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Preface

We would like to present, with great pleasure, the inaugural volume-4, Issue-11, November 2018, of a scholarly journal, *International Journal of Engineering Research & Science*. This journal is part of the AD Publications series *in the field of Engineering, Mathematics, Physics, Chemistry and science Research Development*, and is devoted to the gamut of Engineering and Science issues, from theoretical aspects to application-dependent studies and the validation of emerging technologies.

This journal was envisioned and founded to represent the growing needs of Engineering and Science as an emerging and increasingly vital field, now widely recognized as an integral part of scientific and technical investigations. Its mission is to become a voice of the Engineering and Science community, addressing researchers and practitioners in below areas

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Textile Engineering	Nano Engineering
Algorithm and Computational Complexity	Artificial Intelligence
Electronics & Communication Engineering	Image Processing
Information Retrieval	Low Power VLSI Design
Neural Networks	Plastic Engineering

Each article in this issue provides an example of a concrete industrial application or a case study of the presented methodology to amplify the impact of the contribution. We are very thankful to everybody within that community who supported the idea of creating a new Research with IJOER. We are certain that this issue will be followed by many others, reporting new developments in the Engineering and Science field. This issue would not have been possible without the great support of the Reviewer, Editorial Board members and also with our Advisory Board Members, and we would like to express our sincere thanks to all of them. We would also like to express our gratitude to the editorial staff of AD Publications, who supported us at every stage of the project. It is our hope that this fine collection of articles will be a valuable resource for *IJOER* readers and will stimulate further research into the vibrant area of Engineering and Science Research.

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Constructing an Algorithm for Selecting the Number of Histogram Bins in Statistical Hypothesis Testing for Normal Distribution of Sample Data

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***Abstract*—** *Practice, on the whole, makes extensive use of the vast range of assumptions and conjectures in regards to the type of frequency distribution in statistical samples, the deviations from which would significantly affect the qualities of the model and the estimation accuracy of its parameters. Regrettably, a reliable and clearly defined criterion as to their permissibility is completely absent.*

For instance the fish stock assessment procedure is initially based on assumption that the frequencies in the length-frequency samples used for estimation of growth parameters of fish and analysis of the stock status are normally distributed or follow approximately the normal distribution [15,17].

The purpose of the present study is to construct an algorithm for identification of the statistical distribution of a random variable focusing on the proper selection of the number of histogram bins and further assessment of its impact on the stochastic models delivered. To that effect, appropriate simulation studies have been carried out to compensate for the lack of any concrete evidence related to the potential impact of the number of bins in the histogram and the overall data accuracy on the results of the application of the statistical criterion for the verification of the law of distribution. Applied has been the direct statistical method for determining the law of the distribution - chi-square criteria along with some indirect methods. Provided for the simulation studies were machine-generated data sets and the relevant simulations were held in MATLAB programming environment.

***Keywords*— histogram bins, length-frequency samples, normal distribution, stochastic modeling, stock assessment.**

I. INTRODUCTION

Exploring the law of random variable distribution is the first fundamental step in a researcher's journey into the possibility for obtaining specific targeted information about the object of their study. Analyzing experimental data and displaying it graphically in a histogram offers the scientist a better insight into the intricate pattern of statistical regularity, which, in turn, will help them draw the relevant inferences about the events and processes under study. Undoubtedly, the information thus obtained is often insufficient and requires further refinement through the use of more scientifically-based methods of knowledge acquisition and attainment of improved objectivity and decision quality.

Indeed, thorough awareness of the distribution law, along with its underlying parameters, opens up the possibility for the parameters of the object under exploration to be modeled with sufficient accuracy, and to be validated as unbiased estimates of the general population (herein, class biological objects) with sufficient accuracy and thus, provides an effective means of solving various prediction problems.

In probability theory and mathematical statistics, the normal distribution, or the Gaussian distribution is continuous and gives a good approximate description of the samples, with the data values being tightly grouped round the mean, and distributed symmetrically to form a bell-shaped density curve.

It is widely applicable for mathematical descriptions of real-world phenomena and processes as well. This is ascribed to the validity of the central limit theorem that the sum of a large number of independent random variables with arbitrary laws of distribution is considered as such with a normal distribution of the variables.

The density function of the normal distribution has the form:

$$f(x;m,\sigma) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{(x-m)^2}{2\sigma^2}\right] \quad (1)$$

where, the mathematical expectation m and the standard deviation σ are the distribution parameters characterizing: the distribution center and its scale, and σ^2 the variance around the mean m:

$$m = \int_{-\infty}^{\infty} x.f(x)dx \tag{2}$$

$$\sigma^2 = \int_{-\infty}^{\infty} (x-m)^2.f(x) \tag{3}$$

Here$-\infty < x > \infty$,$-\infty < m > \infty$, σ > 0.

.....The unbiased and significant estimates of the mathematical expectation and variance, upon the splitting of sample into "k" bin intervals are:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{k} x_i^* n_i = \sum_{i=1}^{k} x_i^*.P_i, \text{ where: } P_i = \frac{n_i}{n} \tag{4}$$

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{k} n_{i.}(x_i^* - \bar{x})^2 = \frac{n}{n-1}\sum_{i=1}^{k}(x_i^* - \bar{x})^2.P_i \tag{5}$$

Here x_i^* is the middle of "i_{-th}" interval, and n_i is the number of data occurrences (observed frequencies) within that interval.

Asymmetry (skewness) and excess play an important role in the normal distribution. Their values characterize the deviation of a particular distribution from the norm. Their estimates of the finite number of values of random variables are:

$$m_3 = \sum_{i=1}^{k}(x_i^* - \bar{x})^3/n \tag{6}$$

$$m_4 = \sum_{i=1}^{k}(x_i^* - \bar{x})^4/n - 3 \tag{7}$$

The asymmetry for a symmetric distribution is zero. Conditional upon the sign of asymmetry, the distribution can be left-skewed with (negative) asymmetry with the tail to the left of the centre of the grouped frequency distribution, or right-skewed, i. e. with positive asymmetry.

II. DETERMINING THE LAW OF RANDOM VARIABLE DISTRIBUTION ON THE BASIS OF STATISTICAL ANALYSIS OF EXPERIMENTAL DATA

The most common type of problem is when they obtained experimental data is used to determine the statistical parameters, such as point estimates of the distribution, with the law of distribution not having been completely settled.

Formulated, on this basis, is the following general algorithm with the subsequent estimates of the specific distribution parameters (all the observations have been made by assumed normal distribution of the data in the statistical inferences of experimental sampling):

Step 1. The sample is split into k bin intervals;

Step 2. The indirect criteria are determined–moments of the distribution, the mode, the median, the mathematical expectation and the number of occurrences within the intervals: $M \pm \sigma - 68{,}25\%$; $M \pm 2\sigma - 95.45\%$;$M \pm 3\sigma - 99{,}75\%$. The proper selection of the model for describing empirical data is not determined unilaterally through the above-defined indicators and does not guarantee its adequacy. Statistical methods are required to assess the adequacy of the selected model.

Step 3. Formulating the null hypothesis at level of significance $\alpha$and probability p allows for the empirical distribution to approximate the selected theoretical distribution. Applying statistical methods to verify the consistency of the empirical distribution with a given theoretical distribution–whereupon, the research practice encourages the extensive use of normality tests: the Pearson's criterion χ^2 (chi-square), Kolmogorov-Smirnov test, Fisher exact test and *etc.*

MATLAB with its highly advanced problem-solving tools and capabilities is, indisputably, the most productive programming environment. In cases where certain physical, even biological, processes require further elucidation, additional simulation methods are there to bring more accuracy and efficiency.

Addressed, in light of the discussion so far, are the following issues and tasks related to the analysis and determination of the law of distribution of statistical and experimental samples (growth-frequency, weight characteristics or experimental samples for determining the indices of abundance /biomass of renewable marine living resources):

1) The study of the above described biological objects (BO) should meet the requirement for consistency of data in the experimental and statistical samples with the normal distribution;

2) Determining the law of distribution of random variables, which may refer to the growth (length or weight) characteristics of the surveyed BO, creates two problems associated with data collection and processing: the selection of data splitting bin intervals for the construction of the histogram and the impact of the data accuracy on the derivation of theoretical distribution. The right selection of the number of bins should be considered carefully when applying this criterion since it directly affects the respective number of the degrees of freedom. The larger the number, the more reliable the criterion is in recognizing the correct distribution to the given data.

3) The insufficient information as regards the issues stated above calls for their further elucidation and detailed exploration through the use of simulation modelling.

4) Deriving universal algorithm for research studies into the law of distribution of a random variable and its successful adaptation and application to the actual experimental and statistical data obtained from technical, natural and human systems.

III. SIMULATION STUDY OF THE EFFECT OF THE ACCURACY OF THE EXPERIMENTAL DATA AND THE NUMBER OF HISTOGRAM BIN INTERVALS ON THE PATTERN OF STATISTICAL DISTRIBUTION

The density function of the empirical distribution provides a complete description of the particular characteristic features of a given random variable. The algorithm, adopted to help determine the law of the empirical distribution according to the experimental data, is as follows:

1) Collection of information about the examined random variable through appropriate observations or experiments. As a result, the statistical sequence $x_1, x_2, x_3 \dots x_n$ is registered and x_{min} and x_{max} are there upon computed;

2) The range of x_{min} - x_{max} is split into k intervals;

3) Identified are the observed frequencies within every interval n_i;

4) Determined are the probabilities (empirical) for every interval: $p_i = \frac{n_i}{n}$;

5) A histogram is under construction, which is a corresponding approximation to the density function of the random variable distribution;

6) The resultant histogram is compared to the theoretical distributions and the most appropriate pattern is selected for the purposes of obtaining data approximation with sufficient accuracy;

7) The distribution parameters have been established;

8) The selected law is put to the test to validate the extent to which its underlying parameters are consistent with the relevant experimental data.

The algorithm, thus outlined, makes no reference as to the selected number of intervals k to split the volume of the sample. As specified in [7,8,10,13], the number of the groups k varies from 5 to 20, being contingent upon the amount of data, and when conducting hypothesis testing as to the criterion χ^2, the theoretical frequency n_{i_t} in each group (interval) should be > 5. Serious disruption or failure to comply with this condition is likely to result in intervals being integrated or joined together.

In line with [3], what is normally selected is $k = 7 - 20$ intervals. The width (size) of the group intervals shapes or presupposes the type of the respective histogram. With smaller intervals there are few possibilities of occurrences in them and the subsequent histogram is then a poor "transmitter" of the distinctive characteristic features of the surveyed distribution. Similarly, the larger the intervals, the more distorted is the conjecture of the specific properties of examined distribution.

As stated in [4] a normal approximation which will be sufficiently accurate in practice implies that all the frequencies observed in all of the intervals are $n.p_i \geq 10$, and if not, recommended is consolidation of neighboring groups, so that the condition is fulfilled. With a large number of observations within the range of 200-300 or more, $k = 10 - 20$. Frequently, with an assumed normal distribution, $k = 12$. With a larger number of intervals, the pattern of distribution gets distorted and results in random zigzag motion following the specific changes in the frequency. With a smaller number of intervals, the characteristic features of the distribution are also modified.

In keeping with [6,8], the number of the intervals can be specified in terms of the semi-empirical formula $k \approx 1 + 3.22 * \log_{10}(n)$.

Equally applicable as well are other formulas for calculating the number of intervals:

- $k = \left\lceil \frac{x_{max} - x_{min}}{h} \right\rceil$ such as that of Venables and Ripley, where: h - is a pre-selected value for the width of the interval;
- $k = \sqrt{n}$, *where*: n is the number of observations (the size of the sample), integrated in the statistical analysis functions in Excel (univariate:histograms) and other specialized programs;
- Sturgis' formula: $k = [log_2 n] + 1$ – not recommended for $n < 30$, as the number of intervals will be too small to realistically reflect the actual pattern of distribution and is considered therefore inappropriate for distributions other than normal [9,16];
- The Rice rule [11]: $k = \left\lceil 2n^{\frac{1}{3}} \right\rceil$;
- Doane's formula – modification of the Sturgis' formula proposed by Doane to improve the results in the study of data that do not follow a normal distribution [5]:

  $k = 1 + log_2(n) + log_2(1 + \frac{|g_1|}{\sigma_{g_1}})$, where: $g_1$the calculated value for the third moment of distribution m_3 – or the asymmetry a:$\sigma_{g_1} = \sqrt{\frac{6(n-2)}{(n+1)(n+3)}}$;
- Scott's normal reference rule for determining the optimal bin interval width: $h = \frac{3.5\hat{\sigma}}{n^{\frac{1}{3}}}$, where: $\hat{\sigma}$is the standard deviation of the sample. The Scott's rule is optimal in reference to random normally distributed samples in the sense of minimizing mean integrated square error of the distribution density estimates (empirical and theoretical) [12];
- Friedman-Diaconis' rule to determine the width of the interval: $h = 2\frac{IQR(x)}{n^{1/3}}$, where: $IQR(x)$is the interquartile range (or the distance between the third and the first quartile of the distribution) [6].

The development of computer technologies creates ample opportunities for the research studies to be undertaken in simulated environment which, in turn, allows for further complementation and concretization and, to a certain extent, customization of the recommendations in relation to the analysis and validation of the assumptions that the data follows a normal distribution in the relevant statistical (experimental) samples.

IV. IDENTIFICATION OF THE LAW OF DISTRIBUTION

The law of distribution plays a crucial role in the quality of the estimates for the process and object parameters. There is no data in the literature as to the impact of the random errors accompanying distributed data sets that help assess the quality of the applied criteria for testing normal distribution hypotheses. It is also evident from the previous paragraph that there is a lack of uniformity in the process of selection of the sample splitting bin intervals in the construction of the empirical distribution. This necessitates additional targeted research in this direction.

The present and the following paragraphs deal with the issue of the most effective method for verifying the consistency of the experimental data with a selected theoretical distribution (normal distribution) in the presence of poor data quality (added error of measurement), as well as the effect of the selected number of bin intervals.

The research will focus on the law of normal distribution, since the analysis of the growth-frequency samples and the subsequent estimation of the BO's growth parameters rely on its assumed validity.

According to literature data, there exist two types of criteria for testing the validity of the normal distribution: direct and indirect.

The indirect methods for determining the parameters of the stochastic distribution are reduced to the analysis of: mode, median, mathematical expectation (mean) – and when the data follows a normal distribution, the values for the three mathematical characteristics of the distribution are the same, deviations of asymmetry and excess from the standard type of distribution, range of distribution and the number of occurrences within the intervals:$M \pm \sigma - 68{,}25\%$; $M \pm 2\sigma - 95.45\%$;$M \pm 3\sigma - 99{,}75\%$.

Among the direct methods for determining the law of distribution (criteria), a well–established criterion with practically proven performance characteristics is the χ^2 (chi-square) criterion, which is highly efficient for samples with volume values $n \geq 100$ [3,4,7,13,14,19].

If the observation frequency that has been determined experimentally by data analysis techniques does not differ significantly from the frequency predicted by the selected theoretical law, then, it may be selected as a mathematical model describing the distribution of the random variable.

A parameter that facilitates the estimation of difference between the observed and expected (theoretical) frequencies (or the deviation of the observed distribution from the theoretical one) is the variable χ^2[3,4,7,13,14,19]. In mathematics, it is generally known as chi-square criterion for testing statistical hypotheses. By definition, $\chi^2 = \sum_{i=1}^{k} \frac{(n_i - n_{i\_t})^2}{n_{i\_t}}$, where: n_{i_t}– is the theoretical number of occurrences, in accordance with the selected theoretical law of assumed distribution. For practical implementation of the criterion, raised is a null hypothesis H_0, (at level of significance α, probability p and degrees of freedom $\nu = n - l - 1$, where l is the number of parameters of the law of distribution) which is to certify that the difference between the empirical and theoretical distributions, with the pertinent parameters, is insignificant. If the hypothesis testing validates that the calculated value χ^2 is less than the critical tabular value χ^2_{cr}, then, H_0 shall be accepted.

The proposed research applies the method of simulation and explores lenght-frequency samples obtained from scientific experiments. Conducted in MATLAB programming environment have been simulation studies for 2 biological objects (BO): BO_1 (length of sprat) and similarly for BO_2 (anchovy), with $k = var$ and different accuracy of the data, reflecting the inaccurate measurements of the growth parameters or the variability in the natural environment of the surveyed BOs. Presumably, these effects exert a profound influence on the accuracy of the results when determining the law of BOs parameters distribution. The parameters of the simulation models are close to those of the experimental measurements of randomly selected samples from commercial catches and are:

a) BO_1 – for length: $M = 9.3\ cm; S = 0.8\ cm$; sample size: $n = 1000$ individuals;

b) BO_2 - for length; $M = 12.3\ cm; S = 1.15\ cm$; sample size: $n = 230$ individuals.

The values for L_{sim}, simulated according to the models described, have been contaminated with normally distributed noise, characterized by zero mathematical expectation $M = 0$ and standard deviationσ, generated in the MATLAB programming environment using the function R = normrnd(mu,sigma), which generates random numbers with a normal distribution with a mathematical expectation mu and a standard deviation sigma (which may be vectors, matrices, or multi-dimensional arrays) [18].

- Determined is the standard deviation of the input data: $L(t)$: $S_L = Std(L_{sim})$;
- Calculated is the noise-to-signal ratio: $S_{relL} = \frac{S_e}{S_L} 100(\%)$.

MATLAB program has been developed with the purpose of facilitating the implementation of an algorithm for stochastic analysis and modeling the data distribution in statistical samples with the appropriate graphic representation of the results. In addition, provided is information as to prompt decision-making when the qualities of the model are being verified, by applying the chi-square criteria to validate the consistency of the model with the theoretical distribution. Proposed also is information about the indirect criteria for assessing the consistency of the empirical and theoretical distribution. Since the required arrays are of large dimensions, applied, in statistical processing, is bin interval splitting of the algorithm input data.

The program was developed under the presumed pursuit for a normal distribution and with the explicit aim of eliminating the routine calculations. Created, thus, is an opportunity to explore different numbers of bins and their effect on the stochastic model of empirical distribution.

The results of the program implementation are: the parameters of the distribution and the statistical verification of the law of distribution according to the chi-square criteria. Attained is also information about the indirect indicators of the normal distribution.

V. RESULTS OF SIMULATION STUDIES INTO THE LAW OF FREQUENCY DISTRIBUTION IN THE SIMULATED SAMPLES

5.1 Simulation results of BO_1 - length

The research was conducted under the following initial conditions:

1) $L_{BO_1} = L_{sim}$; characterized by: $M = 9.3086$ cm, $S_{L_{sim}} = 0.8261$;

2) $L_{BO_{1e1}} = L_{sim} + e_1$, the standard deviation of the error being: $S_{e_1} = 0.0457$, the noise-to-signal ratio:

$S_{relL} = \left(\frac{S_{e1}}{S_{L_{sim}}}\right) * 100 = 5.5283\%$ or an added measurement error ≈ 5,5%;

3) $L_{BO_{1e2}} = L_{sim} + e_2$, *the standard deviation of the error being* $S_{e_2} = 0.0997$, *the noise-to-signal ratio:*

$S_{relL} = \left(\frac{S_{e2}}{S_{L_{sim}}}\right) * 100 = 12.0637\%$ or an added measurement error ≈ 12%;

4) Pearson's chi-square test has been applied to a level of significance α.

The results of the simulation studies and graphic interpretation are given in *Appendix1*, tables 1-1to 1-3.

Varying with the number of splitting bin intervals $k(5-20)$ of the array data L, calculated, through the use of the program, are the values of the chi-square criteria χ^2 and the indirect methods of validating the law of distribution: the number of occurrences in the intervals $M \pm S$; $M \pm 2S$; $M \pm 3S$, the asymmetry, the excess of distribution and the number of intervals for which $n_{i\_t} < 5$.

