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Study of the corrosion rate of the paths walls of aluminum heat exchangers in the ethylene glycol antifreezes environment under developed aeration of power fluid

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Annotation. An experimental and theoretical research work on the corrosion processes of heat exchanger channels made from different aluminum alloys in an ethylene glycol antifreeze environment conducted by the authors is described in the article. The hydrodynamic simulation of the flow in the paths was performed. Significant effects of the aeration of the power fluid, the possibility of electrochemical corrosion are proved. The comparative of anti-corrosion property of different aluminum alloys is shown when operating in a wide range of power fluid velocities and temperatures.

Introduction

Currently, heat exchangers made of aluminum alloys are widely used in different technical fields. Aluminum alloys, due to their low density, simple machining and high thermal conductivity, are used to manufacture shell and tube heat exchangers of all types that are used, among others, in engine cooling systems, communications-electronics equipment, hydraulic actuators, etc. Often, ethylene glycol antifreezes of different formulations, such as Tosol-40, Tosol-65 «Lena», etc., are used as power fluids for operation of such systems at low ambient temperatures.

The practice of using such hydraulic systems has shown that in some instances the paths of heat exchangers are intensively corroding, up to the formation of open pittings, and this process develops quite quickly, within a few hundred operation hours. Possible causes of this corrosion may be the presence of a large amount of dissolved air in the liquid (aeration), the presence of copper or bronze elements in the system (electrochemical corrosion), and a surface defects of the heat exchanger paths. This article includes the results of theoretical and experimental studies of corrosion processes in such heat exchangers made of various aluminum alloys.

Methods

Originally estimated, that in the heat exchanger paths developed cavitation erosion can occur, in order to determine the possible zones of which it was necessary to carry out a hydrodynamic simulation of flow. In the future, the flow model in the paths was dilated to atwo-phase flow model, taking into account the occurrence of gas cavitation [1-5].

The 3-D model [6-15] of the heat exchanger paths was created and the flow simulation in the paths, based on score equations and boundary condition described below was carried out.

In general Navier-Stokes vector equation for fluid is written as:



$$\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla) \vec{v} = -\frac{1}{\rho} \nabla p + \nu \Delta \vec{v} + \vec{f}$$

Where t - is time, ∇ - is Nabla, Δ - vector Laplace operator, ρ - is density, p - is pressure, ν - is kinematic viscosity, \vec{v} - velocity field, \vec{f} - field of body forces.

The continuity equation is also applied:

$$\frac{\partial \rho}{\partial t} + \text{div } \rho \vec{v} = 0$$

For the simulation of aeration fluid flow was created a two-phase flow model, consisting of water and air under specified values of density and viscosity. Proportional ratio: 95% of water and 5% of air. For the calculation, physical models of gravity force and a $k-\omega$ turbulence model were used. The velocity inlet was set in accordance with the required flow rate; the outlet pressure was set as zero.

For creation of mesh the following models were used: surface remesher, polyhedral mesher (base size 0,5 mm), prism layer mesher (number of layers – 5, stretching– 1,3, total thickness – 45% of base size) [1-3]. The simulation results were compared with experimental results.

For replication of conditions for the corrosion occurrence, the test bench was developed and created, simulating a real system.

The created test bench all owed to pass through the paths required fluid flow rate (ethylene glycol antifreeze Tosol-65) at the temperature up to 70°C and at the same time to provide aeration of power fluid (through the spout). In which case, accumulated operating time of heat exchangers made from different aluminum compositions (heat exchangers made from alloy D16T [aged-hardening duralumin] and AMg6 [93,5% Al, 5,5% Mg] was up to 140 hours.

Heat exchangers were connected as one by one, as well two and two in series through quick disconnect coupling (QDC), similar to using in real system. The diagram of the test bench is shown in figure 1. To simulate the presence of bronze elements in the real system, inserts and fittings made from bronze without galvanic isolation (flexible pipe in a metal braid were used) between them and the heat exchangers were used in the test bench. The pressure at the inlet of the heat exchanger (before the QDC) was maintained within 3...4 bar, which corresponds to the pressure in the real system.

