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DEVELOPMENT OF RUSSIAN ONCE-THROUGH HEAT-RECOVERY STEAM GENERATORS FOR CCPPS OF VARIOUS CAPACITIES

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The foreign experience of using once-through heat-recovery steam generators (HRSG) in CCPPs is presented. Russian developments of once-through HRSGs of various configurations based on modern gas turbines are considered. Design procedures for ensuring the reliability of the heating surfaces of high- and intermediate-pressure evaporators are developed. Technical requirements for the design of vertical and horizontal once-through HRSGs are formulated.

Keywords: heat-recovery steam generators (HRSG); once-through evaporator; Benson tube panels; reliability measures.

Currently, the development of thermal power engineering is associated with the combined-cycle power and heat generation technology, which allows saving fuel and investments.

The main objective in the development of combined-cycle power plants (CCPP) is maximum efficient use of the exhaust heat of the gas-turbine unit. Modern CCPPs must meet the efficiency, flexibility, and reliability requirements.

Russian CCPPs use drum-type heat-recovery steam generators (HRSG) with natural circulation if the boiler configuration is horizontal and with forced circulation if the configuration is vertical.

Such HRSGs were mainly developed under foreign licenses or delivered by foreign companies.

The modification of modern gas turbines to increase the gas temperature at the inlet to the HRSG allows increasing the pressure and temperature of the steam supplied to the steam turbine. The dispatcher's requirement of high flexibility of CCPPs and the prospect for increasing the steam conditions create opportunities for wider use of HRSGs with once-though high-pressure stage.

Once-through HRSGs are highly flexible owing to the absence of thick-walled elements (drums) in the steam-generating section, which, if present, require longer time to heat up, thus increasing the start-up time substantially.

Dozens of horizontal once-through HRSGs with Siemens vertical Benson tube panels have been successfully operated abroad. Many mainstream manufacturers were licensed by Siemens to manufacture Benson HRSGs.

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The key features and advantages of the once-through high-pressure stage are better dynamics, shorter start-up time, lighter weight, and lower cost of the HRSG and the high-pressure evaporator, lower water flow rate to the once-through evaporator (by the circulation rate of the drum-type boiler), simpler and smaller scope of maintenance due to no need for blow down of high-pressure (HP) drums.

These advantages become more pronounced with increase in the main steam pressure and the wall thickness of the HP drums of HRSGs with natural or forced circulation. Moreover, with increase in pressure, the solubility of salts in water tends to that in vapor and, therefore, the requirements to the quality of feedwater toughen, which deprives the drum circuit of its advantage in water treatment over the once-through circuit.

The mere fact that such sophisticated element as a drum is absent is an advantage, and faster start-up is advantageous as well.

As indicated above, the once-through high-pressure stage of foreign HRSGs includes vertical Benson tube panels instead of the circulating circuit (Fig. 1).

The water flow in these panels determines the configuration of HRSGs with horizontal gas pass: horizontal gas flow is past banks of vertical tubes suspended between the upper and lower headers.

Benson panels connected in parallel are arranged in series because of which they are nonuniformly heated by the exhaust gas from the gas turbine (Fig. 2). To balance the heating of the tubes, orifices of certain diameter were installed in each tube of the panels so that the flow gradually decreased from the upstream panels to the downstream ones.

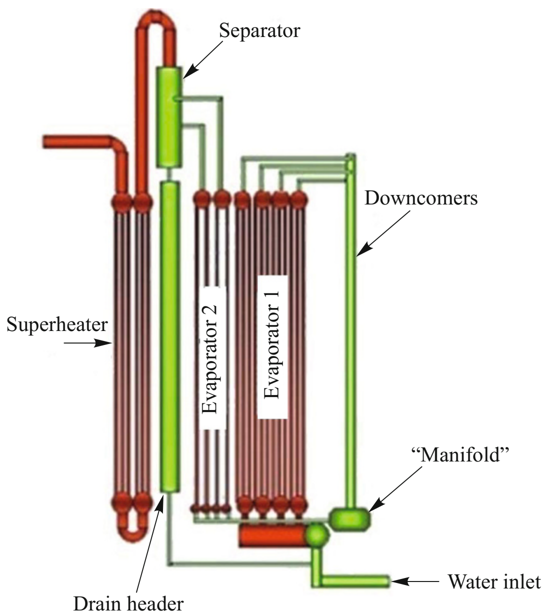

Fig. 1. Benson once-through stage of Siemens heat-recovery steam generator.

