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THESIS

RELIABILITY FOR WASTEWATER TREATMENT PLANT EQUIPMENT

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INTRODUCTORY WORD

Reliability theory is an independent discipline and is a major issue for all areas of industrial production. Reliability comes from the branches of mathematics, but over time, due to the contribution of engineering research, it has become an independent science, based on probability theory, expectation theory and mathematical statistics. Applying reliability requires serious engineering knowledge in various fields. The complexity of industrial products currently manufactured, the multitude of operating regimes, the rapid replacement of damaged elements with new ones, condition the need for global theoretical treatment of problems on increasing product reliability, regardless of their structure and destination.

The collection of product reliability information is usually obtained either by following the behavior of the products in actual operation or during reliability tests. Information from actual use often refers to worn-out products or equipment, so that, at the time of drawing conclusions, they may no longer be relevant for the correction of aspects related to the design and manufacture of products, as reliability.

The need to address this issue stems from the fact that all equipment in sewage treatment plants must operate continuously in difficult working conditions. The requirements imposed on wastewater treatment plants are strict, regulated by current legislation, and involve the continuous operation of the equipment at the initial design parameters in order to maintain the wastewater treatment process at a high efficiency.

The opportunity to develop the chosen topic is to sound the alarm to the authorities in order to introduce in the award documents and in the design regulations the reliability indicators for the equipment to be used.

In this way, I want to thank all those wonderful people who offered me scientific advice and who broke their free time to offer me support and help.

Mr. prof. univ. emeritus dr. eng. Dan Niculae ROBESCU sincere thanks and feelings of gratitude for your support in the elaboration of your doctoral thesis, for your patience, generosity, and understanding, as well as for your entire contribution to my training as a researcher. Thank you for agreeing to share with me your rich experience gained over the years of study and without your support I would not have been able to complete this thesis.

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With special gratitude and love, I dedicate this thesis to my family, who was with me, and who supported me in all respects during this period.

Author

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CHAPTER I General aspects of reliability

Current state of research

Reliability theory has been built as a science in the last 40 ... 50 years and aims to study defects, causes and processes of their occurrence and development, forecast the behavior of products in operation, determine ways to ensure, maintain and increase duration use of the products [1]. The definition of reliability given by STAS 8147 / 1-77 is consistent with that accepted worldwide, namely: reliability is the ability of a product to perform its specified function under given operating conditions, over a given period [2]. There is a close connection between the notions of quality and reliability. Quality is the totality of the properties of a product that make it suitable for use according to the destination specified by a certain document, reliability is the ability of the product to maintain its quality throughout its use.

The theory of reliability was determined by the increasing complexity of equipment and the mass character of modern production. Based on the solutions offered by this new discipline - reliability - great progress has been possible in other areas of activity, such as nuclear power plants, transport (naval, land, air and lately space), data processing and transmission, production of goods wide consumption etc. [5]

After the transition from manufacturing to mass production, there was an increase in the dispersion of equipment parameters due to both increasing complexity and reducing the possibilities of interphase control on production lines. Over time, it has been found that in the case of complex systems and equipment, no matter how much is invested to achieve ideal reliability, it is not possible to obtain equipment that does not degrade over time. For this reason, it is useful to know the real level of reliability, so that, depending on it, to establish the duration of the mission, revision intervals, equipment structure, etc. [5]

Reliability is one of the determining parameters for the competitiveness of a product, as the degree of marketability increases significantly for reliable products. It can be appreciated that reliability has become a national concern. Globally, after 1990, a new stage of development of the field of reliability was entered. If in the '60s reliability referred to Control / Verification, and in the' 70s - '80s to Insurance, now the watchword is Reliability Management, with all that it implies: adequate prediction methods, design for reliability, process reliability , convergent engineering, total quality control, etc. If for types of products that have been in production for a long time (such as microelectronic devices) this concern for reliability seems justified, being products that are looking for a place in increasingly demanding markets, in the case of relatively new products, such as microsystems, reliability seems more of a luxury. The current trend is to move from product certification to technology certification, with obvious advantages in terms of simplifying delivery procedures.

Reliability is a discipline in the field of engineering that uses scientific knowledge to ensure high performance of the functions of an equipment, in a certain time frame and well-specified operating conditions. This includes the design, ability to maintain, test and maintain the equipment at acceptable parameters throughout its life cycle. The reliability of an equipment is best described by maintaining its performance over time in compliance with normal operating conditions.

The reliability performances of an equipment are concretized in the design phase by the judicious choice of the architecture of the equipment, of the materials, of the manufacturing process, of the components - both soft and hard - followed by the verification of the results obtained after the simulations and laboratory tests.

THE PURPOSE OF RELIABILITY

Reliability is one of the main parameters of the quality of any product, presenting the particularity that it is calculated based on the analysis of the behavior of the systems studied in operation. Qualitatively, reliability is the ability of a system to operate without failures over a period of time, under given conditions of use. So, reliability can be seen as an "extension over time" of quality.

The quality of a product is a virtue, a static property, ie consumer satisfaction when accepting the product. Reliability is also a virtue, with a dynamic property, materialized in the permanent maintenance of the product's performance during its use [6].

The quality control allows the appreciation of the quality of the finished product at the moment of delivery to the beneficiary, while the reliability gives an appreciation regarding the behavior in time of using the product. [7]

CHAPTER II

Wastewater treatment plants - General considerations

Wastewater comes from loading natural water with materials and substances that change its quality indicators, polluting it. Water is loaded with pollutants, becoming used by humans. To obtain a ton of paper, about 100-200 m3 of wastewater results; for one tonne of rubber, 150 m3; for processing a ton of fruit results about 10-20 m3 of wastewater. Wastewater from domestic consumption (domestic water) is quite large. Thus, for a non-industrialized neighborhood in Bucharest, a consumption flow of about 0.35 m3 / inhabitant-day was registered.

In the second case, the naturally polluted meteoric waters dissolve during the rain various toxic gases from the air (sulfur oxides, nitrogen, ammonia, etc.) or are loaded with powders containing metal oxides, tars or other substances. Rainwater or those resulting from melting snow can become dirty during their flow to the soil surface, as a result of contact with various products of human activity (household, industrial waste, fertilizers, pesticides, etc.).

A bilateral relationship is established between wastewater and the environment in which it is discharged; through the impurities they contain, wastewater acts on the environment, often in a negative way, and this, in turn, contributes to the removal of pollutants from the water (self-purification).

Wastewater treatment is the set of measures and processes by which chemical (mineral and organic) or bacteriological impurities contained in wastewater are reduced below certain limits, so that these waters no longer harm the receiver in which they are discharged and no longer endanger use of its waters.

The purification processes are, to a large extent, similar to those that take place during self-purification, only that they are directed by man and are carried out at a much higher speed.

The treatment processes are of physico-chemical, chemical and biological nature, following the application of these processes they result as main products:

• treated water (treated effluent) - which are discharged into the receiver or can be used for irrigation or other uses;

• sludge - which is removed from the station and recovered.

Wastewater treatment therefore comprises the following two major groups of successive operations:

· Retention and / or transformation of harmful substances into neutral products,

· Processing of substances resulting in various forms (sludge, emulsions, foams, etc.) from the first operation.

The wastewater treatment processes, named after the processes on which they are based, are:

· Mechanical processes - in which the purification processes are of a physical nature;

· Chemical processes - in which the purification processes are of a physico-chemical nature;

· Biological processes - in which the purification processes are both physical and biochemical in nature.

Types of treatment plants

Depending on their role in the treatment of all wastewater in a given territory or industrial center, treatment plants are classified as follows:

• local treatment plants (or pre-treatment), which have the role of treating wastewater to a degree of purification necessary to be discharged into public, urban or sewage networks, as well as for the retention and recovery of certain useful substances on containing them;

• general treatment plants, which clean all the water collected from an entire territory of a city or industrial center.

The role of mechanical purification is to retain by physical processes the suspended substances by means of installations whose composition and structure differ according to the size of the suspensions and the processes used: grates, sieves, disintegrators (shredders), desanders, grease separators, decanters, filters, and so on in this technology only finite processes of retention by blocking, sedimentation, flotation, gravitational separation are used.

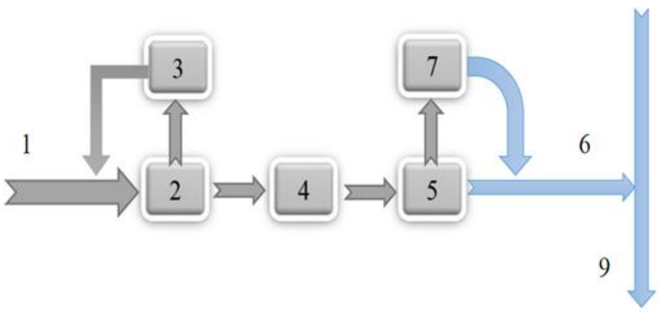


Fig. 2.1– Mechanical treatment scheme [Original scheme F. Nicolescu]

1- influential, 2 - grate, 3 - disintegrator, 4 - desanding, 5 - primary decanter, 6 - decanted water, 7 - drying platforms, 8 - drainage water, 9 - emissary.

Figure 2.1 shows a mechanical treatment scheme with decanter. Suspensions retained from wastewater form sludge which is a viscous, foul-smelling mass with an unpleasant appearance and a high degree of harmfulness. Depending on local conditions, the sludge can be removed fresh or processed in fermentation and then incineration plants. [87]

Mechano-chemical purification

Mechano-chemical purification is a more complex process that involves a mechanical and a chemical step in order to remove the substances present in the water (figure 2.2). Chemical purification aims in particular to retain colloidal suspensions and dissolved substances based on chemical precipitation which is an industrial process of treatment with coagulation and flocculating agents that increase gravimetric deposits by reducing the amounts of suspensions and colloids in wastewater by 60… 85%.

In addition to the frequently used chemical precipitation operation, there are other series of chemical processes such as:

• Neutralization, or correction of the pH index, an operation that applies to acid or alkaline wastewater discharged from various industrial enterprises;

• Ion exchange, based on the acquisition of substances - ion exchangers - to exchange ions in the solution they come in contact with and in which they do not dissolve;

• Chemical oxidation, applied when the wastewater contains bioresistant organic substances or some undesirable inorganic substances by dosing chlorine and its derivatives, potassium permanganate and sodium or potassium ferrites;

• Disinfection, which is based on the principle of destroying the living cell by chemical methods, with reagents that diffuse inside the bacterial cells.

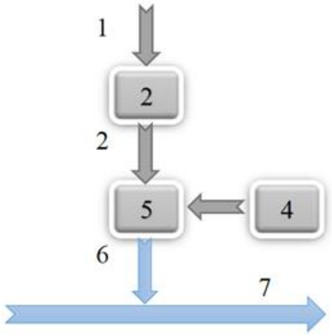


Fig. 2.2 - Scheme of mechano-chemical treatment [Original scheme F.Nicolescu]

1 - influent, 2 - mechanical treatment, 3 - decanted water, 4 - coagulation agent preparation and dosing station, 5 - mixing and reaction tank, 6 - treated water effluent, 7 - emissary.

Mechano-biological purification

Aerobic biological processes are frequently used in the treatment of organic wastewater to achieve a high degree of treatment efficiency and have a high efficiency for wastewater with CBO5 values between 300 - 700 mg / l. The disadvantage of the aerobic process is that the aeration equipment used requires a high energy consumption to introduce air into the system, which means high costs.

