2014 International Pyroprocessing Research Conference

Analysis of Salt distillation equipment characteristics

Oct/20/2014

Korea Atomic Energy Research Institute
Im Hun Suk, S. C. Oh, S. S. Hong, W. S. Park, J. M. Hur, E. Y. Choi

KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

Contents

1 Pyroprocesssing and Oxide reduction

2 Cathode processing and Salt distillation

3 Characteristics of salt distillation equipment

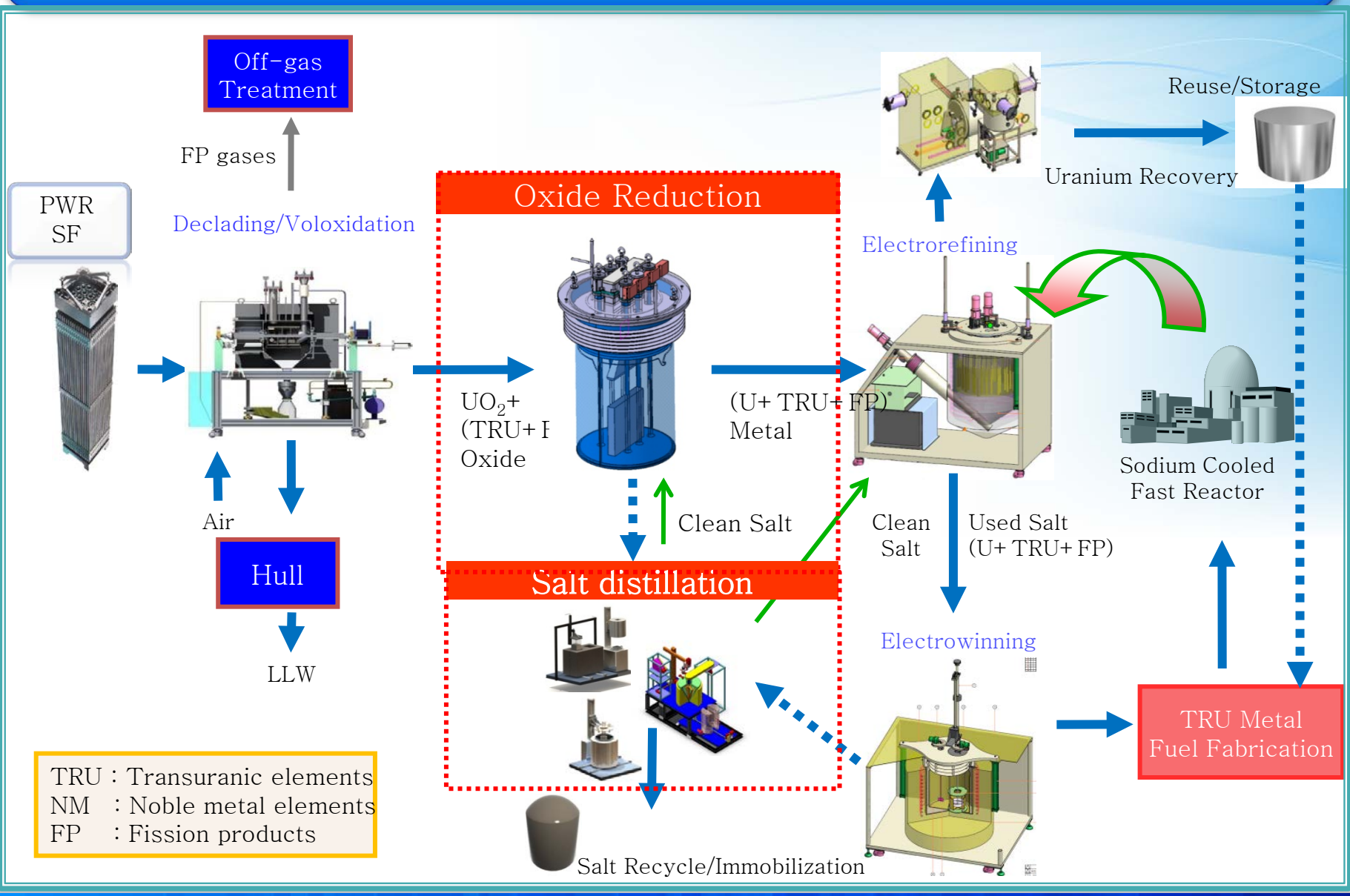
Korea Atomic Energy Research Institute

PART

1

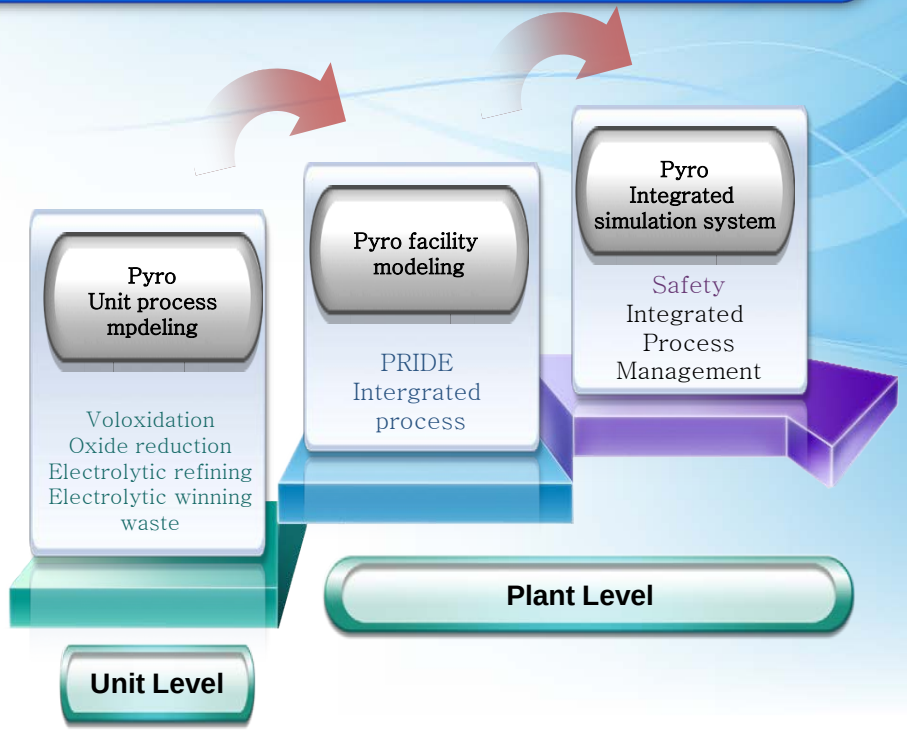
Pyroprocessing and Oxide reduction

Pyroprocessing and Oxide reduction



Pyroprocessing M&S