This is the major disadvantage of such panels because the resistance of the evaporator increases and the orifices must be carefully designed, especially for the downstream tubes, to prevent nonflow modes.

The intermediate-pressure (IP) and low-pressure (LP) stages of a Benson HRSG are of drum-type with natural circulation.

The use of a drum and natural circulation instead of once-through circuit in the IP stage is due to certain design features of vertical Benson evaporators (a mass flow rate sufficient for reliable operation cannot be achieved at low volume flow rates of the water).

The application of the once-through and drum-type steam-generation principles in the same HRSG creates difficulties to the operational personnel. A disadvantage of such an HRSG is the different chemistry requirements to the once-through HP and drum-type IP stages. In CCPPs with Benson HRSG, the concentration of ammonia is high (pH = = 9.8), whereas the concentration of oxygen is low (30 – 40 ppb) in the IP (drum-type stage) stage. In the HP (once-through) stage, the situation is opposite: 8.5 and 50 – 150 ppb, respectively.

The first developments of HP and IP once-through stages by the All-Russia Heat-Engineering Institute (VTI) were intended for vertical double-pressure HRSGs for 65 and 280 MW gas turbines.

The specifications of HRSGs for gas turbines of different capacities are presented below:

GTU 65 MW (double-pressure HRSGs)

Steam capacity of HRSG, tons/h	90/13
Pressure, MPa	14/1.4
Steam temperature, °C	535/200

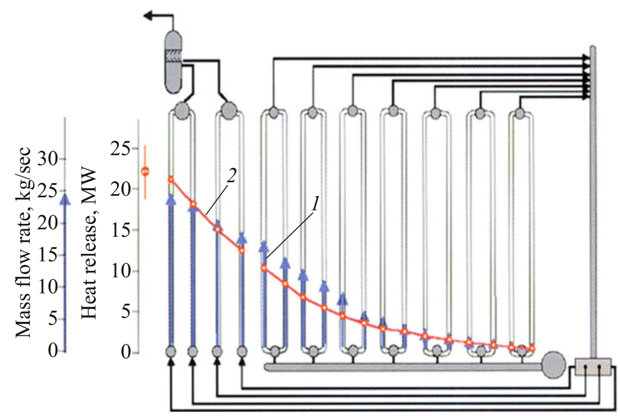

Fig. 2. Nonuniform heating in Benson panel.

GTU 280 MW (double-pressure HRSG with intermediate superheating)

Steam capacity of HRSG, tons/h	307/350
Pressure, MPa	13.0/3.1
Steam temperature, °C	565/560
Steam capacity of IM stage, tons/h	54
Steam pressure in IP stage, MPa	3.2
Superheat temperature in IP stage, °C	330

In designing once-through HRSGs with vertical gas pass (Fig. 3) for CCPPs, a primary task is to ensure the reliability of the heating surfaces. In once-through economizers and evaporators, the water flows downward, while the flue gas moves upward (counterflow). In these conditions, reliability is ensured by preventing substantial flow/temperature unbalance, which is due to the multivaluedness of the hydraulic characteristic curves, and by providing pulsation stability. For the low-pressure (LP) stage, it is necessary to take measures to reduce the corrosive and erosive wear of the tubes from the inside, which is due to the high velocity of the steam-water mixture at high mass steam quality.

Technical solutions and design procedures for ensuring the reliability of the heating surfaces of the once-through stages of vertical HRSGs and approaches to designing once-through LP evaporators and superheaters were developed.

The following work was done by the VTI in cooperation with EMAlliance. They designed a condensing combined-cycle power plant with a MHI M701F4 gas turbine of 301 MW capacity and a horizontal once-through triple-pressure HRSG with intermediate superheating to subcritical (281/51 tons/h, 13/4.8 MPa, 580/580°C) and supercritical (274/66 tons/h, 24/4.8 MPa, 580/580°C) steam conditions.

For the horizontal HRSG, the VTI proposed to use N-shaped coil-tube panels with lower distributing header and upper collecting header as a once-through stage of the evaporator (Fig. 4). Such a design prevents nonuniform heating (typical for vertical tubes connected in parallel) in the Benson evaporator of high pressure and allows making the IP stage once-through as well.

