Experimental Studies on Steel Corrosion in Lead-Bismuth with Steam Injection

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Objectives

Background

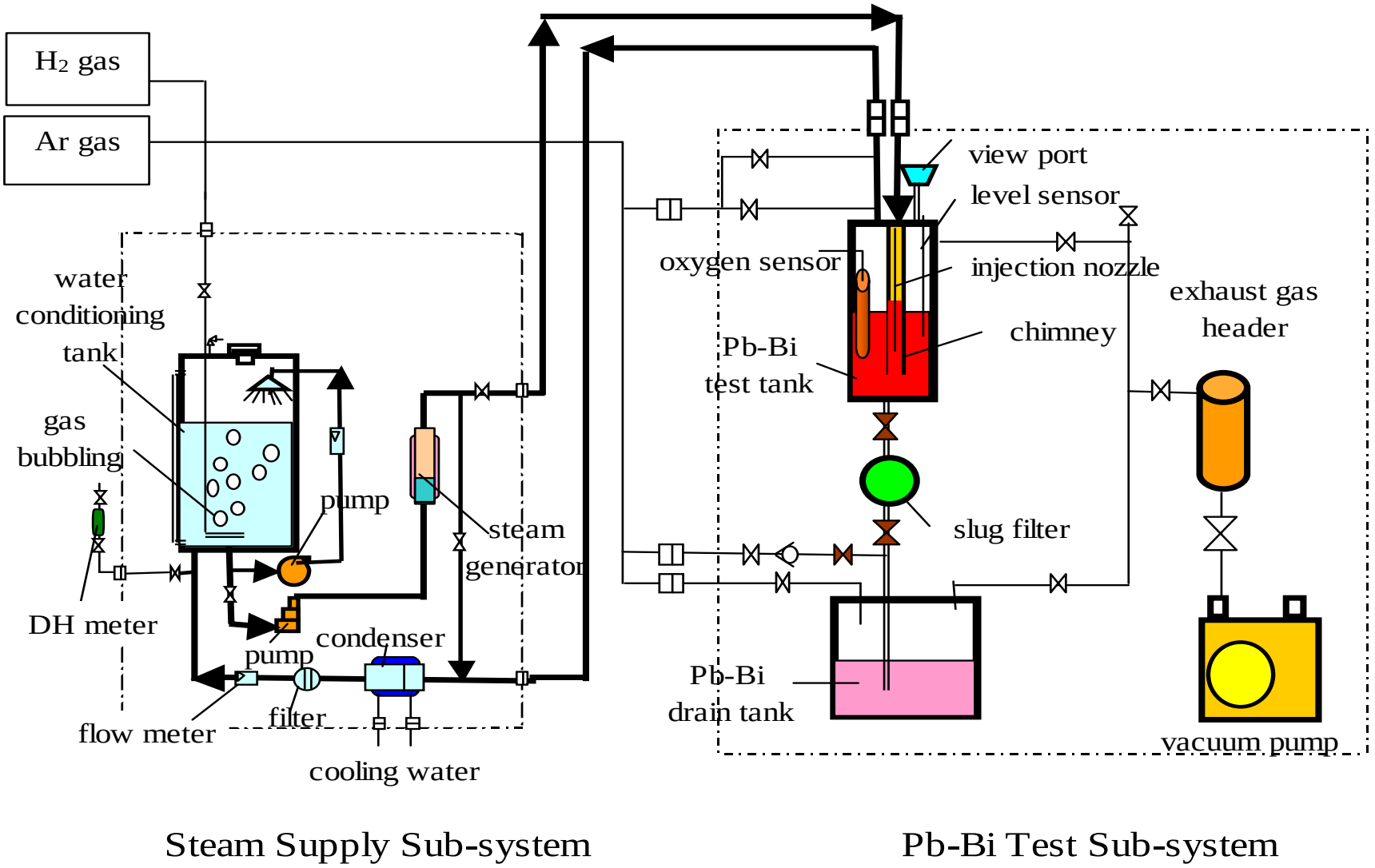
Feasibility study of Pb-Bi direct contact boiling water reactor (PBWFR) for innovated nuclear reactor energy system.

