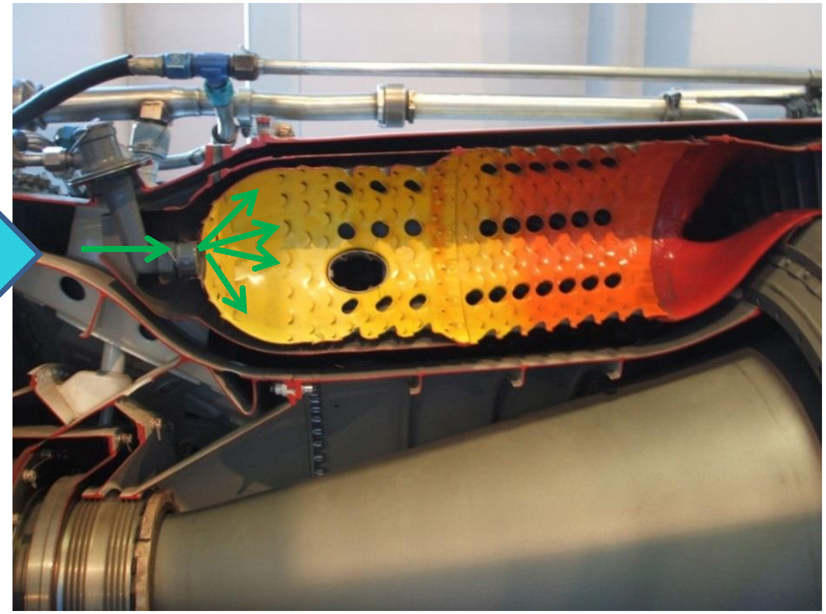
EVALUATION OF THE EVAPORATION PROCESS IN VAPORIZERS OF SMALL TURBOJET AND GAS TURBINE ENGINES

Yeshayahou Levy
Valery Sherbaum
Vladimir Erenburg
Vitali Ovcherenko
Igor Gaissinski
Valery Nadvani
Ori Kam

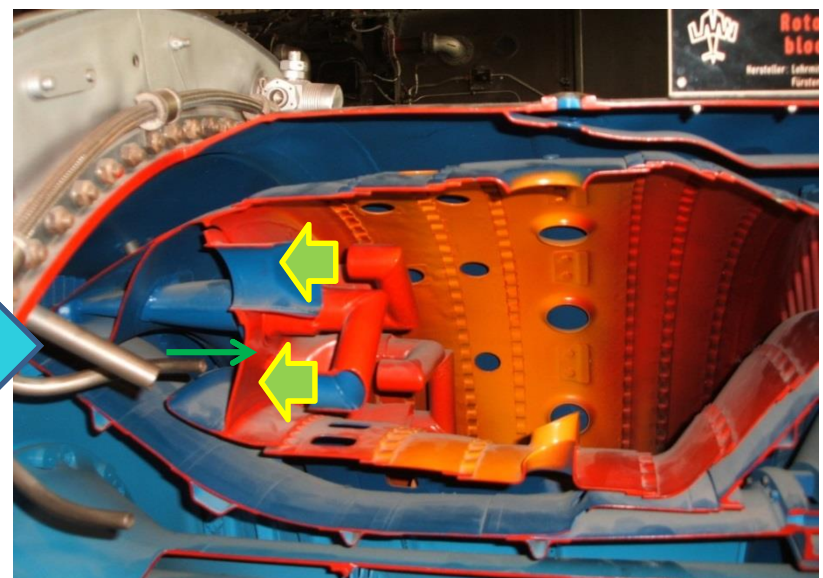
THE 17TH ISRAELI SYMPOSIUM ON JET ENGINES AND GAS TURBINES
Thursday, November 8 ,2018 (9:00-17:00),
Auditoriun (#6), Dan and Betty Kahan Building, the Faculty of Mechanical Engineering, Technion, Haifa

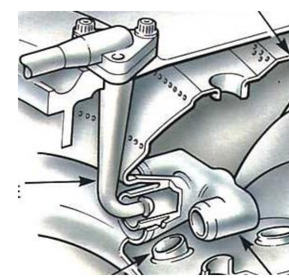
Vaporizer configuration (Introduction)

Jet engine (J79) fuel nozzle (atomizers)

