SINAP loop operations – summary of experience to data

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2016.10

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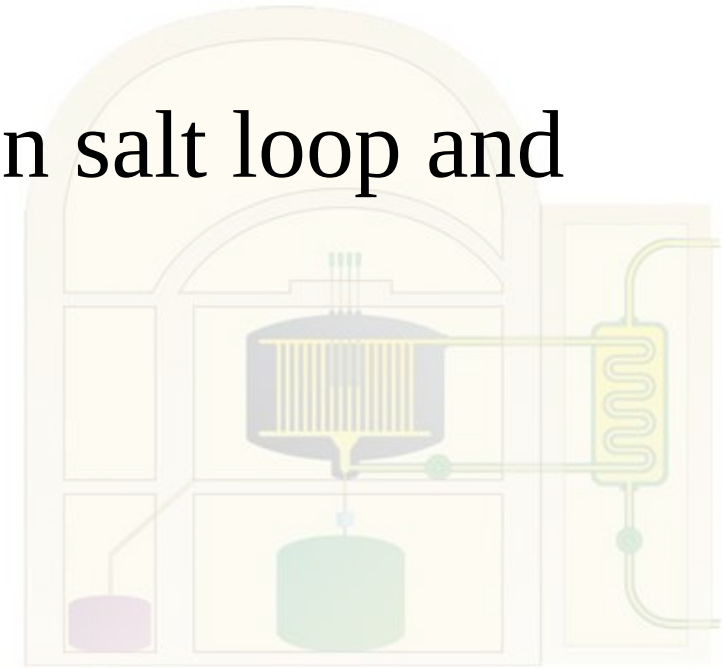
Outline

- General introduction
- Molten salt loop commissioning and operation
- TH experiments of molten salt loop and future planning



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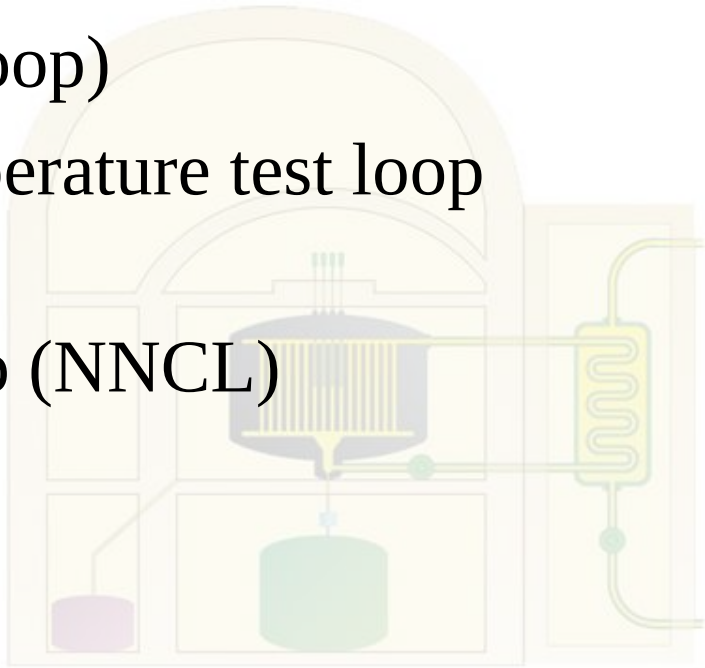
SINAP molten salt loop development

- From 2011, SINAP has developed 3 molten salt loops

- 1. HTS thermal test loop (HTS loop)
- 2. FLiNaK molten salt high temperature test loop (FLiNaK loop)
- 3. Nitrate natural circulation loop (NNCL)



