Metal of cavitation erosion of a hydrodynamic reactor

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Abstract. Cavitation erosion is a major cause of the petroleum equipment hydraulic erosion, which leads to the metal weight loss of the equipment and its breakdown, which can be followed by the full stop of the plant or company work. The probability of the metal weight loss and equipment failure can be reduced by the use of special protective coatings or rivets, made of the sacrificial metals, the use of which significantly increases the service life and the production equipment reliability. The article investigates the cavitation erosion effect, occurred under the condition of the advanced hydrodynamic cavitation on the hydrodynamic cavitation reactor. This article presents the results of the experiments and recommendations for increasing the operational resource.

1. Introduction

The problem of the machine parts and mechanisms service life increase in the aggressive environments and at high loads has always been relevant to all areas of the industry. In the Russian Federation, the most important parameter is the pipelines and the pumping units operating life in the petroleum industry, which is the principle of the federal budget taxable base. The machine parts and mechanisms operating life can be prolonged as at the manufacturing stage, by applying the impurities and additional protective coatings, and at the operational stage. In the context of the techno-economic aspect, the pipelines and pumps service life extension at the manufacturing stage is more beneficial.

Considering the increasing dynamics of the hydrocarbon production and oil and gas companies’ technical and economic difficulties, the cavitation processing technology increasingly finds its application [1, 2]. It improves the oil rheological properties, reduces the pipeline wall buildup, increases the efficiency of the viscous and highly-viscous oil transportation, increases the light cut yield, etc [3-7]. However, the cavitation technology application is associated with the high risks of the operating equipment breakdown, caused by the cavitation erosion effect and the pressure fluctuations.

The analysis of the scientific literature has shown that there are a large number of hypotheses for the explanation of the cavitation mechanism and the physical nature and its effect on the metals destruction, which have both their advantages and disadvantages [7-10]. So, the results of the research have identified two stages of cavitation development (including the cavitation erosion), however the study implies the existence of four stages (periods) of cavitation erosion [11-14]. There is also difficulty in the analysis when the researchers are experimenting with the application of the simulative equipment that is inconsistent with the real process. Thus, often, in the process of the cavitation erosion investigation, the ultrasonic dispersant or the magnetostriction vibrator with the acoustic vibrations concentrator are used. They are inferior by their effect parameters to the hydrodynamic cavitation reactors, which develop stronger cavitation phenomena. Namely the cavitation erosion,
which occurs under the condition of the advanced hydrodynamic cavitation, is the most dangerous for
the pump equipment and the pipeline transport.

A wide range of methods is used for the protection against the cavitation erosion, including the use
of the erosion resistant steel in the constructions base, the inside construction carbide coatings
application, application of multilayer vacuum coatings and rivets made of the sacrificial metals, the
use of chemical and thermal processing and others.

The aim of this article is the investigation of the cavitation erosion effect, occurred under the
condition of the advanced hydrodynamic cavitation on the hydrodynamic cavitation reactor walls and
the investigation of the anti-erosion coating effect on the reactor operating life.

2. Materials and methods
To conduct the research, the hydrodynamic cavitation reactor with the following parameters was used:
length – 100 mm, diameter – 40 mm, confuser inlet angle – 40’, diffusor outlet angle – 50’, channel
contraction ratio – 3. The reactor is made of X39Cr13 steel, having the following chemical
composition distribution: Fe – 84.1%, Cr – 14.2%, C – 0.41%, Mn – 0.48%, Si – 0.33%, Ni- 0.31%.
The remainder of the chemical composition is represented by P, Al, Co, Cu and other substances. It
was decided to cover the reactor inner surface with the titanium, nickel and copper mixture to explore
the ways of the service life improvement. The model and the sample are presented in figures 1 and 2.

![Figure 1](image1.png)

**Figure 1.** The hydrodynamic cavitation reactor model: 1 – confuser, 2 – processing chamber, 3 –
diffusor, 4 – slit-type cylinder arrangement.

![Figure 2](image2.png)

**Figure 2.** The hydrodynamic cavitation reactor sample.

The experiment was carried out on the testing bench, shown in Figure 3, which consisted of the
pumping equipment, a pipeline that pumped the thick liquid, the cavitation equipment and the
temperature and pressure sensors.
The cavitation reactor metal weight loss was measured to evaluate the cavitation erosion effect and the coating efficiency.

3. Results and Discussion
Figure 4 and table 1 show the metal weight loss of the cavitation reactor with the protective coating (2) and without it (1) and its dependence on the time.

