	National University of Science and Technology Politehnica Bucharest	

Doctoral School of MECHANICAL ENGINEERING AND MECHATRONICS

DOCTORAL THESIS

(extended summary – English Language)

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Bucharest 2025

National University of Science and Technology Politehnica Bucharest

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”*CERCETĂRI TEORETICE ŞI EXPERIMENTALE PRIVIND DESHIDRATAREA NĂMOLURILOR INDUSTRIALE CU SITE PLANE, VIBRATOARE* ”

" *THEORETICAL AND EXPERIMENTAL RESEARCH ON THE DEHYDRATION OF INDUSTRIAL SLUDGES USING FLAT, VIBRATING SCREENS* "

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FOREWORD

The elaboration of this doctoral thesis represents the outcome of an in-depth research process carried out within the Doctoral School of the Faculty of Mechanical Engineering and Mechatronics at the National University of Science and Technology Politehnica Bucharest, under the auspices of the Department of Equipment for Industrial Processes. The activities conducted throughout this period have entailed not only sustained intellectual effort but also continuous professional and personal development.

I wish to express my profound appreciation to Professor Emeritus Dr. Eng. **Radu I. IATAN**, the scientific supervisor of this thesis, for his competent guidance, academic vision, and constant support throughout all stages of the research. His high standards, combined with a remarkable intellectual generosity, were essential in shaping the research directions and in completing this work.

The mechanical tests carried out in the Laboratory for Construction Materials Testing of the Faculty of Civil Engineering, under the guidance and supervision of Professor Dr. Eng. **Dorinel Voinitchi,** played a central role in the development of this thesis. I would like to express my sincere gratitude for his ongoing support, professionalism, and openness throughout all experimental activities.

The scientific guidance, insightful observations, and unwavering support of the Doctoral Committee — composed of Professor Dr. Eng. **Ion Durbacă**, Senior Lecturer Dr. Eng. **Georgiana Luminița Enăchescu**, and Associate Professor Dr. Eng. **Iuliana Marilena Prodea** — were essential elements in the development of this thesis. I would like to extend my sincere gratitude to them for the time dedicated and their valuable contribution to strengthening the scientific content of this work.

A special acknowledgment is due to Senior Researcher Grade II **Petru Cârdei** from the National Institute of Agricultural Machinery, whose professionalism and commitment to the research process significantly contributed to the success of this thesis. I am also deeply grateful to Associate Professor Dr. Eng. **Nicoleta Sporea**, Head of Department, for her openness and continuous support throughout the doctoral project.

Last but not least, I express my heartfelt gratitude to my family, who supported me unconditionally throughout this journey. Their patience, understanding, and constant encouragement were essential in bringing this work to completion.

This thesis is dedicated, with profound gratitude and respect, to all those who made its realization possible.

Author

INTRODUCTION

This thesis provides a comprehensive analysis of the challenges associated with sewage sludge management, combining a thorough theoretical examination in the first four chapters with an applied and experimental component presented in Chapter Five. Chapters 1 to 4 establish a solid foundation by addressing the historical and legislative evolution of wastewater treatment, the classification and physico-chemical characteristics of sludge, and a detailed description of the technological processes used in its treatment—from fermentation and dewatering to modern recovery methods such as composting and incineration. The study also explores the correlation between treatment strategies and sludge composition in the context of environmental objectives and the transition toward a circular economy.

Chapter 5 represents the applied section of the research, presenting experimental investigations conducted under controlled conditions. It includes descriptions of the equipment used, the working methodology, and the results obtained concerning particle separation efficiency and sludge behavior under various treatment conditions.

In conclusion, the thesis provides both a rigorous theoretical contribution and relevant practical proposals for optimizing the sustainable treatment and recovery of sewage sludge. Finally, original conclusions and contributions are formulated regarding the optimization of wastewater treatment processes and potential directions for future research.

CHAPTER 1

CURRENT STATE OF SLUDGE DEWATERING AND PRACTICAL APPLICATIONS

1.1. Historical Overview of Sludge Collection and Disposal

The collection and disposal of sludge have a long history, deeply rooted in ancient civilizations and the progressive development of waste management techniques. Today, sludge collection and disposal represent key components of wastewater and waste management systems in communities across the globe. Environmental standards and governmental regulations have become increasingly stringent with regard to the proper treatment and disposal of such materials, aiming to minimize their impact on the environment and public health.

The first wastewater treatment plants began to emerge in the 19th century, in response to the growing need to manage pollution resulting from rapid urbanization and industrialization. One of the earliest documented examples is the sewerage system designed by Sir Joseph Bazalgette for London in the 1850s. This system was intended to collect and transport wastewater away from the urban area, discharging it into the Thames Estuary. Another early example is the wastewater treatment plant in Frankfurt am Main, Germany, inaugurated in 1866, which employed primary sedimentation methods to clean wastewater before discharging it back into the river, as noted in [7].

A significant milestone in water and waste management in Romania was the construction of the first wastewater treatment plant in 1912 in Timișoara, near the Modoș Bridge. It was connected to a sewerage network and operated without pumps, relying on gravity-based flow, as stated in [8].

1. 2. Biodegradable Waste

The main categories of waste are outlined in works [9, 10] and include:

- **Municipal waste**: waste generated by households, as well as similar waste produced by commerce, industry, and institutions.
- **Industrial waste**: materials resulting from industrial or manufacturing processes.
- **Hazardous waste**: products that contain dangerous substances and pose serious risks to human health or the environment.
- **Biodegradable waste**: materials that can decompose naturally, originating from organic sources such as food scraps and garden waste.

In 2015, the European Union implemented a series of initiatives aimed at promoting the transition toward a *circular economy*. These measures focus on revising waste management legislation to minimize waste generation and encourage recycling, thereby reintroducing waste into the economic cycle as secondary raw materials. The main objective is to "close the loop" in the product life cycle, covering all stages from production and consumption to waste management and reintegration into the economy, as illustrated in Figure 1.1. These actions are intended to reduce waste volumes through the use of modern and innovative technologies, enabling minimal resource consumption while fostering recycling and reuse for energy recovery.

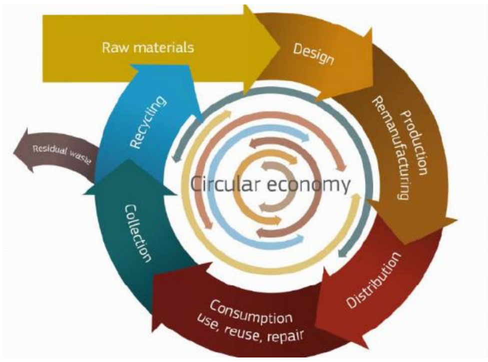


Fig. 1.1. The Pathway of the Circular Economy **[12]**

1. 3. Management of Sewage Sludge

1. 3. 1. Sludge Treatment Processes: General Aspects

Sludge treatment processes are essential for the effective management of sewage sludge and for reducing its negative environmental impact. These processes are employed to stabilize the sludge, dewater it, reduce its volume, and eliminate pathogenic agents.

At the core of sludge treatment are two fundamental and distinct technological processes: fermentation and dewatering. These processes are adapted according to local conditions, the quantity and quality of the sludge, as well as its intended final use. Additional procedures may be incorporated or adjusted to optimize treatment depending on the specific context.

1. 3. 2. Sludge Formation

There are two technological schemes for the treatment of both industrial and municipal wastewater, which result in the production of sludge, as illustrated in **Figures 1.3** and **1.4**.

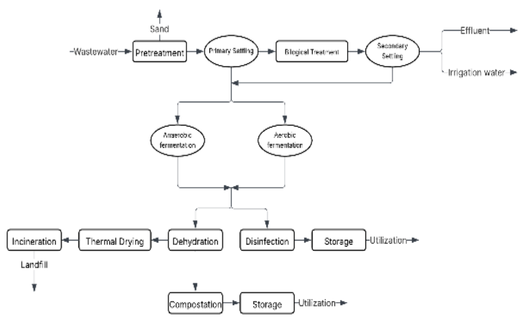


Fig. 1.2 Sludge Sources in the Mechano-Biological Treatment Plant **[9, 11]**

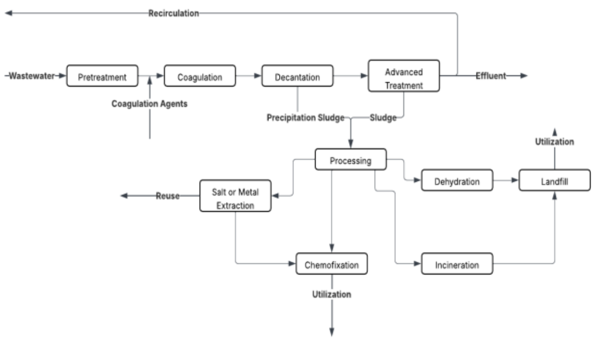


Fig. 1.3 Sludge Sources in the Mechano-Chemical Treatment Plant **[9, 11]**

The major differences between mechano-chemical and mechano-biological wastewater treatment are as follows:

- Mechano-chemical treatment includes a biological treatment stage (using microorganisms), whereas mechano-biological treatment incorporates a coagulation stage (using chemical reagents);

- In the first case, secondary sedimentation is used to remove the remaining solid material after biological treatment, while the second process may include advanced treatment for the removal of additional contaminants;
- In the first case, the sludge is treated through fermentation (either anaerobic or aerobic), followed by various methods of dewatering, sanitization, and composting, whereas in the second, the sludge undergoes processing involving dewatering, incineration, chemo-fixation, and salt or metal extraction;
- The first process includes a sludge sanitization step, while the second does not explicitly mention this, but includes chemo-fixation for sludge stabilization..