Table 1-1 (*Appendix 1*) presents the results of the simulation study for $L_{BO_1} = L_{sim}$. Parameters of distribution are: $Me = 9.4326$; $Mo = 9.3067$; $M = 9.3086$, sufficiently close values, which may serve as a basis for the adoption of the normal distribution.

For all the values of k from 5 to 20, the chi-square criterion and the indirect criteria recognize the normal distribution as valid.

Table 1-2 (*Appendix 1*) shows the results of the simulation study for $L_{BO_{1e1}} = L_{sim} + e_1$.Parameters of distribution are: $Me = 9.4710$; $Mo = 9.3098$; $M = 9.3118$, sufficiently close values, which may serve as a basis for formally acknowledging the status of the normal distribution.

For all the values of k from 5 to 20, the chi-square criterion and the indirect criteria recognize the normal distribution as valid.

Table 1-3(*Appendix 1*) displays the results of the simulation study for $L_{BO_{1e2}} = L_{sim} + e_2$. Parameters of distribution are: $Me = 9.3623$; $Mo = 9.3036$; $M = 9.3026$, sufficiently close values, which may serve as a basis for formally acknowledging the status of the normal distribution.

For all the values of k from 5 to 20, the chi-square criterion and the indirect criteria recognize the normal distribution as valid.

5.2 Simulation results of BO_2 - length

The research was conducted under the following initial conditions:

1) $L_{BO_1} = L_{sim}$; characterized by: $M = 12.3323$см, $S_{L_{sim}} = 1.1035$;

2) $L_{BO_{1e1}} = L_{sim} + e_1$, the standard deviation of the error being: $S_{e_1} = 0.0596$, the noise-to-signal ratio:

$S_{relL} = \left(\frac{S_{e1}}{S_{L_{sim}}}\right) * 100 = 5.3988\%$ or an added measurement error ≈ 5.5%;

3) $L_{BO_{1e2}} = L_{sim} + e_2$, the standard deviation of the error being: $S_{e_2} = 0.1253$, the noise-to-signal ratio:

$S_{relL} = \left(\frac{S_{e2}}{S_{L_{sim}}}\right) * 100 = 11.3523\%$ or an added measurement erro r ≈ 11%;

4) Pearson's chi-square test has been applied to a level of significance α.

The results of the simulation studies and graphic interpretation are given in *Appendix 1*, tables 1-4 to 1-6.

Varying with the number of splitting bin intervals $k(5-20)$ of the array data L,calculated, through the use of the program, are the values of the chi-square criteria χ^2 and the indirect methods of validating the law of distribution: the number of occurrences in the intervals M$\pm S$; M$\pm 2S$; M$\pm 3S$, the asymmetry, the excess of distribution and the number of intervals for which $n_{i\_t} < 5$.

Table 1-4 (*Appendix 1*) presents the results of the simulation study for $L_{BO_1} = L_{sim}$. Parameters of distribution are: $Me = 12.6105$; $Mo = 12.3313$; $M = 12.3323$, sufficiently close values, which may serve as a basis for the adoption (assumption) of the normal distribution.

For all the values of k from 5 to 20, the chi-square criterion and the indirect criteria recognize the normal distribution as valid.

Table 1-5 (*Appendix 1*) displays the results of the simulation study for $L_{BO_{1e1}} = L_{sim} + e_1$.Parameters of distribution are: $Me = 12.5559$; $Mo = 12.3658$; $M = 12.3655$, sufficiently close values, which may serve as a basis for formally acknowledging the status of the normal distribution.

For all the values of$k$from 5 to 20, the chi-square criterion and the indirect criteria recognize the normal distribution as valid.

Table 1-6 (*Appendix 1*) displays the results of the simulation study for $L_{BO_{1e2}} = L_{sim} + e_2$. Parameters of distribution are: $Me = 12.5165$; $Mo = 12.3371$; $M = 12.3397$, sufficiently close values, which may serve as a basis for formally acknowledging the status of the normal distribution.

For all the values of k from 5 to 20, the chi-square criterion and the indirect criteria recognize the normal distribution as valid.

VI. RESEARCH INTO THE LAWS OF BO PARAMETER DISTRIBUTION OF REAL DATA

An experimental approach was adopted for collection of statistical data (total body length measurements of sprat and anchovy) to support the stochastic modeling process and distribution analysis. The samples are taken from commercial catches (stationary pound nets – with mesh size 7.5 mm). The fish was caught on 1st of May 2017, near Varna, Bulgaria - "Trakata" area. The catch composition was presented by two species– Sprat (Sprattus Sprattus) as a targeted catch and anchovy (Engraulis Encrasicolus) as a by-catch. The samples processed for further analysis are: n=1000 individuals of sprat and $n = 230$ individuals of anchovy. The body length measurements of the samples have been recorded and processed to form the input massive for calculations done by the specified in paragraph 4 script developed in MATLAB programming environment. The null hypothesis is formed under the above-described conditions, stating that sample data follows the normal distribution. Respectively an alternative hypothesis is that the sample data do not follow the normal distribution.

6.1 Stochastic model of length frequencies in the sample of BO_1

The results of the research study are registered in table 1-7 of *Appendix 1*.

The minimum and maximum values for this particular BO are: $x_{min} = 6.3$cm, $x_{max} = 13$cm; $n = 1000$; $M = 9.3086$ cm; $S = 0.8261$ cm.

Application of Pearson's chi-square test produces positive results when $k = 6, 8,11,13$, i.e. the distribution of the length frequencies in the sample of BO_1 does not contradict *Ho* for normal distribution.

The indirect criteria as well as the close values: $Me = 9.6500$cm; $Mo = 9.3217$; $M = 9.3217$; also point to this conclusion.

The model has the following form:

$$f(x; m,\sigma) = \frac{1}{0.8261\sqrt{2\pi}} \exp[-\frac{(L_i - 9.3086)^2}{2 * 0.6824}]$$

Fig. 1 introduces the empirical and theoretical probabilities in intervals, as well as the predicted values of the approximating model when $k = 6,8,11,13$.

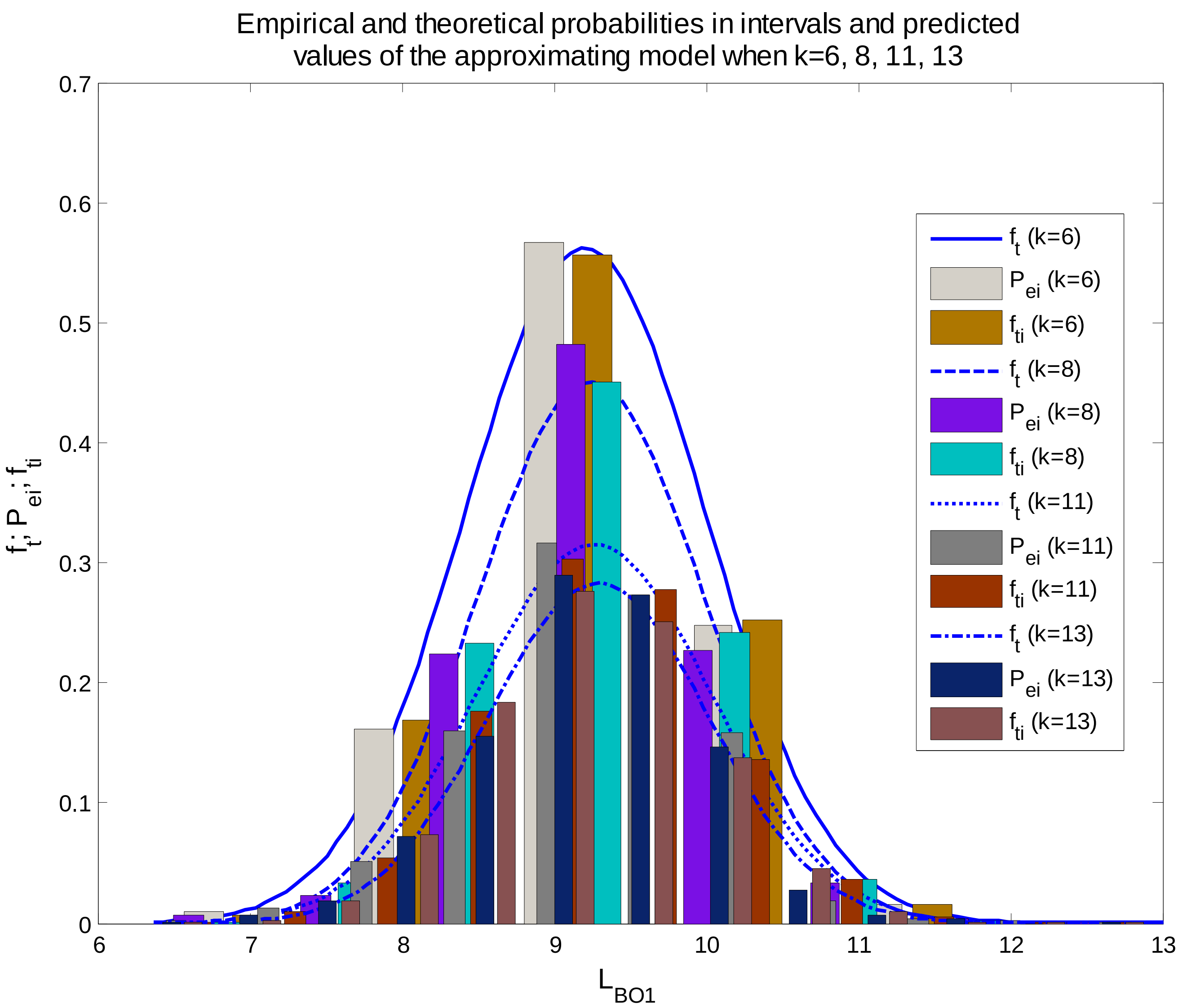

FIGURE 1. Empirical and theoretical probabilities in intervals and predicted values of the approximating model when k =6,8,11,13 (length BO1)

6.2 Stochastic model of linear dimensions (length) of BO_2

The results of the research study are registered in table 2-15 of *Appendix 2*.

The minimum and maximum values for the sample are: $x_{min} = 9.00$ cm, $x_{max} = 14.50$ cm.$n = 230$, $M = 12.0226$ cm; $S = 1.0197$cm.

Application of Pearson's chi-square test produces positive results when $k = 6,8,9,10,12,16$, i.e. the distribution of the linear dimensions of BO_2 does not contradict the raised *Ho* for normal distribution of sample data.

The indirect criteria as well as the close values: $Me = 11.75$cm; $Mo = 12.0250$; $M = 12.0226$; also point to this conclusion.

The model has the following form:

$$f(x;m,\sigma) = \frac{1}{1.0197\sqrt{2\pi}} \exp\left[-\frac{(L_i - 12.0226)^2}{2*1.0398}\right]$$

Fig. 2 introduces the empirical and theoretical probabilities by intervals, as well as the predicted values of the approximating model when $k = 6,8,9,10,12,16$.

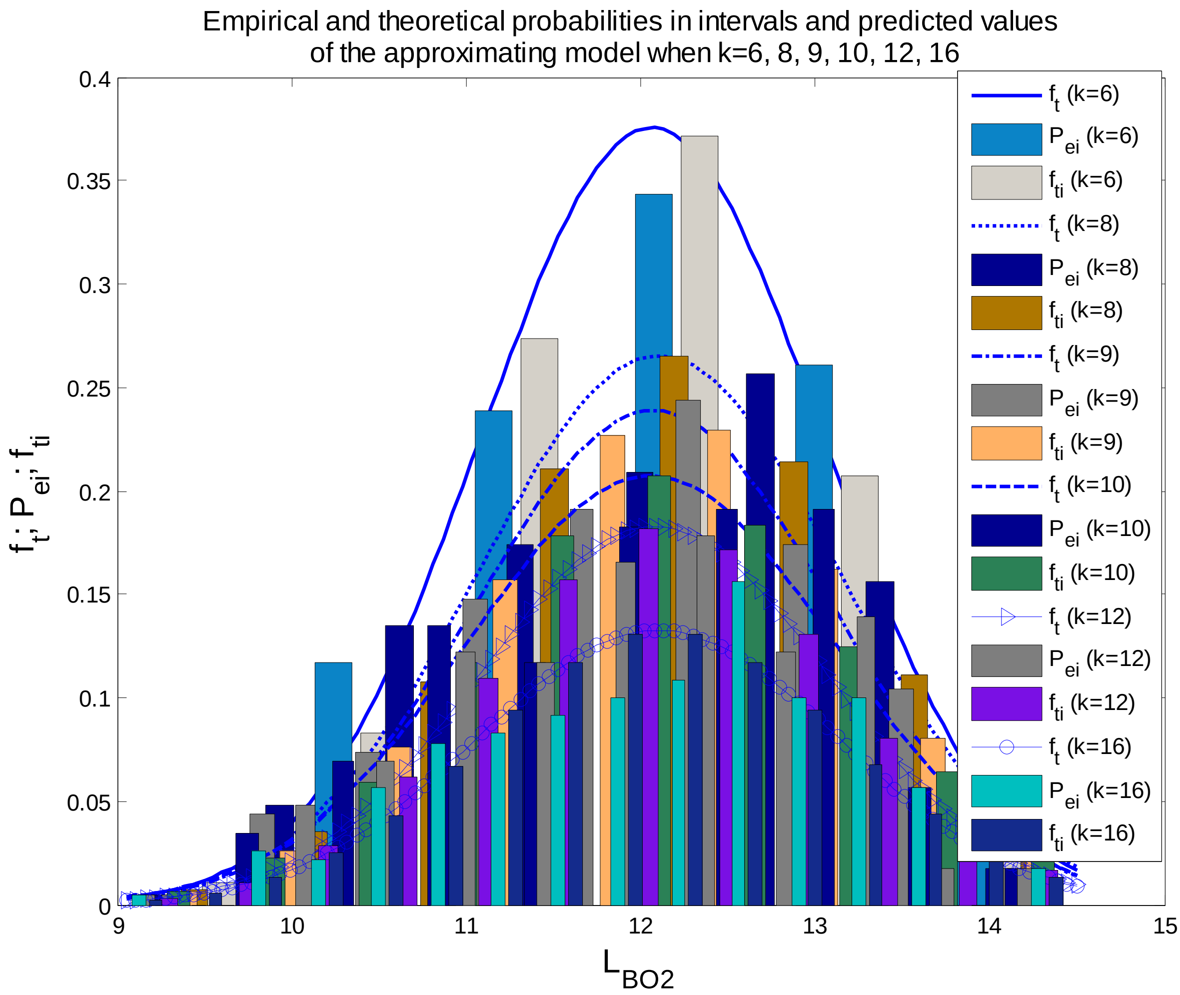

FIGURE 2. Empirical and theoretical probabilities by intervals and predicted values of the approximating model when *k* =6,8,9,10,12,16 (Length BO_2)

VII. CONCLUSION

Through the adoption of an experimental and statistical approach, a passive experiment was carried out to collect relevant information about the growth parameters of BO in the Bulgarian Black Sea coast in the area of "Trakata" in the vicinity of the town of Varna. The aim is to determine the law of statistical distribution of the length of the two types of BO. The lack of specific information on the impact of the accuracy of the data used on the results of the application of statistical criterion for validating the law of distribution has necessitated the completion of additional simulation studies. Accordingly, conducted have been further studies to clarify the number of the splitting sample bin intervals with the formation of empirical distribution, which directly affects the selection of the theoretical law of distribution. A direct approach is used to determine the law of distribution through chi- square criteria in combination with indirect methods. Employed in the simulations were computer-generated data with a normal distribution in MATLAB environment function randn.

The following primary conclusions have been reached:

1) In the study of the distribution law, combining the direct method (chi-square), the recommendations$n_i.p_i < 5$and indirect methods improves the quality of the end solution. The considerable computational work while fusing them together does not pose a problem with the present-day state-of-the-art computer technology.

2) The number of bin intervals k, to which the data necessary for the construction of the histogram is split has a profound effect upon the results obtained in the process of determining the law of the random variable distribution. The selection of only one specific value of k is found to be quite insufficient to bring about a reasonable conclusion. The use of computer equipment with appropriate software provides the opportunity for multiple values to be included in the study towards a more informed decision.

3) The use of k from 5 to 13 is considered sufficient enough to reveal the stochastic regularity. With significant data noise-contamination the smaller values of k produce reliable results, although the degrees of freedom are on decrease. With substantial data noise-contamination, the smaller values of k (5,6), the chi- square is able to detect the normal distribution in spite of the curtailed degrees of freedom.

4) With both uncontaminated and contaminated data, the increase of k, is likely to result in intervals of $n.pi < 5$. This indicator increases with increased number of contamination intervals. The χ^2 criterion recognizes the normal distribution easily, when there are intervals with $n_i.p_i < 5$, and in both cases, following their integration.

5) The proposed recommended values for the number of sample splitting intervals is $k = 5 - 13$, with n > 200. Modern computer technology makes it possible for the distribution of data to be explored with multiple intervals, rather than only one selected value for k, subsequent to the process of decision-making. The availability of information about the level of data contamination is of utmost convenience.

6) The distribution of BO_1 and BO_2 lengths is subject to the law of normal distribution. The accuracy of the experimental data, of 0.1 cm with which they have been obtained is seen as sufficient.

7) The obtained models of the laws of probability distribution with the underlying parameters are viewed as adequate can be used for solving research and practical tasks as well.

REFERENCES

[1] Genov, D., 2000. Modeling and Optimization of industrial processes Manual Lab, Varna: Technical university-Varna, 192p, ISBN-954-20-0263-7.

[2] Krug, G.K. 1973. Planning an experimental Research. Theoretical basis. MEI, M.

[3] Novikov, N.M. 2000. Methodological guidelines for Mathematical statistics for students, (Part II), Voronezh.

[4] Smirnov, N.V. Dunin-Barkovskii, I.V. 1959. Short course of Mathematical Statistics for technical applications, Fizmatgiz.

[5] Doane, D. P. 1976. Aesthetic frequency classification. American Statistician, vol. 30: pp. 181–183.

[6] Freedman, D., Diaconis, P. 1981. "On the histogram as a density estimator: L2theory". Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete. 57 (4): pp. 453–476. doi:10.1007/BF01025868.

[7] Hahn, G. J. and Shapiro, S.S., 1967. Statistical Modeling in engineering, New York, London, Sydney: John Wiley and Sons Inc., 376p.

[8] He, K., Meeden, G. 1997, Selecting the number of bins in a Histogram: A decision Theoretic approach, Journal of statistical Planning and Inference, Vol. 61, Issue 1, pp. 49-59.

[9] Hyndman, R. (1995). The problem with Sturges' rule for constructing histograms. Retrieved December 13, 2017 from: https://robjhyndman.com/papers/sturges.pdf

[10] Knuth, K. 2013. Optimal Data Binning for Histograms, arXiv;physics/0605197v2 [physics.data-an]

[11] Lane, D. M. Project Leader, Online Statistics Education: A Multimedia Course of Study (http://onlinestatbook.com/).:, Rice University (chapter 2 "Graphing Distributions", section "Histograms").

[12] Scott, David W. 1979. "On optimal and data-based histograms". Biometrika. 66 (3): pp.605–610. doi:10.1093/biomet/66.3.605.

[13] Shannon, R.E. 1975. SYSTEMS SIMULATION: The Art and Science, Prentice-Hall, Inc., New Jersey.

[14] Snedecor G.W and Cochran W.G, 1989, Statistical Methods, 8th Edition, Iowa State University Press, 491p.

[15] Sparre P., Venema S.C. 1998. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish Tech. Pap., 306/1 (Rev.2), 407p.

