Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Physicochemical Processes and Regularities of Interaction Between Geothermal Flows and Metals

G.V. Tomarov and A.A. Shipkov

Moscow Power Engineering Institute 14, Krasnokazarmennaya St., Moscow, 111250, Russia

E-mail: tomarov@geotherm.ru

Keywords: Erosion-corrosion, multi-component flow, dissolution, deposits, mass transfer, experimental research, physicochemical model, principles of criterion modeling, calculation model

ABSTRACT

Modern geothermal power plants are a complicated engineering-technical complex where thermalphysic technological processes are accompanied by erosive-corrosive interaction of geothermal multi-component flows with power equipment metal elements.

Reliability, economy and durability of power equipment depend to high extent on a type and intensity of metals erosion-corrosion.

Basing on complex experimental researches at geothermal power units of Mutnovsky reservoir (Kamchatka, Russia) and results of calculation-theoretical works main regularities of metals erosion-corrosion in multi-component geothermal environments were found out, erosive-corrosive stability of various metals was defined, recommendations on improvement of erosive-corrosive stability of geothermal power equipment were worked out.

1. INTRODUCTION

Last decades are characterized by the intensive development of power engineering in Russia (Povarov O., Tomarov G., 1995 and Povarov et al., 2000). Construction of Upper-Mutnovsky GeoPP for 12 MW (in Kamchatka) was completed in 1999 and Mutnovsky GeoPP of total capacity of 50 MW (two power units 25 MW each one) was commissioned in December, 2002.

The working fluid of geothermal power plants (GeoPP) and of thermal plants (GeoTPP) is geothermal fluid which is formed in the contact with rocks various in their chemical composition, accumulates in itself substances, corrosion-aggressive impurities and gases. Behavior of these impurities in two-phase multi-component flow is a main factor determining both process flowsheet and constructive decisions on the equipment and reliability, economy and resource of GeoPP elements (Povarov O.A., Tomarov G.V., 1997).

Creation and mastering of new technologies of electric power generation from geothermal multi-component fluid required solution of a number of scientific and technical tasks both at the design stage and at the stage of manufacturing geothermal power engineering fluid. To achieve these purposes it was necessary to work out the methodology of investigation of metal damaging and destruction processes in geothermal medium. In particular, one of the most important problems of contemporary geothermal power engineering is ensuring erosion-corrosion resistance of metals of GeoPP working section.

2. DAMAGING PROBLEMS AND CLASSIFICATION OF METAL DESTRUCTION KINDS IN GEOTHERMAL MULTICOMPONENT FLOWS

Quality, phase state and local physicochemical parameters of geothermal multi-component fluid determine the kind and intensity of the influence on the metal. Local values of impurity concentration, pH and electroconductivity in some places of the working section of steam preparation system can leap influencing local processes of corrosion and erosion. It is possible to distinguish relatively steam-water, humidity-steam, steam and condensate sections in steam preparation system of GeoPP (Figure 1).

Steam-water section (SWS) is characterized by the biggest extent of humidity and the biggest quantity of impurities in the medium. According to the data on the registered damages of the elements of power engineering equipment, these circumstances promote intensification of the processes of erosion-corrosion (EC) and stress-corrosion cracking (SCC). Metal destruction is especially actively manifested in boring casing, compensator, seats and coupling rods of the armature, lower part of direct sections and bends of pipelines are wearing. The process of drop-impingement erosion (DImE) is probable in the zones of direct impingement influence of flow (in particular, in the zone of interaction between vortexes of steam-water medium and inner case of noise-killer). Figure 1 shows the typical places of metal destruction of the equipment working in steam-water medium of GeoPP, i.e. at the high degree of steam humidity (y>20%).

Humidity-steam section located between well separator (if any) and unit one is remarkable for moderate degree of humidity and big extension of steampipes. Although total content of impurities is lower than in the steam-water section at the expense of moisture separation, their concentrations in the liquid (phase) layer contacting with metal remain as high as in SWS. This circumstance allows to state that steampipe of SWS is subjected to erosion-corrosion and corrosive pitting (CP) is possible in its lower part.

Steam section is less problematic from the point of view of corrosion-erosion. The probability of deposits formation is not high.

Condensate section exceeds all the previous sections by the total content of impurities and electric conductivity. In this connection the intensified manifestation of all kinds of metal destruction is possible here (including cavitation erosion - CavE) and deposits (Dep) formation is also possible in the zones of drastic change of thermodynamic parameters. Figure 1 shows the most probable places of manifestation of various kinds of metal destruction.

3. EROSION-CORROSION MECHANISMS IN ONE- AND TWO-PHASE MULTI-COMPONENT FLOWS

Interaction of geothermal flows with streamline surface of metal can come to be mainly by means of mass exchange, heat exchange and friction. The processes of mass exchange in the interface determine intensity of admission of corrosion-active reagents to metal surface and abstraction of corrosion products into flow which is a main hydrodynamic factor determining the rate of metal erosion-corrosion. Metal erosion-corrosion should be considered as interconnected processes: on the one hand, formation of protective oxidation layer (corrosion products) and deposits layer at metal surface, on the other hand, their dilution and bringing to the flow. Metal erosion-corrosion in circuits of geothermal power plants come to be in one-phase and two-phase flows. Figure 2,a gives the main differences in the mechanism of its passing.

It is possible to consider with the sufficient degree of precision that in the one-phase flow parameters determining the nature and intensity of corrosion factor (pH, electric conductivity æ, concentrations of oxygen, iron-containing compounds, alkalifying additions, corrosion-aggressive impurities etc.) inconsiderably change along the cross-section and along the channel. In other words, while modeling metal erosion-corrosion processes in one-phase geothermal medium it is quite acceptably to use averaged by flow values of parameters of water-chemical conditions (WCC).

In conditions of two-phase flow erosion-corrosion mechanism is determined by local values of physicochemical parameters and of characteristics of corrosion processes (pH, æ, content of corrosion-aggressive components etc.) and of mass exchange processes (Re_f, Re_s etc.) in liquid layer and wall two-phase interface.

As a result of interphase redistribution of gases and impurities local values of pH of liquid layer can significantly differ from the average value pH at the flow and methods of calculation of coefficient of mass transfer of corrosion-active impurities and corrosion products in one-phase geothermal flow can not be applied to liquid layer. Figure 2,a schematically shows protective oxidation layer of corrosion products and deposits at metal surface located in geothermal fluid. According to realized studies the structure and properties of these layers for one- and two-phase geothermal flows considerably differ from each other (Chapter 6).