1. 3. 4. Sludge Characteristics

1. 3. 4. 1. Physico-Chemical Characteristics of Sludge

1. The consistency of sewage sludge is an important characteristic that influences how it is handled, treated, and disposed of. Sludge consistency varies depending on its water content and solid particles, and it is determined by several stages of the treatment process, as noted in relevant studies **[24, 25]**.

2. The specific density of sludge varies depending on its water and solid particle content, and is calculated according to **[26]**:

$$r_s = \frac{Y_s}{100-U(I-Y_s)} \text{ [t/m}^3\text{]} \qquad (1.1)$$

3. **The moisture content of sludge** is defined as the ratio between the weight of water in the sludge (Ga) and the total weight of the sludge (Gn), and is expressed as a percentage according to the relation indicated in the referenced work. **[27]**:

$$U = \frac{G_a}{G_n} \times 100 \qquad (1.2)$$

4. The particle size of sewage sludge is a key characteristic that influences many aspects of its treatment and management..

5. Color and odor are the primary indicators that provide immediate information about the condition of the sludge.

6 **Calorific value** can be determined experimentally using a bomb calorimeter, or estimated approximately using the empirical formula provided in the referenced work**[26]:**

$$P_{Cn} = S_v \times 44{,}4 \qquad (1.3)$$

7. The ***pH of sewage sludge*** influences numerous aspects of the sludge treatment process, including its stability, disinfection, and potential for recovery.

8. The ***dry matter content (DM)***, or the residue dried at 105°C, varies depending on the origin of the sludge, ranging from 10 g to 1300 g per cubic meter of wastewater.

9. The ***fermentability*** of sludge, as discussed in studies [31, 32], refers to its capacity to be decomposed through anaerobic or aerobic biological processes, with the aim of reducing its volume, stabilizing it, and recovering energy from it.

1. 3. 4. 2. Biological and Bacteriological Characteristics of Sludge

Sludge is rich in microorganisms, including bacteria, protozoa, and fungi, which are involved in the decomposition of organic matter. It may also contain pathogenic bacteria, viruses, and parasites, requiring appropriate treatment to reduce the risk of disease transmission.

1. 4. Institutional and Legislative Framework for Sludge Production and Management

1. European Legislative Framework

The production and management of sludge in Europe is regulated through a series of directives and regulations. One of the most important is **Council Directive 86/278/EEC of 12 June 1986**, on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. This directive sets limits for heavy metals and other hazardous substances in sludge applied to agricultural land, in order to prevent soil and water contamination, as indicated in studies **[34, 35].**

2. National Legislative Framework

In Romania, sludge management is regulated by several legal acts that transpose European directives into national legislation, as noted in references **[41, 42, 43]**:

- ***Law No. 211/2011*** *on waste management*
- ***Order No. 344/2004*** *approving the Technical Norms on environmental protection, particularly soil protection, when using sewage sludge in agriculture*

Government Decision No. 856/2002 on waste management records and approval of the list of waste types, including hazardous waste

1. 5. Disposal and Recovery of Sewage Sludge from a Circular Economy Perspective

Sludge with a moisture content below 65% and which complies with the applicable legal standards may be temporarily stored — for a maximum of three years — at the site of generation for subsequent transport, and, in the case of incineration, for up to one year (see **Fig. 1.4**).

Fig. 1.4. Sludge Itinerary:
a) Sludge handling **[49];** b) Temporary sludge storage in bags **[50];**
c) Sludge disposal **[51]**

1. 5. 1. Use of Sludge in Construction and Materials

Sewage sludge can be valorized through its use in the production of ***eco-friendly bricks***, thereby contributing to waste reduction and the conservation of traditional raw materials. These bricks are manufactured by incorporating dewatered and stabilized sludge into the clay mixture used for brick production. During the firing process, the sludge contributes to the formation of the bricks, reducing their density and improving their thermal insulation properties and compressive strength, as noted in studies **[54, 55]**.

1. 5. 4. Use of Sludge in Agriculture

Sewage sludge can be used in agriculture in the following ways:

1. As an organic fertilizer;
2. For improving soil structure;
3. For promoting microbial activity;
4. For reducing soil erosion;
5. For waste valorization.

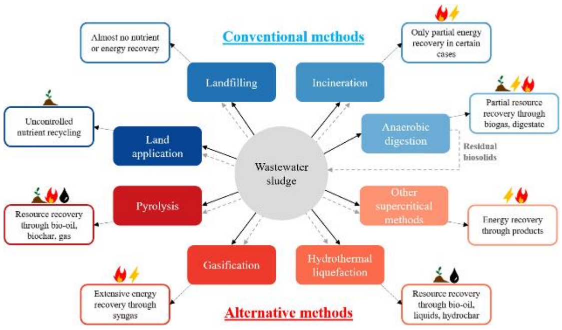


Fig. 1. 7. Conventional and Alternative Methods for Processing Sewage Sludge **[103]**

1. 5. 5. Use of Sludge in Energy Production

The following diagram **(Figure 1.7)** illustrates various methods for processing wastewater sludge, categorized into conventional and alternative thermochemical conversion methods.

1. 5. 5. 3. Co-Incineration of Sludge

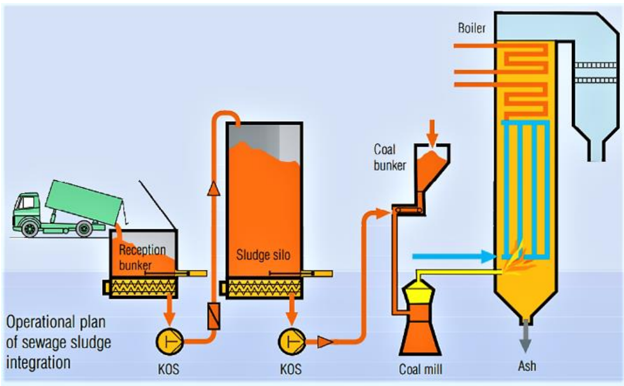


Fig. 1. 8. Operational Plan for the Integration of Sewage Sludge **[119]**

Figure 1.8 presents the operational plan for integrating sewage sludge into the combustion process alongside coal, a method known as **co-incineration**. This diagram illustrates how sewage sludge is processed and mixed with coal to be used as fuel in an industrial boiler, as described in the referenced work. **[120]**.

1. 6. Thesis Objectives

a) General aspects concerning the history of industrial sludge production; sludge classification; sludge formation and technological treatment processes; physico-chemical, biological, and bacteriological characteristics; use of sludge for thermal energy generation and biogas production.

b) Challenges in sewage sludge dewatering; technological treatment processes for sludge: mechanical dewatering (filter pressing, centrifugation, etc.); electro-dewatering, ultrasonic or plasma-assisted dewatering; sludge drying.

c) Specific equipment for sludge dewatering and the technical and economic factors that characterize them; mechanical equipment: filter presses, vacuum filters, centrifuges, etc.; thermal equipment: rotary drum dryers or fluidized bed dryers; hybrid equipment.

d) Granulometric separation processes for polygranular mixtures and the corresponding equipment.

e) Experimental research on sludge dewatering by screening or pressing.

f) Conclusions. Personal contributions. Future perspectives.

CHAPTER 2
SPECIFIC PROCESSES FOR SLUDGE DEWATERING

2. 2. Sludge Treatment Processes

In general, standard technological treatment schemes include the following sludge processing steps (**Figure 2.2**) **[8, 9]**:

- *Preliminary treatment*, aimed at reducing the size of raw materials contained in the sludge;
- *Chemical conditioning*, intended to improve sludge properties for subsequent thickening or mechanical dewatering;
- *Thickening*, to reduce the overall volume of sludge;
- *Stabilization*, which decreases the amount of sludge by removing organic matter;
- *Dewatering*, for further reduction of sludge volume;
- *Drying*, serving the same purpose as dewatering;
- *Incineration*, also aimed at reducing sludge volume;
- *Composting*, with the goal of stabilization.