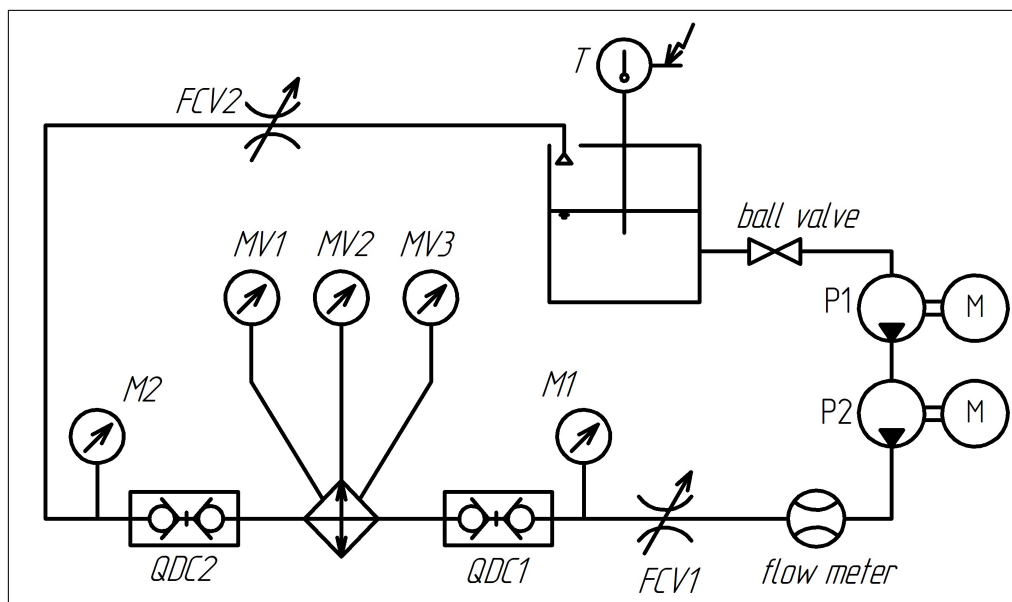


Figure 1.Diagram of the test bench

During the experiments, the temperature and flow rate of power fluid, pressure difference in the heat exchanger elements, operating time, noise and vibration levels on the heat exchanger surfaces

were monitored. After operating time, the condition of heat exchanger paths was estimated through factory-made endoscope, then by cutting a part of paths to access the inner surface.

Results

According to the hydrodynamic simulation results, the following conclusions can be drawn: the occurrence of steam cavitation in the heat exchanger paths is unlikely, because zones of pressure reduction equals to saturated vapor pressure were not detected (figures 2, 3). This pressure distribution pattern was also corroborated by measuring pressures in the holes (about 20 holes were made) along the heat exchanger paths.

