Advanced Vaporization System for Small Jet Engines

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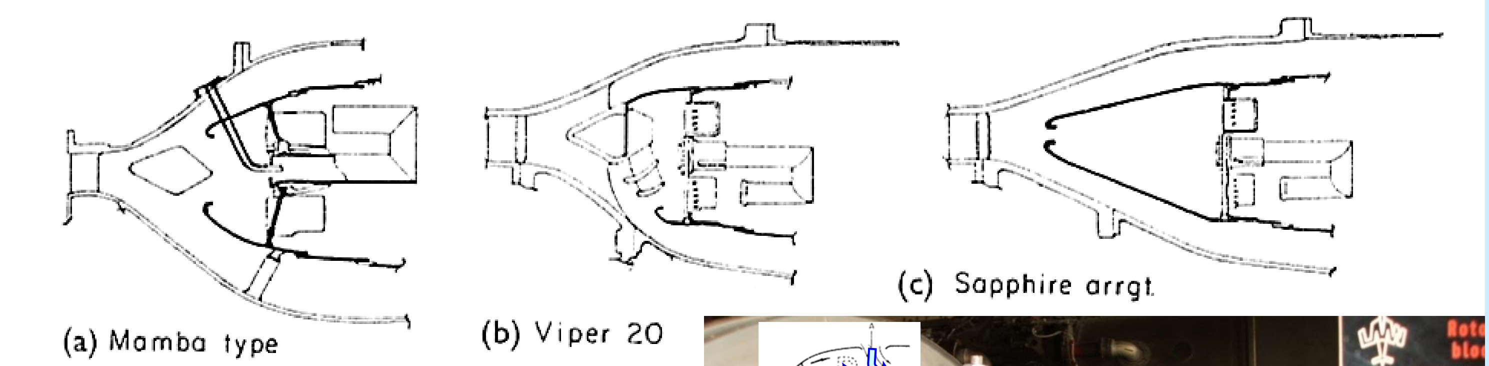
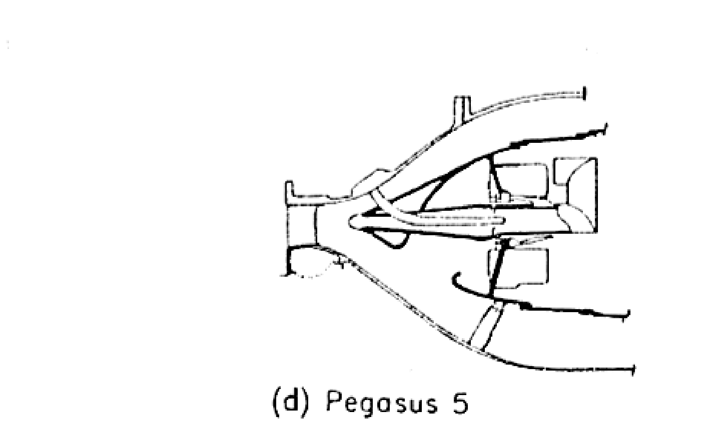
Application of vaporizers

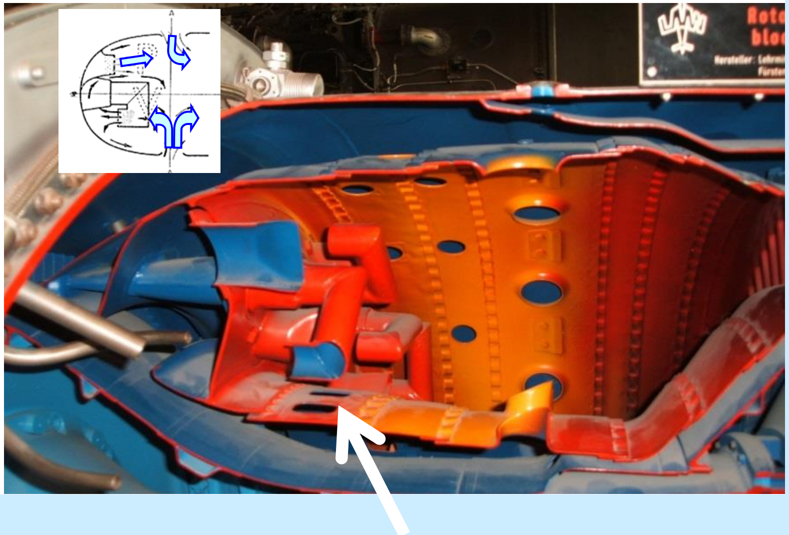
In recent time vaporizers found wide application in small jet engines due to their simplicity. But they have several drawbacks, the main being

- high sensitivity to operation load,
- possible overheating of a vaporizer wall,
- start-up problems.

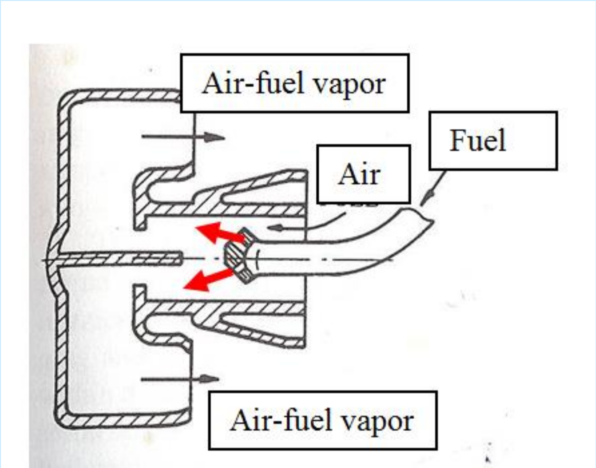
TYPICAL VAPORIZER DESIGN





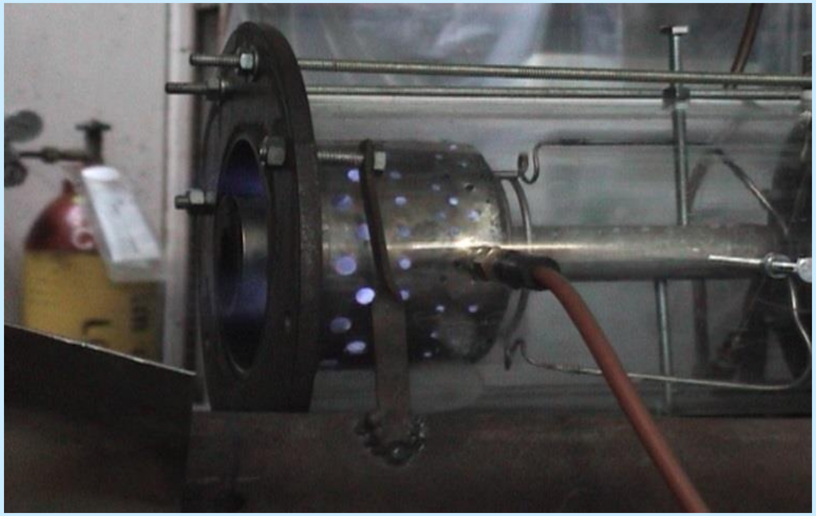


Fresh air cools the vaporizer



Design of vaporizer for large engine. Inlet flow is splitted and this enables to reduce number of vaporizers

TYPICAL VAPORIZER DESIGN (cont.)



Combustor for small jet engine, Turbo&Jet Laboratory test rig

Combustor with 6 vaporizers, small jet engine

Several types of the combustors with vaporizers were tested in the Turbo&Jet Laboratory

