EXPERIMENTAL FACILITIES FOR RESEARCH OF PROPERTIES AND BEHAVIOUR OF FLUORIDE SALTS

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ABSTRACT. ŠKODA JS s.r.o. (Czech leading nuclear technology manufacturer) prepared and manufactured experimental loops for research and verification of properties and behaviour of fluoride salts for primary and secondary circuit, construction materials and ADTT systems technological components for the operation in the Nuclear Research Institute Rez plc fluorine chemistry laboratory. This paper presents charts and experimental program for molten fluoride salts experimental loops with natural circulation. Further on, the paper describes extension of the loops for research with forced circulation and next works for steam generator model verification and connection with the loop of Energovýzkum Brno. The loops are designed and constructed to obtain a sufficient amount of experience on ADTT technology. The research and utilisation program covers questions of corrosion and integranual corrosion of structural materials, research of material properties and welding, research of fluoride fluid properties, measuring of thermo-hydraulic properties of molten salt fluoride fluids, heat transfer and hydraulics, development and tests of some plant components (steam generators, heat exchangers, pumps, valves) and other engineering issues. Two electrolyzers have been manufactured for the research of fuel/coolant fluoride salts mixture purification. One for the production of hydrogen fluoride, and the other for the research of salts purification.

1. INTRODUCTION

International ADTT projects develop new nuclear reactor technologies offering in the long-term a possibility to produce clean fission energy in the safe accelerated protons beam driven subcritical blankets with transmutation of long-lived fission products (e.g. Pu, minor actinides, fission products) into short-lived or stable elements. In power unit project studies,
where used accelerator driven transmutation technology, molten salt systems are the most frequently mentioned and investigated systems.

In Czech Republic a National ADTT Working Group was constituted by scientifical, research and industrial organizations to take part in international programs. Present works in ŠKODA JS s.r.o. are aimed at the construction of experimental laboratory loop with molten fluoride salts. The experimental loop will be the first step to verify the properties of fluoride salts, structural materials and technological components of ADTT systems. The purpose of the ADTT loop is to gain as much experience as possible about the technology.

The final aim is to have a design (or participation in the international design) of a subcritical core controlled by an intensive proton accelerator which utilizes fast neutrons from a spallation source. The whole system serves for the burn-up of actinides and long-term fissile products from NPP spent fuel.

The development and fabrication of the ADETTE loop will be done in collaboration with many other Czech organizations, particularly with Nuclear Physics Institute of the Czech Academy of Sciences, Nuclear Research Institute, specialists in a fluoride technology, and many others. The ADETTE loop was designed by CHEMOPROJEKT Prague (member of Krebs group).

2. ŠKODA ADETTE-1 THERMAL CONVECTION LOOP

In the first stage ŠKODA JS s.r.o. and NRI Rez plc manufactured the small experimental loop ADETTE-0 with molten fluoride salts. This loop is located and operated in the Nuclear Research Institute Rez plc fluorine chemistry laboratory [1].

In the second stage ŠKODA JS s.r.o. will start with the construction of single-circuit loop with natural circulation of medium ADETTE-1 (see Fig. 1). This loop is intended to be made of material MONICR [2], of tubes $\varnothing$ 57 x 3.5 mm, approx. 8 m in length. The loop is heated to the lower operation temperature - approx. 550 °C. In a part called „reactor“ the power supply is simulated by further heating (to 700 °C) and this power is wasted in a cooler. This loop can be built practically immediately without any development.

The entire loop system consists of an insulated loop tubing, preheaters, coolers, pipeline, valves, storage tanks. Also of inert gas + vacuum system, electrical and I&C equipment. All the loop system is situated in the steel frame, easy movable (see Fig. 2).
The loop tubing forms a bevelled trapezoid (angle 15°) with lengths of sides about 1.3 m, where left (A) and bottom (C) sides are preheated, right (B) and top (D) sides are cooled. Convection forces in contained fluid establish flow rates up to fluid velocity 5 cm/s, depending on the temperature difference between the heated and cooled portions of the loop. The left and right sides A, B work as experimental channels - tubes with sealed flange-closing. This gives the possibility to install experiment devices inside the channels.