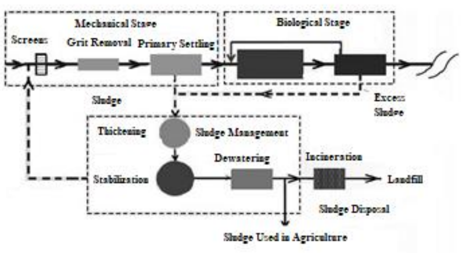


Fig. 2. 2. General Flow Diagram of a Wastewater Treatment Plant **[8]**

2. 3. Sludge Dewatering

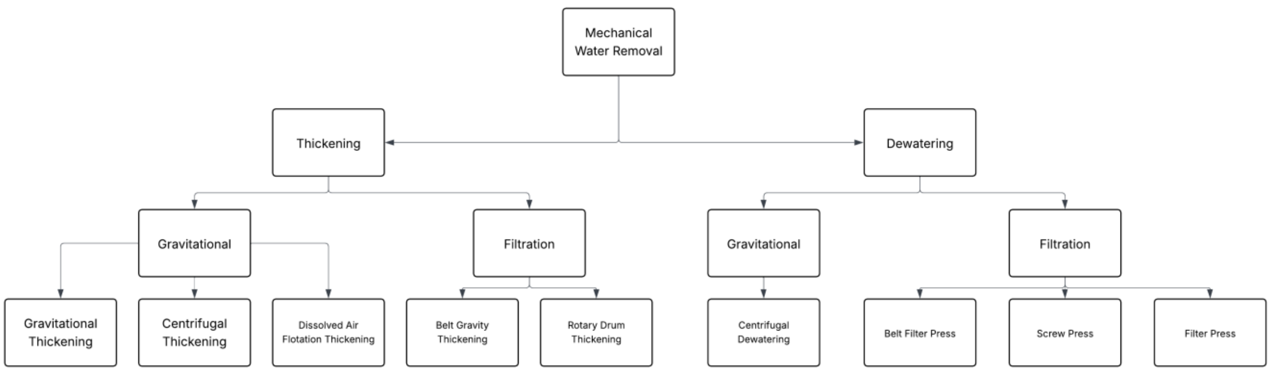


Fig. 2. 4. Thickening and Dewatering Processes **[27]**

Sludge thickening and dewatering are two essential processes in the treatment of sludge from wastewater treatment plants, each aiming to reduce the water content and concentrate the solid material. Both processes contribute to minimizing the volume of sludge that must be managed, but each yields a final product with distinct characteristics and involves different techniques.

A comparison between thickening and dewatering processes is presented in **Figure 2.4**.

2. 3. 1. Mechanical Dewatering Processes

Dewatering processes rely on the application of mechanical force to efficiently remove water. The following mechanisms are commonly used **[27, 28]**:

Mechanical pressing, which involves applying compressive force to the sludge in order to remove water through a permeable medium, using appropriate equipment such as belt filter presses, screw presses, or chamber filter presses.

Centrifugation, in which the sludge is rapidly rotated in a cylindrical vessel to separate the denser solid particles from water. The solids are pushed toward the inner walls of the vessel, while the water (in the form of a diluted concentrate) is directed toward the center.

Dewatering through filtration and evaporation, where sludge passes through a narrow channel with porous walls (e.g., rotary press), allowing water to be filtered and evaporated under ambient conditions. Alternatively, the sludge is placed on a permeable layer in drying beds, where water is removed both by evaporation and gravitational drainage.

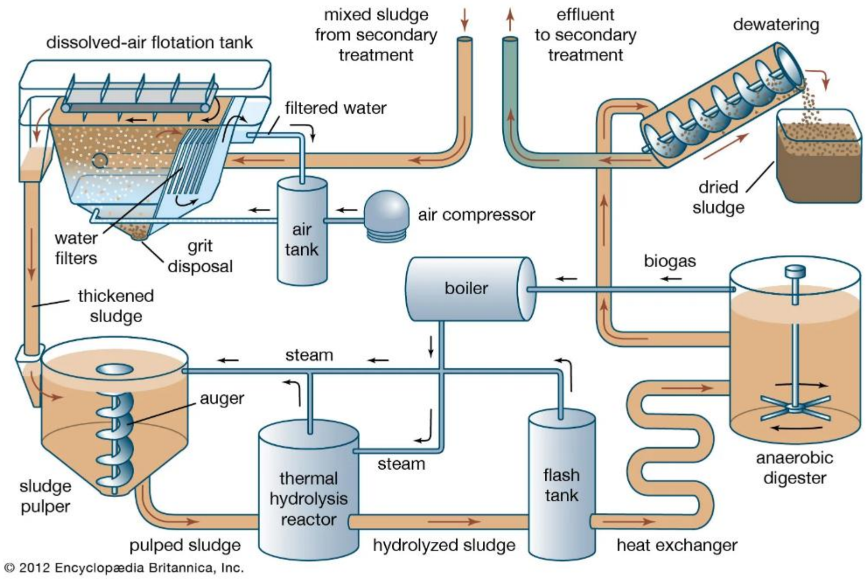


Fig. 2. 5. Sewage Sludge Treatment **[29]**

2. 3. 1. 1. *Filter Pressing*

Figure 2.6 presents an example of a mechanical sludge dewatering system using a filter press. The hydraulic cylinder is actuated by a hydraulic pump and is used to apply pressure to the sludge, forcing water to pass through the filter cloth while retaining solid particles. The control system monitors and regulates the pressure applied by the hydraulic cylinder.

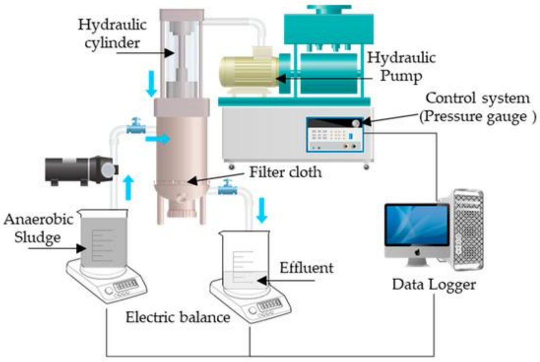


Fig. 2. 6. Mechanical Sludge Dewatering System Using a Hydraulic Filter Press **[33]**

2. 3. 1. 2. *Centrifugation*

Centrifugation is one of the most widely used methods for dewatering sludge derived from wastewater and from industries that generate semi-solid residues. The centrifuge applies centrifugal force to separate the liquid and solid phases. Sludge is fed into the centrifuge and subjected to rapid rotation, generating a centripetal force that causes the dense solid particles to separate from the interstitial liquid. The force generated depends on the rotational speed and the size of the drum.

Another key factor influencing the efficiency of centrifugation is the solids content. The chemical composition and physical structure of the sludge significantly affect the centrifugation process.

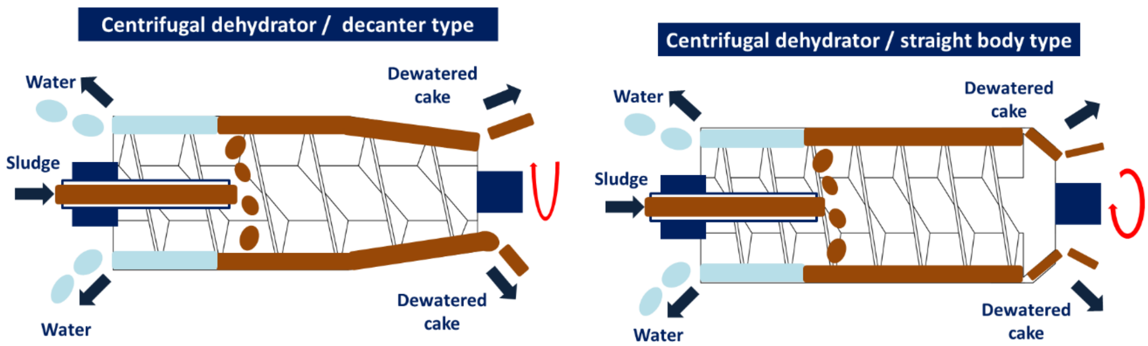


Fig. 2. 7. Types of Centrifuges for Sludge Dewatering **[39]**

2. 3. 2. Other Dewatering Processes

2. 3. 2. 1. Electro-Dewatering

Electro-Dewatering is used to remove water from sludge through the application of an electric field. This method combines the principles of mechanical dewatering with electrostatic forces, making it more efficient than traditional mechanical methods such as filtration or centrifugation.

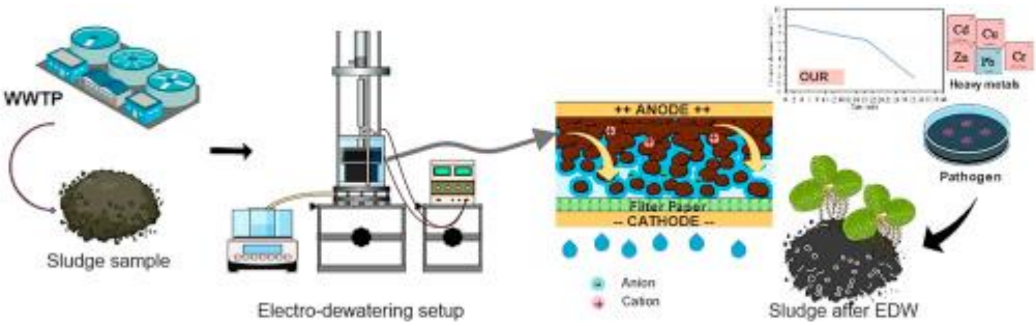


Fig. 2. 10. Electro-Dewatering Process of Sludge from a Wastewater Treatment Plant **[52]**

This method is not efficient for sludge with a very high solids content and involves high equipment costs. However, it offers high dewatering efficiency, consumes less energy compared to thermal drying, and in many cases even less than centrifugation. It can be applied to a wide range of sludge types, including sludge with high organic content or industrial sludge.

Electro-dewatering is an important process in the management and treatment of sludge resulting from wastewater treatment plants or other industrial processes.

As the sludge dries, it passes through three distinct phases as water evaporates **[27]:**

- the adaptation/preliminary phase;
- the constant drying rate phase;
- **the falling drying rate phase**.