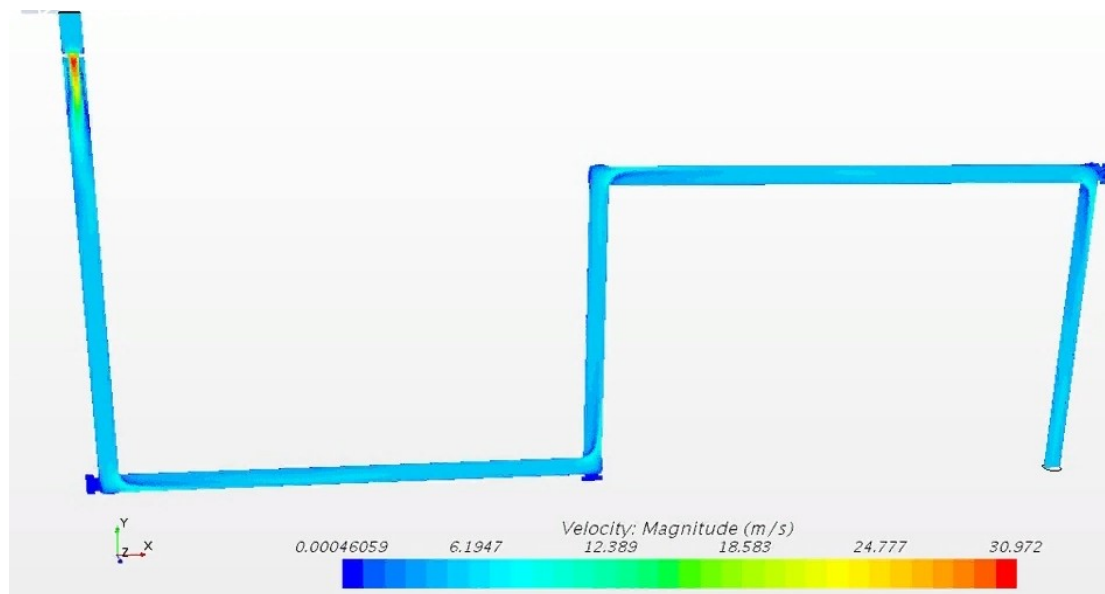


Figure 2. Velocity field distribution pattern in the heat exchanger paths at the flow rate 14 l/min

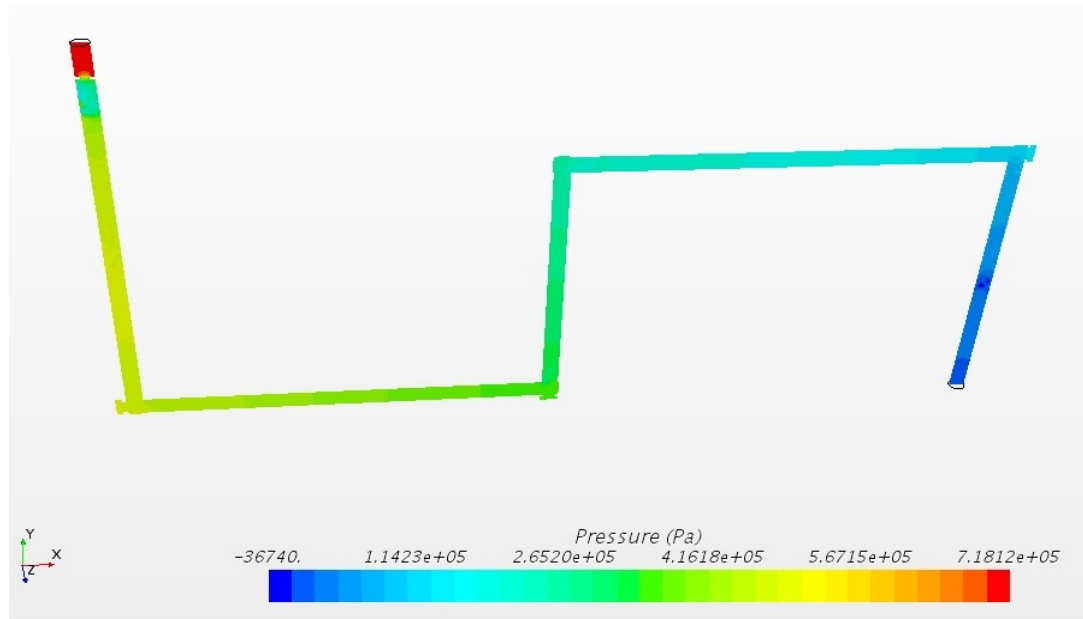


Figure 3. Pressure distribution pattern in the heat exchanger paths at the flow rate 14 l/min

There are no also anomaly high velocity zones, except of zone proximately after the QDC and particularly after flow deflection. However, the rapid decay of pressure after QDC, including the

laminar flow (figure 4), which causes a high probability of gas cavitation, i.e. release of dissolved gas, with a significant aeration of the fluid.

The presence of low flow velocity zones along path centerline of heat exchanger (figure 5), which combined with gas releases and low flow velocity in general can create a local high oxygen content zones in the upper medium paths zones at some distance of flow deflections. The hydraulic simulation of two-phase laminar flow (flow rate is 2 l/min) is shown in figure 6, a zones of high gas content in the upper path part are visible.

It may be concluded that the presence of sharp narrowing and increase of flow, and flow deflection, which combined with high aeration level of fluid, cause intensive gas releases and laminar flow with low velocity results to movement of gas bubbles to upper part of path, causing a large amount of oxygen in wall layers.