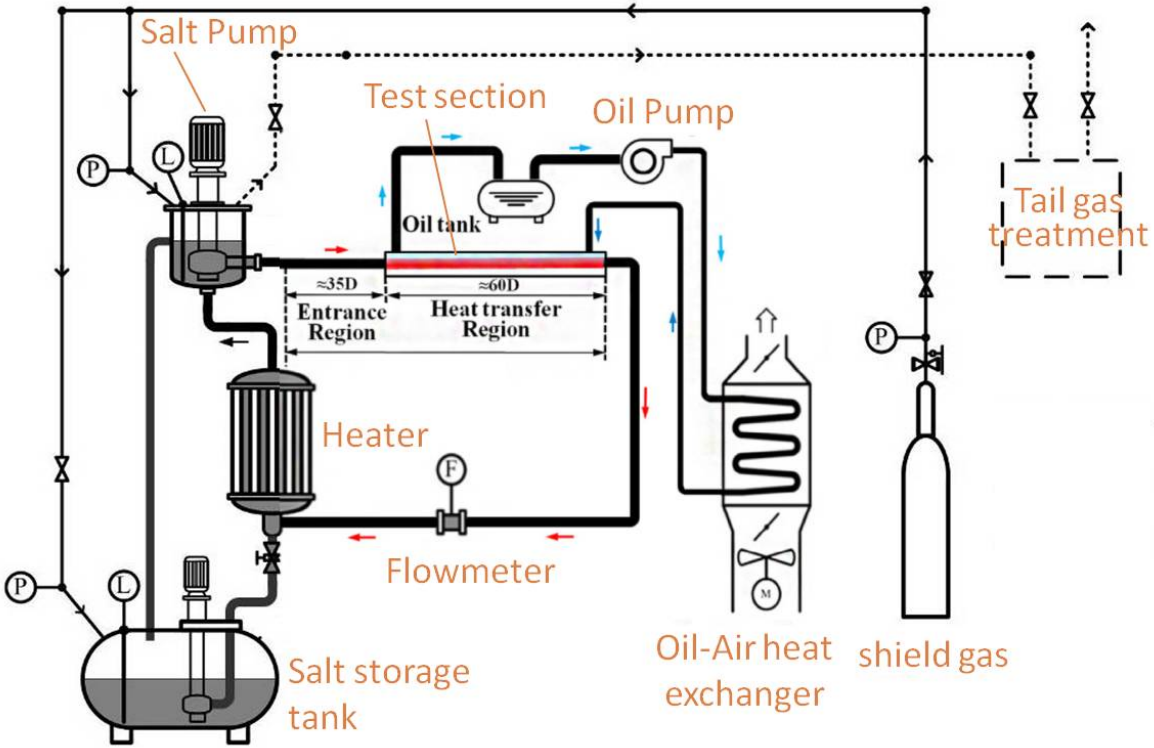
HTS loop

Main design parameters:

Salt	KNO_3-$NaNO_2$-$NaNO_3$(53-40-7mol%)
Design temperature	450℃
Work temperature	200-400℃
Flow rate	<2m/s
Design flux	$2m^3/h$
Material of construction	Inconel600

Achievements:

- Validate system design and integration technologies of molten salt loop
- Carry out HT experiments via nitrate


Salt Pump
Test section
Oil Pump
Oil tank
Tail gas treatment
≈35D
Entrance Region
≈60D
Heat transfer Region
Heater
Flowmeter
Salt storage tank
Oil-Air heat exchanger
shield gas