[16] Sturges, H. A. (1926). "The choice of a class interval". Journal of the American Statistical Association: 65–66. doi:10.1080/01621459.1926.10502161. JSTOR 2965501.

[17] Food and Agriculture organization of the United Nations - http://www.fao.org/home/en/.

[18] MathWorks: Matlab-online: https://www.mathworks.com/products/matlab-online.html.

[19] NIST/SEMATECH e-Handbook of Statistical Methods web-site: http://www.itl.nist.gov/div898/handbook/.

APPENDIX 1

SIMULATION: LENGTH – BO_1 UNCONTAMINATED DATA (L_{sim})

Table 1-1

k	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Direct method for determination of the law of the sample frequencies distribution, Chi-square normality test															
χ^2	0.9347	0.8788	2.2176	2.1416	2.8800	4.0621	5.0216	1.3480	4.3055	6.8472	4.3793	12.3688	5.6879	9.3223	12.9344	12.8948
χ^2_T	1.39	2.37	3.36	4.35	5.35	6.35	6.35	2.18	8.34	9.34	4.57	13.70	11.34	11.34	15.98	13.34
α	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.975	0.50	0.50	0.95	0.25	0.50	0.50	0.25	0.50
v	2	3	4	5	6	7	7	8	9	10	11	11	12	12	13	14
	Indirect methods															
$M \pm S$ %	71.30	70.40	69.50	69.50	69.40	69.30	69.40	69.20	68.90	69.10	68.70	68.80	69.10	69	68.90	69.10
$M \pm 2.S$%	96.50	96.20	96	96	95.80	95.80	95.80	95.80	95.60	95.70	95.50	95.60	95.70	95.60	95.60	95.60
$M \pm 3.S$ %	100	100	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90
b_1	0.0023	$6.6 \cdot 10^{-4}$	0.0054	0.0029	0.0043	0.0024	0.0091	0.0036	0.0030	0.0023	0.0036	0.0035	0.0028	0.0019	0.0024	0.0024
b_2	2.7163	2.7384	2.8097	2.7427	2.8505	2.8407	2.8622	2.8170	2.8082	2.7687	2.7867	2.8383	2.7901	2.8268	2.8517	2.8241
Ase	0.0480	0.0259	0.0737	0.0541	0.0659	0.0491	0.0954	0.0599	0.0544	0.0480	0.0604	0.0594	0.0531	0.0439	0.0492	0.0491
Exe	-0.2837	-0.2616	-0.1903	-0.2573	-0.1495	-0.1593	-0.1378	-0.1830	-0.1918	-0.2313	-0.2133	-0.1617	-0.2099	-0.1732	-0.1483	-0.1759
Intervals with $n.pi < 5$ *to the left*	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Intervals with $n.pi < 5$ *to the right*	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2
S	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261	0.8261
Mo	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067	9.3067
Me	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326	9.4326
M	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086	9.3086
H_0 *(accepted) Yes/No*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Simulation model parameters: simulated sample size $n = 1000$; $M = 9.30$ *cm;* $S = 0.8$ *cm;* $x_{min} = 7.0114$ *cm;* $x_{max} = 11.8538$ *cm*

SIMULATION: LENGTH – BO$_1$ CONTAMINATED DATA ($L_1 = L_{sim} + e_1$)

Table 1-2

k	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Direct method for determination of the law of the sample frequencies distribution, Chi-square normality test															
χ^2	1.2588	1.7520	2.6008	2.7670	2.6152	5.0463	4.3152	2.6806	6.3923	6.1589	7.2743	8.9571	8.8161	6.7539	10.6773	9.4611
χ^2_T	1.39	2.37	3.36	4.35	5.35	5.35	6.35	2.73	8.34	9.34	10.34	11.34	11.34	11.34	12.34	13.34
α	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.95	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
v	2	3	4	5	6	6	7	8	9	10	11	12	12	12	13	14
	Indirect methods															
$M \pm S$ %	71.20	70.20	70	69.80	69.80	69.90	69.60	69.70	69.50	69.70	69.40	69.50	69.70	69.40	69.40	69.70
$M \pm 2.S$%	96.50	96.30	95.80	95.70	95.70	95.80	95.60	95.70	95.30	95.60	95.30	95.40	95.60	95.40	95.30	95.40
$M \pm 3.S$ %	100	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90
b_1	0.0050	$6.1*10^{-4}$	0.0091	0.0077	0.0054	0.0073	0.0057	0.0011	0.0060	0.0045	0.0043	0.0043	0.0027	0.0027	0.0058	0.0070
b_2	2.7484	2.8088	2.8543	2.7835	2.8341	2.8815	2.8689	2.8321	2.8114	2.8139	2.8532	2.8522	2.8029	2.8483	2.8277	2.8746
Ase	0.0707	0.0248	0.0955	0.0877	0.0737	0.0852	0.0757	0.0338	0.0775	0.0671	0.0658	0.0653	0.0521	0.0523	0.0760	0.0838
Exe	-0.2516	-0.1912	-0.1457	-0.2165	-0.1659	-0.1185	-0.1311	-0.1679	-0.1886	-0.1861	-0.1468	-0.1478	-0.1971	-0.1517	-0.1723	-0.1254
Intervals with $n.pi < 5$ *to the left*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Intervals with $n.pi < 5$ *to the right*	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2
S	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283	0.8283
Mo	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098	9.3098
Me	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710	9.4710
M	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118	9.3118
H_0 *(accepted) Yes/No*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Simulation model – contaminated data (measurement error or environmental variability impact on length of BO) with parameters: $S_L = 0.8261$; $L_1 = L_{sim} + e_1$; $S_{e1} = 0.0457$; signal-to-noise ratio: $S_{RelL} = \left(\frac{S_{e1}}{S_L}\right) * 100 = 5.5283\%$ (or added measurement error $\approx 5.5\%$) - $\boldsymbol{x_{min} = 7.0297\ cm}$; $\boldsymbol{x_{max} = 11.9122\ cm}$

SIMULATION: LENGTH – BO_1 CONTAMINATED DATA ($L_2 = L_{sim} + e_2$)

Table 1-3

k	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Direct method for determination of the law of the sample frequencies distribution, Chi-square normality test															
χ^2	*1.1681*	*0.8987*	*3.1955*	*1.3652*	*5.4989*	*7.4669*	*5.8386*	*6.4355*	*5.5585*	*9.8238*	*4.5142*	*10.9679*	*8.4898*	*15.4927*	*8.3760*	*18.0608*
χ^2_T	*1.39*	*2.37*	*3.36*	*4.35*	*7.84*	*9.04*	*7.34*	*7.34*	*8.34*	*12.55*	*9.34*	*13.70*	*11.34*	*15.98*	*13.34*	*21.06*
α	*0.50*	*0.50*	*0.50*	*0.50*	*0.25*	*0.25*	*0.50*	*0.50*	*0.50*	*0.25*	*0.50*	*0.25*	*0.50*	*0.25*	*0.50*	*0.10*
v	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*8*	*9*	*10*	*10*	*11*	*12*	*13*	*14*	*14*
	Indirect methods															
$M \pm S$ %	71.20	69.90	68.90	70.10	68.70	69.20	68.90	68.70	68.70	68.80	68.70	69	68.70	68.60	68.90	68.70
$M \pm 2.S$%	96.60	95.80	95.80	96	95.40	95.70	95.70	95.50	95.30	95.50	95.30	95.60	95.50	95.30	95.60	95.40
$M \pm 3.S$ %	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
b_1	0.0029	$1.4*10^{-6}$	0.0013	$1.5*10^{-4}$	0.0036	0.0015	0.0022	$4.4*.10^{-4}$	$5.8*10^{-4}$	$8.02*10^{-4}$	0.0027	0.0018	0.0025	0.0032	0.0024	0.0022
b_2	2.7358	2.8116	2.8114	2.7131	2.8612	2.8725	2.8369	2.8527	2.8256	2.8453	2.8624	2.8263	2.8647	2.8925	2.8808	2.8661
Ase	0.0536	0.0012	0.0354	-0.0124	0.0601	0.0385	0.0469	0.0212	0.0242	0.0090	0.0516	0.0419	0.0496	0.0569	0.0492	0.0465
Exe	-0.2642	-0.1884	-0.1886	-0.2869	-0.1388	-0.1275	-0.1631	-0.1473	-0.1744	-0.1547	-0.1376	-0.1737	-0.1353	-0.1075	-0.1192	-0.1339
Intervals with $n.pi < 5$ *to the left*	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
Intervals with $n.pi < 5$ *to the right*	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2
S	0.8351	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230	0.8230
Mo	9.3036	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374	9.3374
Me	9.3623	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893	9.3893
M	9.3026	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177	9.3177
H_0 *(accepted) Yes/No*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Simulation model – contaminated data (measurement error or environmental variability impact on length of BO) with parameters: $S_L = 0.8261$; $L_2 = L_{sim} + e_2$; $S_{e2} = 0.0997$; signal-to-noise ratio: $S_{RelL} = \left(\frac{S_{e2}}{S_L}\right) * 100 = 12.0637\%$ (or added measurement error ≈ 12% - $\boldsymbol{x_{min} = 6.9179\ cm}$; $\boldsymbol{x_{max} = 11.8066\ cm}$

SIMULATION: LENGTH – BO_2 UNCONTAMINATED DATA (L_{sim})

Table 1-4

k	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Direct method for determination of the law of the sample frequencies distribution, Chi-square normality test															
χ^2	*6.8265*	*4.5569*	*9.0120*	*2.1416*	*8.4972*	*9.7735*	*6.1660*	*13.3708*	*11.7931*	*11.0899*	*20.3029*	*8.9793*	*14.3961*	*14.8640*	*11.1304*	*15.5750*
χ^2_T	*7.38*	*5.99*	*9.49*	*3.36*	*9.24*	*11.07*	*6.63*	*14.45*	*12.02*	*13.36*	*26.12*	*10.22*	*14.68*	*16.92*	*12.55*	*17.27*
α	*0.025*	*0.05*	*0.05*	*0.50*	*0.10*	*0.05*	*0.25*	*0.025*	*0.10*	*0.10*	*0.001*	*0.25*	*0.10*	*0.05*	*0.25*	*0.10*
v	*2*	*2*	*4*	*4*	*5*	*5*	*5*	*6*	*7*	*8*	*8*	*8*	*9*	*9*	*10*	*11*
	Indirect methods															
$M \pm S$ %	**66.09**	**66.52**	**66.08**	**66.08**	**66.08**	**65.22**	**65.22**	**65.22**	**65.22**	**66.08**	**65.22**	**65.22**	**65.22**	**66.08**	**65.22**	**65.22**
$M \pm 2.S$%	96.09	96.08	95.65	95.65	96.08	95.65	95.65	95.65	95.65	95.65	95.65	95.65	95.65	95.65	95.65	95.65
$M \pm 3.S$ %	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
b_1	0.0167	0.0023	0.0054	$3.2*10^{-7}$	0.0021	0.0020	0.0012	$2.85*10^{-4}$	0.0021	$9.82*10^{-4}$	$6.68*10^{-4}$	$6.5*10^{-4}$	0.0016	0.0010	0.0048	0.0013
b_2	2.3500	2.4599	2.8097	2.6900	2.5083	2.5967	2.6608	2.5810	2.7190	2.6960	2.6725	2.7694	2.6916	2.6824	2.7233	2.6927
Ase	-0.1292	0.0477	0.0737	$-5.6*10^{-4}$	-0.0461	-0.0448	-0.0352	-0.0169	-0.0460	-0.0313	-0.0258	-0.0254	-0.0406	-0.0320	-0.0693	-0.0358
Exe	-0.6500	-0.5401	-0.1903	-0.3100	-0.4917	-0.4033	-0.3392	-0.4190	-0.2810	-0.3040	-0.3275	-0.2306	-0.3084	-0.3176	-0.2767	-0.3073
Intervals with $n.pi < 5$ *to the left*	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2
Intervals with $n.pi < 5$ *to the right*	0	1	0	1	1	1	1	2	2	2	3	3	3	4	4	4
S	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035	1.1035
Mo	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313	12.3313
Me	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105	12.6105
M	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323	12.3323
H_0 *(accepted) Yes/No*	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Simulation model parameters: simulated sample size $n = 230$; $M = 12.23$ *cm*; $S = 1.058$ *cm*; $x_{min} = 9.7018$ *cm*; $x_{max} = 15.5193$ *cm*

SIMULATION: LENGTH – BO_2 CONTAMINATED DATA ($L_1 = L_{sim} + e_1$)

Table 1-5

k	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Direct method for determination of the law of the sample frequencies distribution, Chi-square normality test															
χ^2	6.5619	5.1582	2.2685	8.1942	9.1862	6.6112	8.6436	15.1364	8.7381	6.0770	22.8924	9.7998	13.9518	16.0871	20.4804	18.5003
χ^2_T	7.38	6.25	4.11	9.49	9.24	6.63	9.24	16.81	9.04	7.34	26.12	10.22	14.68	18.31	23.21	19.68
α	0.025	0.10	0.25	0.05	0.10	0.25	0.10	0.01	0.25	0.50	0.001	0.25	0.10	0.05	0.01	0.05
v	2	3	3	4	5	5	5	6	7	8	8	8	9	10	10	11
	Indirect methods															
$M \pm S$ %	66.52	66.09	65.65	65.65	66.09	66.09	64.78	65.22	65.22	65.65	65.65	64.78	65.65	65.65	65.22	65.65
$M \pm 2.S$%	96.09	96.09	95.65	95.65	96.09	96.09	95.65	95.65	95.65	95.65	95.65	95.65	96.09	95.65	95.65	95.65
$M \pm 3.S$ %	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
b_1	0.0216	0.0030	$5.4*10^{-4}$	0.0054	$5*10^{-5}$	0.0030	$8.9*10^{-5}$	0.0040	0.0054	0.0024	0.0048	0.0034	$5.6*10^{-4}$	0.0038	$3.4*10^{-4}$	0.0033
b_2	2.3852	2.4113	2.5903	2.6456	2.6514	2.6216	2.5900	2.5604	2.6974	2.6169	2.6359	2.7285	2.6737	2.7353	2.7286	2.7168
Ase	-0.1470	-0.0549	-0.0232	-0.0736	0.0071	-0.0545	-0.0094	-0.0632	-0.0737	-0.0492	-0.0694	-0.0585	-0.0236	-0.0619	-0.0184	-0.0573
Exe	-0.6148	-0.5887	-0.4097	-0.3544	-0.3486	-0.3784	-0.4100	-0.4396	-0.3026	-0.3831	-0.3641	-0.2715	-0.3263	-0.2647	-0.2714	-0.2832
Intervals with $n.pi < 5$ *to the left*	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2
Intervals with $n.pi < 5$ *to the right*	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4
S	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086	1.1086
Mo	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658	12.3658
Me	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559	12.5559
M	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655	12.3655
H_0 *(accepted) Yes/No*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Simulation model – contaminated data (measurement error or environmental variability impact on length of BO) with parameters: $S_L = 0.8261$; $L_2 = L_{sim} + e_2$; $S_{e2} = 0.0997$; signal-to-noise ratio: $S_{RelL} = \left(\frac{S_{e1}}{S_L}\right) * 100 = 5.3988\%$ (or added measurement error ≈ 5.5% - $\boldsymbol{x_{min}} = \mathbf{9.6752}$ cm; $\boldsymbol{x_{max}} = \mathbf{15.4366}$ cm

SIMULATION: LENGTH – BO_2 CONTAMINATED DATA ($L_2 = L_{sim} + e_2$)

Table 1-6

k	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Direct method for determination of the law of the sample frequencies distribution, Chi-square normality test															
χ^2	*3.0682*	*5.1004*	*3.0702*	*8.0021*	*7.4738*	*3.9229*	*9.`7750*	*13.6714*	*12.5797*	*10.5736*	*15.0008*	*15.8932*	*22.5019*	*16.5125*	*19.3644*	*22.4348*
χ^2_T	*4.61*	*6.25*	*4.11*	*9.49*	*7.78*	*4.35*	*11.07*	*14.45*	*14.07*	*13.36*	*16.01*	*17.53*	*27.88*	*18.31*	*20.48*	*23.21*
α	*0.10*	*0.10*	*0.25*	*0.05*	*0.10*	*0.50*	*0.05*	*0.025*	*0.05*	*0.10*	*0.025*	*0.025*	*0.001*	*0.05*	*0.025*	*0.01*
ν	*2*	*3*	*3*	*4*	*4*	*5*	*5*	*6*	*7*	*8*	*7*	*8*	*9*	*10*	*10*	*10*
	Indirect methods															
$M \pm S$ %	66.09	67.82	66.52	66.09	66.09	65.22	66.09	66.09	66.09	66.09	64.78	66.09	66.09	66.09	66.09	66.09
$M \pm 2.S$%	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09	96.09
$M \pm 3.S$ %	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
b_1	0.0170	0.0210	0.0034	0.0056	$2.4*10^{-5}$	0.0063	$7*10^{-4}$	0.0060	0.0066	0.0065	0.0040	0.0041	0.0054	0.0083	0.0049	0.0091
b_2	2.5735	2.4786	2.6969	2.5375	2.5699	2.7263	2.6798	2.6310	2.6878	2.6671	2.7460	2.6965	2.6728	2.7124	2.7031	2.7579
Ase	-0.1303	-0.1448	-0.0584	-0.0746	-0.0049	-0.0797	-0.0265	-0.0776	-0.0814	-0.0804	-0.0630	-0.0642	-0.0732	-0.0910	-0.0700	-0.0953
Exe	-0.4265	-0.5214	-0.3031	-0.4625	-0.4301	-0.2737	-0.3202	-0.3690	-0.3122	-0.3329	-0.2540	-0.3035	-0.3272	-0.2876	-0.2969	-0.2421
Intervals with $n.pi < 5$ *to the left*	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	3
Intervals with $n.pi < 5$ *to the right*	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4
S	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221	1.1221
Mo	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371	12.3371
Me	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165	12.5165
M	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397	12.3397
H_0 *(accepted) Yes/No*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Simulation model – contaminated data (measurement error or environmental variability impact on length of BO) with parameters: $S_L = 1.058$; $L_2 = L_{sim} + e_2$; $S_{e2} = 0.1253$; signal-to-noise ratio:: $S_{RelL} = \left(\frac{S_{e2}}{S_L}\right) * 100 = 11.3523\%$ (or added measurement error $\approx 11\%$ $\boldsymbol{x_{min}} = \mathbf{9.5272}$ cm; $\boldsymbol{x_{max}} = \mathbf{15.5057}$ cm

STOCHASTIC MODEL LENGTH – BO_1 (REAL DATA)

