Investigation of the saturated steam sampling method influence on the sample representativeness in chemical control systems at thermal power plants

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Abstract. The most important requirement for sampling is the sample representativeness, which is achieved by the design and location choice of sample nozzle, as well as the speed mode and the presence of sharp pressure drops in the saturated steam flow. The Ansys CFX software package simulates the sampling processes saturated steam in power units with low, medium and high pressure boilers which are used on operating thermal power plants. The saturated steam was sampled from low-pressure boiler by a single-strip probe with a Venturi nozzle, from the medium-pressure boiler was sampled by tapping a pipe at 90 to the main steam line, and the steam of the high – pressure boiler was sampled by a wellhead probe. In three sampling cases it is found that of saturated steam, the flow in the sample nozzle loses speed and decreases to values unacceptable for the selection of a representative sample-below tear rate of the moisture film from the surface. It is confirmed that in the industrial sampling conditions, the condition of speeds equality in the main steam line and in the sample nozzle is not met, which leads to a violation of the sample representativeness. The paper studies the change in the composition of the sampled saturated vapor sample after the film formation on the sample’s nozzle wall in relation to power units with ammonia dosing. It was found that the sample received by the chemical control analyzers is depleted due to the formation of a film and the ferrum and ammonia concentration in moisture droplets on the inner surface of the sampling line.

1. Introduction
One of the main requirements for power units is high power unit equipment reliability and the absence of the main and auxiliary elements equipment failure possibility. According to literature sources [1-4], the formation of deposits and damage to the heating surfaces by corrosion processes exert a negative impact on boiler and turbine function, therefore it is necessary to continuously monitor the quality of water and steam along the power unit path. Violations in the sampling process can lead to depleted samples that do not provide accurate information about the state of the water-chemical regime, so it is important to pay attention to sampling two-phase and single-phase media representative sample selection from single-phase homogeneous medium does not cause any difficulties. Therefore, this article considers a two-phase medium sampling. After analyzing a number of works [5-11], the following aspects were formulated that affect the selected saturated vapor representativeness: the type and location of the sample nozzle, the actual flow rate of the sample, a sharp change in the flow pressure along the probe cross-section, and the speed mode. Since the actual flow rate of the sample depends on the flow rate mode, and the pressure differences in the sample nozzle are minimal, this article considers two
aspects influence on the chosen saturated steam sample representativeness, namely: the type and location of the installation, the speed mode.

Currently, the main devices for sampling saturated steam are: slot, wellhead, single-strip with a mixer [5] and there are two ways to sample saturated steam: from the steam pipe mouth, where the moisture is distributed evenly across the cross section, or behind a specially built nozzle. The first method is implemented in the probe, called the wellhead, the second is implemented in various types of probes with mixers.

As noted above, one of the main conditions for proper sampling is sampled flow equality rate observation in the pipeline and in the sample nozzle – isokinetic sample nozzle. When sampling saturated steam, isokinetic sampling absence leads not only to a particles uniform distribution violation of corrosion products along the flow cross-section, but also to the formation of a film on the steam pipe surface, which, in turn, in accordance with the distribution coefficient, affects the selected sample composition. For example, the more hydrated the compound contained in the steam, the easier it is to pass into water, so when the film is formed, this compound will begin to pass into the water environment, and accordingly the sample will be sent to the automatic and laboratory chemical control analyzers depleted.

In order to maintain the equality of velocities in the main stream and in the saturated steam sample nozzle, a significant amount of steam must be sampled when sampling with a slit probe, which is not realized during operation. As a rule, during the operation of the chemical control system, the sample flow rate is lower than the value that provides speeds equality condition in the main steam line and in the sample nozzle, therefore, there is a decrease in the representativeness of the sample [9]. Such a phenomenon is easier to prevent if the sampling is carried out with a single-strip probe with a mixing device or a mouth probe. Further, the change in the flow rate of the medium in the sample nozzle during the sampling of saturated steam by various types of probes is investigated. The Ansys CFX software package simulates the processes of sampling saturated steam by wellhead, single-strip probes, and sampling by tapping the pipe at an angle of 90°. Table 1 shows the main simulation parameters and the thermal selected steam flow parameters.

| Sampling method                   | Thermal engineering parameters of the selected medium | Basic modeling parameters                                                      |
|----------------------------------|------------------------------------------------------|--------------------------------------------------------------------------------|
| Single-strip probe               | 0.32 MPa, 135 °C                                     | Hybrid Mesh: Combines a tetrahedral mesh with triangular prisms to resolve the boundary layer. |
| Wellhead probe                   | 15.2 MPa, 243 °C                                     | Cell element - no more than 0.00025 m                                         |
| Pipe insertion at 90°            | 3.94 MPa, 249.21 °C                                 | The Binding type is RootMeanSquare (RMS). The specified residual level is 0.00001 |
|                                  |                                                      | Turbulence model-K-Epsilon                                                   |
|                                  |                                                      | Boundary conditions: Input – flow rate; Output-relative pressure              |

Thus, the paper investigates three sampling methods saturated steam in relation to boilers of low, medium and high pressure. The single-strip probe selects the saturated steam flow in the low – pressure boiler, the wellhead-high-pressure, and the sampling without sample nozzle – medium pressure. Figure 1 shows the result of modeling the wellhead nozzle.
Figure 1. Velocity change during 15.2 MPa saturated steam sampling by the wellhead nozzle.

After analyzing Figure 1, it can be concluded that the design of the wellhead sample nozzle does not ensure the speed preservation. The steam flow after passing through the inlet opening of the wellhead nozzle undergoes a speed drop of more than 3 times. The steam flow undergoes a 3-fold decrease in speed relative to the initial one.