Difficulties in creation of calculation model of erosion-corrosion in two-phase flows are caused by the complexity and multifactor status of the processes of electrochemical corrosion and mass transfer in two-phase interface, by the absence of representative experimental data on the regularities of erosion-corrosion course in geothermal one- and two-phase flows. Therefore, with the purposes of working out methods of forecasting and prevention of erosion-corrosion of the elements of power engineering equipment of GeoPP and studying metal erosion-corrosion processes in geothermal flows it was necessary to work out the methods and to carry out the complex of laboratory and full-scale studies which is described in more detail in section 5.

Authors proposed classification of metals deterioration mechanisms by controlling factor that also affects kinetics of deterioration process (Figure 2,b). Kinetic curves of chemical and electro-chemical corrosions (“A” and “B” correspondingly) are characterized by lasting initial periods (segments 0-1) of corrosion products protective layer formation (FeS_2, Fe_3O_4, etc.). Then at $\tau>\tau_{est}$ period of established corrosion intensity (metal mass loss) begins that is reflected by incline angle tangent:

$$\bar{S} = \frac{\Delta m}{\Omega \cdot \tau} = \frac{\overline{\Delta m}}{\tau} = tg\alpha \qquad (1)$$

where Δm - metal mass loss, Ω - metal surface space, $\overline{\Delta m}$ - specific metal mass loss (i.e. per space unit), τ – exposition time, α - incline angle at curve.

Occurrence of erosion factor caused by environment movement of direct mechanical effect (for example, drop-percussion erosion) leads to initial period (τ_{est}) decrease and increase of $tg\alpha$ in the zone $\tau>\tau_{est}$ (Figure 2,b). Curves located between “B” and “C” lines will correspond to erosion-corrosion mechanism realization. In multi-component geothermal flows with erosion-corrosion mechanism the superficial sediment formation process competes as a rule, decreasing metal mass loss intensity and affecting the structure of its surface layer (Figure 2,b).

Curve “D” corresponds to extreme case of erosion-corrosion when mechanical deterioration (chips) of corrosion products protective layer (as well as of sediments superficial layer) acts as an erosion factor. During drop-percussion erosion mechanical metal deterioration prevails; this is characterized by kinetic curve “E” (Figure 2,b). At Figure 2,b controlling factor and metals deterioration mechanism realization are conditionally shown.

The basis of physical-chemical model of elementary metals erosion-corrosion in geothermal flow is formed by electro-chemical corrosive processes of forming and dissolving corrosion products with further transfer of them into the flow as well as by processes of forming and carry-over of superficial sediments from metal surface. Intensity of dissolved corrosion products transfer from division border oxide-liquid phase into flow kernel is determined first of all by mass transfer coefficient value.

Mass transfer coefficient value depends upon a complex of flow parameters and characteristics: movement speed, liquid viscosity, channel geometry, streamline surface roughness, temperature etc and is determined by the formula:

$$K = \frac{Sh \cdot \mathrm{D}}{l} \qquad (2)$$

where D - coefficient of dissolved corrosion products diffusion, l – characteristic size.

Analytic determination of Sherwood number values Sh is complicated by multifactor character of processes occurring upon metal surface so empirical dependences are used which, in particular for one-phase water flow, allow presenting formula for determining mass transfer coefficient as:

$$K = \frac{D}{d} f\left(\mathrm{Re}_w, Sc\right) \qquad (3)$$

Principal difference of metals erosion-corrosion in two-phase geothermal flow from the case of one-phase water flow is the fact that metal interaction with wet-steam flow is done through liquid skin. Under these conditions non-dimensional complexes of Reynolds number for liquid skin floating Re_f, and steam flow Re_s, as well as of Schmidt number Sc (see table No 1) should be considered as main criteria of mass transfer. Mass transfer processes in liquid skin are determined by regime of its floating and peculiarities of interaction with two-phase border layer:

$$K = \frac{D}{\delta} f\left(\mathrm{Re}_f, \mathrm{Re}_s, Sc\right) \qquad (4)$$

Besides, mass transfer coefficient value may be essentially affected by peculiarities of inter-phase interaction, surface roughness, channel geometry etc.

Estimation of thickness of corrosion products layer formed upon metal surface is implemented considering tendencies reflecting physical-chemical metals erosion-corrosion processes in geothermal fluid. Thickness of oxide layer during metals erosive-corrosive deterioration in one-phase water flows is assumed as proportional to proportion D/K

$$\delta_{îõ} = f\left(\frac{D}{K}\right) \qquad (5)$$

Implemented experimental studies results analysis shows that corrosion products oxide layer thickness is affected by both density of this layer itself and characteristics of sediments superficial layer being upon its surface. Thus, general structure of formula for determining oxide layer thickness upon metal surface in geothermal flow may be presented as follows:

$$\delta_{ox} = \frac{D}{K} f\left(\rho_{me}, \rho_{ox}, \rho_{dep}, t\right) f\left(\mathrm{C_e}, t\right) \qquad (6)$$

where first multiplier determines effect of diffusion and convective corrosion products transfer, the second one – of density (porosity) of oxide layer and sediments superficial layer upon metal surface, and the third one – of dissolubility of oxide layer at given temperature.

4. METHODOLOGY OF PROCESSES INVESTIGATION AND WORKING OUT METHODS OF FORECASTING AND PREVENTION OF EROSION-CORROSION

Figure 3 shows the main stages of studies and working out calculation model and methods of forecasting and prevention of erosion-corrosion in geothermal media. This scheme has widely developed feedback which allows to increase the accuracy and adequacy of working out methodology. At the same time the majority of measures on making corrections is taken either at one stage or within the limits of adjacent stages, which decreases laboriousness of its creation optimizing measures on its working out.

Creation of physicochemical models of metal erosion-corrosion in geothermal flows is a major stage preceding mathematic modeling of this phenomenon. Adequacy and trustworthiness of such models depends on reliability and precision of data on the regularities of erosion and corrosion constituents behind them. Physicochemical models of erosion-corrosion, where either empirical calculation formulas (where various mechanisms of metal damages are not divided) or semiempirical correlations are behind them, are known at present. Empirical models can be applied only for the preliminary estimations of erosion-corrosion intensity as a result of their low accuracy and limitedness of adaptation (these models are frequently worked out in accordance with certain parameters of particular geothermal well). Besides that, failure to take account in the model of the factors whose influence in the given conditions is not big (but can turn out to be significant in other conditions), absence of taking account of mutual influence of parameters on each other decrease practical value of the proposed models and make impossible transfer of the obtained results to other objects and drawing correlation with the data known from the literature.

Absence of the adequate physicochemical model built-up basing on the principles of criterion modeling metal erosion-corrosion in geothermal media was a serious obstacle at the way of development of erosion-corrosion forecasting and prevention methods. Carrying out experimental studies of erosion-corrosion processes regularities in humid steam on the basis of criterion approach allows to construct physicochemical model of metal erosion-corrosion in geothermal media and to refine it according to the results of carried out studies and correlation of the obtained results.