Table 1-7

k	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Direct method for determination of the law of the sample frequencies distribution, Chi-square normality test															
χ^2	28.0442	1.1463	19.2485	4.2035	18.7612	58.4285	16.5549	23.3963	17.1820	26.9349	69.9811	27.1276	30.3511	45.6662	50.8067	142.85
χ^2_T	-	1.39	-	4.61	-	-	20.52	-	20.52	-	-	-	-	-	-	-
α	-	0.50	-	0.10	-	-	0.001	-	0.001	-	-	-	-	-	-	-
v	1	2	1	2	3	4	5	4	5	5	6	7	8	7	8	9
	Indirect methods															
$M \pm S$ %	73.60	70.20	70.20	64.60	70.20	64.60	70.20	64.60	73.60	64.60	73.60	64.60	64.60	64.60	64.60	64.60
$M \pm 2.S$%	96.60	96.70	96.70	96.30	96	95.70	96	95.40	95.70	96	95.70	95.40	95.40	96	96.30	95.70
$M \pm 3.S$ %	99.20	99.50	99.40	99.10	99.40	98.90	99.40	99.10	98.90	99.10	99.10	98.90	99.10	99.10	99.10	99.10
b_1	0.1560	$3.6*10^{-4}$	0.0371	$3.1*10^{-5}$	$6.1*10^{-6}$	0.0164	0.0046	$5*10^{-5}$	0.0184	0.0093	0.0304	0.0050	0.0080	4.1869	0.0075	0.0019
b_2	4.0433	3.3042	3.6255	3.9483	4.0084	4.2176	3.5701	3.8289	3.8704	4.1181	3.8935	4.3849	3.7461	$3.8*10^{-4}$	3.9928	3.9440
Ase	-0.3950	0.0191	-0.1925	0.0056	0.0025	-0.1282	-0.0678	0.0070	-0.1356	-0.0965	-0.1743	0.0707	-0.0893	-0.0196	-0.0866	-0.0430
Exe	1.0433	0.3042	0.6255	0.9483	1.0084	1.2176	0.5701	0.8289	0.8704	1.1181	0.8935	1.3849	0.7461	1.1869	0.9928	0.9440
Intervals with $n.pi < 5$ *to the left*	0	0	1	1	1	1	1	2	2	2	2	2	2	3	3	3
Intervals with $n.pi < 5$ *to the right*	1	1	2	2	2	2	2	3	3	4	4	4	4	5	5	5
S	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158	0.7158
Mo	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150	9.3150
Me	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500	9.6500
M	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217	9.3217
H_0 *(accepted) Yes/No*	No	Yes	No	Yes	No	No	Yes	No	Yes	No	No	No	No	No	No	No

Distribution parameters: sample size $n = 1000$; $x_{min} = 6.3000$ *cm*; $x_{max} = 13$ *cm*

STOCHASTIC MODEL LENGTH – BO_2 (REAL DATA)

Table 1-8

k	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Direct method for determination of the law of the sample frequencies distribution, Chi-square normality test															
χ^2	*11.2119*	*7.3917*	*21.0941*	*14.8384*	*6.2802*	*16.4486*	*21.1645*	*15.6186*	*29.2748*	*24.7673*	*29.3221*	*15.7895*	*37.7625*	*44.2246*	*41.2959*	*32.3429*
χ_T^2	-	*9.21*	-	*18.47*	*6.63*	*16.81*	-	*16.81*	-	-	-	*16.92*	-	-	-	-
α	-	*0.01*	-	*0.001*	*0.25*	*0.01*	-	*0.01*	-	-	-	*0.05*	-	-	-	-
v	*2*	*2*	*3*	*4*	*5*	*6*	*5*	*6*	*7*	*7*	*8*	*9*	*8*	*9*	*10*	*10*
	Indirect methods															
$M \pm S$ %	68.70	61.30	63.91	63.91	63.91	68.70	66.09	61.30	63.91	63.91	63.91	63.91	63.91	63.91	63.91	63.91
$M \pm 2.S$%	98.70	63.91	95.21	95.22	95.21	97.83	97.83	95.21	95.22	95.22	95.22	95.22	95.22	95.22	95.22	95.22
$M \pm 3.S$ %	100	99.57	99.57	99.57	99.57	100	100	99.57	99.57	99.57	100	100	99.57	99.57	99.57	99.57
b_1	0.0861	0.0353	0.0903	0.0798	0.0660	0.0874	0.0612	0.0284	0.0940	0.0731	0.0562	0.0751	0.0656	0.0663	0.0924	0.0767
b_2	2.4004	2.3413	2.2084	2.2579	2.5236	2.3481	2.3758	2.4063	2.3606	2.4817	2.4404	2.4540	2.4123	2.4208	2.3713	2.4183
Ase	-0.2935	-0.1879	-0.3005	-0.2825	-0.2569	-0.2957	-0.2475	-0.1685	-0.3066	-0.2704	-0.2372	-0.2740	-0.2561	-0.2576	-0.3040	-0.2769
Exe	-0.5996	-0.6587	-0.7916	-0.7421	-0.4764	-0.6519	-0.6242	-0.5937	-0.6394	-0.5183	-0.5596	-0.5460	-0.5877	-0.5792	-0.6287	-0.5817
Intervals with $n.pi < 5$ *to the left*	0	1	1	1	1	1	2	2	2	3	3	3	4	4	4	5
Intervals with $n.pi < 5$ *to the right*	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2
S	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197	1.0197
Mo	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250	12.0250
Me	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500	11.7500
M	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226	12.0226
H_0 *(accepted) Yes/No*	No	Yes	No	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No	No	No	No

Distribution parameters: *sample size* $n = 230; x_{min} = 9.00\ cm; x_{max} = 14.50\ cm$

Experimental Research of Thermal Resistance of Hot Water Heater Insulation

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***Abstract* -** *The present article describes the experimental measurements of thermal resistance of the PUR insulation installed in the selected type of hot water heaters that are necessary for the purpose of identification of heat output or heat loss in the given heater.*

***Keywords* - thermal resistance, heater insulation, hot water heater.**

I. INTRODUCTION

At present, availability of hot water at home is absolutely obvious. There are several ways how to ensure availability of hot water; one of the efficient and multi-purpose methods is heating water in tanks that are also referred to as accumulative heating of water. For the purpose of efficient use of the tanks for the preparation of hot water, optimal operating conditions and parameters (temperature, volumetric flow rate, insulation, efficiency, etc.) must be created. Thermal insulation and its thermal resistance represent two of the most important parameters within the assessment of water heaters in terms of the heat transfer.

II. METHODOLOGY FOR MEASURING THERMAL RESISTANCE OF A HOT WATER HEATER

The experimental measurement was carried out using a stationary hot water heater with indirect water heating (2) in which the heat was conveyed from an external primary source (electric water heater (1)). A hot water tank functions as an exchanger where the heated water circulates in a spiral that is wound in the entire space inside the tank and transfers the heat to the water contained in the tank (Fig. 1).

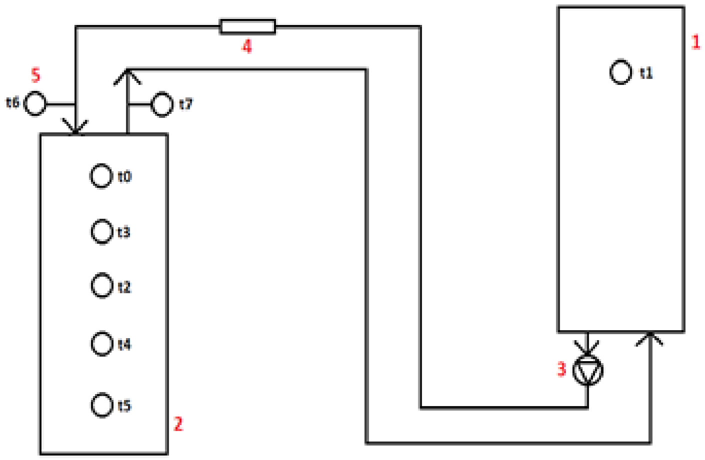

FIGURE 1: Diagram of connecting the tanks in the experimental research
1 – heat source (electric water heater), 2 – examined hot water heater 3 - HALM circulation pump, 4 – flow meter, 5 - temperature sensors

The insulation material used in the examined hot water heater was polyurethane (PUR) foam possessing very good insulation properties and its thermal conductivity coefficient λ reaches the value of 0.03 $W \cdot m^{-1} \cdot K^{-1}$. A disadvantage of such insulation material is that it is not recyclable and therefore it is regarded as unacceptable from the ecological point of view.

The examined hot water heater was used to perform the measurements, as specified in the prepared methodology, aimed at obtaining the data on changes in temperature detected by sensors during the tank cooling process. Such data were required for the purpose of identification of thermal resistance of the polyurethane insulation used in the examined hot water heater.

Prior to the measurement, it was necessary to check the system. Subsequently, the heat source was turned on and its operation was maintained until the temperature in sensor t_1 reached 45 °C. Distribution of hot water through the insulated pipes from the heat source to the examined hot water tank was carried out using a pump. 5 temperature sensors were installed on the hot water heater along its height for the purpose of recording the changes in temperature in time. The hot water heater was equipped with an outlet pipe through which water was drained from the bottom of the tank back to the electric heater. The measurements of changes in temperature were carried out for the period of approximately six days.

FIGURE 2: Electric heater (heat source)

FIGURE 3: Examined hot water heater

III. DETERMINATION OF THERMAL RESISTANCE OF INSULATION USING THE CURVE OF COOLING

The determination of thermal resistance of the insulation requires the use of the measured data regarding the changes in temperature in the analytical calculation of thermal resistance that applies to ideal conditions. For the purpose of clarity, these data were processed and evaluated in Excel (Fig. 4).

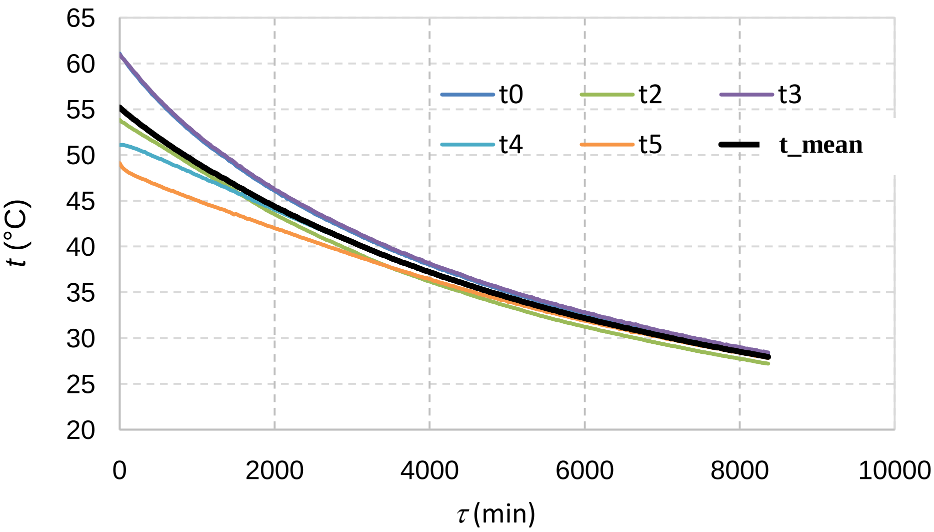

FIGURE 4: Curve of cooling the tank in time
t_1 to t_5 – surface temperatures of the heater wall (°C), t_{mean} – mean surface temperature of the heater wall (°C)

Fig. 5 below presents a simplified diagram of the examined tank in which α_1 and α_2 are heat transfer coefficients, P_s is the heat output, λ expresses the thermal conductivity coefficient of the material (polyurethane), and δ expresses the insulation thickness. This tank contained 5 temperature sensors arranged as shown in the Figure. Temperature t was calculated as the arithmetic mean of the measured temperatures in each period. The cooling period relevant to the calculation of thermal resistance was 660 minutes. Such period was chosen on the basis of bigger differences in the measured temperatures for the purpose of higher accuracy of the calculation.

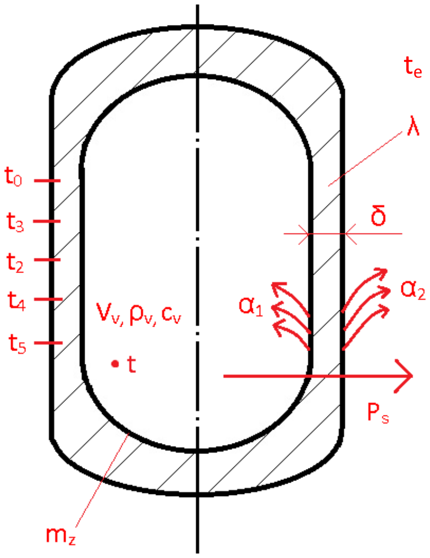

FIGURE 5: Simplified diagram of the tank

Table 1 contains the values of the measured parameters.

TABLE 1
MEASURED TEMPERATURES

Period	t_0 (°C)	t_3 (°C)	t_2 (°C)	t_4 (°C)	t_5 (°C)	t_{mean} (°C)	t_t (°C)	t_e (°C)	Δ_τ (s)
1.	61.08	60.97	53.84	51.09	49.13	55.23		21.63	0
2.	54.57	54.81	50.34	49.06	46.12	50.98	53.10	20.85	39,600

The mean surface temperature of the heater wall t_{mean} was calculated using the following formula:

$$t_{mean} = \frac{t_0 + t_2 + t_3 + t_4 + t_5}{5} \quad (°C) \tag{1}$$

and the total design temperature tt was calculated using the formula (2):

$$t_t = \frac{t_{mean,1} + t_{mean,2}}{2} \quad (°C) \tag{2}$$

The calculation of thermal resistance of the insulation was based on the calorimetry formula (3):

$$E = m \cdot c \cdot \Delta_t \quad (J) \tag{3}$$

which acquired the following form after being divided by the time variation Δ_τ:

$$P_{acum} = \frac{m \cdot c \cdot \Delta_t}{\Delta\tau} \quad (W) \tag{4}$$

or $$P_{acum} = -\sum (m \cdot c) \frac{dt}{d\tau} \tag{5}$$

where P_{acum} is the accumulation capacity of the tank and $\sum(m \cdot c)$ is the sum of the product of the weight and the specific heat capacity of the tank and water.

The real capacity of the accumulation tank may be expressed as follows:

$$P_S = \frac{(t - t_e)}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}} \quad \text{(W)} \tag{6}$$

while the thermal resistance of the insulation is determined by the following formula:

$$R = \frac{S}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}} \quad (\mathrm{K{\cdot}W^{-1}}) \tag{7}$$

Following the substitution of thermal resistance in the formula (6), we obtained the modified formula for the calculation of the real capacity of the tank:

$$P_S = \frac{(t - t_e)}{R}$$

where t is the temperature in the tank, t_e is the temperature of the environment, and *R* is the thermal resistance.

Formulas (4) and (7) are subjected to the condition that $P_s = P_{acum}$. Hence, the thermal resistance was calculated using the formula (8):

$$R = -\frac{(t - t_e)}{\sum (m \cdot c)\frac{dt}{d\tau}} = -\frac{(t - t_e)}{\sum (m \cdot c)\frac{\Delta_t}{\Delta\tau}} \tag{8}$$

The following applies to the sum of the product of the weight and specific heat capacity of the tank and water:

$$\sum (m \cdot c) = m_w \cdot c_w + m_t \cdot c_t \tag{9}$$

where $m_w = \rho_w \cdot V_w$ a $m_t = \rho_t \cdot V_t$.

The following formula applies to the tank volume:

$$V_t = \pi \cdot d \cdot H \cdot \delta_t + 4\pi \cdot r^2 \cdot \delta_t \tag{10}$$

The determination of the value of the thermal resistance of the insulation in the given period at the mean temperature of the environment was based on the following partial values:

- mean temperature of the environment t_e = 21.24 °C;
- density of water ρ_w = 990 kg·m^{-3};
- tank steel density ρ_t = 7,850 kg·m^{-3};
- specific heat capacity of water c_w = 4,180 J·kg-^{1}·K^{-1};
- specific heat capacity of steel in the tank c_t = 470 J·kg^{-1}·K^{-1};
- volume of water V_w = 150 L;
- tank height *H* = 0.915 m;
- tank diameter *d* = 0.439 m;
- outer jacket thickness δ_t = 2.5 mm.

Following the substitution of partial parameters into the formula (8), the value of thermal resistance of the insulation in the given period ***R*** was **0.4662 K·W^{-1}**. The obtained value of thermal resistance can be used to express the heat transfer coefficient *k* that represents an inverse value of thermal resistance.

The relationship between the thermal resistance of the insulation and the cooling of the tank is shown in Fig. 6.

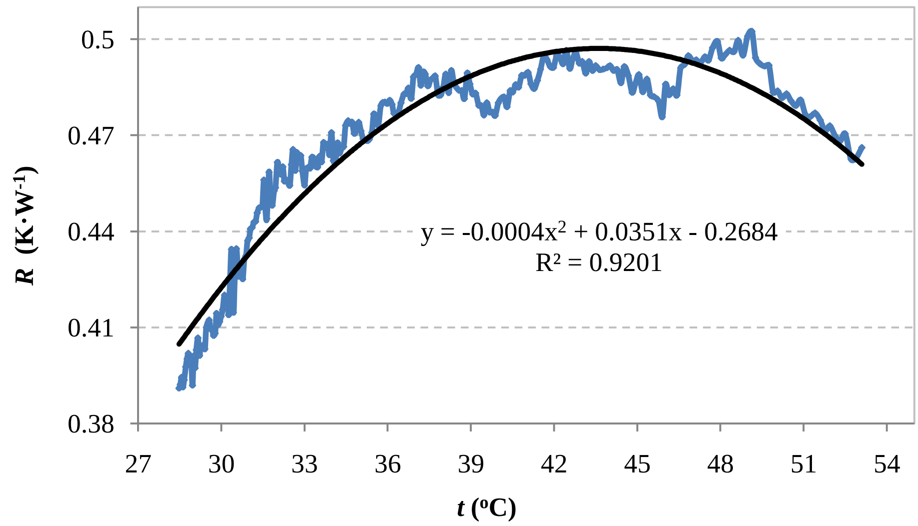

FIGURE 6: Relationship between the thermal resistance of the insulation and the cooling of the tank

The graphical representation above indicates that the value of thermal resistance of the insulation during the period when the tank was cooled ranged between 0.3913 and 0.5024 $K \cdot W^{-1}$.

IV. CONCLUSION

The energy efficiency of the heat accumulation system significantly depends on particular operating conditions in which it is used. The most important factors affecting heat losses in hot water heater tanks include the hot water demand, tank heater output, and the related thermal insulation of the tank. The higher value of thermal resistance of the insulation, the better it resists heat transfer and acquires better thermal insulation properties.

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REFERENCES

[1] K. Ferstl, M. Masaryk, “Prenos tepla”. - 1. vyd. Bratislava : STU, 2011. - 424 s. ISBN 978-80-227-3534-6.
[2] Z. Tobolka, “Nové izolační materiály ve stavebnictví “: Praha ÚSI, 1991. 61 s. ISBN 80-85380-17-X.
[3] L. Kuna, “Príručka pre izolatérov tepla a chladu”. 3. preprac. vyd. Bratislava :Alfa, 1976. - 221 s.
[4] J.P. Holman, “Heat transfer”. 8th ed. New York : McGraw-Hill, 1997. - XVIII, 696 s. ISBN 0-07-114320-3.
[5] E. Papanicolaou, V. Belessiotis, “Phenomena and Conjugate Heat Transfer During Cooling of Water in an Underground Thermal Storage Tank”, In: Journal of Heat Transfer, 126, s. 84-96.

Application of Physical Similarity in the Transfer of Results from a Model to a Prototype

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Abstract - *The process of heat distribution through heat networks is accompanied with significant loss. That is why distributors of heat and hot water are nowadays very interested in these issues. The drawbacks of the existing methods of heal loss calculation brought the necessity of searching new procedures of such calculation.*

The article presents a possibility of using the similarity theory and modelling in order to transpose results from an experimental heat network to any other network that will be similar to the experimental network with regard geometry, kinematics, as well as heat parameters.

Keywords - heat loss, heat network, physical similarity, simplex.

I. INTRODUCTION

The heat loss is identified using the so-called balance method in which it is necessary to know the temperature of a heat-conveying material in the beginning and at the end of the examined section, with sufficient accuracy, and the water flow rate in the supply as well as return pipelines. The measurements of the temperature differential for the heat-conveying material in short sections require the use of the state-of-the-art measuring technology which, however, cannot be permanently installed in every network, especially when the entire distribution system covers several tens of kilometres. Such methodology for the heat loss identification is appropriate mainly for very long heat distribution sections in which an error in the measurement of the temperature differential would not cause a substantial error in the subsequent calculation of the heat loss.

