Oxidation Effect on Pool Boiling Heat Transfer in Atmospheric Saturated Water

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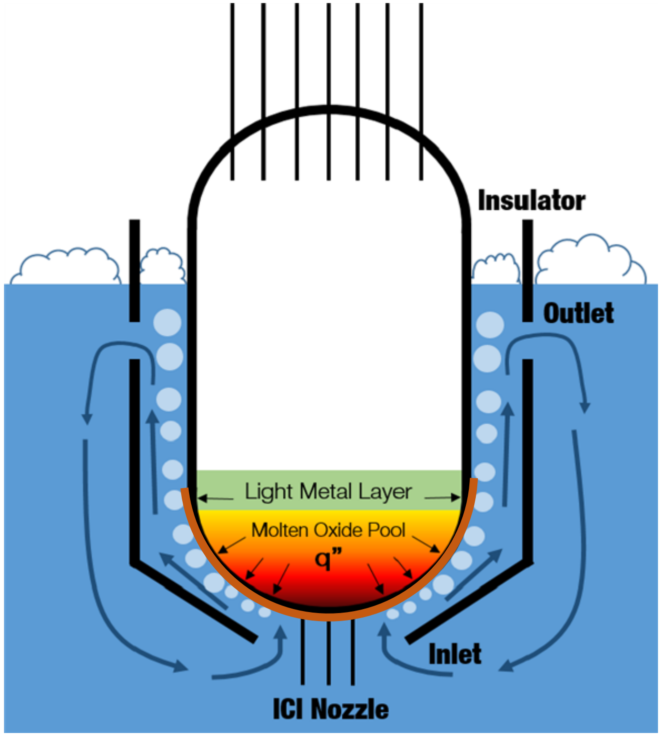
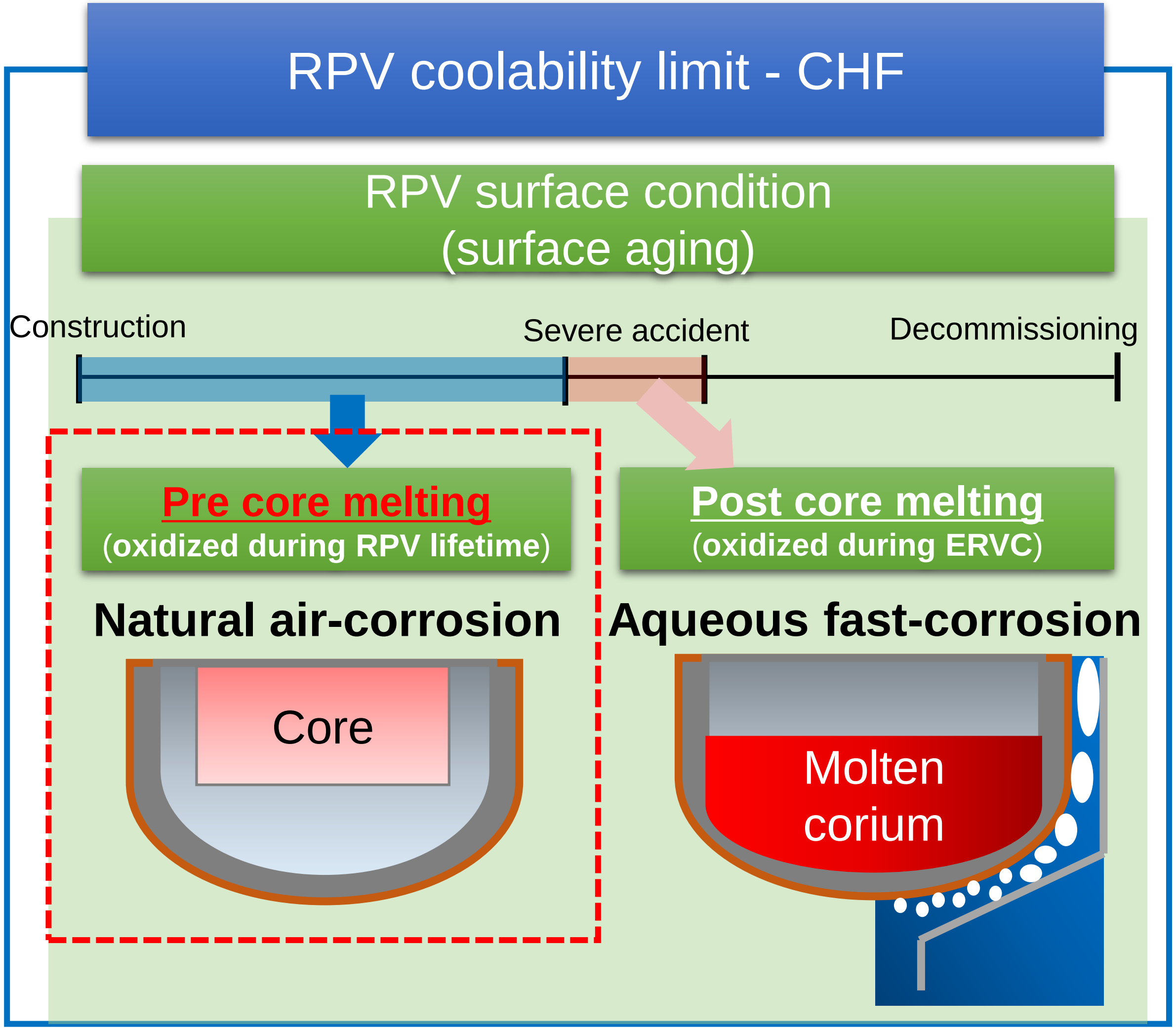
Background

- Coolability limit on conducting IVR-ERVC strategy



<IVR-ERVC>



Objectives

- Evaluating the CHF considering the natural corrosion on the outer surface of RPV lower head

Research scope

Definition of surface condition by natural corrosion → Experimental evaluation of oxidation effect on the CHF → Definition of the CHF enhancement along oxidation period and heater orientation

Experimental description

- Test specimen preparation
  - ✓ Test material: SS316L @Real RPV material: SA508 (Low carbon steel alloy)
  - ✓ Dimension of heat transfer area: 26×8×2 mm^3
  - ✓ Chemical composition (unit: wt%)