Purpose

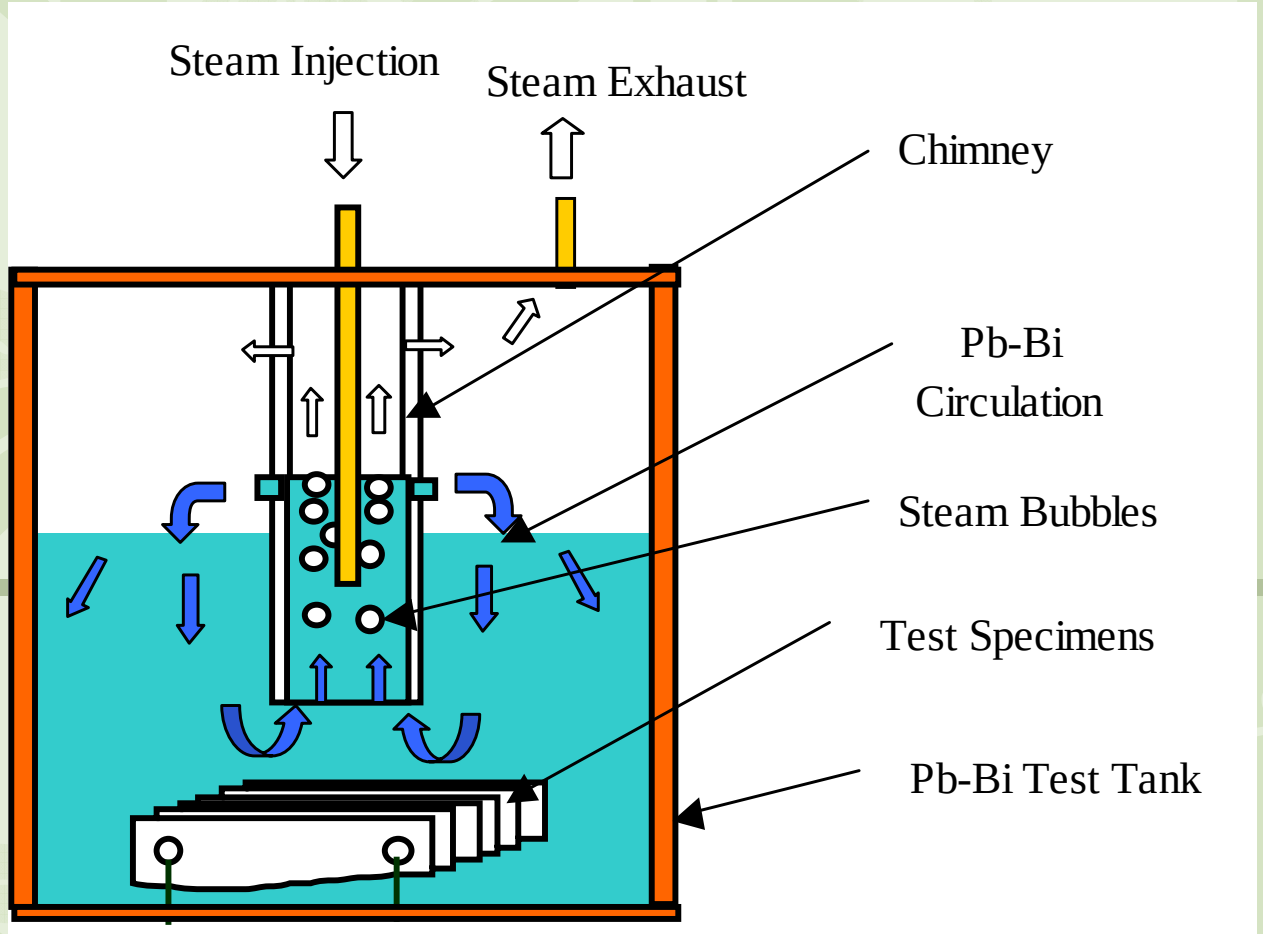
To investigate the compatibility of high Cr steel in the steam injecting Pb-Bi

Study items

- Effectiveness of Cr contents for corrosion resistance
- Influence of (P_{H2}/P_{H2O}) ratio in the injecting steam on corrosion behavior
- Effect of temperature on the steel corrosion
- Selection of more promising Cr steel and evaluation of its applicability



System of the Experimental Apparatus



Corrosion Test Concept

Chemical Composition of Tested Materials (wt.%)

Steel	C	Si	Mn	Ni	**Cr**	Mo	W	V	Nb
F82H	0.1	0.1	0.2	0.02	7.7	~	1.9	0.2	~
STBA28	0.1	0.4	0.4	0.1	8.6	1.0	~	0.2	0.08
NF616	0.1	0.3	0.5	0.3	8.8	0.3	1.9	0.2	0.07
TMK1	0.15	0.1	0.5	0.6	10.0	0.5	~	0.2	~
HCM12	0.1	0.3	0.5	0.2	12.0	1.1	1.0	0.3	0.1
HCM12A	0.1	0.3	0.5	0.3	12.0	0.3	1.9	0.2	0.05
17-5PH	0.01	1.0	0.5	4.5	16.0	~	~	~	0.2
RECLOY	0.01	1.4	0.7	~	17.7	~	~	~	~