II. SIMILARITY THEORY AND MODELLING

The drawbacks of the balance method regarding the expression of heat loss brought the necessity of examining new methods how to express such loss.

The present calculation of heat loss was made applying the physical similarity and modelling.

Two physical phenomena are only similar if all the parameters determining them are similar. In the case of similar phenomena that depend on several physical parameters, there are probably certain relationships between similarity constants.

Similarity criteria are divided into simplexes and complexes. Simplex is the ratio of two physical parameters with identical names. Complex is the ratio of parameters with different names (dimensionless). In other words, complex is an invariant consisting of parameters bearing different names.

A physical phenomenon expressed by an equation that cannot be directly solved is described using criterial equations. The method of their application is based on the substitution of relevant dimensional parameters for similarity criteria. Mutual functional relationships between the criteria are then identified experimentally. Following an experiment, criterial equations represent the main mathematical relationship that is attributable to a group of similar phenomena. The similarity theory facilitates the deduction of a general form of a criterial equation using the method of dimensional analysis. The dimensional analysis is characterised with simplicity of input data as it facilitates the identification of the quantity and types of similarity criteria merely on the basis of the opinion on the problem, without knowing a particular form of the complete physical equation.

In a general case, it is a complete physical equation expressing the relationships between n relevant parameters V_1, V_2, ..., V_n of various dimensions, in particular the following:

$$f(V_1, V_2, \dots V_n) = 0 \qquad (1)$$

According to Buckingham's π - theorem, equation (1) can be written as follows:

$$f(\pi_1, \pi_2, \ldots \pi_k) = 0 \tag{2}$$

$$\text{or} \quad \pi_1 = \psi(\pi_2, \ldots \pi_k) \tag{3}$$

It follows from the requirement of dimensional uniformity that parameters V_1, V_2, ..., V_n together form a group used in the equation (1):

$$\pi_1 = V_1^{x_{1i}} \cdot V_2^{x_{2i}} \ \ldots V_n^{x_{ni}} \tag{4}$$

where i = 1, 2, ...,k and π_1 is a dimensionless variable.

All independent dimensionless π - arguments that may be created from n relevant dimensional parameters V_1, V_2, ..., V_n may be found on the premise that there is a determined system of criteria based on m dimensionally independent units $z_1, z_2, \ldots, z_m$ ($m < n$) and that we know respective defining equations. Exponents x_i may be identified by solving the following equation:

$$A \cdot x_i = 0 \tag{5}$$

where A is the rectangular dimensional matrix (n x m) with the rank $h \leq m$ and $x_{1i}, x_{2i}, \ldots, x_{ni}$ are unknown exponents.

III. APPLICATION OF THE SIMILARITY THEORY TO A PARTICULAR HEAT NETWORK

A mathematical model used for the calculation of total heat losses is based on the dimensional analysis and the mathematical interpretation thereof is affected by a correct choice of relevant parameters which are assumed to have a significant influence on the given phenomenon. Using the selected relevant parameters affecting heat losses in heat networks, one simplex (π_1) and one complex (π_2) were compiled as follows:

$$\pi_1 = \frac{T_i}{T_e} \tag{6}$$

$$\pi_2 = \frac{P}{T_i \cdot \lambda_{ins} \cdot l} \tag{7}$$

Two devices in which physically similar phenomena are taking place are differentiated by names. One is referred to as the Model (M) and the other as the Prototype (P).

In order to derive the characteristics of the Prototype from the characteristics of the Model, the underlying problems must be of the same nature and the corresponding similarity criteria (dimensionally independent dimensionless arguments for which the following applies: $\pi_{(M)} = \pi_{(P)}$) of the Prototype and of the Model must be of identical magnitudes. Conclusions made on the basis of conformity of criteria are referred to as model laws and their number corresponds to the number of dimensionless arguments:

$$c_1 \cdot c_2 \cdot c_3 \ldots\ldots\ldots c_n = 1 \tag{8}$$

where c_1 to c_n are referred to as *similarity constants*.

The similarity constant is the ratio of parameters with identical dimensions that expresses their proportionality in corresponding points within similar systems. It can be mathematically formulated as the following ratio:

$$c_i = \frac{V_{i(M)}}{V_{i(P)}} \tag{9}$$

where V_i is the relevant parameter.

$$c_l = \frac{l_{(M)}}{l_{(P)}} = \text{const.} \tag{10}$$

where c_l is referred to as the similarity constant for the change in length. It can be an arbitrary positive number. If $c_l = 1$, the Prototype and the Model are identical in size.

The network that was subjected to the analysis described in the article is regarded, within the following considerations, as the Model (M). The results may be transferred from the Model to any heat network that is regarded as the Prototype (P) using the similarity indicators.

The heat network characteristics are as follows: the network is lead underground; its nominal diameter is DN125; external diameter of the pipeline d_2 is 133 mm; pipeline wall thickness s is 3.6 mm; insulation thickness s_{ins} is 33.5 mm; length of the examined network L is 78 m; mean value of the coefficient of thermal conductivity of the soil λ_z is 1.35 W·m^{-1}·K^{-1}; mean value of the coefficient of heat transfer from the ground surface to the external environment α_0 is 3 W·m^{-2}·K^{-1}; depth of the pipeline bed H is 1.06 m. The temperature of water supplied to the supply pipeline ranged from 55 to 70 ºC. The temperature of water coming out of the return pipeline ranged from 50 to 60 ºC. The calculated temperature of the environment t_e for the given location was -15 ºC (258.73 K).

When the physical similarity is applied to the Model and the Prototype, two phenomena are only similar if the following conditions apply:

$$\pi_{1(\mathrm{M})} = \pi_{1(\mathrm{P})} \quad (11)$$

$$\pi_{5(\mathrm{M})} = \pi_{5(\mathrm{P})} \quad (12)$$

When we break down dimensionless arguments for the Model and for the Prototype according to formulas (11) and (12), using relevant parameters, we will get the following forms:

$$\frac{T_{\mathrm{i(M)}}}{T_{\mathrm{e(M)}}} = \frac{T_{\mathrm{i(P)}}}{T_{\mathrm{e(P)}}} \quad (13)$$

$$\frac{P_{\mathrm{AS(M)}}}{T_{\mathrm{i(M)}} \cdot \lambda_{\mathrm{ins(M)}} \cdot l_{\mathrm{(M)}}} = \frac{P_{\mathrm{AS(P)}}}{T_{\mathrm{i(P)}} \cdot \lambda_{\mathrm{ins(P)}} \cdot l_{\mathrm{(P)}}} \quad (14)$$

The following applies to the constants of similarity of changes in individual physical parameters that affect heat losses in the Prototype and in the Model:

$$\frac{T_{\mathrm{i\,(M)}}}{T_{\mathrm{i\,(P)}}} = c_{T_\mathrm{i}} \quad (15)$$

$$\frac{T_{\mathrm{e\,(M)}}}{T_{\mathrm{e\,(P)}}} = c_{T_\mathrm{e}} \quad (16)$$

$$\frac{P_{\mathrm{(M)}}}{P_{\mathrm{(P)}}} = c_P \quad (17)$$

$$\frac{\lambda_{\mathrm{ins\,(M)}}}{\lambda_{\mathrm{ins\,(P)}}} = c_{\lambda \mathrm{ins}} \quad (18)$$

$$\frac{l_{\mathrm{(M)}}}{l_{\mathrm{(P)}}} = c_l \quad (19)$$

After the above listed similarity constants are substituted into formulas (11) and (12), we will get two model laws, also referred to as similarity indicators (20 and 21). Their quantity always corresponds to the quantity of dimensionless arguments.

Model laws are as follows:

$$1 = \frac{c_{T_\mathrm{i}}}{c_{T_\mathrm{e}}} \quad (20)$$

$$1 = \frac{c_P}{c_{T_i} . c_{\lambda_{ins}} . c_l} \tag{21}$$

Let us consider the case that the real Prototype differs from the Model, for example, in the quality of the used insulation, i.e., in its thermal conductivity coefficient λ_{ins}. The constants of proportionality of relevant parameters are determined by formulas (14) to (19). Given the requirement of five unknown parameters contained in the model laws and two dimensionless arguments, three constants of proportionality of relevant parameters may be chosen and two will then be calculated from the model laws.

Let the chosen similarity constants be as follows:

$$c_{T_i} = 1$$

$$c_{T_e} = 1$$

$$c_l = 1.$$

This means that the temperatures of the supplied water in the Prototype and in the Model should be identical, the temperatures of the environment around the Prototype and around the Model should be identical, and also the total lengths of the examined distribution system in the Prototype and in the Model should be identical.

The required constant of proportionality of changes in the thermal conductivity coefficient for the insulation can be calculated using the formula 15:

$$\frac{\lambda_{ins\,(M)}}{\lambda_{ins\,(P)}} = c_{\lambda_{ins}} \tag{22}$$

where $\lambda_{ins\,(M)} = 0.04$ W.m^{-1}.K^{-1} and represents the thermal conductivity coefficient for the insulation in the Model.

Let us examine the development of heat loss values for the Prototype if the thermal conductivity coefficients for the insulation in the Prototype $\lambda_{ins(P)}$ are at various levels (better as well as worse than the Model), determined by the following values:

$\lambda_{ins(P)} = 0.02$ W·m^{-1}·K^{-1},

$\lambda_{ins(P)} = 0.05$ W·m^{-1}.·K^{-1},

$\lambda_{ins(P)} = 0.08$ W·m^{-1}·K^{-1},

$\lambda_{ins(P)} = 0.09$ W·m^{-1}·K^{-1}.

The similarity constant for changes in the total heat loss will be calculated using the formula 19:

$$c_P = c_{T_i} . c_{\lambda_{ins}} . c_l \tag{23}$$

Following the substitution of particular values of similarity constants for relevant parameters for all the chosen values of the thermal conductivity coefficient in the Prototype into the formula (23), the similarity constant for heat losses, for example for $\lambda_{ins\,(P)} = 0.02$ 0.02 W·m^{-1}.K^{-1}, will have the following value:

$$c_P = c_{T_i} \cdot c_{\lambda_{iz}} \cdot c_l = 1 \cdot 2 \cdot 1 = 2$$

because if $\lambda_{ins(P)} =$ 0.02 W·m^{-1}·K^{-1}, then $c_{\lambda_{ins}} = \frac{\lambda_{(M)}}{\lambda_{(P)}} = \frac{0,04}{0,02} = 2.$

It follows from the above mentioned that if the quality of the insulation was twice as high as for the network that was subjected to the experimental examination described in the article, the heat loss values for the described Prototype would be twice as low. Such conclusion also follows from the measure of changes in the power dissipation $\frac{P_{(M)}}{P_{(P)}} = c_P$ in which the power dissipation in the Model $P_{(M)}$ is known and was determined for the following conditions:

$T_{i(M)} = 343.15$ K, $T_{e(M)} = 258.15$ K,

$l_{(M)} = 1$ m, $\lambda_{ins(M)} = 0.04\ W \cdot m^{-1} \cdot K^{-1}$

These conditions correspond to a specific value of the total power dissipation of the network that was determined from the constructed Model. Its numerical value is $P_{(M)} = 40$ W.

The value of the power dissipation in the Prototype, identified using the formula 14, is 20 W. It represents a half of the value of the power dissipation in the examined Model.

$$P_{(P)} = \frac{P_{(M)}}{c_P} = \frac{40}{2} = 20\ W\,.$$

Table 1 contains the values of the total heat loss $P_{(P)}$ for a new Prototype that differs from the Model in the quality of insulation. In one case, the insulation was of a higher quality than in the Model ($\lambda_{iz} = 0.02\ W \cdot m^{-1} \cdot K^{-1}$); in three other cases, it was worse than in the Model (λ_{ins} = 0.05; 0.08; and 0.09). For the purpose of comparison, the table also contains the values of power dissipation in the Model that correspond to the thermal conductivity coefficient for the insulation λ_{ins} of $0.04\ W \cdot m^{-1} \cdot K^{-1}$, i.e., the original network subjected to the experiment.

TABLE 1
HEAT LOSS IN THE NEW PROTOTYPE

$\lambda_{ins\ (P)}$	$c_{\lambda_{ins}}$	c_P	$P_{(P)} = \frac{P_{(M)}}{c_P}$
0.02	2	2	20
0.04	1	1	40
0.05	0.8	0.8	50
0.08	0.5	0.5	79
0.09	0.04	0.04	89

Fig. 1 presents the relationship between the heat loss in the Prototype and the quality of insulation, i.e. the value of its thermal conductivity coefficient λ_{ins}. The Fig. 1 indicates that with the improving quality of the used insulation (lower thermal conductivity coefficient λ_{ins}) the heat losses in the network decrease.

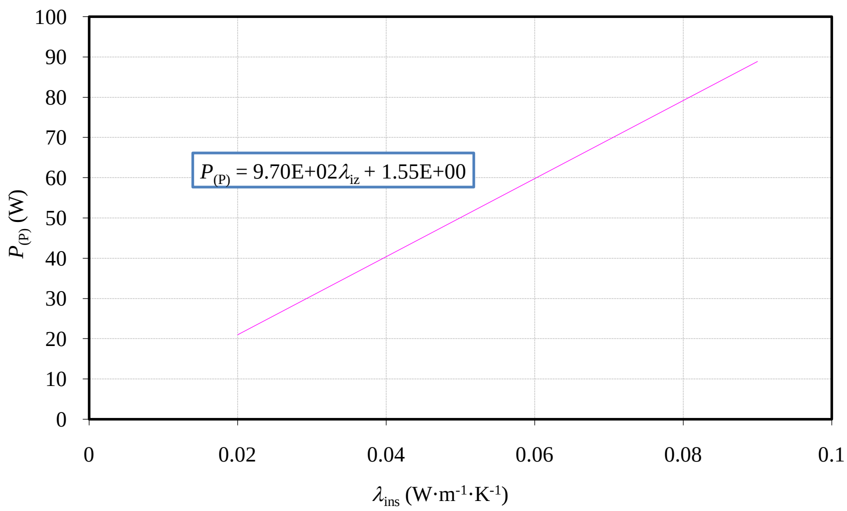

FIGURE 1: Relationship between the heat loss in the Prototype and the quality of insulation

IV. CONCLUSION

In conclusion, it is necessary to note that identification of heat losses through the examination of a physical model will find its practical applications. Introducing this procedure into real practice would not result in increased costs insured to heat manufacturers or distributors; moreover, it would facilitate clear identification of the values of total or specific heat loss in the network.

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REFERENCES

[1] https://actamont.tuke.sk/pdf/1999/n1/1Durove.pdf
[2] M. Čarnogurská, "Zaklady matematického a physicalho modelovania v mechanike tekutín a termodynamike," Viela, Košice, 2000.
[3] STN 383360 - Tepelné sítě. Strojní a stavební část- projektovaní.
[4] A. Verbrugge, "A simulation model of the combined prototypeion of low - temperature heat and electricity", FWI, 8, 1979, 4.5, s. 262.
[5] J. Kuneš, O. Vavroch, V. Franta, "Základy modelování", SNTL Praha, 1989, 263 s.

Material Conversion of Waste Aluminoborosilicate Glass into Faujasite-type Zeolite using Alkali Fusion

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Abstract*—A large amount of liquid crystal display (LCD) television becomes popular for the last decades, and the amount of waste LCD panels will increase soon. LCD panels mainly consist of aluminoborosilicate glass, and it is difficult to recycle aluminoborosilicate glass using the same recycling method of soda-lime glass, due to the high strain point. Therefore, a novel recycling method for aluminoborosilicate is desired. In this study, we attempted to convert waste aluminoborosilicate glass powder into faujasite-type zeolite using alkali fusion method. Waste aluminoborosilicate glass powder (< 300 μm) were mixed with NaOH powder (the weight ratio of NaOH / aluminoborosilicate = 1.0 - 2.0), and then heated at 100 – 800 ^oC for 0.5 - 7 h to make a fused material with high solubility. This fused material was agitated in distilled water for one day, then heated at 80 ^oC for 24 hours to synthesize zeolite product. Most of the aluminoborosilicate glass were converted into soluble phases by alkali fusion with NaOH (NaOH / sample = 1.5) at 400 ^oC for 0.5 h, and could be transformed into faujasite-type zeolite. The cation exchange capacity (CEC) of the zeolite product is 1.9 mmol/g, which is 31 times higher than that of raw glass powder, and is 59% of CEC for commercial faujasite-type zeolite 13X (3.2 mmol/g). Zeolitization process from agitated material can be explained by theconcentrations of Si, Al and B in the product and the crystallinity of faujasite-typezeolite in the product.*

Keywords*—*Waste aluminoborosilicate glass, Faujasite-type zeolite, Alkali fusion, Recycle.

I. INTRODUCTION

In recent years, home appliance recycling law was established to promote the recycling society in Japan. Therefore, a novel recycling technology for typical home appliance, such as televisions (TVs), refrigerators and washing machines were developed to recycle. TV is a typical home appliance. In Japan, liquid crystal display (LCD) TVs began to popular since 2000, and demands for TV change from Cathode Ray Tube TV to LCD TV. LCD mainly consists of aluminoborosilicate glass. Therefore, in the future, a large amount of waste aluminoborosilicate glass will discharge in Japan [1-2]. Aluminoborosilicate glass mainly consists of SiO_2 and Al_2O_3,and is difficult to recycle by the typical method of soda lime glass because strain point of aluminoborosilicate glass (650 ^oC) is higher than that of soda lime glass (550 ^oC). Aluminoborosilicate glass also has high heat and chemical-resistance, and has various composition in each product. Therefore, it is difficult to recycle LCD again. From these background, new utilization of waste LCD is desired.

In recent years, researches have also been made to synthesize zeolite from industrial wastes, such as coal fly ash [3-6], papermaking sludge incineration ash [7-16], rice husk ash [17], waste ceramics [18, 19], stone cake [20, 21] and so on using hydrothermal reaction, andthere is possibility to convert a part of aluminoborosilicate glass waste into zeolite materialsby hydrothermal treatmentvia pretreatment, e.g. acid leaching [22-24]. Zeolite is microporous aluminoborosilicate minerals with regularly arrange pores, and can use as catalyst and ion-exchanger for cleaning polluted environment [25]. Zeolite has a structure in which tetrahedrons share the oxygen located at the apexes of the tetrahedral unit and are regularly bonded three-dimensionally [26]. Furthermore, since aluminoborosilicate glass contains boron, it would be possible to synthesize a boron-containing zeolite having high heat resistance and hydrophobicity by incorporating this boron into the structure of the zeolite [27-29].

In our previous studies,stable minerals, such as quartz, were converted into soluble alkali salts to synthesize zeolite using alkali fusion [30-35], and it would be possible to covert a large part of aluminoborosilicate to zeolite crystals via alkali fusion.

In this study, we tried to convert the aluminoborosilicate glass into zeolite using alkali fusion. For conversion of aluminoborosilicate into zeolite, alkali fusion was applied to convert insoluble oxide into soluble alkali salt to convert aluminoborsilicate glass powder into faujasite-type zeolite including boron.

II. MATERIALS AND METHODS

2.1 Raw material

In this study, we used powder of aluminoiborosilicate glass discharged from one of the company in Japan. Particle size of this sample is under 300 μm and the color is grey. The sample mainly consists of SiO_2 (66 %), Al_2O_3 (22 %), B_2O_3 (10%) and others.

2.2 Experimental procedure

Experiments are two steps. 1st step is alkali fusion. Aluminoborosilicate glass is fused with NaOH on various conditions; temperature, the ratio of NaOH to aluminoborosilicate glass and heating time are parameters. 5 g of aluminoborosilicate powder and 5 - 12.5 g of NaOH were mixed and the mixture was added into nickel crucible. The crucible set in the electric furnace, and then heated at 100 - 800 ^oC for 0.5 - 7 h. After heating, the crucible was cooled to room temperature naturally outside the electric furnace, then fused material were taken out and crashed.