~ 64 times

	Carbon (C)	Manganese (Mn)	Phosphorus (P)	Sulfur (S)	Silicon (Si)	Nickel (Ni)	Chromium (Cr)	Molybdenum (Mo)	Vanadium (V)	Iron (Fe)
SS316L	0.03	2.0	0.045	0.03	0.75	10.0 – 14.0	16.0 – 18.0	2.0 – 3.0	-	balanced
SA508	0.35	0.40 – 1.05	0.025	0.025	0.15 – 0.40	0.4	0.25	0.1	0.05	balanced

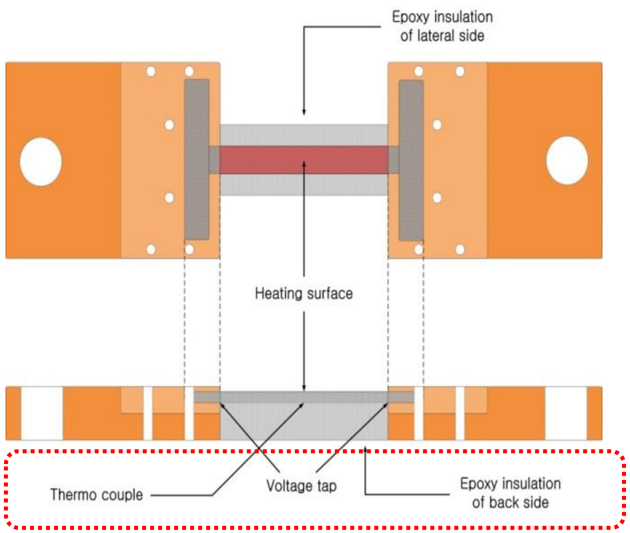
Experimental description

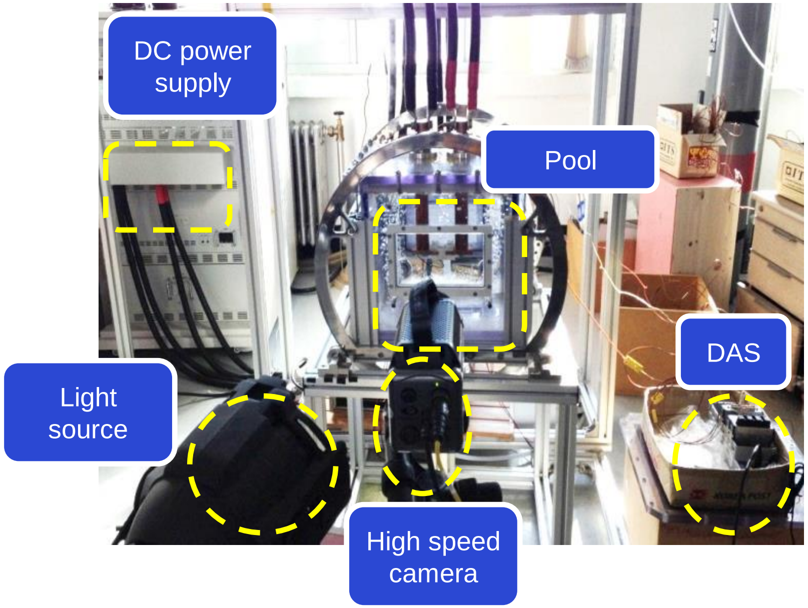
- Oxidation treatment

Surface treatment	Specimen number	Ambient condition	Oxidation Temperature (^oC)	Oxidation period (day)
Clean	D001 D002	Air	-	-
Oxidation	D051 D052 D053		500	5
	D201 D202		700	20
	D251		700	25

Experimental description

- Test section





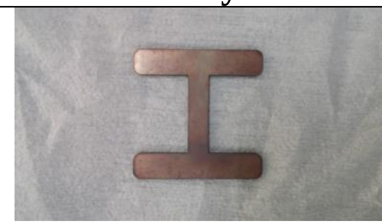
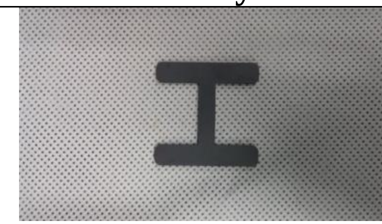
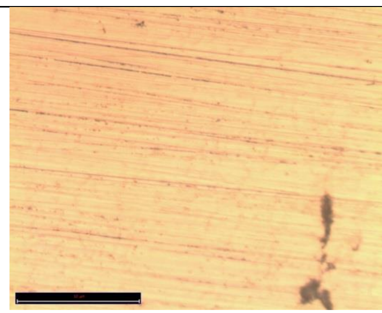
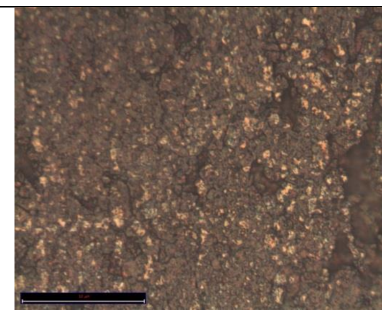
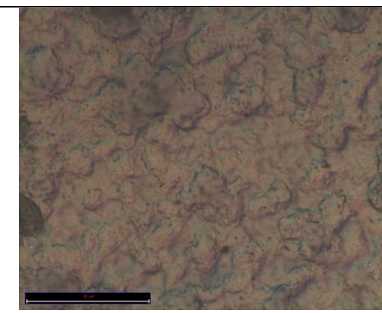
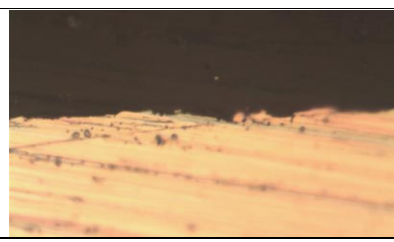
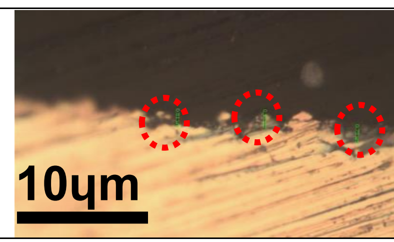
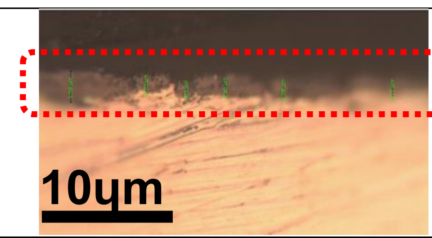
<Pool boiling experiment apparatus>