Reduced Cost	Guiding and minimizing the amount of experimental and piloting work required
Optimized System designs	Reducing design margins and Process control
Increase safety and acceptance	Increasing safety and acceptance of regulatory bodies
Reduced risk of material	Providing accurate predictions of material streams



- Development of cathode process
- Model for scale-up design

Korea Atomic Energy Research Institute

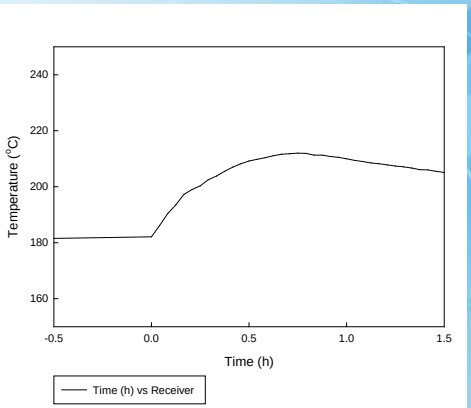
PART 2

Cathode processing And Salt distillation

Cathode processing

1. Salt distillation process study

- Recovery rate of LiCl
- Heat transfer through phase transition



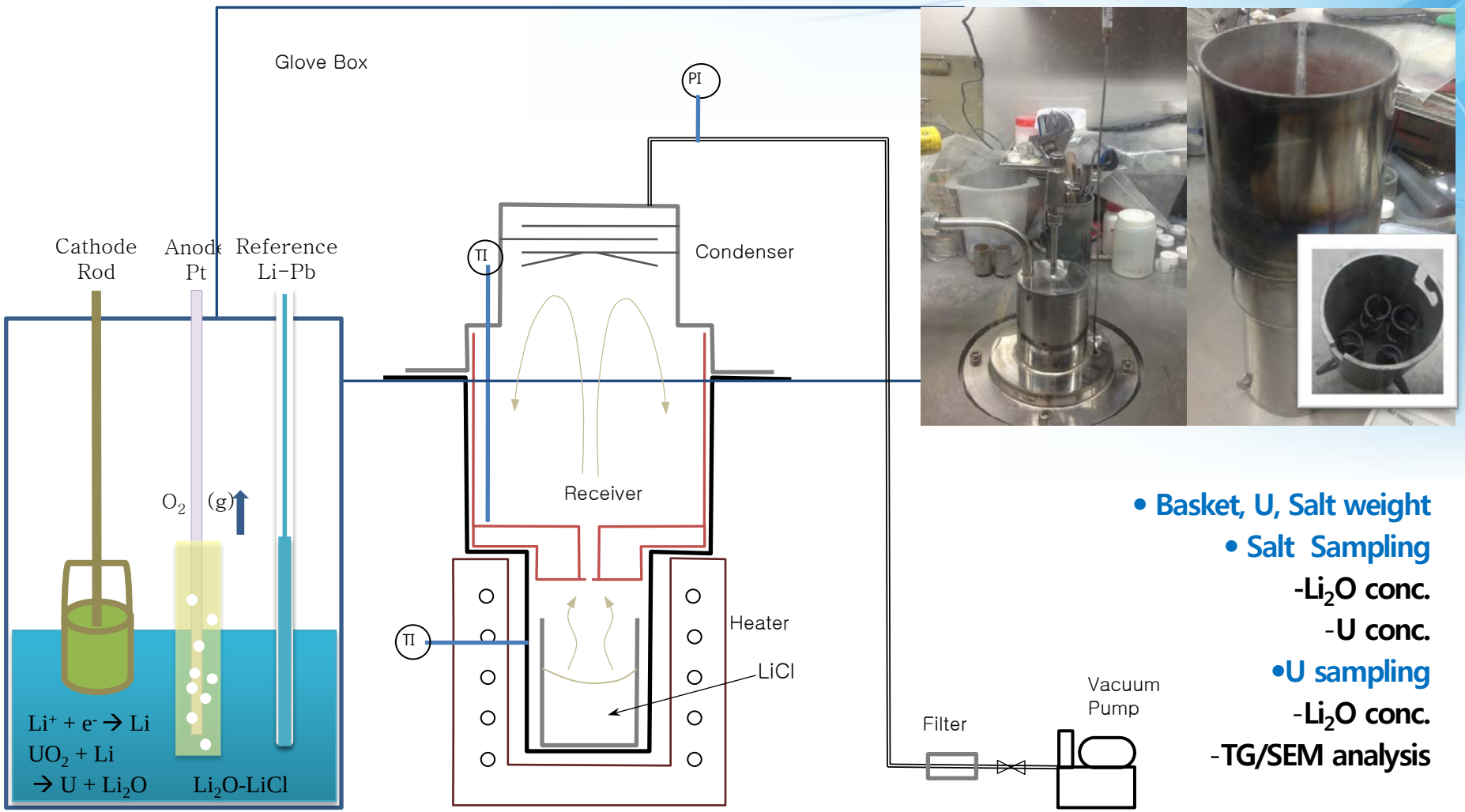
2. Analysis of equipment characteristics