As loop tubing material is used MONICR alloy produced by ŠKODA JS s.r.o. and KOVOHUTE Rokycany, a Czech metallurgical plant. Preheaters are electrical CLASIC-KANTHAL furnace preheaters, with max. temperature 1150 °C, with maximal element surface load up to 130 kW/m². Coolers are simple air-cooled tube in tube constructions. Mechanical shutoff valves with bellows, nominal temperature to 600 °C for fluid auxiliary pipeline, freeze valves for sample removal. Needle valves for gas and vacuum circuits. Set of storage tanks gives broad possibilities of fluids manipulating and for the fluid composition changing. Inert gas/vacuum system consists of inert gas source - pure argon bottle (99.99 %, O₂ max. 3 ppm, N₂ max. 10 ppm, H₂O max. 5 ppm), vacuum pump, valves and pipeline. PC controlled system for collecting operating data (temperature, level, pressure and flow measurements) and processing. Temperature measuring by „S“ thermocouples, molten salt fluid level measurement by bubbler indicator.

Two electrolyzers have been also manufactured for the research of fuel/coolant fluoride salts mixture purification (see Fig. 4). One for the production of hydrogen fluoride, and the other for the research of salts purification.

3. TECHNICAL PARAMETERS OF ŠKODA ADETTE-1 THERMAL CONVECTION LOOP

Medium (1st stage): LiF 46.5 %  
                 NaF 11.5 %  
                 KF 42 %
Melting point: 454 °C
Inert atmosphere: argon
Circulation: natural
Material: MONICR, tube Ø 57 x 3.5 mm, length approx. 8 m
Operation temperature: 550 ÷ 700 °C
Useful fluid volume: about 13 litres
Pressure: 0,6 MPa
Electrical input: about 80 kW

4. PROPOSAL OF AN EXPERIMENTAL PROGRAM FOR ŠKOnda ADETTE-1 THERMAL CONVECTION LOOP

Mechanical and thermal technical properties of structural materials

- Standard material corrosion test
  size of test plates: 80 x 20 x 4(5) mm
  experimental position for: 3 pcs.
  location: one after another, side by side
  medium temperature: 550 ÷ 700 °C

- Weld joint test
  size of test plates: 80 x 20 x 4(5) mm
  type of weld: butt weld

- Stress corrosion test
  size of test specimens: ∅ 6 mm, length 70 mm
  experimental position for: 1 pc

- Brittle fracture test
  size of test specimens: 25 x 25 x 12.5 mm

5. ŠKOnda ADETTE-2/3 FORCED CONVECTION LOOP

In the next stage it is suitable to build ADETTE-2/3 loop (see Fig. 3), which is a general equipment where an extensive experimental program can be realized. The loop design is very similar to the design of a compact primary circuit of a power reactor and can be extended by a secondary cooling circuit with a heat exchanger (medium NaBF₄ + NaF).

Shown in Fig. 3 is schematic diagram of the future ADETTE-2/3 loop which fully answers to the idea of ADTT moderated molten salt cooled reactor blanket.
Central point of the loop primary circuit will be an experimental „heat generating“ channel with graphite „G“ of a unusual irregular cross section. The heat will be supplied to the channel by electrical outer and maybe internal heaters.

The molten salt fluid of the primary circuit is forced by primary pump to the channel „G“ and next to the heat exchanger (U-tube, area 6 m$^2$, primary fluid in shell, secondary in tubes). Primary circuit has filtration and cleaning device and could be interconnected to a chemical transmutation plant. Secondary cooling circuit is fully equipped, filled by molten salt fluid.