- Test matrix

Test material	**SS316L**	
Test condition	Saturated at atmospheric pressure	
Working fluid	DI water	
Test orientation (º)	0	175 - 180
Oxidation period (day)	0, 5, 20	0, 5, 25

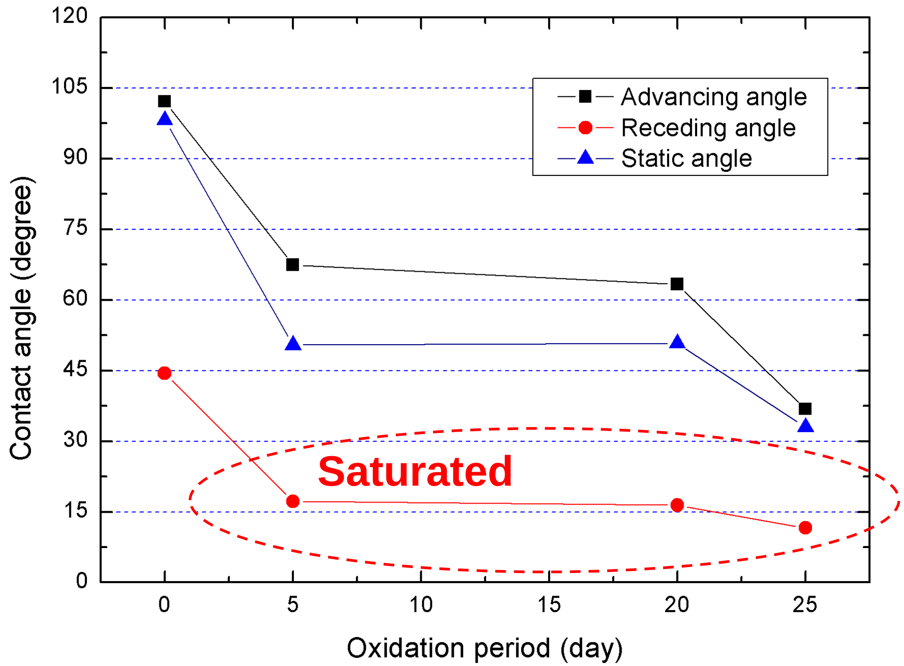
Results and discussion

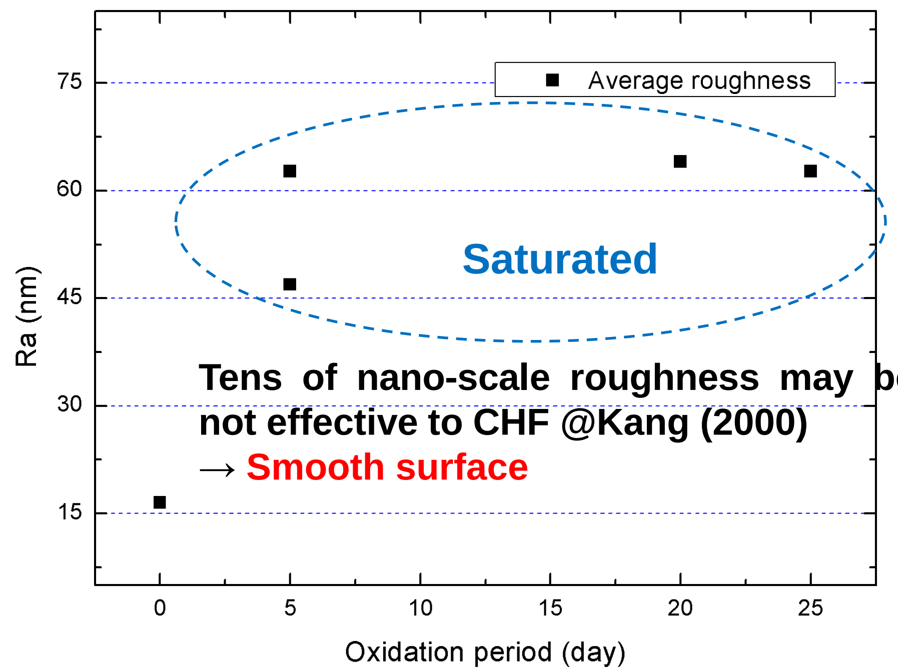
- Surface morphology characteristics

	No oxidation treatment	5 days	20 days
Overall view			
Surface morphology (scale bar: 10 μm)			
Oxide layer thickness (μm)			
	0	**0.38±0.06(localized)**	**0.89±0.28(flattened)**
		Discontinuous oxide layer	Continuous oxide layer

Results and discussion

- Surface characteristics: **Contact angle** and **Roughness**



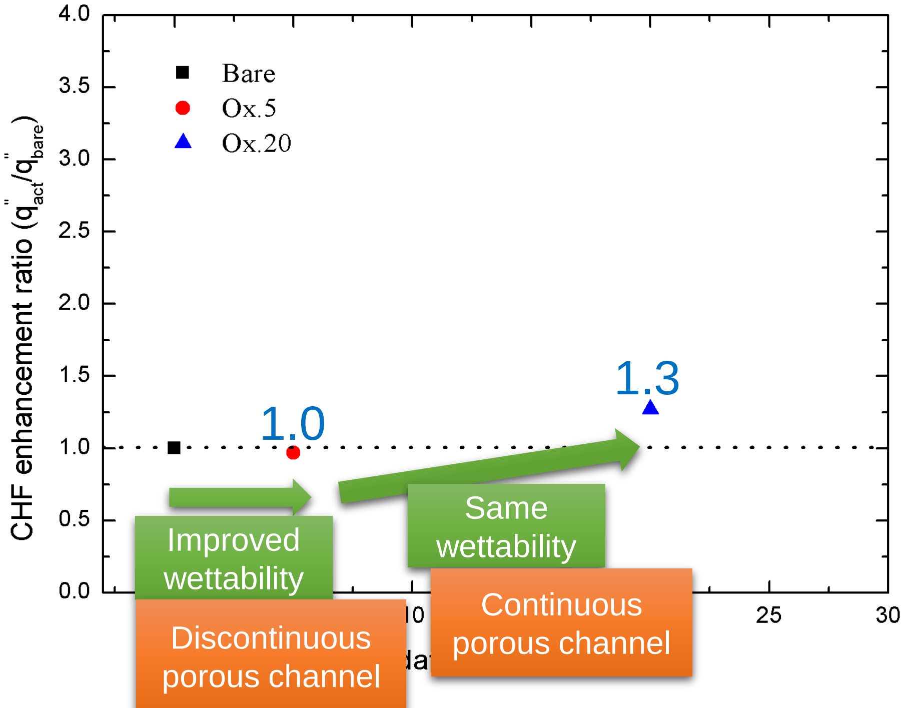


Tens of nano-scale roughness may be not effective to CHF @Kang (2000)
→ **Smooth surface**