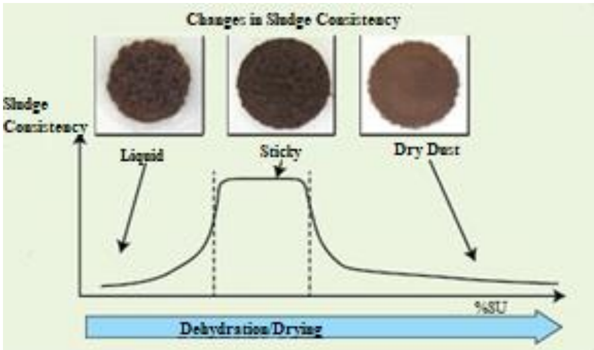


Fig. 2. 14. Changes in the Physical Consistency of Residual Sludge During Dewatering and Drying **[27]**

According to **Figure 2.14**, the following situations are observed **[27]**:

- When the sludge contains a large amount of water, it behaves like a liquid and not like a sticky substance, essentially functioning as a low-concentration biopolymer solution;
- As the water content decreases through drying, the sludge becomes increasingly sticky, as the biopolymer solution becomes more concentrated.;

2. 4. 1. Natural Drying on Drying Beds and in Lagoons

Sludge drying beds are structures that allow water removal through two mechanisms: gravity drainage through a permeable layer and open-air evaporation. In contrast, ***lagoons*** rely solely on natural evaporation for sludge dewatering.

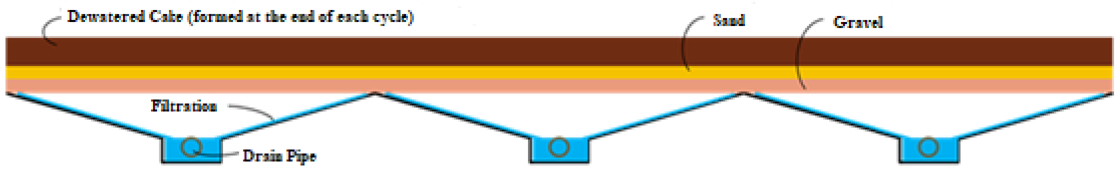


Fig. 2. 15. Sludge Drying Bed **[20]**

2. 4. 2. Thermal Drying

Thermal drying uses energy sources such as fossil fuels (gas, liquid fuel, electricity) or biogas to achieve a dry solids content between 60% and 95%. There are three main thermal drying methods **[63–65]**: *direct dryers*, *indirect dryers*, and *combined dryers*.

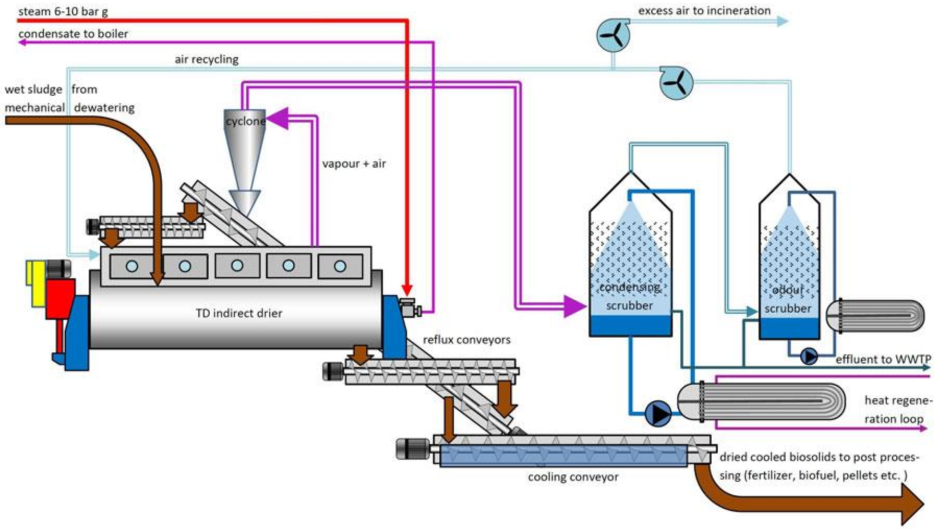


Fig. 2. 18. Sludge Drying Process Using an Indirect Dryer and a Vapor and Odor Treatment System **[66]**

CHAPTER 3
SPECIFIC EQUIPMENT FOR SLUDGE DEWATERING

3. 2. Mechanical Dewatering

This process, used for the mechanical dewatering of sludge, involves introducing the sludge into equipment where mechanical forces—such as shear or compression—are applied. Typically, flocculants must be added to the sludge to improve the mechanical dewatering process **[13]**, and the required dosage depends on the type of equipment used.

3. 2. 1. Filter Presses for Sludge Dewatering

The filter press is equipment used for dewatering sludge generated from various water treatment or purification processes, including those from industrial and domestic wastewater treatment plants or water treatment facilities. This method produces sludge in the form of cakes **(Figure 3.1)**, characterized by a high solids content and an advanced degree of dryness.

The filter press is one of the most effective solid-liquid separation systems and is also the most widely used filtration method across various industrial applications.

A filter press consists of a series of vertical frames covered with filter cloth stretched on both sides **(Figure 3.3)**. These frames are placed adjacent to one another and compressed using a hydraulic jack. A filtration chamber is formed between every two plates.

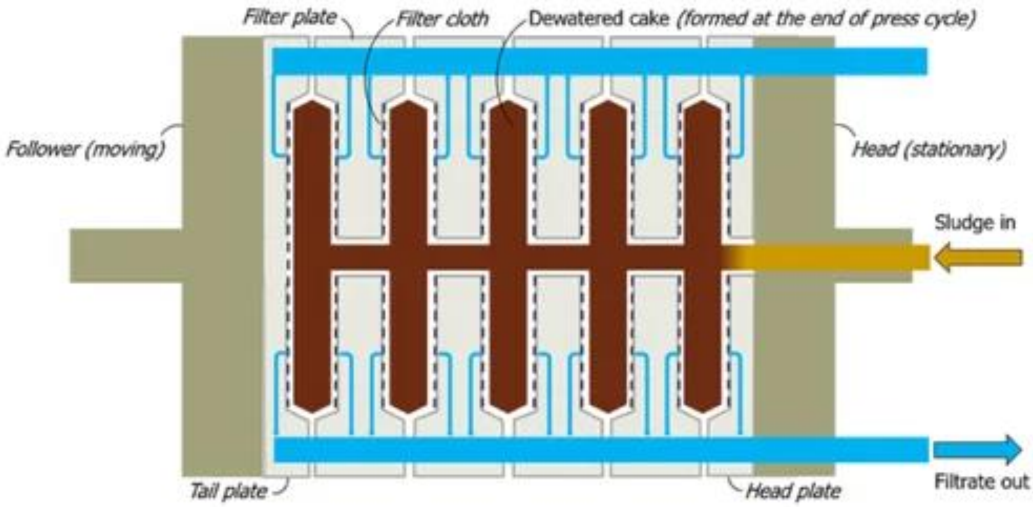


Fig. 3. 3. Main Components of the Frame Filter Press **[23]**

3. 2. 2. Belt Filter Press

A belt filter press (BFP) dewaters sludge by pressing it to force water through a permeable medium. The process produces a **cake** (dewatered product) with a dry solids (DS) content of 30% or more in the case of primary sludge **[31–34]**.

Modern belt presses rely on a combination of chemical conditioning, gravity drainage, and mechanical pressure in a continuous feed system for sludge dewatering. The sludge is squeezed between tensioned serpentine belts and a series of rollers with decreasing diameters (to increase pressure), which remove moisture and form a dewatered sludge cake **[35–37]**.

3. 2. 3. Screw Press Filter

A screw press (SP) **(Figure 3.11)** dewaters sludge by conveying it through the interior of a permeable cylinder. It operates based on a slowly rotating Archimedean screw (~5 rpm) inside a cylindrical screen (also referred to as a drum or basket).

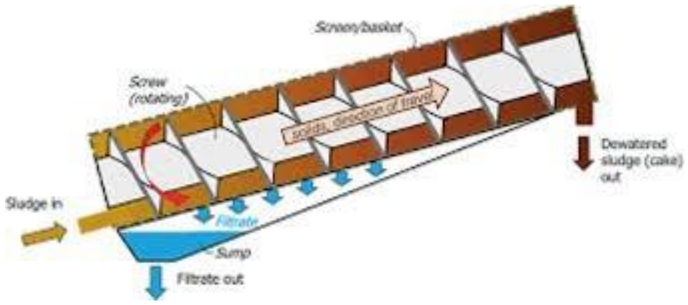


Fig. 3. 11. Screw Press **[24]**

3. 2. 5. Centrifuge

3. 2. 5. 1. Horizontal Screw Centrifuge

Centrifugation is a phase separation process based on differences in density (solid–liquid). Under the action of centrifugal force, the denser solid phase settles on the inner walls of the rotating drum, from where it is continuously removed by a conical screw conveyor. This device not only extracts the material but also directs it toward the discharge port located at the conical end. Meanwhile, the liquid phase, separated by gravitational flow, is guided toward the liquid outlet, located opposite the solid discharge port.