For the evaluation of the performance of the aeration equipment, the basic size is the energy index E [kg O2 / kWh] which is recommended to be higher than 3 kg O2 / kWh [60]. Numerous studies have considered that the intensity of hydrodynamics induced in the aeration basin can be assessed globally by the index δ [W / m3], which represents the power of the equipment used for insufflation of oxygen relative to the unit volume of the basin and whose values must exceed 20 W / m3, considered as the lower limit of the evaluation of sludge flakes [39].

Mechano-biological treatment can be achieved through two large groups of buildings in which treatment can occur in conditions close to natural ones - irrigation fields, infiltrations and biological ponds - from which drainage water is collected and discharged as treated water in emissary and constructions in which biological treatment is performed under artificial conditions - biological filters and tanks with activated sludge (figure 2.3).

The natural mechano-biological treatment method (irrigation and infiltration fields) is used less and less rarely due mainly to the large area occupied by the infiltration field, removed from the agricultural circuit and especially due to the danger of infection of the groundwater with pathogenic bacteria. The figure shows the general scheme of a treatment plant.

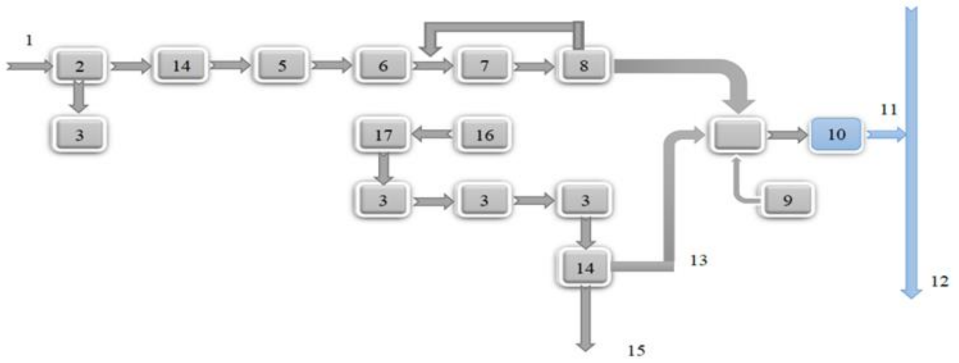


Fig. 2.3 - Scheme of biological treatment with activated sludge [Original scheme F. Nicolescu]

1 - Influential, 2 - grate, 3 - disintegrator, 4 - desanding, 5 - leveling equalization basin, 6 - primary settling tank, 7 - aeration tank with activated sludge, 8 - secondary settling tank, 9 - chlorination plant, 10 - pool contact, 11 - treated water, 12 - emissary, 13 - drainage water, 14 - drying platforms, 15 - sludge for recovery, 16 - sludge concentrator, 17 - sludge pumping station.

Fig. 2.4 Overview of the SEAU Constanța Sud site [internet]

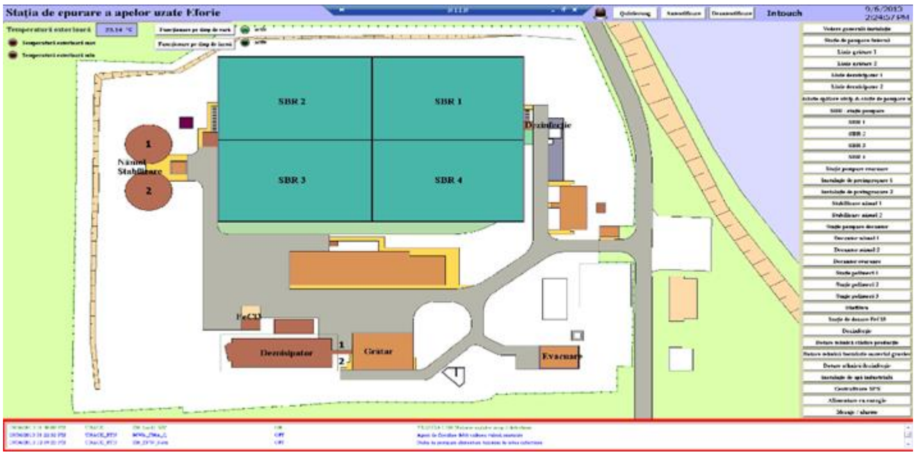


Fig. 2.5 Positioning scheme of SEAU Eforie equipment [internet]

Description of electrical equipment within the SEAU

2.3.1 List of electrical equipment and appliances within the SEAU

Within a wastewater treatment plant there are a multitude of electrical equipment and devices whose role is to ensure the development in good condition and without interruption of the treatment process. When choosing electrical equipment and appliances, it will be considered that their number is equal to the number of necessary equipment plus a spare one.

2.3.2 Transformation stations, transformers

The substations that ensure the power supply of the SEAU are of the type MT / LT, 20 / 0.4 kV and being equipped with electrical transformers whose powers vary between 400 and 630 kVA depending on the value of the active powers of the consumers served by each station transformation in part.

Fig. 2.6 20 / 0.4 kV substation [Original photo F. Nicolescu]

These transformers are three-phase oil-cooled, with adjustment, the circulation of the cooling oil being forced and the cooling of the oil being natural.

Fig. 2.7 - Three-phase transformer with oil cooling 20 / 0.4 kV [Original photo F. Nicolescu]

The medium voltage cells supplied from the national energy system through the 20kV MT network, supply the transformers that discharge voltage on the 0.4 kV LT distribution panels.

Fig. 2.8 - Medium voltage cell [Original photo F. Nicolescu]

2.3.3 Spare generators

Although such objectives are considered particularly important and as such, in theory, the national energy system through local energy distributors must ensure a continuous supply scheme of theirs, there may be situations in which the power supply is interrupted for various periods of time, which would produce major effects at the level of the SEAU. Therefore, when designing the internal power supply system of such an objective, backup power supplies are provided to ensure continuity in the power supply. These backup power supplies are electric generators or generators that are thermal machines coupled to shafts with electric generators.

Fig. 2.9 Electric generator as a backup power supply [Original photo F. Nicolescu]

Since there is no notion of failure in the SEAU, the power of the generators for the backup power supply will be chosen so as to ensure all the necessary power for the operation of the entire SEAU.

The automatic transition from the basic power supply, from the mains, to the backup power supply is done by means of an automation scheme of A.A.R. type, the automatic switching of the reserve.

2.3.4 Electrical switchboards, electrical appliances

Electrical switchboards are complex electrical equipment that have the role of distributing electricity from transformers to consumers powered by its bars. Depending on the complexity of the electrical panels and the functionality they must meet, they are divided into:

• general jt switchboards - they are usually found in the transformer station and ensure the distribution of electricity through cables, main and secondary switchboards;

• main and secondary panels - are fed from the general panels and in turn supply separate sections or technological equipment within the technological process;

• dedicated panels of various equipment (pumps, ventilation, compressors, etc.) - ensures the supply of separate equipment in the technological process.

Fig. 2.10 General electrical panel [Original photograph by F. Nicolescu]

The composition of electrical panels includes several types of electrical appliances, each of them having a well-defined role in the electrical scheme of energy distribution. automatic circuit breakers devices that ensure the connection and disconnection of the power supply circuits of the consumers supplied from the electrical panels.

A contactor is a switchgear with mechanical, electromagnetic or pneumatic actuation, with a single stable position, capable of establishing, supporting and interrupting currents under normal operating conditions for a circuit, (including overload currents).

Due to the very large number of connections that a contactor has to deal with, its contacts are strongly stressed both mechanically, by the strong shocks they withstand at closing, and by electrical and thermal, through the effect of the breaking spring.

Reactive energy compensation is also done at the level of general electrical panels by installing automatic reactive energy compensation batteries.

The regulators shall detect the amount of reactive energy required to be compensated at any given time and shall control the entry into operation of a sufficient number of steps necessary to cover the required reactive energy in the supply system.

The compensation of the reactive energy can be done both at the level of the general low voltage electrical panels from the transformation stations, on each power supply separately, but also locally, at the level of the large consumers that generate the reactive energy.

Figure 2.11 shows an electrical power factor compensation installation (capacitor bank) with 12 compensation stages.

Fig. 2.11 - Automatic local reactive energy compensation battery [Original photo F. Nicolescu]

CHAPTER III

Reliability modeling

3.1. The stages of making a simulation model

The construction of simulation models is a broad process that generally involves the following steps: Defining the problem, this being a very important stage, with great consequences in the development of the simulation model; it must be clear, concise and precise. In this stage the objectives of the simulation are established; the questions to be answered, the hypotheses to be tested and the effects to be estimated. The questions must be clear, the assumptions must be accompanied by acceptance or rejection criteria, and for the effects to be estimated the statistical accuracy of the estimates must be established.

Primary data collection, analysis, interpretation and processing

At this stage it is established what are the observation data necessary for the study of the considered system and what are the ways to collect them. This stage is essential because the collection of erroneous data has great consequences in obtaining the final results, which is why a preliminary analysis and an interpretation of them is necessary to detect any inconsistencies with reality.

Formulation of the simulation model

In order to build a mathematical model for simulating a system, its components are associated with certain variables and parameters, some of which are known (controllable) which are called input variables and parameters, and others unknown (uncontrollable) called variables and output parameters.

The simulation model must contain certain variables that describe the states of the system components (state variables), an agenda that stores the events that occur in the system and routines for producing (generating) different types of events.

The construction of a simulation model differs from one problem to another, which is why some generally valid rules cannot be established. One of these refers to the number of variables that the model uses; too many variables would create difficulties in establishing functional relationships, make the model less flexible, and the computation time would be much longer.

Of great importance in the realization of the simulation models is the obtaining of a reduced calculation time, fact that allows the simulation of the different system variants with reasonable costs (efforts). Another requirement that must be taken into account when building simulation models refers to the means by which the correctness of the model can be verified and the variants to be simulated using the electronic computer - model validation.

Estimation of model input parameters

The input parameters of the mathematical simulation model are estimated by statistical methods, using the data collected (in the first stage) about the real system. Operational characteristics can take the form of equations or systems of equations depending on certain parameters that can be estimated using specific regression analysis techniques.

Model performance evaluation and parameter testing

This "step" aims to check the model before it is programmed. It is checked if the input parameters of the model have been well estimated (using tests of statistical significance), it is checked if the model contains all the essential variables and parameters as well as the functional relations necessary to represent the essential interdependencies of the real system. If following these checks it is found that a question or hypothesis is not formulated correctly, the variables and parameters were not well chosen, the input parameters were not well estimated, or other inconsistencies are found in the model, then all previous steps will be resumed in order to correct them.

Description of the simulation algorithm and writing of the calculation program

Based on the results of the previous stages, the calculation algorithm is built, which represents the logical sequence of events to be reproduced with the electronic computer.

The choice of programming language depends on several factors, from which are mentioned: the computer time required for the simulation, the form in which the simulation results must be printed, the experience as a programmer in the languages mentioned above, etc. Simulation (specialized) languages make it much easier to describe a system and its behavior over time.

Model validation

Validating a model, ie determining the adequacy of the model to reality, is usually a complex and difficult task. The value of a model in relation to its contribution to the study of the concrete modeled situation is determined by its degree of adequacy, ie by the way in which the predictions agree with the observations.

The methods for validating mathematical simulation models are not unique. A first method is to test the model in a particular case, in which the solution is known or can be easily deduced analytically. The second method consists in comparing the simulation results with the data obtained by observing the behavior of similar systems or by comparison with the past evolution of the real system that was simulated. The variants of the model that prove to be inappropriate are modified until solutions are reached that agree with reality.

