Numerical analysis of liquid spray combustion

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Abstract Analysis of liquid sprays plays important role presently, when liquid fuel is used in large applications. Scope of this article is to show interactions between particles of spray and also between droplets and surroundings atmosphere, with respect to its turbulences and swirling. Software used for numerical simulations is ANSYS CFX. Simulations are made with N-Heptane as a fuel and air at the inlets of NIST (National Institute of Standards and Technology) computational domain. Euler physical model is described and assumed, k – ε turbulence model is describing the turbulence in domain. For vaporization of droplet, d^2 – law is analysed and used. In case of combustion of spray, Flamelet model is used with reduced chemistry scheme – without NO_X.

1 Introduction

The aim of this article is to describe behaviour of particles of a liquid spray. A NIST computational domain is used.

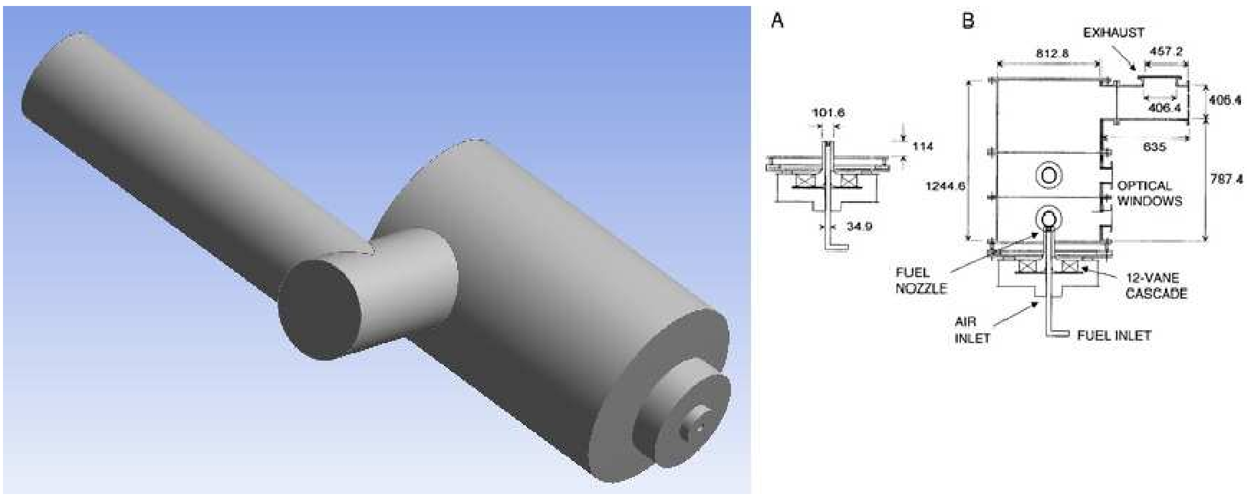

Fig. 1 NIST computation domain

The exhaust of modelled domain is longer in compare with real domain. This is made for elimination of recirculation zone located in front of outlet. In the inlet of air, there is a 12- vane's swirler. Simulations are made with vane angle 30°, 40°, 50° and 60°.

2 Data and Methods

Data available from publications [1], [2] are used for boundary conditions. For experiment described in [2], methanol is used as a fuel with flow rate 3,0 kg h^{-1} ± 0.02 kg h^{-1}, the nominal upstream pressure of the liquid feed to the nozzle is 690 kPa and temperature is 300 K.

N-Heptane (C_7H_{16}) instead of methanol but with the same parameters is used as a fuel in our simulations. Initial conditions of air, described in [2], are set on a flow rate 56.7 m^3 h^{-1} and temperature 300 K. Simulations was made in Ansys CFX by using Euler physical model and k-ε turbulence model. Swirling intensity presented in experiment is on **Fig. 2**.