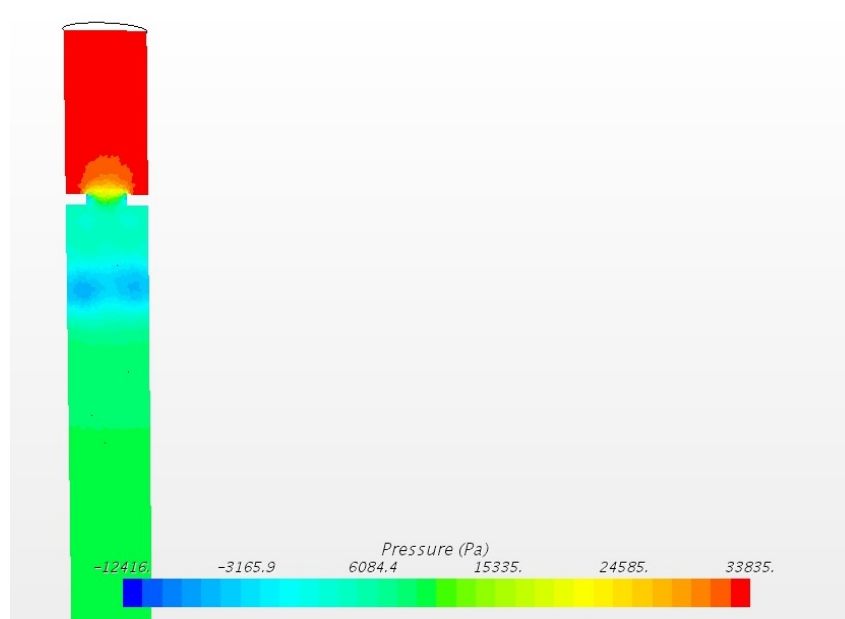


Figure 4. Pressure reduction zone after local flow narrowing in the heat exchanger inlet