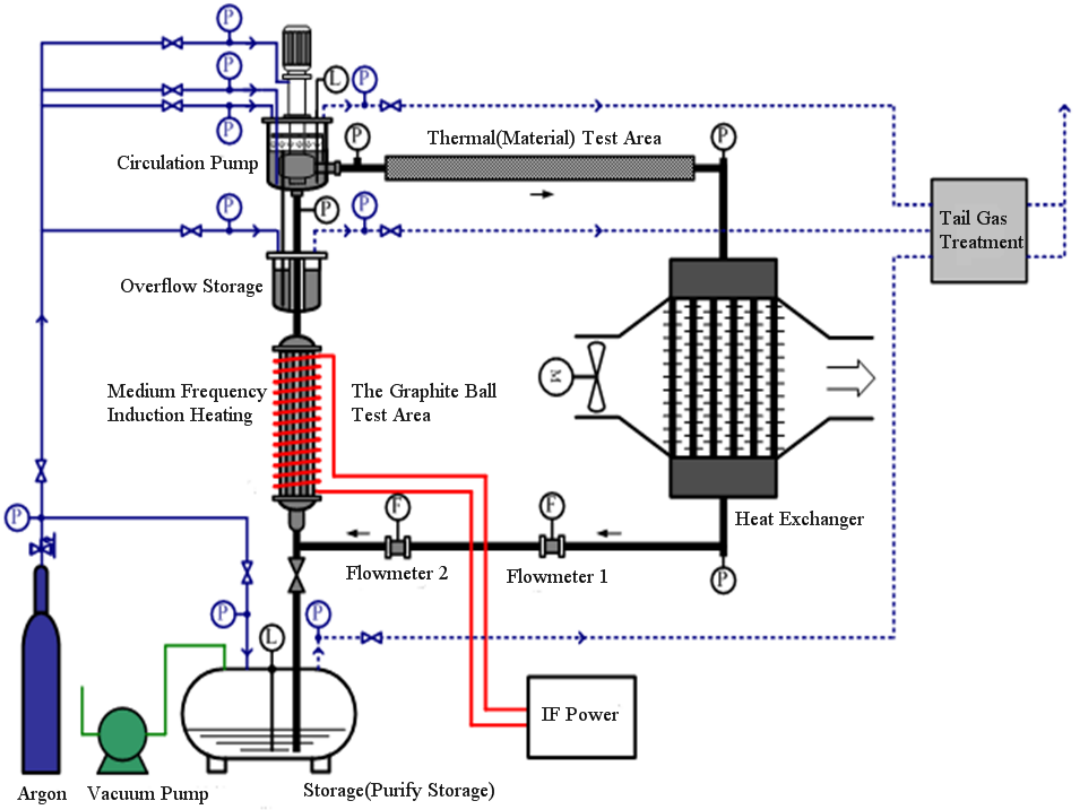
FLiNaK Loop

Main design parameters：

Salt	LiF-NaF-KF（46.5-11.5-42mol%）
Design temperature	650℃
Work temperature	500-600℃
Design flux	15m^3/h
Design pressure	<0.5MPa
Material of construction	Hastelloy-C276

Achievements：

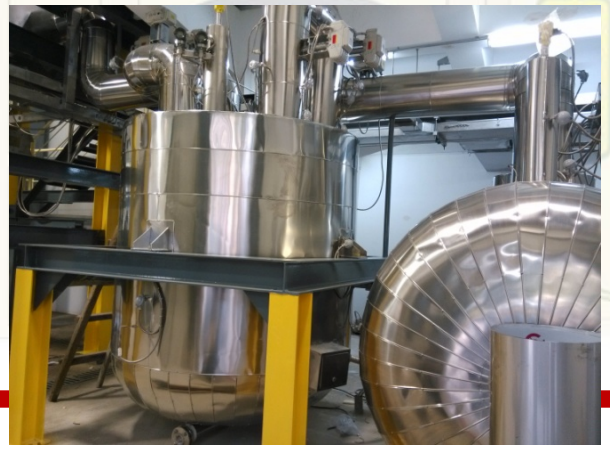
- Validate system design and integration, loop layout and seal technologies of high temperature fluoride loop
- Develop principle prototypes of molten salt pump, valves, heat exchanger and high-temperature instrumentation, etc.


Circulation Pump
Thermal(Material) Test Area
Tail Gas Treatment
Overflow Storage
Medium Frequency Induction Heating
The Graphite Ball Test Area
Heat Exchanger
Flowmeter 2
Flowmeter 1
IF Power
Argon
Vacuum Pump
Storage(Purify Storage)

NNCL

Main design parameters：

Salt	KNO_3-$NaNO_2$-$NaNO_3$(53-40-7mol%)
Design temperature	450℃
Work temperature	200-400℃
Material of construction	ss316



Achievements：

- Establish experimental platform to study molten salt natural circulation
- Gather experience on design and validation of passive decay heat removal system for the future fluoride-salt-cooled high temperature reactor

- General introduction
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Main steps and contents of molten salt loop commissioning

1、 system check

2、 pretreatment

3、 molten salt transportation

4、 shakedown test without molten salt

5、 molten salt loading

6、 shakedown test with molten salt

7、 operation and experiment

Failures and solutions during loop commissioning

Storage tank

- Failure：crack happened between cylinder and head
- Reason：no heat-treatment after machining of vessel heads
- Solution：replace the old tank with a new one with heat-treated

Freeze valve

- Failure：valve body crack
- Reason：salt frozen at both ends of the valve body when valve opened
- Solution：install additional heaters on both ends of freeze valve to keep salt melted

Crucial commissioning and operation techniques for loop

Quality control of FLiNaK salt

- To control the content of water and oxygen under a low level(about 100ppm) by vacuum pumping and argon charging.
- Sampling and analysis of molten salt indicate that loop corrosion control keeps in a well condition and salt's quality is not going worse any more after loop operation.

Anti-freezing technology of loop system

- Heaters are installed outside all equipment and piping of the loop, which can preheat the loop system and add heat during operation.