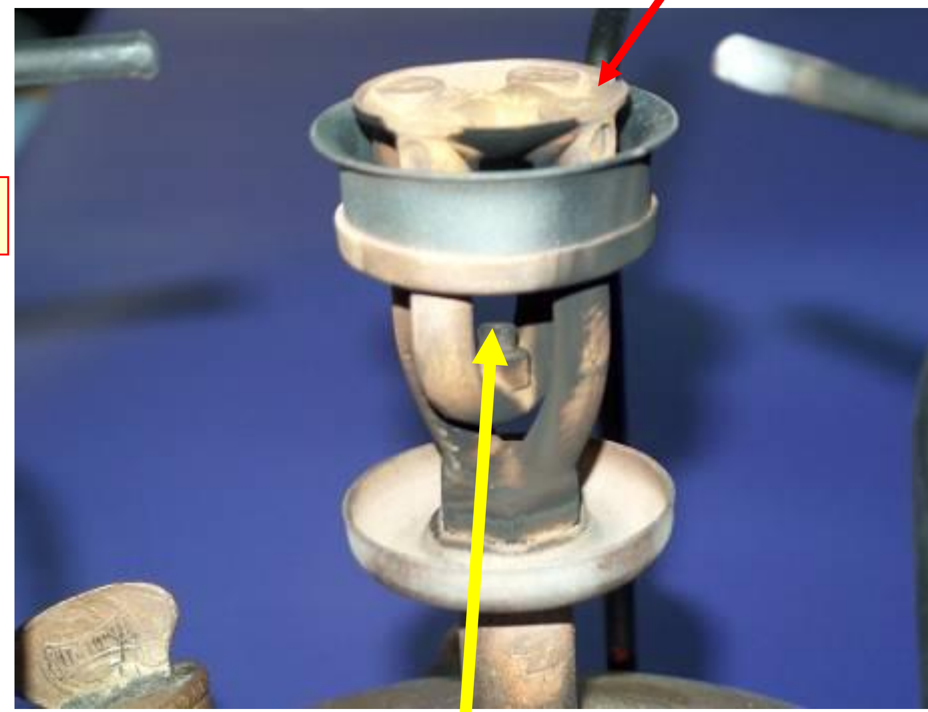


Jet engine with fuel vaporizer

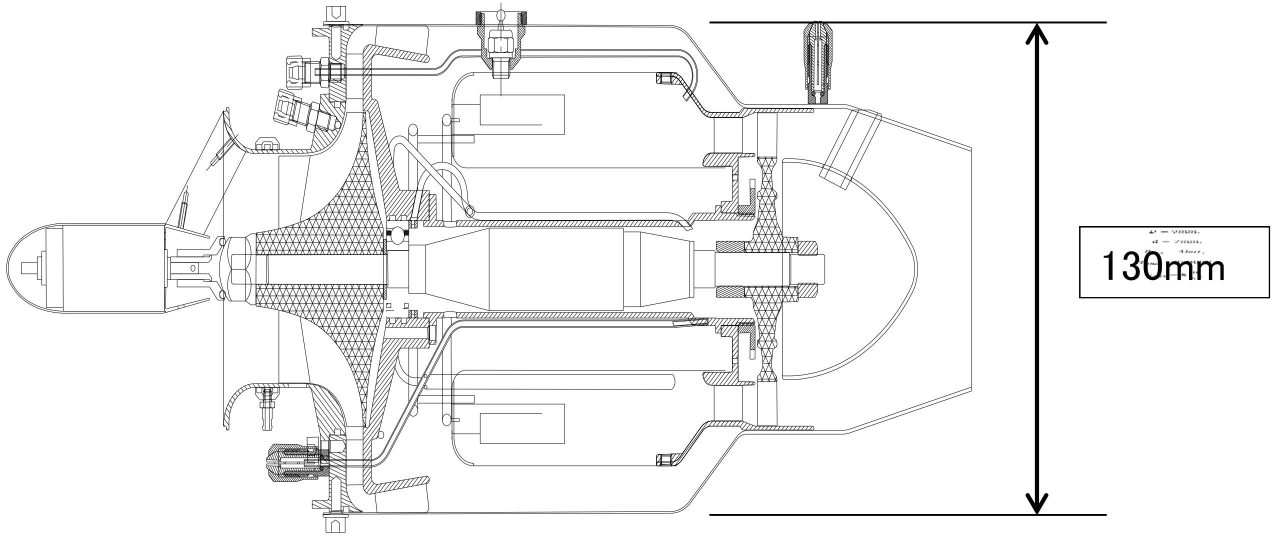




Vaporizer = פרימוס

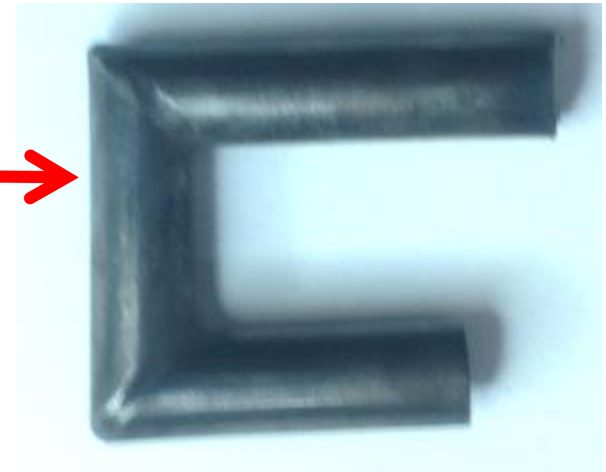


Micro-jet combustor with vaporizer (Olympus, AMT)



Vaporizer Over Heating

The liner of a micro jet engine's combustor

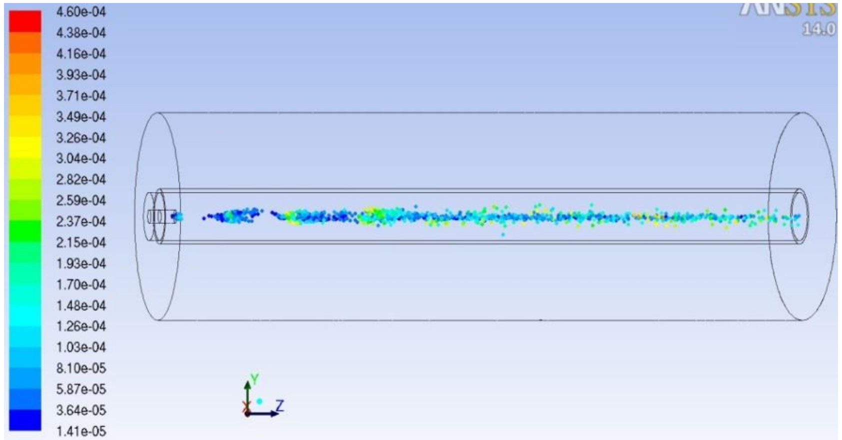


Air and fuel inlet

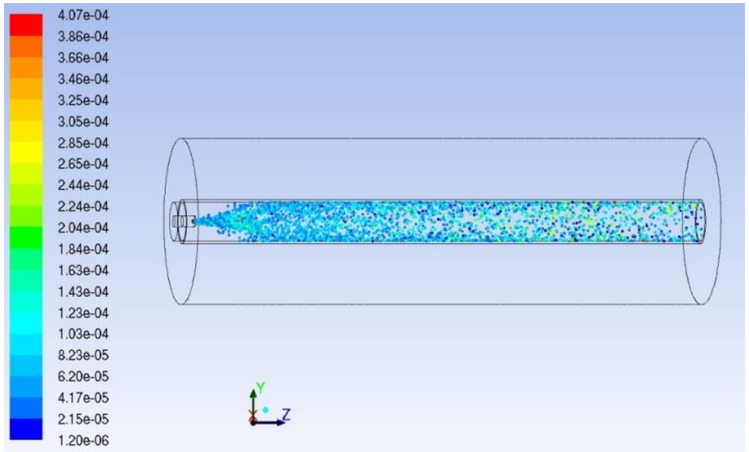
Π-shape vaporizer

Tube melting

Previous study: Convective evaporation



axial inlet flow



axial & swirl inlet flow

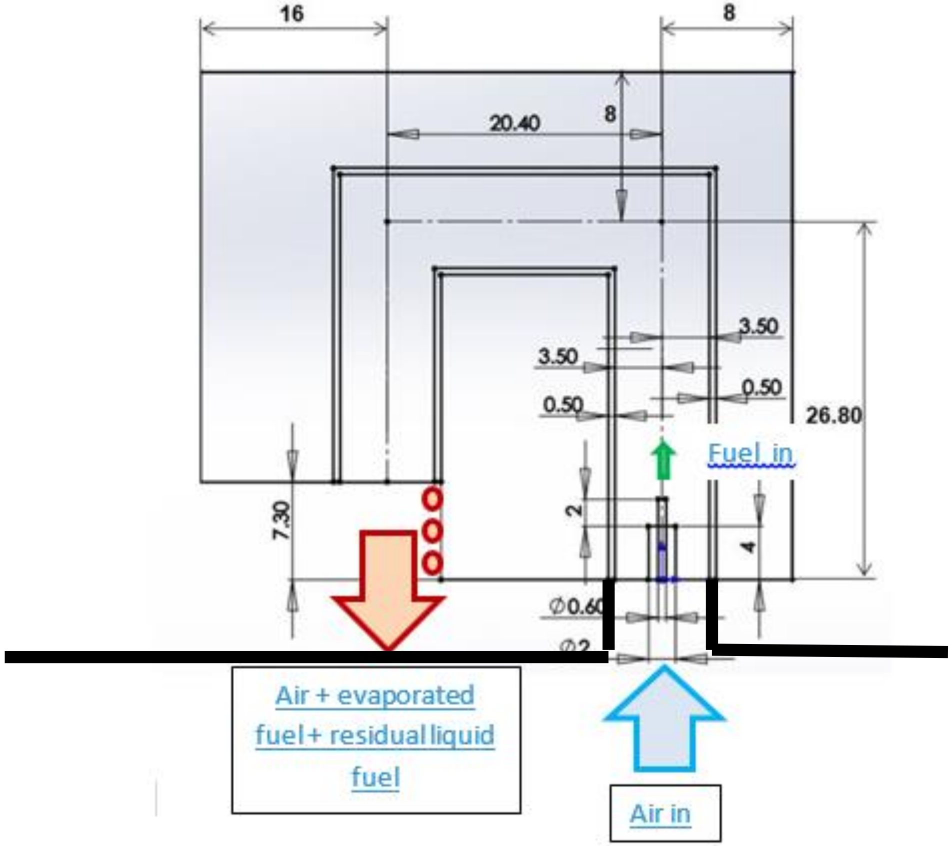
Option	Axial inlet flow, spray angle 5^0	Axial & Swirling inlet flow, spray angle 5^0	Axial inlet flow, spray angle 60^0	Axial & Swirling inlet flow, spray angle 60^0
Evaporated Fraction, %	0.1	6.4	1.9	5.8
Residence time, s	0.007	0.009	0.0064	0.0079
Pressure drop, %	0.46	0.84	0.5	0.79

Although droplets that are spread as a spray evaporate more extensively, convective heat transfer can only evaporate 6 –7% of the fuel.