Working out mathematic model of erosion-corrosion in two-phase flow is based on physicochemical conceptions of the regularities of this phenomenon and is connected with simplification of the real course of processes by means of establishing certain assumptions (Figure 3). The worked out mathematic model of metal erosion-corrosion in geothermal media and program complex created on its basis open up wide possibilities on the solution of applied tasks connected with forecasting, diagnostics and monitoring of erosion-corrosion in the working section of GeoPP, increase of erosion-corrosion resistance of metals, estimation and prolongation of operation life of power engineering equipment of power plants.

5. BASIC CRITERIA AND PRINCIPLES OF MODELING EROSION-CORROSION

While studying the phenomenon of metal erosion-corrosion in geothermal flows the theory of similarity and laws of modeling process gain in importance since otherwise correlation of the results of carried out experimental studies and their correct transfer to other objects will be impossible. First of all, this is the result of multifactor status of the process and big quantity of gasdynamic, thermodynamic, water-chemical and corrosion parameters determining erosion-corrosion processes. Experimental investigations of metal erosion-corrosion mechanism as a basis of construction of mathematic model of the phenomenon carried out on the basis of the principles of approximate criterion modeling increase considerably the accuracy of calculation models and applied programs carried out on their basis.

To describe metal erosion-corrosion processes in geothermal fluid, physical constants and non-dimensional complexes, determining erosion-corrosion processes in geothermal flows of working circuit of GeoPP, were singled out. Along with that, the extent of the influence of these parameters and criteria on the results of investigations varies significantly, besides that, it turns out that a number of parameters either directly or indirectly depends on each other. Thus, to correctly establish program of experimental investigations it is necessary to unambiguously determine possibilities and boundaries of erosion-corrosion modeling.

Metal erosion-corrosion in geothermal fluid is an aggregate of erosion and corrosion constituents and because of that criteria and parameters of erosion-corrosion are divided conventionally into two groups. Criteria of similarity of erosion and corrosion constituents are brought together in Table 1.

Thus, for example, Reynolds numbers characterize the ratio of inertial and viscous forces in the liquid layer (Re_f) and bearing steam phase (Re_s). The value of steam humidity extent determines the amount of liquid phase and ratio of phase densities determines correlation between speed head. Schmidt number (Sc) characterizes correlation between convective and diffusion transfer in liquid layer. Weber number determines the possibility of location of solid liquid layer at metal surface. The account of influence of channel geometry and of possibility of activation of mass transfer processes (for example, close to the local places of geometry change) is taken in practice by means of introduction of empirical coefficient. To take an adequate account of this effect in geothermal flows it is necessary to carry out additional studies of dependences connecting channel geometry with the degree of turbulence.

Criterion base of corrosion constituent of erosion-corrosion in geothermal flows should be formed from the parameters which the processes of deposits formation, their dilution and bringing out, formation and decomposition of protective layer at metal surface depend on. It is possible to distinguish properties of metal, geothermal medium and corrosion products as basic factors of the influence on corrosion constituent.

The basic criteria of corrosion constituent of erosion-corrosion are accepted according to Table 1. It is necessary to stress that in geothermal fluid of GeoPP comparing to two-phase flows of traditional power plants (Tomarov G.V., 2001 and Tomarov G.V., Shipkov A.A., 2002) the total mineralization of the medium is considerably higher, there are substances in gaseous state, i.e. the content of corrosion-aggressive components is quite high. Chemical composition of geothermal fluid depending on the field is characterized by the presence of several tens of various chemical elements and compounds in greatly varying combinations. At the same time, according to carried out investigations it was managed to isolate a few components influencing most notably corrosion processes and scales formation. For the reason of the high mineralization of geothermal fluid heat-carrier has heightened electric conductivity which leads to the intensification of electrochemical corrosion at metal surface.

Complexity of distinguishing basic parameters in the processes of interaction between geothermal flows and metals is explained also by the fact that in a number of cases there is mutual influence of criteria of erosion and corrosion constituents of erosion-corrosion. For example, ratio between phases densities ρ' / ρ'' influences both erosion constituent through number Re_s and corrosion constituent through the value of the coefficient of interphase distribution of substances. Temperature of geothermal fluid is of special interest. According to the results of the carried out investigations temperature influences behavior of both corrosion and erosion constituents of the process including number Re_s, steam density etc. and coefficient of interphase distribution, value of pH of the liquid phase etc.

Table 1: Parameters and dimensionless criteria of erosion and corrosion constituents in two-phase flows which have to be taken into account while studying erosion-corrosion processes in geothermal fluid.

Criteria of erosion constituent similarity	Criteria of corrosion constituent similarity
1. Reynolds number of liquid film flow, $Re_f = \frac{\delta_f \cdot W_f}{\nu'}$	1. Value of hydrogen index pH
2. Reynolds number of steam flow, $Re_s = \frac{d \cdot W_s}{\nu''}$	2. Temperature, t, ^0C
3. Steam humidity degree, y	3. Specific electric conductivity, æ, [μS/cm]
4. Ratio of phases densities, $\bar{\rho} = \frac{\rho''}{\rho'}$	4. Coefficient of interphase distribution, $\hat{E}_d = f(\rho' / \rho'')$
5. Schmidt number (for the liquid phase), $Sc = \frac{\nu'}{D}$	5. Content of Cr and Mo in metal, %
6. Sherwood number (for the liquid phase), $Sh = \frac{\hat{E} \cdot \delta_f}{D}$	6. Content of basic corrosion-aggressive components, O_2, Cl, H_2S, CO_2, NH_3
7. Weber number (continuity of liquid layer), $We_f = \frac{\rho'' \cdot (w_s)^2 \cdot \bar{\delta}_f}{\sigma}$	

The constants and similarity criteria of the approximate modeling defined above allow to ensure representative character and reliability of the investigations of erosion-corrosion in geothermal flows. The analysis of statistics of geothermal power units equipment damaging allowed to formulate basic tasks on carrying out experimental studies of regularities of metal erosion-corrosion of GeoPP power engineering equipment: study of the influence of temperature factor, modes of stream of steam flow and liquid layer on corrosion and erosion constituents of erosion-corrosion; studies of the influence of the value of pH of the liquid layer, content of corrosion-aggressive components on erosion-corrosion; determination of the role of chemical composition of steels in erosion-corrosion.

To reveal regularities of the influence of basic parameters and criteria on erosion-corrosion processes in geothermal media the special test-modules, methods were created, program was worked out and complex laboratory and full-scale experiments were carried out.

