Biomass as Raw Material for the Production of Biofuels and Chemicals

EDITED BY

Waldemar Wójcik
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ROUTLEDGE

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Routledge
Taylor & Francis Group
LONDON AND NEW YORK

Routledge is an imprint of the Toylor& fronds Group, on informo business

Typeset by codcMancra

Library of Congress Cataloging-in-Pubi/cation Data
Names: W6jcik, Waldemar, editor.| Pawtowska.Matgorzaca. 1969- editor.
Title: Biomass as raw material for the production of biofuels and chemicals / edited by WaldemarWojcik.MalgorzataPawtowska. Description: Leiden, The Netherlands : Routledge, Taylor & Francis Group, [2022] I Includes bibliographical references.
Identifiers: LCCN 2021031137 | ISBN 978103201IS8S (hardback) | ISBN 9781032064574 (paperback) | ISBN 9781003177593 (ebook) Subjects: LCSH: Biomass energy. | Biomass chemicals.| Biomass. Classification: LCCTP339 . B5475 2022 | DDC 662Л88—dc23 LC record available at https://lccn.loc.gov/202l03H37

Published by: Routledge
Schipholweg I07C, 2316 XC Leiden, The Netherlands e-mail:
Pub.NL@taylorandfrancis.comwww.routlcdgc.com - www.taylorandfrancis.com

ISBN: 9781032011585 (hbk)
ISBN: 9781032064574 (pbk)
ISBN: 9781003177593 (ebk)

DOI: 10.1201/9781003177593

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Preface

Plant biomass, a common source of valuable raw materials, has been used by humans as food, fodder for farm animals, fuel, building and furniture material, as well as a natural medicine or fertilizer for centuries. With the development of civilization, accompanied by the emergence of more efficient energy sources, new structural materials, fertilizers and other chemicals used in various spheres of life, its importance has still not diminished. It is still the basic food for humans and animals, a popular energy source currently used not only as a solid fuel but also after appropriate processing - as a liquid or gaseous biofuel used in means of transport, a valuable material employed in various industries, as well as a source of bioactive chemicals for the production of pharmaceuticals, nutraceutics, cosmetics or natural agents that improve soil quality.

Today, in addition to the undeniable application values of biomass, special attention is paid to the key role that biomass plays for the Earth’s ecosystem, emphasizing its renewable nature, which ensures the circulation of carbon in the global cycle. The growth of biomass is related to the absorption of carbon from the atmosphere *via* photosynthesis. Naturally, the combustion of biomass releases carbon in the form of COo, but it can be assumed that the pool of this element in the atmosphere does not increase because it is built up back into the plant tissues. Although treating biomass as a carbon-neutral fuel is an exaggeration, as fossil fuels arc also used during the biofuels production, it should be noted that the energetic use of biomass, especially the waste biomass or the mass of hydrobionts such as cyanobacteria, which pose the threat for water ecosystems, certainly contributes to the reduction of the pollutant emissions and provides many other environmental benefits. Such kinds of biomass arc especially valuable as a raw material used in biorefincries. The idea of biorefining is gaining more and more popularity around the world. It is based on multidirectional processing of biomass, as a result of which various products are obtained, while maintaining the lowest possible CO2 emission rate. Biorefiningis closely related to another global mainstream concept the circular economy, in which attention is paid to the fact that by-products generated at various stages of raw material processing arc used as substrates in another production process.

Biomass, as a raw material for industry and energy, has a number of advantages including wide availability, renewable nature, and usually low acquisition cost (especially in the case of waste biomass). However, it also has certain disadvantages. Its biodegradable nature can be a problem during transport and storage. Additionally, the use of special preservation methods, such as drying and ensiling, or protection against external factors is sometimes required. On the other hand, in some types of applications, it is necessary to increase the biodegradability of biomass. The high share of polysaccharides and lignin in lignocellulosic structure limits the efficiency of biomass conversion to the targeted products when the biological processing is realized. Enhancement of biodegradability is achieved through a number of processes based on various mechanisms, ranging from the simple mechanical processing consisting in grinding or crushing to complex and multi-stage chemical or physicochemical methods.