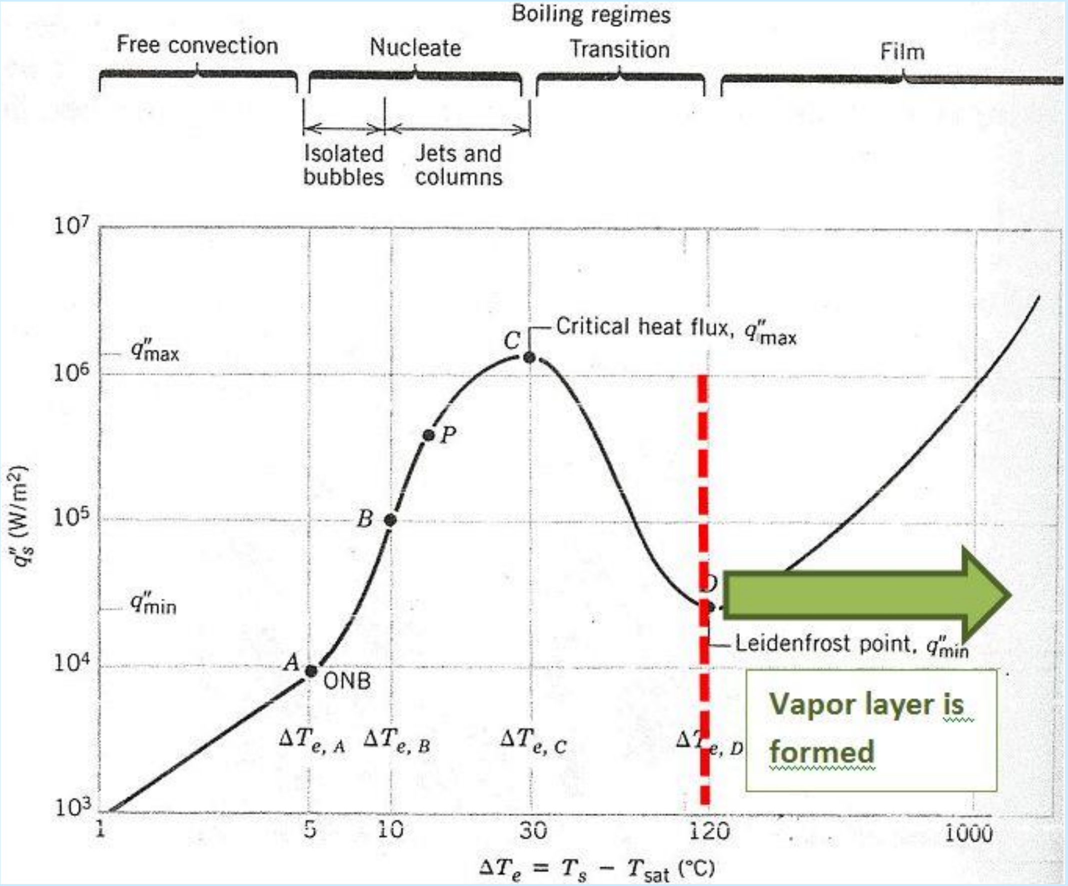
THE OBJECTIVES OF THE PRESENTED STUDY:

- Qualitative analysis of influence of thermodynamic and aerodynamic parameters on evaporation rate of a single droplet.
- CFD study of effect of two-phase flow rotation on evaporation rate and wall temperature in a straight tube.
- CFD study of rotation effect on evaporation in the generic vaporizer.

THEORETICAL BACKGROUND

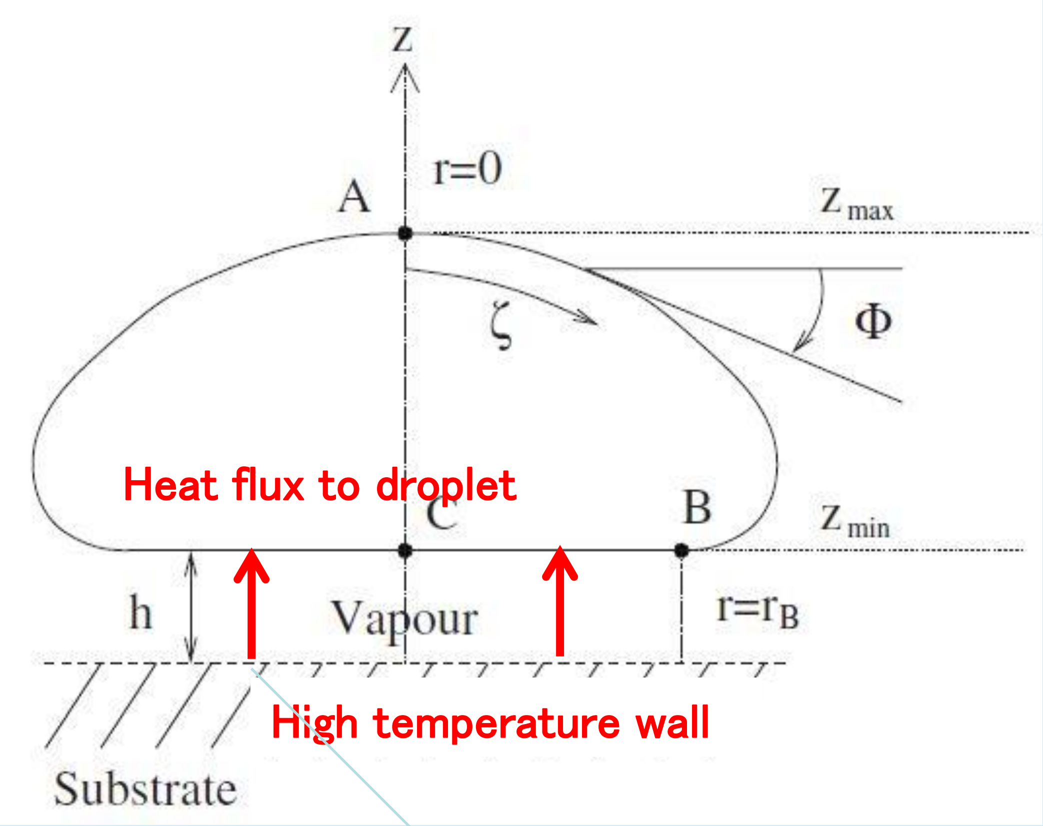
Vaporizer operation field

Typical boiling curve of liquid at one atmosphere presents specific heat flux q_s as a function of a difference temperatures of wall and boiling liquid , Te = Ts – Tb*



*Nucleate boiling, Wikipedia, https://en.wikipedia.org/wiki/Nucleate_boiling

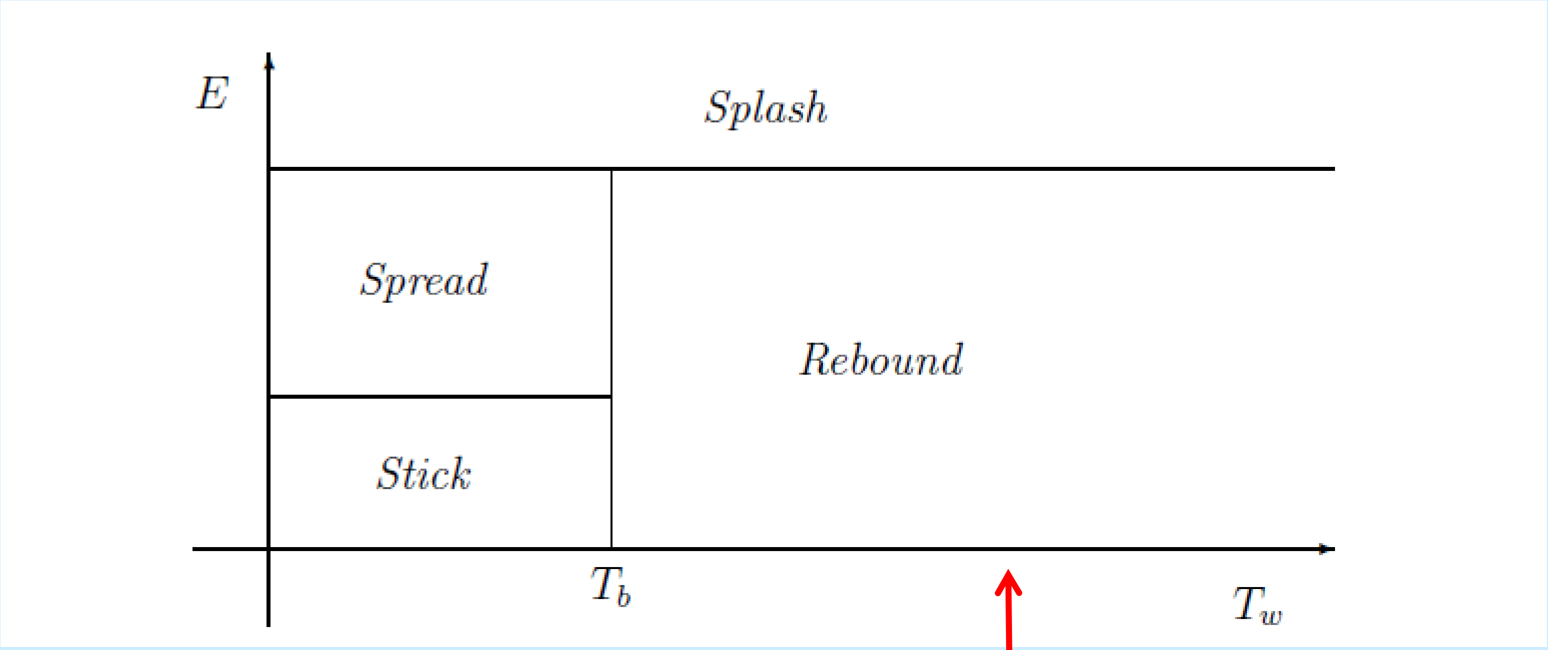
THEORETICAL BACKGROUND (cont.)
Single droplet evaporation near the wall*