6. EXPERIMENTAL TEST-MODULE TO STUDY EROSION-CORROSION PROCESSES MONITORING

Problems of GeoPP operation are mainly caused by the impact of the fluid on metal and by influence of its quality upon the efficiency of the equipment operation. The most prevalent kind of metal damaging of the working section of GeoPP is erosion-corrosion which the elements of flow part of turbine, organs of steam distribution, well equipment, pipelines, armature etc. are prone to (J. Ikeuchi, 1982 and Povarov O.A., Tomarov G.V. et al., 2000). In spite of the urgency and importance, this problem is investigated just a little by now. This is conditioned by the complexity and multi-factor nature of metal erosion-corrosion process in conditions of geothermal fluid.

To estimate erosion-corrosion resistance of metals in multi-component geothermal flows of GeoPP the scheme of the experimental test bench with test-modules was worked out. Figure 4,a presents the appearance of this test bench of erosion-corrosion (EC) investigations. Real geothermal multi-component two-phase fluid (steam-water mixture - SWM y=67%) and one-phase (separate) fluid were used in full-scale tests.

Test-benches on the investigation of erosion-corrosion processes in geothermal fluid allow to model processes proceeding in bends of pipelines, case of armature, separators etc.; working medium is steam-water mixture and separate of dilator. Test-benches LGC are installed right after the cameras ECI (Figure 4,a). Horizontally located plates, which are situated at three levels, are installed there. Test-benches LGC allows to determine regularities of general and local corrosion of metals in geothermal medium depending on the humidity of the flow, corrosion processes proceeding in stagnant zones of the working section (working medium is SWM and separate) are modeled in these cameras.

Full-scale erosion-corrosion tests carried out on the basis of criterion modeling principles allowed to reveal basic regularities of behavior of construction steels in geothermal multi-component fluid and to work out the approaches to construction of calculation model of erosion-corrosion of this phenomenon.

7. SOME OF THE REGULARITIES OF INTERACTION BETWEEN METAL AND GEOTHERMAL MEDIUM

To reveal regularities of behavior of construction steels in geothermal fluid the full-scale experiments were carried out in Upper-Mutnovsky GeoPP according to the scheme described in Section 5. Such erosion-corrosion tests in real geothermal working media considerably heighten representative character and reliability of the obtained results and allow to adapt calculation models of erosion-corrosion to the power engineering object under consideration. Besides that, the worked out principles of criterion modeling, on whose basis large-scale program of experimental investigations was carried out, allowed to estimate adequacy and to draw correlation of the data according to the results of tests. Geothermal multi-component fluid (steamwater mixture y=67%) was used in the full-scale tests.

Using developed test-modules and principles of erosion-corrosion modeling, experimental studies were implemented at Verkhne-Mutnovsky GeoPP (experiments were conducted with participation of Semenyuk A.V., Retivov M.K., Povarov K.O.).

As overwhelming majority of GeoPPs use steam-water mixture, acquired dependences of various metals erosion-corrosion intensity from geothermal fluid humidity extent at Verkhne-Mutnovsky GeoPP may be considered an important result of experimental studies (Figure 4,b). Chemical composition of real geothermal fluid during experiments is presented in Table 2.

Character of acquired curves reflects the change of liquid skin floating upon metal surface regime; this coordinates well with results of similar studies in conditions of NPP and HPP (Mikhailov V.A., Tomarov G.V. et al., 1987 and Tomarov G.V., 2001). All experimental curves for EC-samples, in the range of considered parameters may be described with sufficient accuracy by following analytic expression:

$$\Delta m / \Omega = \alpha + \beta \bar{y}^{1.5} + \gamma \exp(\bar{y}) \qquad (7)$$

where $\bar{y}$ - extent of geothermal environment humidity $\bar{y} \in [0, 1]$, α, β, γ [μg/cm^2] – numerical coefficients depending upon temperature, flow hydro-dynamics, steel type and some other parameters.

Location of curve at Figure 4,b is mostly determined by extent of hydrodynamic effect on the part of geothermal multi-component flow and erosive-corrosive metal stability. Thus, curve No 2 is lower than curve No 1 as in the last case steam flow Reynolds number values Re_s are lower and vortical flow effect after inlet sharp edge is absent (see Figure 4,a). Steels alloyage by chromium and molybdenum also leads to decrease of mass loss intensity (see curves No 3 (30XMA) and No 4 (08X18H9T). At low environment movement speeds, which take place in test-modules LOK, mass loss intensity is low (see curve No 5 (08X18H9T)).

Results of studying change of erosive-corrosive stability of metals containing different amounts of alloying elements (first of all chromium and molybdenum) are presented at Figure 5. With formation of protective layer upon metals surface which contains corrosion products and superficial sediments, essential decrease of metals mass loss takes place (it should be taken into account at the same time that upon initial metals surface corrosion products and sediments were absent). Not such a big difference is noted (as this takes place at NPP and HPP) in deterioration intensity of carbonaceous (St.20) and highly alloyed (08X18H9T) steels; this may be explained by superficial sediments formation processes.

At Figure 6 experimental data on effect of Reynolds number values for steam Re_s and separate Re_w, i.e. of hydrodynamic factor upon erosion-corrosion intensity for various metals, are presented. It was stated that erosive-corrosive sensibility of steels towards change of Reynolds number increases with decrease of per cent contents of chromium and molybdenum in them as well as with transition from steam-water mixture to separate.

Figure 7 shows the results of the experiments carried out in camera of local and general corrosion (LGC) at the samples manufactured from St. 20, located in steamwater mixture and separate of geothermal steam with characteristic stand-up of 1766 hours.

Samples were installed in camera LGC by three storeys along the height of the cross-section, therefore, geothermal media humidity degree was the biggest in the lower storey. Location of the samples in separate of geothermal steam led to the formation of considerable deposit layer at their surface. Peculiarities of districution of impurities in two-phase geothermal steam between steam and liquid its phases determine the bigger mass of deposits at the samples, located in separate, comparing to steam-water mixture more than twice. The values of deposits and erosion-corrosion wearing of metal samples, located in geothermal media during 72 hours, demonstrate results although not dropping from the general tendency, but by absolute values having insignificant deviations from them.

This fact is conditioned by relatively small time of stand-up of the samples in geothermal fluid. One can expect that further the tendencies, which will correspond to the obtained results, will be determined by dot line shown by Figure 7.

The values of the speed of erosion-corrosion of samples of carbonaceous steel (Figure 7), measured by the results of full-scale tests, completely confirm the assumption about the fact that erratic deposits in multi-component geothermal working fluid play the role commensurable with oxides and sulfides formed at material surface as a result of corrosion processes and playing protective role in relation to erosion-corrosion of metals (Povarov O.A., Tomarov G.V. et al., 2000 and Thomas D.M. et al., 1989). Big specific mass of deposits at metal surface (for example, in the lower storey of the camera LGC) corresponds to minimum values of erosion-corrosion wearing of samples and vice versa.

CONCLUSION

Classification of metal destruction mechanisms under the influence of geothermal multi-component media. It was ascertained that erosion-corrosion is a most wide-spread and complicated kind of destruction of the elements of GeoPP and GeoTPP.