SPECIFC OBJECTIVES

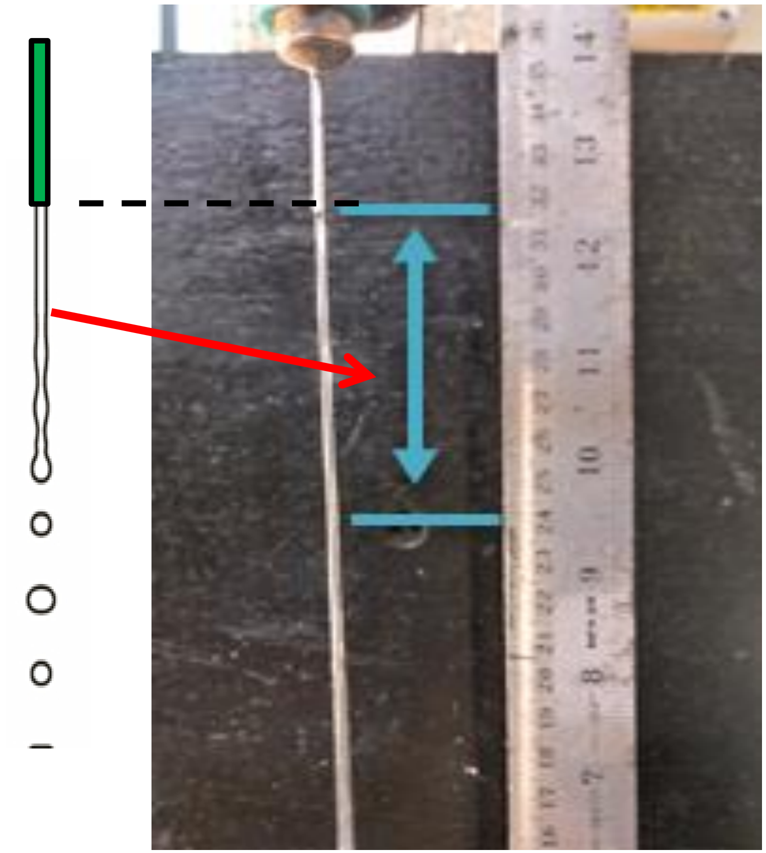
- Investigation processes inside the vaporizer:
- Breakup length of the injected jet;
- Primary jet impingement;
- Liquid film motion;
- Heat transfer from the vaporizer wall to fuel;

Basic model of a vaporizer, schematic



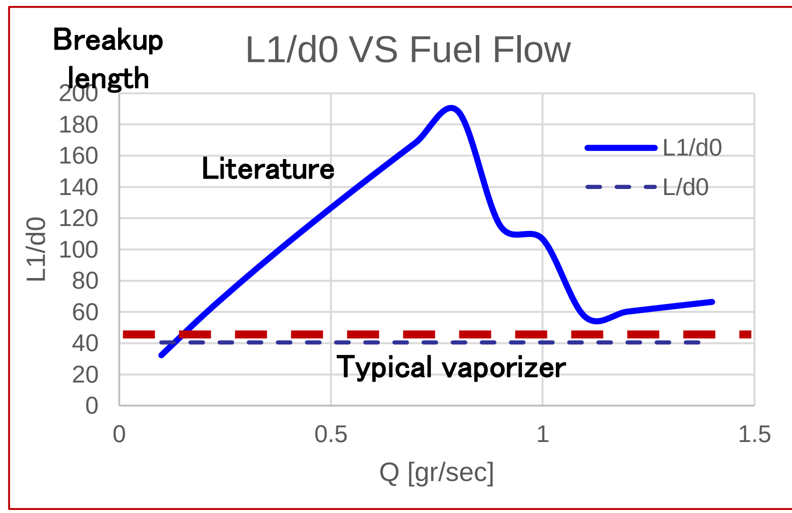
Injected jet length (experimental study).