Simulated data analysis

The results of the simulation show us the “reaction” of the system to the change of the values of the input variables and, moreover, in them we will look for the answers to the questions formulated at the beginning. This is possible by collecting the simulated data, processing it by calculating the statistics for the significance tests and then interpreting the results.

Simulation of the reliability of a system in the design phase

The realization of systems with high reliability in the design phase can be done by simulating different structures (system variants), choosing the one that corresponds to the user's requirements.

Algorithm for calculating the reliability of a system

Calculating the reliability of a complex system is a difficult problem; leads to a large volume of work and is difficult to algorithmize. In such cases, a numerical evaluation of the reliability function can be performed by an experimental method, based on the MatLAB program, using the computer.

Simulation using the Matlab program

The reliability of a system can be assessed if the reliability of its components is known through statistical and probability studies. To simulate a reliability study, it must be specified whether the components are connected in a structural or parallel reliability scheme (Fig. 3.1). In order for the information to pass from A to B, in the series scheme all components must be operating state, while in a parallel reliability scheme at least one component must be in working order.

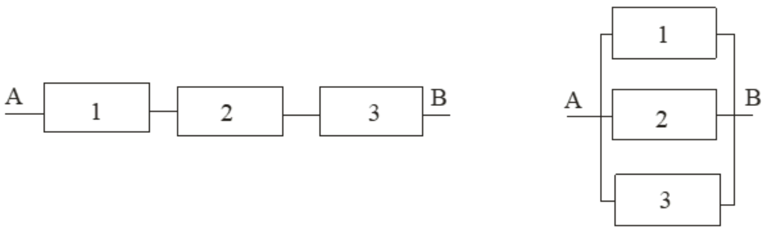


Fig. 3.1 - Structural schemes of serial reliability, parallel [167]

The numerical simulation of the reliability of a system is done according to the following algorithm:

• for n components connected in series, each with reliability p, n numbers are evenly distributed between zero and one. If all n numbers are less than or equal to p, it is estimated that the system works.

• for n components connected in parallel, each with reliability p, n numbers uniformly distributed between zero and one are generated. If at least one of the n numbers is greater than or equal to p, it is estimated that the system is working.

Case study - thermal scanning of electrical panels of a SEAU

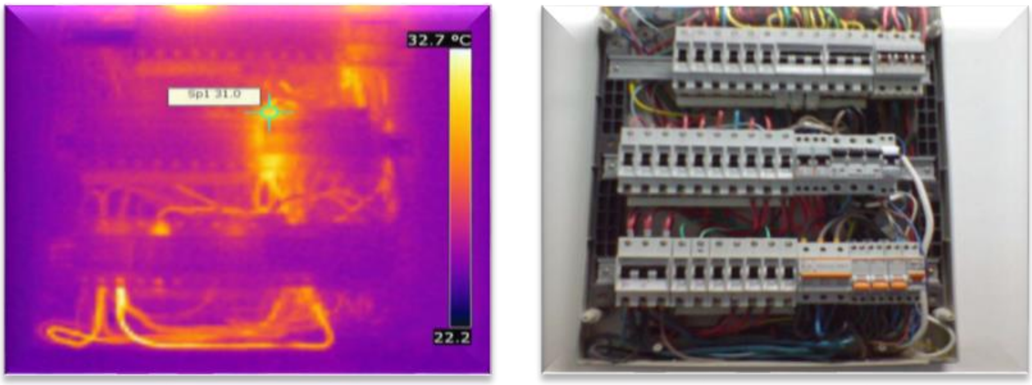
The experimental researches in SEAU Constanța Sud were performed using a FLIR E53 thermographic camera, the electrical panels distributed from the treatment plant were analyzed and analyzed, as well as the identification of real problems with the electrical equipment serving the objective. As can be seen below, the majority of electrical panels operate on nominal parameters, but they have also been identified as a defect in contact or underestimation of the faults of the conductors due to their consumption.

From the images below (Fig. 3.19) a heating is observed at the level of a contact, due to the attachment of two conductors with different sections in the same contact. At the hottest point there is a temperature of 59.2˚C, not very high compared to the temperature of the media observed in the rest of the table, but it is enough to identify the defect. It is recommended to redo the contact.

a) b)

Figure 3.19 - Fault at the terminals of a switch [Original photo F. Nicolescu]

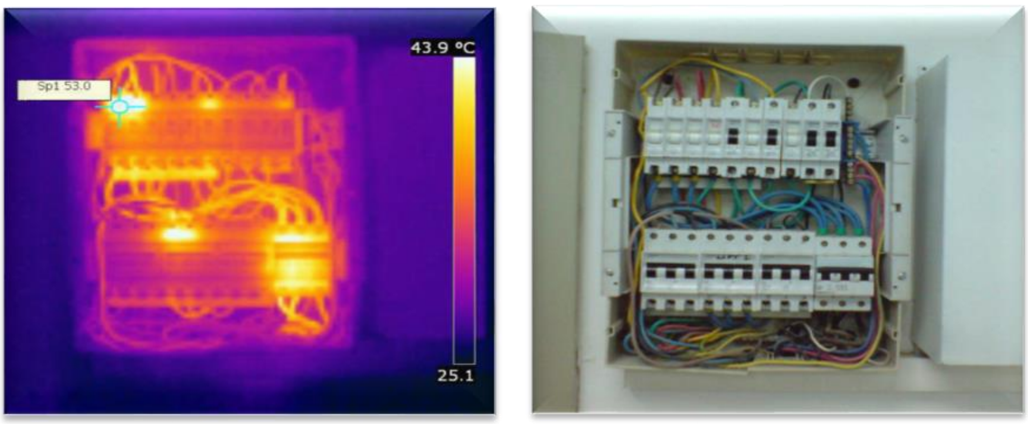
In the second image (Fig. 3.20) is presented a safety panel in which imperfect contacts were identified due to its insufficient tightening of the electrodynamic effect. The temperature determined by the room is 310C. It is recommended to tighten the contacts and replace the two fuses (restore the electrical connections). [151]



a) b)

Figure 3.20 - Fault in the safety panel [original photo F. Nicolescu]

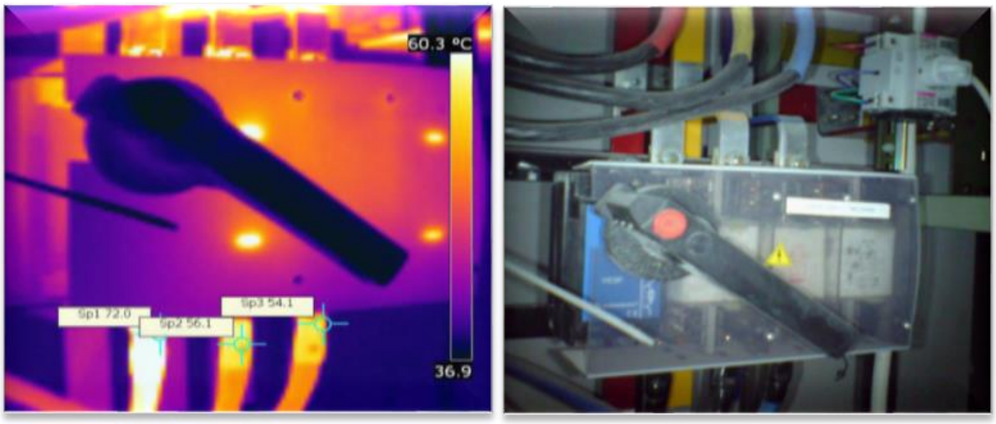
In the images below (Fig. 3.21) it can be seen that in this panel the majority of the contacts are weakened. [151]



a) b)

Figure 3.20 - Fault in the safety panel [original photo F. Nicolescu]

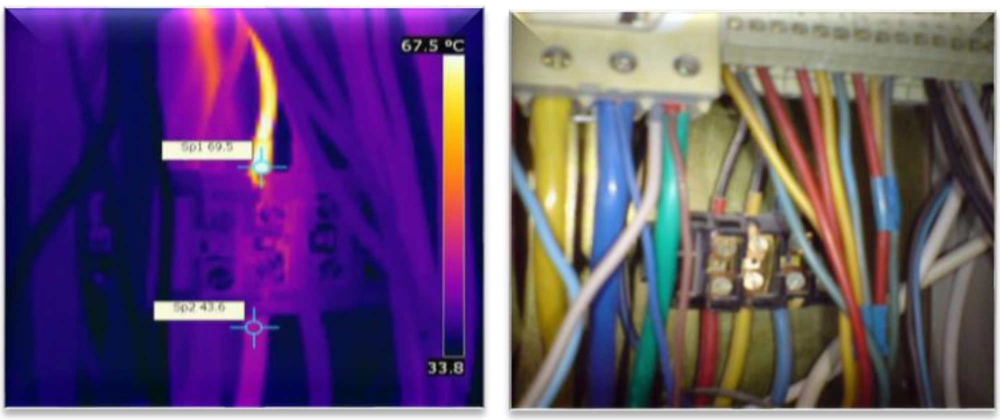
The figure below (Fig. 3.22) shows a separator with MPR type fuses (high breaking power) where an imbalance between phases is observed. In two of the 3 phases, an appropriate temperature is observed (approx. 54˚C), and in the third one a temperature of 72˚C. It is recommended a check in time of the loading on the phases and the permutation of some consumers on the other 3 phases so that it does not exceed a difference of the loading, between the three phases, 15%.



a) b)

Figure 3.22 - Phase separator in imbalance [Original photo F. Nicolescu]

In this image (Fig. 3.23) a defect can be observed at the level of a contact clamp. At the entrance there is a temperature of 69.5˚C per conductor and at the exit 43.6˚C, at a distance between cables of maximum 4-5 cm. It is recommended to replace the respective clamps and to check / repair the contacts. [151]



a) b)

Figure 3.24 - Imperfect contacts [Original photo F. Nicolescu]

CHAPTER IV

4.1. Experimental research on the reliability of treatment equipment.

In this chapter are presented in tabular form the data from the operation of the treatment plant, for a period of three years. A significant period was granted to extract from the registers the data available for the period January 2017 - December 2019, because there was no electronic database. This activity consisted in establishing the type of equipment, the date of finding the defect, the date of entering the repair, the date of leaving the repair and the remedied defects.

The remedied faults were distributed in the table according to the type of equipment, (table no. 4.1). The table is presented in the following form: current number, type of equipment, date of finding the defect, type of defect or corrective action, date of repair.

To evaluate the reliability of a system, mathematical statistics use a series of indicators that characterize certain quantitative properties. These indicators are statistical expressions, based on which certain periods of time are evaluated and analyzing the causes of defects we will establish an appropriate maintenance strategy in order to improve the reliability and availability of a system.

The indicators of the mathematical statistics that characterize the reliability and on the basis of which comparative analyzes are made between different elements, systems of the same type and operated in the same conditions of use are:

1. Average operating time - MTBF

The average good operation time is a reliability indicator frequently used in specialized studies and has two aspects: in the case of non-repairable systems it represents the average value of the operating time until failure - MTTF (mean time to failure) and in the case of repairable systems it represents the value average operating time between failures - MTBF (mean time between failures).

In order to establish the distribution law, a statistical observation of the good operation time of the product is organized.

2. The mean square deviation

The mean square deviation characterizes the scattering of the random variables - times of good operation compared to the mean value.

3. Experimental function of reliability

It is determined as the ratio between the absolute frequency of the elements remaining in operation at time t and the total number of elements.

