GDAŃSK UNIVERSITY OF TECHNOLOGY

Journal of Polish CIMEEAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

PROBLEMS OF EXPERIMENTAL DETERMINATION OF COEFFICIENTS OF THE WEAR OF SHIP PIPING SYSTEMS

Roman Liberacki

Gdansk University of Technology
ul. Narutowicza 11/12, 80-950 Gdańsk, Poland
tel.: +48 58 3471850, fax.: +48 58 3472430
e-mail: romanl@pg.gda.pl

Abstract

The article presents series of considerations relating to experimental evaluation of the reliability of ship piping systems. The aim of this study is to attempt to answer the following questions: What should be the tested element? How to choose the diameter of the tested item? What should be the result of measurements and calculations? How to measure? How to choose the duration of the test? How to choose the sample size and elaborate the results? Can we use a linear relationship between the weight loss of the test piece and the time? At the end of the article, the initial conception of the laboratory stand is proposed.

Keywords: *reliability, pipeline, weight loss, corrosion*

1. Introduction

Designing a ship power plant to a predetermined reliability or availability requires, among other models, the development of models to assess the reliability of ship piping components. The early works of the author were focused on the problem of reliability assessment based on the statistical data about component failures. It was not possible to collect enough data to make the usual statistical processing. The solution was to use the fuzzy logic methods. However, the fuzzy approach is associated with high uncertainty. The next step was looking for mathematical models that identify the reliability factors of components taking into account properties and characteristics of transported medium, component's material and ambient conditions. Unfortunately, there are no ready models found. So, it is necessary to develop models based on experimental studies. This article is a continuation of the work presented in [1] and [2]. The final goal is still the same: to develop a method to assess the reliability of ship piping systems. This article contains considerations how to build the laboratory stand to solve some of the reliability assessment problems.

2. Initial assumptions

The laboratory stand should make possible testing elements with the use of medium with physical properties and parameters identical or similar to the real one. Those real media are: sea water, fresh water, fuel oils, lubricating oils, compressed air, steam.

The tests should be carried out in a flowing medium. Simultaneously, the tests in stationary medium is provided. It will allow to determine the impact of the flow existence on the degradation rate of the tested item.

Moreover, the stand should give the possibility to locate the tested items in the horizontal and the vertical position. The position, of course, can affect the rate of degradation.

In order to accelerate research, the laboratory stand should enable the tests on a few items in the same time. Measurements should be made using more than one method. Those methods must be adopted to the nature of destructive phenomena.

For economic reasons, it is advisable to use reduced flow rates and reduced item size at the laboratory stand.

The impact of ambient conditions on degradation rate of tested component should be tested on a separate stand.

3. The tested item

There are two ways to study the destruction rate of pipeline components. First way is to test the real items. Those items can be: straight pipe sections, elbows, valves, tees and the other pipe fittings. The second way is to use substitutes, for example the corrosion coupons. According to [9]: "Coupons are pieces of metal that are available in varying shapes, sizes and materials. They are composed of the same chemical composition as the equipment to be monitored. Corrosion coupons are exposed to a corrosive solution similar to that in process facilities for a specified period of time, and can give visual signs of the corrosion rate and type". Examples of the real elbow and the corrosion coupon are presented in Fig.1.

Elbow [4] Corrosion coupon [10]

Fig.1. The elbow and the corrosion coupon

The advantages of using coupons are: a possibility of testing many samples, made of different materials, simultaneously; the rate of the degradation of the material and the type of destructive phenomena can be observed; the coupons can be placed in existing piping systems; the preparation of the coupon, measurements and the observations of the surface of the coupon are easier, then on real fitting. The problem is how to transfer the results obtained by testing the coupon on the real object. The conditions of exposure to damaging factors are different for coupons and real fittings. However, we should use coupons and real elements together. This will allow to find the correlation between the results obtained from coupon testing and the results obtained from real fitting testing.

4. The diameter of the tested element

For piping components the basic dimension is the diameter. The question is then: How to choose the diameter of the tested item? There are two options. The first, is to keep the flow velocity on the same level as in the existing pipelines. The second, is to keep the Reynolds number, used to characterize different flow regimes within a similar fluid, such as laminar or turbulent flow. The right answer is to keep a constant flow rate. The Reynolds number in the real systems is not constant, it decreases, when the diameter of the pipeline decreases.