Continuous stream boundary



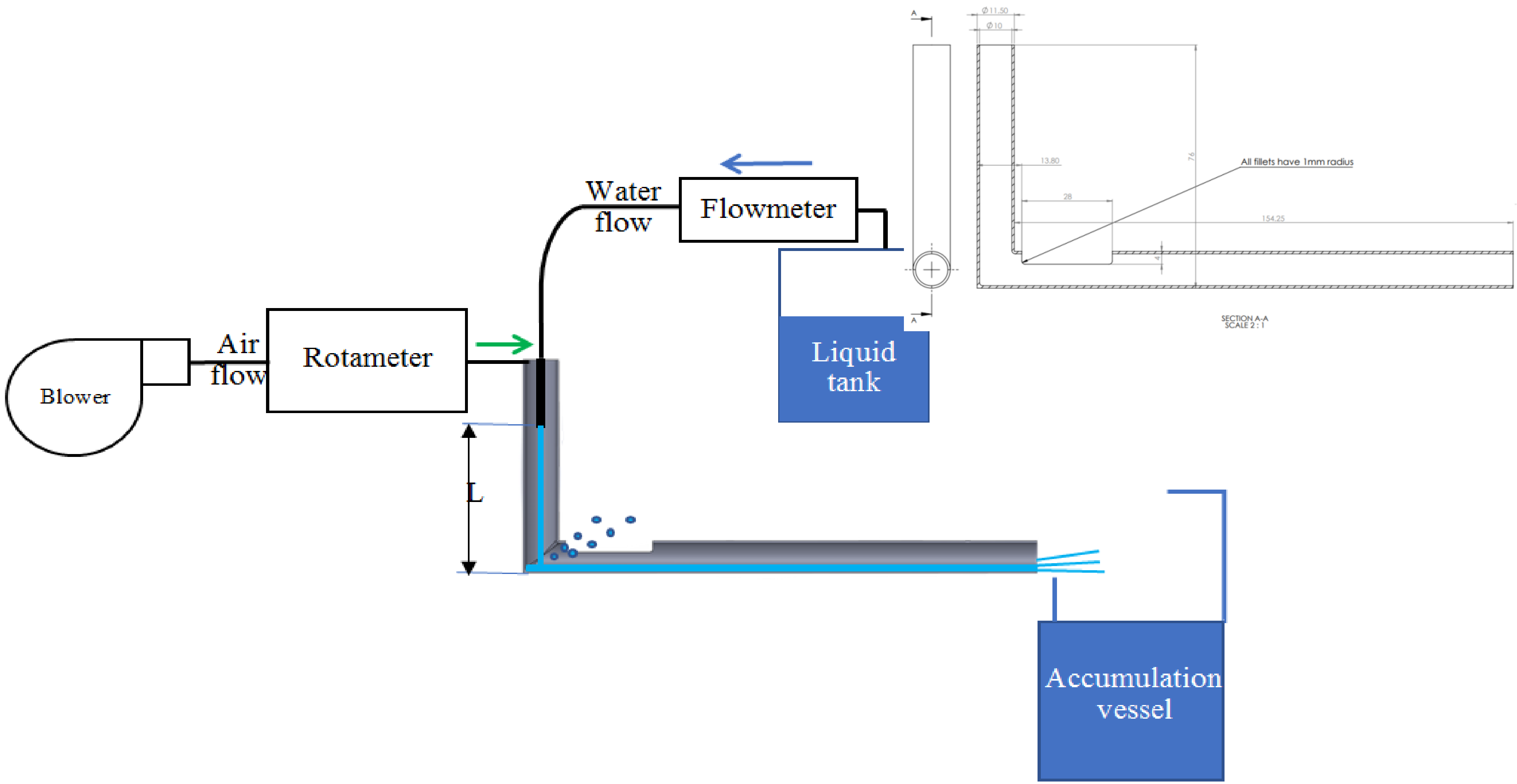
Measured values

Pin	Breakup length (mm)	
	D=0.38mm	D= 0.8mm
0.5 bars	20	15
4 bars	75	115



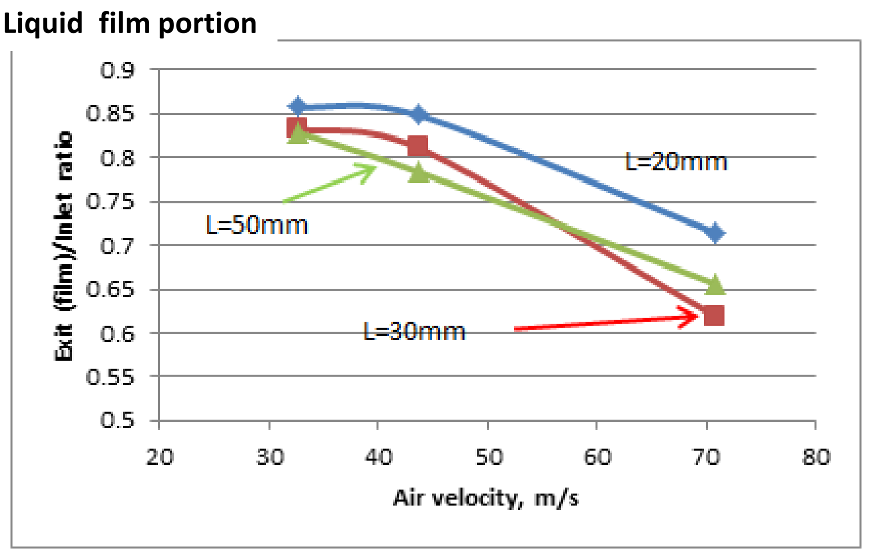
Typically, impingement point occurs when the jet is still as a continuous stream or at a beginning of its breakup.

Experimental study of jet impingement

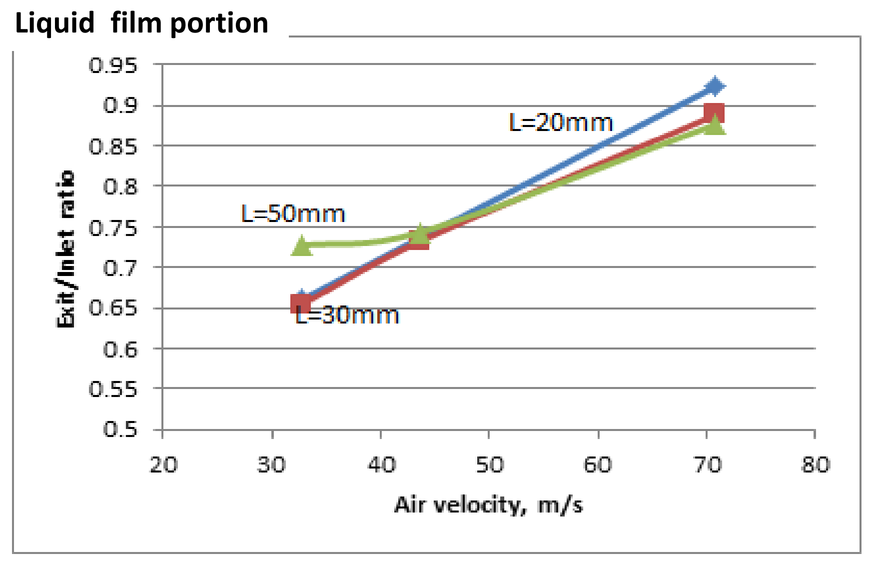


Test-rig for measuring the spray (splash) fraction measurement

Experimental study of impingement (test results)



m_{water}=0.3g/s



m_{water}=1.05g/s

Liquid film to inlet water mass flow rate ratio Vs. air velocity and impingement distance and water mass flow rate.

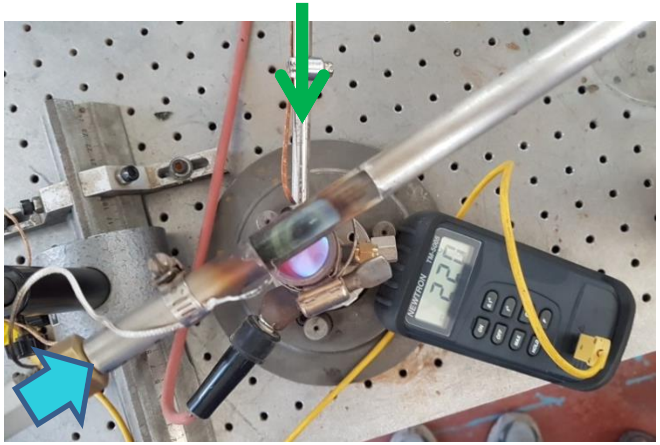
Splashing to inlet mass flow ratio depends on Re, We numbers, distance between injector and the solid surface and is in a range of **0.1– 0.35.**

$$\mathrm{Re} = \mathrm{U}d/\nu \qquad We = \frac{\rho U^2 d}{\sigma}$$

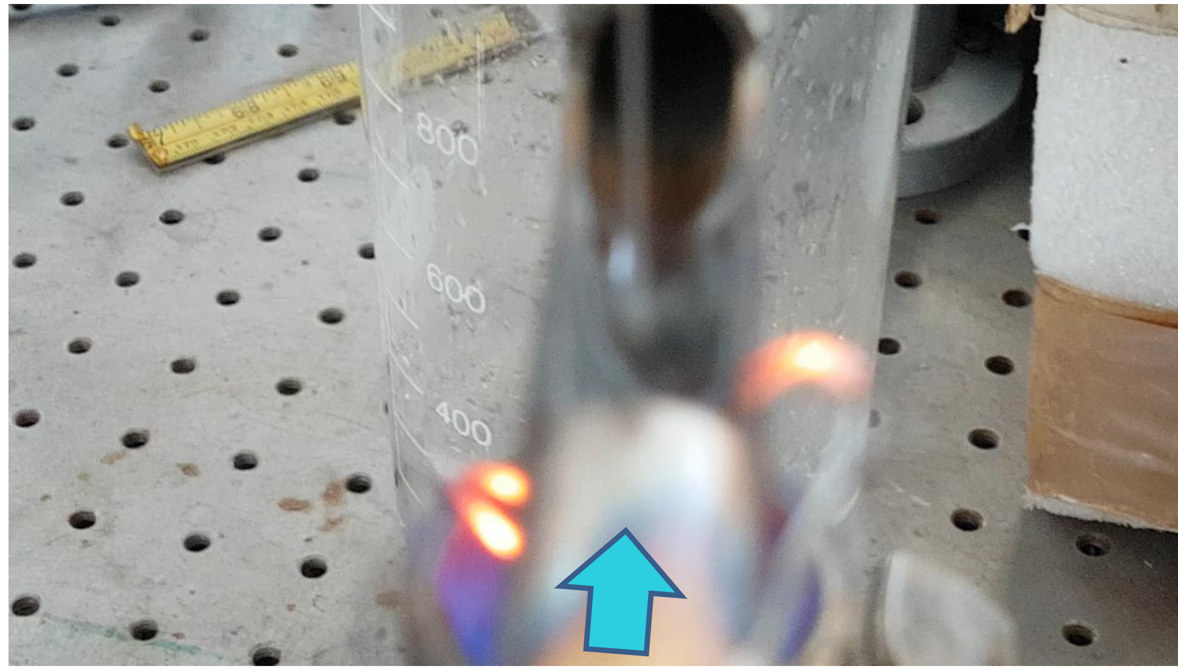
Additional tests with the generic vaporizer are carried out at the present time

Formation of liquid film

LIQUID

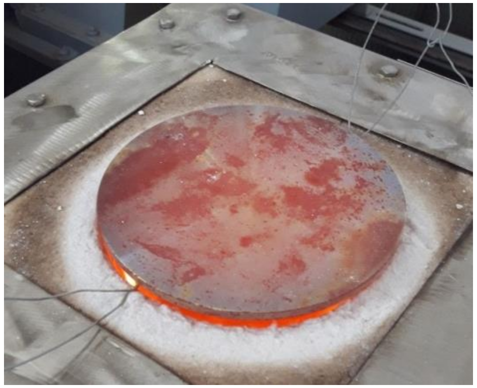


AIR

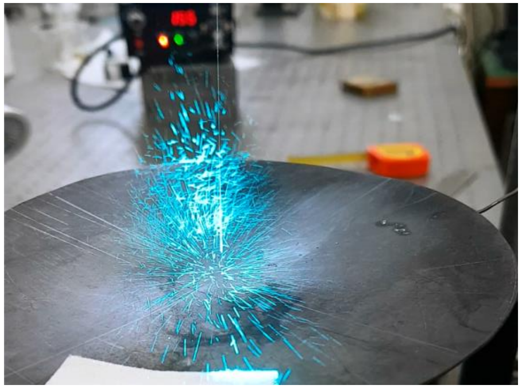


video.