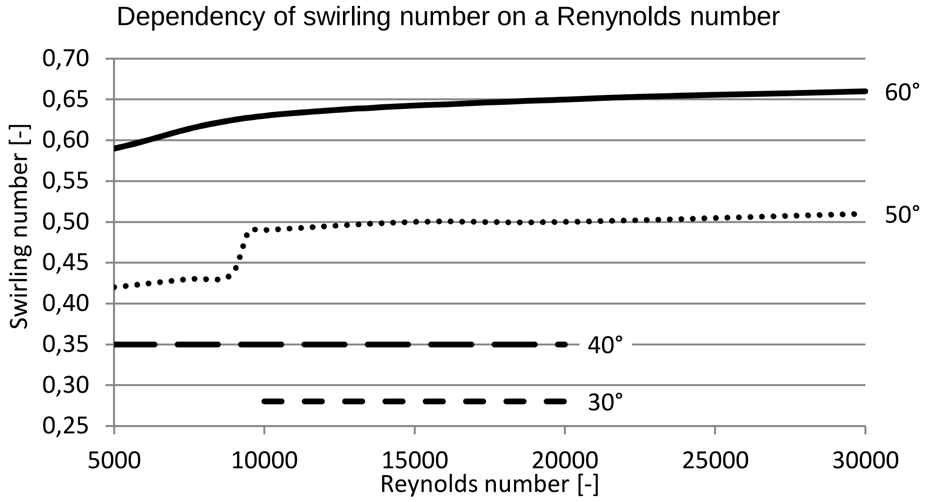

Fig. 2 Relation between Reynolds number and swirling number

3 Properties of the droplets and results

A representative sample of a spray is used in simulations. It includes 100 droplets with uniform diameter 50 µm entering to the domain from one point. Spray is also characterized by full cone which angle is 40° ± 5°. Collisions between the dro plets are neglected. Flamelet combustion scheme is used. It predicts combustion processes involved inside the domain. As liquid particles of the spray are travelling in a surroundings hot atmosphere, they heat up, evaporate and change the diameter. This is represented by evaporation rate given by equation

$$\frac{\mathrm{d}d^2}{\mathrm{d}t} = -\frac{8\lambda_g}{\rho_L c_{p,g}} \cdot ln[1+B] \cdot \tag{1}$$

Integration of this relation leads to the d^2 – law for droplet lifetime:

$$d^2(t) = {d_0}^2 - Kt \tag{2}$$

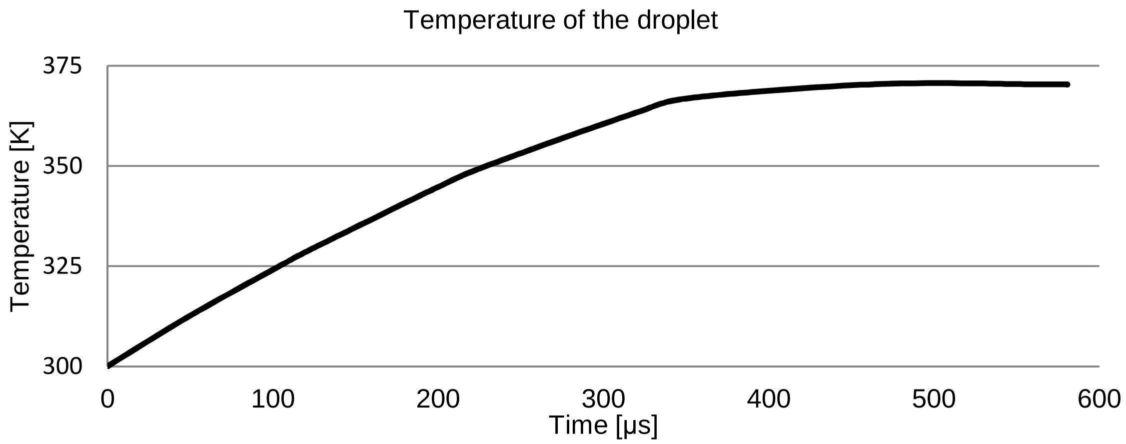

Fig. 3 Relation between the droplet temperature and lifetime

4 Properties of burning mixture and results

Burning gases in the combustor are swirling around longitudinal axis, but not symmetric by reason of the position of exhaust. We assume constant mean thermal conductivity of a gas mixture. Flamelet library is generated using Ansys CFX-RIF module.

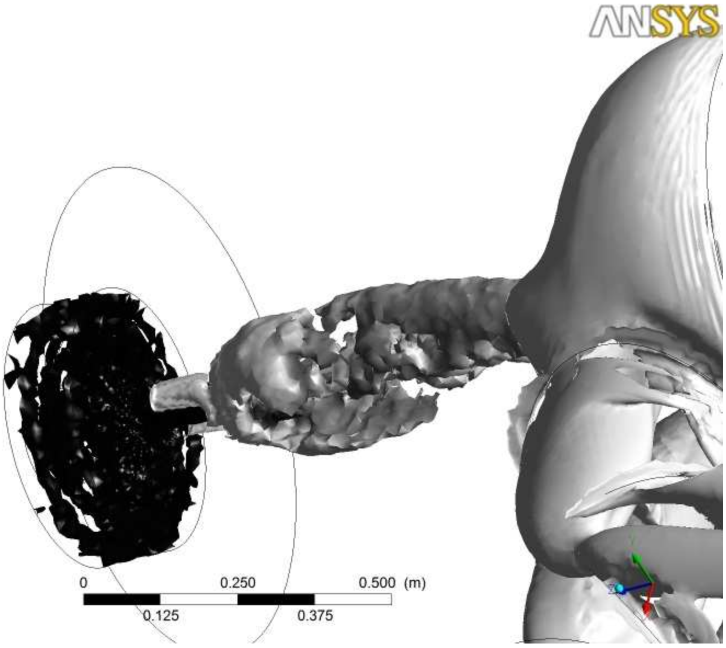

Fig. 4 Vortexes in a computational domain

Position of a flame front is situated to the shape, where the mass fraction of N-Heptane and air is in stoichiometric equilibrium.