Manufacturers of marine engines recommend that water flow in the cooling systems should not exceed 3 m/s. Assuming the capacity of the pump on the test stand of 1.2 m^3/hr and the flow rate equal to 3 m/s - the internal diameter of the test piece should be 12 mm. It can be the tube 16x2 in accordance with DIN 2448. Table 1 shows calculations of the Reynolds number and internal diameter to keep flow velocity 3 m/s for different flow rates.

Tab.1. The diameter and the Reynolds number for a flow rate of 3 m/s

V [m^3/hr]	d [mm]	Re [-]
300	188	1 541 502
200	154	1 258 631
100	109	889 986
1.2	12	97 493

The diameter of the test piece will be determined by the constant flow rate. There is a big difference in the values of the Reynolds numbers. So, the effect of Reynolds number on the rate of degradation should be tested. The character of flow may significantly affect the erosion rate of pipeline.

5. Expected results of measurements and calculations

From the perspective of marine systems designer, who wants to ensure a given level of reliability, the time to failure of pipeline is the object of interest. In particular: time to loss a corrosion allowance, time to perforation, time to loss of tightness of connections and non-metallic elements.

The corrosion is usually measured by mass loss and corrosion rate of material. The degradation of the pipeline's component may be the result of several destructive phenomena occurring at the same time. It is difficult to consider them separately. The most reasonable solution, in that case, is to set: the loss of mass of the tested element in g/cm^2 per year. This will allow to calculate the degradation rate mm per year. Due to the possibility of pitting corrosion, the depth of the largest hole in the tested element should be measured too.

6. The measurements and the test duration

Measurement of mass loss should be performed using an analytical balance with an accuracy of 0.1 mg. Prior to the weighing it is necessary to remove corrosion products from the sample so as not to remove healthy metal, this can be done only by dissolving those corrosion products by chemical methods. Dissolution can be made using boiling solution of sodium hydroxide and zinc: 20% NaOH + 200 g/dm^3 Zn or using concentrated hydrochloric acid, stannous chloride and antimony trichloride: HCl + 50 g/dm^3 SnCl2 + 20 g/dm^3 SbCl3 at room temperature [5].

Another problem is the measurement of the depth of corrosion pits. There are two possibilities: the method of mechanical processing and measurement with the use of needle devices or microscopic methods.

Total test time is determined depending on the rate of corrosion. For example, for samples with the corrosion rate at elevated temperature (calculated after 24 h):
- corrosion rate more than 0.3 mm / year - time of test is at least 168 hours (7 days) [6],
- corrosion rate less than 0.3 mm / year - time of test is at least 769 hours (33 days) [6].

Piping components usually are made of cast iron, steel, or cast steel. Sometimes such items are made of corrosion-resistant materials like copper alloys or non-metallic materials.
Gray cast iron has a high rate of corrosion [7]:
- atmospheric corrosion rate does not exceed 1.5 mm/year
- the corrosion rate in the aerated sea water is 0.5 - 1.3 mm/year
- the corrosion rate in fresh water of 0.13 - 1 mm/year.

Tab.2. The scale of the corrosion resistance of steel [8]

Corrosion rate I [mm/hr]	Resistance scale	Designation
< 0.1	0	Corrosion resistant
0.1 -1.0	1	Not resistant to corrosion, applied conditionally
>1	2	Serious corrosion, not suitable for use

In conclusion, it can be assumed, that in the case of testing of cast iron the test duration will be 7 days, in the case of steel elements 33 days or more.

7. The sample size and elaboration of results

Three samples usually are tested. For each sample the loss of mass is determined. Then, the mean value and the standard deviation of the mass loss is calculated. Finally, the corrosion rate is evaluated. Such an approach to the problem is shown in [3]. The advantage of this method is its simplicity. However, the result obtained by this method, is valid true only for the tested items. Not for the whole population. Of course, it's not possible to examine the entire population. But the interval estimation of mean corrosion rate can be used, instead the point estimation.