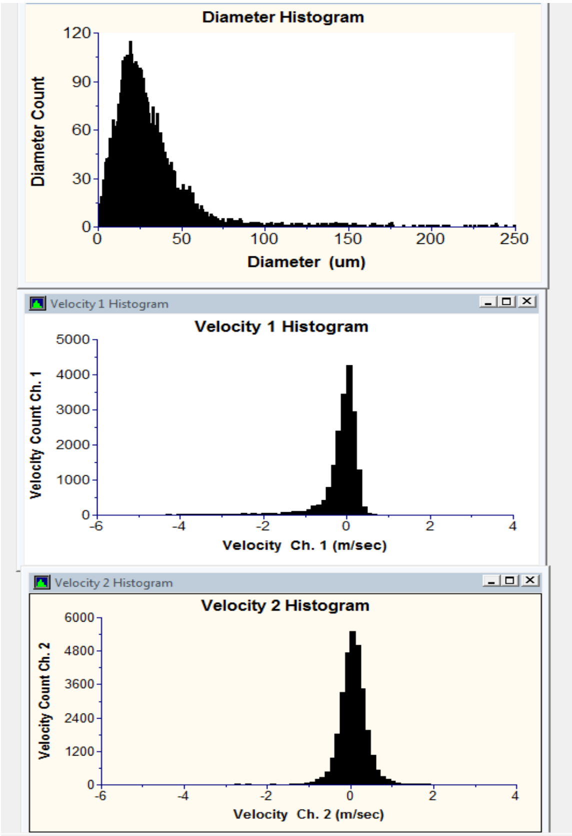
Measurements of splashed droplets

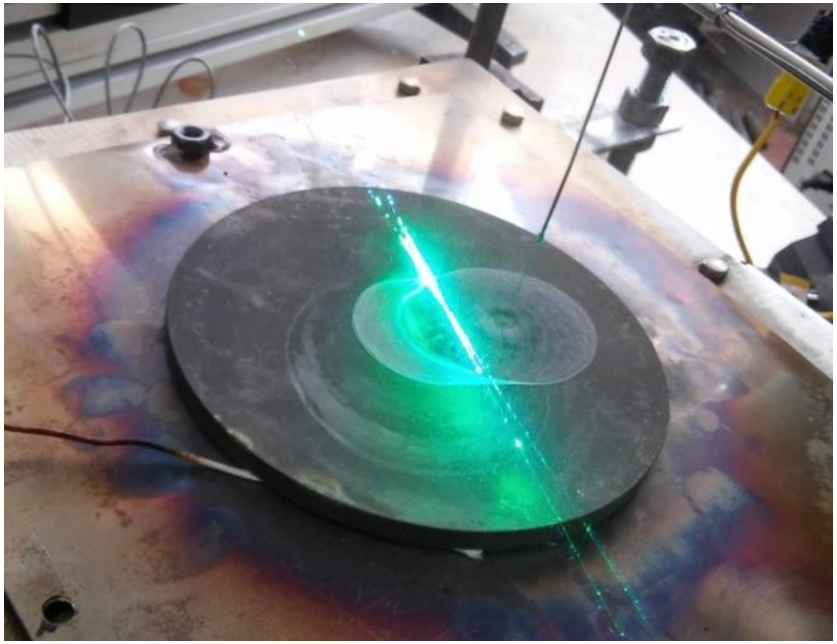


the heated cylinder temperature 600 °C.

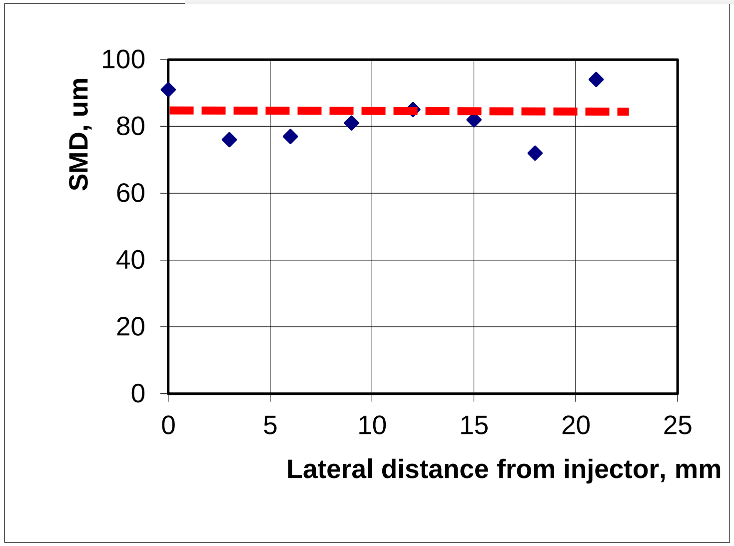


the splashed droplets (illuminated with background light)





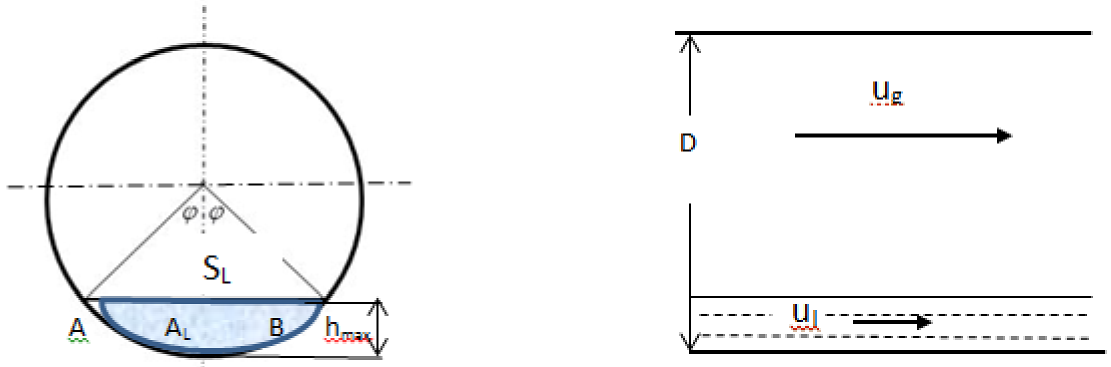
PDPA (droplet) measurements.



FILM FLOW

- As significant portion of the liquid flow inside the vaporizer in the form of a film.
- The study is directed towards analyzing the film velocity (residence time) and heat transfer.