Summary of the Experimental Parameters

Oxygen Potential Relatives		Temperatures (℃)			Pressures in Test Tank	Exposure Periods
P_{H2}/P_{H20}	*DH*	400	450	500		
$< 3 \times 10^{-7}$	< 30 ppb	O	~	~	0.25 MPa	500 hours
1×10^{-6}	100 ppb	O	O	O		
5×10^{-6}	500 ppb	O	~	~		
1×10^{-5}	1,000 ppb	O	~	~		

O : tested, ~ : not tested

relashionship between (P_{H2}/P_{H2O}) and *DH*

$$\left[\frac{P_{H2}}{P_{H2O}}\right] = (DH)\left[\frac{M_{H2O}}{M_{H2}}\right]$$

(DH) = disolved hydrogen concentration

M_{H2O} = molecular weight of H_2O

M_{H2} = molecular weight of H_2

Oxygen Potential: O_x Electro-motive Force: E and Oxygen Concentration: C

Nernst's equation for electro-motive force

$$E = (O_{REF} - O_{Pb\text{-}Bi})/nF$$

where E: electro-motive force for an electrochemical system

O_{REF} : oxygen potential of reference electrode

$O_{Pb\text{-}Bi}$: oxygen potential of Pb-Bi

n: atomic valence of oxygen ion, F: Faraday's constant

Calculation of E for oxygen concentration of C

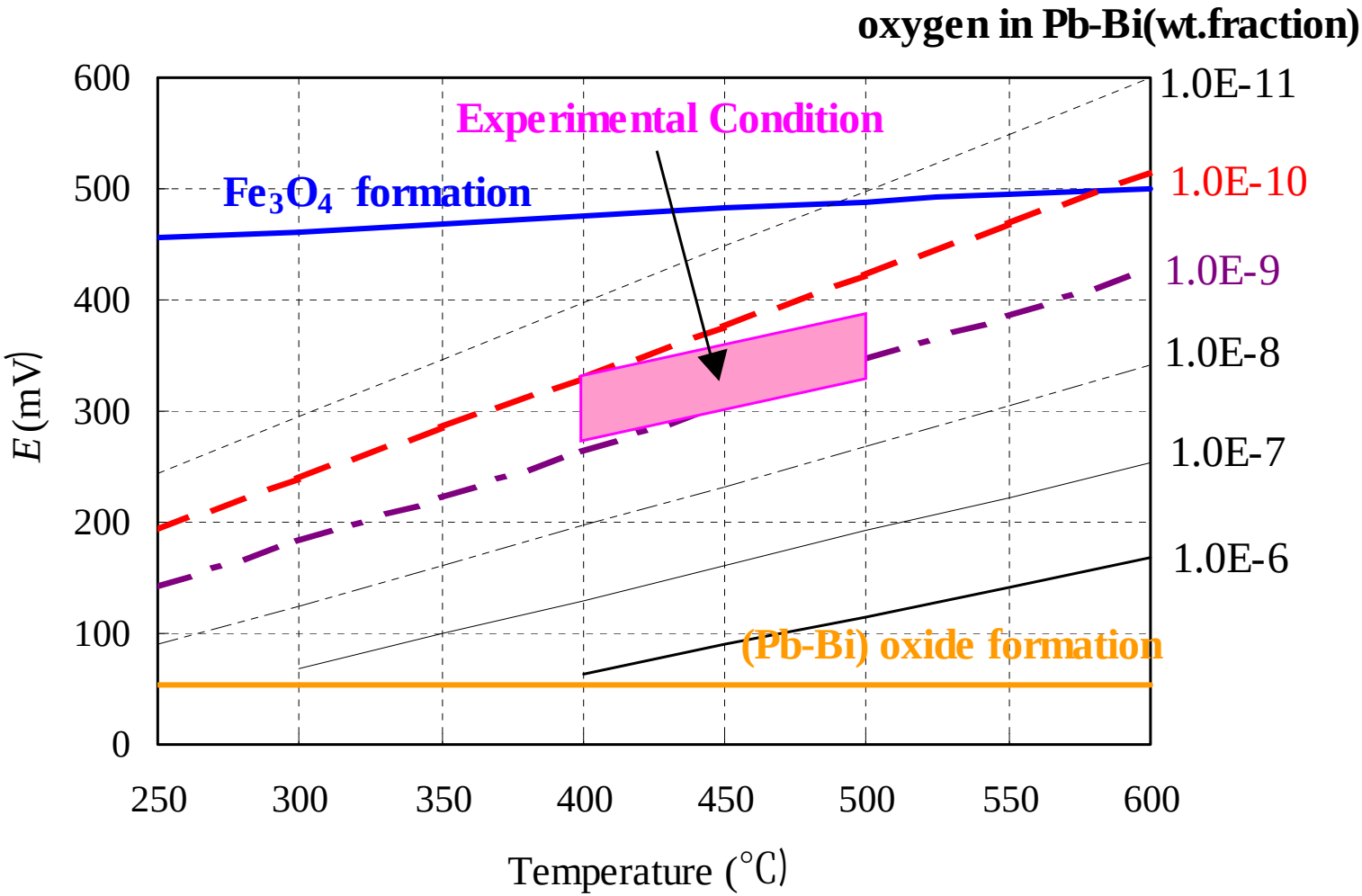
$$E = [O_{REF} - \triangle G_{Pb(Bi)\text{-}oxide} - RT\ln(C/C_0)] / nF$$