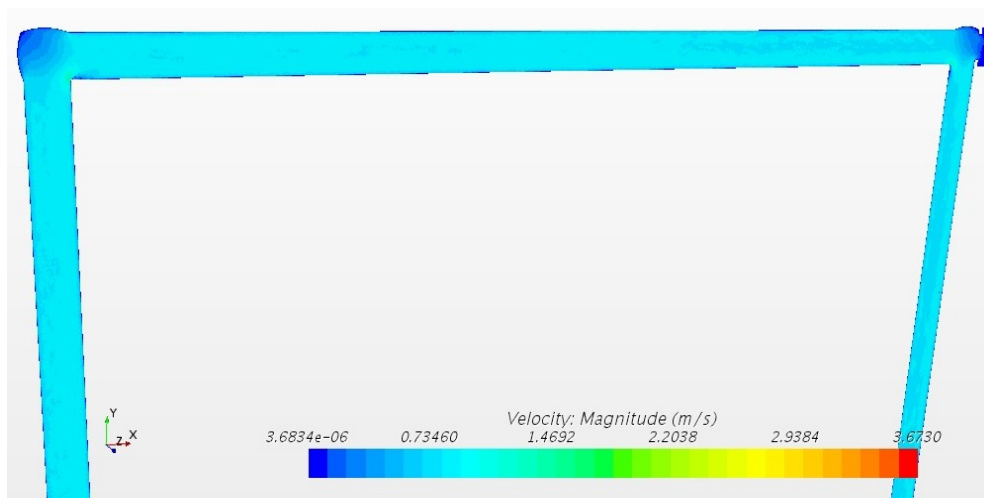


Figure 5. Local zones of velocity reduction

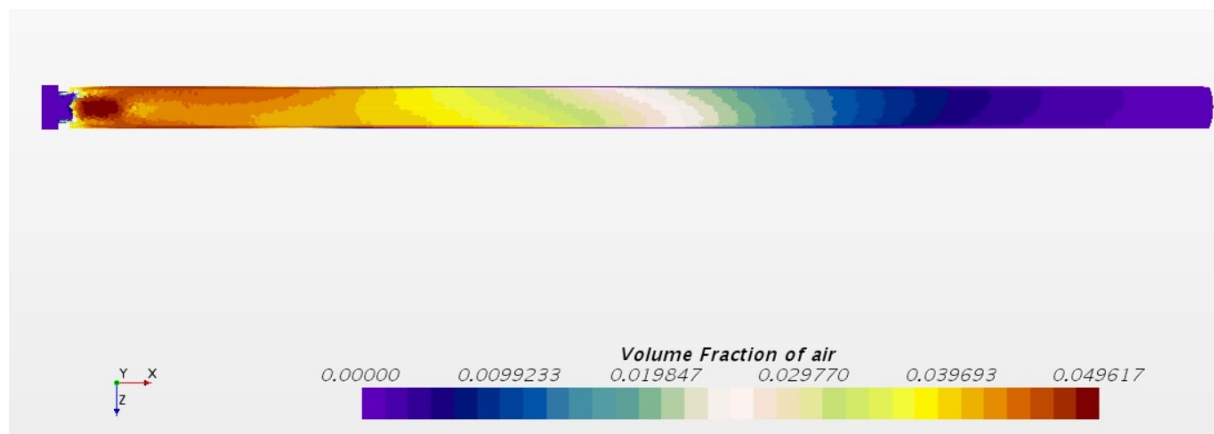


Figure 6.Two-phase laminar flow of fluid motion

The occurrence of intensive gas cavitation during the operating is confirmed by acoustic image of fluid flow in the heat exchanger [2]. The acoustic spectrum of the results of noise level measurement among the path (spectrum corresponds to zone after inlet part) is shown in figure 7. White shows the acoustic background in the room, orange - the noise in the path. Visible peak at frequency of about 1 kHz, arising due to the occurrence of steam cavitation. When the flow rate decreases, the peak amplitude decreases, but it does not disappear completely as long as there is a flow process.

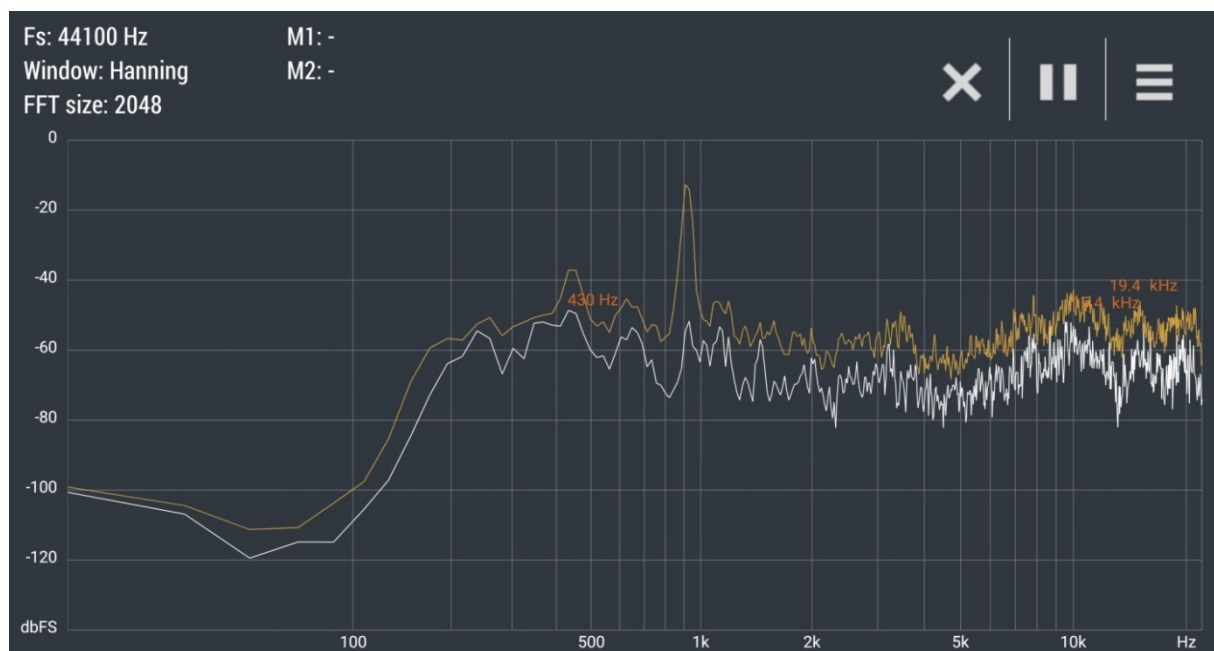


Figure 7. Noise levels measurement during the testing

After the testing, the study of paths surface was carried out by bore scope and milling for opening of some path parts. Among other things, was created the fluid precipitation in the reservoir, where numerous aluminum particles up to 0,1 mm in size were found out. Signs of corrosion in the opening path of heat exchanger made from D16T [aged-hardening duralumin] are shown in figures 8 and 9, the inner surface of the same path is shown in figure 10.