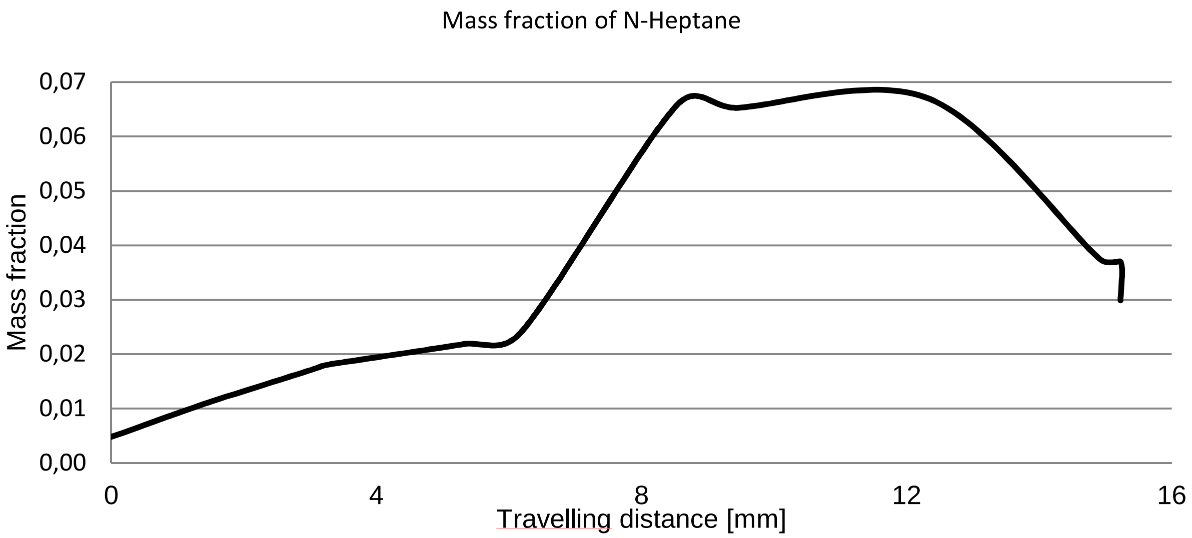

Fig. 5 Change of mass fraction with increasing of droplet travelling distance

The highest temperature of a flame in the domain is in a position of a flame front. Is it possible to see it on a **Fig. 6**. The plane included temperature profile is situated to the axis of a combustor. The flame shape is not symmetrical. The highest temperature of a burning gas mixture is 2269 K.

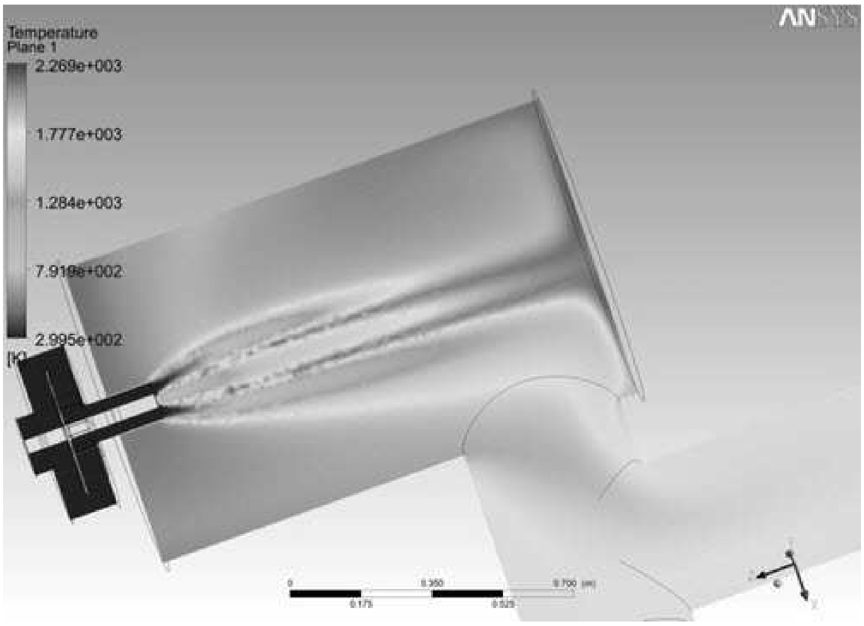

Fig. 6 Temperature profile of a gas mixture in the domain.

5 Conclusions

Precision of a solution is affected by the simplification of the spray behaviour. Even though is possible to see, that a Reynolds number in low wane angle have not effect on the swirling number. Swirling of the air inside the combustor has only effect on a movement and evaporation of droplets and thus for burning of mixture.

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Literature and sources

[1] JAGER, Bram De. Combustion and Noise Phenomena in Turbulent Alkane Flames, PhD thesis, Enschede: Gildeprint Drukkerijen BV, 2007, ISBN 978-90-365-2484-1

[2] WIDMAN, John F. A Benchmark Experimental Database for Multiphase Combustion Model Input and Validation in *Combustion and Flame published by Elsevier Science Inc. In co-operation with The Combustion institute*, Gaithesburg: National Institute of Standards and Technology, 2002. p. 47 – 86.