where E: electro-motive force calculated for oxygen concentration of C

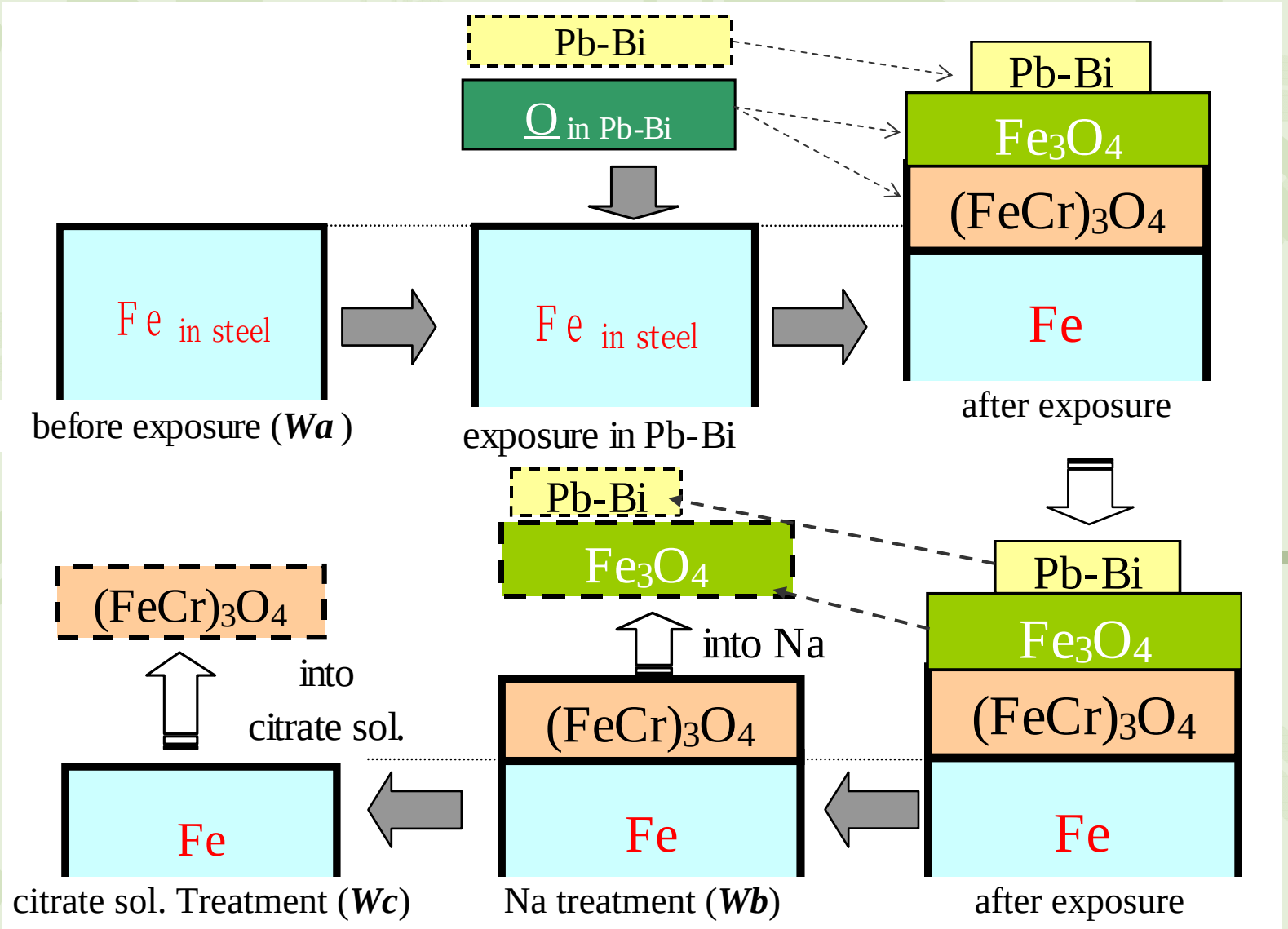
$\triangle G_{Pb(Bi)\text{-}oxide}$: Gibb's free energy of formation for Pb(Bi)-oxide