4. Experimental failure rate

The experimental failure rate or failure rate is defined as the probability of failure at a given time, conditioned by the proper functioning of the system up to that point λ (t). It is calculated as the ratio between the number of k_i elements that fell in the time interval (t_{i-1}, t_i) and the number of N_{i-1} products that did not fall by the time t_{i-1}

5. Fault statistics

By processing the statistical data (observed) according to the attention intervals, the statistical distribution of failures is obtained. Using the graphical method we will pass on the abscissa axis the equal time intervals and on the ordinate axis the number of defective elements and we will obtain the histogram of the absolute frequencies.

A complex table was created in the Excel program with the data regarding the operation time and the repair time for the equipment studied for the period January 2017 - December 2019.

4.2. Wastewater supply pumps

The purpose of determining the statistical parameters of reliability is to obtain indices on the type of distribution law that best adjusts the experimental data.

Procedure:

Preliminarily the n experimental data, denoted by xi are ordered in ascending order. The indicators of location, variation and shape of the distribution are determined.

Location indicators:

Arithmetic mean:

$$Ma = \bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i \tag{4.1}$$

Geometric mean:

$$Mg = \sqrt[n]{\prod_{i=1}^{n} x_i} \tag{4.2}$$

Harmonic average:

$$Mh = \frac{n}{\sum_{i-1}^{n} \frac{1}{x_i}} \tag{4.3}$$

Square mean:

$$Mp = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (x_i)^2} \tag{4.4}$$

Median:

$$me = \frac{x_{\frac{n}{2}} + x_{\frac{n}{2}+1}}{2} \tag{4.5}$$

Central value:

$$x_c = \frac{x_{\min} + x_{\max}}{2} = \frac{x_1 + x_n}{2} \tag{4.6}$$

Variation indicators:

Dispersion:

$$D = \frac{1}{n} \cdot \sum_{i-1}^{n} (x_i - \bar{x}) \tag{4.7}$$

Corrected dispersion:

$$s^2 = \frac{1}{n-1} \cdot \sum_{i-1}^{n} (x_i - \bar{x})^2 \tag{4.8}$$

The mean square deviation:

$$\sigma = \sqrt{\frac{1}{n} \cdot \sum_{i-1}^{n} (x_i - \bar{x})^2} \tag{4.9}$$

Corrected mean square deviation:

$$s = \sqrt{\frac{1}{n-1} \cdot \sum_{i-1}^{n} (x_i - \bar{x})^2} = \sigma \sqrt{\frac{n}{n-1}} \tag{4.10}$$

Coefficient of variation:

$$c_v = \frac{\sigma}{\bar{x}} \tag{4.11}$$

In order to determine the parameters of the function of distribution of the defects of the hydromechanical equipments that are found in the treatment plant used as a case study, the above mentioned methods are applied for each sample of observed data.

Using the Excel program, tables will be compiled with the data necessary to determine all the parameters of the distribution function.

Distribution function parameters for case 1 **Table 4.2**

n	Echipament	Xi	1/Xi	Xi^2	Xi-Xm	(Xi-Xm)^2
1	Pompă apă uzată Nr.1	720	0,001389	518400,00	-11949,88	142799688,25
2	Pompă apă uzată Nr.6	792	0,001263	627264,00	-11877,88	141084089,19
3	Pompă apă uzată Nr.7	936	0,001068	876096,00	-11733,88	137683995,07
4	Pompă apă uzată Nr.4	1704	0,000587	2903616,00	-10965,88	120250575,78
5	Pompă apă uzată Nr.6	2760	0,000362	7617600,00	-9909,88	98205768,25
6	Pompă apă uzată Nr.4	3216	0,000311	10342656,00	-9453,88	89375891,54
7	Pompă apă uzată Nr.3	3768	0,000265	14197824,00	-8901,88	79243509,43
8	Pompă apă uzată Nr.5	4656	0,000215	21678336,00	-8013,88	64222310,37
9	Pompă apă uzată Nr.8	6816	0,000147	46457856,00	-5853,88	34267938,60
10	Pompă apă uzată Nr.3	10320	0,000097	106502400,00	-2349,88	5521947,07
11	Pompă apă uzată Nr.4	10896	0,000092	118722816,00	-1773,88	3146658,60
12	Pompă apă uzată Nr.4	11856	0,000084	140564736,00	-813,88	662404,48
13	Pompă apă uzată Nr.4	11952	0,000084	142850304,00	-717,88	515355,07
14	Pompă apă uzată Nr.8	12384	0,000081	153363456,00	-285,88	81728,72
15	Pompă apă uzată Nr.7	12792	0,000078	163635264,00	122,12	14912,72
16	Pompă apă uzată Nr.9	13056	0,000077	170459136,00	386,12	149086,84
17	Pompă apă uzată Nr.1	14424	0,000069	208051776,00	1754,12	3076928,72

n	Echipament	Xi	1/Xi	Xi^2	Xi-Xm	(Xi-Xm)^2
18	Pompă apă uzată Nr.2	14544	0,000069	211527936,00	1874,12	3512316,96
19	Pompă apă uzată Nr.4	14712	0,000068	216442944,00	2042,12	4170244,48
20	Pompă apă uzată Nr.6	14808	0,000068	219276864,00	2138,12	4571547,07
21	Pompă apă uzată Nr.5	14928	0,000067	222845184,00	2258,12	5099095,31
22	Pompă apă uzată Nr.9	15600	0,000064	243360000,00	2930,12	8585589,43
23	Pompă apă uzată Nr.8	16200	0,000062	262440000,00	3530,12	12461730,60
24	Pompă apă uzată Nr.5	16296	0,000061	265559616,00	3626,12	13148729,19
25	Pompă apă uzată Nr.6	16392	0,000061	268697664,00	3722,12	13854159,78
26	Pompă apă uzată Nr.4	16680	0,000060	278222400,00	4010,12	16081043,54
27	Pompă apă uzată Nr.4	17376	0,000058	301925376,00	4706,12	22147543,31
28	Pompă apă uzată Nr.3	18792	0,000053	353139264,00	6122,12	37480324,48
29	Pompă apă uzată Nr.4	18888	0,000053	356756544,00	6218,12	38664987,07
30	Pompă apă uzată Nr.8	21072	0,000047	444029184,00	8402,12	70595580,96
31	Pompă apă uzată Nr.6	21432	0,000047	459330624,00	8762,12	76774705,66
32	Pompă apă uzată Nr.5	21600	0,000046	466560000,00	8930,12	79747001,19
33	Pompă apă uzată Nr.6	23952	0,000042	573698304,00	11282,12	127286178,60
34	Pompă apă uzată Nr.2	24456	0,000041	598095936,00	11786,12	138912569,19

Pompa apa uzata = Waste water pump

The studied sample refers to a number of nine pumps that have the role of transporting wastewater from a collection basin to treatment plants. The studied period was three years, from January 1, 2017 to December 31, 2019. The studied pumps are electromechanical equipment driven by electric motors that have an installed power / unit Pinst = 11 kW. During the studied period, a number of thirty-four defects were identified and registered. Causes vary from equipment to equipment, but a detailed observation of them draws attention to working conditions.

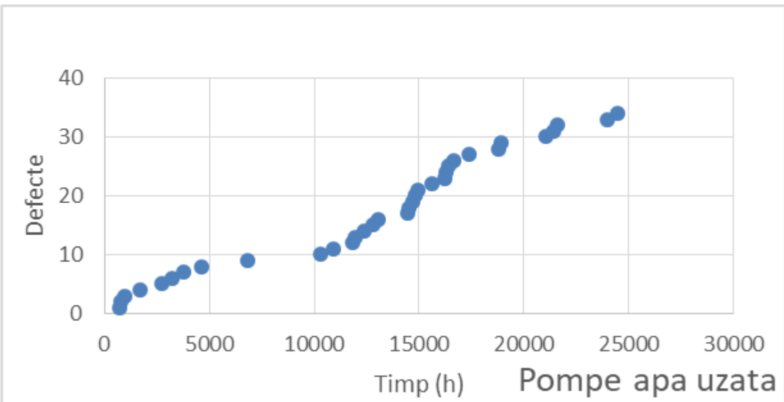


Fig. 4.1- Cumulative rate of defects observed in the time interval studied for raw water pumps [Original figure F. Nicolescu]

Following the statistical analysis of the data in Table 4.2, using the formulas (4.1-4.11) were determined the location and variation indicators of the experimental data series. These are presented in Table 4.3

Tabel 4.3

Location indicators					
Arithmetic mean (Xm)	Geometric mean	Harmonic mean	Square mean	Median	Central value
12669,88	9304,25	4699,65	2469,76	14484	12588
Variation indicators					
Dispersion D	Corrected dispersion s^2	Mean square deviation σ	Corrected mean square deviation	Amplitude W	Coefficient of variation
46864592,22	48284731,38	6845,77	6948,72	23736,00	0,54032

4.3. Polyelectrolyte food pumps

Preliminarily the n experimental data, denoted by xi are ordered in ascending order. The indicators of location, variation and shape of the distribution are determined.

In order to determine the parameters of the function of distribution of the defects of the hydromechanical equipments that are found in the treatment plant used as a case study, the above mentioned methods are applied for each sample of observed data.

Using the Excel program, tables will be compiled with the data necessary to determine all the parameters of the distribution function.

Repatision function parameters for case 2 **Table 4.4**

nr	Echipament	Xi	1/Xi	Xi^2	Xi-Xm	(Xi-Xm)^2
1	Pompă alimentare polielectrolit Nr.1	432	0,0023148	186624	-13172,09	173504034,61
2	Pompă alimentare polielectrolit Nr.8	552	0,0018116	304704	-13052,09	170357132,29
3	Pompă alimentare polielectrolit Nr.3	552	0,0018116	304704	-13052,09	170357132,29
4	Pompă alimentare polielectrolit Nr.4	552	0,0018116	304704	-13052,09	170357132,29
5	Pompă alimentare polielectrolit Nr.8	552	0,0018116	304704	-13052,09	170357132,29
6	Pompă alimentare polielectrolit Nr.2	792	0,0012626	627264	-12812,09	164149727,64
7	Pompă alimentare polielectrolit Nr.4	2592	0,0003858	6718464	-11012,09	121266192,75
8	Pompă alimentare polielectrolit Nr.2	2832	0,0003531	8020224	-10772,09	116037988,10
9	Pompă alimentare	2976	0,0003360	8856576	-10628,09	112956361,31

nr	Echipament	Xi	1/Xi	Xi^2	Xi-Xm	(Xi-Xm)^2
	polielectrolit Nr.1					
10	Pompă alimentare polielectrolit Nr.1	7224	0,0001384	52186176	-6380,09	40705586,99
11	Pompă alimentare polielectrolit Nr.2	7224	0,0001384	52186176	-6380,09	40705586,99
12	Pompă alimentare polielectrolit Nr.1	7344	0,0001362	53934336	-6260,09	39188764,66
13	Pompă alimentare polielectrolit Nr.10	7464	0,0001340	55711296	-6140,09	37700742,33
14	Pompă alimentare polielectrolit Nr.11	8904	0,0001123	79281216	-4700,09	22090874,43
15	Pompă alimentare polielectrolit Nr.1	10176	0,0000983	103550976	-3428,09	11751821,78
16	Pompă alimentare polielectrolit Nr.8	11712	0,0000854	137170944	-1892,09	3580016,01
17	Pompă alimentare polielectrolit Nr.8	14568	0,0000686	212226624	963,91	929116,66
18	Pompă alimentare polielectrolit Nr.6	14904	0,0000671	222129216	1299,91	1689758,15
19	Pompă alimentare polielectrolit Nr.1	15432	0,0000648	238146624	1827,91	3341243,92
20	Pompă alimentare polielectrolit Nr.2	15456	0,0000647	238887936	1851,91	3429559,45
21	Pompă alimentare polielectrolit Nr.10	16104	0,0000621	259338816	2499,91	6249534,89
22	Pompă alimentare polielectrolit Nr.4	16680	0,0000600	278222400	3075,91	9461203,73
23	Pompă alimentare polielectrolit Nr.3	16728	0,0000598	279825984	3123,91	9758794,80
24	Pompă alimentare polielectrolit Nr.1	17688	0,0000565	312865344	4083,91	16678296,19
25	Pompă alimentare polielectrolit Nr.2	17688	0,0000565	312865344	4083,91	16678296,19
26	Pompă alimentare polielectrolit Nr.1	17904	0,0000559	320553216	4299,91	18489200,01
27	Pompă alimentare polielectrolit Nr.2	18288	0,0000547	334450944	4683,91	21938984,57
28	Pompă alimentare polielectrolit Nr.10	18456	0,0000542	340623936	4851,91	23541001,31
29	Pompă alimentare polielectrolit Nr.3	19080	0,0000524	364046400	5475,91	29985557,22

