Multiple Boundary Layer Stripping Model by Plateau-Rayleigh Instability for Fuel-Coolant Interactions

Division of Advanced Nuclear Engineering, POSTECH

Jung Woo Hyun (정우현)

Two Phase Flow Laboratory

2016.05.13

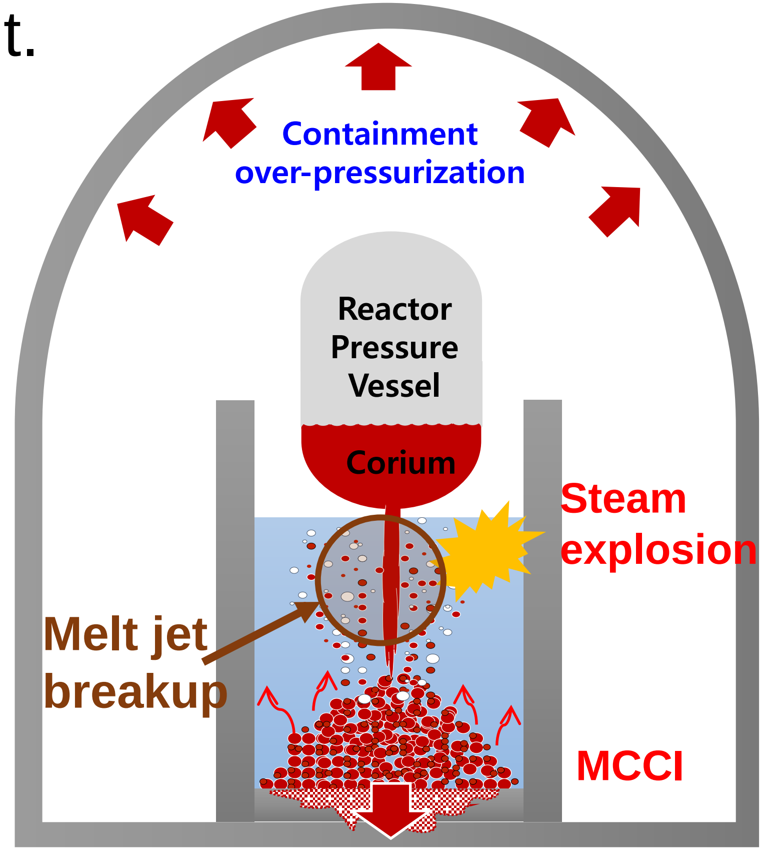
Contents

- Introduction
- MATE Facility
- MATE Tests Results
- Multiple Boundary Layer Stripping Model
- Application to MATE results
- Conclusion

In Ex-vessel severe accident, there are two severe phenomena threatening the integrity of containment.

1. Steam explosion
- It happens along four steps : **Premixing** -> Triggering -> Propagation -> Expansion

2. MCCI
- Dependent on characteristic (Coolability) of debris bed.
- Many parameters are related with characteristic of debris bed, such as **'particle size distribution', 'jet breakup length'** and 'initial condition of melt jet'