R: gas constant, T: temperature

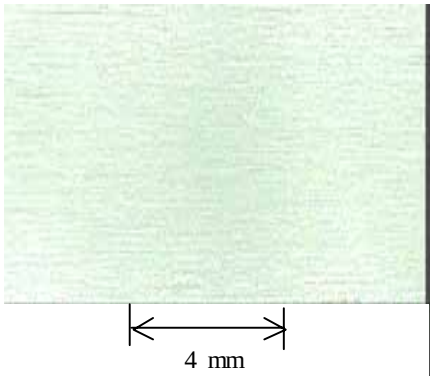
C : oxygen concentration in Pb-Bi, C_0 : oxygen solubility in Pb-Bi



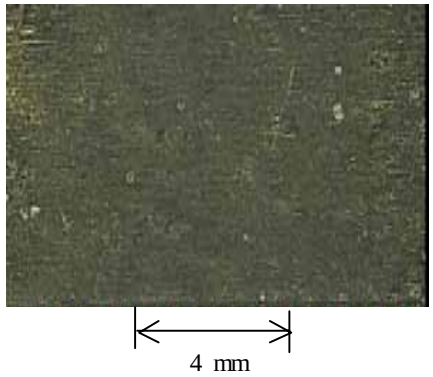
Experimental Conditions for *E*, *C*, and T



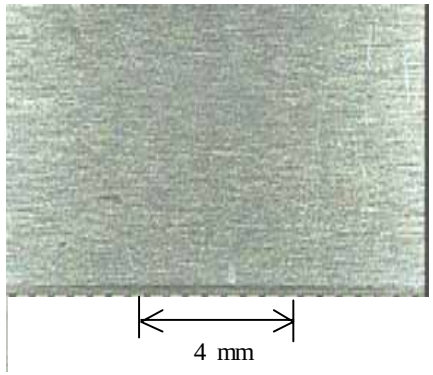
Process Flow for the Post-Exposure Treatment



before exposure test

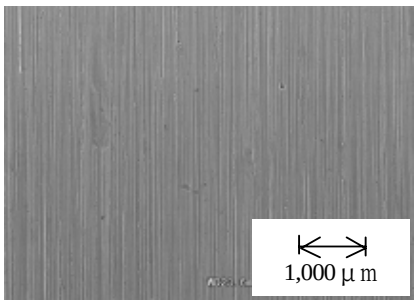


Na-ethanol treatment

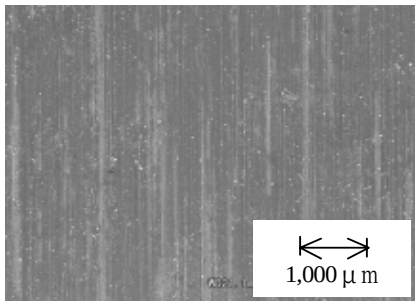


citrate teatment

optical microscope



before exposure test



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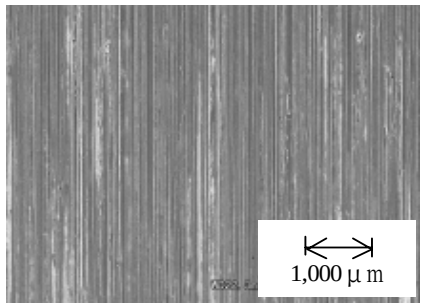
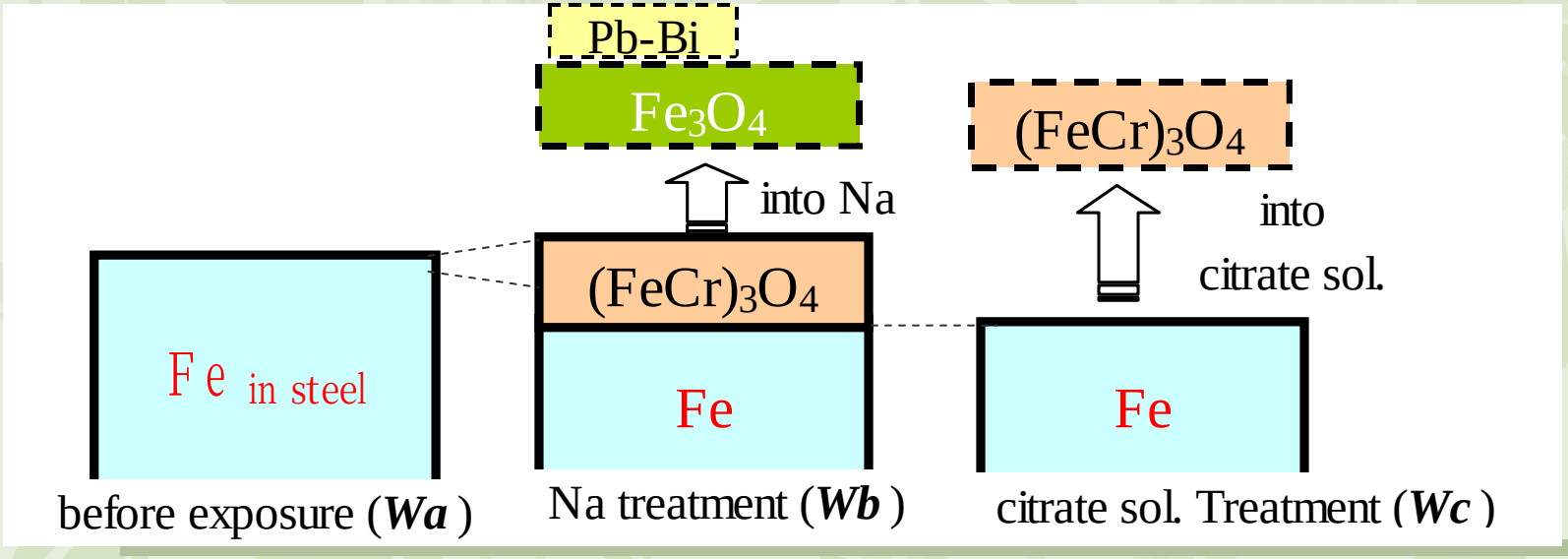