Liquid film velocity inside a tube under influence of gas flow



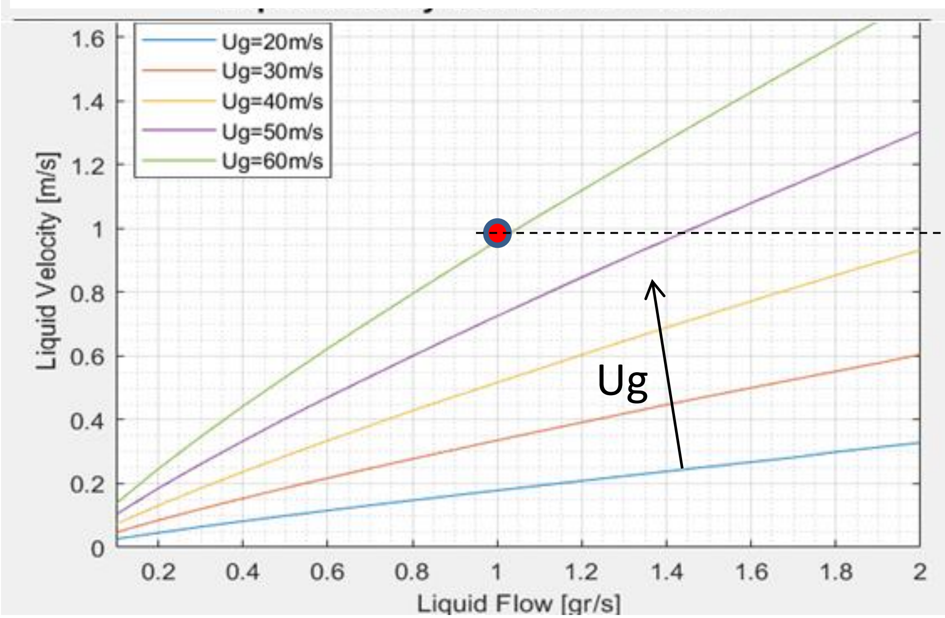
Schematics of two-phase flow inside the cylindrical tube

The calculation is based on the following assumptions:

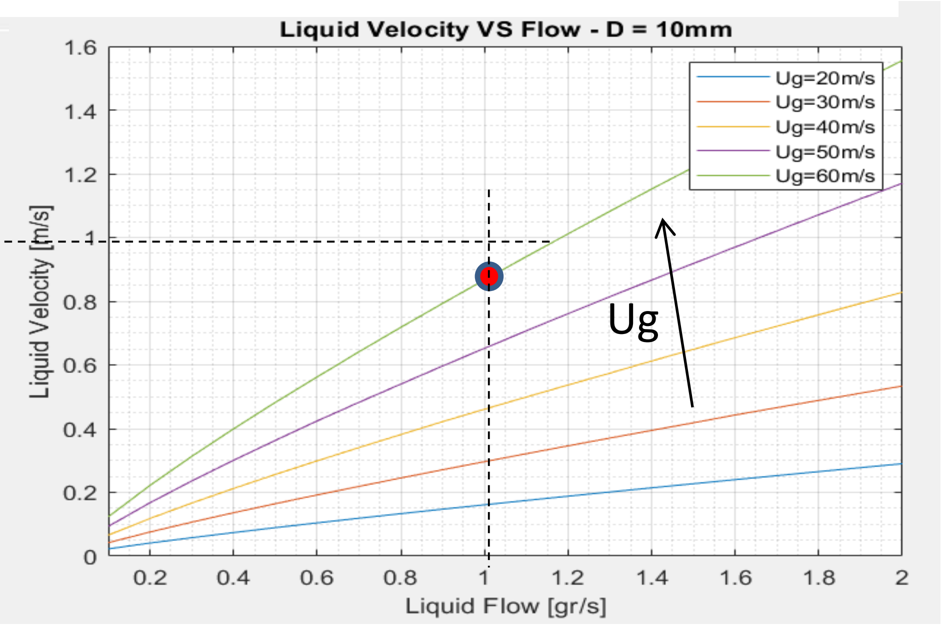
1. Shear stress at the interface between the air and liquid is equal for both, the gas and the liquid.
2. The velocity profile across the (thin) liquid film is linear.
3. The liquid forms a wavy surface with known empirical correlations.

Liquid film velocity inside a tube under: effect of gas flow (cont.)

D= 7mm

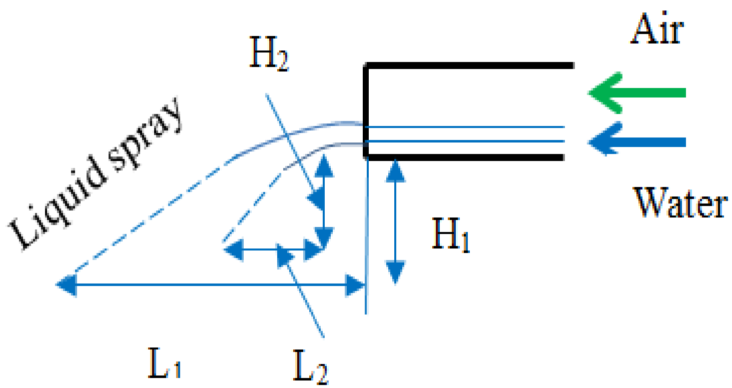


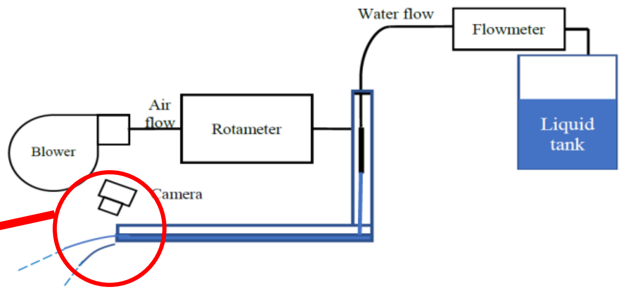
D=10mm



Effect of liquid mass flow rate on mass averaged velocity for tube diameters 7mm and 10mm, liquid=water, T=30^{0}C

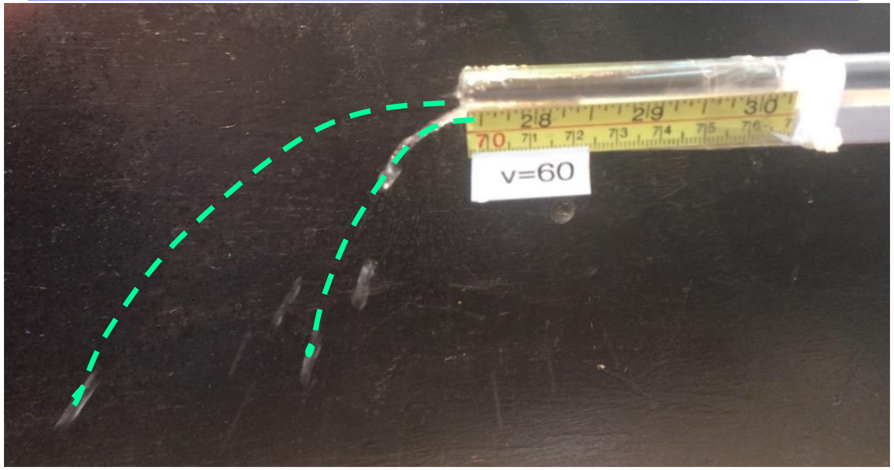
Liquid film velocity inside a tube under influence of gas flow (test results)





$$\tau = \sqrt{2H/g} \qquad V_f = L / \tau$$

Schematics of the experimentally based calculation of liquid velocity



Liquid film at the exit from a glass tube.

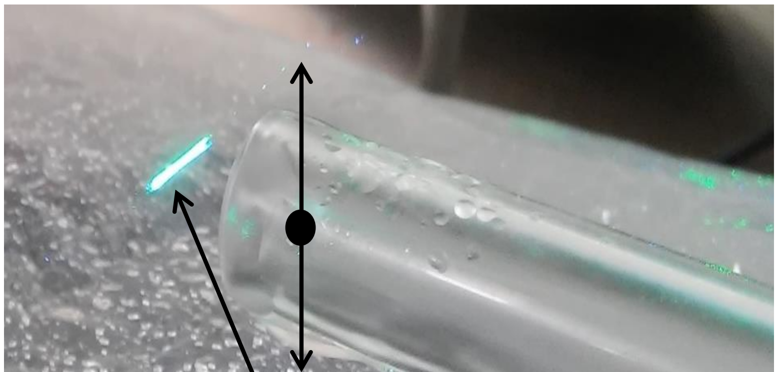
Average film velocity is equal to 0.4 - 0.5m/s

Limited measurements with PDPA system confirmed these low values

Droplet size distribution at the exit of a tube under influence of gas flow (PDPA measurements)

