Propagation and Morphology of Premixed Flames in Obstructed Tubes

Orlando Ugarte[1], Berk Demirgok[1], Damir Valiev[2], Vitaly Bychkov[3],
Satyanarayanan Chakravarthy[4], Amit Kumar[4], **V'yacheslav Akkerman[1]***
[1]Department of Mechanical and Aerospace Engineering, West Virginia University
[2]Department of Mechanical and Aerospace Engineering, Princeton University
[3]Department of Physics, Umea University, Sweden
[4]Department of Aerospace Engineering, Indian Institute of Technology, Madras, India
***Corresponding author: Vyacheslav.Akkerman@mail.wvu.edu**

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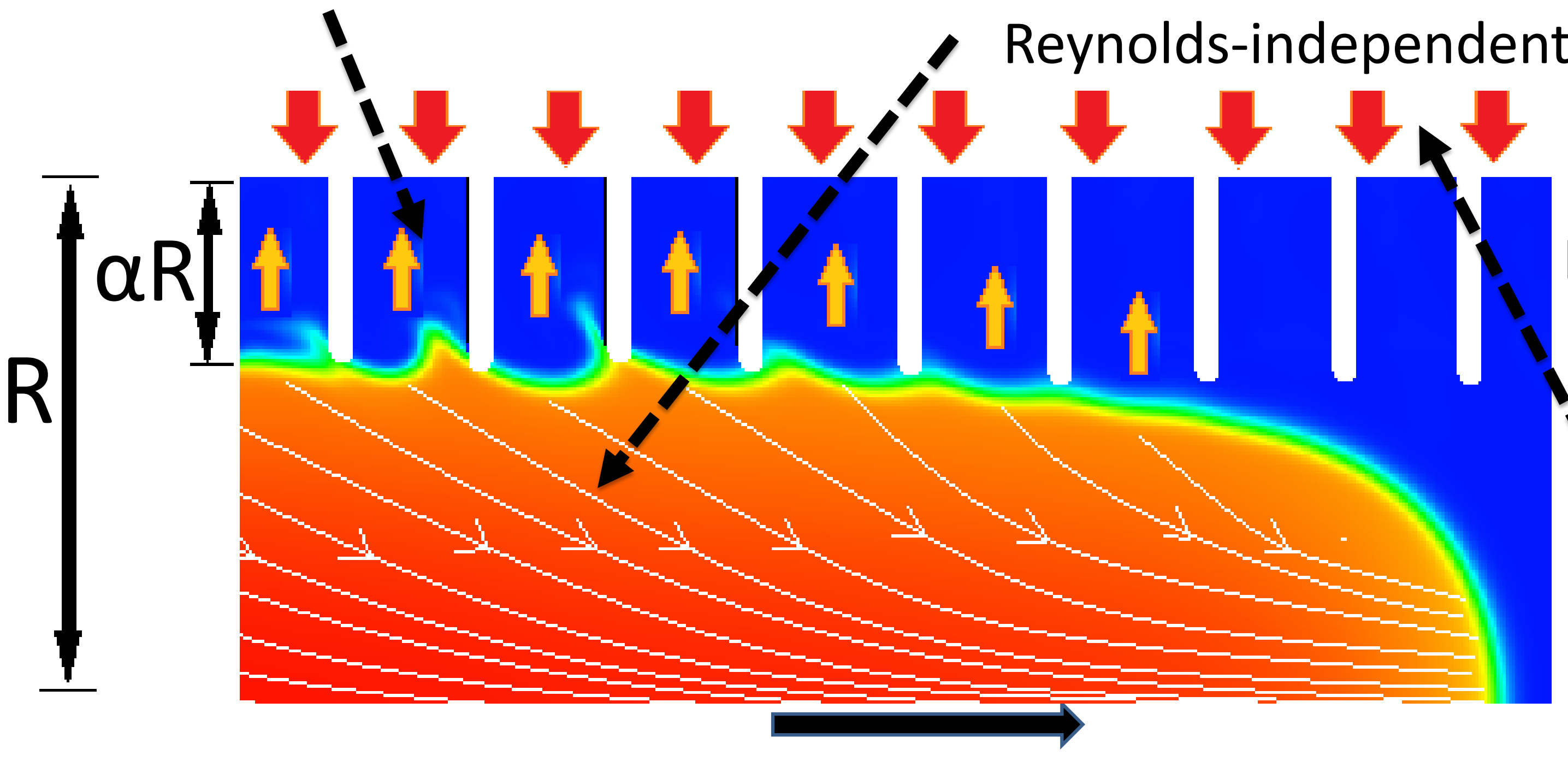
Motivation