An interval estimate is defined by two numbers, between which a population parameter is expected to lie. We can find then the confidence interval for the mean corrosion rate at a specified level of confidence. This way we can express the uncertainty of the estimation. The point estimation and interval estimation of degradation rate are shown in the example below.

Let us assume that three items have been tested. We have received than three values of corrosion rate: 0.085; 0.092; 0.099 in mm/year. Using the point estimation we obtain as the results: the mean value $\overline{x}$ = 0.092 mm/year and the standard deviation σ = 0.0057 mm/year. Those values are valid only for the sample, not for population.

There are three models for interval estimation. The first model is used when: time to failure of the population has a normal distribution; mean time to failure for the population is not known but the standard deviation of the time to failure is known. The second model is used when: time to failure of the population has a normal distribution, the mean time to failure for the population is not known and the standard deviation of the time to failure is also not known. The third model is used when: time to failure of the population has an unknown distribution, mean time to failure for the population is not known and the standard deviation of the time to failure is not known, the sample size should be large. Sample size is large when it contains more than 100 data [11] or at least 30 data [12].

We can't use the first model, because the standard deviation for the population is not known. The third model also isn't suitable, we have only 3 data. The second model can be used. The condition is the normal distribution of the degradation rate. We need than to state and verify the hypothesis that the degradation rate has the normal distribution:

Ho: Degradation rate of items has the normal distribution with the mean value $\overline{x}$ = 0.092 mm/year and the standard deviation σ = 0.0057 mm/year.

If the sample size is small, in our case 3, and the considered feature is continuous, we should use the Kolmogorov's test to verify the hypothesis. The test statistic is [11]:

$$D_n = \sup | F_0(x) - S_n(x) | \quad (1)$$

where:

$F_0(x)$ – theoretical distribution,

$S_n(x)$ – empirical distribution.

Tab.3. Calculations of the Kolmogorov's test statistic

i	x_i	$\frac{i}{n}$	$F_o(x)$	$\frac{i-1}{n}$	$\left\|\frac{i}{n} - F_o(x)\right\|$	$\left\|F_o(x) - \frac{i-1}{n}\right\|$
1	0.085	0.333	0.110	0.000	0.223	0.110
2	0.092	0.667	0.500	0.333	0.167	0.167
3	0.099	1.000	0.890	0.667	0.110	0.223
					Dn=	**0.223**

95% qantile of the Kolmogorov's statistics for sample size n = 3 is equal $d_{3(\alpha = 0.05)} = 0.708$.
Since $Dn < d_{3(\alpha = 0.05)}$ we fail to reject the hypothesis Ho on the significance level $\alpha = 0.05$. So there is no reason to reject the hypothesis Ho: Degradation rate of items has the normal distribution with the mean value $\overline{x} = 0.092$ mm/year and the standard deviation $\sigma = 0.0057$ mm/year on the significance level $\alpha = 0.05$. We can use the second model to find the confidence interval now [11]:

$$\left\langle \overline{x} - t(\frac{\alpha}{2}, \nu)\frac{s}{\sqrt{n-1}}, \quad \overline{x} + t(1-\frac{\alpha}{2}, \nu)\frac{s}{\sqrt{n-1}} \right\rangle \tag{2}$$

where:
$1 - \alpha = 0.95$ - confidence level,
$\alpha = 0.05$ - significance level,
$n = 3$ - sample size,
$\overline{x} = 0.092$ - sample mean value,
$s = 0.0057$ - sample standard deviation,
$\nu = 2$ - degrees of freedom,
$t = 4.303$ - t-Student distribution 0.025 and 0.975 qantiles.

95% confidence interval for mean degradation rate for population is: ⟨0.075; 0.109⟩ mm/year.

In practice, the sample size must be limited to 3 maybe 5 elements. This is due to the cost of the samples and the long duration of the test (more than a month). It is recommended to use the interval estimation instead of point estimation. The advantage of the interval estimation is that the result reflects the population, not only the sample, and the uncertainty of estimation is determined. Uncertainty can be reduced by choosing a larger sample for testing. Additionally the inaccuracy of measuring instruments should be taken into account.