- Dimensionless information of salt distillation equipment
- Data acquisition of facility parameters (electricity, temperature, pressure, etc)

3. Monitoring of fission product

- Ba, Sr, Cs material stream

Oxide reduction and Salt distillation



- Basket, U, Salt weight
- Salt Sampling
  - -Li_2O conc.
  - -U conc.
- U sampling
  - -Li_2O conc.
  - -TG/SEM analysis

Salt distillation model

Ar
Convection

T_{ar}

Reactor Wall
Conduction
T

LiCl vapor
Convection & Phase change
(Evaporation/Deposition)
T_f

$$q_{cv} = h_{ext}A(T - T_{ar})$$
$$q_{cd} = -kA\frac{\partial y}{\partial x}(T - T_s)$$

$$q_{cv} = h_{ext}A(T - T_{ar}) + m'h$$
$$q_{cd} = -kA\frac{\partial y}{\partial x}(T - T_s)$$

Factor 1 – Equipment characteristics

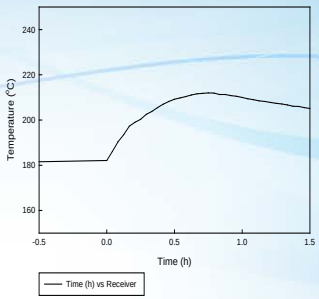
H_{ext} : Heat transfer coefficient
system- dependent parameter

Dimensionless analysis is demanded for high capacity process and scale-up and for prediction of efficiency.

Factor 2 – Process characteristics

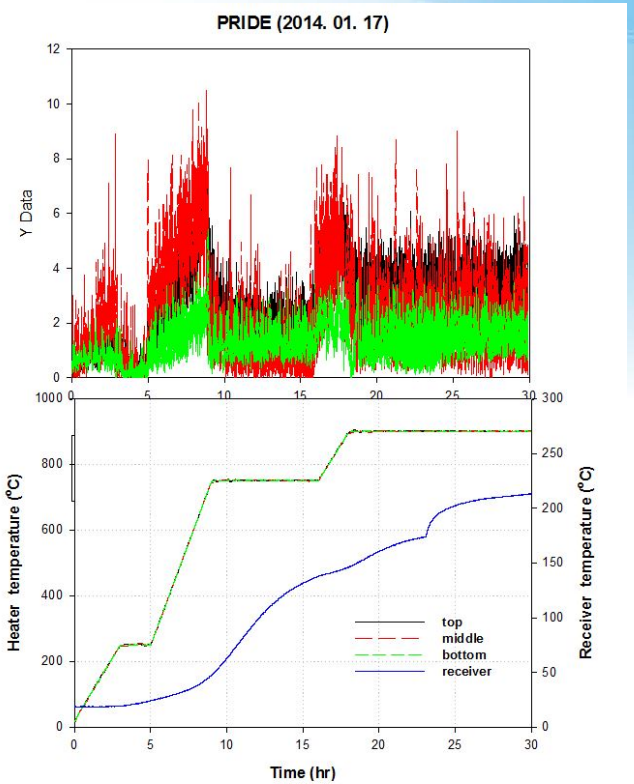
m': phase change velocity (g/s)
experiment data
Calculation from Vacuum system (Pvap, P, R, L)

H : the enthalpy of phase change (kJ/g) H_{evap} & H_{dep}



Receiver Temp.
Evap. Temp = 900 ° C

* Dr. Kim



상온 → 250℃(3 시 간 가열, 2 시 간 유 지) → 750℃(4시 간 가열, 7 시 간 유 지)
→ 900℃(2시 간 가열 후 5 시 간 유 지) → 진 공

Korea Atomic Energy Research Institute

PART

3

Characteristic analysis Of Salt distillation equipment

Dimensionless parameters

- Correlation between heat and fluid flow without limit of size of process equipment.
- Information for the scale-up design and the manufacture of process equipment