nr	Echipament	Xi	1/Xi	Xi^2	Xi-Xm	(Xi-Xm)^2
30	Pompă alimentare polielectrolit Nr.4	19080	0,0000524	364046400	5475,91	29985557,22
31	Pompă alimentare polielectrolit Nr.1	19104	0,0000523	364962816	5499,91	30248976,75
32	Pompă alimentare polielectrolit Nr.1	19248	0,0000520	370485504	5643,91	31853685,96
33	Pompă alimentare polielectrolit Nr.3	19320	0,0000518	373262400	5715,91	32671592,57
34	Pompă alimentare polielectrolit Nr.1	19680	0,0000508	387302400	6075,91	36916645,59
35	Pompă alimentare polielectrolit Nr.3	19944	0,0000501	397763136	6339,91	40194420,47
36	Pompă alimentare polielectrolit Nr.2	20904	0,0000478	436977216	7299,91	53288641,87
37	Pompă alimentare polielectrolit Nr.2	21480	0,0000466	461390400	7875,91	62029910,71
38	Pompă alimentare polielectrolit Nr.8	21792	0,0000459	474891264	8187,91	67041820,66
39	Pompă alimentare polielectrolit Nr.5	21792	0,0000459	474891264	8187,91	67041820,66
40	Pompă alimentare polielectrolit Nr.6	21792	0,0000459	474891264	8187,91	67041820,66
41	Pompă alimentare polielectrolit Nr.4	22680	0,0000441	514382400	9075,91	82372087,45
42	Pompă alimentare polielectrolit Nr.3	23184	0,0000431	537497856	9579,91	91774617,68
43	Pompă alimentare polielectrolit Nr.3	24120	0,0000415	581774400	10515,91	110584299,54

Pompa alimentare electrolit = Polyelectrolyte feed pump

The studied sample refers to a number of 10 pumps that have the role of transporting water with coagulating agent ($FeSO_4$) from a mixing and reaction tank. The studied period was three years, from January 1, 2017 to December 31, 2019. The studied pumps are electromechanical equipment driven by electric motors that have an installed power / unit Pinst = 5 kW. During the studied period, a number of 43 defects were identified and registered. The main causes vary from equipment to equipment, but a detailed observation of them draws attention to working conditions.

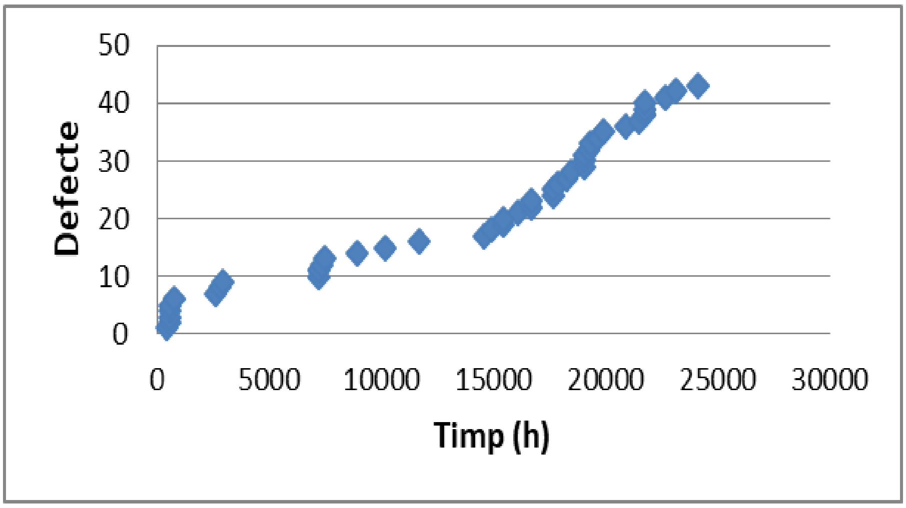


Fig. 4.2- Cumulative rate of defects observed in the time interval studied for polyelectrolyte supply pumps [Original figure F. Nicolescu]

Following the statistical analysis of the data in Table 4.4, using the formulas (4.1-4.11) the location and variation indicators of the experimental data series were determined. These are presented in Table 4.5

Tabel 4.5

Indicatori de localizare					
Media aritmetică (Xm)	Media geometrică	Media armonică	Media pătratică	Mediana	Valoare centrală
13604,09	8862,00	0,000330	2381,69	16392	12276
Indicatori de variație					
Dispersia D	Dispersia corectată s^2	Abaterea medie pătratică σ	Abaterea medie pătratică corectată	Amplitudinea W	Coeficient de variație
58843783,06	60244825,51	7670,97	7761,75	23688,00	0,56387

4.4. Electric panels

Preliminarily the n experimental data, denoted by xi are ordered in ascending order. The indicators of location, variation and shape of the distribution are determined.
In order to determine the parameters of the function of distribution of the defects of the hydromechanical equipments that are found in the treatment plant used as a case study, the above mentioned methods are applied for each sample of observed data.
Using the Excel program, tables will be compiled with the data necessary to determine all the parameters of the distribution function.

Distribution function parameters for case 3 **Table 4.6**

nr	Echipament	Xi	1/Xi	Xi^2	Xi-Xm	(Xi-Xm)^2
1	Tablou Electric Nr.1	144	0,00694	20736	-10654,40	113516239,36
2	Tablou Electric Nr.1	240	0,00417	57600	-10558,40	111479810,56
3	Tablou Electric Nr.6	912	0,00110	831744	-9886,40	97740904,96
4	Tablou Electric Nr.8	2688	0,00037	7225344	-8110,40	65778588,16
5	Tablou Electric Nr.4	3384	0,00030	11451456	-7414,40	54973327,36
6	Tablou Electric Nr.5	7224	0,00014	52186176	-3574,40	12776335,36
7	Tablou Electric Nr.8	9408	0,00011	88510464	-1390,40	1933212,16
8	Tablou Electric Nr.9	10536	0,00009	111007296	-262,40	68853,76
9	Tablou Electric Nr.5	14760	0,00007	217857600	3961,60	15694274,56
10	Tablou Electric Nr.5	14880	0,00007	221414400	4081,60	16659458,56
11	Tablou Electric Nr.6	15600	0,00006	243360000	4801,60	23055362,56
12	Tablou Electric Nr.2	17688	0,00006	312865344	6889,60	47466588,16
13	Tablou Electric Nr.6	20952	0,00005	438986304	10153,60	103095592,96
14	Tablou Electric Nr.9	20976	0,00005	439992576	10177,60	103583541,76
15	Tablou Electric Nr.4	22584	0,00004	510037056	11785,60	138900367,36

The studied sample refers to a number of 9 Electrical Panels that have the role of powering and protecting the equipment of the treatment plant from possible voltage variations. The studied period was three years, from January 1, 2017 to December 31, 2019. During the studied period, a number of 15 defects were identified and registered. The main causes vary from equipment to equipment, but a detailed observation of them draws attention to working conditions.

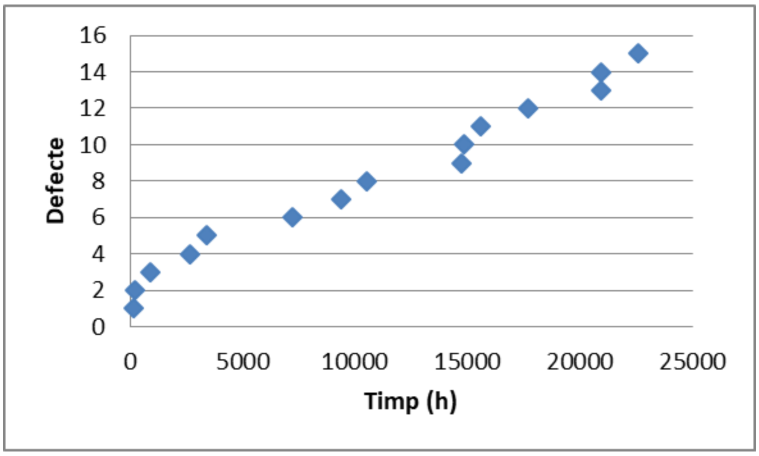


Fig. 4.3- Cumulative rate of defects observed in the time interval studied for Electrical Panels [Original figure F. Nicolescu]

Following the statistical analysis of the data in table 4.6, using the formulas (4.1-4.11) the location and variation indicators of the experimental data series were determined.These are presented in Table 4.7

Indicatori de localizare					
Media aritmetică (Xm)	Media geometrică	Media armonică	Media pătratică	Mediana	Valoare centrală
10798,40	5488,34	0,000907	3435,63	9972	5471,2
Indicatori de variație					
Dispersia D	Dispersia corectată s^2	Abaterea medie pătratică σ	Abaterea medie pătratică corectată	Amplitudinea W	Coeficient de variație
60448163,84	64765889,83	7774,84	8047,73	22440,00	0,72000

4.5. Grills

Preliminarily the n experimental data, denoted by xi are ordered in ascending order. The indicators of location, variation and shape of the distribution are determined. In order to determine the parameters of the function of distribution of the defects of the hydromechanical equipments that are found in the treatment plant used as a case study, the above mentioned methods are applied for each sample of observed data.