- CHF enhancement comparison with the other studies

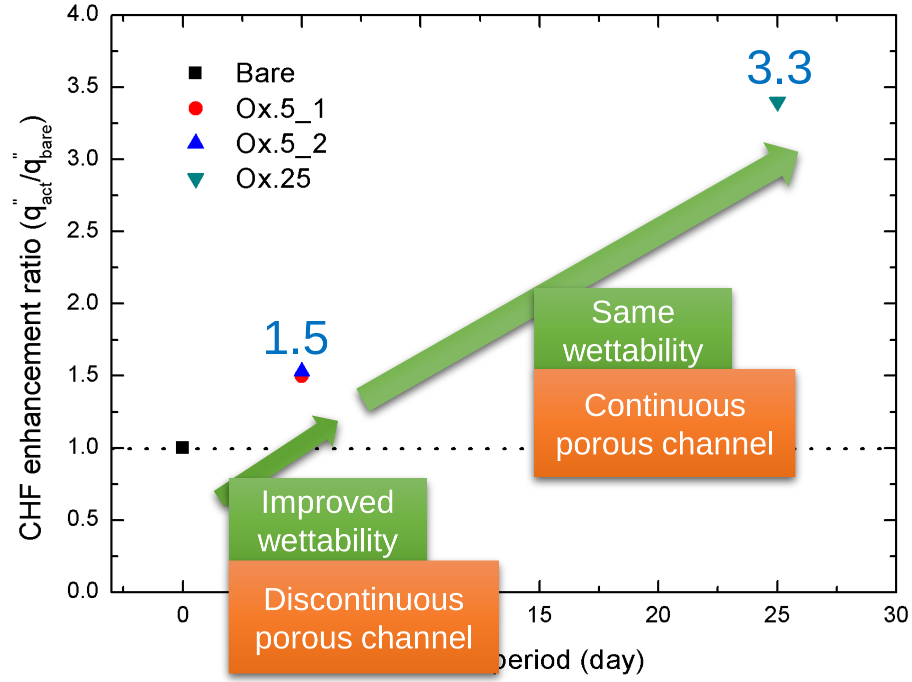
Upward-facing (0º)

1.7 / boiling time of 50 min. @Lee et al. (2012)
1.5 / SWCNT random coating @Seo et al. (2014)
1.5 / CNT (0.05g/l) @Lee et al. (2012)
1.3 / Al_2O_3 (0.05g/l) @Lee et al. (2012)



Downward-facing (175º, 180º)

2.2 / Al_2O_3(0.05% vol.)+CNT(0.05% vol.) @Pham et al. (2012)
2.1 / micro porous aluminum coating @Yang et al. (2005)
2.0 / CNT(0.05% vol.)@Pham et al. (2012)

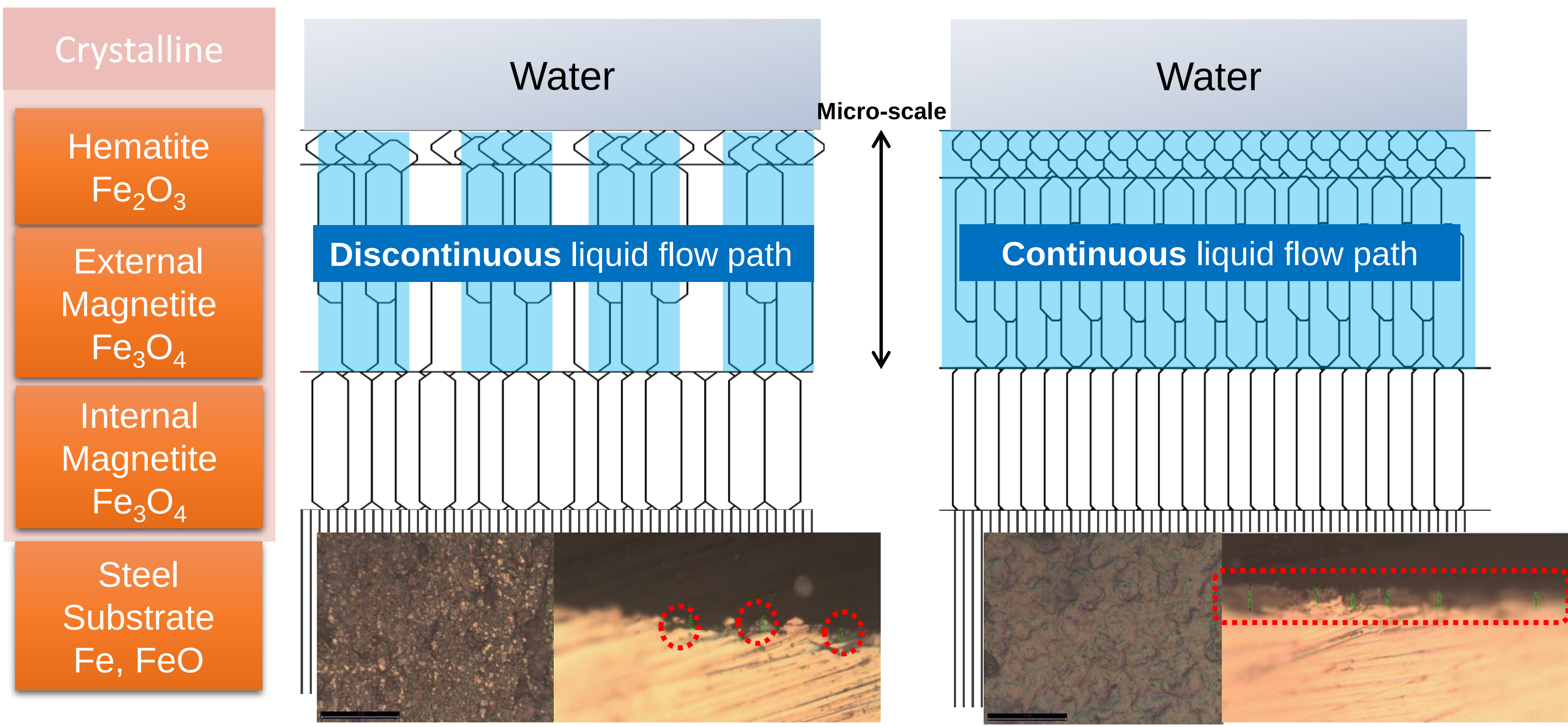


- **Improved wettability can enhance the CHF. @Kandlikar (2001)**
- **Wettability may be effective when coupled with continuous porous media. @O'Hanley et al. (2013)**