Strategy

- Selection of model equipment conducting successful salt distillation
  - sd_M salt distillation equipment
  - Guaranteed process efficiency
- For a given condition, calculation of dimensionless parameters through correlation equation (Colburn analogy)
- Control of the scale-up design based on optimized parameters

Dimensionless parameters

Re	Reynolds number	▪ Ratio of the inertial and viscous forces
Pr	Prandtl number	▪ Ratio of the momentum and thermal diffusivities
Nu	Nusselt number	▪ Dimensionless temperature gradient at the surface ▪ Ratio of convective to conductive heat transfer at the surface
St	Stanton number	▪ Modified Nusselt number ▪ Ratio of heat flux to wall and energy flux in flow relative to wall

2) Chilton and Colburn *j*-factor analogy

- Similarities among the transport of momentum, mass, and energy
- *j* -factor : dimensionless heat transfer coefficient
- Dittus-Boelter's equation (for turbulent flow)

Dittus-Boelter's equation (L/D > 10, 0.7 < Pr < 120, 10^4 < Re < 1.2 X 10^5)

$$j_h = St\,Pr^{0.67}\left(\frac{\mu_b}{\mu_w}\right)^{-0.14} \approx St\,Pr^{0.67} = \frac{Nu}{Re\,Pr^{1/3}} = \frac{f}{2} \qquad \left(\frac{\mu_b}{\mu_w}\right) \approx 1$$

Based on the analogy between heat and momentum j-factor is used for calculation of each dimensionless numbers, velocity, and temperature.

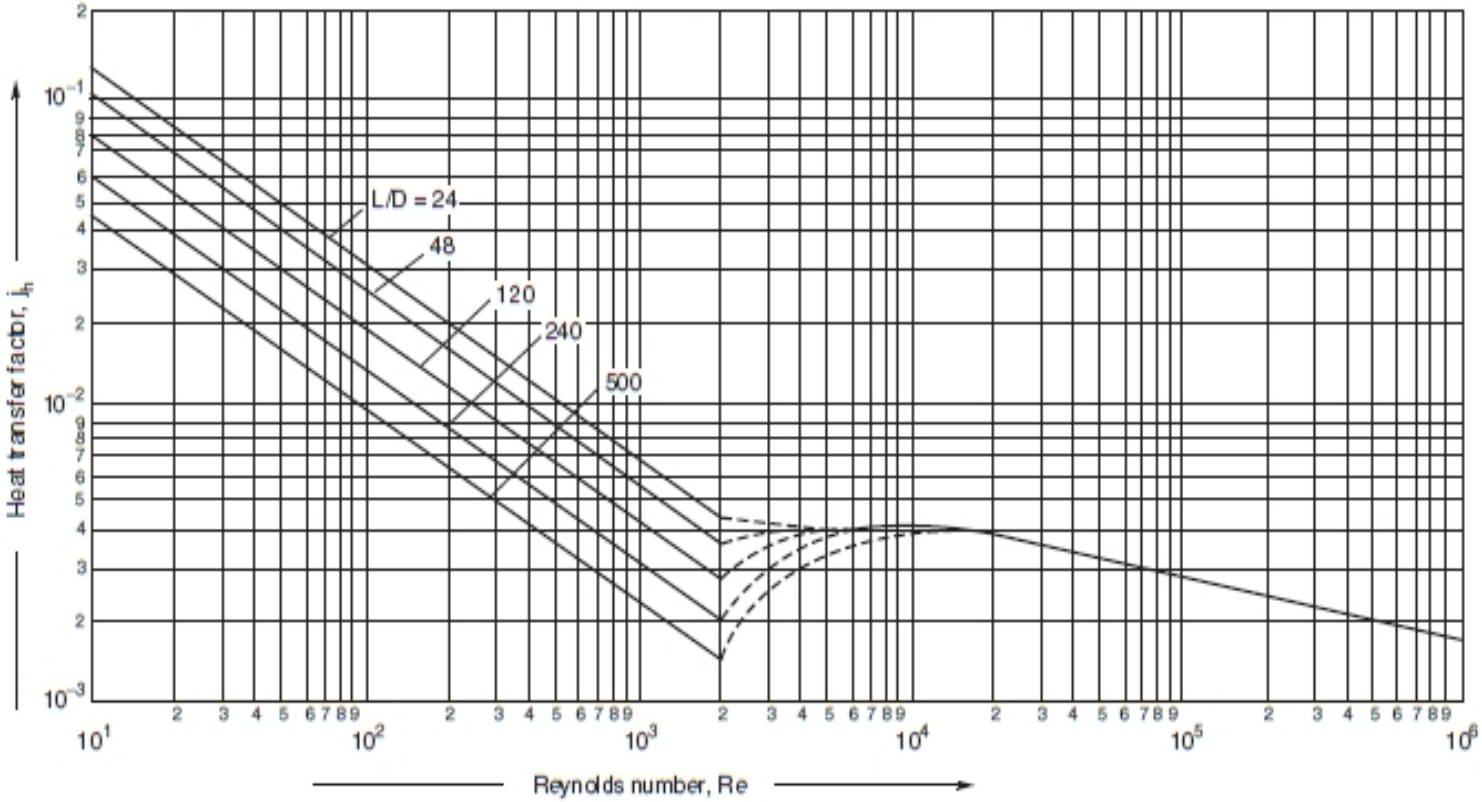
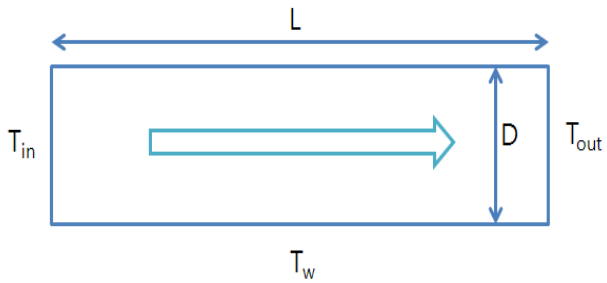