Overall operation conditions of molten salt loop

- HTS Loop: 15,000 hours of accumulated running time; During the process heat transfer test section has been upgraded
- FLiNaK Loop: Thousands of hours of accumulated running time; During the process the high-power heater has been upgraded, now undergoes the installation of a prototype of SF0 heater
- NNCL: Thousands of hours of accumulated running time

Operation and Experiment contents

System Operation

- Isothermal Operation
  - Isothermal operation within various flux
- Temperature difference Operation
  - General adjustment via electrical heating and air cooling
  - Design verification of heat exchanger

Equipment performance test

- Molten salt pump performance experiment
- Freeze valve switching test
- Air cooling performance test of heat exchanger
- Functional validation of flexible supports for equipment

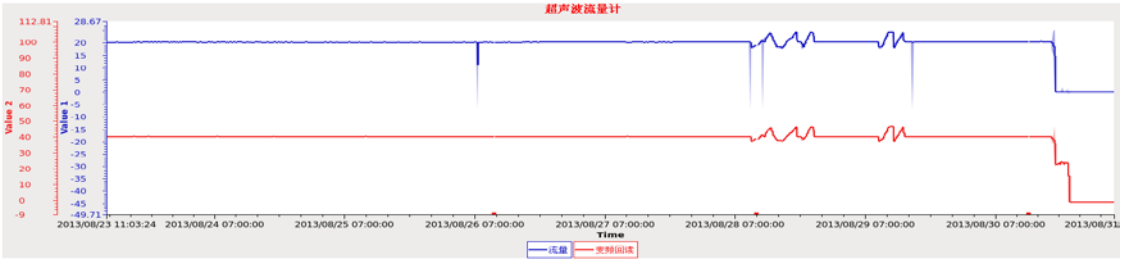
TH experiments

… …

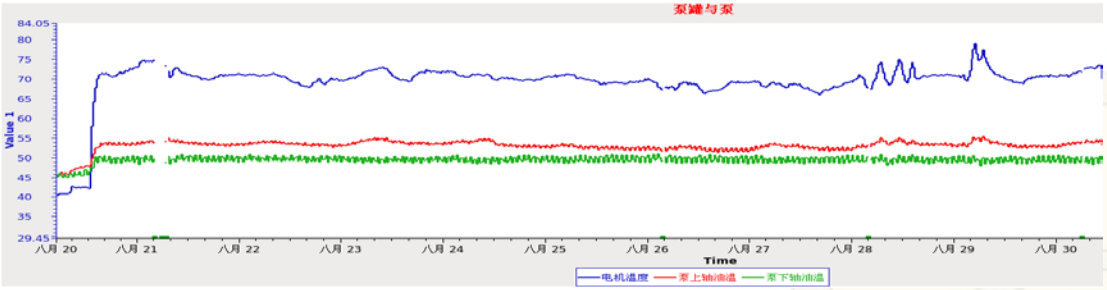
- Successful operation of principle prototype of pump, heat exchanger, freeze valve and instrumentation such as flow meter, pressure transmitter and level meter, and test data has been collected.
- Technical supports and data reference for R&D of engineering prototype and nuclear equipment.

Principle prototype of molten salt pump and salt-air heat exchanger

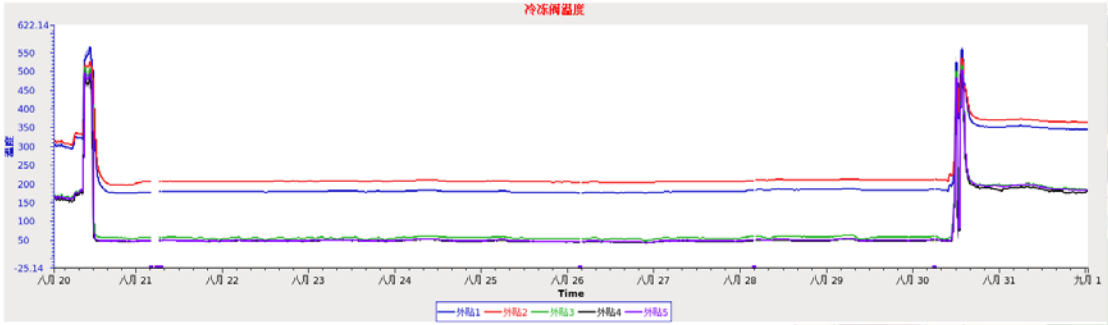
Testing results of molten salt loop equipments