6. TECHNICAL PARAMETERS OF ŠKODA ADETTI-2/3 FORCED CONVECTION LOOP

<table>
<thead>
<tr>
<th>Medium (1st stage):</th>
<th>LiF</th>
<th>45 %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NaF</td>
<td>12 %</td>
</tr>
<tr>
<td></td>
<td>KF</td>
<td>43 %</td>
</tr>
<tr>
<td>Melting point:</td>
<td>454 °C</td>
<td></td>
</tr>
<tr>
<td>Medium (2nd stage):</td>
<td>LiF</td>
<td>66 (mol %) or 47.5 (mol %)</td>
</tr>
<tr>
<td></td>
<td>BeF$_2$</td>
<td>34 (mol %) or 52.5 (mol %)</td>
</tr>
<tr>
<td>Melting point:</td>
<td>458 °C or 375 °C</td>
<td></td>
</tr>
<tr>
<td>Inert atmosphere:</td>
<td>argon</td>
<td></td>
</tr>
<tr>
<td>Circulation:</td>
<td>centrifugal pump</td>
<td></td>
</tr>
<tr>
<td>Material:</td>
<td>MONICR</td>
<td></td>
</tr>
<tr>
<td>Total volume of salts:</td>
<td>approx. 30 liters</td>
<td></td>
</tr>
<tr>
<td>Operation pressure:</td>
<td>0.13 MPa</td>
<td></td>
</tr>
<tr>
<td>Operation temperature:</td>
<td>550 / 700 °C</td>
<td></td>
</tr>
<tr>
<td>Primary fluid temperature:</td>
<td>550 ÷ 700 °C</td>
<td></td>
</tr>
<tr>
<td>Pressure:</td>
<td>0.6 MPa</td>
<td></td>
</tr>
<tr>
<td>Primary flow rate:</td>
<td>about 2.5 - 5 kg/s</td>
<td></td>
</tr>
<tr>
<td>Channel „G“ fluid velocity:</td>
<td>about 1 - 2 m/s</td>
<td></td>
</tr>
<tr>
<td>Electrical in-put:</td>
<td>about 100 kW</td>
<td></td>
</tr>
</tbody>
</table>
7. PROPOSAL OF AN EXPERIMENTAL PROGRAM FOR ŠKODA ADETTE-2/3 FORCED CONVECTION LOOP

- Structural materials mechanical and thermal technical properties
- Mechanical, chemical and thermal technical properties of glass graphite
- Chemical, hydraulic and thermal technical properties of media
- Testing individual basic components
- Long-term testing of auxiliary systems
- Thermal - hydraulic measurements
- Measurements of the loop operational data
- Modelling of basic operational situations
- Operation characteristics

8. CONCLUSION

We attach importance to transmutation technology as the transmutation of long-life active nuclides to short-life active nuclides is obviously the only way to solution of fuel cycle end, i.e. the problem of spent fuel disposal. Waste problems solution of nuclear power increases its acceptation by inhabitants. Besides it, a new power source from burn-up nuclear fuel with significantly lower (and relatively short-term) waste quantity then in present reactor, are being created. From fuel used aspect, the accelerator driven transmutation of wastes (ATW) [3], appears to be of Czech republic interest, where commercial origin nuclear wastes and uranium enriched fuel and transuranides arisen from it are to be processed.

The objective of mentioned above ADTT experimental loops is to gain maximal technological experiences, mainly in fields as follow:
- technological salts thermo-technical properties
- verification of media used flow properties
- verification of circuit operation and technologic parameter check possibilities
- verification of basic loop operation, mainly to start inclusive heating, operational parameters changes (pressure, temperature), outage and shutdown without or with circuit drainage
- possible other experiments (insertin and withdraw of material samples to corrosion and chemical resistance tests, etc.
ŠKODA JS s.r.o. as nuclear equipment manufacturer has professional interests in development of some loop and further plant components of ADTT systems (e.g. blanket, pumps, heat exchangers, steam generators, pipeline etc.).

9. REFERENCES