![Figure 3](image)

**Figure 3.** The laboratory unit.

![Figure 4](image)

**Figure 4.** The metal weight loss of the cavitation reactor with protective coating (2) and without it (1) and its dependence on the time.
Table 1. The cumulative difference in metal weight loss

| Time, h | \( \sum (\Delta m_1 - \Delta m_2) \), mg |
|---------|---------------------------------|
| 0-2     | 2                               |
| 3-4     | 16                              |
| 5-6     | 41                              |
| 7-8     | 83                              |
| 9-10    | 129                             |
| 11-12   | 192                             |

Figure 4 shows that the coating increases the erosion resistance of the construction and reduces the metal weight loss. It can be observed that the reactor with the protective coating has the highest corrosion resistance since the lowest weight was lost during the exposure period. After 2 hours of test, the reactor inner surface starts presenting plastic deformation, after 4 hours, the plastic deformation becomes more severe. The cracks are initiated from the internal defects of the material and along the weakest spots. After 8 hours surface cracks join each other, increase erosion rate.

Figure 5 and table 2 represents the dependence of metal loss on the periods of cavitation for the uncoated and coated reactor.

![Figure 5. Metal weight loss according to the periods of cavitation.](image)

The figure illustrates that the metal weight loss rate decreases and thereafter increases to a given value, and then again decreases. The coating increases the incubation (first) period time, during which the minimum metal weight loss and the plastic deformations accumulation occur. These results are in good agreement with other conducted researches [15-18].
Table 2. The periods of cavitation

| Period | Time, h |
|--------|---------|
| 1      | 0-2     |
| 2      | 2-6     |
| 3      | 6-10    |

The metal weight loss results according to the periods of cavitation can be roughly divided into 3 stages: an incubation (first) period where little weight loss occurs, a transition period with the increasing weight loss rate and finally a stable period during which the weight loss rate is approximately constant. The figure demonstrates that the coating application has a positive effect on the service life. On the basis of the conducted experiment and scientific papers analysis, the optimum coating composition is the mixture of titanium - 55%, nickel 25% and copper 20%.

4. Conclusion

The service life and the processes reliability are the most important technical parameters in the industry. The careful approach to the selection of the construction material brand, used in the cavitation treatment, and the coating materials, protecting the base metal from the rapidly developing cavitation erosion, can enable us to achieve the high rates of performance. The results obtained in the experiment and the scientific literature analysis have shown that the most optimal way is the usage of the titanium, nickel and copper mixture. The given results can be used in the engineering design of the pumps and pipelines by the research and design institutes in the petroleum industry.

References

[1] Brand A E, Vershinina S V, Vengerov A A and N A Mostovaya 2015 IOP Conf. Ser.: Mater. Sci. Eng. 93 012005
[2] Bordeaus I, Popoviciu M O, Mittelea I, Ghiban B, Ghiban N, Sava M, Duma S T and Badarau R 2014 IOP Conf. Ser.: Mater. Sci. Eng. 57 012006
[3] Khvatov B N 2002 J. Trans. of the TSTU 8(3) 507
[4] Tôn-Thất L 2012 8th Inter. Sympos. on Cavitation Singapore
[5] Vakulenko K V, Biblik I V, and Kazak I B 2014 J. Aerospace Eng. and Tech. 7 (114) 116
[6] Linderov M L and Merson D L 2010 J. Vektor Nauki of TSU 3(13) 43
[7] Shestoperov V Yu 2014 J. Trans. of NSTU n.a. R.E. Alexeev 5 (102) 79
[8] Shestopyorov V Yu 2014 J. Trans. of NSTU n.a. R.E. Alexeev 5 (107) 361
[9] Vyas B and Preece C 1977 Metal. and Mater. Trans. A 8(6) 915
[10] Gireń B G and Frączak J 2016 J. Wear 364 1
[11] Hattori S, Ishikura R and Zhang Q 2004 J. Wear 257 1022
[12] SangKi Chi, JinHwan Park, MinYoung Shon 2015 J. of Indust. and Eng. Chem. 26 384
[13] Dular M, Stoffel B and Sirok B 2006 J. Wear 261(5) 642
[14] Matevž D, Bernd S and Brane Š 2006 J. Wear 261 642
[15] Koukouvinis P, Bergeles G and Gavaises M 2015 J. of Hydrom. Ser. B 27(4) 579
[16] Mittelea I, Bordeas I, Pelle M, and Craciunescu C 2015 J. Ultrason Sonochem 23 385
[17] Santa J, Blanco J, Giraldo J and Toro A 2011 J. Wear 271 1445
[18] Wood R J K, Wharton J A, Speyer A J and Tan K S 2002 J. Tribol. Int. 35 631