citrate teatment

electron microscope

Surface of HCM12A by Post-Exposure Treatment



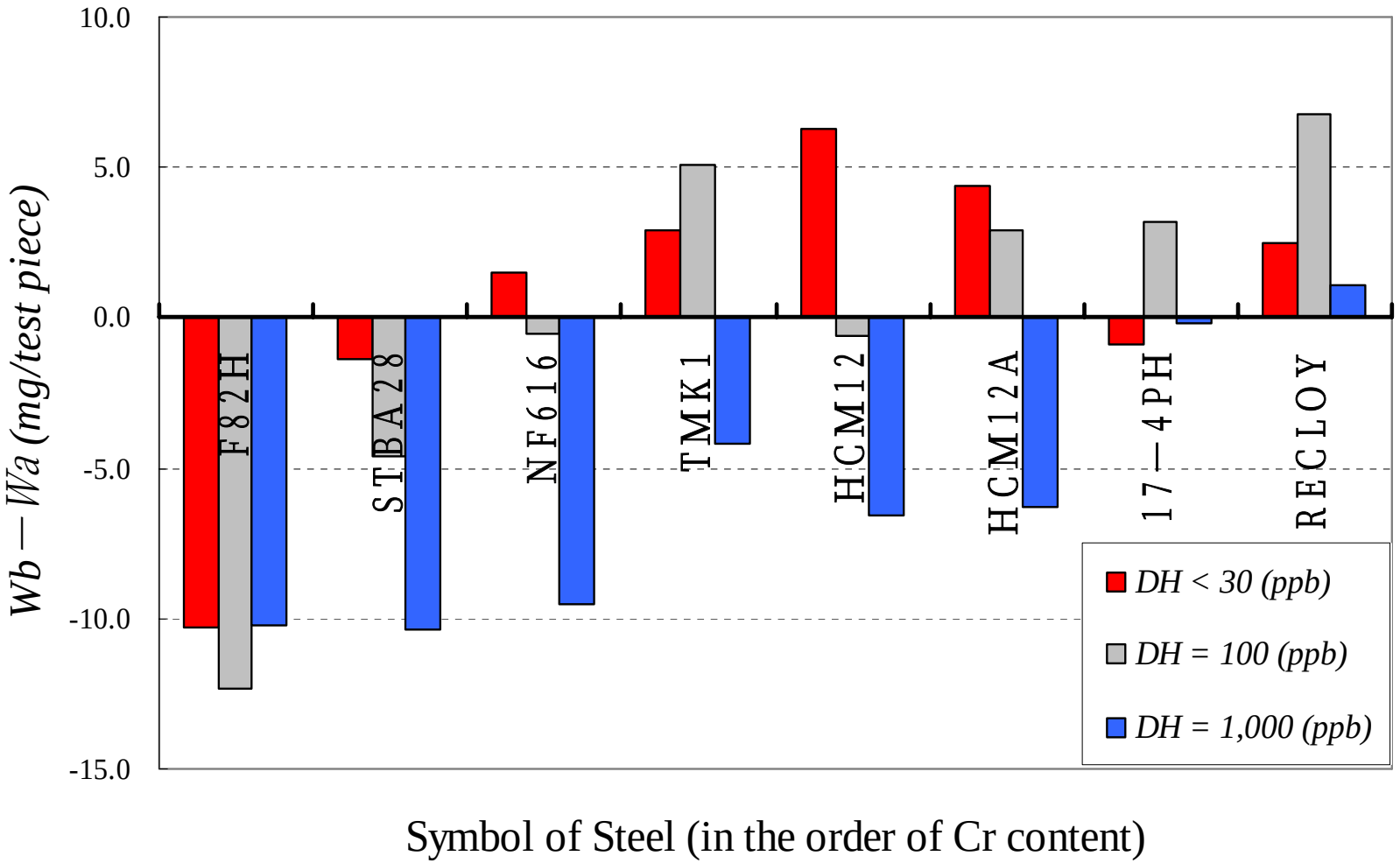