Distribution function parameters for case 4 **Table 4.8**

n	Echipament	Xi	1/Xi	Xi^2	Xi-Xm	(Xi-Xm)^2
1	Grătar Nr.5	360	0,002778	129600,00	-20808,00	432972864,00
2	Grătar Nr.4	960	0,001042	921600,00	-20208,00	408363264,00
3	Grătar Nr.3	984	0,001016	968256,00	-20184,00	407393856,00
4	Grătar Nr.3	1248	0,000801	1557504,00	-19920,00	396806400,00
5	Grătar Nr.3	1416	0,000706	2005056,00	-19752,00	390141504,00
6	Grătar Nr.3	1584	0,000631	2509056,00	-19584,00	383533056,00
7	Grătar Nr.3	1704	0,000587	2903616,00	-19464,00	378847296,00
8	Grătar Nr.3	3408	0,000293	11614464,00	-17760,00	315417600,00
9	Grătar Nr.5	6816	0,000147	46457856,00	-14352,00	205979904,00
10	Grătar Nr.4	6888	0,000145	47444544,00	-14280,00	203918400,00
11	Grătar Nr.5	8112	0,000123	65804544,00	-13056,00	170459136,00
12	Grătar Nr.5	8112	0,000123	65804544,00	-13056,00	170459136,00
13	Grătar Nr.3	8496	0,000118	72182016,00	-12672,00	160579584,00
14	Grătar Nr.5	8976	0,000111	80568576,00	-12192,00	148644864,00
15	Grătar Nr.3	9624	0,000104	92621376,00	-11544,00	133263936,00

16	Grătar Nr.4	9624	0,000104	92621376,00	-11544,00	133263936,00
17	Grătar Nr.4	9696	0,000103	94012416,00	-11472,00	131606784,00
18	Grătar Nr.3	9696	0,000103	94012416,00	-11472,00	131606784,00
19	Grătar Nr.1	10128	0,000099	102576384,00	-11040,00	121881600,00
20	Grătar Nr.2	10272	0,000097	105513984,00	-10896,00	118722816,00
21	Grătar Nr.5	10752	0,000093	115605504,00	-10416,00	108493056,00
22	Grătar Nr.1	10632	0,000094	113039424,00	-10536,00	111007296,00
23	Grătar Nr.5	11112	0,000090	123476544,00	-10056,00	101123136,00
24	Grătar Nr.5	12384	0,000081	153363456,00	-8784,00	77158656,00
25	Grătar Nr.4	12528	0,000080	156950784,00	-8640,00	74649600,00
26	Grătar Nr.1	12528	0,000080	156950784,00	-8640,00	74649600,00
27	Grătar Nr.5	12792	0,000078	163635264,00	-8376,00	70157376,00
28	Grătar Nr.4	14640	0,000068	214329600,00	-6528,00	42614784,00
29	Grătar Nr.3	14952	0,000067	223562304,00	-6216,00	38638656,00
30	Grătar Nr.2	15024	0,000067	225720576,00	-6144,00	37748736,00
31	Grătar Nr.4	15216	0,000066	231526656,00	-5952,00	35426304,00
32	Grătar Nr.5	16032	0,000062	257025024,00	-5136,00	26378496,00
33	Grătar Nr.4	17496	0,000057	306110016,00	-3672,00	13483584,00
34	Grătar Nr.4	20712	0,000048	428986944,00	-456,00	207936,00

The studied sample refers to a number of 5 grids that have the role of retaining the sedimentable colloidal particles from the wastewater. The studied period was three years, from January 1, 2017 to December 31, 2019. The screws are driven by electric motors that have an installed power / unit Pinst = 30 kW. During the studied period, a number of 34 defects were identified and registered. The main causes vary from equipment to equipment, but a detailed observation of them draws attention to working conditions.

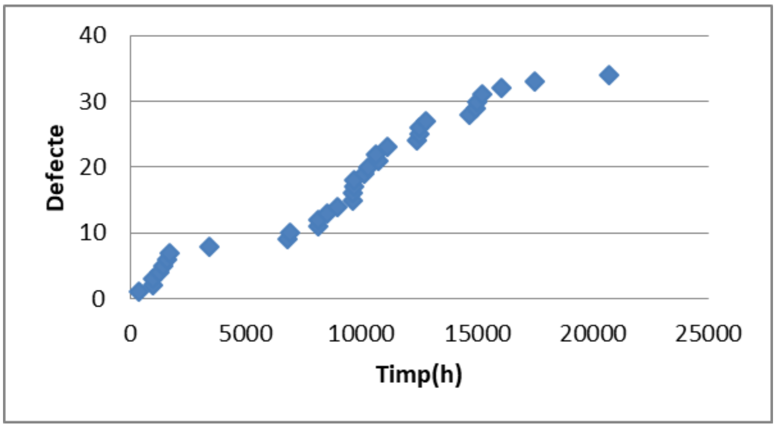


Fig. 4.4 - Cumulative rate of defects observed in the time interval studied for Grills [Original figure F. Nicolescu]

Following the statistical analysis of the data in table 4.8, using the formulas (4.1-4.11) were determined the location and variation indicators of the experimental data series. These are presented in Table 4.9

Tabel 4.9

Indicatori de localizare					
Media aritmetică (Xm)	Media geometrică	Media armonică	Media pătratică	Mediana	Valoare centrală
21168,00	6676,54	3312,74	1825,55	9696	10536
Indicatori de variație					
Dispersia D	Dispersia corectată s^2	Abaterea medie pătratică σ	Abaterea medie pătratică corectată	Amplitudinea W	Coeficient de variație
169282351,06	174412119,3	13010,86	13206,52	20352,00	0,61465

CHAPTER V

5.1 Mathematical modeling of the reliability function of the equipment in the mechanical stage of the treatment plants

Case 1 - Wastewater pumps

Reliability indicators are mathematically estimated based on the “history of events” - respectively, following the analysis of some available information, related to the behavior of the equipment during the period when it was subjected to observation.

The notion of random variable is the one that realizes the mathematical modeling of the desideratum. This provides the possibility to calculate the probabilities of all events of interest in relation to a certain random variable. Examples of random variables, used in reliability theory, are the number of failures that occur in a certain period of operation of a system, the time of malfunction of an element, the level of technological parameters of a system, etc. [119]

From the database created following the time observations of the installations from the studied Wastewater Treatment Plant, a database belonging to the author and comprising the Incident / Intervention Sheets, for all the equipments, the following random variables were chosen:

• the times, tzi (expressed in days), in which the operation of the raw water pumping equipment to the screening plant was interrupted, only those events were taken into account which were followed by corrective actions in the plant in order to restore the system to function;

• the duration of the three corrective actions (expressed in minutes), for the restart of the line.

Following the running of the program, the following graphs are obtained: the graph of operating times between repairs, the graph of repair times and the histogram of repair and operating times.

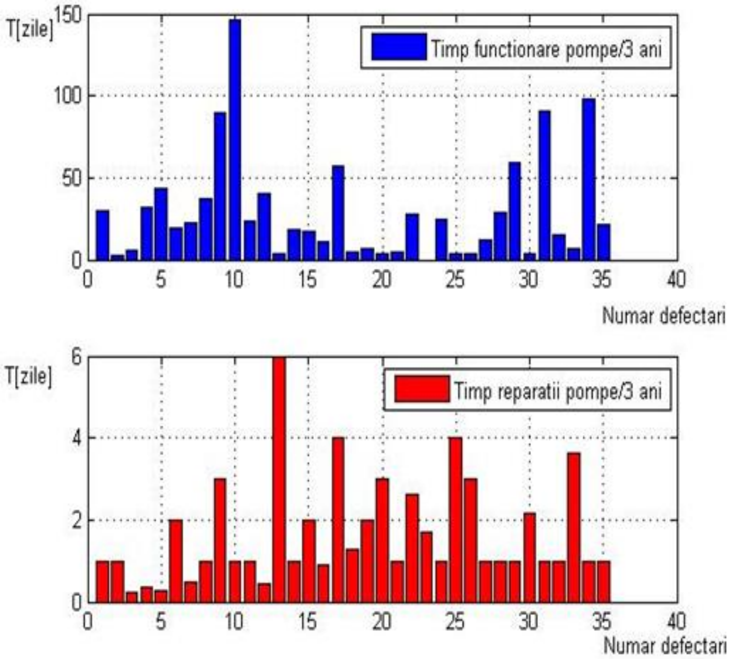


Fig. 5.2 Variation of operating and repair times for wastewater pumps
[Original figure by F. Nicolescu]

Figure 5.2 shows the period of use of wastewater pumping equipment between two consecutive failures. It is also noted that for 10 of the defects the operating period until the next fall was about 150 days.

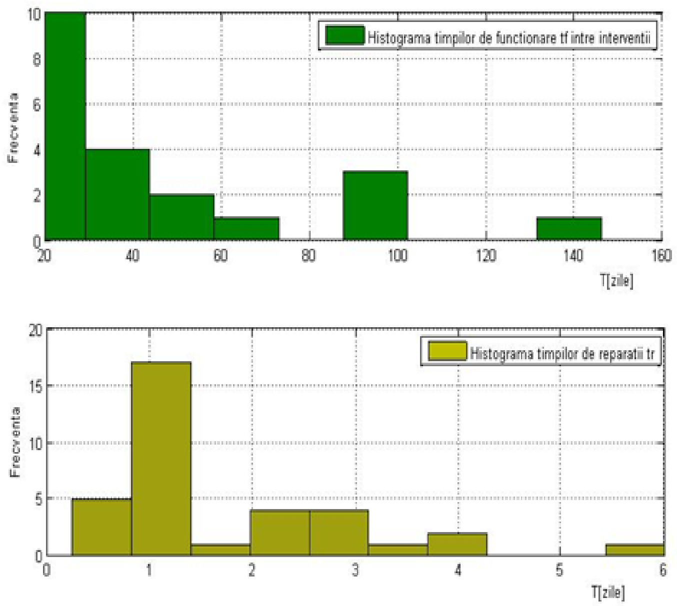


Fig. 5.3 Histogram of operating and repair times for wastewater pumps
[Original figure by F. Nicolescu]

Figure 5.3 shows that most defects, over 90%, were remedied in a very short period, respectively 24 hours.

For the random (experimental) values in Table 5.1, the graph of the reliability and non-reliability function is plotted.

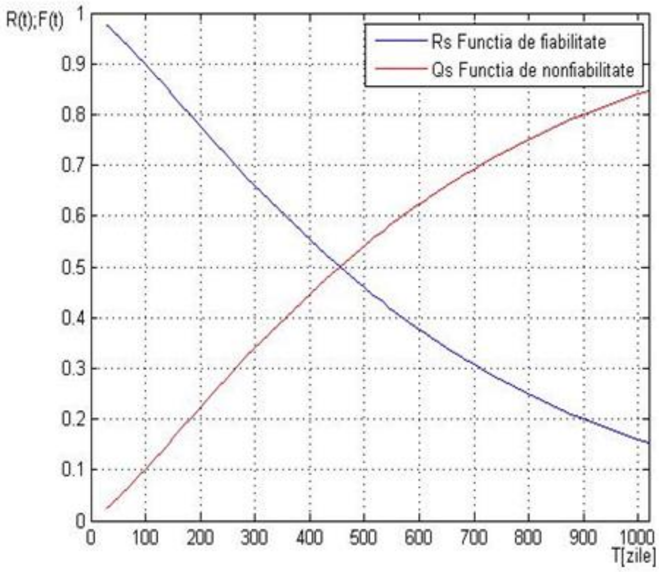


Fig. 5.4 Variation as a function of reliability and non-reliability for wastewater pumps [Original figure by F. Nicolescu]

It is observed that the reliability of the equipment, figure 5.4, studied decreases rapidly, reaching the value of 50% after only 450 hours of operation. As the values obtained from operation are truncated, the observation period does not coincide with the period of commissioning of the installation, the graph of the variation of the reliability function is considered correct. The studied period can be considered the period of late defects, where the defect rate is very high and the probability of a defect is very high.

The chosen experimental function does not take into account the external factors that influence the reliability rate. It is based only on the durations determined in Table 5.1. Table 5.3 shows the factors that influence the equipment failure rate.

Tabel 5.3

Nr evenimente	10	5	12	8
Anotimp	Iarnă	Primăvară	Vară	Toamnă
Pondere	29%	14%	34%	23%

After analyzing the types of defects and the period of time in which they occur, it can be concluded that an important influence on the reliability of pumping equipment has defects caused by bearing failure, mechanical blockages and failures in the sealing system and bearings. Most faults occur in cold periods and high flow periods, when equipment is more demanding, according to the data in Table 5.3.

Taking into account the experimental data from tables 5.2 and 5.3 in the analyzed experimental function, a series of coefficients will be introduced that take into account these types of defects.