- Obstacles placed at the walls of pipe-shaped combustors have been found to provide a mechanism of extremely fast flame acceleration, followed by a deflagration-to-detonation transition (DDT) [1,2].
- Up to now, this obstacle-based acceleration mechanism, along with that generated by wall frictional forces in unobstructed combustors [3,4], has been studied assuming adiabatic surfaces. Nevertheless, a strong dependence of the flame spreading dynamics on the combustor wall conditions could be clearly identified.
- In this investigation, flame propagation regimes in obstructed chambers are modeled including adiabatic and isothermal wall conditions. A comparison of this obstacle-driven acceleration mechanism and that generated by non-slip wall friction is performed by varying the blockage ratio (α), who quantify the obstacle size.

Flame Propagation in Obstructed Tubes



As a flame propagates, delayed combustion occurs in the pockets between the obstacles

This results in a late thermal expansion of the burning mixture in the pockets, which once added to that obtained in the core-unobstructed region, produces an intense jet-flow, generating a Reynolds-independent flame acceleration

Heat transferred by the walls reduces the thermal expansion ratio and thereby moderates the flame acceleration mechanism

Flame propagation direction

Results and Discussion

Effect of the Obstacle Size on the Flame Propagation

- The intensity of the flame propagation in obstructed pipe-shaped combustors is strongly linked to the size of the placed obstacles as seen in Figure 1, relating the scaled flame tip position with time as $\xi_{tip} = X_{tip}/R$ and $\tau = S_L t/R$ for various blockage ratios α.
- The acceleration of the flame front changes with the blockage ratio since it determines the region where the delayed combustion takes place, which drives this mechanism. In the absence of obstacles at the walls, the flame accelerates as a result of the frictional forces acting at the pipe wall, although this acceleration mechanism is much weaker.