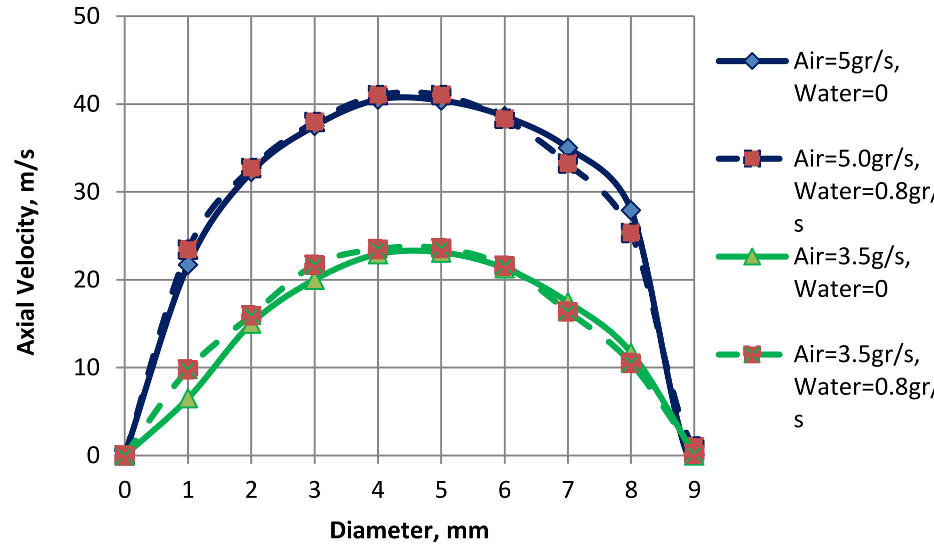
SMD & Velocity distribution across the tube diameter, vertical scan.

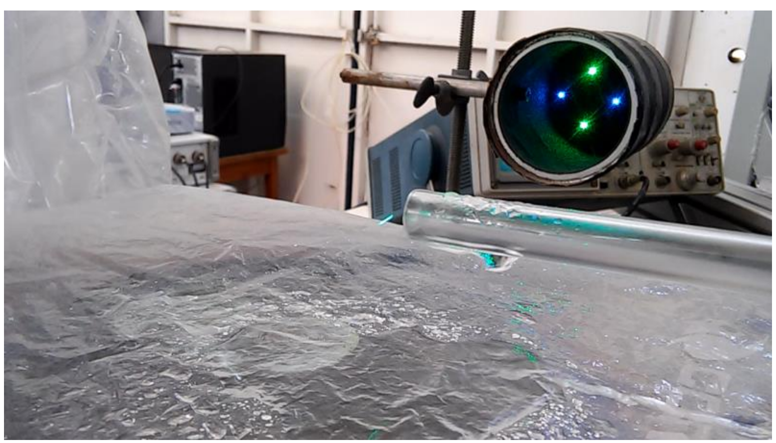
Tube length=300mm



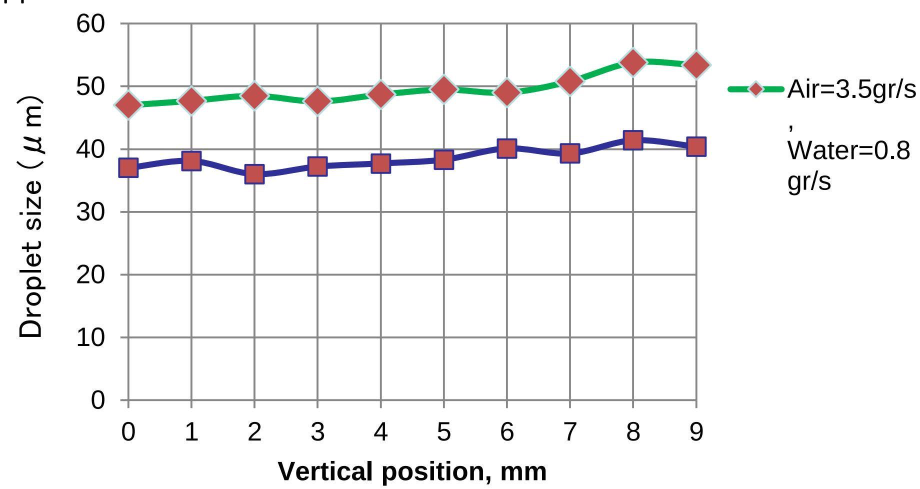
Illumination of droplets flowing out from the exit of the tube.