The basic physicochemical peculiarities and criteria of modeling erosion-corrosion in two-phase multi-component flows were determined.

The experimental test-module was created and data on the regularities of erosion-corrosion in full-scale conditions of operation of GeoPP were obtained.

REFERENCES

Povarov O., Tomarov G. Geothermal power plants for electricity generation and heating purposes from Russia // World Geothermal Congress: Proc. WGC, 18-31 May, 1995. – Florence, Italy, 1995. – P. 2115-2119.

Povarov O.A. Geothermal power engineering in Russia – today // Proceedings World Geothermal Congress 2000. May 28-June 10. Japan. 2000.

Povarov O.A., Tomarov G.V. Physical-technical problems of geothermal energy // Izvestiya RAN. Energy. – 1997 – No 4. – P. 3-17 (in Russian)

Corrosion and erosion-corrosion of iron based alloys in a geothermal resource area (Onikobe) in Japan / J. Ikeuchi, N. Sanada, O. Asano et al. // Geoth. Energy: Proc. of the Int. conf. 11-14 May, 1982. – Florence, Italy, 1982. – P. 383-394.

Povarov O.A., Tomarov G.V., Semenov V.N. Physical and chemical processes of geothermal fluid impact on metal of geothermal power plant equipment // Proceedings World Geothermal Congress 2000. May 28-June10. Japan.2000.

Mikhailov V.A., Tomarov G.V., Shalobasov I.A. Metals deterioration at high-speed flow of wet steam and water effect // Power engineering industry. – 1987. – No 12. – P.11-14 (in Russian).

Thomas D.M., Gudmundson J.S. Advances in the study of solids deposition in geothermal systems//Geothermics. – 1989. – № 7. – P. 33-38.

Tomarov G.V. Physical-chemical processes and regularities of metal erosion-corrosion of power equipment in two-phase flow // Teploenergetika. 2001. No 9. P. 59-67 (in Russian)

Tomarov G.V., Shipkov A.A. Modeling of physical-chemical processes of metals erosion-corrosion in two-phase flows // Teploenergetika. 2002. N0 7. P. 7-17 (in Russian)

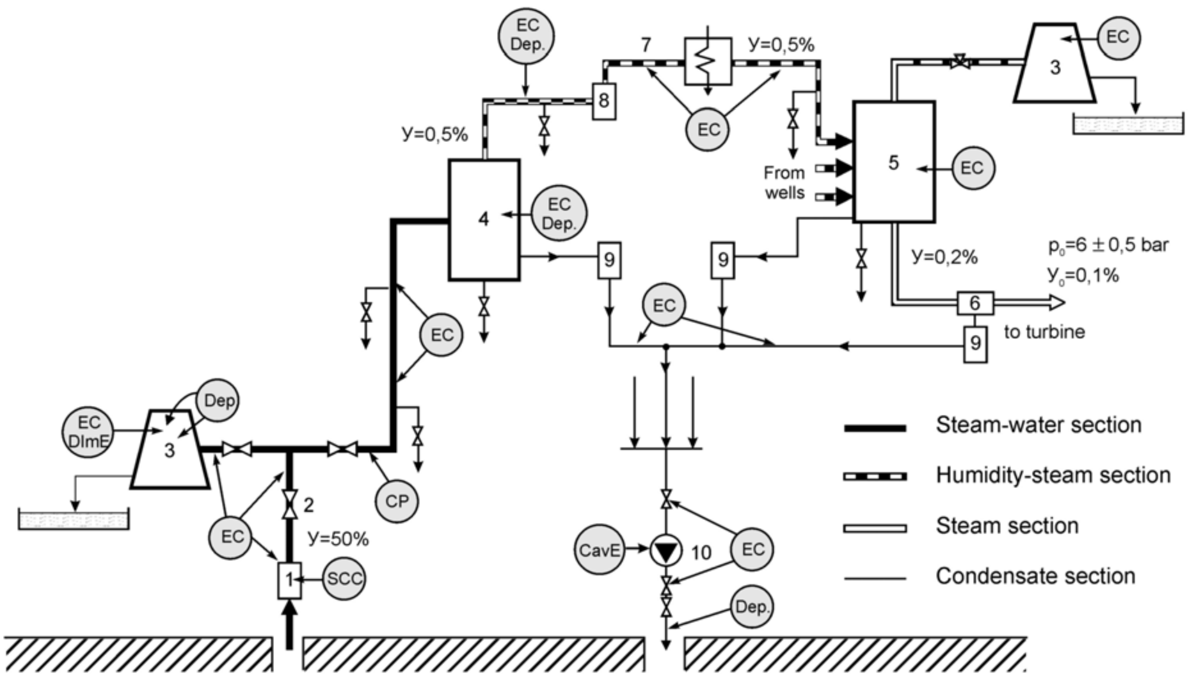

Figure 1: Schematic diagram of steam preparation system of typical GeoPP with direct cycle and basic kinds of metal destruction: 1 – compensator at the well; 2 – main well gate valve; 3 – noise-killer; 4 – well separator; 5 – unit separator; 6 – separator in front of the turbine; 7 – humidifier; 8 – emergency valve; 9 – condensate gathering tank; 10 – injecting pump.