The book shows the exemplary applications of different types of biomass for the production of biofuels and other useful products, such as fertilizers, chemicals, and drugs. Special attention is paid to the practical directions of using the biomass of hydrobionts and microorganisms of activated sludge. Considering different applications of the biomass-derived products, the environmental, economic and energetic aspects were taken into account.

Editors

WaldemarWojcik was born in Poland in 1949. He is the Director of the Institute of Electronics and Information Technology, former long-time dean of the Faculty of Electrical Engineering and Computer Science at Lublin University of Technology, and Doctor Honoris Causa of five universities in Ukraine and Kazakhstan. He obtained his Ph.D. in 1985 at the Lublin University of Technology, and D.Sc. in 2002 at the National University Lviv Polytechnic, Ukraine. In 2009, he obtained the title of professor granted by the President of Poland. In his research, he mainly deals with process control, optoelectronics, digital data analysis and also heat processes or solid-state physics. He pays particular attention to the use of optoelectronic technology in the monitoring and diagnostics of thermal processes. He is a member of Optoelectronics Section of the Committee of Electronics and Telecommunications of the Polish Academy of Sciences and Metrology Section of the Committee of Metrology and Scientific Equipment of the Polish Academy of Sciences. He is also a member of European Academy of Science and Arts (Austria); Academy of Applied Radioelectronics of Russia. Ukraine and Belarus; the International Informatization Academy of Kazakhstan; and many other scientific organizations of Poland as well as Europe and Asia. In total, he has published 56 books and over 400 papers, and authored several patents. He is also a member of the editorial board of numerous international and national scientific and technical journals.

MalgorzataPawtowska, Ph.D., is a researcher and lecturer at the Faculty of Environmental Engineering of Lublin University of Technology. In 2013 2019, she was the Head of the Department of Alternative Fuels Engineering at the Institute of Renewable Energy Sources Engineering. Currently, she heads the Department of Biomass and Waste Conversion into Biofuels. She received her M.Sc. in philosophy of nature and protection of the environment at the Catholic University of Lublin in 1993. In 1999. she received her Ph.D. in Agrophysics at the Institute of Agrophysics of the Polish Academy of Sciences, and in 2010, she obtained a postdoctoral degree in the technical sciences in the field of environmental engineering at the Wroclaw' University of Technology. In 2018, she was awarded (he title of Professor of Technical Sciences. Her scientific interests focus mainly on the issues related to the reduction of the concentrations of greenhouse gases in the atmosphere, energy recovery of organic waste, and the possibility of using the waste from the energy sector in the reclamation of degraded land. Л measurable outcomes of her research is the authorship or co-authorship of 105 papers, including 40 articles in scientific journals, 4 monographs, 24 chapters in monographs, co-cdition of 5 monographs, co-authorship of 15 patents and dozens of patent applications. She has participated in the implementation of nine research projects concerning, first of all, the prevention of pollutant emissions from landfills and the implementation of sustainable waste management.

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CONTENTS

6.1 INTRODUCTION

The use of new energy-saving technologies has led to a significant development of the designs of vibrating machines and their widespread use, in particular for processing biomass. During their operation, the question of the efficiency and reliability of using this type of machine is quite relevant, due to the presence and possibility of using the reserves of its operation. The machines of this type must meet the requirements of quality and reliability in order to fulfill their official purpose.

The reliability and performance characteristics of vibrating machines are important technical and economic indicators related to the operation of systems for processing biomass. The increase of these characteristics opens the direction for the scientifically sound designation of reliability indicators, the achievement of these indicators in an economically optimal way. Improving the reliability and durability of vibrating machines has a serious reserve for saving money, materials, energy, and labor. To a large extent, the reliability and durability of a vibrating machine depend on extreme overloads. The qualification choice of materials and the correct calculations, taking into account the presence of a priori statistical information about the load at

DOI: 10.1201/9781003177593-6

the design stage, are the main sources of improving reliability without significantly raising the cost of the machine. Therefore, this research topic is relevant.

ANALYSISOFLITERARYSOURCESANDPROBLEMSTATEMENT

Known published monographs, textbooks and periodic sources on the subject. In the textbook [1,2], issues of ensuring the reliability of machines at the stages of design and operation are disclosed. An interconnected set of tasks is considered here: friction, aging, wear. Revealed causes of changes in the technical condition of machines and the physics of their failures. In the monograph [5], the presented approach for assessing the reliability of the effectiveness of ensuring the conditions of failure-free automated process.