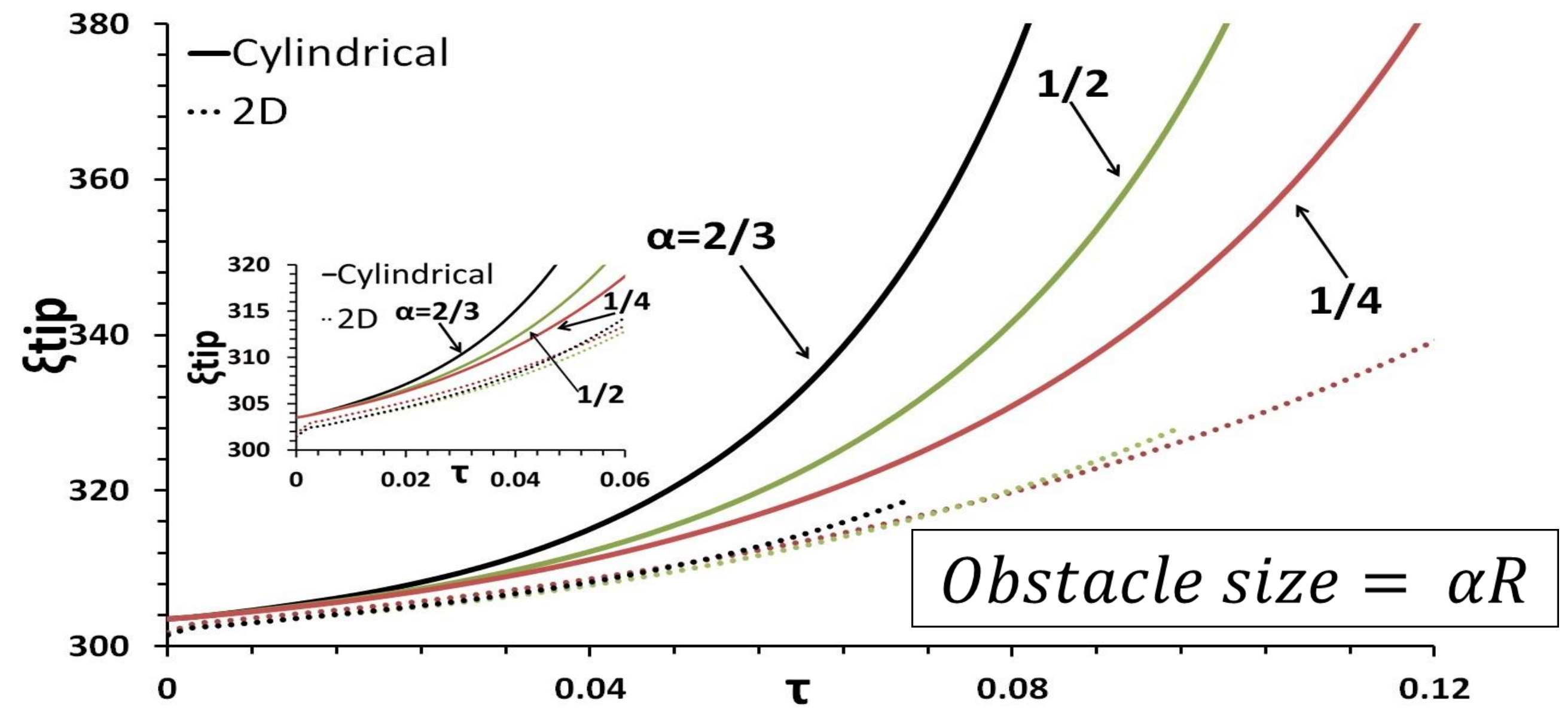


Figure 1. Flame tip position evolution for pipes at different blockage sizes.

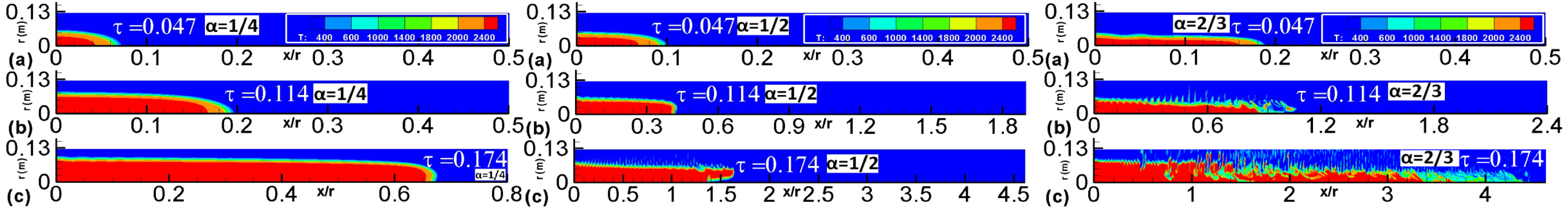


Figure 2. Instantaneous temperature distribution in axisymmetric cylinders. Width $48L_f$ (L_f: flame thickness),variable blockage ratios.

- Figures 2 and 3 show the evolution of the flame in adiabatic tubes and channels, increasing the blockage ratio from left to right. We can see that the laminar propagation is broken sooner in the cylindrical configuration (tubes). Also the mentioned blockage effect can be noted.

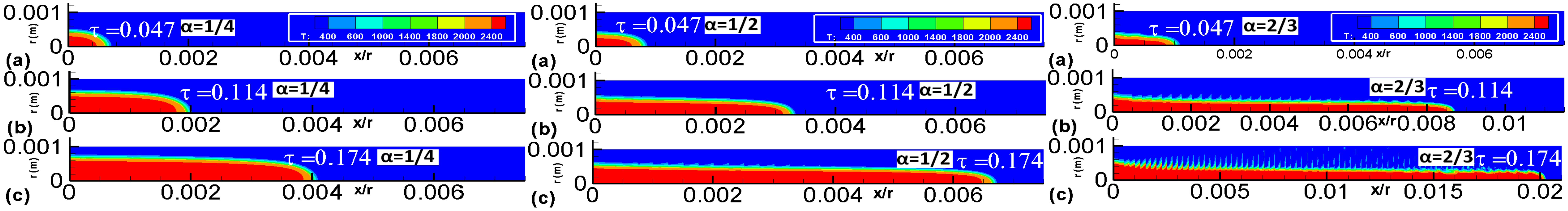


Figure 3. Instantaneous temperature distribution in planar 2D channels. Width $48L_f$ (L_f: flame thickness), variable blockage ratios.