Next, we consider the saturated steam sampling with a pressure of 0.32 MPa using a single-strip probe. The steam velocity in the inlet is 57.9 m/s. The speed distribution over the length of the sample nozzle is shown in Figure 2.

Figure 2 shows that the flow has 57.9 m/s only at the sampling time and turning by 90°, where the selected medium accelerates. The further speed drop is 15 m/s for the first 20 cm of the sampling line (calculated data of the Ansys software package), which contradicts the conditions of isokinetic sample nozzle.

The saturated steam sampling by tapping a pipe at 90° is considered in relation to the MPEI thermal power plant. The simulation result is shown in Figure 3.
Figure 3. Change in the rate of saturated steam extraction at the MPEI thermal power plant.

It is obvious that the speed of the sampled flow in the sampling line decreases significantly compared to the main flow, which significantly affects sample the representativeness, since the process of droplet formation occurs – the impurities concentration. The flow rate at exit 2 is 6.23 m/s, which is seven times slower than the original one.

To confirm the film formation with a drop in velocity and a change in the sample composition, we consider the graph dependence of the critical moisture film tear rate on the pressure. Based on the guidance document content [7], it follows that at a speed lower than the moisture film tear rate, moisture droplets will form on the pipe walls. Figure 4 shows a graph of the moisture film breakdown from the pressure.

Figure 4. Graph of the critical rate of moisture film breakage as a function of pressure [7].

The analysis of this dependence shows moisture film formation on the sample’s nozzle inner surface. The condition for selecting a representative saturated steam sample is not met in the absence of ensuring moisture film tear rate. Table 2 shows the results of the analysis of the three sampling cases.

Table 2. Results of the study of three selection methods.

| Sampling method              | Steam pressure, MPa | Moisture film tear rate, m/s | Moisture film tear rate, m/s | Film formation on the nozzle surface |
|------------------------------|----------------------|------------------------------|------------------------------|-------------------------------------|
| Single-strip nozzle          | 0.32                 | 12                           | 6                            | Yes                                 |
| Wellhead nozzle              | 15.2                 | 90                           | 3                            | Yes                                 |
| Pipe insertion at 90°        | 3.94                 | 40                           | 2                            | Yes                                 |
From the analysis of the data in table 2, it follows that in three cases saturated steam sampling, the flow in the sample nozzle loses speed and decreases to values unacceptable for the selection of a representative sample-below moisture film tear rate from the surface. Thus, in the industrial sampling conditions, the condition of speeds equality in the main steam line and in the sample nozzle is not met, which leads to a violation of the sample representativeness. It should be noted that the flow of the sampled sample from the sample nozzle undergoes a sharp decrease in speed, which leads to an uneven suspended particles distribution throughout the steam flow, so in stagnant (dead-end) zones, the corrosion products deposition occurs.

Let us consider the ammonia and ferrum examples present in the saturated steam composition in relation to power units with ammonia dosing, how the composition of the selected sample will change after the formation of a film on the wall of the sample nozzle. For example, a saturated steam entered a sample nozzle with a temperature of 150°C, where a drop formation occurred due to a decrease in the speed. The chemical composition of the film will be calculated relative to the impurity distribution coefficient.

\[
C_{\text{impurity}}^{\text{film}} = \frac{1}{K_p} \cdot C_{\text{impurity}}^{\text{steam}}
\]

where \(C_{\text{impurity}}^{\text{film}}\) – impurity concentration in steam, mol/l; \(K_p\) – impurity distribution coefficient; \(C_{\text{impurity}}^{\text{steam}}\) – impurity concentration in the selected steam, mol/l.

Table 3. Results of the calculation of the concentration of ammonia and ferrum in the film on the wall of the sample nozzle.

| The compound under study | \(K_p\) | \(C_{\text{impurity}}^{\text{steam}}, \text{mcg/l.}\) | \(C_{\text{impurity}}^{\text{film}}, \text{mcg/l.}\) |
|-------------------------|--------|-----------------|-----------------|
| Ammonia                 | 4.2    | 600             | 142.85          |
| Ferrum                  | 0.25   | 10              | 40              |

Based on the data in Table 3, it can be seen that the ammonia and ferrum content in the steam will significantly decrease relative to the initial flow, which will lead to unrepresentative data when measuring the ammonia and ferrum concentrations. Thus, saturated steam representation is significantly affected by the type and sample nozzle location used and the flow rate. It is necessary to minimize the speed differences in the sample nozzle, so that the flow rate over the entire cross-section of the probe is higher than the minimum speed of tearing the moisture film from the surface, then the droplet formation process will not occur. The study showed that the film formation leads to underestimated results of the chemical saturated steam analysis.

2. Conclusions:

- The process of sampling saturated steam using wellhead, single-strip nozzle and pipe tapping at 90°in the software package Ansys CFX is simulated. As a result of the sampling process saturated vapor simulation, it is proved that there is a change in the velocity along the probe cross-section, therefore, there is no isokinetic sampling.
- It was found that the greatest decrease in the sample rate during the sampling process occurs in the sample nozzle absence, and the smallest-when sampling with a single-strip sample nozzle.
- It was found that due to the drop in the speed as a result of sampling, the impurities concentration in the sample decreases, which leads to a depletion of the initial composition of the sample.
- It is established that the sample entering the chemical control analyzers is depleted due to the film formation and the ferrum concentration in moisture droplets on the inner surface of the sampling line.
Acknowledgments
The work was carried out within the framework of the project "Development of an intelligent system of chemical control and management of the water-chemical regime of a TPP power unit (on the example of the MPEI TPP)" of the National Research University "MPEI" for the implementation of the research programs "Energy", "Electronics, Radio Engineering and IT" and "Industry 4.0 Technologies for Industry and robotics" in 2020-2022»

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