8. How to check the accuracy of the linear model of degradation?

The linear model of degradation rate was used in the example above. There are also described other metal lows like: parabolic, cubic, exponential and logarithmic. Determination of the nature of the degradation will be very difficult due to the low rate of degradation of the tested items. The solution may be the use of ultrasonic or magnetic thickness gages to get an answer to this question. This would allow the measurement of wall thickness losses during the test without removing the item from the stand. The problem is to get an instrument with a very high resolution, for instance 0.001mm.

9. The block diagram of the test stand

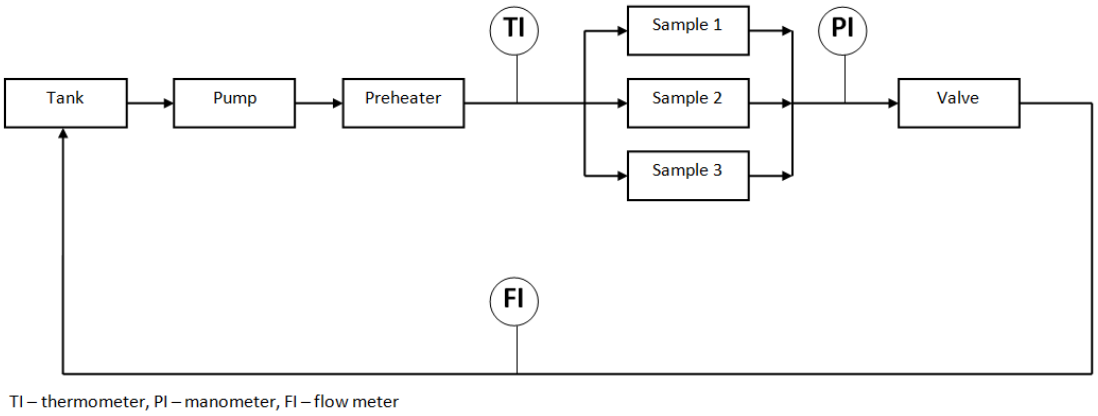

Fig.2. The block diagram of test stand

10. Final remarks

The results of measurements should be developed using interval estimation, taking also into account the measurement inaccuracies (reading inaccuracy, repeatability and linearity of the applied laboratory balance). An important issue is the adequacy of the obtained results on the laboratory stand in relation to the real objects. The question is still open: how to verify this? It is necessary to consider the problem of testing items which are protected against corrosion. Significantly reduced rate of degradation will make the test very difficult or even impossible to do. It remains to be solved in the future, the problem of the ambient conditions influence on the external part of components. There are a lot of questions for further research, in the theoretical and experimental area.

References

[1] Liberacki R.: The possibilities of estimating the reliability of ship pipelines' elements including destructive fenomena acting on them. Journal of Polish CIMAC, Gdansk, 2014.
[2] Liberacki R.: Approach to evaluation of time to the critical degradation of ship pipelines. Journal of Polish CIMEEAC, Gdansk, 2015.
[3] Agnieszka Stachowicz: Korozja rur w odwiertach oraz dobór ochrony inhibitowanej w płynach nadpakerowych, Nafta-Gaz nr 7/2013.
[4] Kolano hamburskie spawalnicze Onninen.
[5] Andrzej Zieliński, Paulina Antoniuk: Mechanizm i sposoby oceny korozji.
[6] Barbara Surowska: Wybrane zagadnienia z korozji i ochrony przed korozją. Lublin 2002.
[7] Badanie przebiegu korozji w żeliwach i stalach niskowęglowych. Politechnika Łódzka.
[8] Glinicka Aniela, Kozłowska Barbara: Przykład modelowania okresu utrzymania wybranych elementów konstrukcji stalowych poddanych korozji. Logistyka 3/2012.
[9] https://www.corrosionpedia.com/definition/1332/corrosion-coupon (10.11.2016)
[10] http://www.sandvikstainlesswebshop.com/article/sandvik_saf_2205_flat (10.11.2016)
[11] Krysicki W., Bartos J., Dyczka W., Królikowska K., Wasilewski M.: Rachunek prawdopodobieństwa i statystyka matematyczna w zadaniach.Część II Statystyka matematyczna. PWN. Warszawa. 1995.
[12] Kołowrocki K. Wybrane wykłady z rachunku prawdopodobieństwa i statystyki matematycznej. WSM. Gdynia. 1994.