(1) Validation of pump frequency and flow meter reading



(2)Temperature distribution of molten salt pump key parts



(3) Switching response of freeze valve

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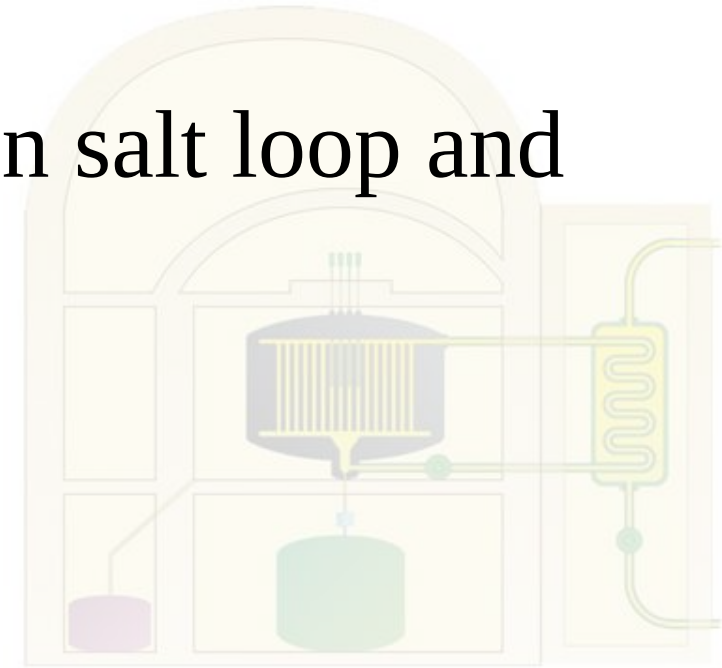