Upper side Lower side

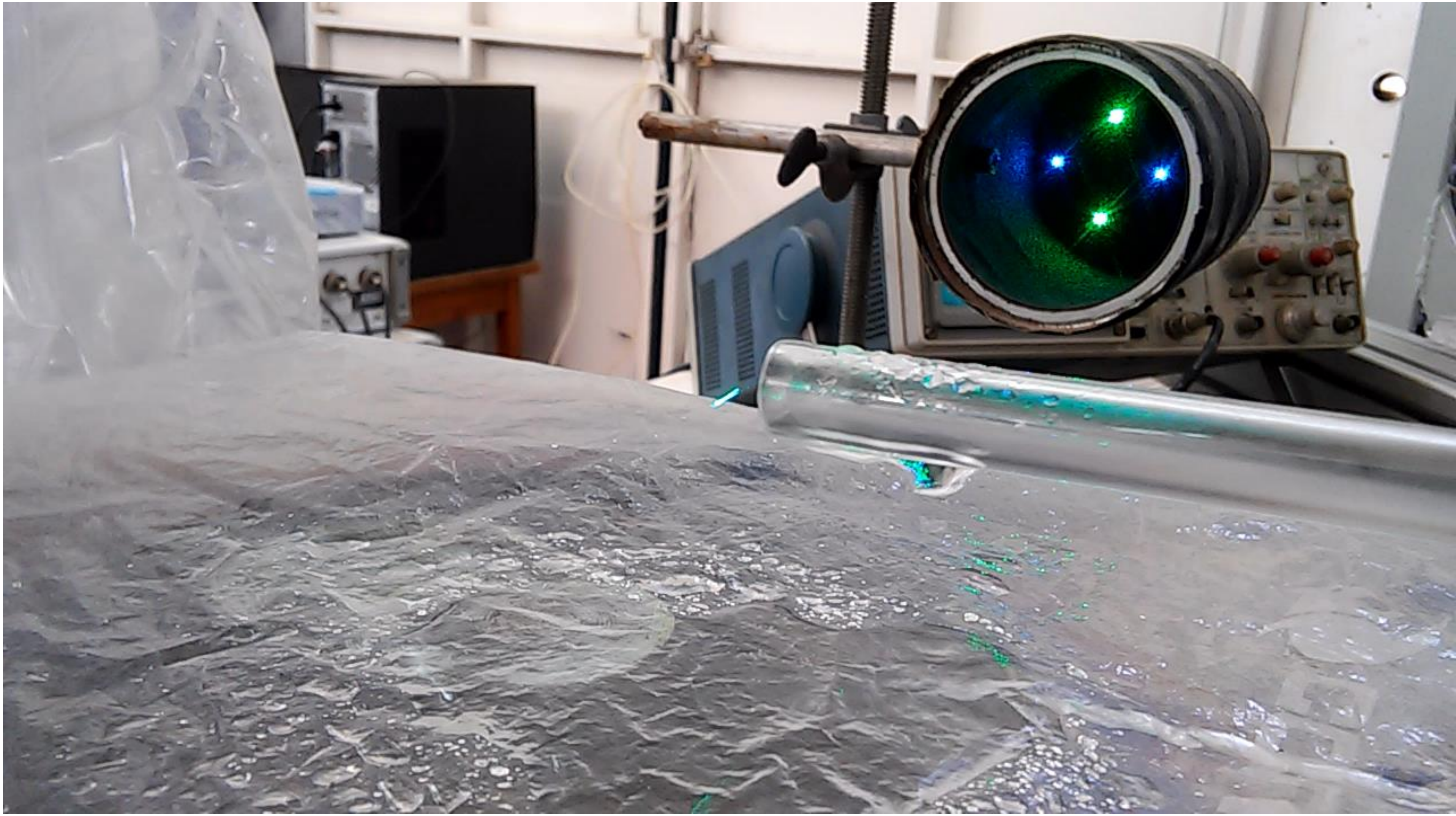




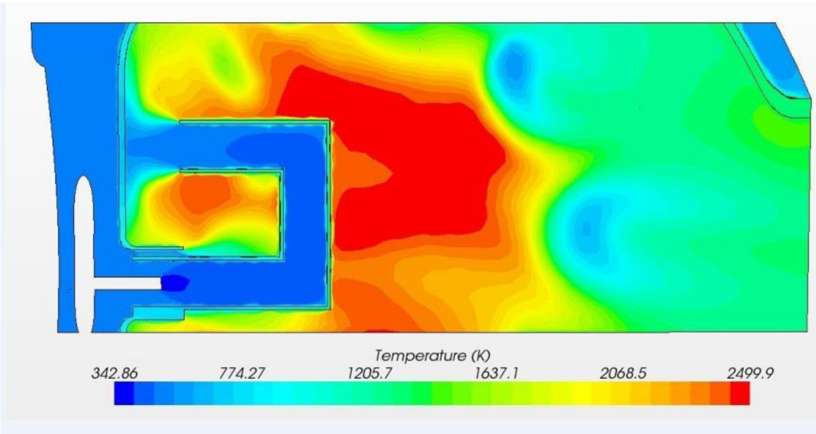
Upper side Lower side



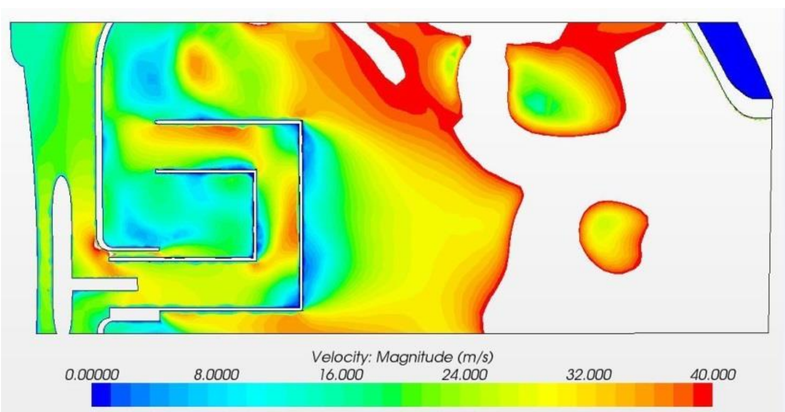
video.



Heat transfer to liquid in the vaporizer (Best case scenario).



Temperature Distribution



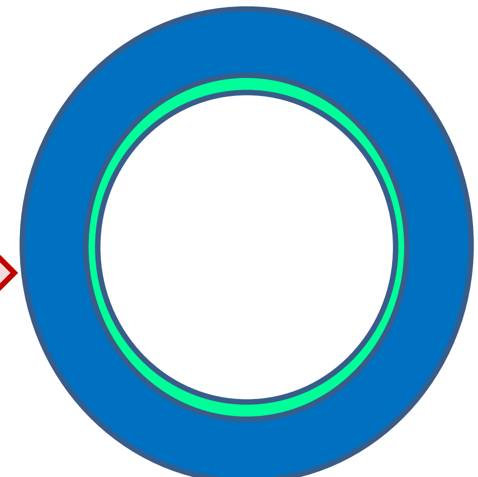
Velocity Distribution

1. Liquid film spread all around the inner tube

$$P_{gas} = 4bar$$

$$T_{gas} = 2500k$$

$$v_{gas} = 5\frac{m}{s}$$



Required area

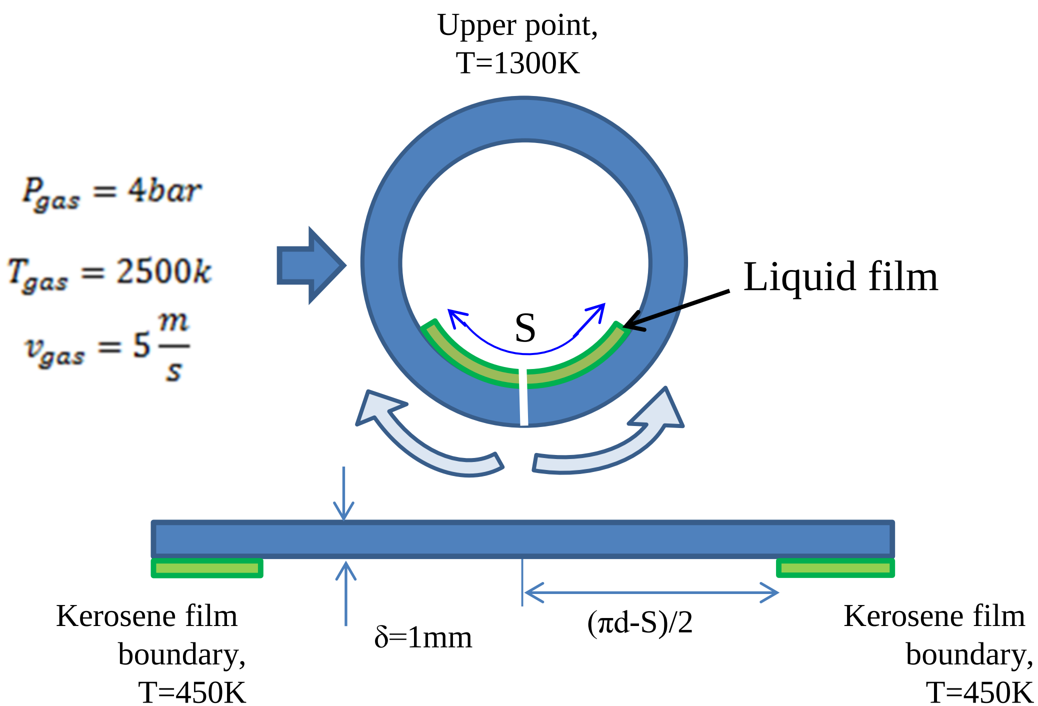
$$A_{\text{ideal}} = \frac{\dot{m}_f c_p (470 - 300) + \dot{m}_f h_{ev}}{h\left(2500 - \bar{T}_{\text{wall}}\right)} \approx 13.4 \ \text{cm}^2$$

Available area

$$A_{vap} = \pi D \cdot L = \pi \cdot 0.87 \cdot 6 \approx 16.4 \quad cm^2$$

Very small margin…

Heat transfer to liquid in the vaporizer (cont.).



Scheme of accepted model for conductivity calculation)

Final results:

Total heat flux to the liquid film is equal
$Q_{total}=Q_{cond}+Q_{rad}+Q_{conv}=$

204+20.4+46=270.4W

Temperature rise of kerosene film

$$\Delta T = Q_{tot} \cdot \tau_{res} / c_{pk} \cdot \dot{m} = 38.7K$$

τ_{res} Residence time of the film
c_{pk} Kerosene specific heat

HEAT IS NOT SUFFICIENT TO EVAPORIZE ALL THE FUEL

Conclusion

- Breakup length of the injected jet was found and compared with existing empirical relationships. Liquid jet impinges to vaporizer wall as continuous jet.

- Splashing during liquid jet impingement onto a solid surface was studied. Splashing to inlet mass flow ratio depends on the Re and We and is in a range of 0.1-0.35. Hence, significant fluid moves as a film.

- A calculation method for the liquid film velocity is proposed. Limited experimental results showed satisfactory agreement with the proposed method.

- Calculations showed that the liquid heating inside the vaporizer considering all heat transfer mechanisms is insufficient for its evaporation.

- Further study:
    1. Liquid film breakup to spray
    2. Interaction of single droplet and spray with hot wall.