The proposed function has the following mathematical expression:

$$RN(t)=K*\beta*\left(\frac{Fp*F*Fu}{t}\right)^{(\beta-1)}*\exp\left[-\lambda*\left(a+b*\frac{t}{T_N}\right)\right] \quad (5.19)$$

where:
k - calibration constant
Fp - power factor; $F_p=\frac{P_{nom}}{P_{abs}}$
F- season factor
Fu- use factor - takes into account the operating mode: intermittent or continuous

$$F_u=\frac{Ore_{fct}}{24} \quad (5.20)$$

a- environmental factor
b-correction factor that takes into account the importance of the equipment
TN - standard operating time - for raw water pumping equipment is considered to be 15 years
λ - scale parameter
β- shape parameter

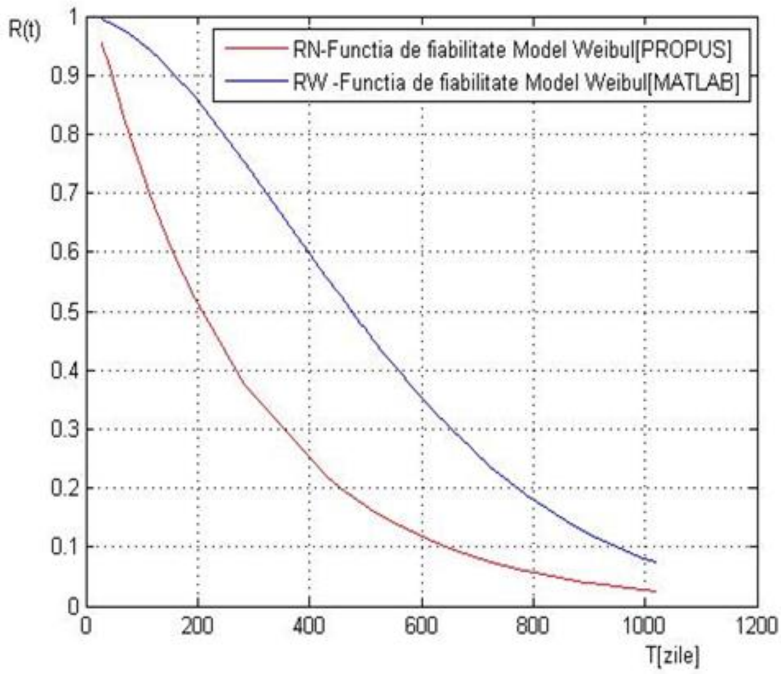


Fig. 5.5 Variation of the reliability and non-reliability function for the improved mathematical model [Original figure F. Nicolescu]

Following the running of the program, the following values result for the coefficients of the considered function:

General model:
f(x) = a*exp(-b*10^-3*(c+d*x/10000))
Coefficients (with 95% confidence bounds):
a =1.176 (-4.348e+07, 4.348e+07)
b =140.7 (-5.248e+08, 5.248e+08)
c =0.1901 (-2.628e+08, 2.628e+08)
d =141.2 (-5.267e+08, 5.267e+08)
Goodness of fit:
SSE: 0.094
R-square: 0.9698
Adjusted R-square: 0.9668
RMSE: 0.05506

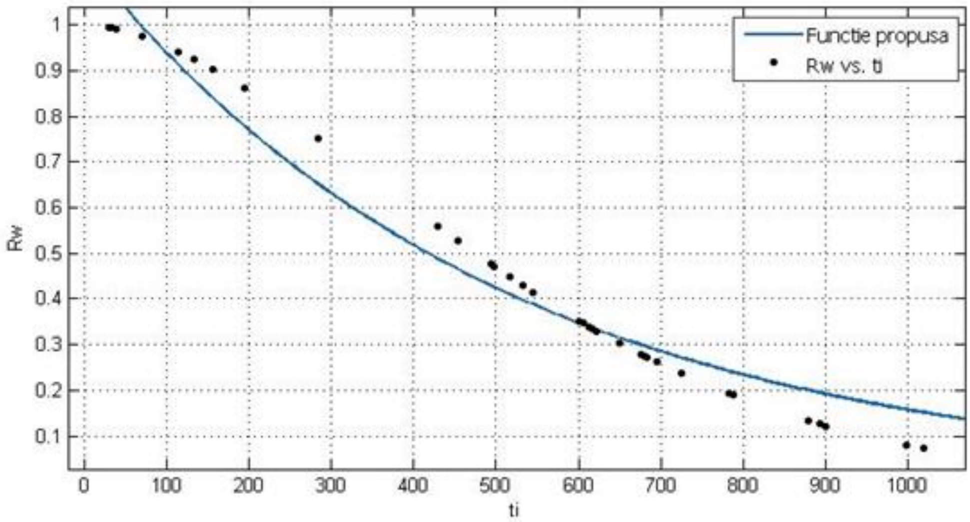


Fig. 5.6 Variation of the reliability function for the improved mathematical model [Original figure F. Nicolescu]

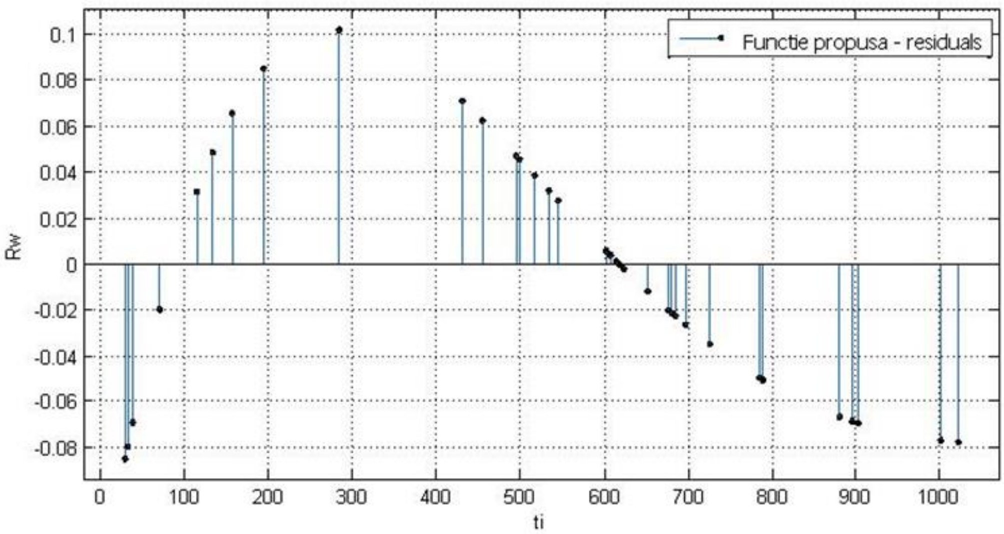


Fig. 5.7 The value of errors [Original figure F. Nicolescu]

Figures 5.6 and 5.7 show that the calculated error between the proposed and the actual function falls within the value limits [+0.1; -0.08], so it is less than 1%. It can be stated that the proposed function is viable.

From the analysis performed, the following mathematical function results to determine the reliability:

Case 1		
		k=1
	f(x) = a*exp(-b*10^-3*(c+d*x/10000))	Fp=0,75
	Coefficients (with 95% confidence bounds):	Fu=0,33
	a =1.176 (-4.348e+07, 4.348e+07)	F=3,415
	b =140.7 (-5.248e+08, 5.248e+08)	a=0,1901
	c =0.1901 (-2.628e+08, 2.628e+08)	b=141,2
	d =141.2 (-5.267e+08, 5.267e+08)	
Case 2		
		k=1
	f(x) = a*exp(-b*10^-3*(c+d*x/10000))	Fp=0,8
	Coefficients (with 95% confidence bounds):	Fu=0,08
	a = 1.134 (-1.045e+06, 1.045e+06)	F=13,15
	b = 198.7 (-8.016e+08, 8.016e+08)	a=0,07419
	c = 0.07419 (-4.673e+06, 4.673e+06)	b=198,6
	d = 198.6 (-8.014e+08, 8.014e+08)	
Case 3		
		k=1
	f(x) = a*exp(-b*10^-3*(c+d*x/35000))	Fp=0,62
	Coefficients (with 95% confidence bounds):	Fu=0,04
	a = 1.286 (-1.1e+06, 1.1e+06)	F=29,37
	b = 256 (-6.806e+08, 6.806e+08)	a=0,866
	c = 0.866 (-2.208e+06, 2.208e+06)	b=256
	d = 256 (-6.806e+08, 6.806e+08)	
Case 4		
		k=1
	f(x) = a*exp(-b*10^-3*(c+d*x/8500))	Fp=0,7

	Coefficients (with 95% confidence bounds):	Fu=1
	a = 1.098 (-1.539e+06, 1.539e+06)	F=1,21
	b = 439.6 (-1.253e+09, 1.253e+09)	a=0,008092
	c = 0.008092 (-3.189e+06, 3.189e+06)	b=439,6
	d = 439.6 (-1.253e+09, 1.253e+09)	

GENERAL CONCLUSIONS

The need to address this issue stems from the fact that all equipment in sewage treatment plants must operate continuously in difficult working conditions. The requirements imposed on wastewater treatment plants are strict, regulated by current legislation, and involve the continuous operation of the equipment at the initial design parameters in order to maintain the wastewater treatment process at a high efficiency.

It is emphasized that the SEAU processes have a continuity character imposed by the very fact that water always enters the station from the sewerage network. Processes cannot be managed independently. This requires a special approach and justifies the special nature of the operation of machinery and equipment that must have a high reliability and endurance.

The opportunity to develop the chosen topic is to sound the alarm to the authorities in order to introduce in the award documentation and in the design regulations the reliability indicators for the equipment to be used in operation.

Reliability analyzes aim to study the determination of performance and improve reliability, achievable based on data from tests and operation. One of the important requirements in the calculation of treatment equipment is to maintain the values of reliability indicators for as long as possible.

The importance of studying the reliability of treatment plants is due to the following factors: increasing the complexity of technical systems of facilities and functions that such systems must perform, intensifying equipment operating regimes, diversifying operating conditions, high requirements for quality of systems, introduction partial or total automation and increased operating costs require a mathematical approach to reliability issues.

Regardless of the atmospheric conditions, the season or the parameters of the wastewater, the equipment serving the treatment plant must ensure the efficiency of the treatment process and ensure the fulfillment of the discharged water discharge parameters over a standard working period (endurance and operational reliability) of 20 -50 years.

The limitations encountered in the literature have led to the development of new mathematical models for determining reliability, thus creating a better correlation between theoretical models and experimental reality.

Probability theory is a very useful tool in the study of processes, systems, elements that have a character of repeatability of data or take place under similar conditions.

The study carried out on the current state of research on reliability tests allows the formulation of the following conclusions:

• reliability is a complex issue given the probabilistic nature of reliability characteristics and the fact that their determination involves long tests of reliability;

• it is necessary to establish a concordance between the results and indicators established on the basis of mathematical modeling and those estimated on the basis of operational information;

• reliability is based on the calculation and statistical analysis of data obtained from the study of product behavior during testing, so as to estimate the reliability indicators;

• when the long duration of the tests raises the cost of operations unacceptably much and when the need to obtain information quickly on a product is pressing, accelerated reliability tests are used;

Reliability analyzes are based on the notions of probability, random variables, distributions for random variables, but also methods and statistical models of analysis.

Among the distributions presented in the thesis it can be stated that:

• Poisson distribution plays a special role in reliability studies, it describes the law of occurrence of random defects in a complex system, when defects occur suddenly;

• the law of normal distribution is frequently used in error theory;

• the exponential distribution has an essential role in the theory of reliability and in the practical calculation, this, because there are complex systems or elements from the system that have the good functioning time distributed according to an exponential law;

• The Weibull distribution is used in the reliability study due to the fact that the intensity of the faults has multiple forms (depending on the values of the parameter □). Reliability indicators are characteristic quantities that allow the quantitative assessment of the level of reliability of the systems.