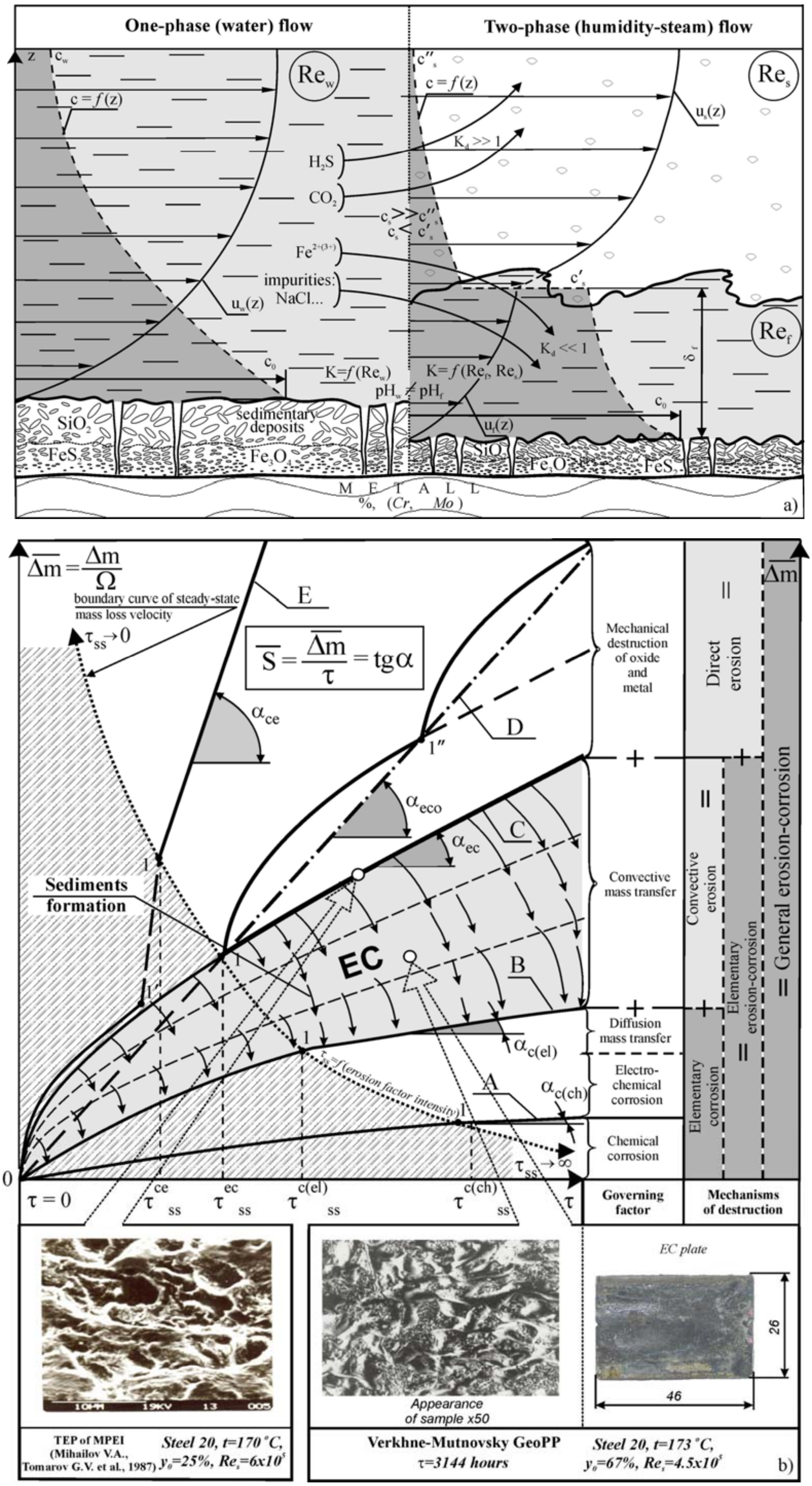

Figure 2: Peculiarities of erosion-corrosion physical-chemical processes (a) and kinetics of metals failure mechanisms (corrosion, erosion-corrosion, drop-impingment erosion) under impact of one- and two-phase multi-component flows (b).

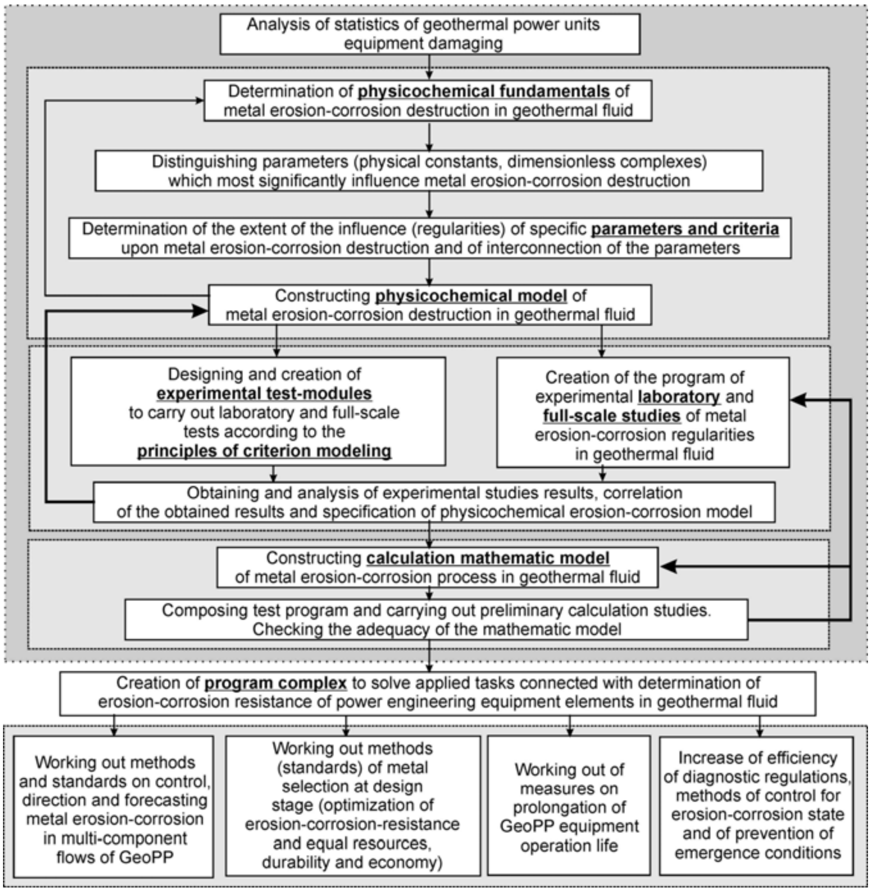

Figure 3: Basic stages of studying and working out calculation model and methods of forecasting and prevention of erosion-corrosion in geothermal media.

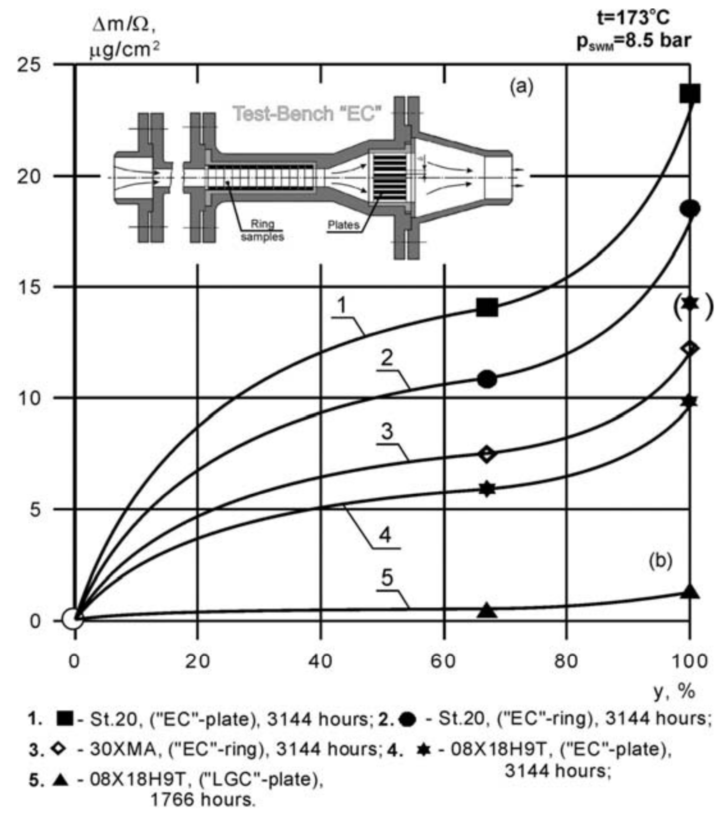

Figure 4: Test-module for studying erosion-corrosion (EC) (a) and experimental dependencies of metals mass loss intensity at GeoPP from geothermal fluid humidity extent (b).

