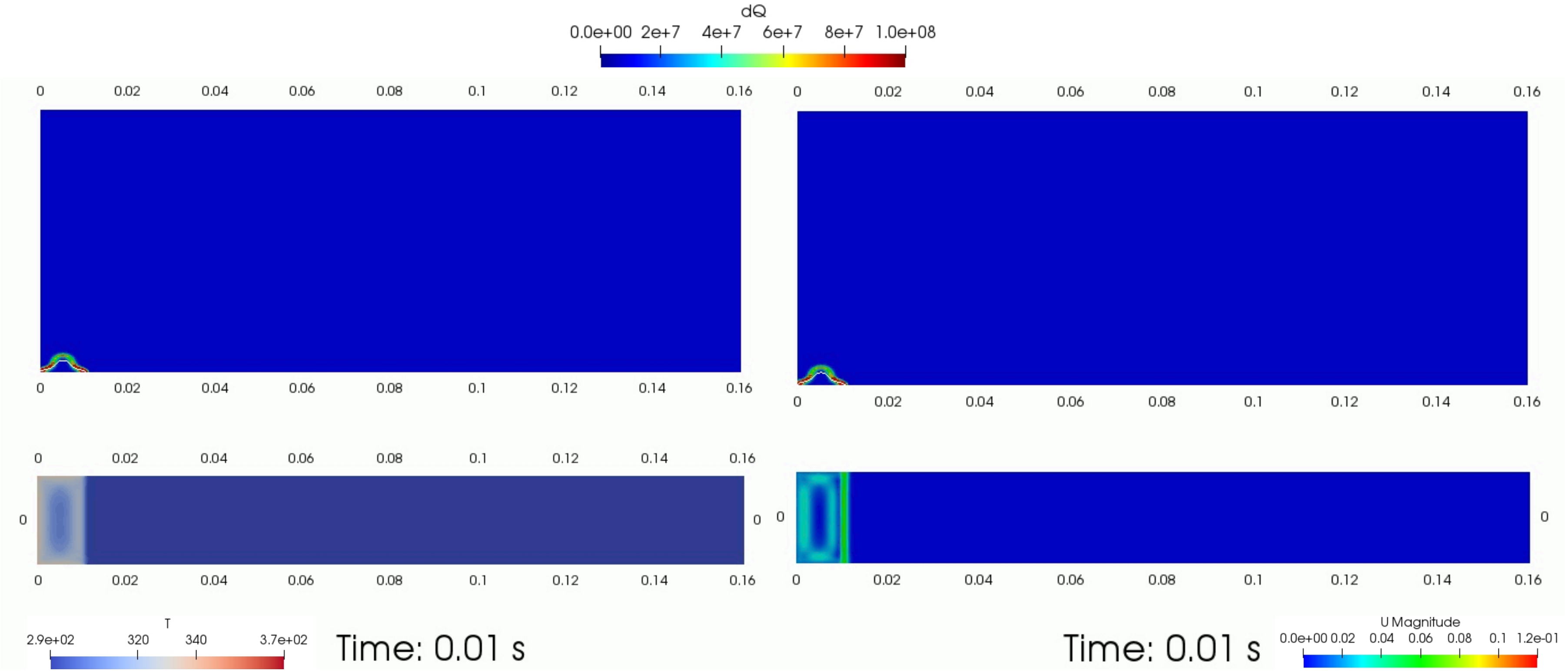
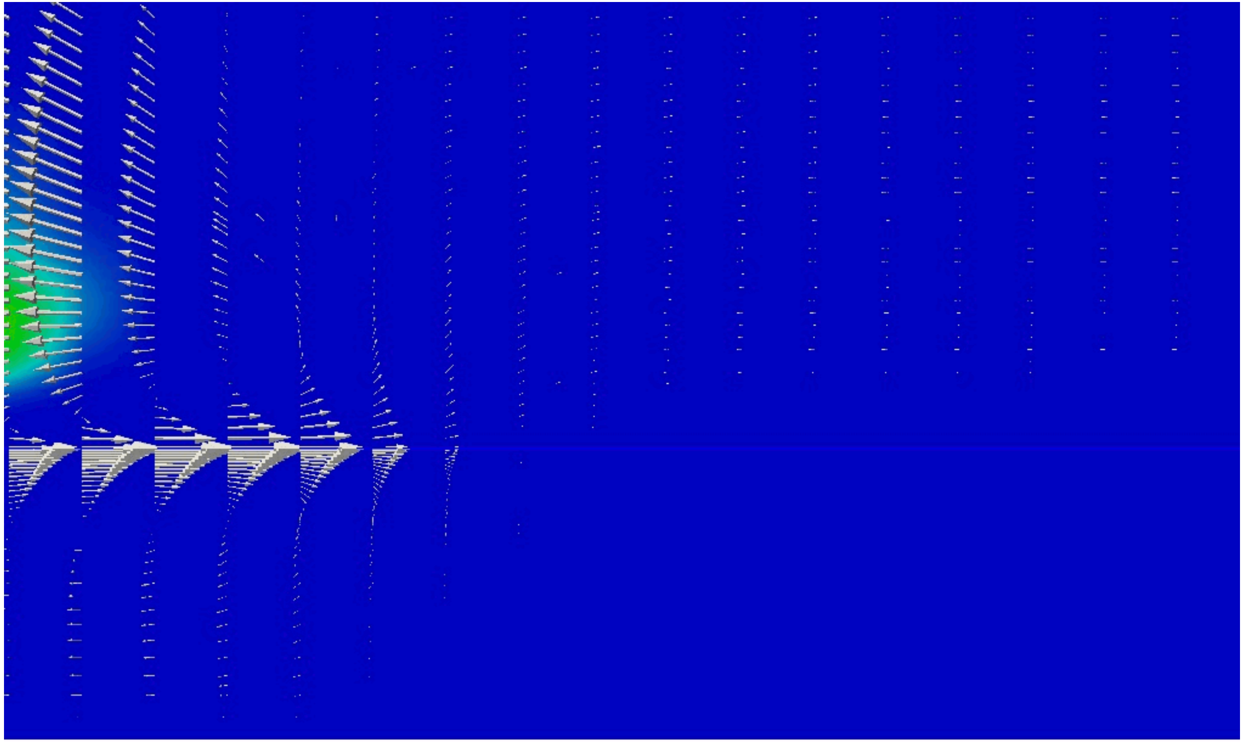


Uniform (steady) spread (293 K)



Pulsating spread (287 K)



Conclusions

- Quantitative agreement between the predicted and measured flame edge propagation speeds;
- Both the pulsating and uniform spread phenomena at different sub-flash temperatures are well captured;
- The predictions revealed find flow features like the gas phase re-circulation cell, thermocapillary/Marangoni effects at the interface.