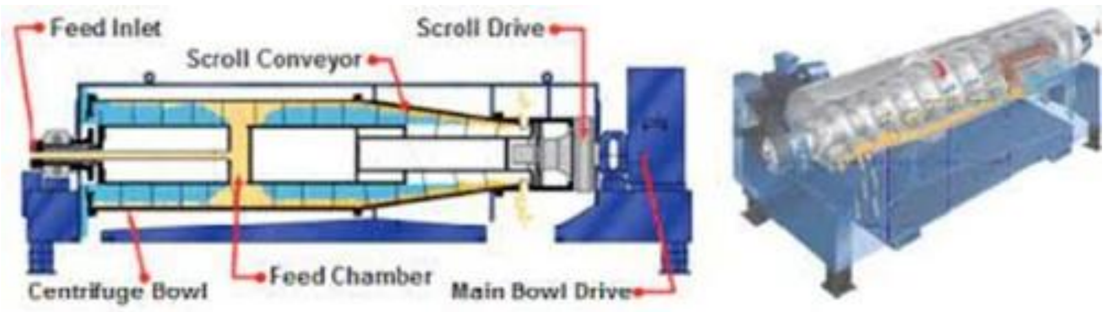


Fig. 3. 16. Components of the Solid Bowl Centrifuge **[54]**

The solids that accumulate on the drum wall are pushed to the opposite end of the liquid flow by a screw conveyor, which rotates at a slightly different speed than the drum. Centrifugal force is constantly applied to the solids in order to produce the desired consistency in the discharged product **(Figure 3.16)**.

3. 2. 5. 2. Sludge Dewatering by Dissolved Air Flotation (DAF)

Sludge dewatering and filtration systems based on dissolved air flotation (DAF) are used to remove suspended solids, fats, oils, and greases from a variety of wastewater streams across multiple industries and applications. DAF systems operate by injecting dissolved air (microbubbles) into the waste stream, which attaches to the solid particles, causing them to float to the surface, where the floating sludge cake is then removed.

3. 3. Thermal Equipment

Such equipment used for sludge dewatering is essential in the management of waste generated from wastewater treatment, with the primary goal of reducing sludge volume and preparing it for disposal or further use. These systems rely on heat transfer to evaporate the residual water remaining in the sludge after mechanical dewatering processes. The selection of an appropriate technology depends on the characteristics of the sludge, processing requirements, and economic constraints.

3. 3. 1. Rotary Drum Dryers

Rotary drum dryers are widely used thermal equipment for sludge dewatering due to their capacity to handle large volumes and their compatibility with various types of materials. They are employed in a broad range of industrial applications, including wastewater sludge treatment, as well as the processing of organic and industrial materials.

3. 3. 2. Fluidized Bed Dryers

These types of equipment are used for the dewatering and drying of granular materials or powders, offering high efficiency and versatility across diverse industrial sectors, including sludge treatment. Fluidized bed dryers use an air stream to suspend solid particles in a manner similar to a fluid, ensuring effective heat and mass transfer. They are commonly applied in the drying of sludge from the sugar and spice industries, in the chemical industry, for plastic processing, in wastewater treatment plants, and in the food industry for drying cereals and pigments. Additionally, they are used in the pharmaceutical industry for drying active substances and excipients.

3. 4. Hybrid Equipment

Unlike conventional methods, this system consists of membrane filter plates and heat exchanger plates, which are alternately installed in a filter press **(Figure 3.23)**.

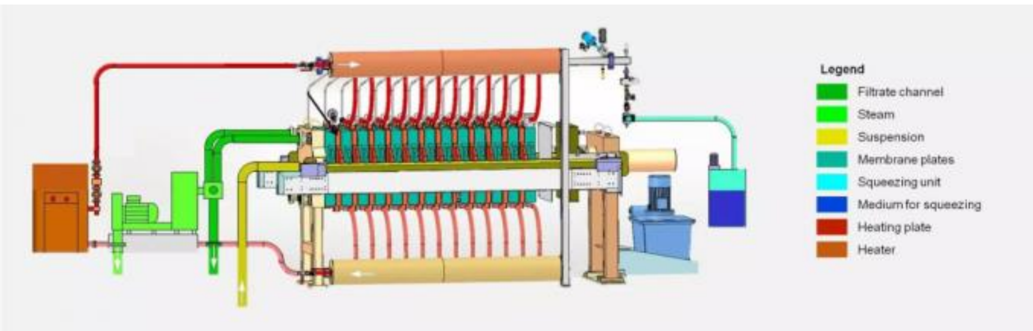


Fig. 3.23. Heated Plate Filter Press **[72]**

CHAPTER 4
GRANULOMETRIC SEPARATION PROCESSES AND EQUIPMENT USED

4. 3. 4.3. Factors Influencing the Screening Process

The efficiency of material separation through screening depends on several factors, which can be grouped into three main categories **[7, 8]**:

Characteristics of the screened material – The particle size distribution and the physical-mechanical properties of the particles significantly influence the efficiency of the process. Relevant factors include:

- *Particle size distribution* – A homogeneous material is easier to separate than a heterogeneous one that contains particles of widely varying sizes.
- *Mass* – Heavier particles are less affected by the screen's vibrations, reducing the probability of separation..
- *Particle shape* – Spherical particles are easier to separate than flat or elongated ones.
- *Friction coefficient* – Materials with high friction tend to adhere more to the screen surface, reducing screening efficiency..
- *Moisture content* – Wet materials tend to clump and block the screen openings.

Characteristics of the vibratory excitation – Particle motion across the screen surface is generated by controlled vibrations, whose efficiency depends on several parameters:

- **Amplitude of vibration (A)** – Higher amplitude promotes the release of fine particles and reduces the risk of screen clogging.
- **Vibration frequency (f)** – An optimal frequency improves particle separation while preventing material buildup.
- **Vibration angle** – Determines the direction of particle movement; a smaller angle facilitates sliding, while a larger angle may cause particle blockage.
- **Type of vibration** – Motion can be linear, circular, or elliptical, influencing particle distribution on the screen.

These characteristics can be described using the basic equation of vibratory motion:

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{A}} \quad , \qquad (4.1)$$

4. 5. Probability of a Particle Passing Through Sieve Openings

4. 5. 1. Probabilistic Models for Particle Passage Through Sieves

The *static probability model* is based on the geometric analysis of the interaction between particles and the sieve openings, without considering any relative motion between them. The probability of a particle passing through the sieve, *Ps*, is determined by the ratio between the particle size and the mesh opening size, according to the following relation **[12]**:

$$P_s = \left(\frac{d_s - d_p}{d_s}\right)^2 \quad , \qquad (4.2)$$

The *dynamic probability model* is more complex and requires a detailed analysis of the interactions between particles and the sieve under specific operating conditions. This model provides a more realistic representation of the screening process and is useful for optimizing operational parameters in order to maximize separation efficiency **[12]**:

$$P_d = 1 - e^{-k\left(\frac{d_s - d_p}{d_s}\right)}, \quad (4.3)$$

Another well-known model is the one proposed by ***Gaudin***, which expresses the probability of passage (*PP*) as a function of the ratio between the particle size and the sieve opening size **[12]**:

$$P = \left(\frac{d_s - d_p}{d_s}\right)^n \quad , \quad (4.4)$$

4. 5. 2. Probability of a Particle Passing Through Circular Mesh Openings

To establish the calculation formula for the probability of particle passage through the sieve openings, **Figure 4.6** is used, where **[9]**:

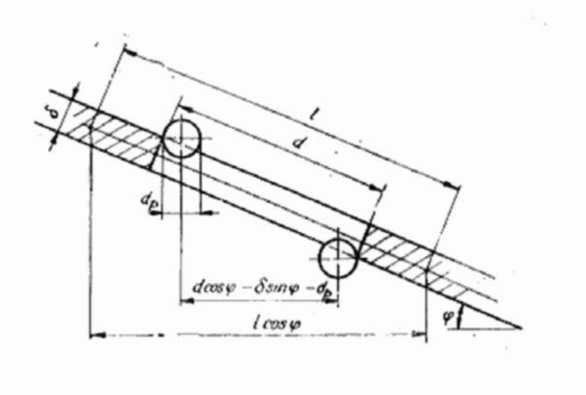


Fig. 4. 6. Diagram for Establishing the Probability Calculation Formula **[9]**

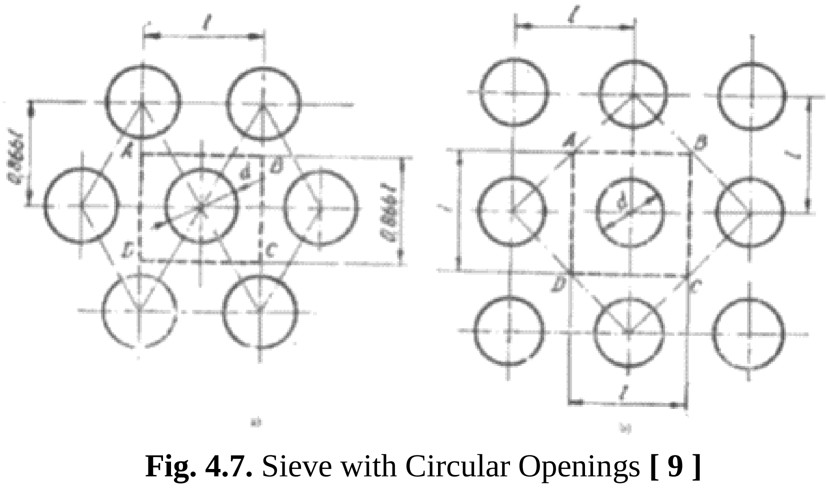


Fig. 4.7. Sieve with Circular Openings **[9]**
a) - configuration I; b) - configuration II

The probability of passage is determined as the ratio between the projected area of the sieve opening and the projected area of the influence zone (**Figure 4.7** – outlined with a dashed line), on a plane perpendicular to the particle movement direction. Since the projection of the opening is an ellipse, the following expression is obtained through calculations **[9]**:

$$P_{0,I} = 0{,}907\left(\frac{d}{l}\right)^2\left(1-\frac{d_p}{d}\right)\left(1-\frac{\delta}{d}tg\varphi-\frac{d_p}{d}\cdot\frac{1}{cos\varphi}\right) , \quad (4.5)$$

for configuration I, and:

$$P_{0,II} = 0{,}785\left(\frac{d}{l}\right)^2\left(1-\frac{d_p}{d}\right)\left(1-\frac{\delta}{d}tg\varphi-\frac{d_p}{d}\cdot\frac{1}{cos\varphi}\right), \quad (4.6)$$

for configuration II.