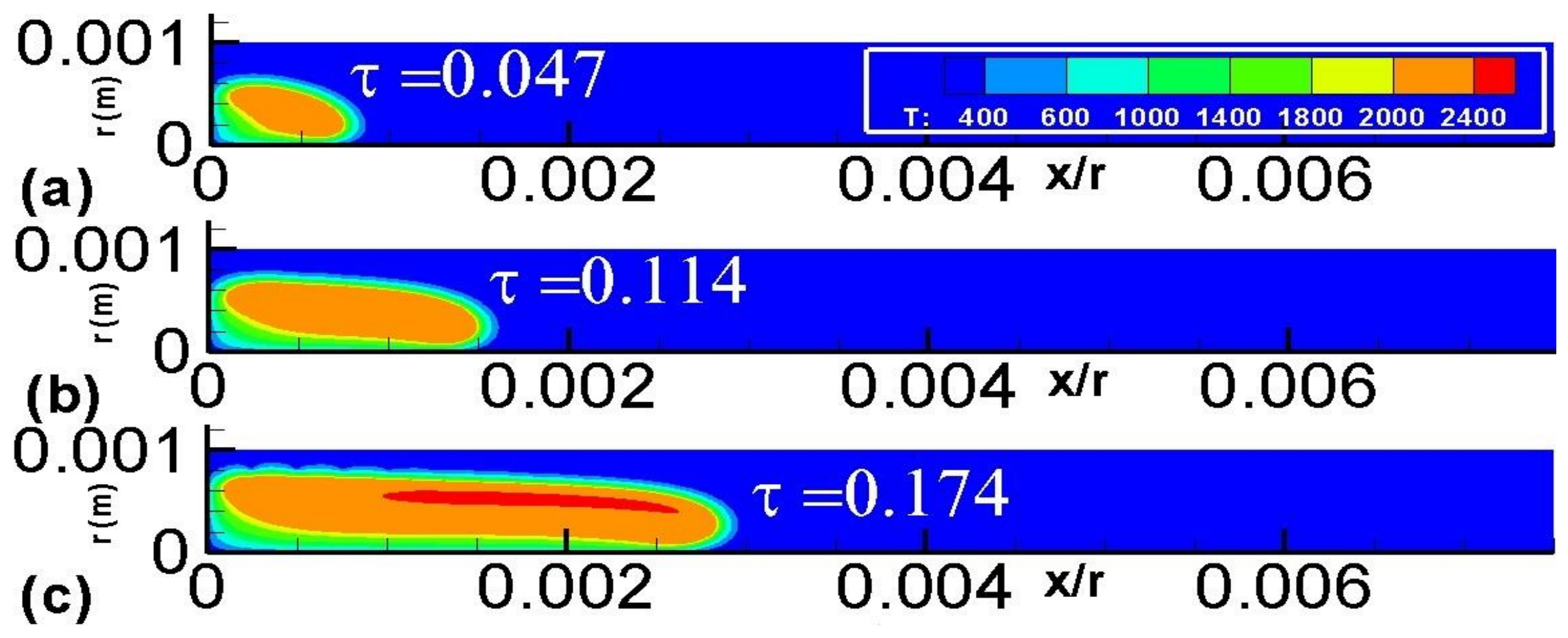


Figure 4. Channel of width $48L_f$, surface temperature 298K, α = 1/4.

Effect of heat losses at the walls

- The effect of the surface thermal condition on the flame propagation can be seen in Figure 4, as compared to Figure 3, left. By keeping the wall and obstacles at a constant temperature, much lower than that of the flame front, heat is being lost in this region, mitigating the burning process. Also, preheating of the fresh mixture in the pockets by heat transferred by the surfaces reduce the thermal expansion rate, and consequently, the flame acceleration.

Conclusions

- Flame propagation in obstructed tubes and channels is investigated.
- The flame acceleration in obstructed cylindrical tubes is found to be more intense than that in 2D planar channels.
- Isothermal boundary conditions mitigate the flame acceleration as compared to the adiabatic ones.
- With the reduction of α, the flame acceleration scenario eventually approaches that observed in non-slip unobstructed wall conditions.

Ongoing and Future Work

- Comparison of these results with those obtained experimentally at IIT Madras, India, to validate the present simulations.
- Variation of the thermal expansion ratio to allow the analysis of real fuel mixture effects, observed in practical applications, in a more accurate manner.
- Tubes and channel characteristics such as width, both sides open and opposite direction of flame propagation will be included.

References

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