Accepted geometry of the droplet:
The droplet is above hot surface

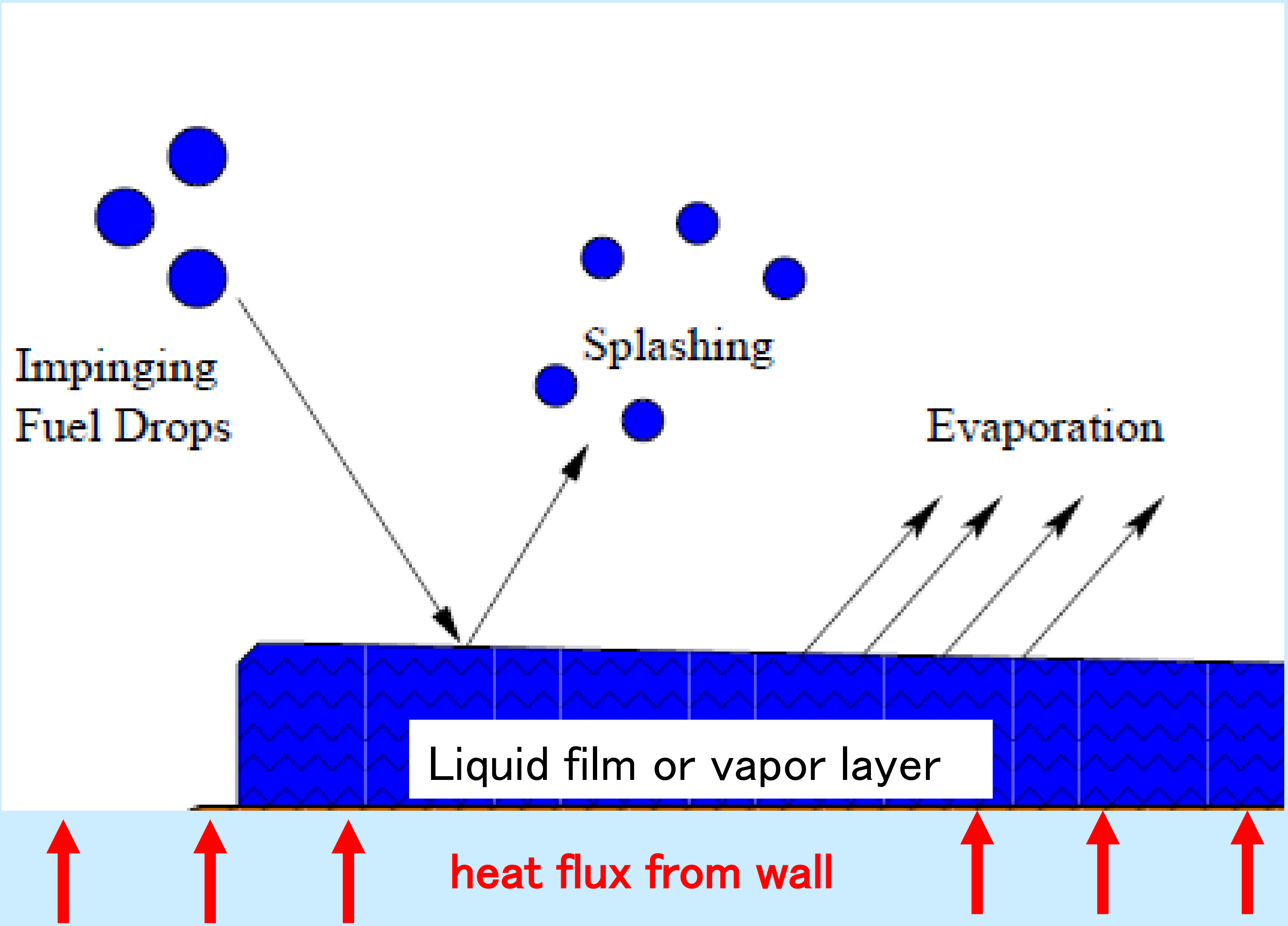
*Myers T.G. and Charpin J.P.F., (2009), "A Mathematical model of the Leidenfrost effect on an axisymmetric Droplet", *Phys. of Fluids*, Vol. **21**, 063101, pp. 063101-1 – 063101-8

DROPLET – WALL INTERACTION



vaporizer wall temperature, Tw>1000K

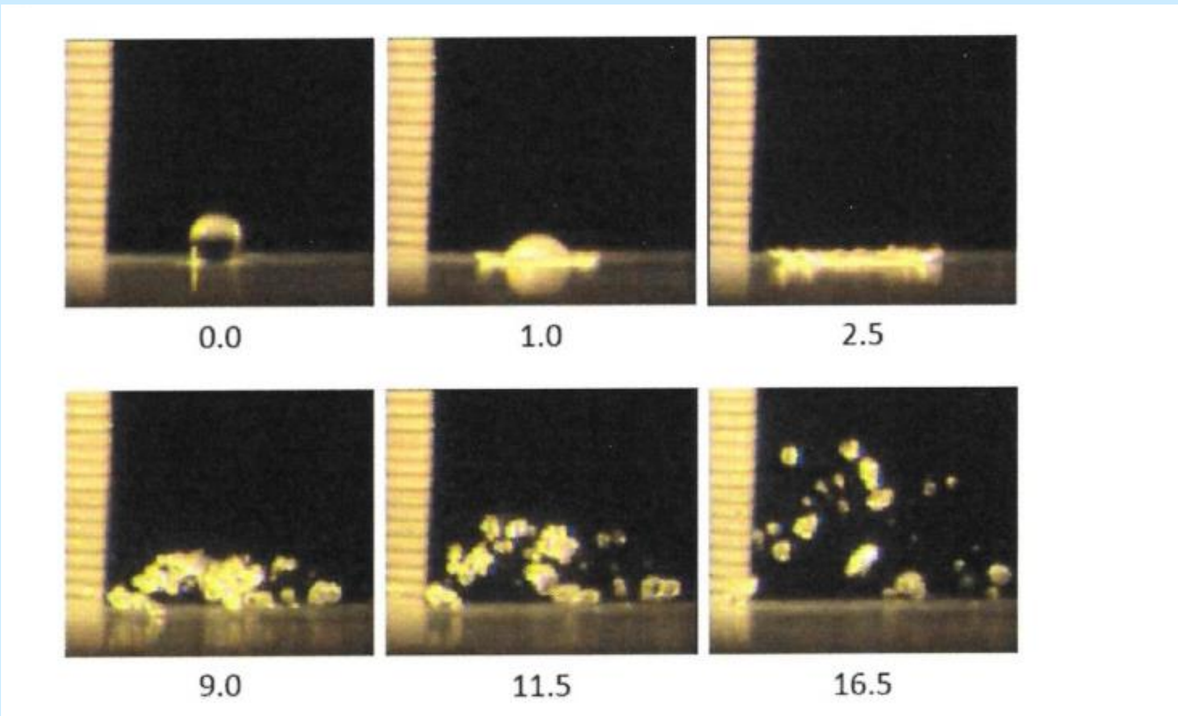
EVAPORATION PROCESS SCHEME (FLUENT)

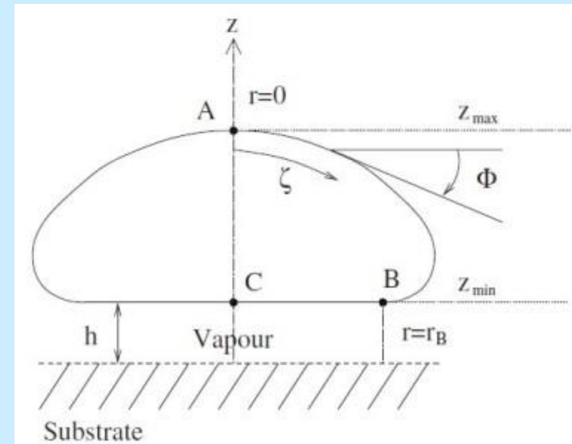


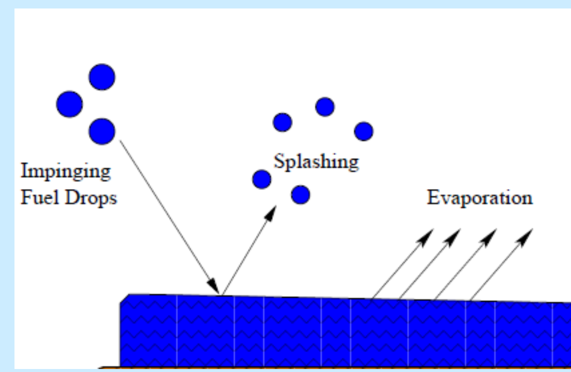
EVAPORATION PROCESS test results

There are very limited results of interaction between superheated wall and droplets during impinging.