Figure 12.23. Tube-side heat-transfer factor

Nozzle throat

- Calculation of salt vapor temperature based on a nozzle size, heat and fluid condition
- Heat and fluid behavior through nozzle depends on the ratio of length and diameter (L/D) and temperature inside nozzle or tube
- Turbulent fluid temperature in pipe is the function of temperature, St number, length and diameter of pipe.



$$\frac{T_{out} - T_w}{T_{in} - T_w} = \exp(-4\,St\,\frac{L}{D})$$

T_{in} : inlet temperature, T_{out} : outlet temperature,
T_w : wall temperature, D : diameter of tube, L : length of tube

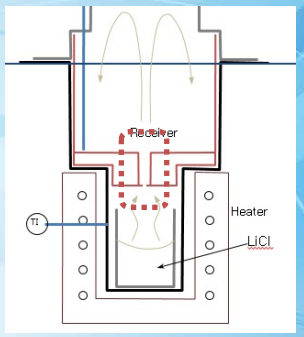
Therefore Stanton number, for a given geometry, is proportional to the temperature change in the fluid divided by the driving temperature difference.

Salt distillation device data

SD R		
	Inlet (D)	2.72cm
	Outlet (D)	2.72cm
	L	11.6cm
	L/D	4.26

SD M		
	Inlet (D)	1.70 cm
	Outlet (D)	3.40 cm
	L	13.6 cm
	L/D	8

SD P		
	Inlet (D)	2.66 cm
	Outlet (D)	7.62 cm
	L	26.6 cm
	L/D	10



SD : Salt Distillation

Table1. Velocity of nozzle sd_M

Operation Temp. (°C)	Inlet velocity [m/s]	Outlet velocity [m/s]
	D 1.7cm	D 3.4cm
800	0.3049	0.1630
850	0.3285	0.1730
900	0.3320	0.1903

Table 2. Velocity of nozzle sd_P

Operation Temp. (°C)	Inlet velocity [m/s]	Outlet velocity [m/s]
	D 2.66cm	D 7.62cm
800	0.2538	0.1073
850	0.243	0.1149
900	0.2323	0.1227

Comparison results (sd_M vs. sd_ P)

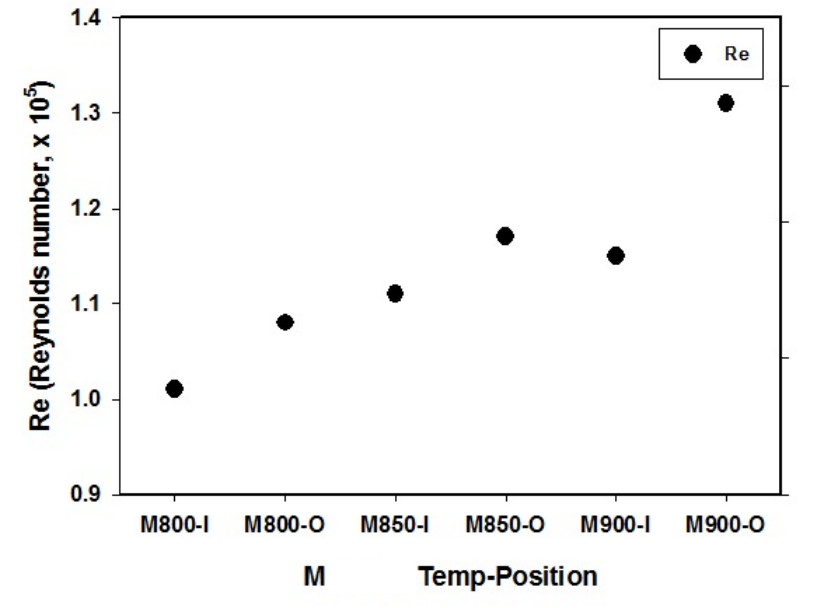
Table 3. Dimensionless parameters of sd_M salt distillation equipment