There are both fundamental and periodic sources where the results of the operation of vibratory-press equipment are published [3,4]. However, there are virtually no publications evaluating the efficiency and reliability of the operation of vibrating machines. In this regard, the topic of the article is relevant.

PURPOSE OF PUBLICATION

To propose and develop a system for evaluating the effectiveness and reliability of quantitative characteristics that is probabilistic-statistical in nature.

The main results of the study:

The problem of improving the reliability and efficiency of machines and structures is an important technical and economic task, the solution of which opens the way for the science-based designation of reliability indicators, the achievement of these indicators in an economically optimal way. Improving the reliability and durability of machines represents a serious reserve for saving money, materials, energy and labor costs. To a large extent, the reliability and durability of machines depend on current loads and actions. The correct choice of materials and the correction of calculations, taking into account a priori statistical information about the load at the design stage, are the main sources of improving reliability without significantly raising the cost of the machine.

The problem of the efficiency and reliability of the use of vibrating machines is associated with the presence and possibility of using the reserves of operation of the machine.

Therefore, to assess the effectiveness and reliability, it is necessary to introduce quantitative characteristics that are probabilistic in nature. Since they can be determined not only experimentally, but also by theoretical analysis, where it is advisable to consider them from a statistical and probabilistic point of view.

As the quantitative characteristics of failure-free operation, we use the probability of the absence of failures, the frequency of failures, the failure rate, and the mean time between failures.

These questions are quite important in the direction of increasing the efficiency of technical diagnostics of the operation of vibrating machines [1].

The probability of the absence of failures *P (t)* is the probability that, under certain operating conditions, within the specified duration of operation, failure does not occur, and the probability of failure *Q (t)* is the probability that, under the same conditions, a failure occurs during the specified time. The mill of serviceability (absence of failures) and malfunctions (presence of failures) of the system are incompatible and opposite events. The sum of the probabilities of such events, as is known from probability theory, is equal to unity. That is, the probability of failure, and the probability of failure are related by:

$$P(t) + Q(t) = 1 \tag{6.1}$$

as defined

$$\left.\begin{aligned} P(t) &= R(T \geq t); \\ Q(t) &= R(T \leq t); \end{aligned}\right\} \tag{6.2}$$

where

R - is the probability symbol of an arbitrary event,

T - is the operating time of the system to failure,

t - is the operating time of the system for which we determine the reliability.

By the definition of probability theory [1], the probability distribution function *F(x)* of a random variable is the probability that the quantity will take a value less than some quantity *x*, that is,

$$F(x) = R(\xi < x) \tag{6.3}$$

It follows that the function of the probability of failure *Q (t)* is similar to the distribution function of the operating time of the system to failure.

In a statistical assessment, the empirical probability of the absence of failures is defined as the relationship:

$$P_e(t) = \frac{N_0 - n(t)}{N_B} = \frac{N_0}{N_0} - \frac{n(t)}{N_0} = 1 - \frac{n(t)}{N_0}, \tag{6.4}$$

and the empirical probability of failure as a relationship

$$Q_e(t) = n(t) / N_0 \tag{6.5}$$

где

N_0 - the number of nodes of the hydraulic pulse drive,
n (t) - is the number of hydroimpulse drive units that failed during time *t*.

The values of the empirical probabilities of the absence of failure and failures obtained by a statistical method always differ from theoretical ones [2]. With an increase in the number of tested nodes *Pe(t)* and *Qe(t)*, they asymptotically approach *P(t)* and *Q(t)*. The same can be said about other quantitative characteristics of reliability. The initial conditions of the functions *P(t)* and *Q(t)* are defined in this way, at *t = 0* the hydro-pulse drive retains its original characteristics and meets the requirements presented to it, that is:

$$P(0) = 1;\ Q(0) = 0. \tag{6.6}$$

Like any continuous function, the failure probability Q (t) can be differentiated for all values of the argument. In probability theory, the derivative of the distribution function is called the distribution density:

$$f(x) = dF(x)/dx, \tag{6.7}$$

where $f(x)$ - is the probability density of a random variable ξ.