Results and discussion

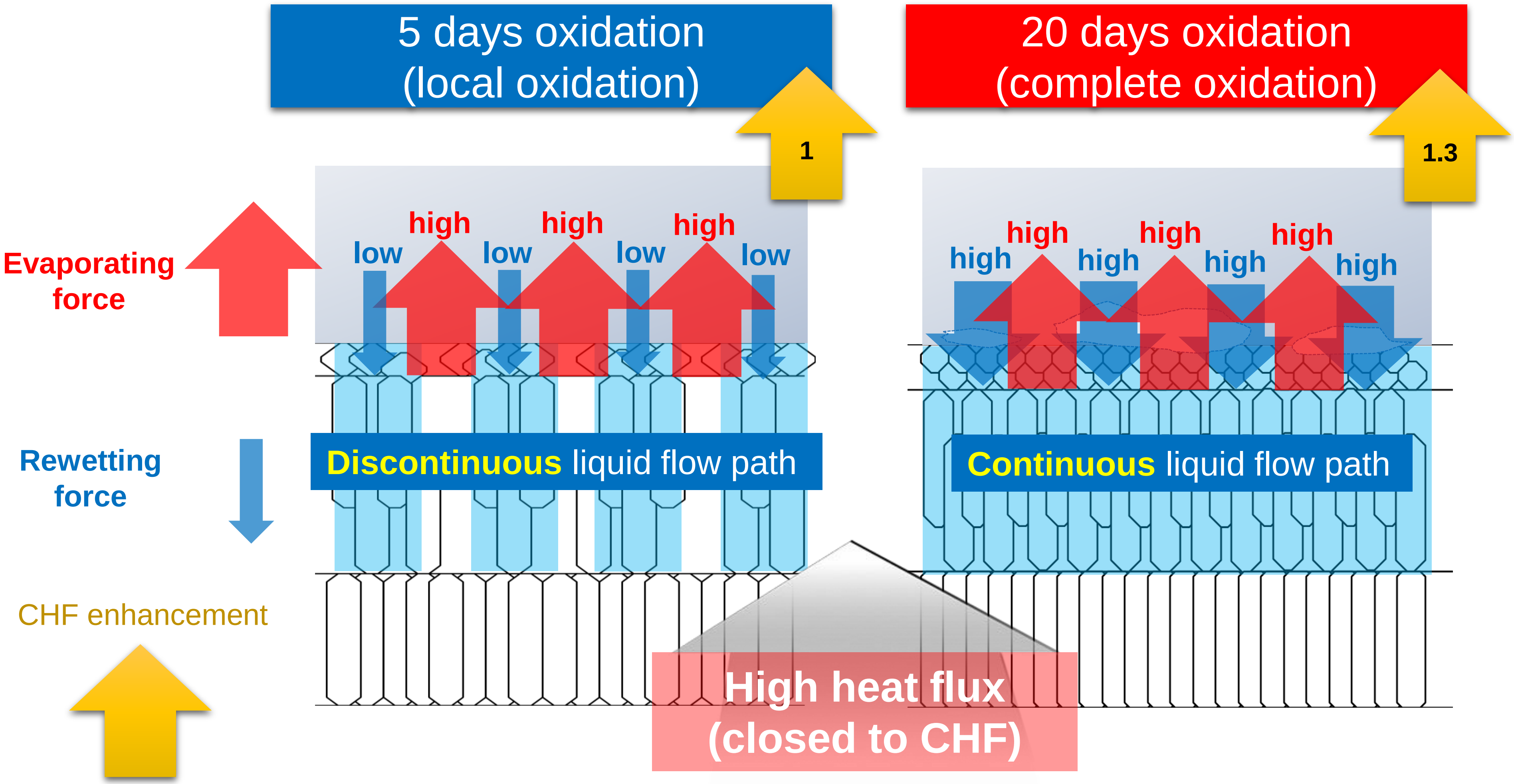
- Microstructure of the oxidized specimens @Bertrand et al. (2009)

5 days oxidation (local oxidation)	20 days oxidation (complete oxidation)