Table 2: Chemical composition of geothermal fluid.

Determined component	Samples (contents, mg/l)			
	Steam-water mixture (from stand)	Condensate from condensation tank	Steam condensate from turbine	Separate (from extender)
pH	7,65	5,82	5,31	6,31
HCO_3	104,9	3,7	19,5	90,3
SO_4	144,1	18,2	3,8	115,3
Cl	218,4	< 0,7	< 0,7	167,4
NH_4	3,00	3,00	7,5	2,55
Ca	1,05	< 0,5	< 0,5	1,00
Na	230,0	0,10	0,015	170,0

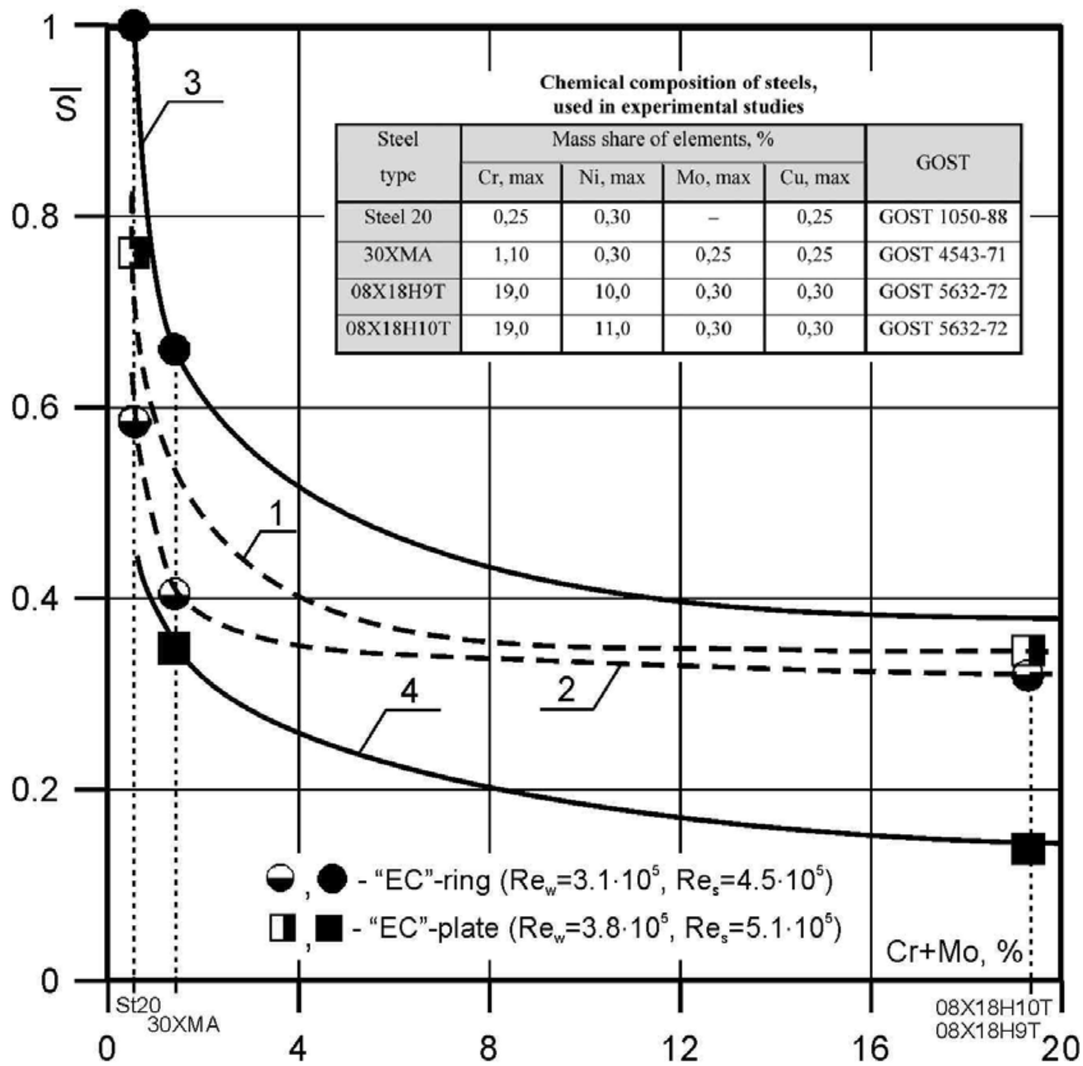

Figure 5: Effect of steels chemical composition upon EC intensity in multi-component geothermal fluid of Verkhne-Mutnovsky GeoPP (at exposition – 3144 hours).
1, 2 – steam-water mixture (y=67%, t=173 ^oC, p_{swm}=8.5 bar); 3, 4 – separate (t=173 ^oC).