In reliability theory, this density of the distribution of the system's operating time *k* for failures is called the failure rate $a(t)$ [2]. We carry out the following transformations:

$$Q(t)=1-P(t). \tag{6.8}$$

Find the differential of the left and right sides of the dependence (8):

$$dQ(t)/dt = a(t) = \frac{d}{dt}[1 - P(t)] = -dP(t)/dt. \tag{6.9}$$

Integrating the left and right sides of equality (9), we obtain:

$$Q(t) = \int_0^t a(t)dt \tag{6.10}$$

$$P(t) = 1 - \int_0^t a(t)dt. \tag{6.11}$$

By definition, the failure rate is the ratio of the number of nodes that failed per unit time to the number of all nodes that are tested, provided that they are not restored and are not replaced by serviceable ones

$$a_e(t) = n(\Delta t)/N_0 \Delta t\ , \tag{6.12}$$

Here $n(\Delta t)$ - the number of nodes that failed in the time interval Δt.

A typical time dependence of the failure rate is shown in Fig. 1.

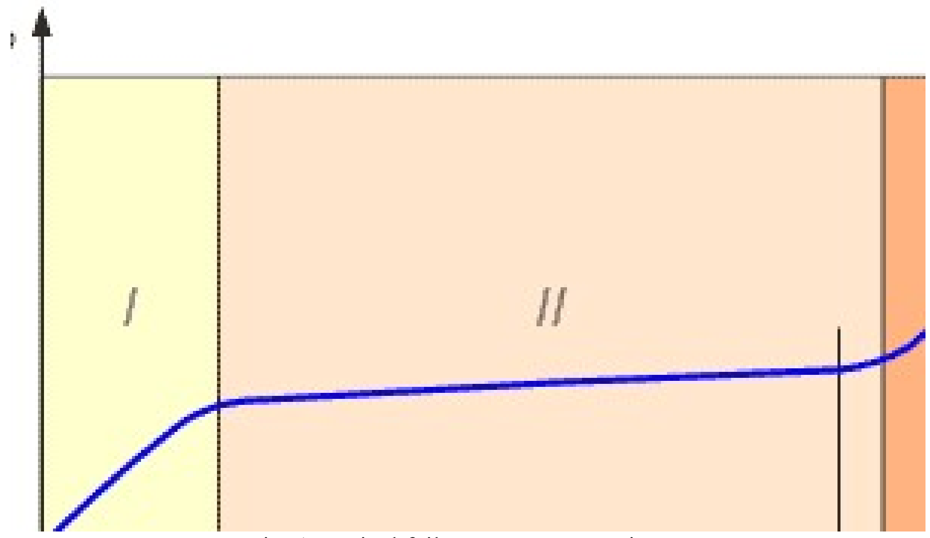

Fig. 1.Typical failure rate a versus time t.

Three gaps are highlighted on the curve. Gap 1 is caused by a large number of failures at the beginning of operation of the hydro-pulse drive due to gross defects of its elements, errors of the operating personnel. The initial period is different for different hydroimpulse occasions. It can be reduced, or completely removed, using the methods of training and testing.

Gap 2 characterizes the normal operation of the hydraulic drive. Failures in this period are mostly unexpected in nature, their average frequency decreases.

The aging period is caused by the wear of the hydro-pulse drive, when, due to the aging of the elements (nodes), the failure rate gradually increases.

If the failure rate makes it possible to assess the reliability of the hydro-pulse drive for the desired period of time without taking into account the time of the previous operation, then the failure rate takes this effect into account. The distribution density, which takes into account the previous value of a random variable, is called the conditional density. Thus, the failure rate is the conditional density of the distribution of the failure time, which represents the instantaneous failure rate of the system at time t, provided that there are no failures up to this point.

The failure rate is defined as the ratio of the number of nodes of the hydraulic pulse drive that failed per unit time to the average number of nodes that worked correctly in a given period of time, provided that the nodes that failed failed to be restored and not replaced by serviceable ones

$$\lambda_e(t) = n(\Delta t) / N_{cep}\Delta t\,, \tag{6.13}$$

where $N_{cep} = (N_i + N_{i+1})/2 = N_0 - n(\Delta t)$ - average number of serviceable nodes at the beginning and end of the time interval Δt .

We obtain the probability representation of intensity using the main theorems of probability theory [1]. The proposed approach is new, which has its own elements of the novelty of the relation between reliability theory and probability theory and mathematical statistics.