Fe_3O_4: defective(porous) structure

$(FeCr)_3O_4$: sound structure

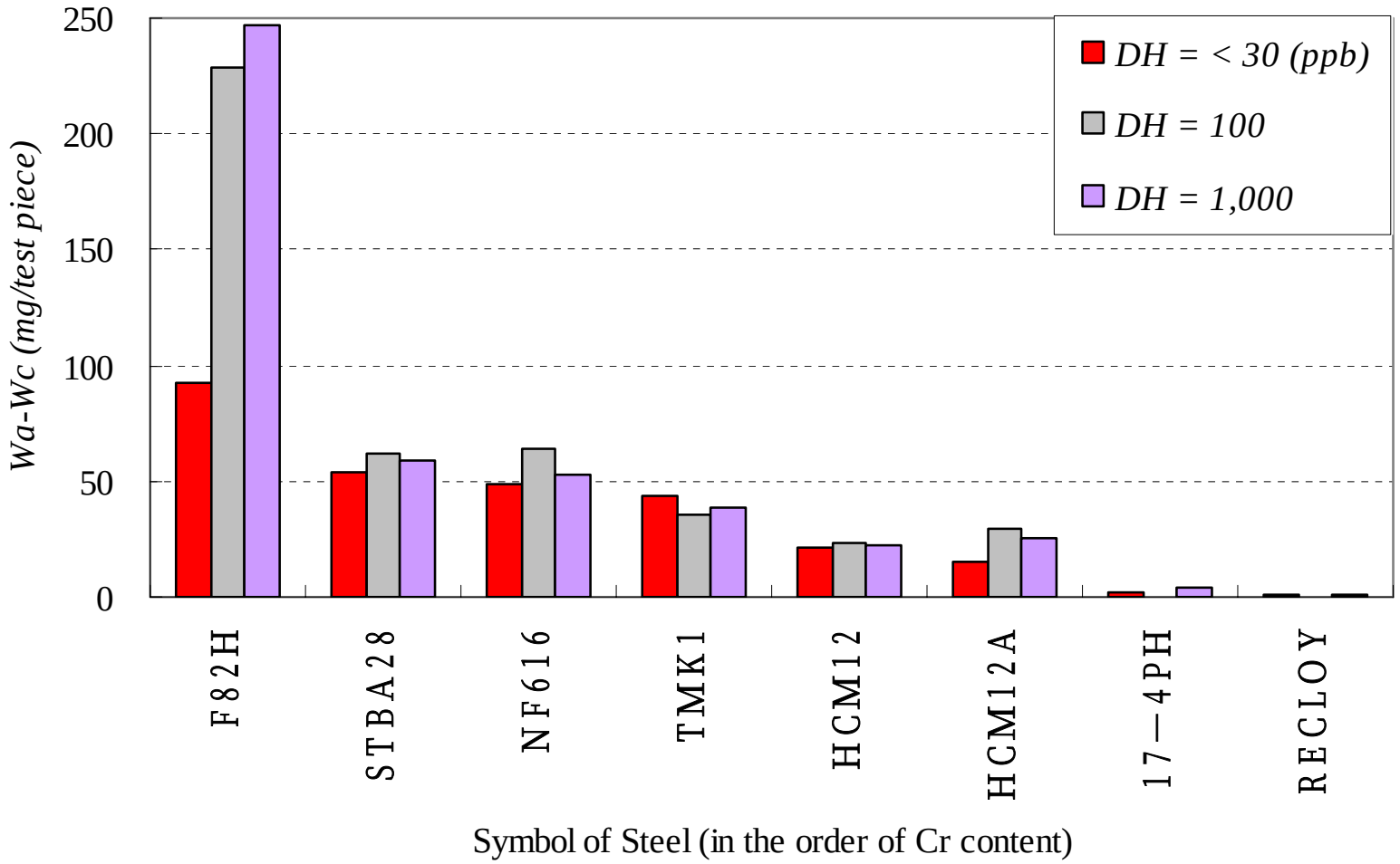
Weight Changes

after Na treatment : (*Wb* – *Wa*)

