10.3 Investigation of corrosion damages of heat-exchanging tubes a steam generator pgv-1000 NPP of Ukraine

A steam generator (SG) PGV-1000 in a power-generating unit of a nuclear power plant (NPP) with pressurized water reactor (water-water energetic reactor (WWER)) is one of the most important and significant element of reactor safety. Cracks and further development of corrosion defects in heat-exchanging tubes (HET) in an SG may lead to depressurization of the primary coolant circuit of a reactor plant. The main reason behind HET damage is stressed corrosion cracking caused by a joint effect of tensile stress and concentrated solution of corrosion-active impurities formed owing to concentrating in sediments [489, 490].

To ensure the safe operation of steam generators (SG), heat-exchanging tubes (HET) are subjected to nondestructive testing. As a consequence, the tubes with defects impermissible for further operation are blanked off. As a certain number of blanked off HET is achieved, the SG is to be replaced. This is connected with economic losses and radiation exposure for NPP personnel [490].

The results based on the analysis of HET corrosive defects of the NPP SG with WWER at Ukrainian and foreign NPP are cited in papers [491-494]; it was determined that the corrosion defects on free areas and under spacing elements tend to appear mainly at a bottom of SG tube bundles (Fig. 1) [489].

Whereupon the defects on free areas localize mainly near hot header (HH). The defects under spacing grates are also situated at the SG bottom but distributed more evenly along with the tube bundle.

On the whole, the SG with HET active degradation is characterized by the formation of so-called “critical areas” where the defects are located. This is due to sedimentation of corrosion product of significant thickness up to complete blocking between tubes [489, 491]. The analysis of service data indicates that first systematic HET blank off done based on ECT results are carried out after accumulation on the HET surface of the significant sedimentation of corrosion products with specific contamination equal to 300-400 g/m^2 [489].

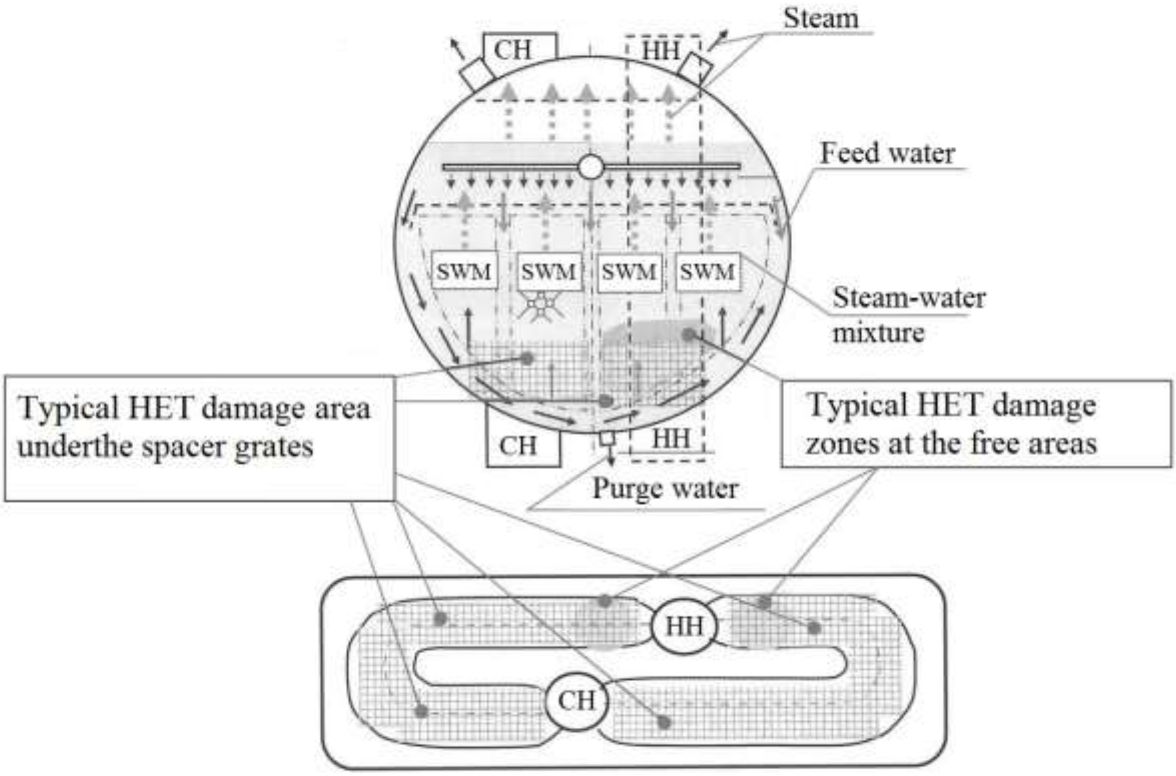

Fig. 1. The steam generator in cross section and plan

The scale formed by SG operation at power is mainly represented by finely dispersed particles (measuring no more than 10 μm) containing dehydrated oxides, notably the corrosion products of carbon steel and copper alloys which are used as a constructional material for a turbine condenser, tubing and condensing-feeding equipment (Fe_2O_3, Fe_3O_4, CuO, Cu_2O, *etc*.). Moreover, the scale often include slightly soluble salts (usually sulphates, silicates, calcium and magnesium hydrates) which infiltrate into condensing-feeding circuit owing to the leakage of cooling water through rolled-on condenser tubes.

The lower scale layers are of low porosity. The HET scale in SG mainly consists of iron oxide (>70%), copper oxide (is not more than 30%) and calcium, magnesium, silicon oxides (1 to 5% each).