TH experiments completed in molten salt loop

HTS loop

- Circular tube HT tests
- Enhanced HT tube tests

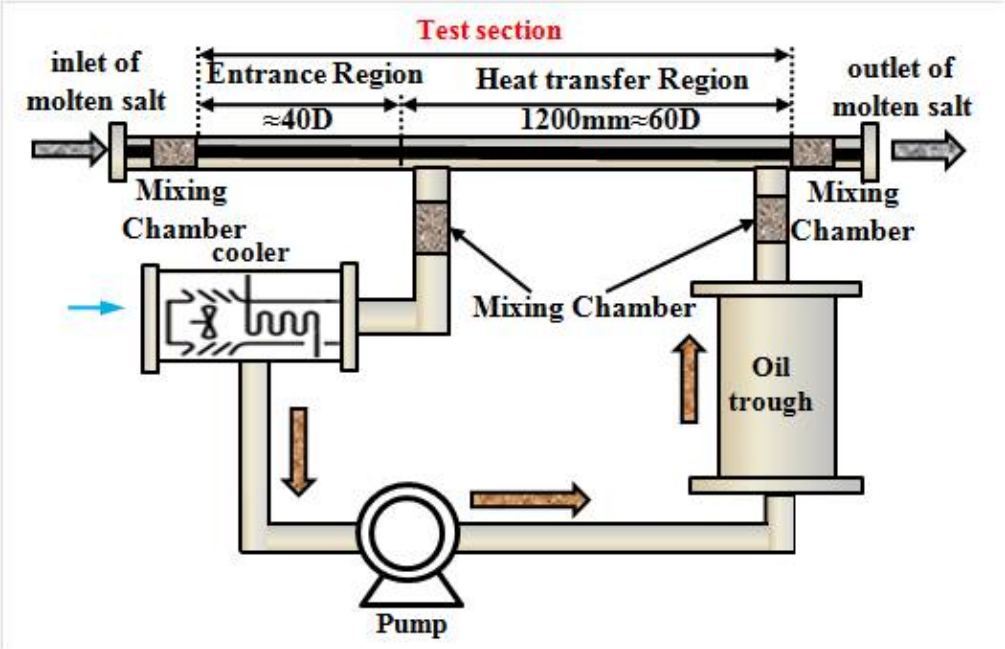
FLiNaK loop

- Salt-air heat exchanger steady HT tests
- Molten salt pump hydraulic tests

NNCL

- Nitrate natural circulation
- Residual heat removal validation

HTS loop HT experiments



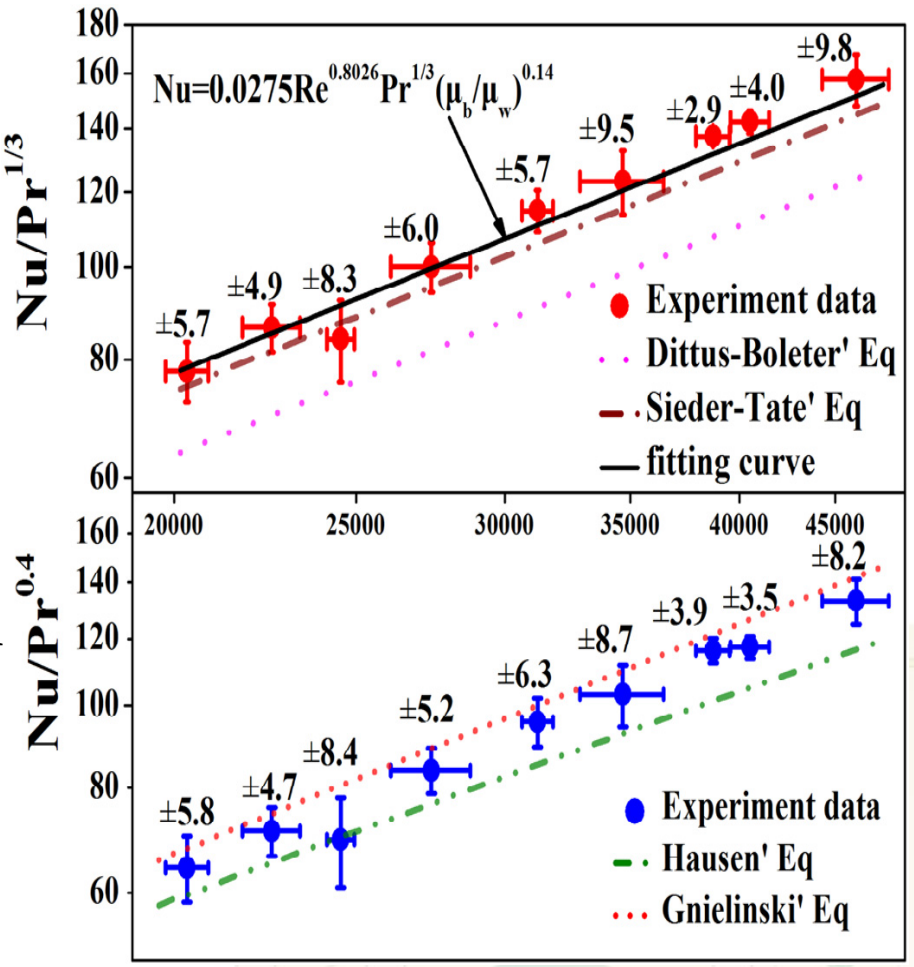
Schematic diagram of the test section and the oil loop in the HTS loop

Circular tube HT tests

- Suggested new correlation

$$Nu = 0.0275\,Re^{0.8026}\,Pr^{1/3}\,(\mu_b/\mu_w)^{0.14}$$
$$(20000 < Re < 50000,\ 11 < Pr < 27)$$

  - Uncertainty of Nu: ±7.8%
- HT correlations comparison (deviation)
  - Gnielinski (+7%)
  - Sieder–Tate (-8%)
  - Hausen (-10%)
  - Dittus–Boelter (-20%)



Comparison of the suggested new correlation for turbulent flow with classical HT correlations

