DEVELOPMENT OF STEAM-WATER CYCLE CHEMISTRY FOR STEAM GENERATOR OF RESEARCH REACTOR MBIR

Yurmanov V.A.[1], Shutko K.I.[1], Yurmanov E.V.[1], Nikel O.A.[1]

[1]JSC “NIKIET”, Moscow, Russia

E-mail contact of main author: yurmanov@nikiet.ru

Abstract. The compatibility of water chemistry with structural materials of steam-water cycle is most important condition for long-term operational reliability of steam generators (SGs). The reverse type steam generators (RSGs) were selected for the multipurpose fast research reactor MBIR under development in Russia by NIIAR and NIKIET. The main design feature of RSG is sodium coolant circulation within the tube bundle while the steam-water medium is going through the shell side. The design of RSG should ensure their reliable and safe operation during 200 thousand hours of service life. The above RSGs will provide both heat removal from the secondary sodium coolant loop to steam-water environment of the third coolant circuit and the generation of superheated steam for steam turbine. Neutral water chemistry was proposed for RSGs of MBIR reactor due to a number of advantages over alternative options, in particularly it will reduce the capital and operating costs, improve environmental performance and ensure high reliability and design life of RSGs.

Key Words: steam generator, heat exchanger tube, water chemistry, corrosion damages.

1. Introduction

The compatibility of water chemistry with structural materials of steam-water cycle is most important condition for long-term operational reliability of steam generators at nuclear power plants. Limiting service life factor of the steam generators is usually corrosion damages of heat exchanger tubes (HET) from the steam-water side. In view of this the mostly proven in practice reference design and engineering solutions were used to ensure efficient, reliable and safe operation of the multipurpose fast nuclear research reactor (NRR) MBIR under development in Russia by NIIAR as an operator and NIKIET as a chief designer [1-2].

Recently the reverse type steam generators (RSG) for MBIR were developed by JSC "TASMO" and the Czech company ENERGOVÝZKUMO. The main design feature of RSGs is sodium coolant circulation within the tube bundle while the steam-water medium is going through the shell side. The failure of RSGs does not lead to an extended shutdown of NRR. The design of these RSGs should ensure their reliable and safe operation during service life of 200 thousand hours. The above RSGs will provide both heat removal from the secondary sodium coolant loop to steam-water environment of the third coolant circuit and the generation of superheated steam for steam turbine.

2. Design Features of the Reverse Type Steam Generators for Nuclear Research Reactor MBIR

Each of the two circulation loops of third cycle includes a propulsive RSG, consisting of three parallel-arranged heat exchanger modules with a capacity of 24 MW (figure 1). Table I presents the characteristics of RSG.

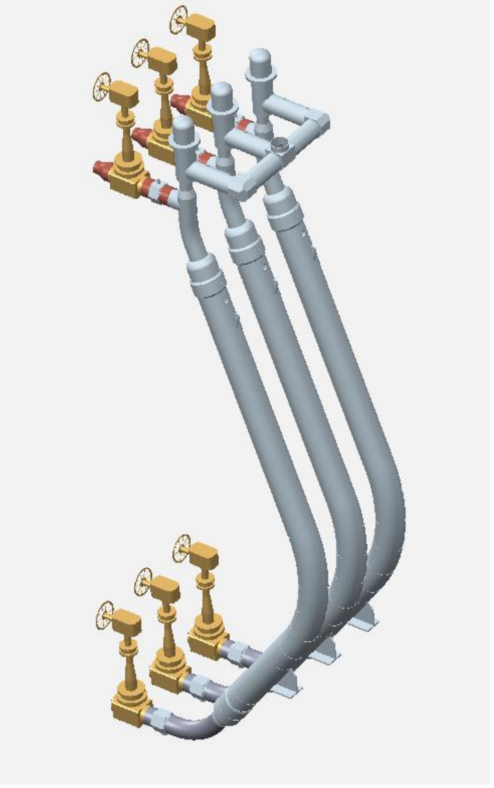

FIG. 1. The design of RSG

TABLE I: THE MAIN CHARACTERISTICS OF RSG OF MBIR NRR

Parameter	Value
RSG thermal power, MW	72
RSG module thermal power, MW	24
Flow rate of the secondary loop coolant, kg/sec	310
Flow rate of the sodium coolant in the module, kg/sec	103,3
The secondary loop coolant temperature, ºC: - at the entrance to the RSG - at the output from RSG	479 298
Pressure of the secondary loop coolant, MPa	0,76
Flow rate of the third loop coolant, kg/sec	30,1
The third loop coolant temperature (enabled / disabled high pressure heater), ºC: - at the entrance to the RSG - at the output from RSG	210 / 190 471 / 460
Pressure of the third loop coolant, MPa: - at the entrance to the RSG - at the output from RSG	9,5±0,2 8,8±0,2
Flow rate of the steam at the output from RSG, kg/sec	30,1
Flow rate of the steam at the output from the RSG module, kg/sec	10,03
Service life of the RSG, h	200 000
Coefficient of MBIR power rate usage	0,65