The photographs below demonstrate difference between models and actual interaction process*







Droplet evolution during impingement at the wall, Twall = 195deg. C, time in ms

*Eitan Kompinsky Single droplet impact and droplet-droplet collision on a solid, non-heated and heated surfaces. Doctorat thesis, 2015

To accelerate the evaporation process we propose to swirl air inside the vaporizer

What are the expected effects of flow rotation?

Example

Inner vaporizer diameter D = 10 mm

Droplet tangential velocity V_t= 10m/s

Centrifugal acceleration of a droplet is equal to $a=V^2/R=20,000 m/s^2$

this is in factor 2000 more than gravity acceleration

Benefits

1. Droplets move to the vaporizer inner wall and cool the vaporizer case.
2. Spray distribution does not depend on the vaporizer orientation in space.
3. Droplets are pressed against the vaporizer wall and that leads to acceleration of vaporization process.

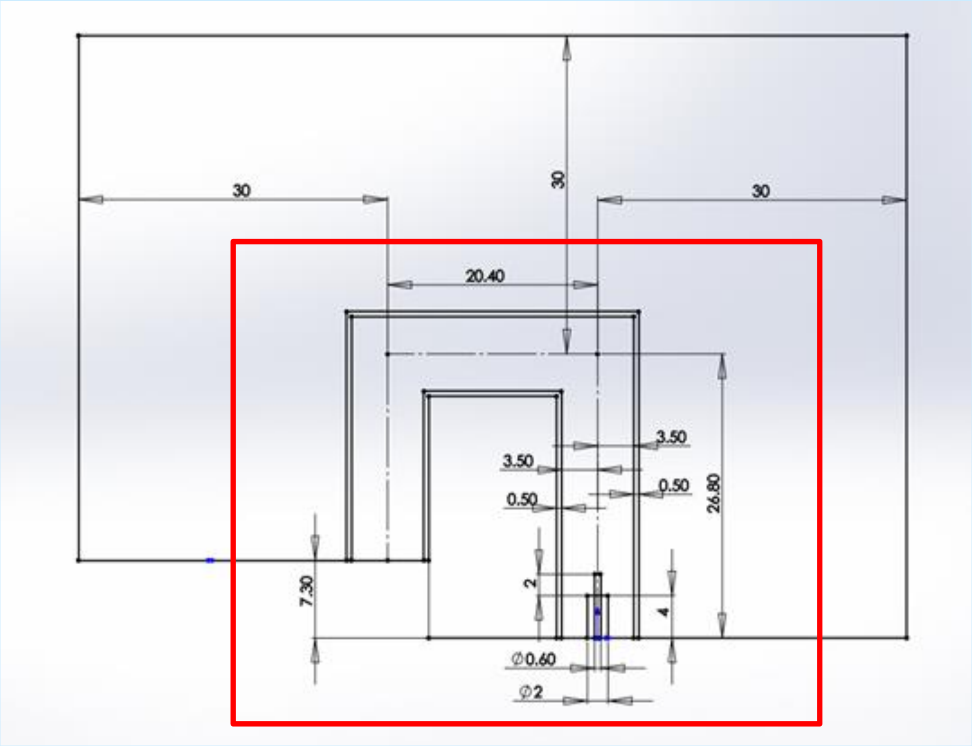
Drawbacks

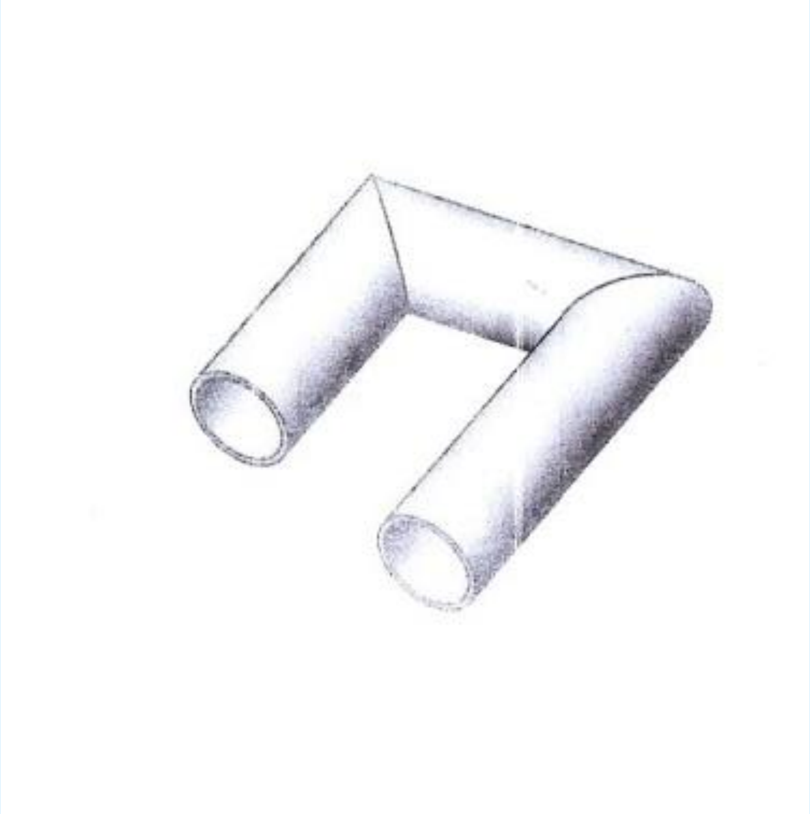
1. Swirler should be added
2. Pressure drop of a vaporizer increases

CFD SIMULATION

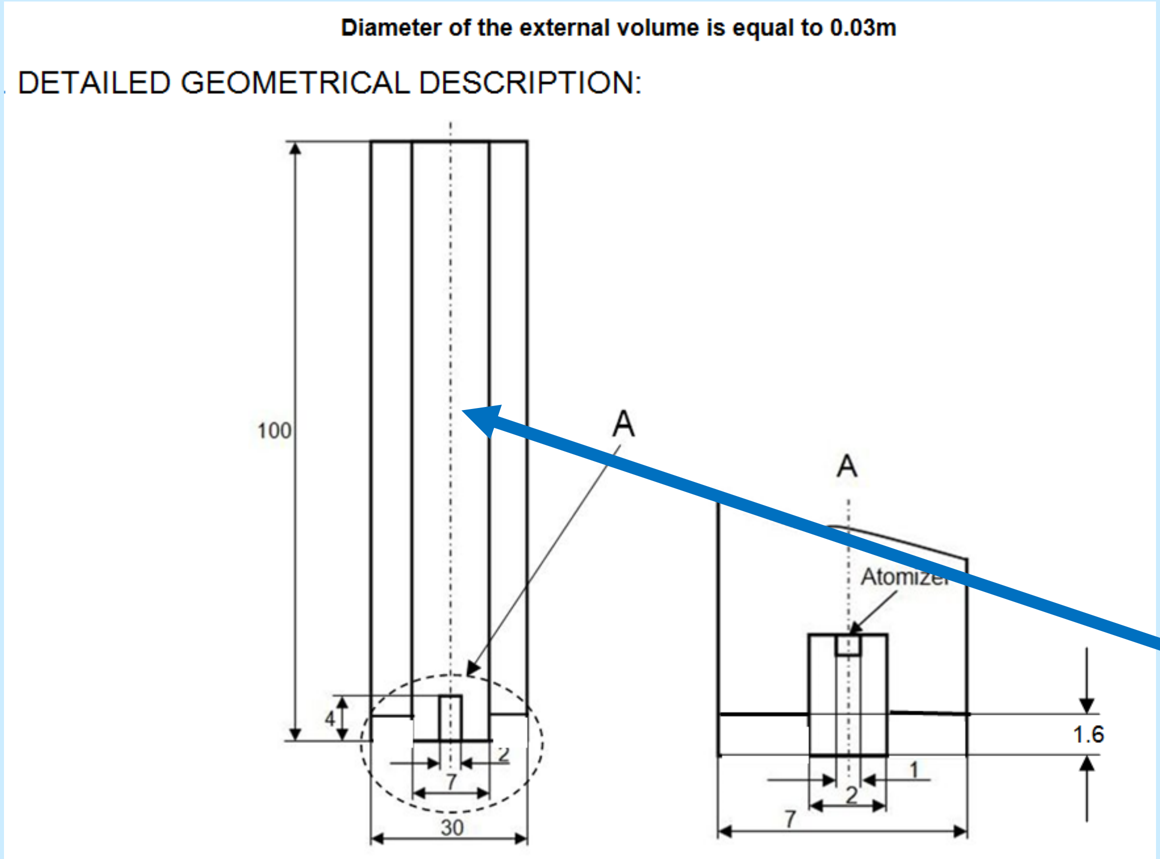
Swirling and non-swirling case

Typical vaporizer design was chosen for the simulations





SIMULATION MODEL-1 (straight tube)