For horizontally positioned sieves, the following result is obtained **[9]**:

$$P_{0,I} = 0{,}907\left(\frac{d}{l}\right)^2\left(1-\frac{d_p}{d}\right) , \quad (4.7)$$

for configuration I, și:

$$P_{0,II} = 0{,}785\left(\frac{d}{l}\right)^2\left(1-\frac{d_p}{d}\right) , \quad (4.8)$$

for configuration II.

4. 5. 3. Probability of a Particle Passing Through Square Mesh Openings

This type of sieve is manufactured in two variants (Figure 4.8), and the probability of particle passage through the square mesh openings is determined using the following calculation formulas **[9]**:

$$P = \left(\frac{d}{l}\right)^2\left(1-\frac{d_p}{d}\right)\left(1-\frac{\delta}{d}\cdot tg\varphi-\frac{d_p}{d}\cdot\frac{1}{cos\varphi}\right). \quad (4.9)$$

4. 6. Screening Efficiency

The ratio between the quantity of material actually screened and the total quantity of particles smaller than the mesh openings is expressed as a percentage and is referred to as screening efficiency, which characterizes the quality of the separation process **[14]**.

The screening efficiency, E, is defined by the following relation: **[14]:**

$$E = \frac{G_1\cdot 100}{\frac{G_a}{100}}\ [\%], \quad (4.12)$$

or:

$$E = 10000\frac{G_1}{G_a}\ [\%] , \quad (4.13)$$

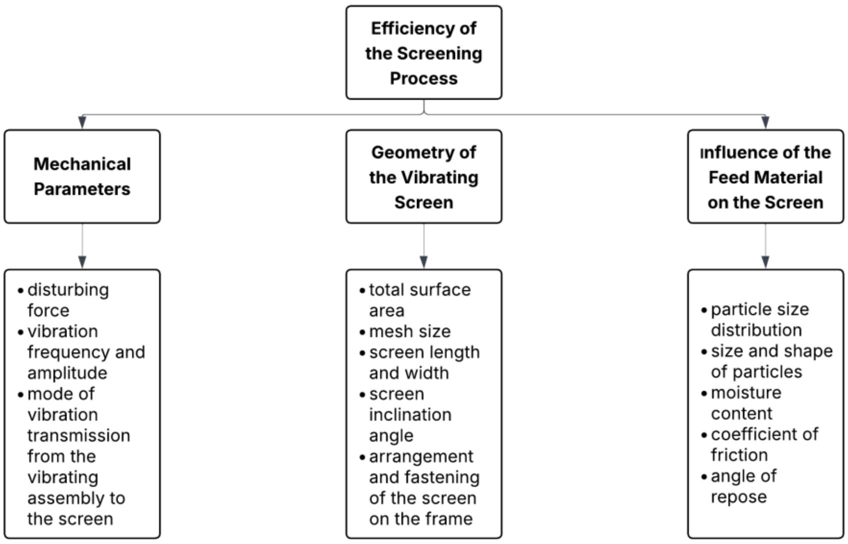


Fig. 4. 11. Structure of Efficiency Factors **[16]**

4. 7. Vibratory Screens

4. 7. 1. Structural Types of Screens [12]

In vibratory screens, the material can move across the mesh either by sliding or by jumping, depending on the values of the **throw coefficient** (the ratio of accelerations in the direction normal to the screen). The expression for this coefficient is given in **[12, 18]**:

$$C = \frac{r \cdot \omega^2}{g \cdot cos\alpha} \quad , \qquad (4.14)$$

4. 7. 2. Particle Behavior on a Horizontally Vibrating and Oscillating Surface

According to source **[22]** and **Figure 4.13**, the behavior of particles on a horizontally vibrating surface can be classified into three main situations, depending on the relationship between the particle velocity and the surface (screen) velocity:

1) **State of relative rest**: when the velocity of the particle and the velocity of the screen are equal ($v_1 = v_2$), the particle does not move and remains at rest relative to the screening surface.
2) **Movement in the same direction as the screen**: if the particle velocity is greater than the screen velocity ($v_1 > v_2$), the particle moves in the same direction as the screen motion, resulting in a **positive relative velocity** ($v_{1,2} > 0$).
3) **Movement in the opposite direction to the screen**: if the particle velocity is less than the screen velocity ($v_1 < v_2$), the particle moves in the opposite direction to the screen motion, resulting in a negative relative velocity ($v_{1,2} < 0$).

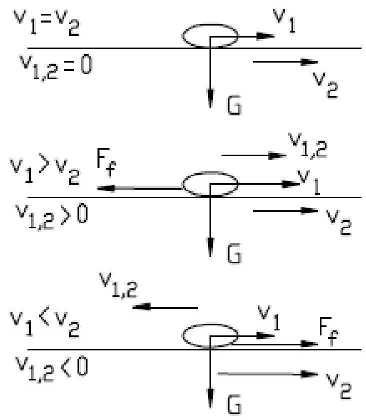


Fig. 4. 13. Possible Cases of a Particle on a Horizontally Vibrating Surface **[22]**

4. 7. 4. Sonic Vibrating Screen

Operating principle: Sonic vibrating screens use high-frequency sound waves to induce vibrations in the screening surface. These mechanical vibrations ensure the continuous movement of material across the screen, facilitating the separation of particles based on size. The ultrasonic waves, generated by a transducer, produce high-frequency oscillations that reduce friction between particles and the screen surface, thereby preventing clogging and ensuring higher screening efficiency.

4. 7. 5. Rolling Motion Screen

Figure 4.18 illustrates the operating principle of the rolling motion screen. In the simplest configuration **(Figure 4.18b)**, points on the screen describe circular trajectories around the system's axis, without the screen itself rotating around its own axis. In more complex configurations, the screen's axis is inclined relative to the system's axis and describes a conical trajectory **(Figure 4.18c)** or even a rotational hyperboloid (**Figure 4.18d**), depending on the distance between axes and the inclination angle. These configurations influence the propagation of vibrations and, consequently, the behavior of the material during screening.

In **Figure 4.18a**, the screen rotates around its own axis, and its points follow circular trajectories. This is a synchronous and stable motion, which promotes material homogenization **[30, 31]**.

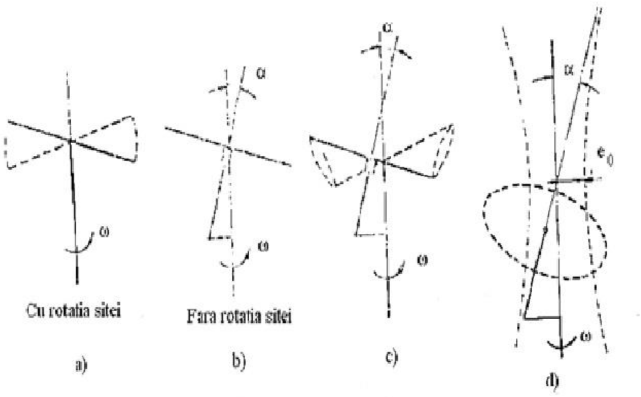


Fig. 4. 18. Schematics of Rolling Motion Screens **[30, 31]**

4. 7. 7. Inertial Vibratory Screens with Circular Oscillations

The following section presents the schematic diagram of such a screen **(Figure 4.23) [7, 18, 36]**, along with a detailed explanation of its structural components and operating principle.