< Severe accident scenario >

- **Two phenomena are all strongly related to the 'Melt Jet Breakup'**

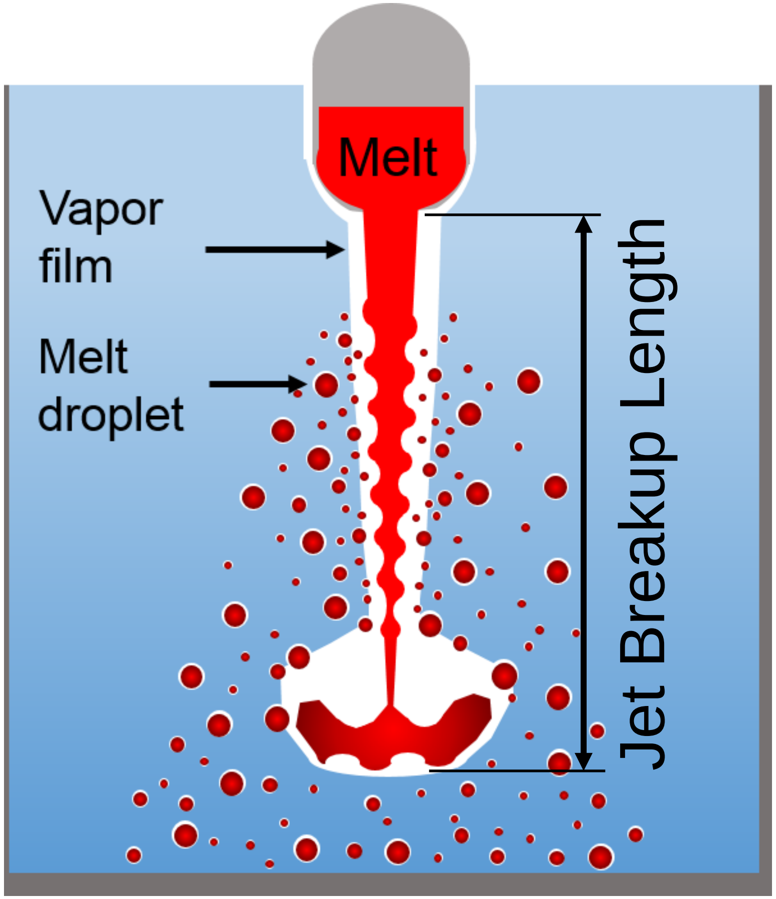
Introduction

- Jet breakup phenomenon can be analyzed on two effects :

  Hydrodynamic effect (‘Rayleigh-Taylor instability’, ‘Kelvin-Helmholtz instability’, ‘Plateau-Rayleigh instability’ and ‘Boundary layer stripping’)

  Thermal effect (‘Vapor film effect’ and ‘Solidification effect’).

- Jet breakup length is the distance for the total breakup of continuous core.



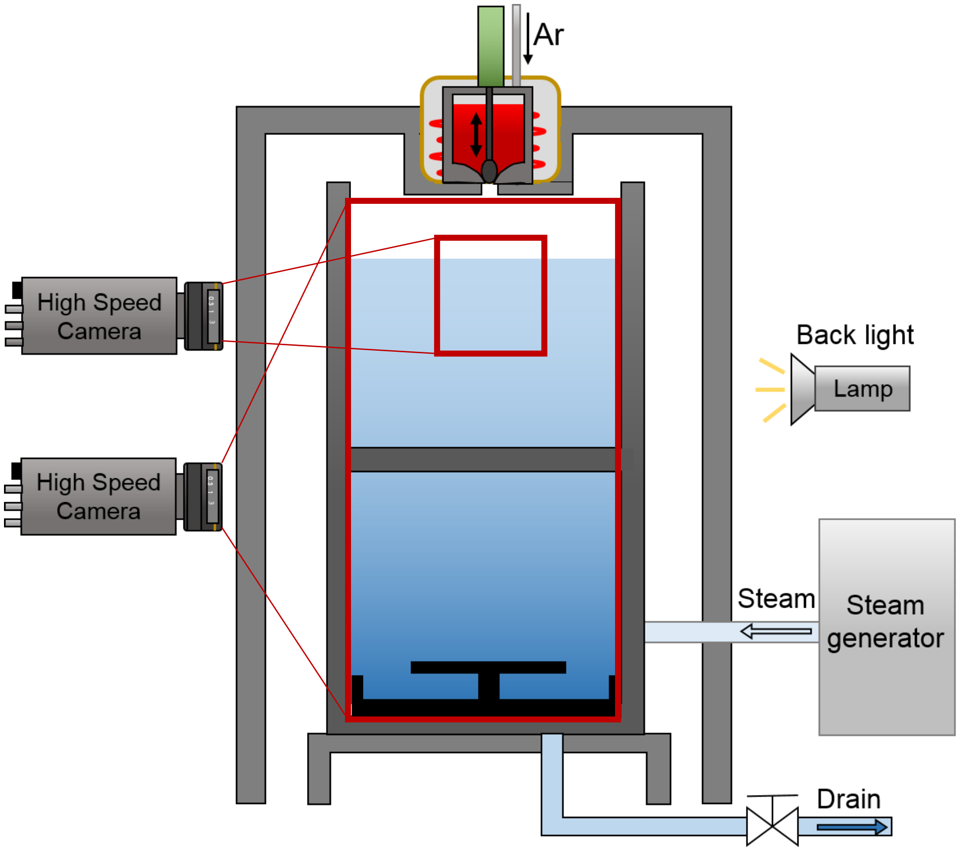
< Conceptual figure of melt jet breakup >