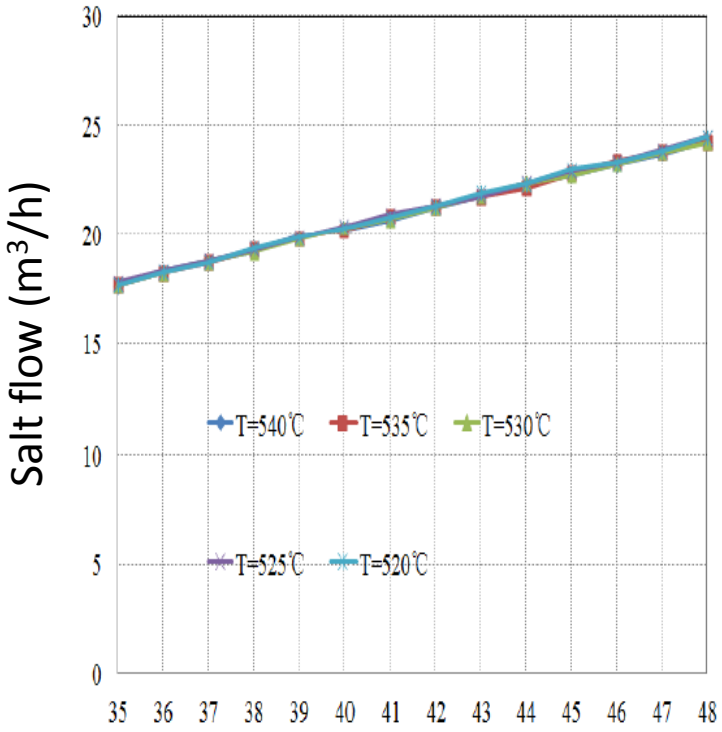
FLiNaK loop experiments

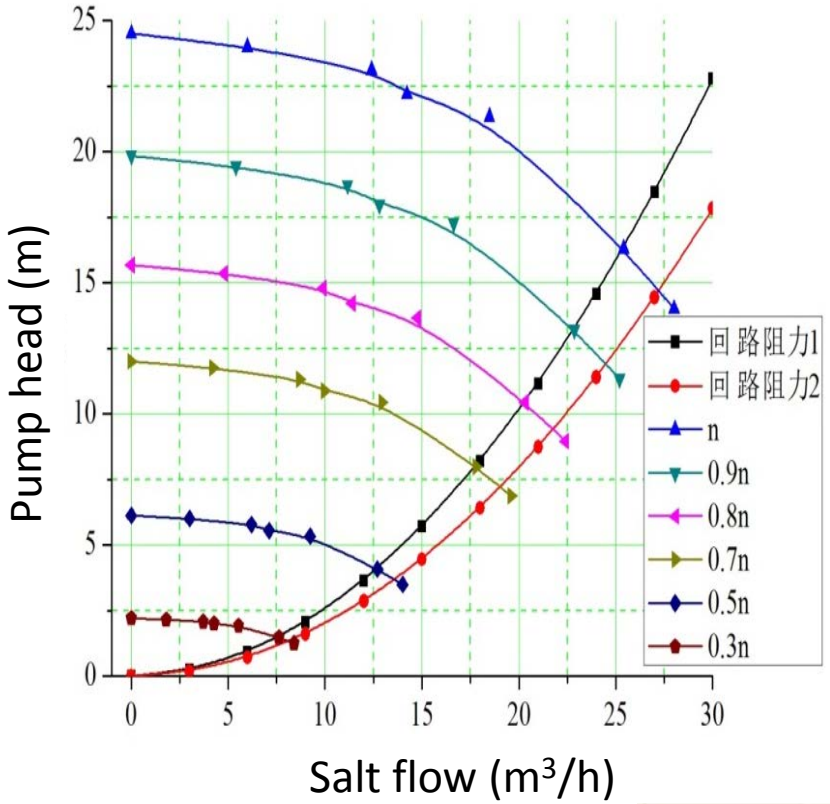
Salt-air heat exchanger steady HT tests

- To obtain the heat transfer coefficients of the salt-air heat exchanger at different flow conditions
- To validate the heat exchanger design (HT coefficient design value: 70W/m^{2}K)