Mineral phases in raw and fused material were analyzed by powder X-ray diffraction apparatus (XRD, Rigaku MiniFlex600). The solubility of Si, Al and B in raw and fused materials (meaning that reactivity of fused material to be converted into zeolite,) were investigated as follows. 0.1g of sample was added into 20 mL of 1 mol/L HCl solution and shaken for 24 hours. After shaking, filtration was carried out, and the concentrations of Si and Al in the filtrate were measured by atomic absorption spectrometer (AAS, Perkin Elmer, AAnalyst200) and that of B was measured by inductirely coupled plasma method (ICP, ICP-7500, Shimadzu) to calculate the solubility of fused material.

2nd step is zeolite synthesis. Fused material was converted into the precursor by shaking in distilled water, and then heated to synthesize zeolite crystals. 1 g of fused material was added into 5 mL of distilled water in 10 mL tube, and the tube was shaken for 24 hours to prepare the precursor. The precursor was heated to be converted into faujasite-type zeolite. The precursor was heated at 80^{o}C for various times in oil bath. After heating, the solid was filtered and washed with distilled water, and dried at 80^{o}C to obtain the product. Mineral phases in the product were analyzed by XRD and the concentrations of Si, Al, and B in the solid were measured by AAS and ICP as mentioned above for the solubility measurement. The cation exchange capacity (CEC) of raw material and the product were examined by modified shöllenberger method [7]. The specific surface area of the product was measured by specific surface area meter (Mascorb HM model-1208/1210, Mountech).

III. RESULTS AND DISCUSSION

Effect of heating temperature on the property of fused material was examined. Heating time was 3 hours, the ratio of NaOH to aluminoborosilicate glass was 2, and heating temperature was changed between 200^{o}C and 800^{o}C.

Figure 1 shows XRD patterns of fused materials heated at various temperatures. While the peak of the liquid crystal glass is broad, the peaks of alkali salts, such as Na_4SiO_4, $NaAlSiO_4$ and Na_2SiO_3, in the glass via alkali fusion at each temperature was confirmed. It was found that alkali fusion can be applied for the conversion of aluminoborosilicate glass with high chemical stability into alkali salts.

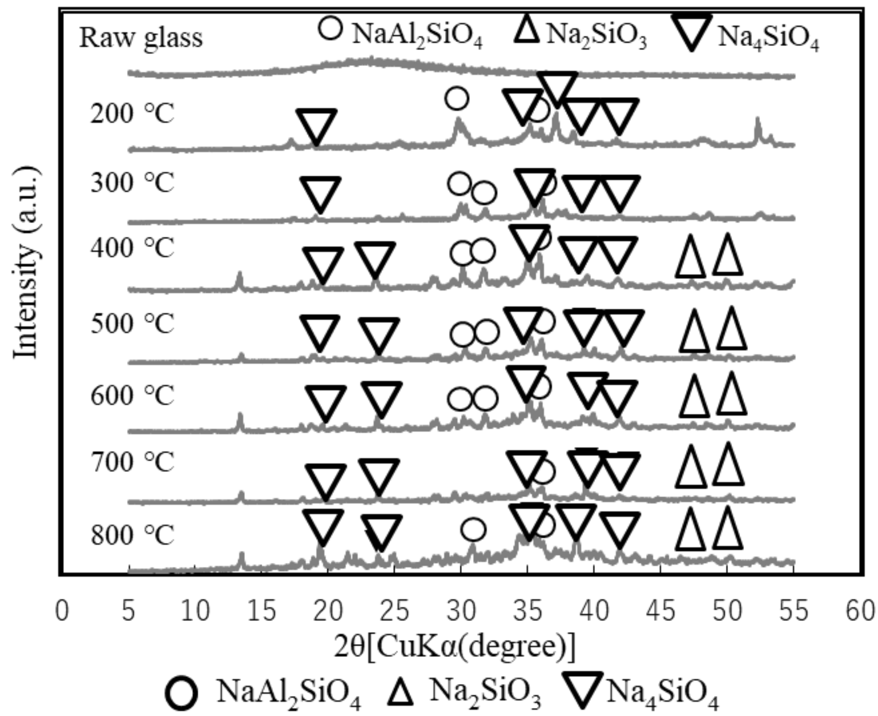

FIGURE 1: XRD patterns of fused materials at various temperatures.

Figure 2 shows the solubility of Si, Al and B from fused materials obtained at various temperatures. Before the alkali fusion treatment, solubilities of Si, Al and B from raw glass are 1.36 mmol/g, 0.028 mmol/g, and 0.022 mmol/g, respectively. With increasing the fused temperature, solubilities of these elements increased, and were almost constant (Si = 4.74 mmol/g, Al= 1.41 mmol/g, B= 1.04 mmol/g) above 400^{o}C. Therefore, the fused materials with high reactivity were obtained by alkali fusion above 400^{o}C.

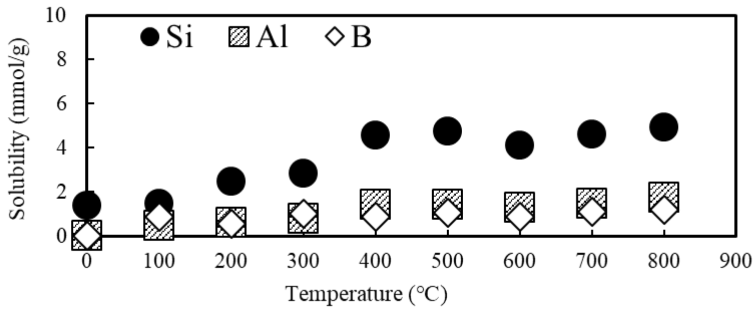

FIGURE 2: Solubility of the aluminoborosilicate glass fused with NaOH at various temperatures.

The effect of NaOH addition on the property of fused material was examined. Heating time was 3 hours, heating temperature was 400^{o}C, and the ratio of NaOH to aluminoborosilicate glass was changed between 1 and 2.5.

Figure 3 shows the XRD patterns of fused material with various amounts of NaOH addition. Alkali salts such as Na_4SiO_4, $NaAlSiO_4$ and Na_2SiO_3, were confirmed in all fused materials. With increasing the NaOH addition peaks of Na_4SiO_4 and $NaAlSiO_4$ appeared at the additional ratio of NaOH per raw glass = 1, their peaks increased, and peaks of Na_2SiO_3 appeared at the ratio of 1.5. Above the ratio of more than 2.0, the peak intensities decreased. The fused material obtained at the additional ratio of NaOH per raw glass = 1.5 has the highest intensity of alkali salts.

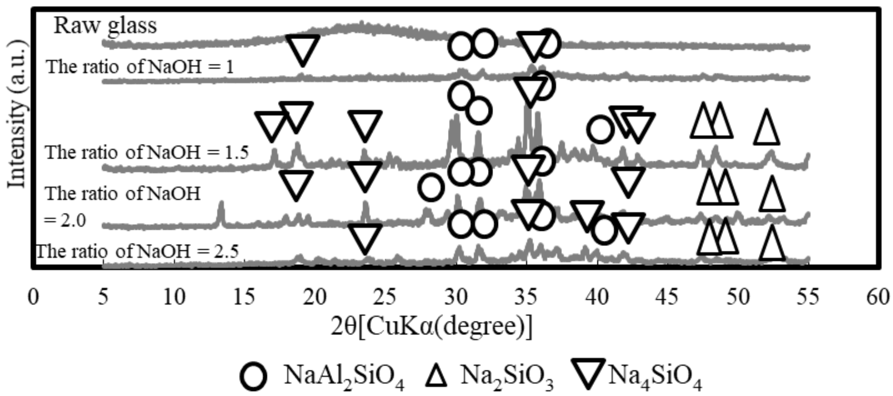

FIGURE 3: XRD patterns of fused material at various amount of NaOH.

Figure 4 shows the solubilities of Si, Al and B from fused material with various amount of NaOH addition. With increasing the addition amount of sodium hydroxide, solubility of Si, Al and B increased, and were almost constant (Si = 4.37 mmol/g, Al= 1.25 mmol/g, B=0.62 mmol/g) above the additional ratio of the 1.5. Therefore, fused materials with high reactivity were obtained above the ratio of 1.5 of NaOH per aluminoborosilicate glass.

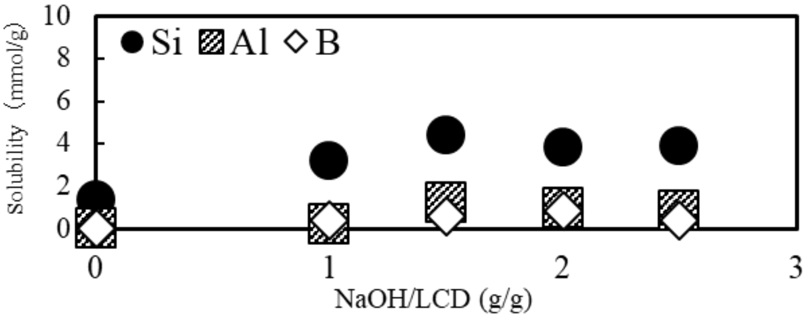

FIGURE 4: Solubility of the LCD fused with various weight of NaOH.

Effect of reaction time on the property of fused material was examined. The ratio of NaOH was 1.5, heating temperature was 400°C, and heating time was changed between 0.5 and 7.

Figure 5 shows the XRD patterns of fused material during the alkali fusion reaction. It was confirmed that alkali salts were rapidly formed in fused material after 0.5-h reaction.

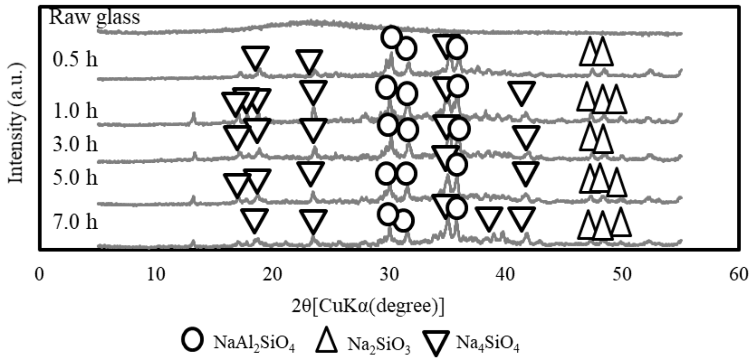

FIGURE 5: XRD patterns of fused material heated at various heating time.

Figure. 6 shows the solubilities of Si, Al and B from fused materials during the alkali fusion reaction. The solubilities of Si, Al and B rapidly increased at the initial stage of 30 min, and were almost constant (Si = 3.50 mmol/g, Al= 1.17 mmol/g, B=0.42 mmol/g) above 0.5 h. Therefore, high reactivity fused materials were obtained rapidly after 0.5-h heating.

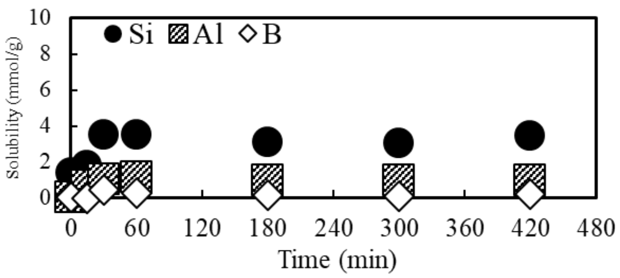

FIGURE 6: Solubility of the LCD fused with NaOH for various heating time.

From these results, we converted waste aluminoborosilicate glass into fused materials with high reactivity in the condition that heating condition is above 400°C, the weight of NaOH/aluminoborosilicate glass is above 1.5, and heating time is above 0.5 h.

We attempted to synthesize zeolite from fused material obtained on the condition mentioned above.

Figure 7 shows the XRD patterns of the products. The precursor indicates broad peaks, which means that the precursor is formed as amorphousmaterials. During the reaction, the peaks of faujasite-type zeolite increase in the products, and is constant after 8 hours.

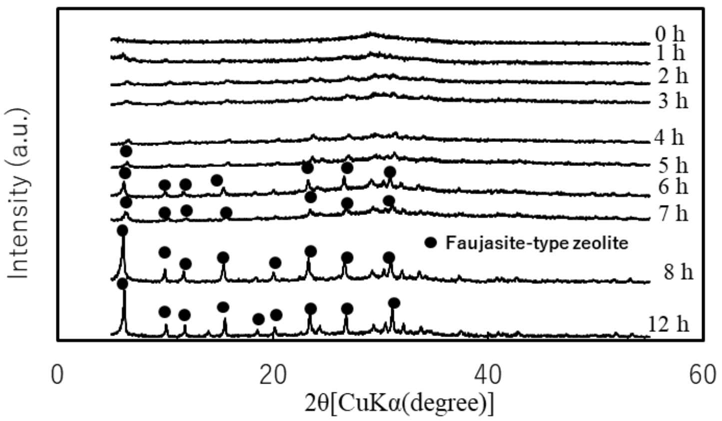

FIGURE 7: XRD patterns of the products during heating at 80°C.

Figure 8 shows the contents of each element in the product. The contents of Si, Al and B in the product increase in the initial stage for 3 h, and then be almost constant (Si=2.95 mmol/g, Al=1.84 mmol/g, B=0.26 mmol/g,), which are good accordance with XRD patterns as shown in Fig. 8. It would be considered that the reaction between the solution and the solid mainly occurs for 4 h, and crystallization of the solid mainly occurs after 4 h. It is noted that the Si/Al molar ratio of the product after 8 h is 1.89, which is almost same as that of faujasite-type zeolite X, and the boron content of the product was about 3 wt%.

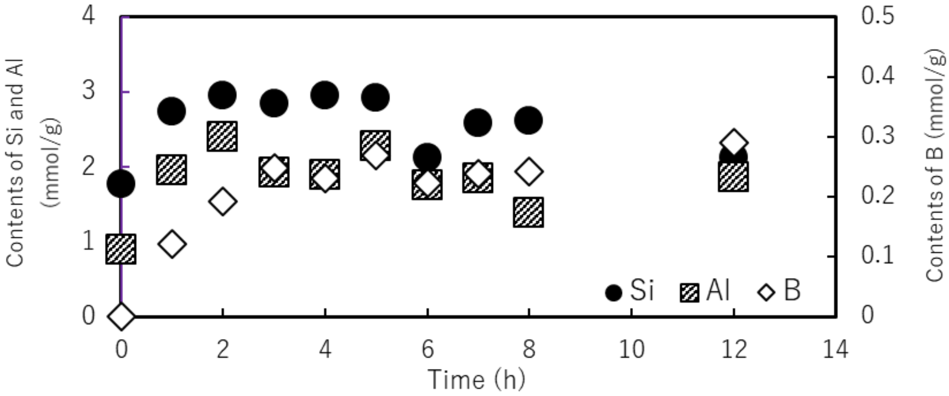

FIGURE 8. The contents of Si, Al and B in the product during the reaction.

Figure 9 shows SEM images of (a) aluminoborosilicate glass, (b) fused material, (c) the precursor and (d) the product. Raw glass was particle like amorphous glass pieces, and fused material was particle with melted surface like alkali salts. The precursor was amorphous gel particles, and the product has faujasite-type zeolite octahedral crystals.

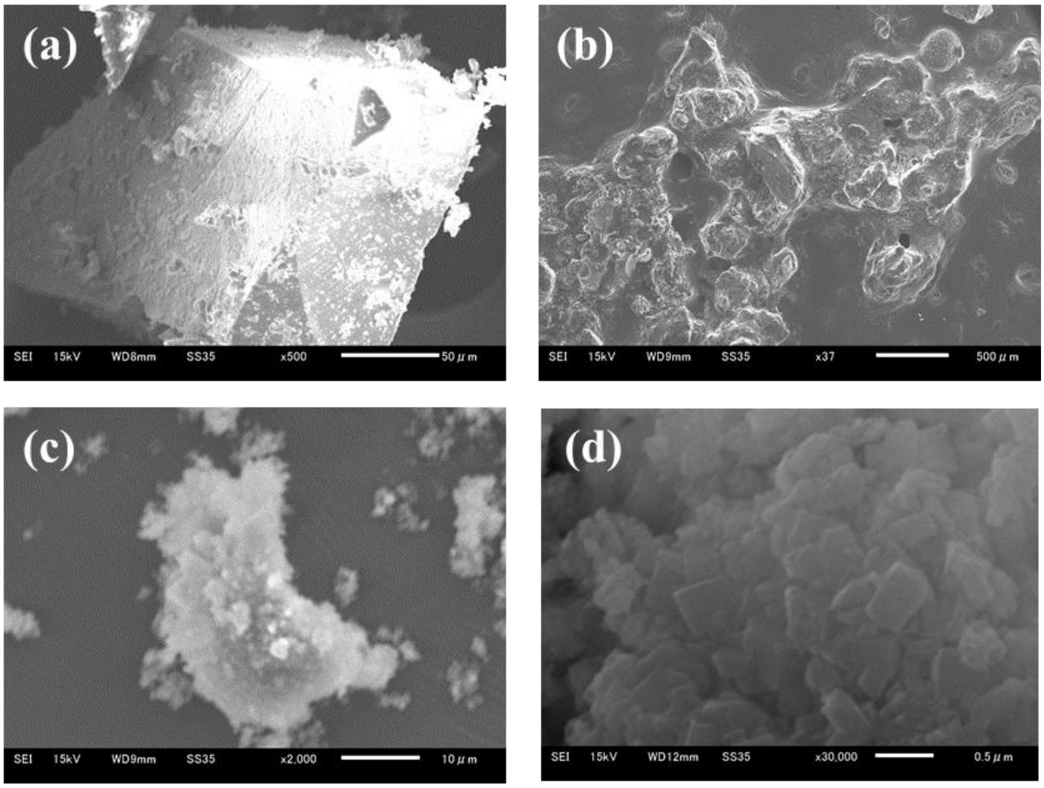

FIGURE 9: SEM image of (a) aluminoborosilicate glass, (b) fused material, (c) the precursor and (d) the product.

The CEC of the product was 1.9 mmol/g, which is 31 times higher than that of raw glass powder. It is noted that the CEC of commercial faujasite-type zeolite was 3.2 mmol/g. The specific surface area of the product was 201 m^2/g, which is 55 % of the commercial molecular sheives 13X (365 m^2/g).

These results indicate that waste aluminoborosilicate glass can be converted into faujasite-type zeolite containing 3 % boron using alkali fusion.

IV. CONCLUSION

We attempted to synthesize faujasite-type zeolite from waste aluminoborosilicate glass using alkali fusion. The processing conditions to obtain fused material with sufficiently high reactivity for zeolite formation was investigated. By alkali fusion, we converted waste aluminoborosilicate glass into fused materials with high reactivity on the condition that heating condition is above 400^{o}C, the weight of NaOH/aluminoborosilicate glass is above 1.5 and heating time is above 0.5 h. Faujasite-type zeolite can be synthesized from aluminoborosilicate glass using alkali fusion, and the CEC of the product with 3 wt% boron content is CEC of 1.9 mmol/g and specific surface area of 201 m^2/g.

REFERENCES

[1] M. Tsujiguchi, in Design for Innovative Value Towards a Sustainable Society, Ed. By M. Matsumoto, Y. Umeda, K. Masui, and S. Fukushige, Springer, Dordrecht, 743-746, 2012.

[2] H. Koyama, and R. Nakazawa, “The present situation and challenge of recycling of glass from the flat panel display”, Ceramics Japan, 47, 81-85, 2012.

[3] C. Amrhein, G. H. Haghnia, T. S. Kim, P. A. Mosher, R. C. Gagajena, T. Amanios, and L. D. Torre, “Synthesis and properties of zeolites from coal fly ash”, Environmental Science and Technology, 30, 735-742, 1996.