- **Jet breakup length is one of the main parameter**

MATE Facility

MATE(**M**elt jet **A**nalysis with **T**hermal **E**ffect) facility specification

- ✓ Water pool depth : 2.0 m
- ✓ Free fall length of melt : 0.5 m ~ 0.8 m
- ✓ Mass of melt : ~20 kg
- ✓ Temperature of melt : ~350℃
- ✓ Pool temperature : ~100℃
- ✓ Nozzle diameter : 14 mm ~ 35 mm



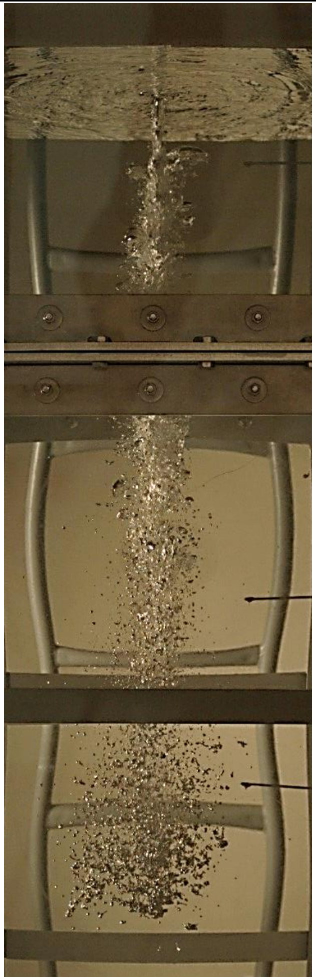
< Schematic diagram of MATE facility >

- **Main method is Visualization with two high speed camera**

MATE Tests Results

< MATE tests conditions >

Parameter	MATE 00	MATE 00-2
Melt	Bi-Sn Alloy (58%+42%, M.P 138℃)	
Melt mass	2.42 kg	2.488 kg
Free fall height	0.75 m	0.5 m
Nozzle diameter	14 mm	14 mm
Pool temperature	95℃	99℃
Melt temperature	310℃	300℃
Pool depth	1.25 m	1.5 m