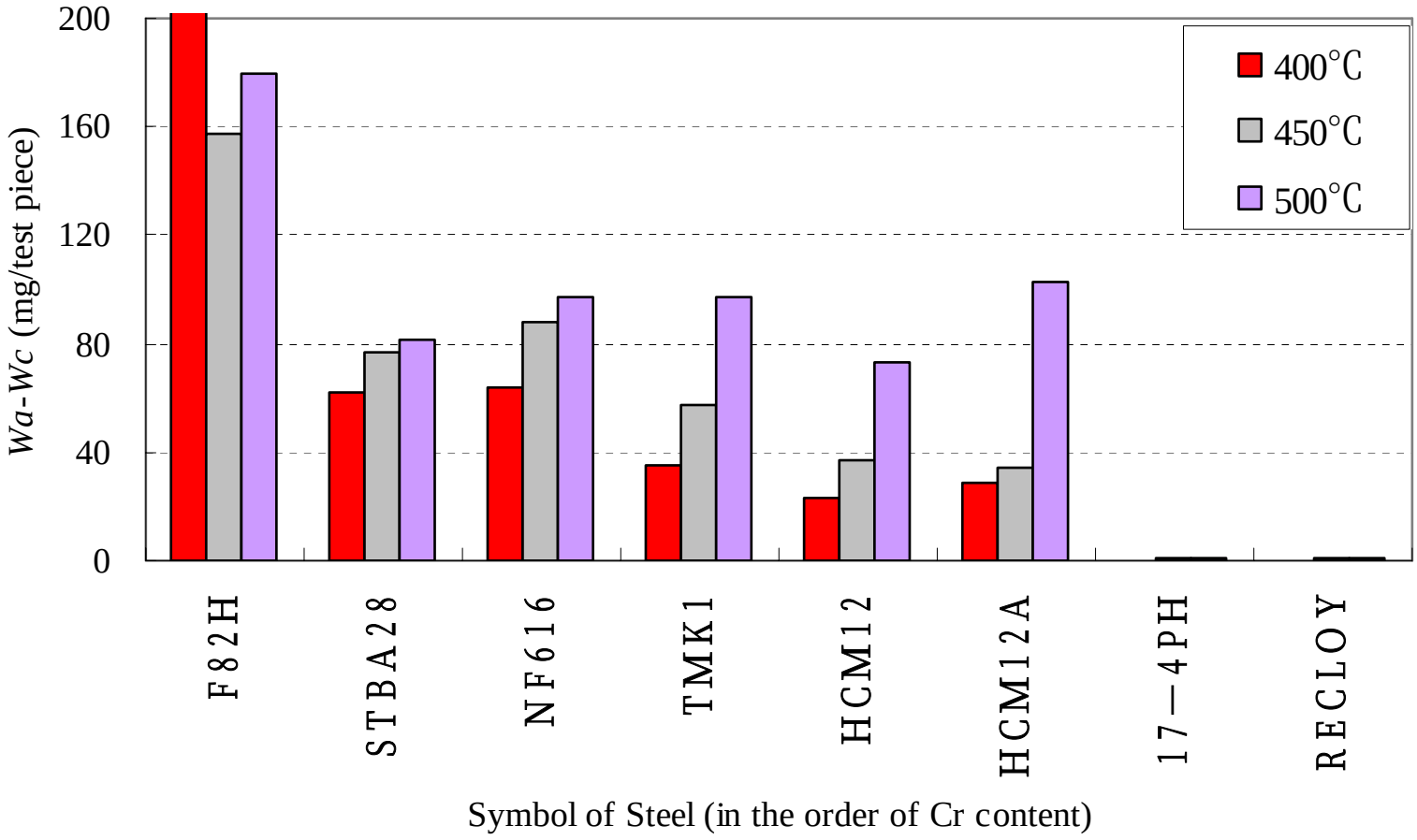
after citrate treatment : (*Wc* – *Wa*)



Weight Changes after Na Treatment (400℃)



Weight Losses after Citrate Treatment (400℃)



Weight Losses after Citrate Treatment (DH=100 ppb)

Conclusions & Future Works

Corrosion behaviors for some types of high Cr steel were examined.

It was identified that :

- Higher Cr content lead more corrosion resistance to Cr steel, and more than 9 % Cr content would be feasible for an application.
- *DH* seemed to be little effective to control corrosion, but would be effective to avoid PbBi-slug formation or its precipitation.
- *DH* should be limited less than 1,000 ppb to lower the amount of corrosion product (Fe-oxide) released in Pb-Bi.
- Corrosion rate increased with temperature, and Cr content effectiveness decreased at temperatures 500^{o}C.
- Corrosion rate of 12Cr steel were estimated as a few μm /y at 400^{o}C and evaluated to be promising for a large reactor structure.

Further experiments are in progress to investigate the corrosion behavior of 12Cr steel and other advanced materials (refractory metals and ceramics).