[4] X. Querol, N. Moreno, J. C. Umaña, A. Alastuey, E. Hernández, A. López-Solar, and F. Plana, “Synthesis of zeolites from coal fly ash: an overview”, International Journal of Coal Geology, 50, 413-423, 2002.

[5] D. Wu, B. Zhang, L. Yan, H. Kong, and X. Wang, “Effect of some additives on synthesis of zeolite from coal fly ash”, International Journal of Mineral Processing, 80, 266-272, 2006.

[6] S. S. Bukhari, J. Behin, H. Kazemian, and S. Rohani, “Conversion of coal fly ash to zeolite utilizing microwave and ultrasound energies: A review”, Fuel, 140, 250-266, 2015.

[7] T.Wajima, K.Kuzawa, H. Ishimoto, O.Tamada, and T.Nishiyama, "The synthesis of zeolite-P, Linde Type A, and hydroxysodalite zeolites from paper-sludge ash at low temperature (80^{o}C): Optimal ash-leaching condition for zeolite synthesis", American Mineralogist, 89, 1694-1700, 2004.

[8] T.Wajima, M.Haga, K.Kuzawa, H. Ishimoto, O. Tamada, K. Ito, T.Nishiyama, R. T. Downs, and J. F. Rakovan, "Zeolite synthesis from paper sludge ash at low temperature (90^{o}C) with addition of diatomite", Journal of Hazardous Materials, 132, 244-252, 2006.

[9] T.Wajima, T. Shimizu, and Y. Ikegami, "Synthesis of zeolites from paper sludge ash and their ability to simultaneously remove NH_4^+ and PO_4^{3-}", Journal of Environmental Science and health-A, 42, 345-350, 2007.

[10] T.Wajima, H. Ishimoto, K.Kuzawa, K. Ito, O.Tamada, M. E. Gunter, and J. F. Racovan, "Material conversion from paper sludge ash in NaOH, KOH, and LiOH solutions", American Mineralogist, 92, 1105-1111, 2007.

[11] T.Wajima, and Y. Ikegami, "Zeolite synthesis from paper sludge ash via acid-leaching", Chemical Engineering Communications, 195, 305-315, 2008.

[12] T.Wajima, T. Shimizu, and Y. Ikegami, "Zeolite synthesis from paper sludge ash with addition of diatomite", Journal of Chemical Technology and Biotechnology, 83, 921-927, 2008.

[13] T.Wajima, and K.Munakata, "Synthesis of zeolitic material from paper sludge ash using diatomite", Materials Transactions, 53, 592-596, 2012.

[14] T.Wajima, and K.Munakata, "Effect of alkali species on synthesis of K-F zeolitic materials from paper sludge ash for soil amendment", Chemical Engineering Journal, 207-208, 906-912, 2012.

[15] T.Wajima, and K.Munakata, "Preparation of zeolitic material with simultaneous removal of NH_4^+ and PO_4^{3-} from paper sludge ash via acid leaching", Journal of Material Cycles and Waste Management, 16, 367-372, 2014.

[16] T. Wajima, "Synthesis of hydroxysodalite from paper sludge ash using NaOH-LiOH mixtures", Mechanics, Materials Science & Engineering Journal, 9, 309-314, 2017.

[17] T.Wajima, O.Kiguchi, K. Sugawara, and T. Sugawara, "Synthesis of zeolite-A using silica from rice husk ash", Journal of Chemical Engineering of Japan, 42, s61-s66, 2009.

[18] T.Wajima, and Y. Ikegami, "Zeolitic adsorbent synthesized from powdered waste porcelain, and its property for heavy metal removal", ARS SEPARATORIA ACTA, 4, 86-95, 2006.

[19] T.Wajima, and Y. Ikegami, "Synthesis of zeolitic materials from waste porcelain at low temperature via a two-step alkali conversion", Ceramics International, 33, 1269-1274, 2007.

[20] T. Wajima, "Synthesis of zeolitic material from green tuff stone cake and its adsorption properties of silver (I) from aqueous solution", Microporous and Mesoporous Materials, 233, 154-162, 2016.

[21] T. Wajima, "Alkali conversion of waste clay into zeoliticmaterials using NaOH and KOH solution", International Journal of the Society of Material Engineering for Resources, 23, 30-35, 2018.

[22] M. Tsujiguchi, T. Kobayashi, M. Oki, Y. Usumi, N. Kakimori, and A. Nakahira, “Synthesis and characterization of zeolite A from crushed particles of aluminoborosilicate glass used in LCD panels”, Journal of Asian Ceramic Societies, 2, 27-32, 2014.

[23] M. Tsujiguchi, T. Kobayashi, Y. Usumi, N. Kakimori, and A. Nakahira, “Synthesis of zeolite A from aluminoborosilicate glass used in glass substrates of liquid crystals display panels and evaluation of its cation exchange capacity”, Journal of American Ceramic Society, 97, 114-119, 2014.

[24] M. Tsujiguchi, T. Kobayashi, Y. Usumi, N. Kakimori, and A. Nakahira, “Synthesis of FAU zeolite from aluminoborosilicate glass and

elution behavior of glass components", Journal of the Ceramic Society of Japan, 122, 104-109, 2014.

[25] D.W. Breck, Zeolite Molecular Sieves, Wiley, New York, 1974.

[26] R. M. Barrer, Zeolites and Clay Minerals as Sorbents and Molecular Sieves, *Academic Press*, London, 1978.

[27] S. Kallus, J. Patarin, P.Caullet, A. C. Faust, "Synthesis of boron-beta zeolite from near-neutral fluoride-containing gels", Microporous Materials, 10, 181-188, 1997.

[28] S. Mi, T. Wei, J. Sun, P. Liu, X. Li, Q. Zheng, K. Gong, X. Liu, X. Gao, B. Wang, H. Zhao, H. Liu, and B. Shen, "Catalytic function of boron to interconnected mesoporosity in microporous Y zeolites and its high performance in hydrocarbon", Journal of Catalysis, 347, 116-126, 2017.

[29] R. Liu, S. Young, S. Dangwal, I. Shaik, E. Echeverria, D. McIlroy, C. Aichele, and S. J. Kim, "Boron substituted MFI-type zeolite-coated mesh for oil-water separation", Colloids and Surfaces A, 550, 108-114, 2018.

[30] T.Wajima, and Y. Ikegami, "Effect of a chelating agent on the synthesis of zeolitic materials from waste sandstone cake using alkali fusion", ARS SEPARATORIA ACTA, 5, 76-87, 2007.

[31] T.Wajima, K.Yoshizuka, T. Hirai, and Y. Ikegami, "Synthesis of zeolite X from waste sandstone cake using alkali fusion method", Materials Transactions, 49, 612-618, 2008.

[32] T.Wajima, and Y. Ikegami, "Synthesis of crystalline zeolite-13X from waste porcelain using alkali fusion", Ceramics International, 35, 2983-2986, 2009.

[33] T.Wajima, and K.Munakata,"Conversion of waste sandstone cake into crystalline zeolite X using alkali fusion", Materials Transactions, 51, 849-854, 2010.

[34] T.Wajima, and K.Munakata, "Material conversion from waste sandstone cake into cation exchanger using alkali fusion", Ceramics International, 38, 1741-1744, 2012.

[35] T. Wajima, "Alkali fusion synthesis of zeolitic materials from waste dehydrated cake discharged from recycling of construction waste soil, Natural Resources, 8, 300-305, 2017.

Cybernetic Approach to Fisheries Management

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***Abstract*—** *The management of the living marine resources (stocks) exploitation entails the pursuit of a science-based policy in order to preserve the reproductive capacity of the stocks and their sustainable development in the course of time i.e. maintaining the stocks biomass levels within safe biological limits [27,28].*

The excessive increase in catches (fishing effort) due to unscrupulous exploitation can result in irreversibly collapsed biological basis for their existence [19,27,28]. The situation thus created is further exacerbated by the incomplete or poor-quality information about the development of the stocks potential. The present paper advances the adoption of cybernetic approach to the analysis of the management and exploitation of the living marine resources. Proposed also is a block diagram of the stock management system in a context of uncertainty and the use of the precautionary approach and step algorithm for the collection, analysis, processing of information and evaluation of the parameters and the reference biological indicators of the respective biological objects, on the basis of which the target (the target management indicator) is to be set.

***Keywords*— Cybernetic approach, Fisheries management, Stocks, Biological objects, precautionary approach.**

I. INTRODUCTION

A great number of researchers have made remarkable efforts to create valid management technologies for efficient exploitation of the resources [3,4,6,7,14,15,18]. That policy is additionally complemented by the introduction of internationally agreed normative documents, appropriate process control and management organizations, ensuring maximum sustainable yields (MSYs) and/or total allowable catches (TACs) within the context of uncertainty. On the whole, it is at the heart of the management strategies to secure maximum yields, while maintaining the optimal reproductive capacity of the stocks. The most recent status of the stocks necessitates the formation of management strategies and strict definition of the levels of exploitation in a highly uncertain environment with a view of minimizing the possibilities of risk being incurred upon the relevant resources and their living environment, the which, in turn, calls for drastic changes to be implemented in the field of the science and technology applied for their proper management. An integral part of that change is the requirement for the development of a precautionary approach in the management and exploitation of BO stocks. The concept of precautionary approach aims at improving the immediate environment and protecting the living (life-sustaining) renewable resources as a result of reduced risks of losses of their biological diversity and reproductive capacities [1,6,7,10,15,19,21,22].

The current paper will examine the required technology and algorithm for successful application of the precautionary approach in order to make an appropriate assessment of the possibility for attaining maximum total allowable catches that has been adapted to suit the relevant exploitation of stocks (biological objects).

II. CONSOLIDATED BLOCK DIAGRAM OF THE STOCKS AS OBJECTS OF MANAGEMENT

The present analysis gives a sharper focus on those issues that are particularly related to provision of a distinct and well-constructed formulation of the object of management, its input and output variables (factors and target parameters), as well as the technology of management specifically tailored for the unique properties and characteristics of the object's habitat, along with the relevant collection of information necessary for the formation of effective management strategies. The present article, as can readily be perceived in its heading, will be actively "engaged" with the topic of information, i.e. its collection, processing and transmission through the channel of management.

Represented in fig.1 is a consolidated block diagram of the object – a given stock of species considered as biological object (BO) for the purpose of the present analysis with pre-regulated variables and notational system as follows:

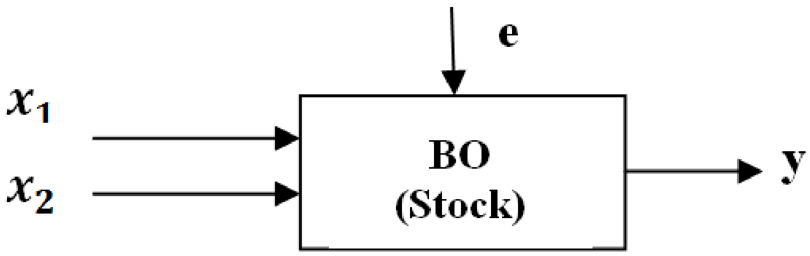

FIGURE. 1: Consolidated block diagram of the object

where:

y - output variable (reaction, target function) of the object, referring herein to the biomass of BO;

x_1- controllable factor: catches (fishing mortality as a result of BO's exploitation);

x_2 – vector of uncontrollable but measurable (calculable) factors: BO's natural mortality and stock recruitment;

e – vector of uncontrollable and immeasurable factors and environmental factors, (noise) – accidental or randomly occurring events with a direct or indirect effect on the biodiversity and abundance of BO's (environmental catastrophes, natural disasters –abrupt and abnormal patterns of extreme weather conditions, intrusion of invasive species, occurrence of overpopulations and violation of the inter-species equilibrium), as well as water temperature, oxygen saturation levels, salinity, acidity, environmental effects (wind speed, water transparency, rough sea), presence of nutrients (phyto-, zoo-plankton, abundance of other species necessary for the sustenance of the surveyed BOs), anthropogenic factors (human activities – industrial, organic and other pollutants) in their natural habitat.

Effective BO management is determined by the availability of full and qualitative information not only about the factors but also about the output variable y.

Regrettably, the collection of relevant information to compile a mathematical model for management purposes is constrained on account of the following peculiarities: large dimensions of the space in which the biomass is allocated; it is controlled by the physical parameter of time (non-stationary object); it is heterogeneous and is unevenly distributed within the vast expanse of that immense body of water (object with distributed parameters). There is, accordingly, considerable difficulty in the provision of a genuine biomass stock assessment (abundance indices). It is usually accomplished through experimental data sets or sampling methods with the right technical means and in the appropriate seasonal time [2,8,24].

III. BO MANAGEMENT SYSTEM

A block diagram has been composed in light of the vital prerequisite for effective stock biomass management and with regard to the distinctive features of the object-environment interrelation as displayed in fig. 2:

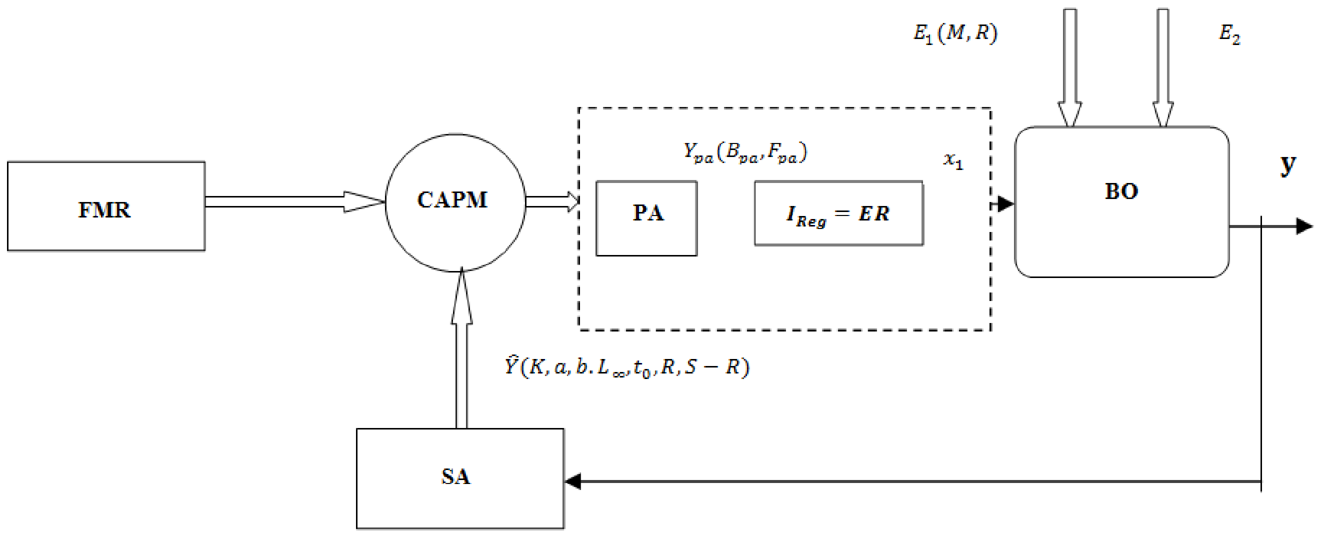

FIGURE 2: Block diagram of the system for BO management

The diagram components are represented by the following symbols:

FMR – fisheries (catch) management rules refer to the entire range of technical and regulatory measures and to the biological reference indicators of BO;

CAPM – comparative analysis of predictive models – model selection and subsequent management formation, operates with current BO state information at different levels of exploitation – fishing mortality (F_i), with the BO biomass being analyzed relative to the reference values;

ER– block for selection of the exploitation level (I_{Reg});

PA – precautionary approach + ER perform the functions of the control structure;

x_1 – control variable – TAC, MAC, MSY (total allowable or maximum allowable catch);

$E_1(M, R)$– vector of BO's natural mortality and recruitment, being determined by experimental and analytical methods (as regards SA);

$E_2 \equiv e$– vector of all external factors (noise) that are immeasurable in the process of BO management and the environmental factors as well;

SA – stock assessment– experimental research studies, sampling that provides information as to the biomass, BO growth parameters and the mortality parameters.

IV. CHARACTERISTIC FEATURES OF THE COMPONENTS OF THE BO MANAGEMENT SYSTEM

4.1 Control object

BO is the principle constituent of the system whose biomass (abundance indices) becomes the object of control – assuming that the stock biomass (y) is treated as output variable (target function). As for the input, control variable (x_1), it will be governed by TAC or MSY. Moreover, BO is greatly affected by the measurable but uncontrollable factor $E_1(M, R)$.The immeasurable and uncontrollable factors along with the environmental factors will form the vector E_2.

4.2 Stock assessment

It is closely connected with the analysis and evaluation of growth and mortality parameters of BOs, coupled with an assessment of one or more biological characteristics such as: abundance (number of individuals) or biomass (in tones), with their management being based on a comparative analysis between the calculated and defined (reference) values for the corresponding BO. Regardless of the fact that there are quite a few biological indicators that provide useful data for determining BO's status, a great number of management programs propose the use of stock biomass and fishing mortality as basic indicators, [8,11,16,17,24].

The data series of the biomass or, alternatively, the total weight of the individuals constituting the BOs are analyzed relative to the reference levels that have been defined as sufficient to enable their reproduction into young individuals during the next breeding season and replenish the BO under conditions of intensive exploitation [3,4,5,6,7,13,25,27,28]. It is assumed that the maintenance of BOs biomass above these reference values provides excellent conditions for sustainable biological development of that particular BO. Conversely, when the biomass is below the standard reference levels, it is deduced that that BO is overexploited [27,28].

The second indicator which underlies the formulation of BO management plans is the fishing mortality (or the exploitation level of the stock). If the fishing mortality exceeds the standard reference levels - BO is overexploited, otherwise, the current levels of exploitation are inferred to be optimal. Management, in its most simplified form, refers to the pursuit of measures to reduce the levels of BO exploitation and, respectively, to ensure the necessary conditions for its natural replenishment - through restrictive measures such as: decrease in the fishing effort applied to BOs and introduction of various prohibitions and restrictions towards that end. Fisheries management also intends to develop a comprehensive strategy for such plans and modes of exploitation that will prevent the values of the monitored biological indicators for the surveyed stock of species (BO) from falling below the standard reference values [27,28].

Despite the improvement and rapid development of computer technologies, the mathematical and statistical models for BO analysis, still existing in this field of study, contain significant uncertainties [1,2,8,24,20] that defeat every computer program and analytical approach and they are mainly due to three factors:

- available data for BO is of insufficient quality and have a significant degree of uncertainty and incompleteness [24];
- it is impossible for analytical models to cover and adequately reconstruct BO real dynamics operating within a vast natural environmental system [2,9,24];
- for management purposes, analytical models have to provide reliable projections of the potential future behavior of the object under study.

The available data for BOs are imprecise since the process of collecting information about marine populations proves to be incredibly difficult and rather costly to implement; on the other hand, the very nature of the object itself (the inborn character of the marine biological species) indicates that collecting information about them, even in the most simplified assessment methods, is associated with a multitude of assumptions. Consequently, it naturally follows that the quality of the available information is to have serious repercussions on the precision of the BOs status assessment [2,8,9,24].

BOs assessment aims to process the input data/observations about BO and to yield data which are projections of expectations for its potential behavior through the use of a definite mathematical apparatus. The input data about BO is of the type: historical information and knowledge about its behavior, whereas the observations are related to the utilization of sampling methods and experimental research studies into the identified areas of distribution (e.g. experimental determination of abundance indices and stock biomass by the swept area method). To explore such a BO, there are two routes to follow– one that deals with BO physiology – modeling of growth parameters, mortality, reproduction, etc., and the other one that probes into the population dynamics [8,24].