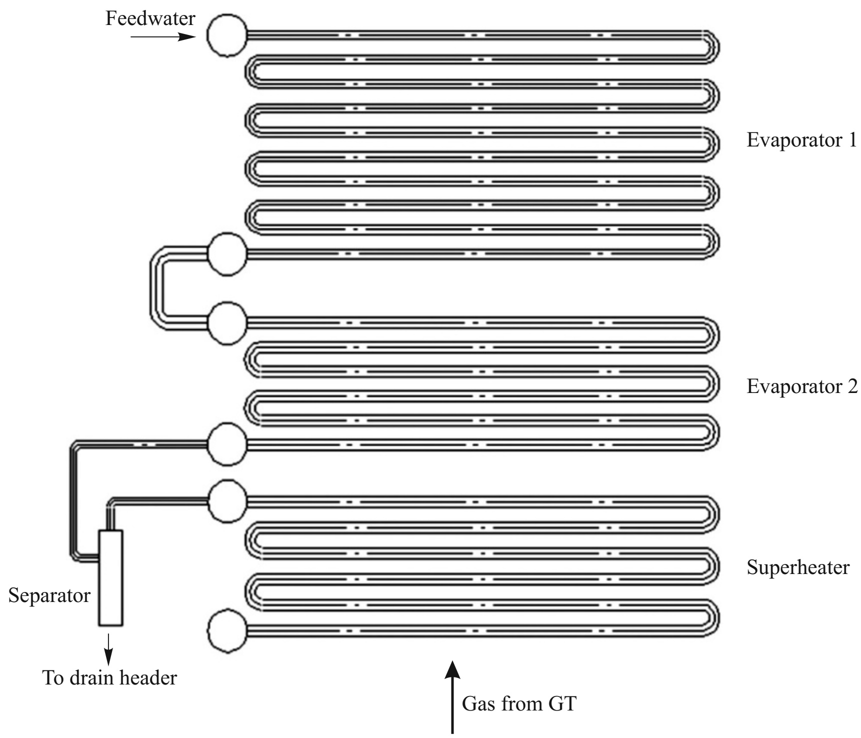

Fig. 3. Once-through downward-flow evaporator for vertical HRSG.

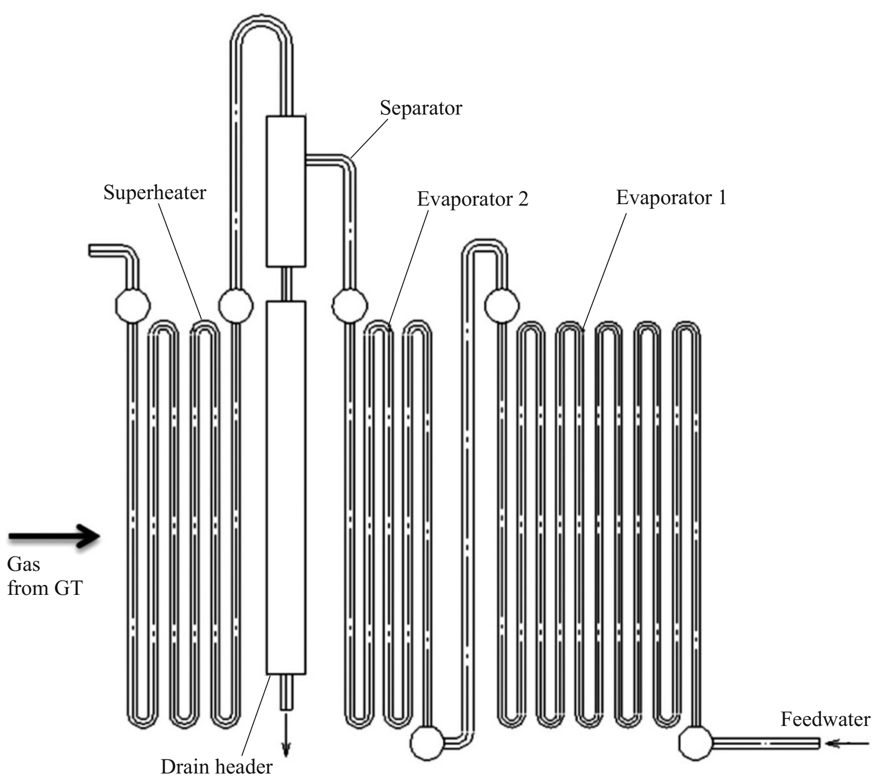

Fig. 4. Once-through evaporator with N-shaped tube coils for horizontal HRSG.

The LP drum is used as a deaerator. Thus, all the stages of the horizontal HRSG are once-through. The control range for this HRSG is from 30 to 100%.