Geometrical scheme

A tube is surrounded by volume to imitate flow around the actual vaporizer installed in a combustor

INITIAL CONDITIONS:

m_{fuel} = 0.0018kg/s

T=298K

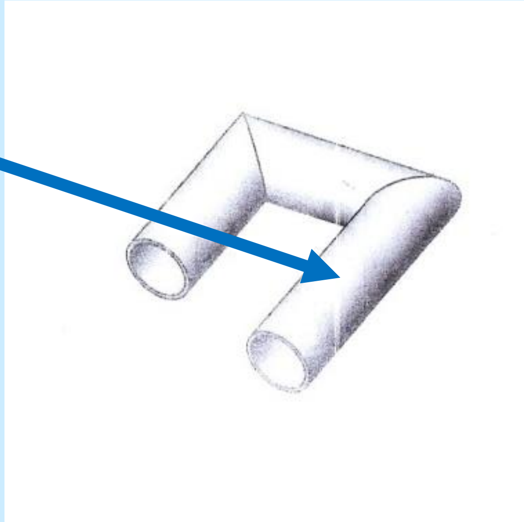
m_{air} = 0.004kg/s

T=480K

$V_{air\ around}$ = 20 m/s

$T_{air\ around}$=2500K

P=400kPa



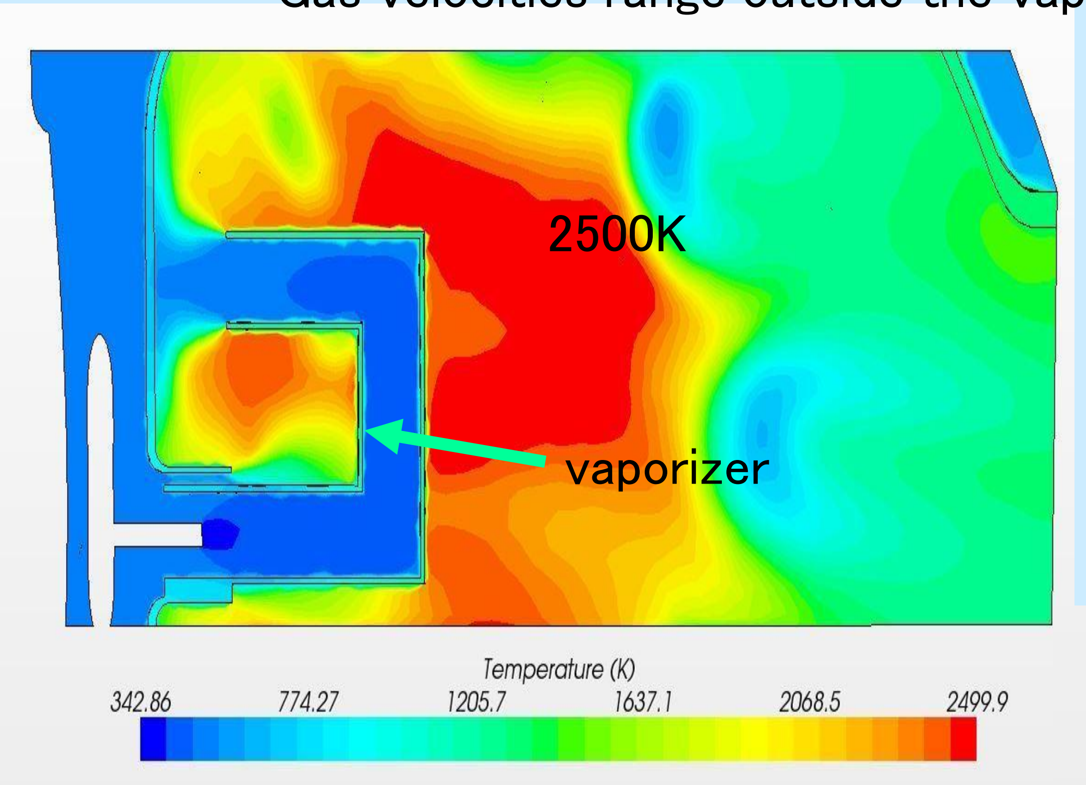
A straight tube presents an initial part of the vaporizer