If the resultant analytical models represent the reality with some approximation, then it is necessary to analyze whether that approximation is satisfactory for the purposes of the analysis of BOs management or not. If the results obtained provide an inadequate reflection of the reality– then, the underlying assumptions should be appropriately modified. Changes effected in the underlying assumptions used for the construction of the model may be in the direction of adapting the model to other cases.

The most applicable models for BOs assessment are the production models that examine the stock on a global scale – mainly in reference to the BO abundance indices (in total weight or number of individuals from which it is represented) and inquire into its evolution in relation to the levels of exploitation. They do not consider BO as regards the age composition or length-weight characteristics of individuals [8,24].

The other models are the structural models – they examine BO structure by age groups of their constituent individuals (cohorts) and the evolution of this structure in the course of time. These models design and analyze BOs, as well as the expected catches, following the evolution of its cohorts. Prior knowledge of BO assessment and the available basic information determine the type of assessment model to be used, and, on that account, the adoption of a more analytical approach to the formation of management [24].

BO assessments are made on the basis of population models that require three primary categories of data (input data in the procedure of modeling BO dynamics) and subsequent formation of a strategyfor their management under conditions of exploitation:

- **catch data–** the quantity of fish removed from the stock by fishing activities;
- **data about BO abundance–** measure, associated index, biomass quantity or weight– these data are usually available through experimental studies (trawl images using the swept area method for pelagic and demersal species) conducted in BO distribution zones;
- **biological data–** information about the individual growth parameters of the concrete species and their natural mortality, mortality as a result of predatoriness committed byspecies at a higher level in the food chain; general knowledge of the species (breeding seasons, migration, etc.). Information as to the exploitation of the species – seasonality, fishing gear and methods used, distribution zones, prohibited zones and seasons in modes of exploitation and others [24].

4.3 Precautionary approach in the management of BO stocks

4.3.1 Precautionary approach

The principle of precaution herein is based on the “concept of sustainable development” and is associated with warning signs for adverse events under conditions of uncertainties in the exploitation of natural resources. The methodology of the precautionary approach in the field of fisheries is built upon the concept of sustainable development and the principle of precaution. In view of this, introduced are the following 4 important principles of the leading philosophy [1,28]:

- Warning related to the possibility of losses in the exploitation of stocks and the ecosystem;
- Taking justified and approved measures in the event of impending hazard to the status of the exploited stock;
- Taking due consideration of the uncertainties (incomplete knowledge of the stocks and their habitat) as an objectively unavoidable factor in the regulation of the levels of exploitation;
- Restoring the exploited stocks to high performance levels and their proper maintenance during exploitation.

4.3.2 Making allowances for uncertainty in TAC forecasting

Mathematical modeling is widely used for stock assessment and TAC forecasting. If all the factors and uncertainties that act upon the processes thereof are not taken into full account, then even the most superior model is likely to prove partially or insufficiently effective. Put differently, here, the principle focus is on the incomplete and insufficient knowledge about the parameters of the object under study. In accordance with [1,28] the following types of uncertainties are defined when considering the precautionary approach:

- Uncertainty caused by errors in measurement due to unrepresentativeness of the data collected;
- Uncertainty of the modeling approximation of catch dynamics;
- Uncertainty of the natural variability of the stock parameters.

In addressing the problems above, all the processes affecting the formation of TAC are considered static within the surveyed horizon. The forecast results will, obviously, be conditioned by the implementation of this particular assumption even with the provision of the most reliable information. The statistical characteristics were determined through the employment of the probability theory.

Applying the precautionary approach to determine the proper levels of BO exploitation requires thorough examination of a number of additional biological indicators for TAC formation, such as:

- valid management procedures still in effect and consequences of their application;
- scope of applicable management activities;
- BO structure, object of management;
- Analysis of the basic patterns in “predator-prey” relationships; environmental effects upon the growth and replenishment parameters;
- BO geographical distribution in view of the established fishing areas;
- breeding areas;
- areas for the development of juvenile forms;
- migration routes of size – age groups;
- effect of BO density on the growth/distribution;
- variability of the recruitment;
- analysis of the stock/biomass-recruitment relationship;
- composition of the fishing fleet;
- analysis of the selectivity of the fishing gears;
- advantages and precision of the different approaches for assessing BO;
- factors which would undermine or cause damage to BO (analysis of the historical information for BO and analysis of information about BO with similar physiological, growth-weight and age structure, nutrition and feeding);

The precautionary principle implies close attention wherever information as to certain BO stocks is insufficient or there are clear signs of excessive variability in BO biological indicators or environmental factors, with the primary focus being mainly on the safety of resources and fisheries [1,27,28].

V. STOCK MANAGEMENT ALGORITHM WITH THE APPLICATION OF PRECAUTIONARY APPROACH

The problems, identified from the perspectives of what has been discussed so far, are listed below:

- strong need for taking into account and reducing uncertainty in the output data used to form a target indicator in the process of management;
- critical need for taking into account and analyzing all the controllable and uncontrollable factors in the process of management that can directly impact the current status of the object of management E_1 and E_2;
- Considerable need for reducing the risk of the impact of data uncertainty upon the formation of the target indicator of management.

Proposed on the basis of the synthesised block diagram of the management system (fig. 2) is the following algorithm for the synthesis of target indicator of management:

TABLE 1
STEP ALGORITHM FOR STOCK MANAGEMENT SUPPORTING THE IMPLEMENTATION OF PRECAUTIONARY APPROACH TO MANAGEMENT

Step1. Collection of preliminary information and retrospective analysis of BO stocks
- collecting information on the geographic distribution - seasonality - biological and physiological features of BO - specificity of the diet, etc. - interspecies and intraspecies interactions
Step2. Identification of $E_1(M, R)$
- sampling (experimental studies/surveys using the swept area method and samples of commercial catches) and identification of the growth parameters - sampling (experimental studies/surveys using the swept area method and samples of commercial catches) and estimation of the length - weight relationship– calculating the theoretical and trace weight, Fulton coefficient, indirect methods for analysing the availability and abundance of nutrients necessary for the normal development and growth of BO; - sampling (experimental studies/surveys using the swept area method and samples of commercial catches) and identifying mortality parameters; collecting information on the catches, systematizing and identifying total mortality assessing mortality due to interspecies interactions (predator-prey relationship), assessing the effects of overpopulations and invasive species - sampling(experimental studies/surveys using the swept area method and samples of commercial catches) and identifying stock recruitment (accounting for the variability of recruitment) assessing the effects of anthropogenic activities – industrial pollution, organic pollutant emissions, etc.;
Step 3. Collecting current information about E_2
- analysis and assessment of habitat effects – chemical composition of water, temperature, salinity, oxygen saturation, presence of nutrients, impact of specific climatic factors of the environment – water density, currents, wind, vertical mixing of water layers with different temperature values; occurrence of environmental catastrophes and climatic cataclysms
Step 4. Collecting current information about the status of BO
- sampling (experimental studies/surveys using the swept area method and samples of commercial catches) and measuring the current levels of stock biomass or abundance indices
Step 5. Stock-recruitment curve analysis (after completion of steps 1-4)
- Identification of Y_{MSY}
Step6. Biomass- recruitment curve analysis (after completion of steps 1-4)
- Identification of B_{MSY}
Step 7. Production models. Linear-cohort analysis, Virtual population analysis. Identification of equilibrium catch per recruit and equilibrium biomass per recruit.
Step 8. Calculation of biological reference (target) levels of the biomass, maximum sustainable yield and fishing mortality
Step 9. Checking, analyzing and comparing the current values with reference values. Forecast models– for different levels of exploitation (F_i)
- Producing a recommendation for the target indicator of management x_1– TAC with the use of precautionary approach in the management of BO stocks

The execution of the algorithm, the selection of the model and the accuracy of the assessments obtained in steps 2 and 3 depend, to a greater extent, on the nature, quality and volume of the information collected, assuming normal distribution of the data in the samples being analyzed [12,28], the number of surveys/sampling, the selection of mathematical tools and the available software.

VI. SOFTWARE

To facilitate the process of management formation, expanded is the independent application software system presented in [26], with the software code being developed in the MATLAB environment to cover the methods described below.

6.1 Applied in the developed software system are mathematical methods of modeling, analysis and evaluation of the stock parameters and formation of the target indicators of management with the relevant methodological and mathematical provision:

A. Verification of the statistical hypothesis for normal distribution of the samples with the possibility of examining the impact of the number of intervals and introduced noise (error of measurement of BO parameters, variability of environmental factors)

B. Study into the analytical model of length - weight relationship$W(i) = q * L(i)^b$and evaluation of the parameters q and b

C. Study into the type of length-weight relationship within the BO exploitation phase (Validity of linear, polynomial and non-linear models)

D. Determining BO growth parameters K, L_∞ according to von Bertalanffy model [24]

E. Determining BO growth parameters K, $L_\infty$by Gulland and Holt method [24]

F. Determining BO growth parameters K, L_∞byFord-Walford method [24]

G. Determining BO growth parameters K, L_∞according to Chapman-Gulland method

H. Calculating K and t_0 by von Bertalanffy model with foreknown L_∞ [24]

I. A two-step procedure based on the Least Squares and Instrumental Variable methods for simultaneous evaluation of von Bertalanffy growth parameters K, L_∞ and t_0

J. Calculating the coefficient of total mortality Z by the linearized catch curve according to data about the stock age composition and the catches [24]

K. Calculating the coefficient of total mortality Z on the basis of data about the stock size composition and the catches [24]

L. Determining Z by the Beverton - Holt method on the basis of data about the stock size composition [24]

M. Jones and Van Zalinge method for calculating the coefficient of total mortality Z – Cumulative catch curve from data about the BO size composition and the catches [24]

N. Calculating the CM by the Powell-Wetherall method [24]

O. Calculating the coefficient of natural mortality M and the coefficient of catchability q through the use of the coefficient of total mortality Z and the fishing effort f [24]

P. Determining the coefficient of natural mortality M by Pauli empirical formula [24]

Q. Determining the coefficient of natural mortality Mby Rikhter-Efanov formula [24]

R. Analysis of the curves Stock-recruitment Beverton-Holt model and stock biomass –recruitment model. Applying the precautionary approach to the calculation of the biological reference levels of BO and target indicators in relation to the management of the biomass and the fishing mortality:

- ➢ Stock-recruitment curve analysis [24]
- ➢ Identification of target biological reference levels
- F_{MSY}
- The biomass reference limit levels B_{lim} and the fishing mortality F_{lim}
- The biomass reference limit levels B_{pa} and the fishing mortality F_{pa} upon the application of the precautionary approach [19,36,75]

6.2 Primary program structures used in the development of the software system:

The selection of the method of implementation is arranged through the introduction of a switch – case structure [26]:

```
SWITCH switch_expr
      CASE case_expr,
statement, ..., statement
         CASE {case_expr1, case_expr2, case_expr3,...}
statement, ..., statement
        ...
        OTHERWISE,
statement, ..., statement
      END
```

A selected method can be performed repeatedly for the purposes of the analysis or reproduced with different input data. The input data for the implementation of a given method have been pre-stored in text files (.txtfiles), which allows them to be automatically loaded when the method is implemented. If additional processing (transformation or calculations) of the input data is required – for example, to form input-output vectors for regression analysis, then the transformation is performed automatically using a loop or if..end structures [26]

The developed software system functions as a standalone application and records the results of the implementation of the selected research method in a filepre-created in advance for this particular purpose (.txtfile), which is arranged within the programming structure. As part of the implementation of the methods, the program requires the user to implement interactively the critical tabular values of specific variables associated with the assessment of the model parameters or to issue a conclusion of the type "The model is proved functional/non-functional" or to be used for further calculations of the model parameters.

6.3 Verification of the performance specifications of the proposed software system

The performance of the proposed software system has been tested with experimental, simulation data and examples of numerical solutions as given in [24].

VII. CONCLUSIONS

7.1 Proposed are:

- block diagram of stock management with the use the precautionary approach under conditions of uncertainty;
- step algorithm for the collection, analysis, processing of information and evaluation of the parameters and the reference biological indicators for BO, on the basis of which the assignment is formed (target indicator of management);
- A software system for the management of BO has been developed to enable the calculation of the growth parameters, the mortality parameters BO, examination of the law of distribution and verification of statistical hypotheses– assumptions of normal distribution of the sample data; stock-recruitment and biomass - recruitment curve analysis and calculation of reference points for the stock biological indicators, which are target indicators of the management of BO stocks in the context of uncertainty. The performance of the system thereof has been tested with experimental, simulation data and examples of numerical solutions as provided in [24].

The results delivered lead to the following conclusions:

1) The developed software system allows the precise calculation of the growth parameters, parameters of BOs mortality, examination of the law of distribution and verification of statistical hypotheses– assumptions of normal distribution of the sample data; stock-recruitment and biomass - recruitment curve analysis and calculation of reference points for the stock biological indicators, which are target indicators of the management of BO stocks in the context of uncertainty.

2) The input data may be current or historical information (observations/measurements) about BO, which opens up the opportunity for the software system to be applied for a retrospective and current analysis of the BOs stock status.

3) When implementing methods related to statistical evaluation of parameters, envisaged is a statistical analysis of the significance of the results (application of the Fischer's criterion and/or analysis of the studentized residuals) with the relevant conclusion regarding the performance specifications of the models obtained.

4) The methods can be performed repeatedly, depending on the user's needs– with the same or new input data. If there is sufficient data for the implementation of different methods that evaluate the same parameters, then, for purposes of the analysis, the results may be compared and the accuracy of the modelling parameters assessments evaluated.

5) The developed system is functionally efficient as a standalone application which does not necessarily require installation and knowledge of the MATLAB software environment in order to run.

6) The results of the implementation of a given method are kept in text files, which, if necessary, can be processed with other software applications.

REFERENCES

[1] Babayan, V.K. 2000, Precautionary Approach to Assessment of Total Allowable Catch (TAC), Analysis and Practical Recommendations, Moscow, VNIRO Publishing, 192pp.

[2] Brander, K., 2003. What Kind of Predictions do we need and what kinds of information will help us to make better predictions? In: O. Ulltang and G. Blom (eds.) Fish stock assessments and predictions: Integrating relevant knowledge, Sci. Mar. 67 (Suppl. 1): pp. 21-33.

[3] Caddy J.F, 1993. Reference points for fishery management: their potential application to straddling and highly migratory resources. FAO Fish Circular., 864, 52 pp.

[4] Caddy J.F, 1997. Checks and balances in the management of marine fish stocks: organizational requirements for a limit reference point approach. Fisheries Research, 30, 1-15.

[5] Caddy J.F., Csirke J. , 1983. Approximations to sustainable yield for exploited and unexploited stocks. Ocean. Trop., 18 (1), 3-15.

[6] Caddy J.F., Mahon R., 1995. Reference points for fisheries management. FAO Fisheries Technical Paper, 347, 83 pp.

[7] Caddy J.F, McGreevy R., 1996. Targets or Limits for Management of Fisheries. North American Journal of Fisheries Management, 16, 479-487.

[8] Cadima, E.L. 2003. Fish Stock Assessment Manual. FAO Fisheries Technical Paper. No 393, Rome, FAO, 161p.

[9] Chapman, D. G., 1961. Statistical Problems in Dynamics of Exploited Fisheries Populations. Proceedings of the Fourth Berkeley Symposium on Mathematical Statistics and Probability, Volume 4: Contributions to Biology and Problems of Medicine, 153--168, University of California Press, Berkeley, Calif.,

[10] Deriso, R.B. 1987. Optimal F0.1 criteria and their relationship to maximum sustainable yield. Canadian Journal of Fisheries and Aquatic Sciences, 44 (Suppl. 2), 339–348.

[11] Hilborn R., Walters CJ. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York, 570 pp.

[12] Hoggarth D.D., Abeyasekera S., Arthur R.I., Beddington J.R., Burn R.W., Halls A.S., Kirkwood G.P., Mcallister M., Medley P., Mees C.C., Parkes G.B., Pilling G.M., Wakeford R.C., Welcomme R.L. 2006. Stock assessment for fishery management: A framework guide to the stock assessment tools of the Fisheries Management Science Programme (FMSP). FAO Fisheries Technical Paper., Rome, 487, 261 pp.

[13] ICES Advice. 2017, Book 12, ICES Advice Technical Guidelines, 20th January, DOI: 10.17895/Ices.pub.3036.

[14] Kragt, M., 2012. Bioeconomic modelling: Integrating economic and environmental systems?, International Environmental Modelling and Software Society (iEMSs), 2012 International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.).

http://www.iemss.org/society/index.php/iemss-2012-proceedings

[15] Kulatska, N., January 2016. Bridging the gap between ecosystem modelling and ecosystem-based fisheries management solutions for the Baltic Sea, Swedish University of Agricultural Sciences, Department of Aquatic Resources, Institute of Marine Research, Aqua Introductory Research Essay 2016:1, ISBN: 978-91-576-9374-7 (electronic version).

[16] LLEONART, J, 1-4 July, 2002. OVERVIEW OF STOCK ASSESSMENT METHODS AND THEIR SUITABILITY TO MEDITERRANEAN FISHERIES, 5th session of the SAC-GFCM, Rome.

[17] Lleonart, J., & Maynou, F. 2003. Fish stock assessments in the Mediterranean: State of the art. Scientia Marina, 67(1), 37–49.

[18] Munro G. 1979. The Optimal Management of Transboundary Renewable Resources, Canadian Journal of Economics, 3, 271-296.

[19] Nguyen, T. V., September 2009. Ecosystem-Based Fishery Management: A Critical Review of Concepts and Ecological Economic Models, Department of Environmental and Business Economics, IME WORKING PAPER 94/09 ISSN 1399-3224.

[20] Pitcher, T. J., 1999. Beverton and Holt Equations: Spreadsheets Functions and Uncertainty, Naga, ICLAPM Quarterly (vol. 22, No. 1) Jan-Mar 1999.

[21] Plaganyi, E., 2007. Models for an Ecosystem Approach to Fisheries, FAO Fisheries Technical Paper, 477, FAO, Rome.

[22] Rose K. A., Allen I. J, Artioli, Y., Barange, M., Blackford, J., Carlotti, F., Cropp, R., Daewel, U., Edwards, K., Flynn, K., Hill, S. HilleRisLambers, R., Huse, G., Mackinson, S., Megrey, B., Moll, A., Rivkin, R., Salihoglu, B., Schrum, C., Shannon, L., Shin, Y., Smith, L., Smith,C., Solidoro, C., St. John, M., Zhou, M., 2010. End-To-End Models for the Analysis of Marine Ecosystems: Challenges, Issues, and Next Steps, Marine and Coastal Fisheries, 2:1, 115-130, DOI: 10.1577/C09-059.1

http://dx.doi.org/10.1577/C09-059.1

[23] Ross, S. M. 2009. Introduction to probability and statistics for engineers and scientists (4th ed.). Associated Press. pp. 267. ISBN 978-0-12-370483-2.

[24] Sparre P., Venema S.C. 1998. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish Tech. Pap., 306/1 (Rev.2), 407p.

[25] Wendy L. Gabriel and Pamela M. Mace, 1999. A Review of Biological reference Points in the Context of the Precautionary Approach, Proceedings, 5th NMFS NSAW. NOAA Tech. Memo. NMFS-F/SPO-40.

[26] Zlateva, I., Nikolov, N., Alexandrova, M., 2018. Matlab-based Standalone application for Estimation of Growth and Mortality Parameters of Fish. International Journal of Engineering Research and science, Vol-4, Issue-1, January-2018.

[27] EC 2017. Official web site of the European Commission – Fisheries:
http://ec.europa.eu/fisheries/cfp/management_resources

[28] Food and Agriculture organization of the United Nations - http://www.fao.org/home/en/.

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