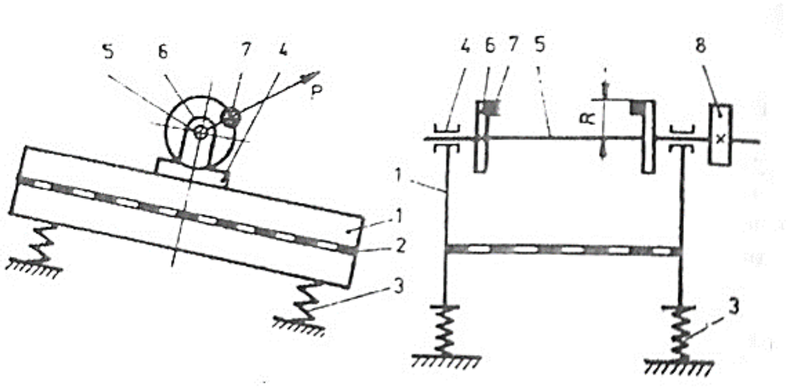


Fig. 4. 23. Inertial Circular Oscillation Screen (schematic **[18]**
1 – screen housing; 2 – screen mesh; 3 – springs; 4 – bearings; 5 – shaft; 6 – discs;
7 – eccentric masses (counterweights); 8 – belt pulley

CHAPTER 5
EXPERIMENTAL RESEARCH ON SLUDGE DEWATERING FOR PRACTICAL APPLICATION

5. 1. Granulometric Analysis

Fig. 5.1. Standard Sieve Set for Powder Separation `

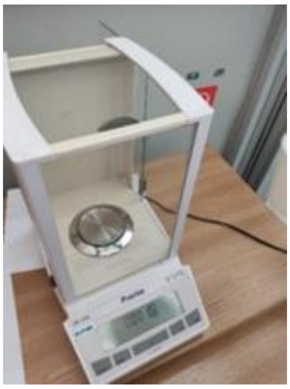


Fig. 5.2. Analytical Balance

Fig. 5.3. Vibratory Screening Apparatus

5. 1. 3. Interpretation of Results

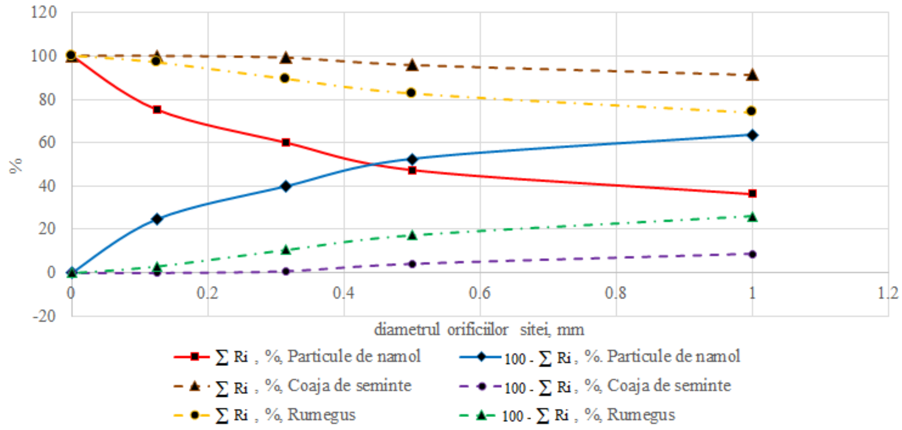


Fig. 5. 8. Data Processing for Sludge, Seed Shells, and Sawdust **[3]**

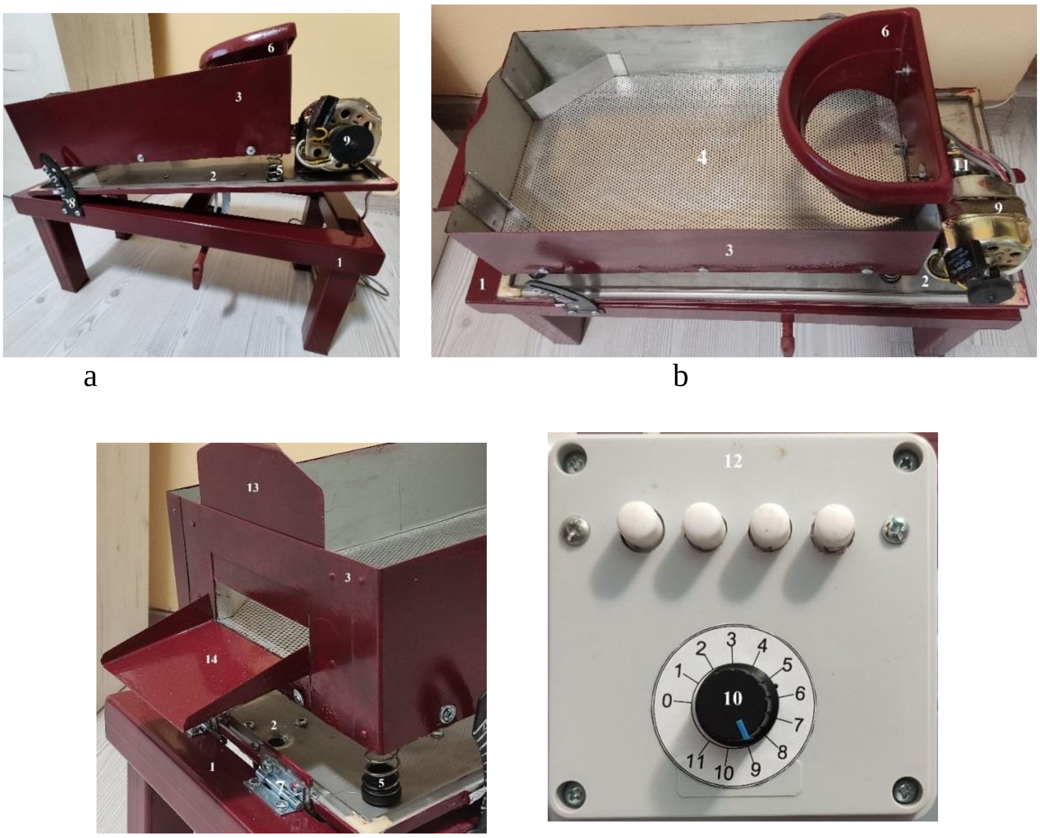
Analizând diagramele din **figura 5. 8**, prin interpolare, se constată că dimensiunea medie a particulelor are valoarea Dmed = 0,463 mm, pentru particulele de nămol. Pentru diametrul mediu al învelișului seminței și al particulelor de rumeguș, s-a procedat prin extrapolare și s-au obținut valorile de 5,548 mm, respectiv, 2,359 mm.

5. 2. Sludge Dewatering by Screening

5. 2. 2. Equipment Used in the Experiment

The following equipment was used for the experiment:

- Soil moisture hygrometer;
- Digital scale;
- Digital laser tachometer;
- Clamp meter – Ditz model 266;
- Sludge dewatering device: vibratory screen shown in **Figure 5.12.**



a b

c d

Fig. 5. 12. Ciur vibrator pentru deshidratarea nămolului
a - side view; b - top view; c - rear view; d - control box, regulator.
1 - support frame; 2 - drainage tray; 3 - sludge separation tank;
4 - sieve; 5 - feed hopper; 6 - helical springs; 7 - inclination adjustment system;
8 - protractor; 9 - motor; 10 - voltage regulator; 11 - eccentric mechanism;
12 - control box; 13 - flap; 14 - drainage chute.

5. 2. 3. Experimental Procedure

The purpose of the experiment is to determine the dewatering intensity achieved through vibratory screening. In addition to evaluating dewatering intensity, the experiment also aims to estimate potential material losses and perform an energy consumption assessment, in order to compare the proposed dewatering method with other commonly used processes from multiple perspectives.

5. 2. 6. Interpretation of Experimental Data

The regression models obtained for dewatering, as a function of initial moisture content (*ui*), sieve inclination angle (α), and motor speed (v), indicate that:

- ***Dewatering is significantly influenced by both the initial moisture content and the sieve inclination angle;***
- ***Dewatering is more intense when the initial moisture content is lower;***
- ***Dewatering becomes more effective as the sieve inclination angle decreases;***
- ***Dewatering also slightly depends on the motor speed, with a lower level of statistical significance, increasing gradually as motor speed increases;***

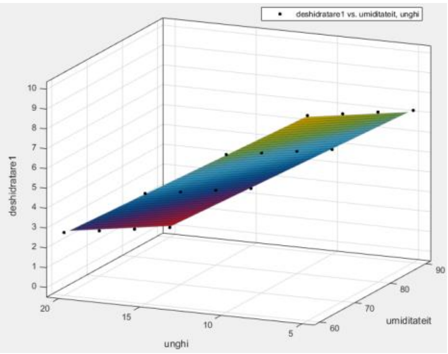


Fig. 5.21. Dewatering Variation (First-Degree Polynomial Interpolation, %) as a Function of Initial Moisture Content (%) and Sieve Inclination Angle (degrees)

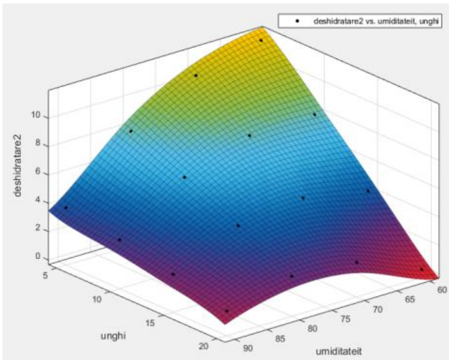


Fig. 5.22. Dewatering Variation (Second-Degree Polynomial Interpolation, %) as a Function of Initial Moisture Content (%) and Sieve Inclination Angle (degrees)

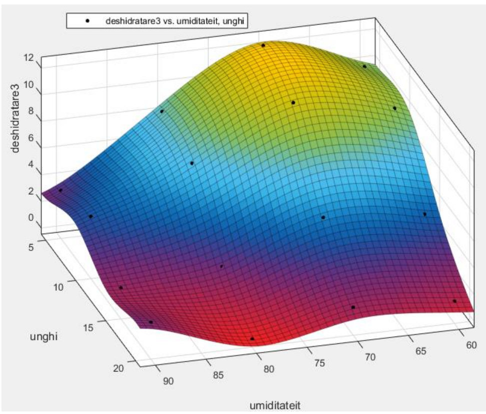


Fig. 5. 23. Dewatering Variation (Third-Degree Polynomial Interpolation, %) as a Function of Initial Moisture Content (%) and Sieve Inclination Angle (degrees)