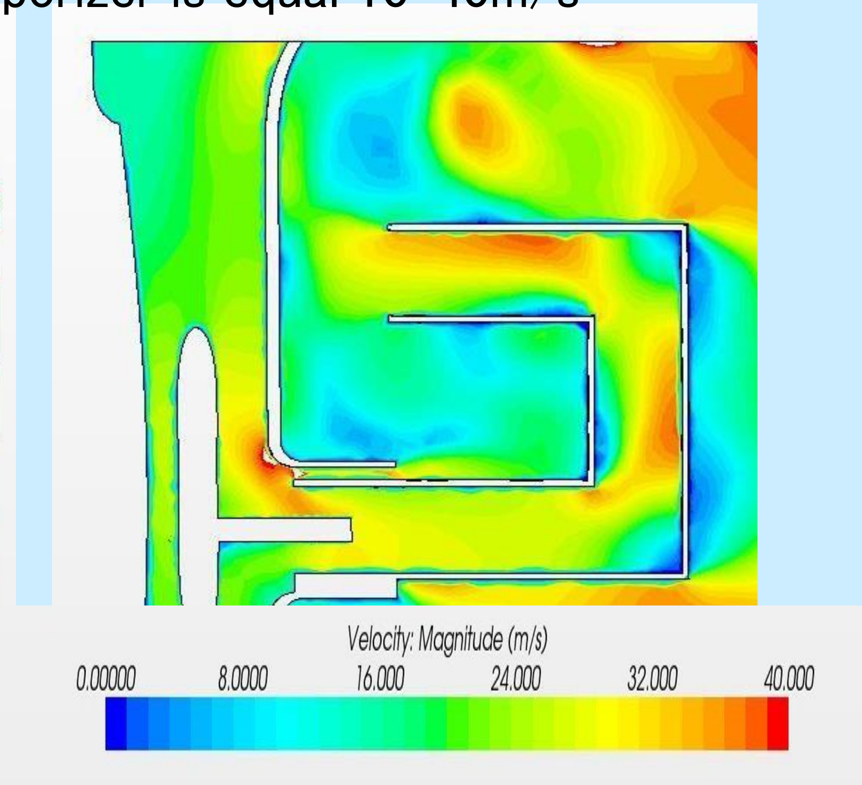
SIMULATION RESULTS OF SMALL JET ENGINE*

were used as initial conditions around the vaporizer

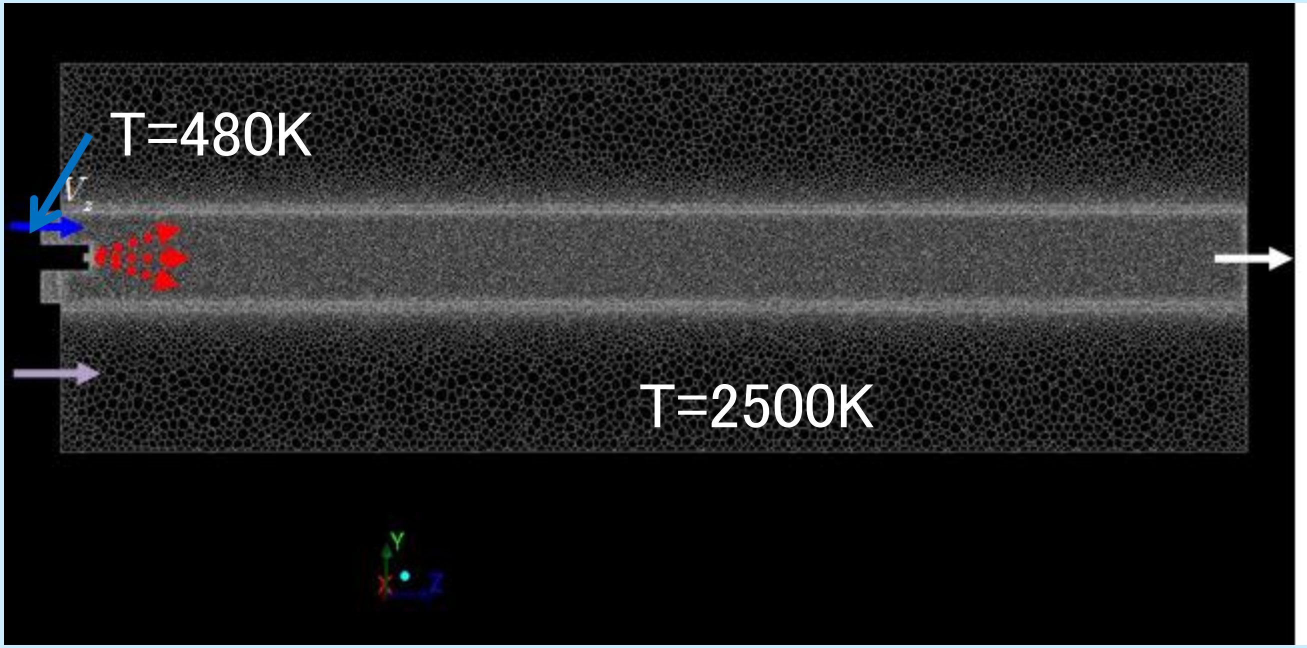
Temperature around the vaporizer was accepted = 2500K

Gas velocities range outside the vaporizer is equal 10–40m/s





*Simulations were carried out by Alex Dolnik



Mesh consists of 2,085,587 polyhedral cells; red arrows – fuel inlet, lilac – external heating flow, blue – air inlet, white – outlet,

K-ε turbulence model for air flow and wall-film model for discrete phase were used in a final simulations. Wall-jet discrete model showed close results

SIMULATION MODEL (straight tube)

The following options were simulated:

Spray angle α =5 deg.:

- Axial air flow
- Tangential air flow velocity is equal to axial component

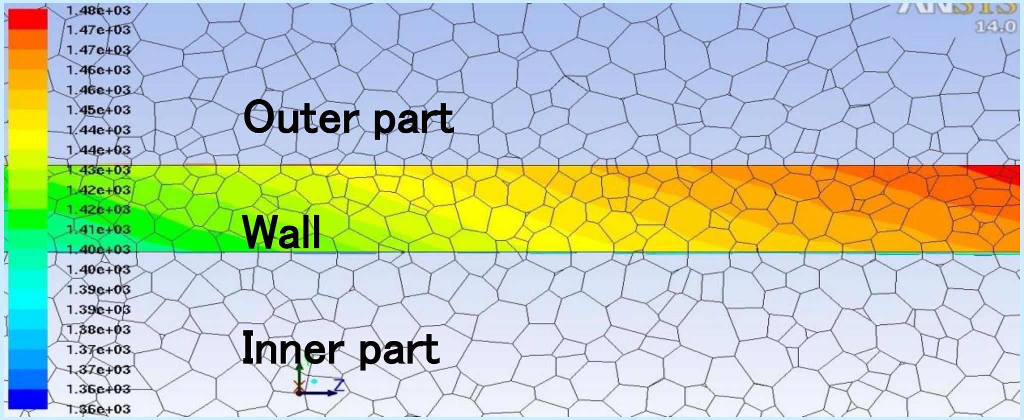
Spray angle α =60 deg.:

- Axial air flow
- Tangential air flow equal to axial component

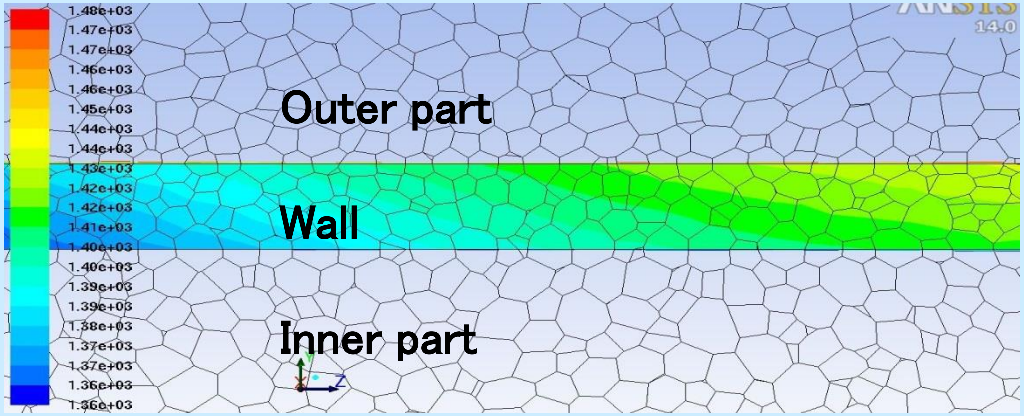
The following parameters were obtained during simulation process

- Evaporation rate
- Temperature distribution in the vaporizer wall
- Air velocity distribution
- Air temperature distribution
- Average residence time of droplets

Temperature distribution in the wall, inlet region (1-10)mm



axial inlet flow

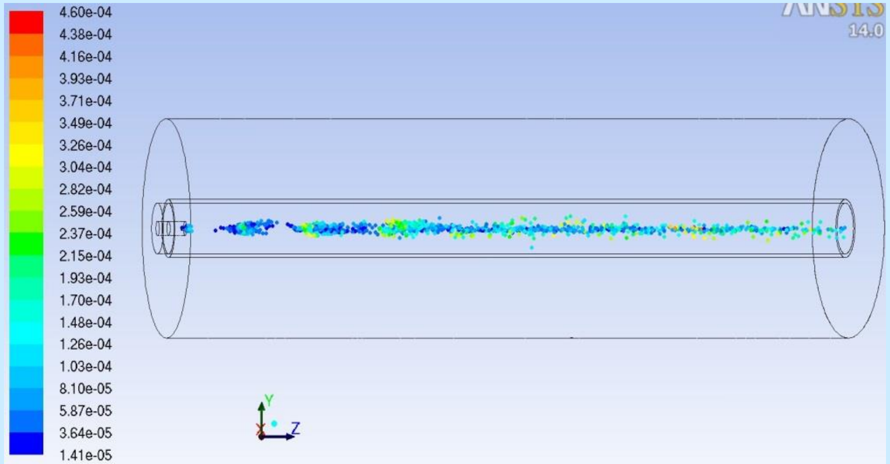


axial & swirl inlet flow

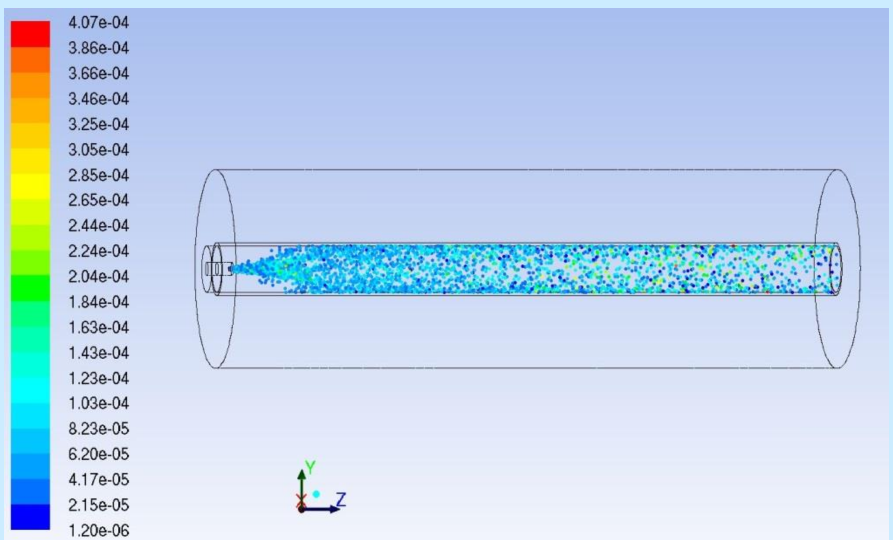
In case of rotating air, maximum wall temperature is lower in 40 deg.