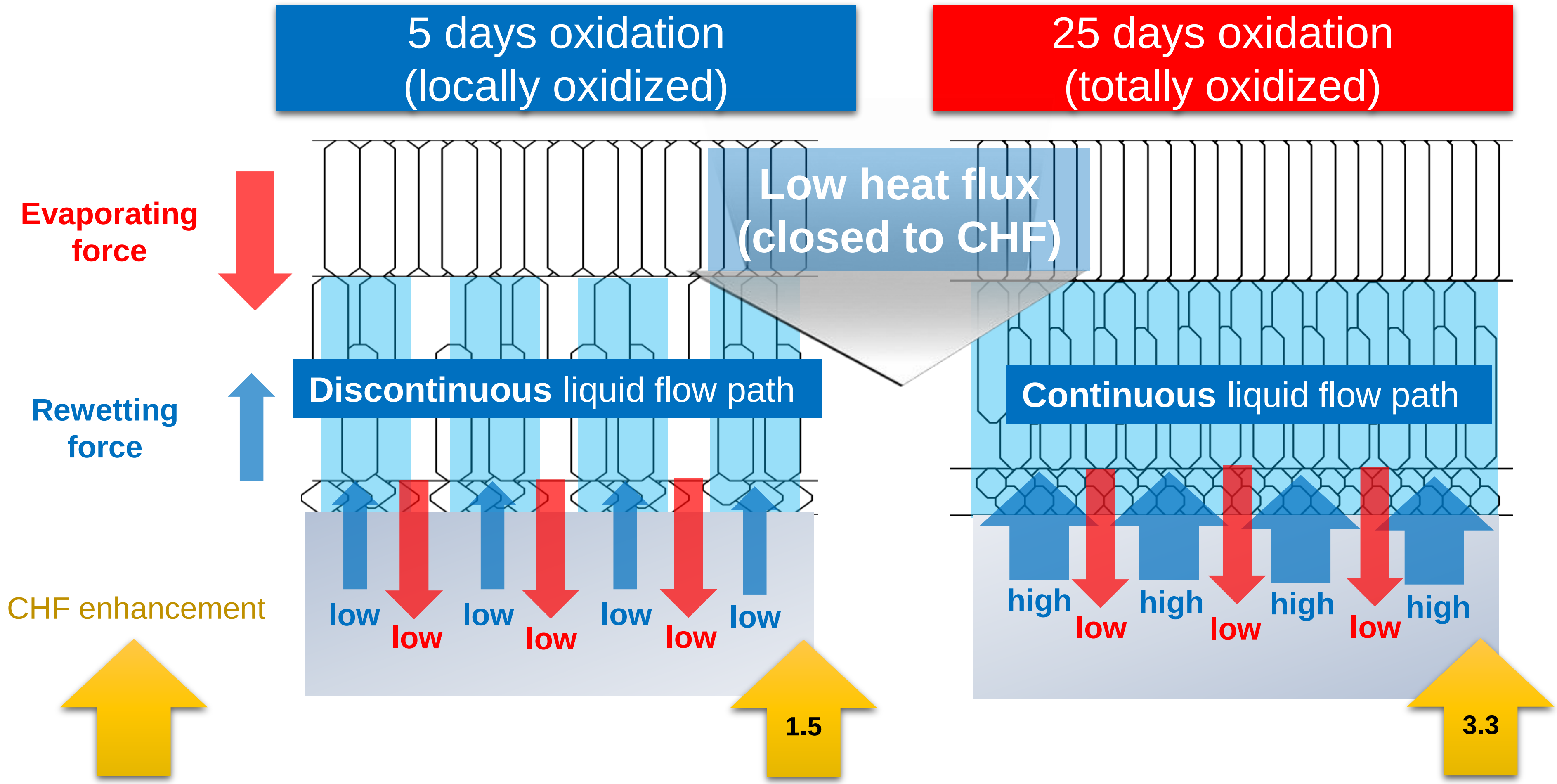
Results and discussion

- Boiling mechanism **(upward-facing): High heat flux (~ 10^3 kW/m^2)**



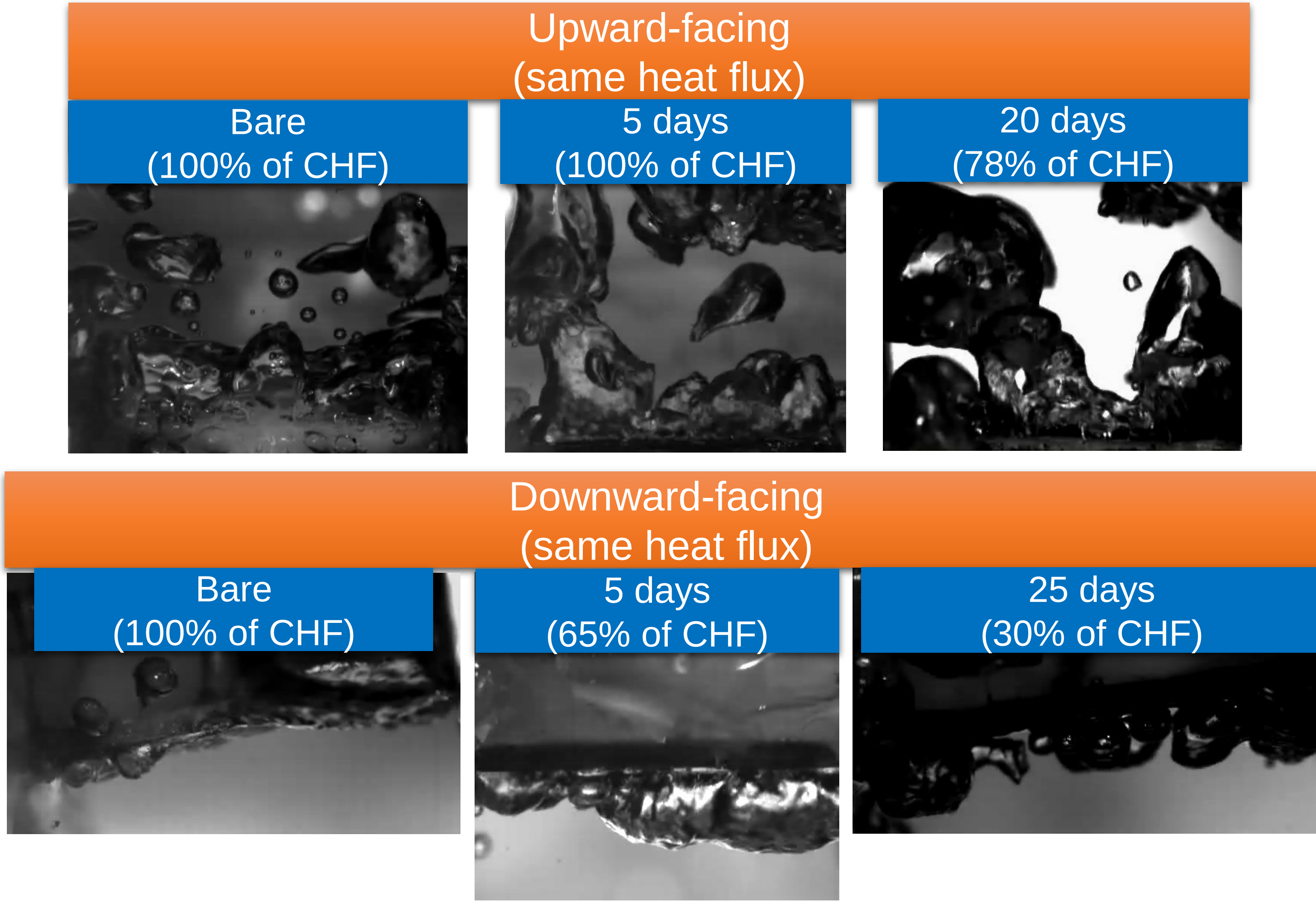
Results and discussion

- Boiling mechanism **(downward-facing): Low heat flux (~ 10^2 kW/m^2)**



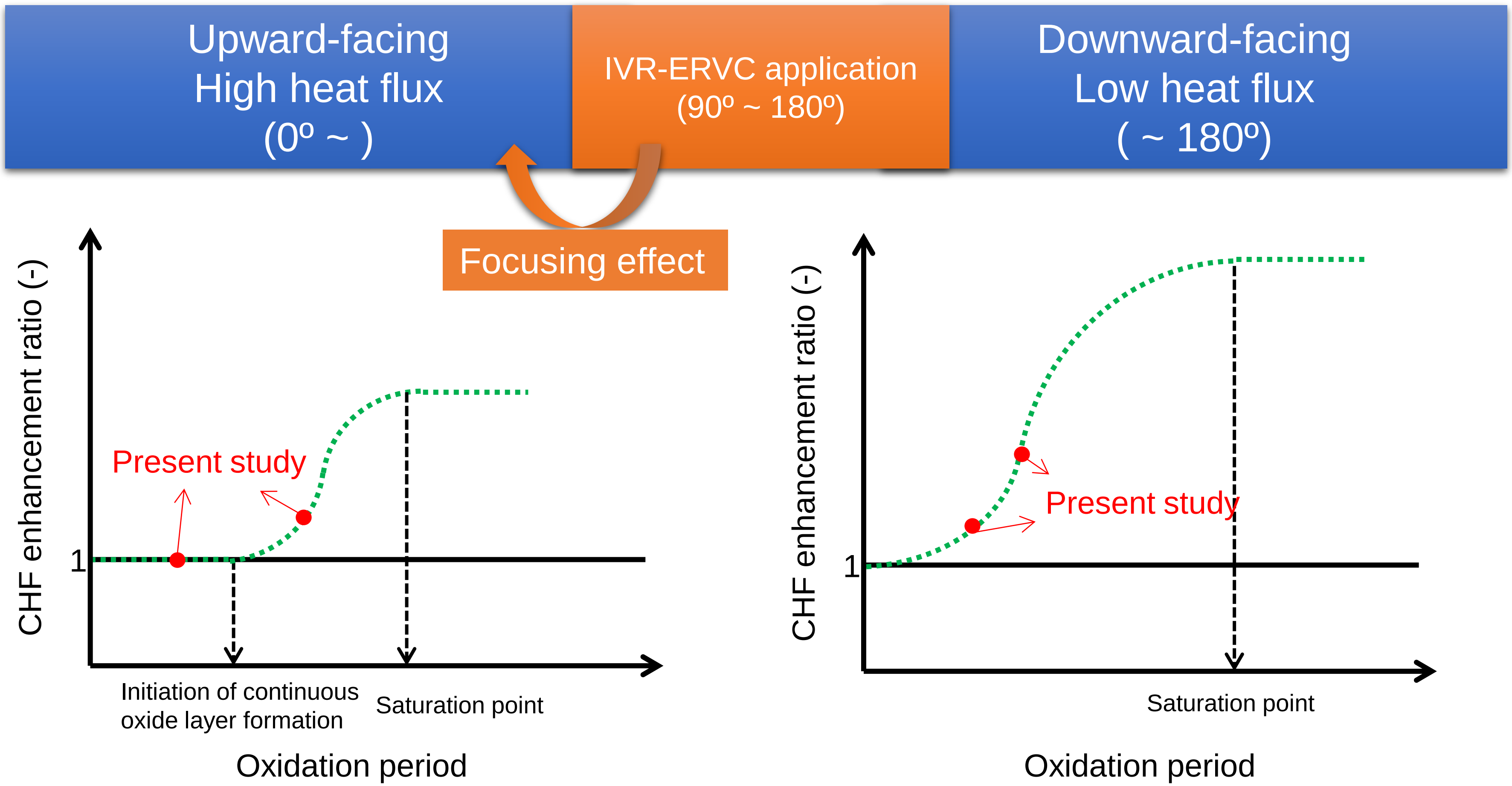
Results and discussion

- Boiling visualization



Results and discussion

- The hypothesized CHF-oxidation curve



Conclusion

- Natural corrosion on RPV surface may be helpful for enhancing the coolability of IVR-ERVC.
- Oxidation effect on the CHF is different for oxidation period and heater orientation.