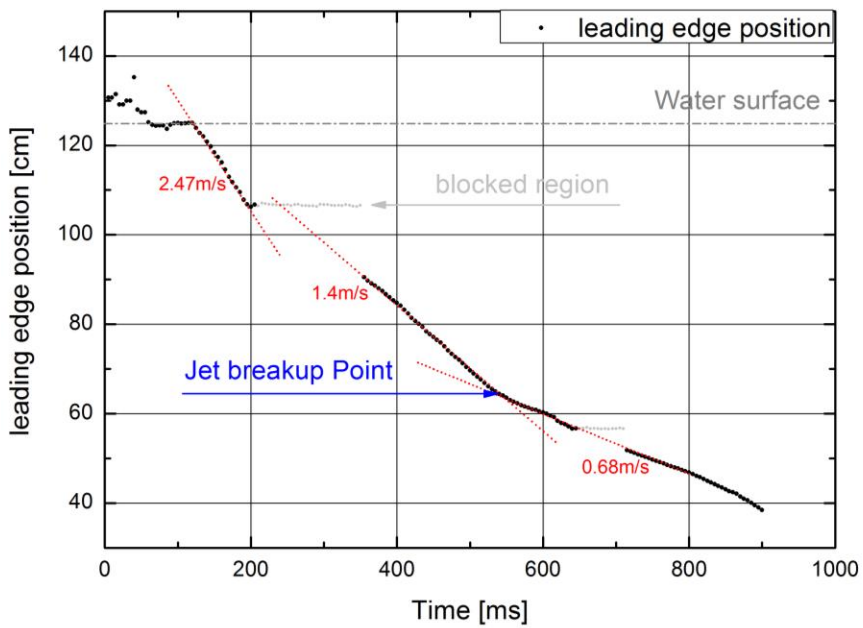
< MATE 00 >

< MATE 00-2 >

MATE Tests Results

< Leading edge position of melt jet>

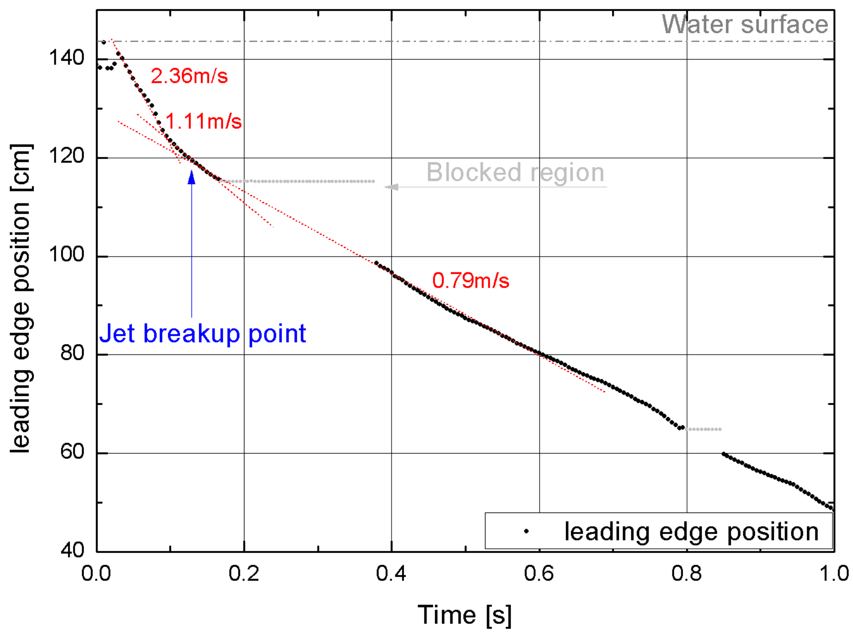
< MATE 00 >



Jet breakup length = **0.63 m**

- 10.5% than Saito's correlation

< MATE 00-2 >



Jet breakup length = **0.35 m**

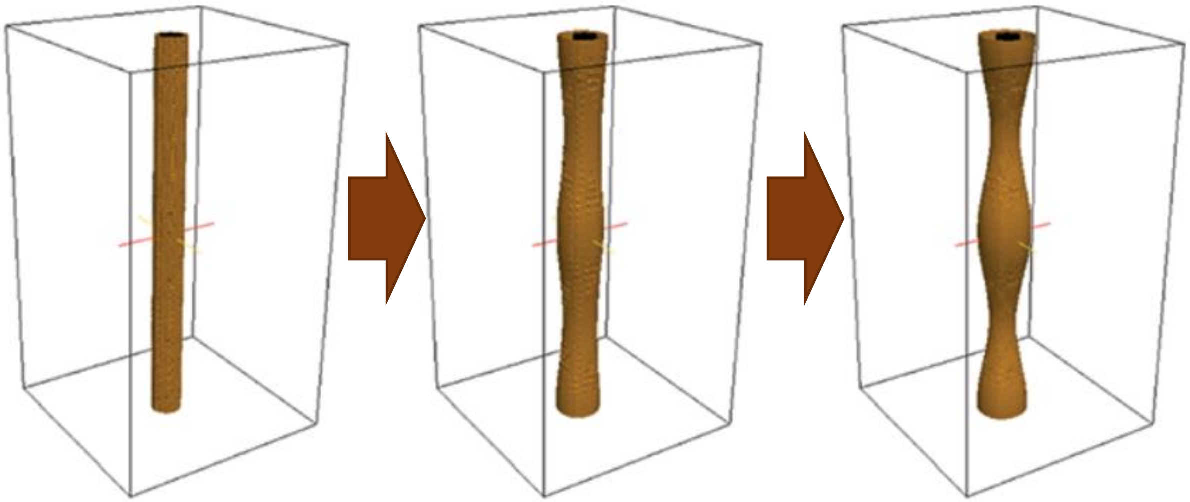
- 41.2% than Saito's correlation

- **Despite of the similar condition, jet breakup length shows large difference**