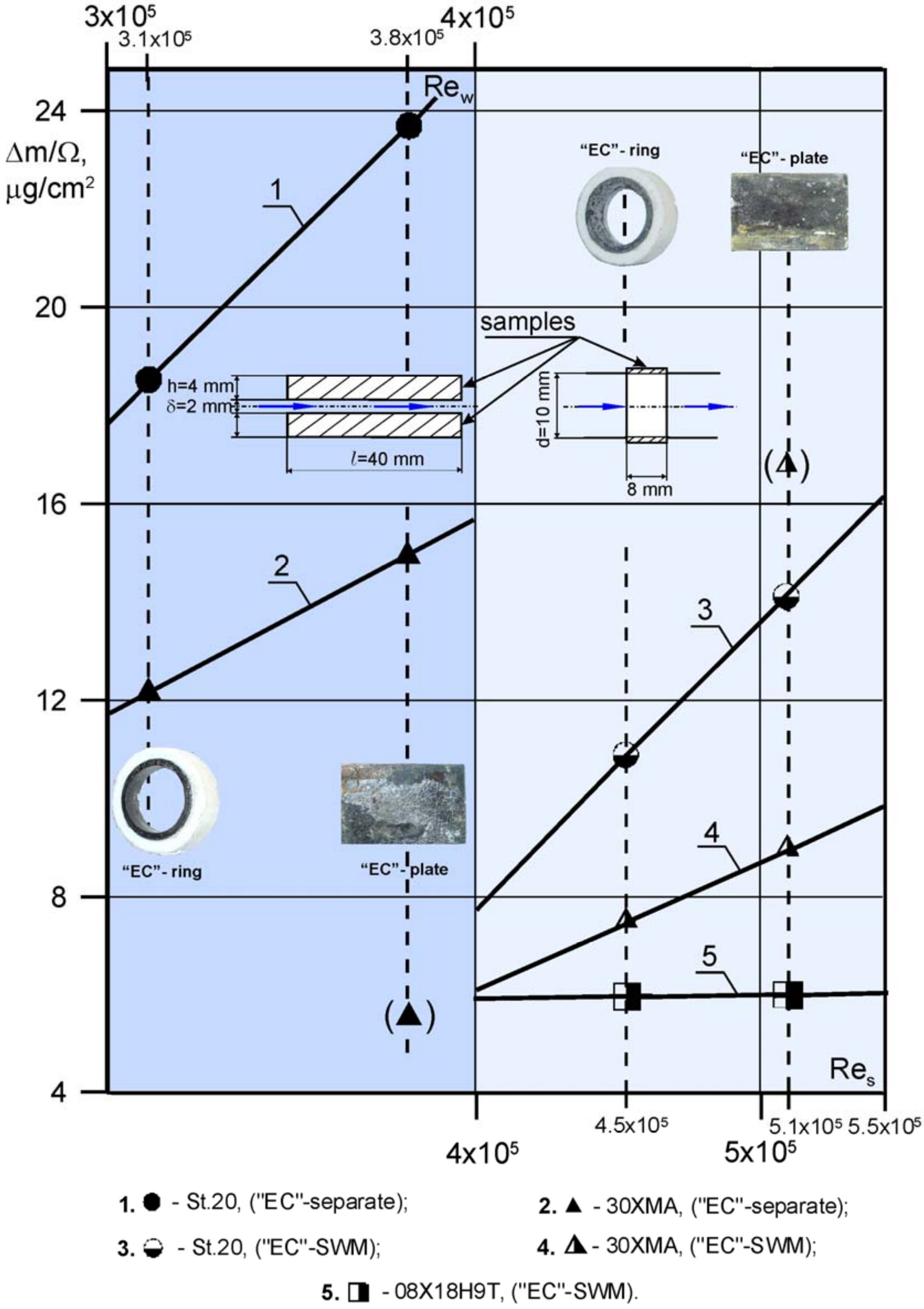

Figure 6: Effect of Reynolds number value Re_w (curves 1,2 t=173 ^oC) for separate flow and Re_s (curves 3-5 y=67%, t=173 ^oC, p_{swm}=8.5 bar) for steam flow upon intensity of metals mass loss at exposition of 3144 hours

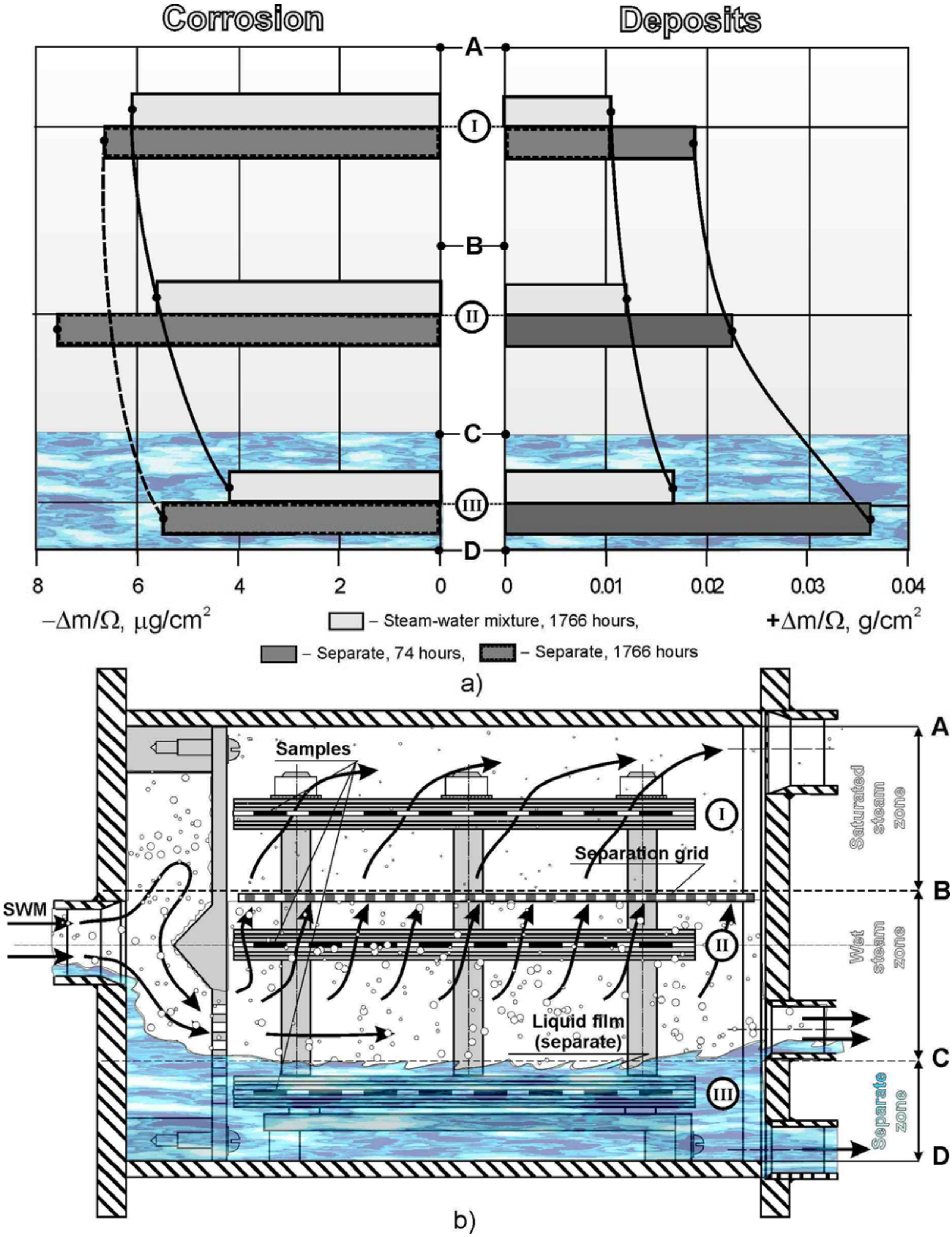

Figure 7: Results of investigation of deposits formation and course of corrosion processes at the samples surface from Steel20 (a) in camera of local and general corrosion (LGC) (b) (y=67%, t=173 °C, p_{swm}=8.5 bar)