  → The hypothesized CHF-oxidation curve

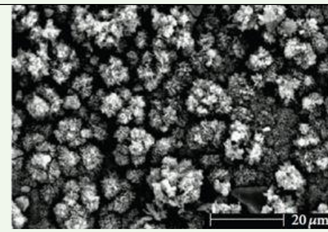
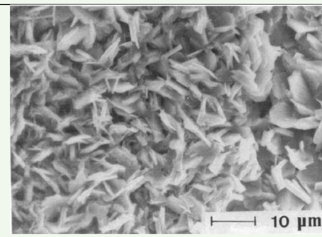
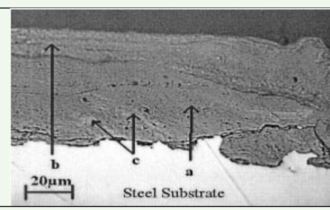
Future works

- Defining realistic RPV surface condition
- Necessity of more experiments for different oxidation period and heater orientation
- Proving and completing the hypothesized CHF-oxidation curve along oxidation periods or heater orientations

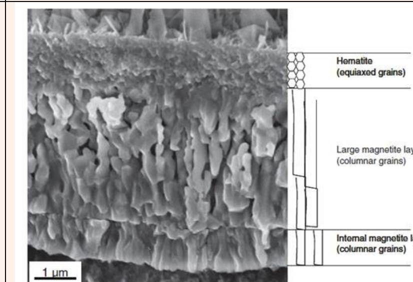
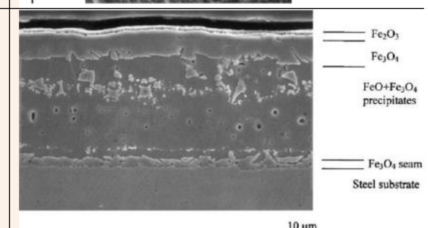
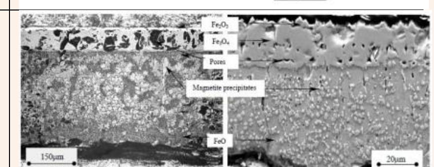
Thank You for Your Attention