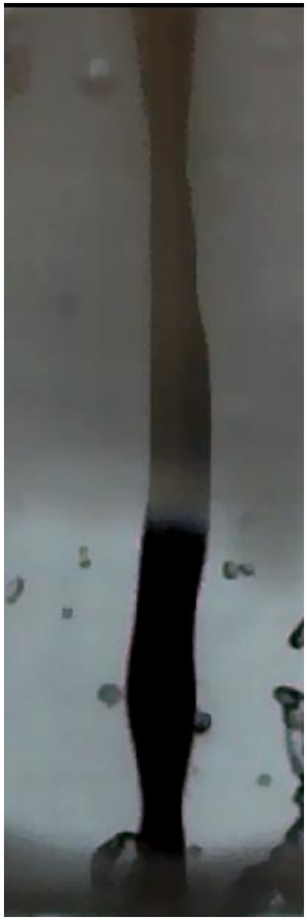
MATE Tests Results

< Plateau-Rayleigh Instability >

- Plateau-Rayleigh instability is derived by surface tension, tend to minimize the surface area of jet.



< Simulation of Plateau-Rayleigh Instability (Hunter,2012) >

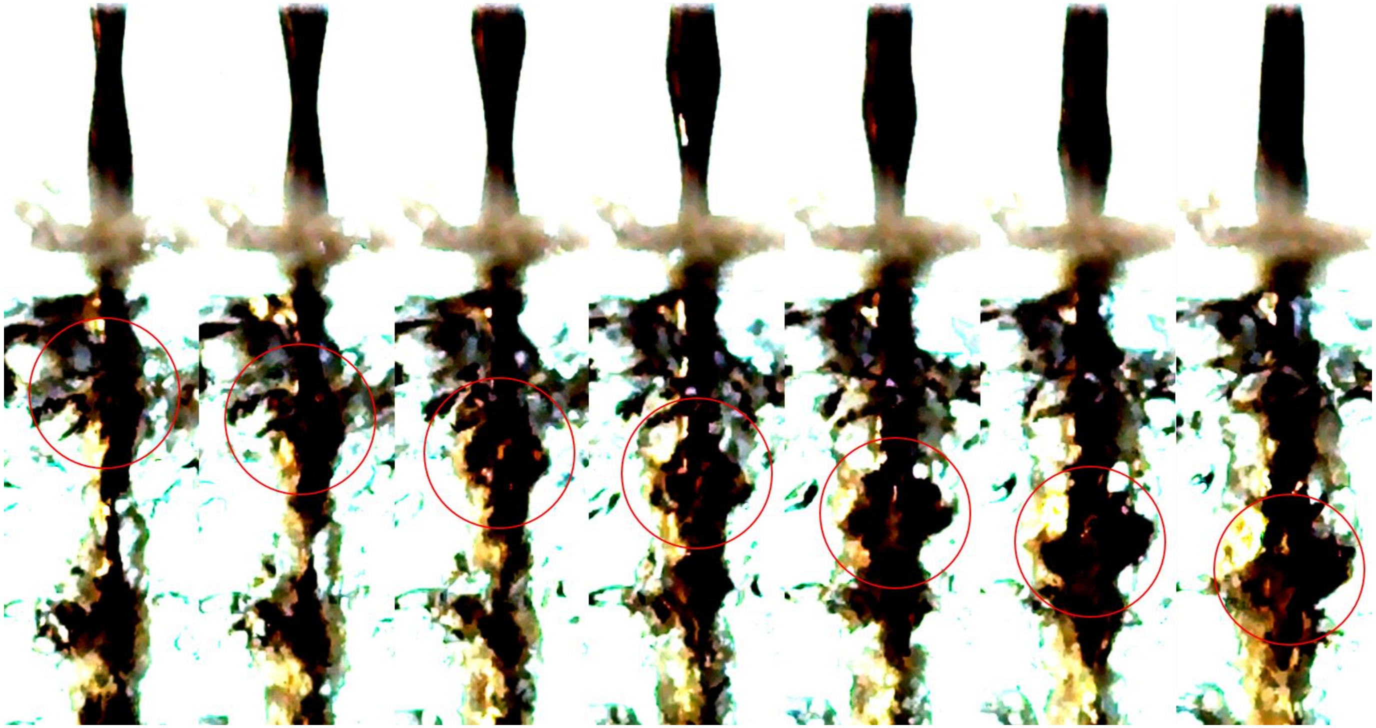


< P-R instability of melt jet on MATE 00-2 >

- **MATE 00-2 shows well developed P-R instability**

MATE Tests Results

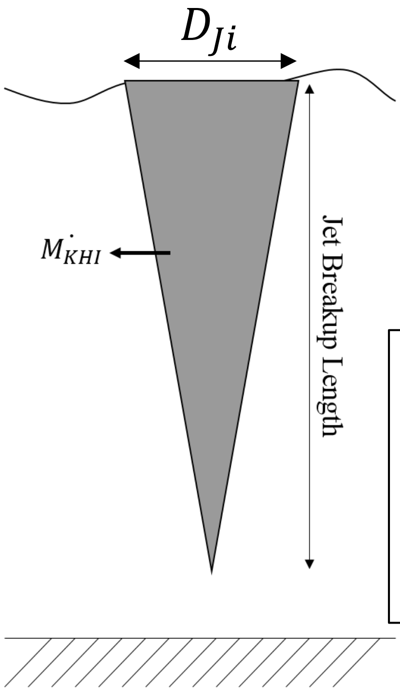
< Multiple Boundary Layer Stripping induced by P-R instability >



< Existence of the boundary layer stripping(BLS) on the middle of the jet ; red circle : mushroom-like breakup>