3. Operational Experience of Prototype Steam Generators in Nuclear Research Reactor BOR-60

The currently operated RSG-2 at NRR BOR-60 was selected as a reference analogue to RSG MBIR with a lifetime of 50 years. High reliability of RSG-2 was confirmed by ~150 thousand hours the trouble-free operation since 1991. RSG-2 of BOR-60 is characterized by safety, simplicity during operation, the best efficiency and minimal specific metal consumption as compared to other SG types (Table II).

TABLE II: SPECIFIC METAL CONSUMPTION (ton/MW) OF DIFFERENT DESIGN SG OPERATED IN NRR BOR-60

SG Hull coil	SG-1 Micromodular	SG-2 PGN-200M (BN-600)	RSG-1 Micromodular	RSG-2 Modular
0,51	0,7	1,2	1,0	0,33

Low specific metal consumption of RSG is achieved through the use of spacer devices and intensifiers in heat exchanger design. This design improvement eliminates the formation of sluggish circulation zones, the possibility of sediment accumulation, the risk of undersludge corrosion and prevents interloop small leak development into a big one. The rate of destruction of HET from ferrite steel 10Cr2Mo with an internal diameter of 16 mm opposite the location of the leak in RSG two orders of magnitude lower than that of the traditional SG.

The proportion of hydrogen effluent into the gas cavity of the buffer tank in RSG is close to 80-100%, which reduces the time of leak detection and helps to use cheap and simple water leakage analyzers by the hydrogen flow measurement into gas cavity.

A design feature of the RSG is the circulation of the sodium in the tube bundle and the flow of steam fluid through the annular space. Sodium is located within the case of the traditional SG design of domestic and foreign nuclear power plants, while water and steam are going through the tube bundle. HET operation in RSG is exposed to external overpressure of steam-water environment in the 40-90 times higher the pressure of sodium inside the one. It prevents the development of cracks and other defects on the outer surface of HET. Water or steam leaks react with a large amount of sodium during interloop leakage. In view of this the leakage flow is growing due to the corrosion damage of this tube. The torch of chemically active products of the interaction between water and sodium destroys adjacent tubes of the tube bundle. The above scenario increases the risk of an accident consequence. In contrast, in RSG flow cross-section of the HET with a stream of sodium is much less space between HET therefore the appearance of small leaks in a damaged HET leads to displacement of sodium from the corrupted HET in total cross section with localization of the products of sodium interaction with the steam and water environment.

30 years of NRR BOR-60 experience has proven compatible with neutral water chemistry of 12CrMoV and 10Cr2Mo steel grades used for the manufacture of RSG and the water-steam circuit.

4. Structural Steels of Steam Generators in Nuclear Research Reactor MBIR

The structural steels adopted for the manufacture of RSG at NRR MBIR are presented in table III, including 10Cr2Mo and its improved modifications such as 10Cr2Mo-VD and 10Cr2Mo1VNb with additional alloying by niobium and vanadium.

TABLE III: BASIC CONSTRUCTION MATERIALS OF RSG IN NRR MBIR

Name	Material brand
RSG body	12CrMoV
Inner shell superheater/economizer	08Cr18Ni10Ti
Connections inlet/outlet sodium, the input/output chamber, tube sheets	10Cr2Mo1VNb
The transitions of the casing module, the casing module, knee evaporator process areas, the pipes of feed water and superheated steam	12Cr1MoV and 15Cr1MoV
The heat exchange tubes of the module	10Cr2Mo-VD
The central tube of the module, inner shell of the module, the intensifiers	08Cr18Ni10Ti