Appendix – 1

Dry and wet natural corrosion

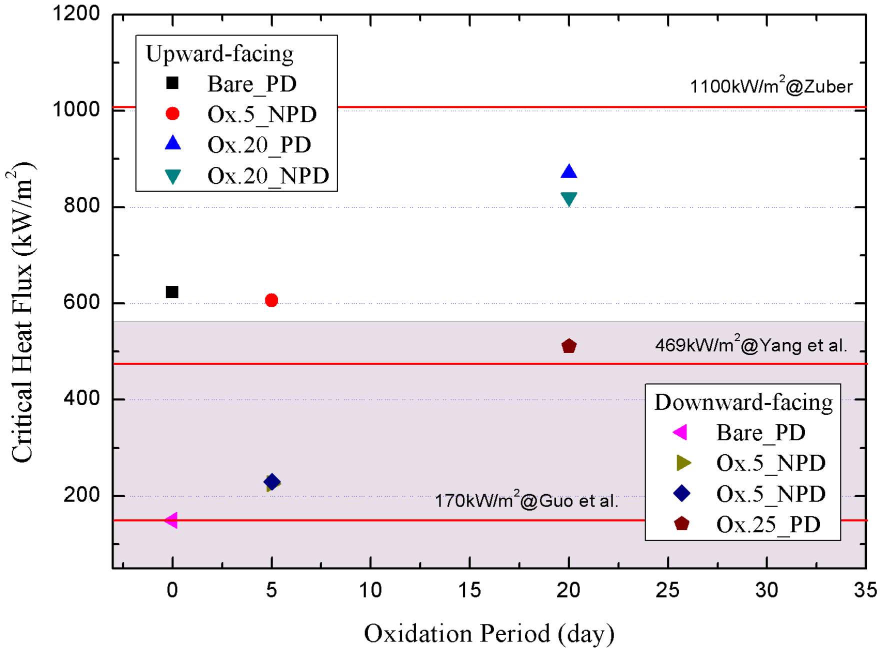
Author	Oxidation condition	Chromium composition (wt%)	Oxide product	image
Renato et al. (2003)	Natural weathering, 9 month	0.52	γ-FeOOH β-FeOOH α-FeOOH Fe_2O_3 Fe_3O_4	
Raman et al. (1989)	Natural corrosion wet(20m)/dry(10m) cycling	-	α-FeOOH γ-FeOOH γ-Fe_2O_3	
Oh et al. (1999)	Rural, industrial, marine, 16 yrs	0.52 ~ 0.59	α-FeOOH γ-FeOOH γ-Fe_2O_3 Fe_3O_4	

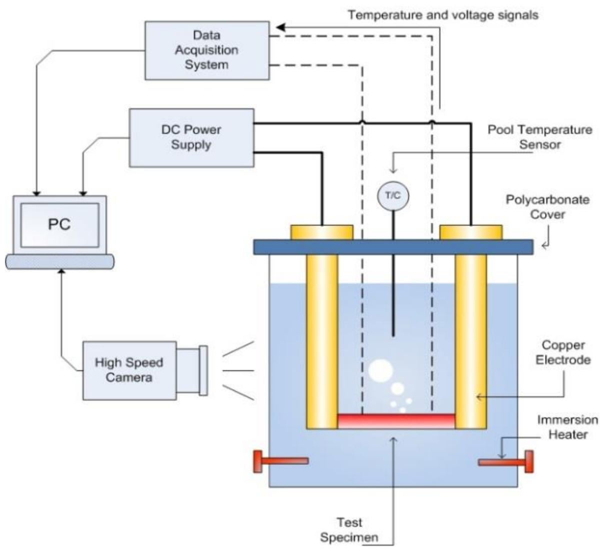
High temperature corrosion

Author	Oxidation condition	Cr composition (wt%)	Oxide product	image
Bertrand et al. (2009)	Dry and wet air, 260 - 500℃, ~ 1000 hrs	0.013	Fe_2O_3 Fe_3O_4	
Chen and Yuen (2003)	Air, 570℃	-	Fe_2O_3 Fe_3O_4 FeO	
Birosca et al. (2005)	Flowing air, 900 – 1000℃, 1200 – 1800 sec	-	Fe_2O_3 Fe_3O_4	

Appendix – 2

- CHF comparison with respect to oxidation periods



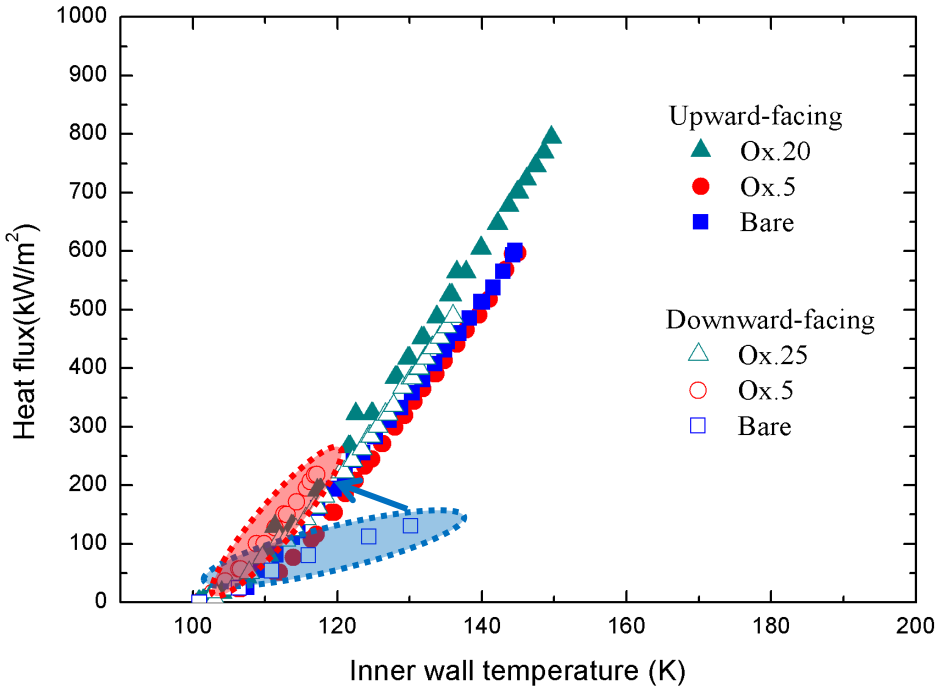


Voltage drop

Appendix – 3

- Nucleate boiling heat transfer coefficient with respect to oxidation period

Our result
(natural corrosion)



Rainey et al. (2001)
(microporous coating)