- **Mushroom-like shape breakup on the middle of the jet may accelerate the jet breakup**

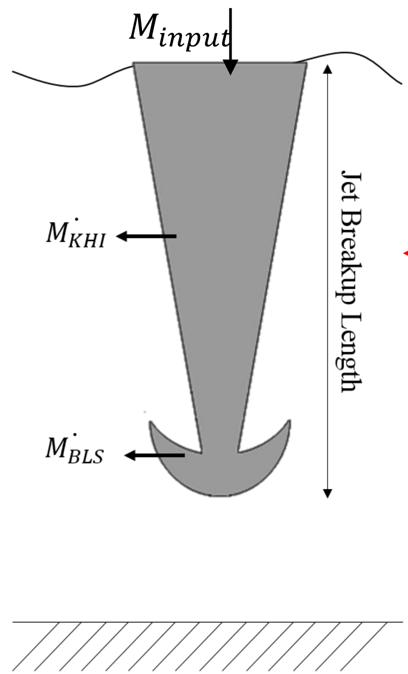
< Conventional simplified jet breakup model >



(a) KHI model

Linear cone shape jet model
(moriyama, 2006)

$$m_e = \frac{1}{2}\rho_m \frac{D_{Ji}V_{Ji}}{L_{brk}}$$



(b) KHI + BLS model

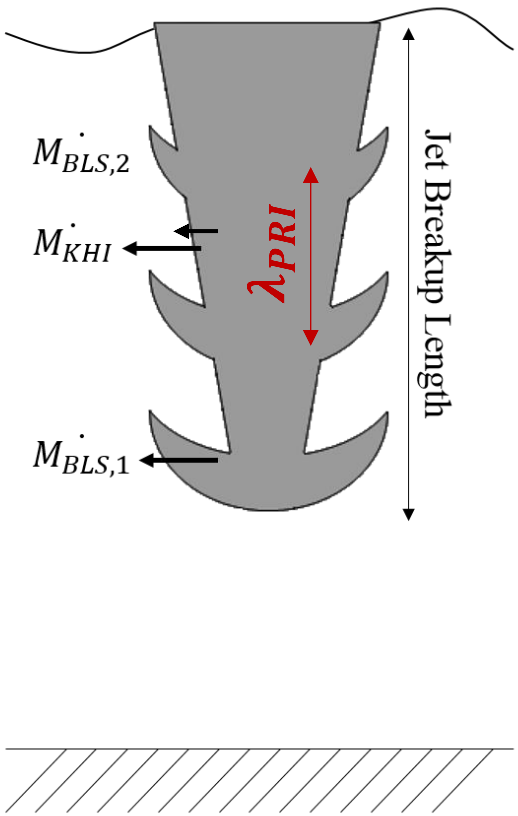
Linear cone shape jet model + leading edge
(Bang, 2009)

$$M_{input} = M_{KHI} + M_{BLS}$$

Where, D_{Ji} is jet diameter at water surface, V_{Ji} is jet velocity at water surface, L_{brk} is jet breakup length