According to the cut research from SG HET their corrosion damage develops from the steam-water environment, therefore, the main task of water-chemistry regime is maintaining its low corrosion activity, which is achieved by forming on the surfaces of the protective oxide films and reduce the content of corrosive impurities in steam-water environment (copper, chloride ion, sulfate ion, etc.). The stress corrosion cracking under tension is not typical damage mechanism of HET made from ferrite-pearlite steel grade 10Cr2Mo in comparison to steam generator tubing made from austenite steels and nickel alloys at PWR and VVER nuclear power plants. The main mechanism of local corrosion damaged of steam generator HET made from ferrite-pearlite steels at nuclear power plants with sodium cooled fast reactor is pitting induced mainly chloride ions present in feed water. Their main source in the secondary system water are raw cooling water input through a damaged packing of turbine condenser tubing. That is why very stringent requirements are used for density of turbine condenser during the choice of a turbine.

5. Chemical Control Specification for Feed Water of RSGs During NRR MBIR Operation

The intensity of HET corrosion is enhanced by the porous layer of iron oxide deposits where the chloride ions and other impurities are concentrated. Therefore the thickness of the deposits on the secondary side surfaces of the HET of steam generator is limited by maximal permissible value of 0.05 mm. In this regard, the iron content should be reduced in RSG feed water during NRR MBIR operation according to chemical control specification in Table IV.

The investigations of HET cuts made from 10Cr2Mo steel after long term operation of steam generators at nuclear power plant with fast sodium cooled reactor BN-600 has shown that the corrosion pitting are localized in zones of copper deposits. In view of this the elimination of copper alloy components decreases the damage of the steam generators. That is why the use of copper alloys was prohibited for the manufacture of heat exchange equipment at NRR MBIR.

The main goal of water chemistry is the formation of the protective oxide films on HET surfaces which provides their low corrosion rate. Pitting corrosion of HET could be under control thanks to limitation of corrosion-active impurities in the steam-water environment, including copper, chloride ion, sulfate ion, etc.

TABLE IV: THE PROPOSED CHEMICAL CONTROL SPECIFICATION FOR FEED WATER OF RSG DURING NRR MBIR OPERATION

Control chemical indicators		
Chemical quality indicators	Ranges of normal operation	Temporarily admissible deviations
Specific conductivity, µS/cm	0,2, not more	0,5, not more
pH value	6,5-7,5	6,0-6,5; 7,5-8,5
Dissolved oxygen, mg/dm^3	0,1, not more	0,5, not more
Diagnostic indicators		
Quality indicators	Expected levels	
Total iron, µg/dm^3	3, not more	
Total hardness, mg-eq/dm^3	0,3, not more	
Total silica, µg/dm^3	10, not more	
Sodium, µg/dm^3	1, not more	
Chlorides, mg/dm^3	1, not more	
Total organic carbon, mg/dm^3	0,1, not more	

Neutral water chemistry was proposed for the RSG of MBIR NRR based on comparative analysis due to a number of advantages over alternative options:

- Simple chemistry control and monitoring due to absence of any chemical reagent dosing into feed water

- Reduction of capital costs and the amount of waste due to absence of dosing system

- The absence of hydrazine and ammonia dosing eliminates both toxicological hazards for personnel and ballast exchange capacity of ion exchangers in condensate polisher system

- Elimination of deposits from RSG surfaces during operational transients.

Thus the proposed neutral chemistry mode for steam-water cycle of NRR MBIR will reduce the capital and operating costs, improve environmental performance and ensure high reliability and design life of RSGs.

Conclusion

Neutral water chemistry was proposed for the RSG of MBIR NRR based on comparative analysis due to a number of advantages over alternative options, in particularly it will reduce the capital and operating costs, improve environmental performance and ensure high reliability and design life of RSGs.

References

[1] TRETYAKOV, I.T., et al., “MBIR, a reactor facility for validation of innovative designs”, III International Scientific and Technical Conference “INNOVATIVE DESIGN AND TECHNOLOGIES OF NUCLEAR POWER”, October 7-10, 2014, Moscow, JSC “NIKIET”, Book of abstracts, JSC “NIKIET” publ. (2014) 49-50.

[2] TUZOV, A.A., ZVIR, A.I, DRAGUNOV, Y.G., et al., “Development of research nuclear facility with MBIR multi-purpose fast neutron research reactor”, IV International Scientific and Technical Conference “INNOVATIVE DESIGN AND TECHNOLOGIES

OF NUCLEAR POWER", September 27-30, 2016, Moscow, JSC "NIKIET", Collection of abstracts, JSC "NIKIET" publ. (2016) 62-64.