The main mechanism of scale formation is the crystallization of corrosion products from evaporating boiler water, settling finely dispersed impurity particles under the impact of physical and physicochemical driving forces. While scales are forming, during water boiling, a porous continuous canal network grows through which water is fed to HET surface and generated steam is drawn aside.

Taking into account scale porosity and its significant heat conductivity (≈1.1 W/m^2·K) it is worth considering that water boiling inside scale occurs in the sheet of superheated liquid at a HET surface as well as on the surface and within scale. Replacing evaporated water new portions of water come to together with dissolved impurities come to HET surface from flow core. Since the solubility of impurities in steam is lower compared to water, impurities removal by steam does not compensate for their ingress with vaporizing water. So, the difference in concentrations between a boundary layer and flow core appears; as the consequence diffusion materializes directed to concentration leveling. At steady-state operation of the SG, the equilibrium condition appears when convective impurity transport is compensated by their steam removal and diffusion.

The study and analysis of eddy-current testing (ECT) HET SG and metallographic investigations of the HET SG were the topics of this paper. All the identified metal defects can be conditionally divided into four parts: the corrosion pitting of different size, the separate cracks, corrosion cracks and corrosion spots on separate metal areas. The representative examples of HET SG defects and the ECT results obtained by ECT systems “TEDDY-8”, “MIZ-30” and their comparison are demonstrated further.

Based on the results of the performed analyses, it was determined that corrosion pitting is the most frequent one to occur. The pitting corrosion is known as the most dangerous type of local corrosion. Corrosion pitting defects were conditionally distributed into critical and subcritical during the test performance. Critical defects are those which make a further HET operation dangerous. The tubes having such defects should be blanked off. From the standpoint of ECT, the critical corrosion pitting is characterized by a great percentage of metal loss (from 60 to 100%) at signal amplitude equal to 10…20 V (Fig. 2) [489]. Characteristic properties of these defects from the metallography standpoint are as follows. In all the analyzed cases these are large corrosion pitting which have round, oval or elongated longwise shape of the tubes. The defects have the dimensions in 2…4 mm range on the tube metal surface. The corrosion products sediments have the intricate shape in the form of coaxial circles positioned around a central hollow – a pitting core. In most cases the cracks are propagated from corrosion pitting predominately longways the tube surface; the cracks may be up to 20 mm long [489].

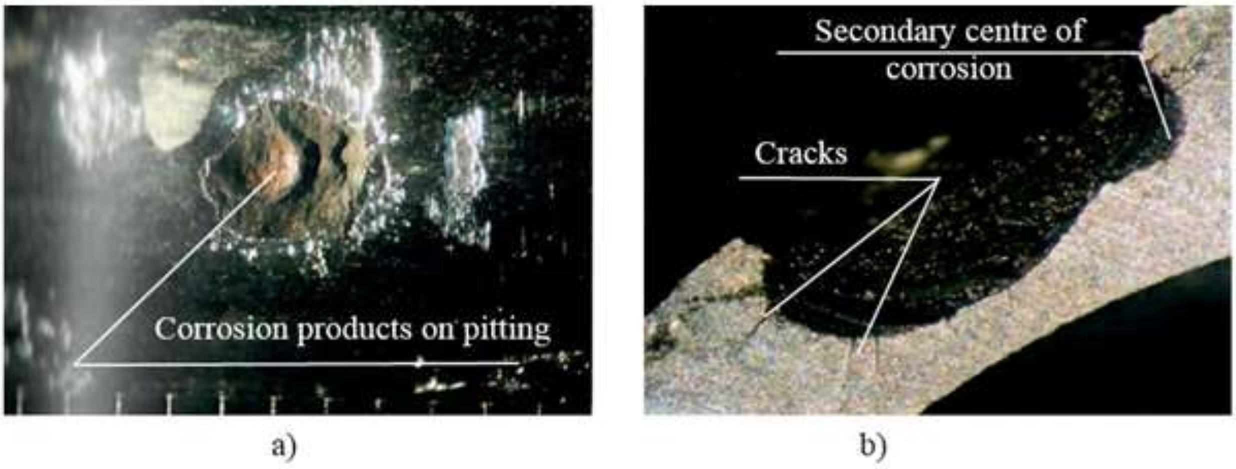

Fig. 2. Critical round shape corrosion pitting:

a) Defect appearance on the HET surface;

b) Defect appearance on the metallographic section

So, the course of corrosion processes on HET surface for various SG operational conditions is peculiar. These processes are not always inevitable and may be eliminated or minimized if we follow the below rules:

- avoidance of exceeding the limiting specific contamination at HET by limiting the corrosion product ingress into SG:
- exclusion of copper-bearing alloys from condensation-feeding equipment of NPP with WWER-1000 reaction plant;
- limitation of oxygen access to HET during SG life cycle, observing the conservation rules.

This paper discusses mechanisms of corrosion damage for heat-exchanging tubes (HET) of a PGV-1000 steam generator (SG), the effect of different SG operation conditions that influence the HET corrosion damages. The analysis and classification of the defects which form in SG HET was performed, as was the comparative analysis of eddy-current testing (ECT) which was formed by two various ECT “TEDDY-8” and “MIZ-30” systems (according to the signal amplitude and “metal loss”) and juxtaposed with metallographic analysis data. According to the ECT data, the peculiarities of current-carrying sediment on the SG HET within so-called “critical zone” where the defects localize were confirmed.