Multiple BLS model

< New simplified jet breakup model >



(c) KHI + multiple BLS model

Multiple Boundary Layer Stripping Model

$$M_{input} = M'_{KHI} + (a-1)M_{BLS,2} + M_{BLS,1}$$

$$a = \frac{L_{brk}}{\lambda_{PRI}}$$

$$\lambda_{PRI,max} \cong 9.02R_0$$

Where, λ_{PRI} is the wavelength of the PRI, $M_{BLS,2}$ is fragmentation mass rate by BLS on the middle of the jet, $M_{BLS,1}$ is fragmentation mass rate by BLS on the leading edge, and M'_{KHI} is the fragmentation mass rate by KHI with shorten jet breakup length.

- **Multiple BLS term increases the fragmentation mass rate than conventional model**

Multiple BLS model

TPFL Two Phase Flow Laboratory

< Method to predict $M_{BLS,2}$ >

(1) Obtain $M_{BLS,1}$ from conventional model

$$M_{input} = M_{KHI} + M_{BLS,1}$$

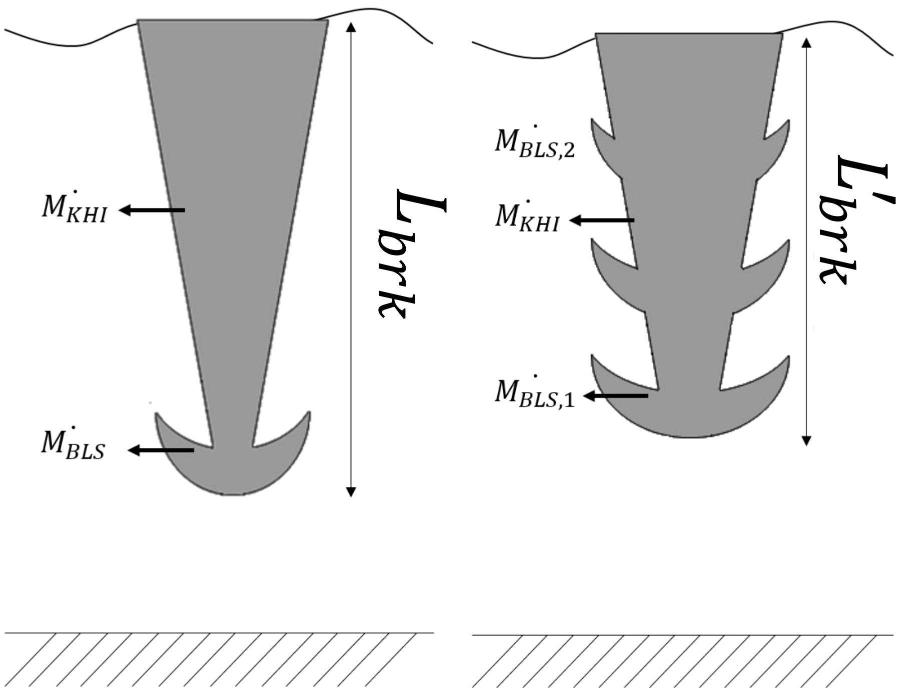
$$M_{KHI} = m_e A = \underbrace{\frac{1}{2}\rho_m \frac{D_{Ji}V_J}{L_{brk}}}_{m_e} \underbrace{\frac{\pi D_{Ji}}{2} L_{brk}}_{A}$$

(2) Predict $M_{BLS,2}$ using $M_{BLS,1}$

$$M_{input} = M'_{KHI} + (a-1)\boldsymbol{M_{BLS,2}} + M_{BLS,1}$$

$$a = \frac{L'_{brk}}{\lambda_{PRI}}$$

$$M'_{KHI} = m_e A' = \underbrace{\frac{1}{2}\rho_m \frac{D_{Ji}V_J}{L_{brk}}}_{m_e} \underbrace{\frac{\pi D_{Ji}}{2} L'_{brk}}_{A'}$$



(b) KHI + BLS model (c) KHI + multiple BLS model

- **To calculate the $M_{BLS,2}$, measured values of L'_{brk} is necessary**

POSTECH POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Application to MATE results

- To evaluate the PRI effect in MATE 00-2, multiple BLS model is applied.