Molten salt pump hydraulic tests

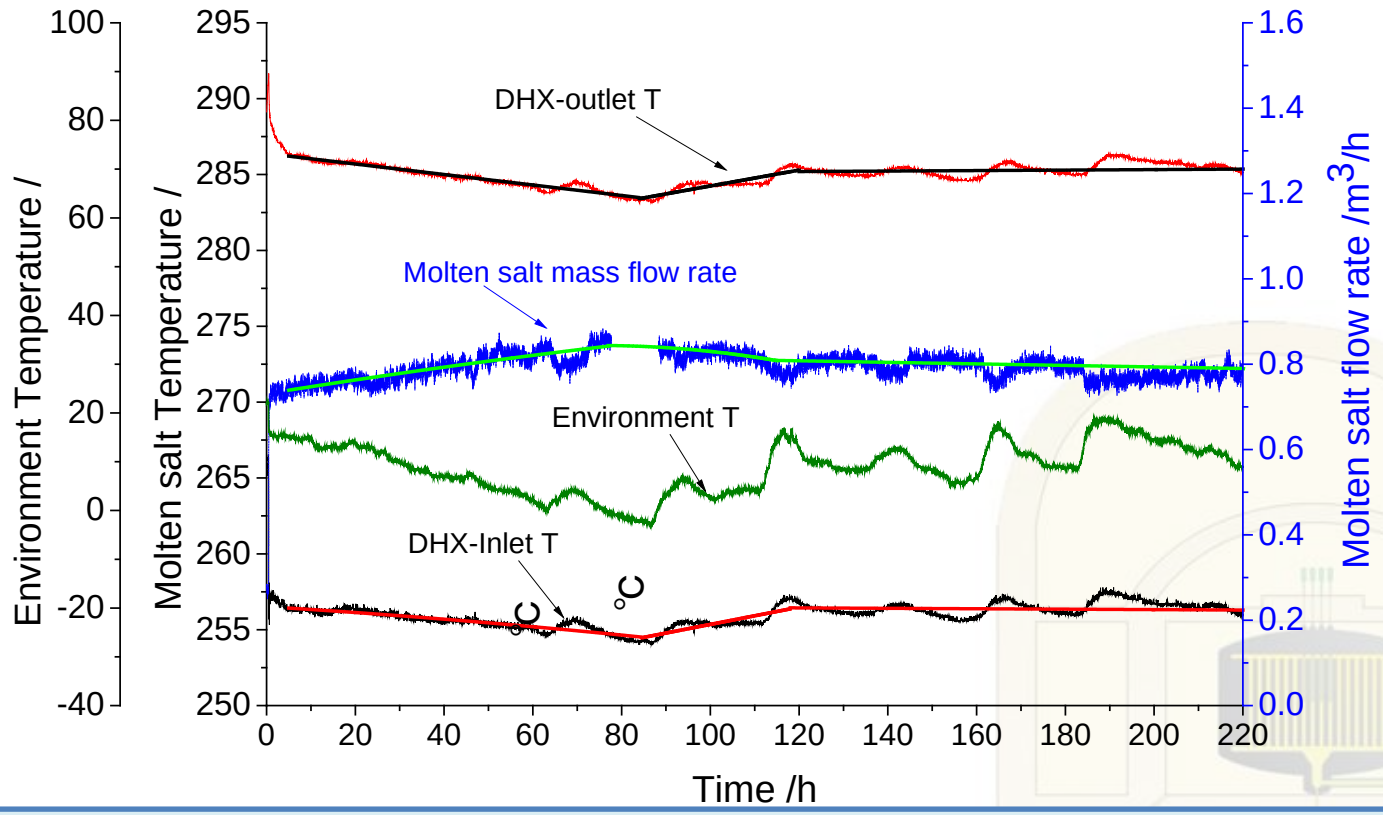
- To obtain the pump hydraulic characteristics at steady state





Molten salt pump hydraulic test result

NNCL experiments

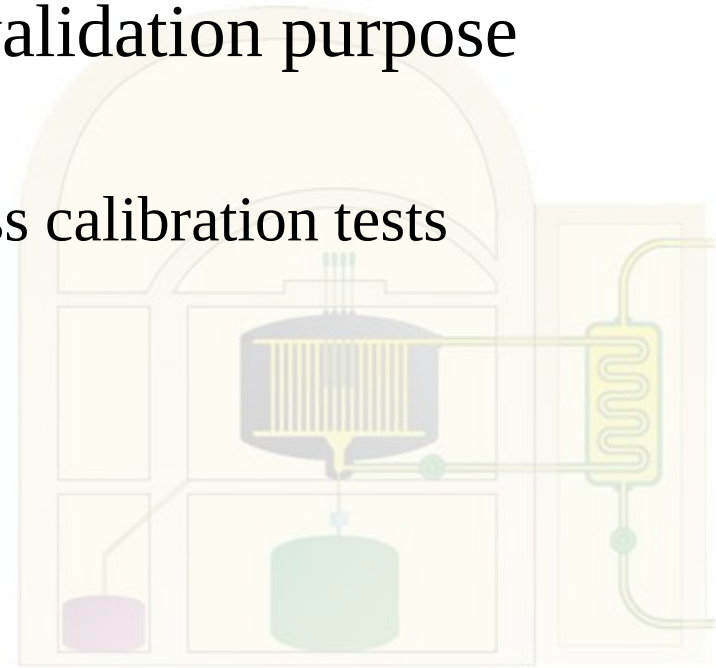


The experimental prove that:

- A stable natural circulation can be formed in a short time, and the heat can be removed continuously.
- The molten salt natural circulation loop is feasible for the residual heat removal of molten salt reactor.

Test plans for the loops

- Heat transfer tests on the FLiNaK test loop
  - Pebble-bed heat transfer tests
  - Convectional heat transfer tests in a circular pipe
- Transient tests for system code validation purpose on the two loops
  - System and key equipment heat loss calibration tests
  - Power transients
  - Salt flow rate transients
  - Heat exchanger load transients



THANKS !