It can be seen according to color of the wall

Spray propagation inside the vaporizer



axial inlet flow



axial & swirl inlet flow

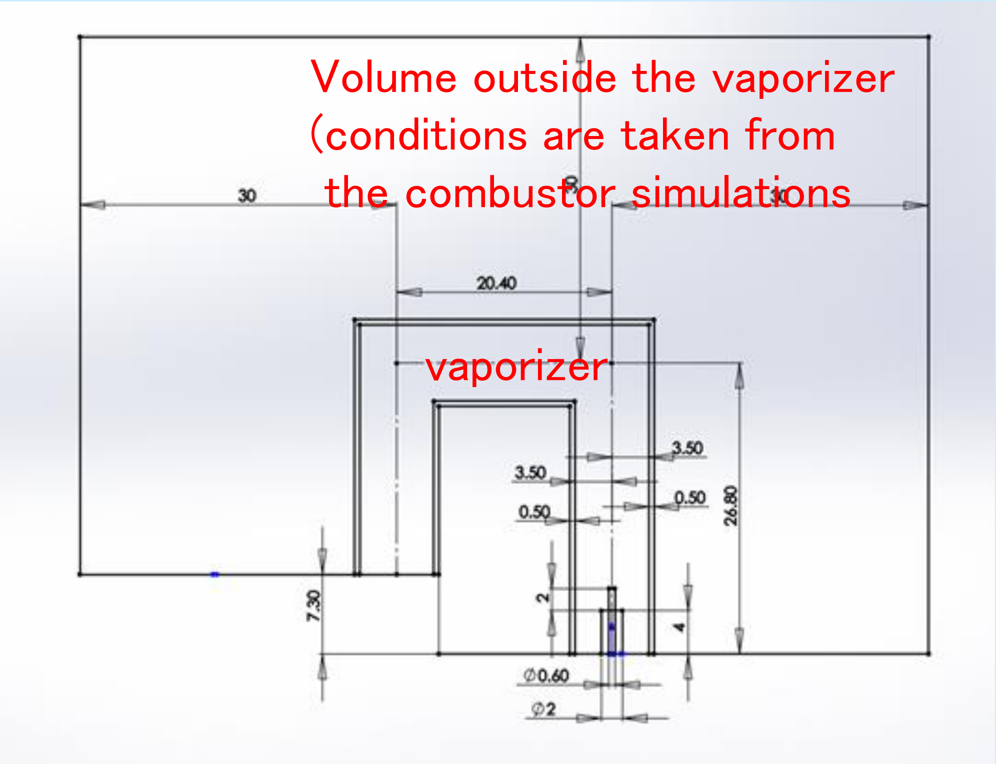
Droplets spread in a whole volume of the tube and evaporate more Intensive

Main results (straight tube)

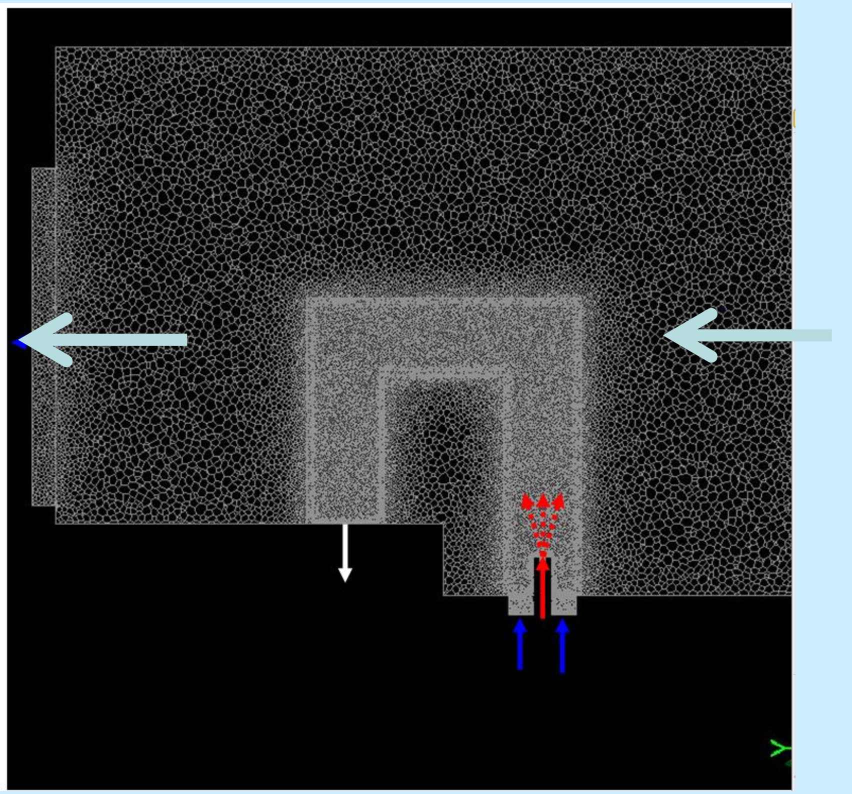
Option	Axial inlet flow, spray angle 5^0	Axial & Swirling inlet flow, spray angle 5^0	Axial inlet flow, spray angle 60^0	Axial & Swirling inlet flow, spray angle 60^0
Evaporated Fraction, %	0.1	6.4	1.9	5.8
Residence time, s	0.007	0.009	0.0064	0.0079
Pressure drop, %	0.46	0.84	0.5	0.79

AIR SWIRLING PROVIDES BETTER EVAPORATION,

Full scale vaporizer simulation scheme

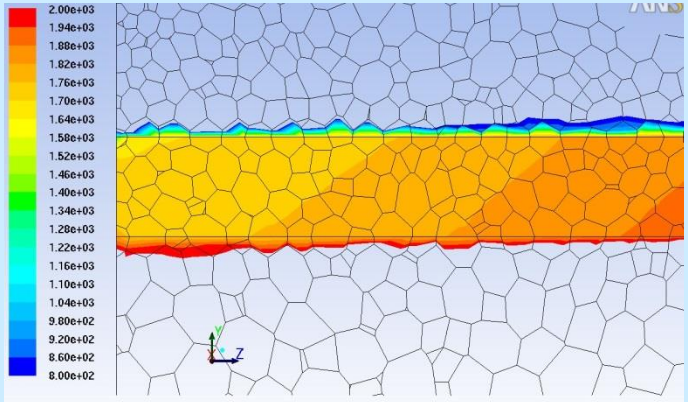


Vaporizer model with surrounding volume for imitation conditions outside the vaporizer

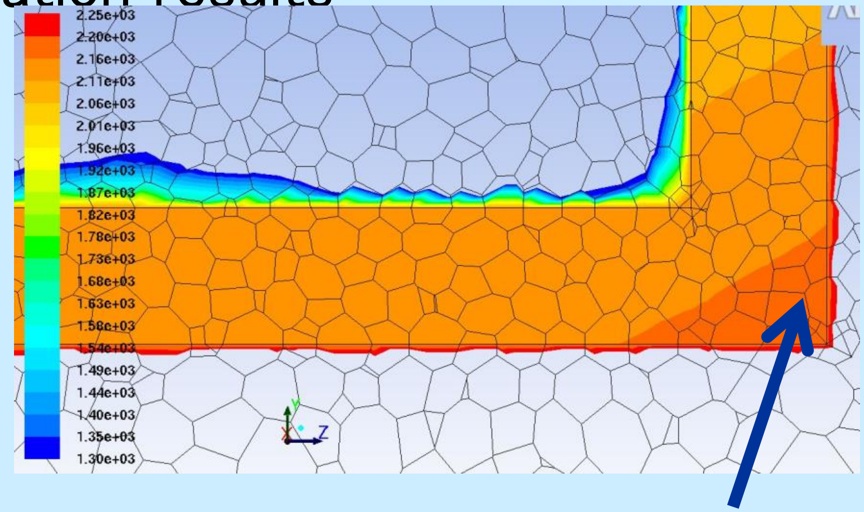


Mesh consists of 2,098,512 polyhedral cells; red arrows – fuel inlet, blue – air inlet, light blue – outer flow

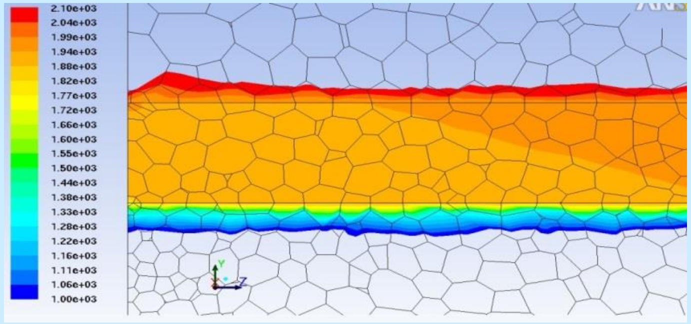
Full scale vaporizer, simulation results