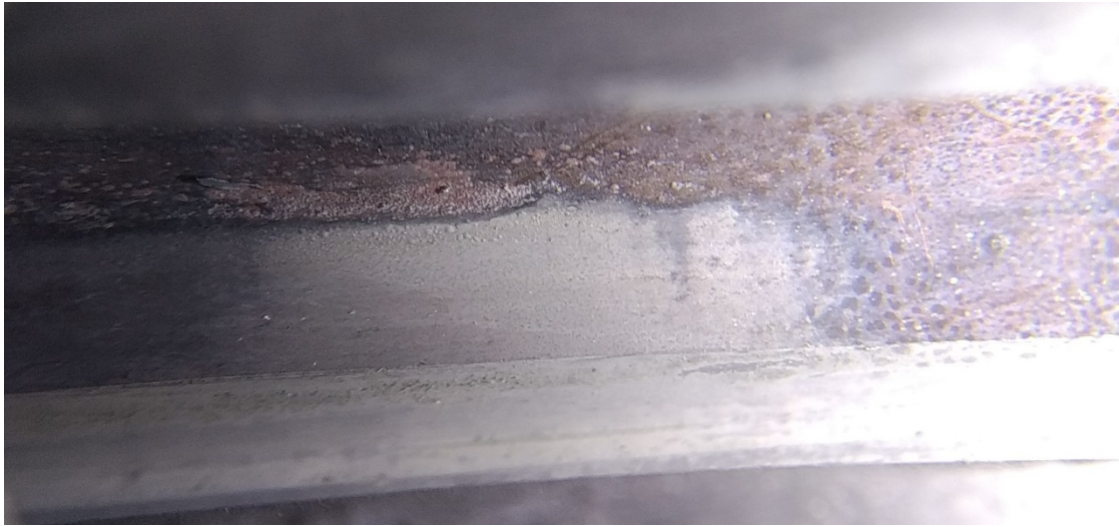


Figure 8.Corrosion of the path surface

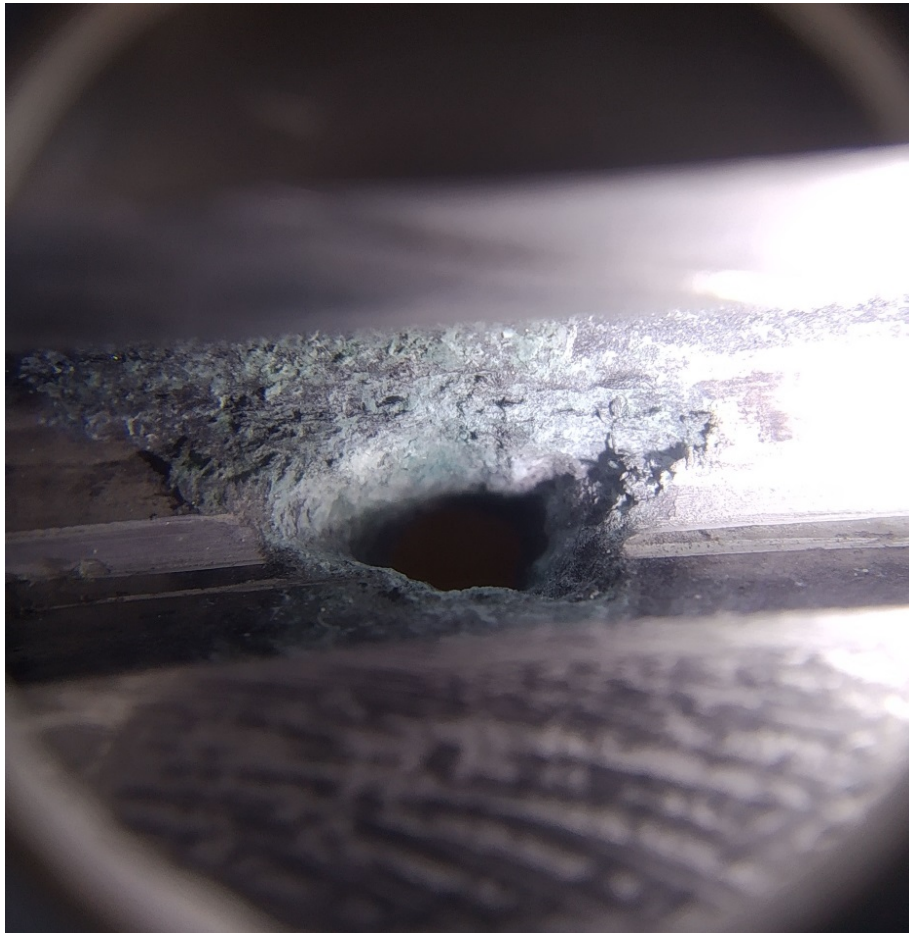


Figure 9. Open pitting corrosion on inside of heat exchanger path

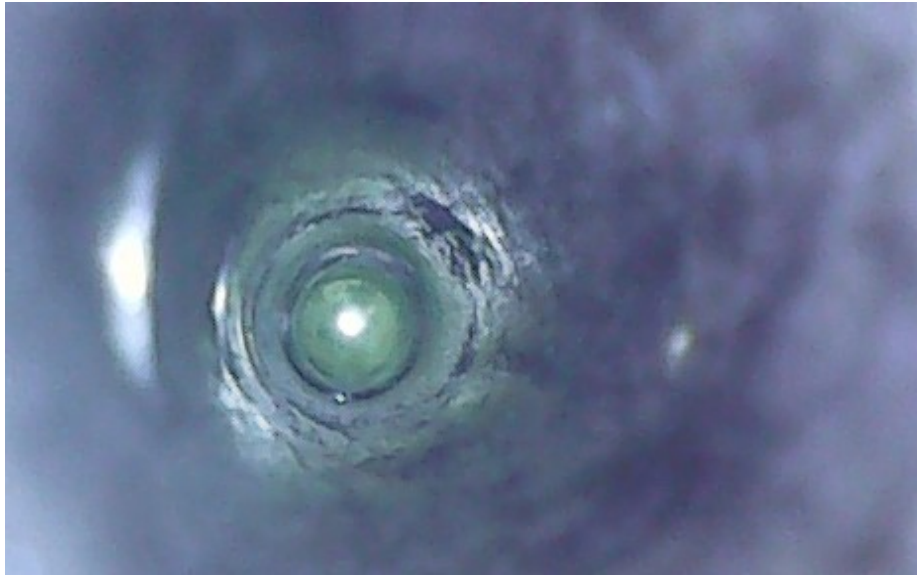


Figure 10. The path of heat exchanger made from D16T [aged-hardening duralumin], operating time is 130 hours, corrosion is visible

The effect of spray coating Sn-Bi on the corrosion developing is interesting. Zone of the path interface with and without spray coating that, perhaps, proves electrochemical type of corrosion [10,11].



Figure 11. Corrosion zones in the path with and without spray coating

The testing of heat exchanger made from AMg6 [93,5% Al, 5,5% Mg] has shown the absence of corrosion signs on the surface (figure 12):



Figure 12. The path of heat exchanger made from AMg6 [93,5% Al, 5,5% Mg], operating time is 100 hours, there are no corrosion signs (there are signs of treatment)

Discussion

1. Hydrodynamic simulation and acoustic flow pattern showed that in the heat exchanger in the zone of rapid decay of pressure gas can be released. It appears to suggest that the released gas can (especially at low velocities of fluid in the paths) be accumulated in the upper parts of paths and thereby sharply accelerate the corrosion of the walls of the paths in the presence of excess oxygen;
2. The presence of copper color tone on the paths walls and a lot of corrosion rate mean the possible electrochemical corrosion in the system, especially in copper aluminum combination.
3. D16T [aged-hardening duralumin] alloy in the circumstances is extremely unstable to corrosion, in any case, without additional coating the inner surface of the paths walls;
4. D16T [aged-hardening duralumin] alloy within the time of testing, proved to be corrosion resistant;
5. The detection of a significant amount of small aluminum pieces shows the developed cavitation of the paths walls with carry-over of metal from the affected zones.

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