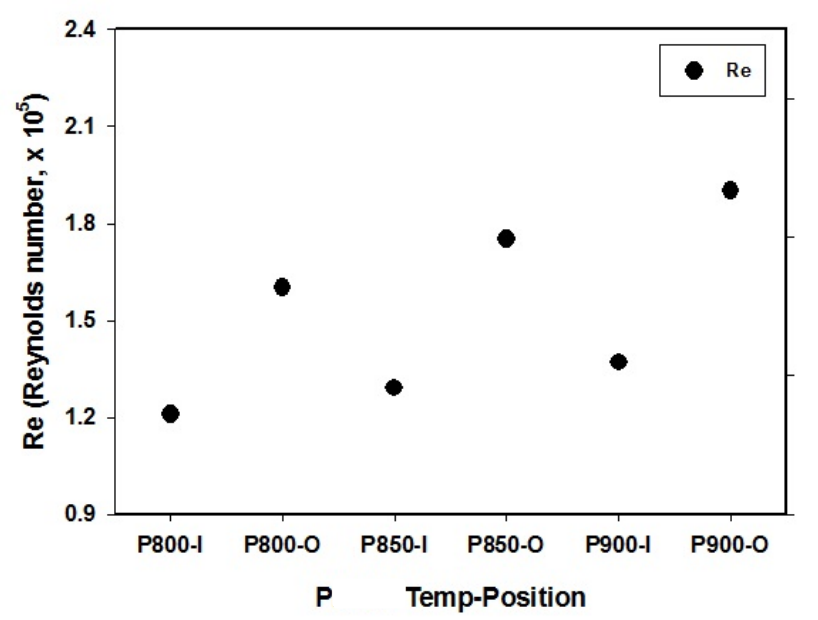
Temp. (°C)	velocity [m/s]	Re (x10^5)	Nu	$j_h \approx 0.08Re^{-0.25}$	1) $St = \frac{Nu}{RePr}$	2) $St = j_h/Pr^{2/3}$
800	0.163	1.08	302	0.00220	0.00149	0.00145
	0.3049	1.01	287	0.00224	0.00151	0.00147
850	0.173	1.17	322	0.00216	0.00147	0.00142
	0.3285	1.11	309	0.00219	0.00148	0.00144
900	0.1903	1.31	352	0.00210	0.00143	0.00138
	0.332	1.15	316	0.00217	0.00147	0.00142

Table 4. Dimensionless parameters of sd_P salt distillation equipment

Temp. (°C)	velocity [m/s]	Re (x10^5)	Nu	$j_h \approx 0.08Re^{-0.25}$	1) $St = \frac{Nu}{RePr}$	2) $St = j_h/Pr^{2/3}$
800	0.1073	1.60	413	0.00199	0.00138	0.00131
	0.2538	1.21	330	0.00214	0.00145	0.00141
850	0.1149	1.75	443	0.00196	0.00136	0.00129
	0.243	1.29	348	0.00211	0.00144	0.00139
900	0.1227	1.90	473	0.00192	0.00133	0.00126
	0.2323	1.37	365	0.00208	0.00142	0.00137

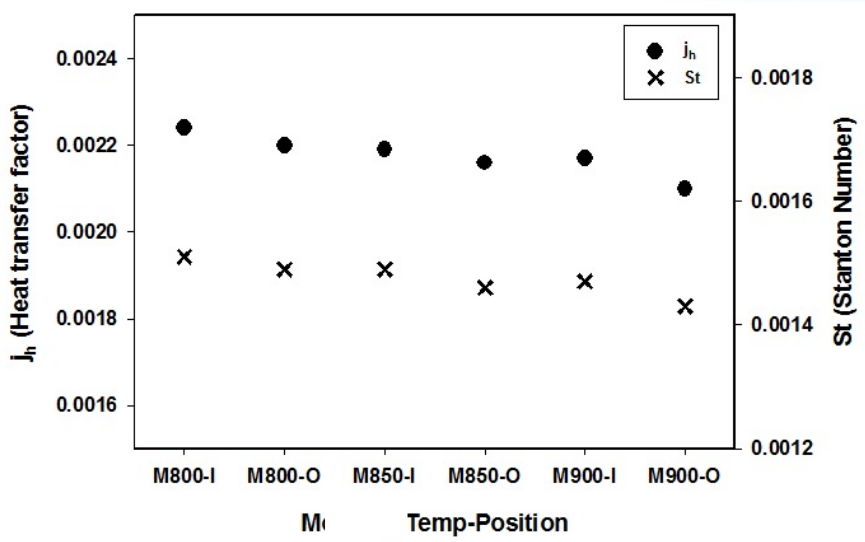
Re comparison (sd_M vs. sd_P)

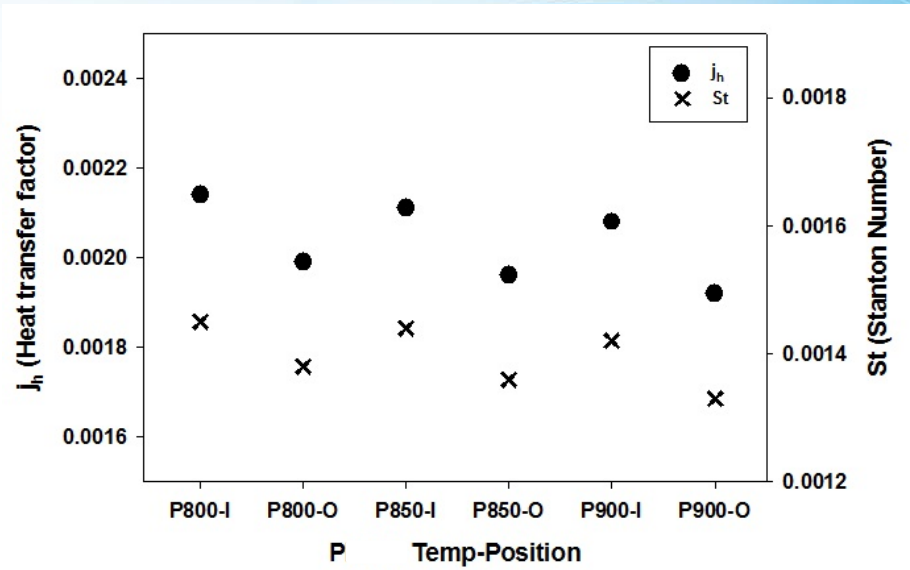




- Turbulent flow range (Re > 4000)
- sd_P Re > sd_M Re ➔ more Turbulent flow (broad tube diameter)
- sd_P equipment has relatively the larger deviation of Re numbers between inlet and outlet than sd_M equipment