Wall temperature nearby inlet
Tmax = 1900K



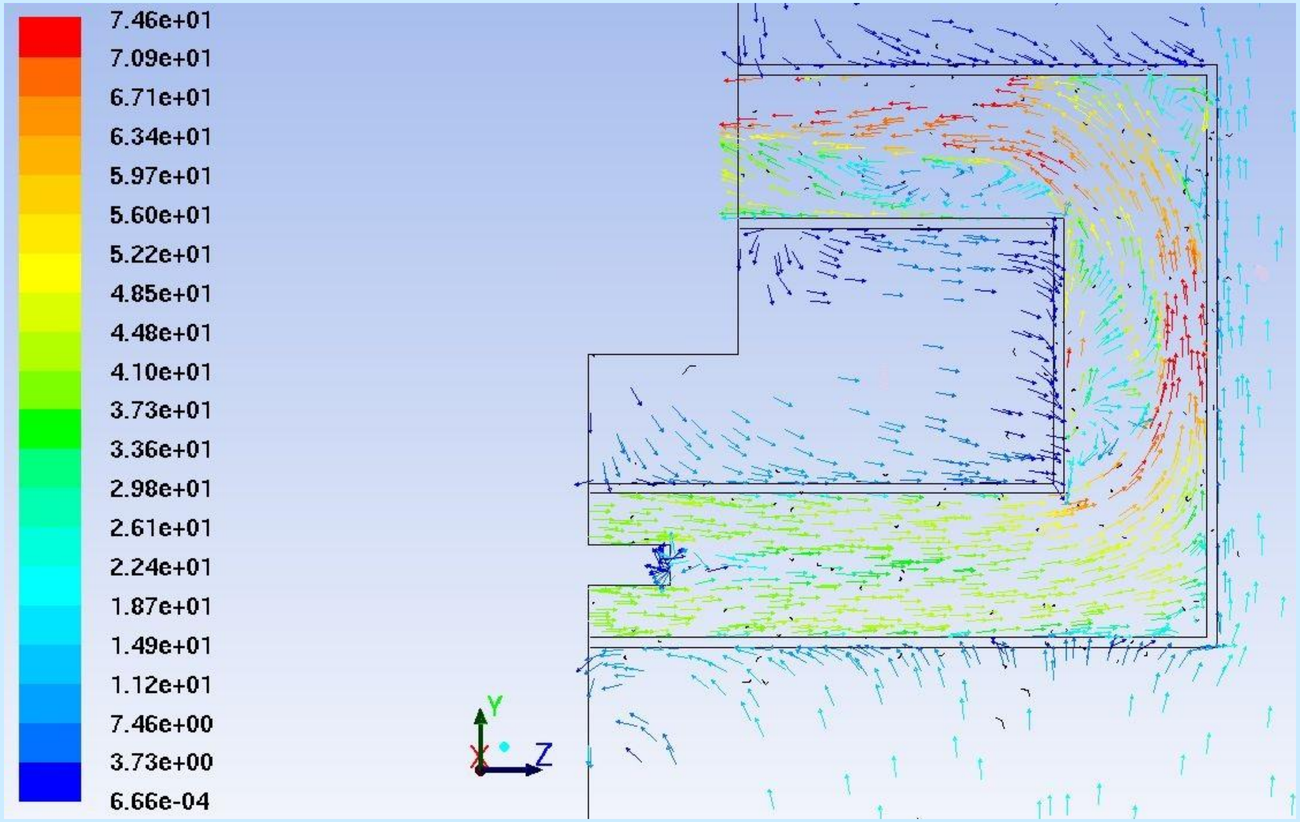
The highest temperature region
Tmax=2200K



Wall temperature nearby outlet
Tmax = 2000K

The results are not shown actual temperature values but give reference about temperature distribution as the evaporation model has serious assumptions

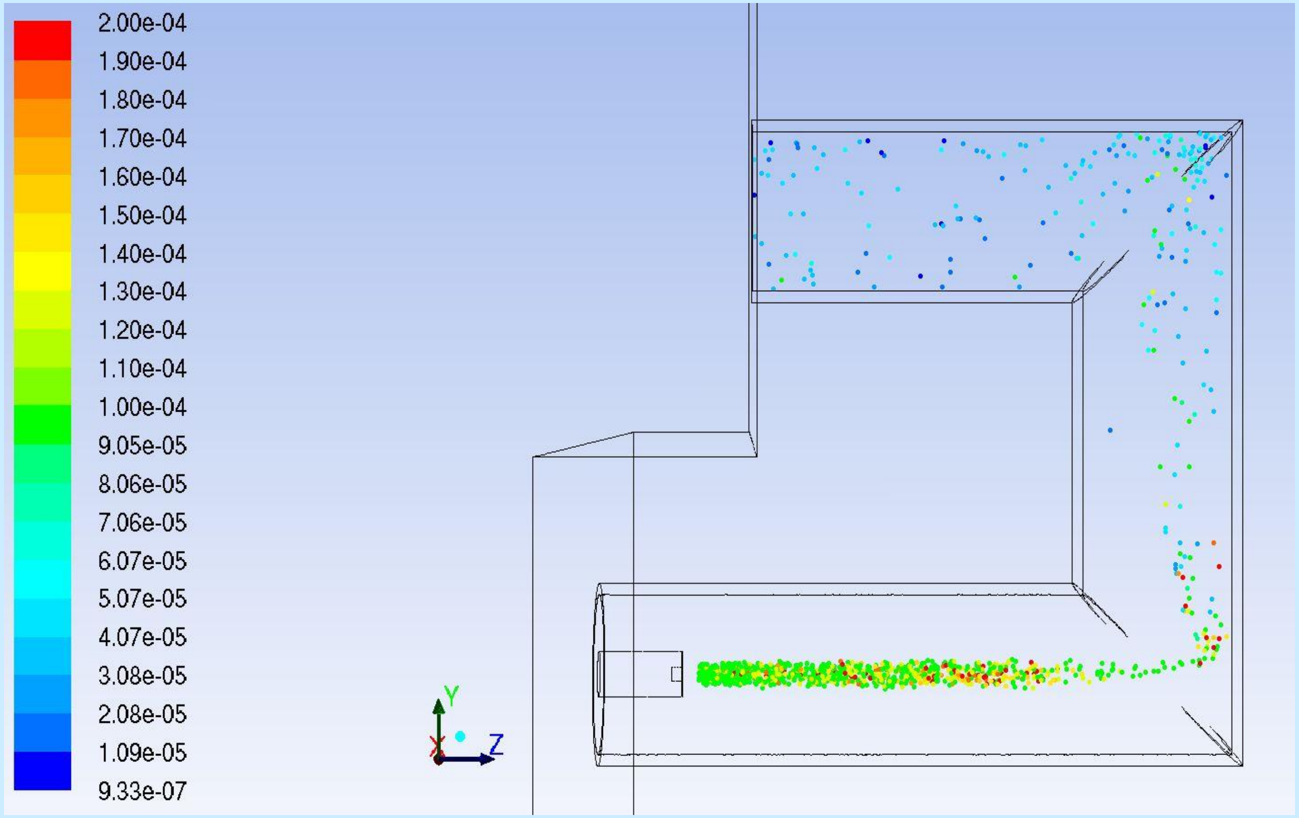
Full scale vaporizer, simulation results (cont.)



Air velocity field

Air flow is pressed to the outer side of the tube

Full scale vaporizer, simulation results (cont.)



Droplets propagation inside the vaporizer

Conclusions

Rotation effect on the vaporizer operation is considered. The qualitative analysis and CFD studies of interaction of two-phase rotating flow with superheated wall is carried out. The following results are obtained:

1. Rotation of the two-phase flow increases force which presses droplets to the superheated wall. This force outperforms gravity force by many times, so the vaporizer operation does not depend on its spacial orientation.

2. The qualitative analysis shows that due to rotation the droplet becomes flatter or disintegrated.

In both cases heat transfer by conductivity and radiation increases.

3. The CFD simulations of two-phase flow in a straight hot tube and generic vaporizer showed that rotation leads to increasing of evaporation rate and decreasing of maximum temperature of wall.

4. The next stages of the study are improvement of vaporization model using theoretical analysis and tests simulations of a full scale generic vaporizer with different operation modes, experimental study of rotation effect, recommendations for optimal vaporizer design.

THANK YOU FOR YOUR ATTENTION!

Swirler option and manufactured models