The reliability function allows:

• assessing the level of confidence in using a system at a certain time in his life;

• comparing the level of reliability of some systems made by different manufacturers;

• comparison of the conditions of use of some systems made by the same manufacturer, but with different users.

The density function of the good operation time represents the ratio between the number of failures that occur in the unit of time during a subinterval and the number of systems initially observed, so it represents the failure rate of the systems.

Probability density of good operation time:

• allows the appreciation of the production if it refers to devices made by a single company (homogeneity of production);

• provides information on the homogeneity of the requirements in use and the quality and frequency of maintenance operations;

• is useful in planning the maintenance activity.

The failure rate is the ratio of the number of failures per unit time produced in a time sub-interval to the number of devices in good working order at the beginning of the observation sub-interval.

Failure rate:

• allows the comparison of the reliability level of the devices made by different manufacturers;

• allows the comparison of the conditions of use of the same type of devices;

• allows the identification of the stage in the life of the devices and, implicitly, of the nature of the faults;

• Expressed in malfunctions / unit of time.

The failure rate is in the form of a bathtub and is characteristic for three periods:

• the period of early failures - or the running-in period, where premature falls occur that have a high frequency, due to hidden causes and deficiencies in quality control of manufacturing. Early failures occur due to assembly errors, quality defects in execution, running in over the nominal value of the parameters, operator and maintenance errors. Period I is characterized by Weibull - type distributions with $\beta < 1$ or hyper - exponential.

• the basic period - or the useful life period, is the main period of operation (maturity period) of a system, with the longest duration. Under normal conditions the falls are random, relatively constant, the general characteristic of this period being the low frequency of failures. For this period, applying a maintenance strategy characteristic of the system in relation to the intensity of failures, we increase the life period, but until its moral depreciation. The base period is characterized by a Weibull distribution with $\beta = 1$, becoming exponentially negative.

• late failure period - the aging period is characterized by a sudden increase in the frequency of failures due to accelerated wear, fatigue or aging of the system. Maintaining the product during this period is uneconomical. This period is not very reached, because the moral depreciation of the system occurs. The aging period is characterized by a normal distribution.

MTBF is an indicator that assesses the overall level of reliability of the devices, is expressed in hours and is used to make comparisons between different components of the same type taking into account the price of those products.

The mean square deviation represents the degree of scattering of the values of the random variable during good operation compared to the mean value m.

Increasing reliability is a condition characterized by a progressive improvement in an entity's reliability performance over time.

The improvement of reliability is represented by a process carried out with the deliberate intention of improving the reliability performance, by eliminating the causes of systematic failure and / or by reducing the probability of occurrence of other failures.

The problem of choosing the statistical model represents, from the point of view of statistical theory, a problem of establishing the concordance between an empirical distribution - provided by a certain experiment - and the theoretical distribution chosen as a model.

The quality and reliability requirements require statistical-mathematical analysis and modeling for the planning, analysis, control and engineering interpretation of statistical data, in order to optimize the system requirements.

Ensuring the continuity of the operating regimes of the installations and equipment serving the treatment plants is a basic requirement of the processes in the field of environmental protection and especially in wastewater treatment. A treatment technology is a sum of unitary processes based on physical, chemical and biochemical phenomena, which requires a detailed analysis of the optimal solution used. The wastewater treatment process is characterized by phenomena that evolve continuously, which requires a continuous operation of installations and equipment in the parameters imposed by the specifications or design regulations.

The level of training of the operating personnel, as well as of the professionals, the intervention technique on the faults, but also the methods and procedures for their realization are the main assets to carry out the operation of the treatment plant operatively, efficiently and safely.

Reliability is maintained through the use of appropriate methods of preservation, transport and commissioning and by properly organized operation and service with suitably qualified personnel.

Technical systems can be considered to be composed of a certain number of elements that are arranged in a certain configuration to fulfill their mission.

Logical (structural) reliability models are used in most reliability analyzes. By logical model of reliability is meant an equivalent logic diagram, which describes the operation of the system from a reliable point of view, so we find schemes of series, parallel, mixed (parallel - series or series - parallel), backup systems, and non-decomposable systems that is analyzed by methods known to engineers.

The analysis of the functional scheme of the installations in the treatment plant leads to the realization of the logical scheme of reliability, this appealing to the theory of conditioned probabilities, because the treatment process depends on the operation of each piece of equipment.

Increasing reliability is a condition characterized by a progressive improvement in the reliability performance of an entity over time.

The improvement of reliability is represented by a process carried out with the deliberate intention of improving the reliability performance, by eliminating the causes of systematic failure and / or by reducing the probability of occurrence of other failures. In order to increase reliability, it is possible and necessary to act in all the stages that a device or installation goes through: conception, design, manufacture, test, transport, assembly, commissioning, operation, maintenance and repair.

The influence of the human factor on the operational reliability of treatment plants is major. This can be manifested in the design, installation and maintenance stages. Failure to take into account the contribution of the human factor to the determination of operational reliability leads to overestimated assessments of this indicator which, in practice, can have serious consequences for the health of the human population and the environment.

The reliability of the installations and equipment in the treatment plants depends on factors of a physical, chemical, mechanical nature. These factors were not taken into account in the study of the reliability of the equipment in the treatment plants, which makes it necessary to determine the coefficients and parameters specific to the treatment process to be introduced in original reliability laws and allow theoretical data to approach the experimental reality.

Statistical processing of experimental data is required to determine reliability indicators.

The main stages of the experimental data processing procedure are the following:

a. collection of experimental data, based on tests and trials in operation and / or laboratory, or following the simulation of the operation of the products;

b. the verification of the statistical homogeneity of the experimental data, which consists in the verification of their random character and the elimination of the aberrant values;

c. the graphical representation of the experimental data, in order to determine the experimental distribution that the experimental data follow;

d. adopting the theoretical distribution, based on the experimental one, using one of the usual distributions used to study reliability: exponential, normal, lognormal distribution, Weibull, Gamma, etc .;

e. estimating the reliability indicators, using one of the methods: the graphical method, the least squares method, the moments method, the maximum likelihood method;

f. proposing a new relationship to take into account "in situ" operating factors

g. validation of the theoretical distribution adopted based on analytical tests (general or special) such as: Chi2 test, Kolmogorov-Smirnov test, Lilliefors test, Hahn-Shapiro test, Nancy Mann test, tec.

The analyzed data from the operation correspond to the wastewater treatment plants, which are in the third period of operation in terms of reliability analysis (aging period).

The hypothesis H0 regarding the type of distribution function was stated and the methods of maximum probability were used, for the statistical estimation of the parameters, finally applying the Chi2 concordance test. The hypotheses stated for the maximum likelihood method verify the Weibull distribution of the parameters λ and β.

So the reliability function of the equipment in the treatment plant, original proposed by the author is of the type:

$$R(t)=K^{*}\beta^{*}\left(\frac{Fp^{*}F^{*}Fu}{t}\right)^{(\beta-1)} {}^{*}\exp\left[-\lambda^{*}\left(a+b^{*}\frac{t}{T_N}\right)\right]$$

It is also observed that the average maintenance time for fault repairs is 48 hours, a very high value in relation to the operating conditions imposed by the specifics of this activity. These huge differences are due to the management of maintenance logistics, which includes: the limit of spare parts, the availability of repairers and their performance and last but not least planning the execution of general repairs, taking into account the current repairs.

The mathematical function that models the values from the operation for the fall times of the equipment from the treatment plant through the Matlab program is of Weibull type but has been improved by introducing some operating and environmental parameters. The average good operation times being 549.16 hours, it results that once a month one of the equipment will fail. After 2 years, the reliability function decreases to 50%, a relatively short time, so the hydromechanical equipment, due to exceeding the normal use period, no longer behaves very well in operation and a rigorous calculation must be performed to determine a policy to ensure effective maintenance.

Original contributions

The doctoral thesis includes a synthesis of the newest and most effective theoretical methods for the study, maintenance and improvement of reliability, and its contents do not lack complex original elements based on the analysis and modeling of operating values.

The original contributions that were the basis for the completion of the Doctoral Thesis, consist of:

- Elaboration of the current state of reliability theory in Chapter I, knowing that reliability analyzes are based on the notions of probability, random variables, distributions for random variables, but also methods and statistical models of analysis.
- Analysis of the types of defects of the installations and equipment in the treatment plants and realization of the logical scheme of reliability for different types of equipment.
- Cataloging the defects according to their nature and determining the factors that influence the operation in good conditions of the equipment.
- Determination of the theoretical distribution for the failure values of the equipment in the treatment plant, based on mathematical statistics, obtaining the mathematical function of the type: $R(t)=e^{-\lambda t^{\beta}}$
- Improving the initial mathematical model by adding its own coefficients, which take into account the working conditions. Following the study, it was found that the determination of the reliability of the equipment in the treatment plants does not take into account the external factors that act on the installations as well as the flow regimes. It was wanted to improve the classical mathematical models used to determine reliability by adding new coefficients that take into account the operating conditions.
- Modeling the reliability of hydromechanical equipment, using the maximum likelihood method and the MatLAB program, thus resulting in the mathematical function of the form:

  $$R(t)=K*\beta*\left(\frac{Fp*F*Fu}{t}\right)^{(\beta-1)}*\exp\left[-\lambda*\left(a+b*\frac{t}{T_N}\right)\right],$$

  where, $F_p=0,75$, $F_u=0,33$, $F=3,415$, $a=0,1901$, $b=141,2$.
- Completion in the Excel program of a complex table with data on operating time and repair time for the equipment studied for the period January 2010 - December 2012.
- Modeling the values from the operation for the fall times of the equipments from the treatment plant through the MatLAB program with the help of some calculation algorithms of own conception. These mathematical models are determinations made for more intense stress regimes, compared to the theoretical nominal regime determined by the manufacturer, and aim to intensify the degradation processes of products, and as an economic result shorten the test period and costs, keeping the same modes. , fault mechanisms and fault structures.

- Modeling these values in the MatLAB program on the Weibull type distribution, for which the parameters λ, β, Fp, Fu, F, a and b were determined. The purpose of these mathematical modeling was to identify the external factors that influence the operation of the equipment. and their introduction into complex mathematical functions to better determine the reliability of mechanical equipment used in sewage treatment plants.
- Synthesizing the theoretical and technical solutions for maintaining the reliability of the equipment in the treatment plant in order to use viable methods to solve the real situations of operational logistics.
- For the first time, research was carried out by thermal vision methods on electrical equipment. These allowed the formulation of the conclusions of the presence of the doctoral thesis as well as a clear identification of the place where the defects appear in the electrical part and of the ways for removing them.

Future research directions

The paper is based on theoretical mathematical foundations and engineering applications and opens new research horizons in the field of reliability, availability and maintenance to solve the real situations of operational work in the SEAU.

Analysis of the reliability of modern installations during late faults, determination of the mathematical function that characterizes this period of operation, determination of reliability indicators, and monitoring the behavior of equipment during running-in and normal operation.

Evaluation of costs for ensuring the maintenance of the installations in the treatment plants.

Analysis of the operation of the equipment from the point of view of the forced operation, determination of the forcing coefficient by categories of equipment.

Determining the optimal solutions for diagnosing defects during operation.

Achieving an optimal maintenance logistics based on the mathematical functions determined in the thesis.

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