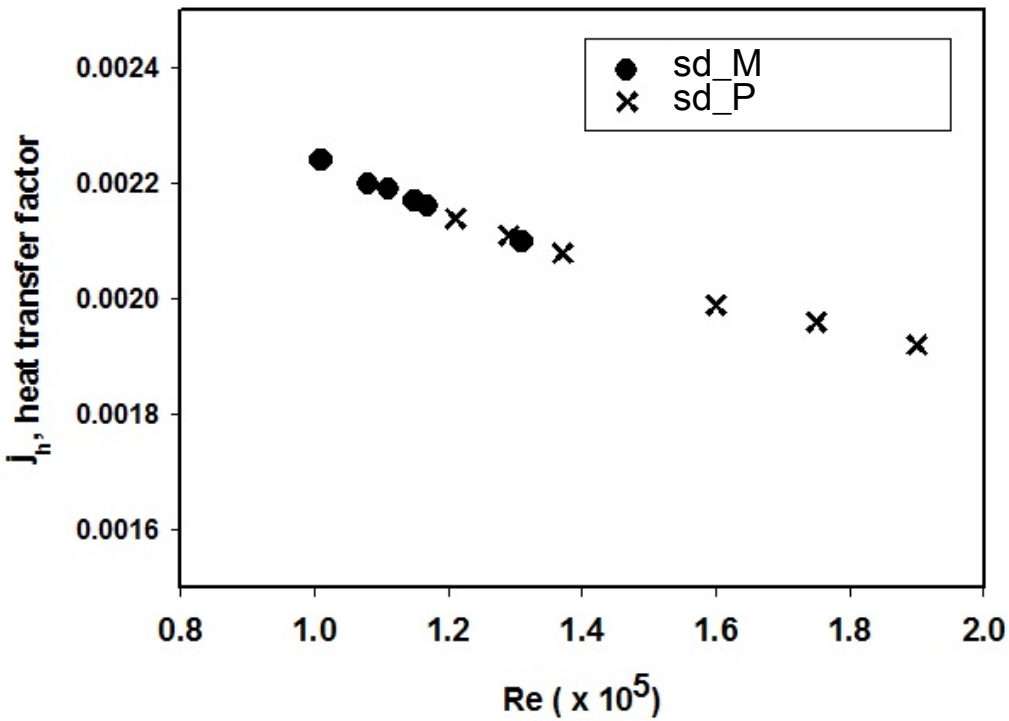
j-factor and St number





- Both M and P show the similar behaviors of parameters at the inlet and outlet.
- sd_P St number < sd_M St number
- sd_M has faster fluid velocity and high heat transfer to wall.
- sd_P shows the larger deviation of j-factor and St number between inlet and outlet.
- Relatively longer ratio of L/D (sd_P : L/D = 10, sd_M : L/D = 8)
- Longer pathway of fluid induces lower velocity, larger pressure drop, and lower temperature.

J-factor (sd_M vs. sd_P)