From expression (13), we replace $n(\Delta t)$ it with the values obtained from formula (12), and N_{cep} - with its value from expression (4) we obtain:

$$\lambda(t) = a(t) / P(t) = -\frac{dp(t)}{dt} / P(t). \tag{6.14}$$

In accordance with this, we finally define one more way $P(t)$, $Q(t)$, $a(t)$:

$$P(t) = \exp(-\int_0^t \lambda(t)dt), \tag{6.15}$$

$$Q(t) = (1 - \exp(-\lambda(t)dt)), \tag{6.16}$$

$$a(t) = \lambda(t)\exp(-\int \lambda(t)dt). \tag{6.17}$$

The obtained expressions (15), (16), (17) establish the relationship between the probability of no failure, the probability of failure and the failure rate of the nodes of the hydraulic pulse drive.

The result of this approach is the determination of mathematical expectation *T*, variance $D(t)$, standard deviation $\sigma(t)$ as compound probability theory [1].

Use of the failure rate $\lambda(t)$, failure probability $P(t)$, failure probability $Q(t)$ as part of a reliability theory [2]. The proposed analysis approach will find its place in the educational process.

Define the mathematical expectation *T*.

From the point of view of probability theory, this is the mathematical expectation of the average value of a point estimate $\overline{t_i}$ of the average time, as the average operating time of the *i*-th node. Here indicators are reliability characteristics calculated using the tools of the mathematical apparatus of probability theory and mathematical statistics.

Thus, the mean failure time *T* is the mathematical expectation of the operating time of the corresponding hydraulic pulse drive unit to failure.

In probability theory, the mathematical expectation of a random continuous variable ξ is called an integral of the form $\int xf(x)dx$.

Turning to the theory of reliability, we can write:

$$T = \int_{-\infty}^{+\infty} ta(t)dt. \tag{6.18}$$

Substituting the value $a(t)$ with (17) in expression (18), integrating by parts and taking into account that $P(0) = 1,\ P(\infty) = 0$, and time cannot be negative, we obtain:

$$T = \int_{-\infty}^{+\infty} tP'(t)dt = -tP(t)\int_0^{\infty} + \int_0^{\infty} dt = \int_0^{\infty} P(t)dt. \tag{6.19}$$

Given the formula (17) we get:

$$T = \int_0^{\infty} \exp(-\int_0^{tt} \lambda(t)dt)dt \tag{6.20}$$

Expression (19) shows that the average time of absence of failures *T* is completely determined by the probability of the absence of failures *P(t)* and represents the area that limits the curve *P(t)* and the coordinate axes.

To determine the average time of absence of failures with statistical empirical data, we use the formula of a small sample of the form:

$$T_e = \sum_{i=1}^{N} t_i / N_0\,, \tag{6.20}$$

where t_i is the operating time of the *i-th* hydropulse drive unit before a failure occurs.

This quantitative characteristic is important, as it allows in some cases to visually judge the reliability of hydraulic pulse drive units.

When assessing reliability using the average time of absence of failure, it is necessary to know the variance of the time of occurrence of failure *D(t)*, which characterizes the discrepancy of the studied value. We define it as the mathematical expectation of the squared deviation of a random variable t from the mathematical expectation of this random variable (*T*):

$$D(t) = \int_0^\infty (t - T)^2 a(t)dt. \qquad (6.21)$$

Moreover, we note that it is necessary to minimize. We will develop this direction in further studies. For example, in classical sources, it is indicated that *D(t) = 1*.

At the variance level *D(t)*, the root-mean-square deviation of the no-failure time is important. The standard deviation is:

$$\sigma(t) = \sqrt{D(t)}. \qquad (6.22)$$

It is quite complete and simple to determine all quantitative characteristics of reliability from the law of distribution of the operating time of nodes to failure. Time is a random continuous quantity; therefore, arbitrary continuous distributions that are used in probability theory can be used as theoretical distribution laws.

CONCLUSION

The assessment of the efficiency and reliability of the operation of hydraulic pulse drives. To assess the effectiveness and reliability of the introduced quantitative characteristics that are probabilistic in nature. Since they can be determined not only experimentally, but also by theoretical analysis, where they are examined from statistical and probabilistic points of view.

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