< Results of MATE 00 >

$$M_{input} = 1.78\ kg/s$$
$$M_{KHI} = 1.06\ kg/s$$
$$M_{BLS,1} = 0.72\ kg/s$$

< Measured parameters of MATE 00-2 >

a = 5 (with λ_{PRI} = 50 ~ 120 mm)

$$L'_{brk} = 0.35\ m$$

MATE 00-2

$$\boldsymbol{M'_{KHI} : M_{BLS,1} : M_{BLS,2} = 33\ \% : 40\ \% : 27\ \%}$$

- **Plateau-Rayleigh instability contribute to the jet breakup approximately 30%**

Conclusion

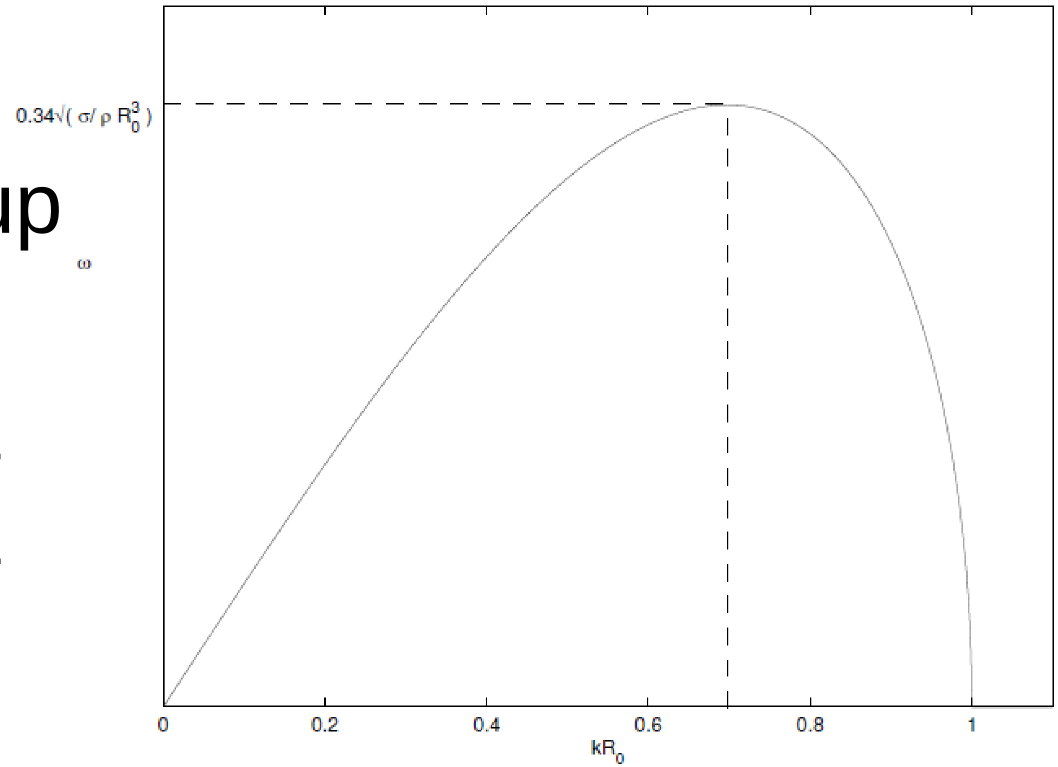
1. New multiple boundary layer stripping jet breakup model is suggested.
2. Plateau-Rayleigh instability of melt jet before entering the water should be considered on jet breakup length calculation in particular cases.
3. Newly suggested model need verification with various condition such as a large diameter and a long free fall height.

Thank you

< Plateau-Rayleigh Instability >

Characteristic breakup time is

$$t_{breakup} \cong 2.91\sqrt{\frac{\rho R_0^3}{\sigma}}$$



< growth rate – wavenumber plot >
(MIT lecture note)