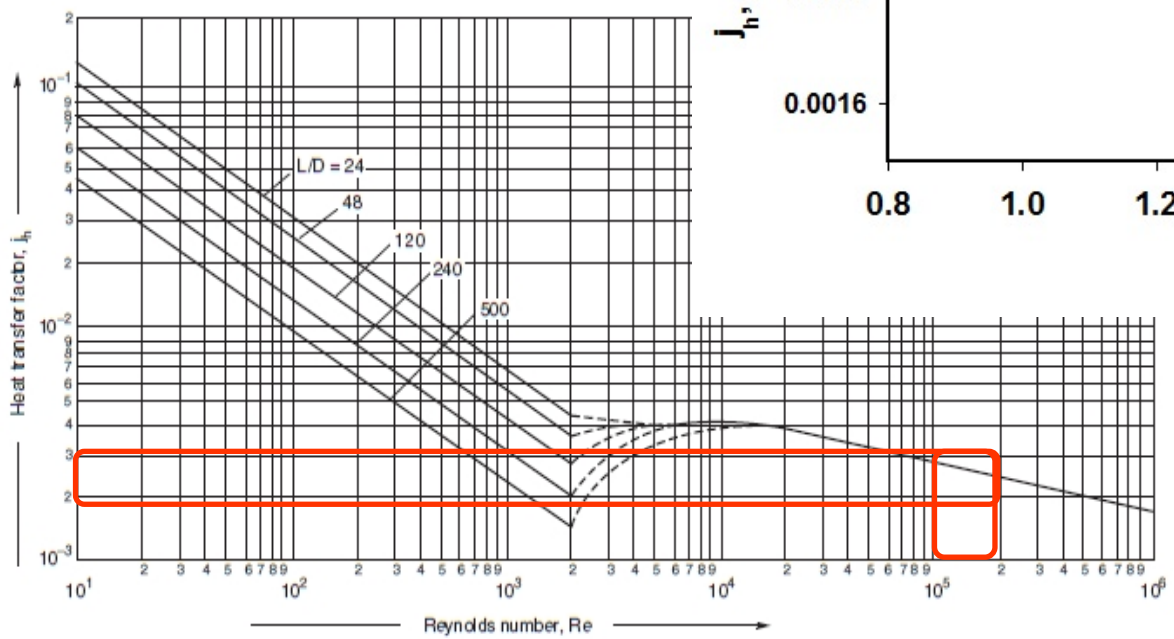
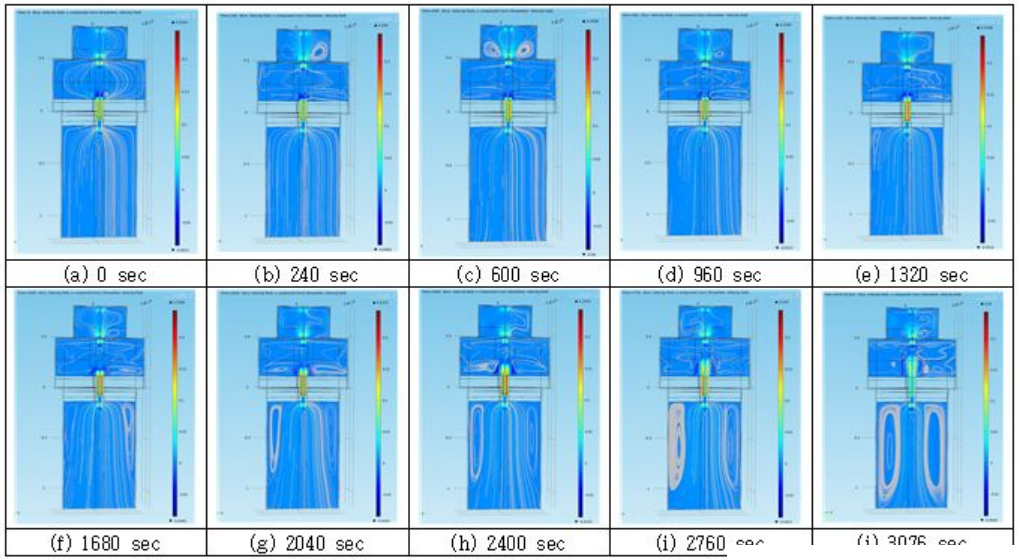
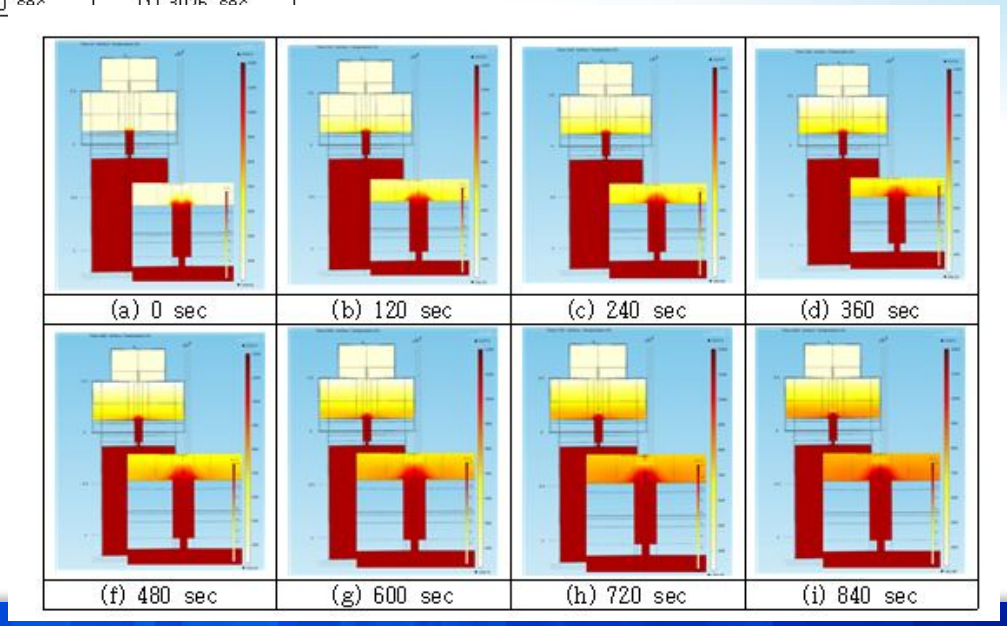


Figure 12.23. Tube-side heat-transfer factor

Temperature distribution & fluid behavior





Conclusions and future works

1. Characteristic analysis of process equipment is still on the beginning step.
2. Fundamental characteristics of each equipment was acquired for scale-up (sd_M and sd_P)
3. It shows the possibility to control the equipment design under the guaranteed process efficiency.
4. Supplementary experimental data are demanded for application of characteristic analysis into real scale-up procedure forwards.