As a result, the following requirements were imposed on the design of evaporators for horizontal once-through HRSGs:

— to prevent corrosive and erosive wear in the IP evaporator, the linear velocity at the coil outlet must be no higher than 10 m/sec;

— the superheater design is similar to the heating surfaces in drum-type HRSGs;

— the economizer and the IP and HP evaporators are made from N-shaped tube-coil panels with lower distributing header and upper collecting header;

— to ensure uniform distribution of water in the evaporator, the water at the economizer outlet must be underheated over the entire load range of the HRSG;

— conditions for uniform distribution of the steam-water mixture in the IP and HP stages of the evaporator must be provided;

— the place for installing the separator for the IP and HP stages must be selected so as to ensure the necessary turbine loading sequence during start-ups.

Vertical HRSGs with LP and HP once-through stages are used at foreign CHPPs of 5 to 50 MW capacity.

The production of vertical once-through HRSGs for high-power CCPPs is limited by the necessity of ensuring the reliability of the heating surfaces when the water flows downward, while the flue gas upward.

The largest and most significant development of such an HRSG was for 570 MW CCPP with SGT5 – 8000H gas turbine. Horizontal and vertical configurations were considered. These are triple-pressure HRSGs with intermediate superheating to steam conditions 369/399 tons/h, 17.0/3.7 MPa, 600/600°C in the once-through stages; the steam capacity of the IP stage is 48 tons/h; the load control range is from 100 to 25% of the gas turbine load.

The reliability of the heating surfaces of once-through HRSGs was assessed by analyzing:

— aperiodic stability (absence of flow unbalance, which is due to the mutlivaluedness of the hydraulic characteristic curves);

— periodic stability (intercoil pulsations of water flow rate);

— the velocity of steam-water mixture in the outlet bends of the IP stage must be no higher than 10 m/sec to reduce the corrosive and erosive wear of the heating surfaces.

The heating surface of the evaporators in horizontal and vertical HRSGs consists of two banks.

Design solutions for the once-through evaporator elements of a horizontal HRSG were chosen by dividing the evaporator into stages with heating surfaces formed by N-shaped coils with an odd number of passes. To ensure the hydrodynamic stability of a bank, it is necessary that the boiling point of the underheated water at the inlet to it be at the end of the odd pass of an N-shaped element over the entire load range.

The designs of the economizer and IP and HP superheaters are similar to the heating surfaces of drum-type HRSG.

For vertical HRSGs with downward water flow, the reliability of the heating surfaces should be tested not only for the evaporator, but also for the economizer.

For the LP economizer with downward flow and multivalued hydraulic characteristic curve, the appropriate choice of the mass flow rate at a rated load allows the operating point to be on the right branch of the characteristic curve in the stability region over the entire load range of the HRSG.

At the outlet from the first bank of both evaporators, conditions must be provided for uniform distribution of the steam-water mixture with a volumetric steam quality of no less than 0.9 to the next bank.

To prevent water ingress into the superheater, stable overheat must be provided at the evaporator outlet over the entire load range.

Of all the reliability measures (aperiodic stability, periodic stability (pulsation), and corrosion of bends of IP heating surfaces), only aperiodic stability is related to the configuration of once-through HRSG.

Developments performed by the VTI using standard design procedures indicate that the aperiodic stability of the evaporator and economizer heating surfaces in the entire load range of the gas turbine can easier be ensured for a vertical once-through HRSG with downward water flow. The resistance of an element depends on friction losses only, and the pressure head is insignificant (lower by an order of magnitude).

The bank height being small compared with the coil length, the hydraulic characteristic curves of the evaporator and economizer heating surfaces are single-valued.

The pressure head in a horizontal once-through HRSG is comparable to the friction loss at a rated load. As the load is reduced, the pressure head increases, while the friction loss decreases with decrease in the mass flow rate. Thus, the aperiodic stability of an N-shaped coil element is mainly determined by the pressure head at low loads. Because of this, the total resistance of the evaporator heating surfaces of a horizontal HRSG is much higher than that of a vertical HRSG.

This advantage of vertical once-through HRSGs is even better pronounced when comparing with foreign Benson HRSGs.

The VTI's design of HRSGs with IP and HP once-through stages appeared to provide better flexibility and performance than those of the drum-type triple-pressure HRSGs currently operating in Russia. The VTI has developed start-up sequences that include vertical and horizontal once-through HRSGs. They are much simpler than foreign developments, especially for horizontal once-through HRSGs.

Better flexibility allows doing without IP and HP drums, while easier operation introduces an additional controlled parameter (feedwater flow rate) for once-through sections, which allows maintaining the required overheat temperature of steam without desuperheaters and controlling the underheating of water at the economizer outlet without controllable bypasses.