In **Figures 5.21, 5.22, and 5.23** (generated using MATLAB software **[27]**), the dewatering functions are graphically represented and interpolated using first-, second-, and third-degree polynomials, respectively. Each figure represents a function of three variables, two of which are shown: initial moisture content and sieve inclination angle. The third variable, motor speed, is fixed at 670 rpm. These figures illustrate how dewatering varies as a function of the two displayed variables. ***The dewatering values range between 1% and 18%.***

5. 2. 6 .2. Analysis of Relative Dewatering Variation

The regression models obtained for relative dewatering, as a function of initial moisture content, sieve inclination angle, and motor speed, indicate that:

- ***Relative dewatering depends significantly on the initial moisture content of the raw material and the sieve inclination angle (relations (5.9 - 5.10));***
- ***Relative dewatering is more intense as the initial moisture content decreases (relations (5. 9 - 5. 10));***
- ***Relative dewatering increases as the sieve inclination angle decreases;***
- ***Relative dewatering also depends slightly, with a lower level of statistical significance, on motor speed, increasing with it, as shown by relation (5.10).***

5. 2. 6. 4. Analysis of Energy Consumption Variation for Batch Processing

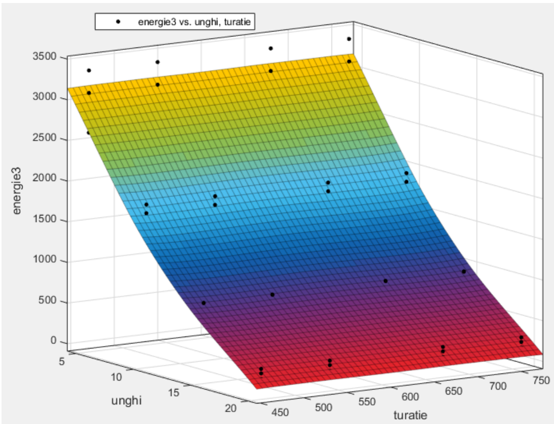


Fig. 5. 33. Function of Energy Consumption per Batch (Ws or J) as a Function of Sieve Inclination Angle (degrees) and Motor Speed (rpm), Third-Degree Interpolation. The Black Dots Represent Experimental Data.

Figures 5.31, 5.32, and **5.33** present representations of the energy consumption function as a function of sieve inclination angle and motor speed. Within the domain of the energy consumption function, no critical points are observed in these representations. Consequently, energy consumption decreases with increasing sieve inclination angle (due to the faster evacuation of the material being dried, which results in less intense dewatering) and increases with motor speed.

5. 3. Sludge Dewatering by Pressing

5.3. 2. Comparative Analysis of Sludge Dewatering by Pressing and Screening

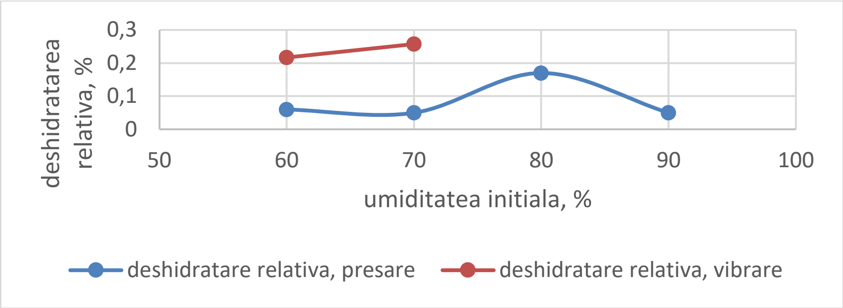
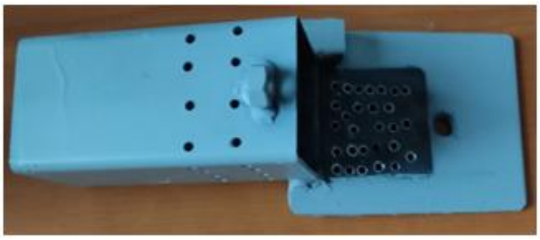


Fig. 5. 41. Relative Dewatering of Sludge Using the Two Dewatering Methods.

The two curves show that the experimental data demonstrate that vibratory dewatering is more intense than press-based dewatering, relative to the initial moisture content range of 60% to 70%.

5. 3. 3. Experimental Setup

5. 3. 3. 1. Equipment and Accessories Used During the Experiment



a.

b.

Fig. 5. 42. Composite Material Forming Mold
a – matrix; b - piston

The matrix (Figure 5.42a) used for forming the composite material was paired with a **piston (Figure 5.42b)** for compacting the material, pressed using calibrated weights.

Soil moisture hygrometer – used to measure the moisture content of the mixture before and after forming.

Digital kitchen scale with a maximum capacity of 5 kg and 1 g precision – used to weigh the material content of the mixture.

5. 3. 3. 2. Raw Materials Used for Obtaining Composite Materials with Sludge Matrix

Sludge resulting from wastewater treatment processes constitutes a complex colloidal system characterized by a heterogeneous composition. It contains **colloidal particles** with diameters below 1 mm, **dispersed elements** ranging from 1 to 100 mm, and **aggregates** of suspended material. The texture of sludge is typically gelatinous, and its high water content gives it a specific consistency that complicates handling and transportation without a prior dewatering stage **[36, 37].**

Fig. 5. 42. Materials Used for Obtaining Composites with a Sludge Matrix and Sawdust and/or Seed Shell Insert.

5. 3. 3. 3. Experimental Procedure Steps

5. 3. 3. 3. 1. Sludge Dewatering by Pressing

100 grams of sludge were weighed, and the initial moisture content was measured using a hygrometer. The sludge was poured into the mold, and the following were recorded: the dimensions before pressing, the pressing force, the pressing time, and the dimensions of the samples after removal from the mold.

5. 3. 3. 3. 2. Experimental Procedure for Obtaining Composite Material Samples with a Sludge Matrix and Seed Shell/Sawdust Insert

The concentrations of sludge and additive material were determined: N100, N95S5, N90S10, N85S15, N80S20, N75S25, N70S30, N50S50, N95R5, N90R10, N85R15, N80R20, N75R25, N70R30, N65R35, N60R40, N50R50 (where **N** is the code for the sludge matrix, **S** is the code for the seed shell insert, and **R** is the code for the sawdust insert).

The same steps described in **5.3.3.3.1** were followed.

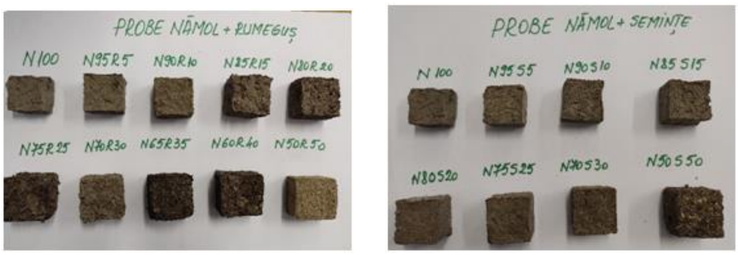


Fig. 5. 48. Composite Material Samples Two Weeks After Removal from the Forming Mold.

After two weeks at constant temperature **(Figure 5.48)**, the samples are weighed and measured to study their evolution over time.

5. 3. 3. 4. Experimental Data Processing

The **relative volume reduction** of the brick is defined using the following formula:

$$\delta V = \frac{V_i - V_f}{V_i}; \qquad (5.23)$$

relative dewatering:

$$\delta u = \frac{u_i - u_f}{u_i} \quad ; \qquad (5.24)$$

relative mass loss:

$$\delta m = \frac{m_i - m_f}{m_i} \quad ; \qquad (5.25)$$

densification or relative increase in density:

$$\delta \rho = \frac{\rho_i - \rho_f}{\rho_i} \quad . \qquad (5.26)$$

5. 3. 3. 4. 1. Sludge Dewatering Analysis

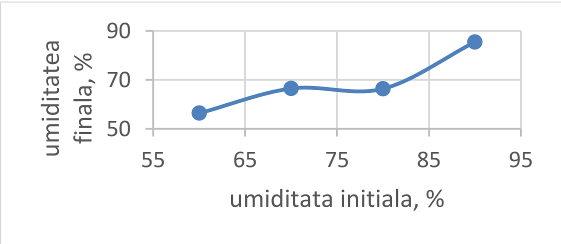


Fig. 5. 49. Distribution of Experimental Data for Final and Initial Sludge Moisture Values

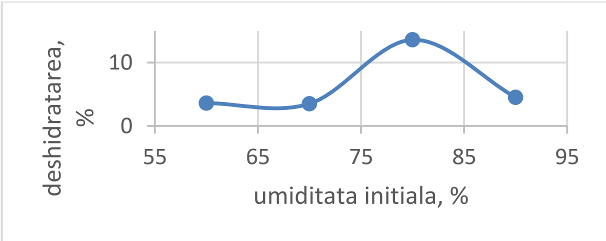


Fig. 5.50. Distribution of Experimental Data on Relative Sludge Dewatering Based on Initial Moisture Content

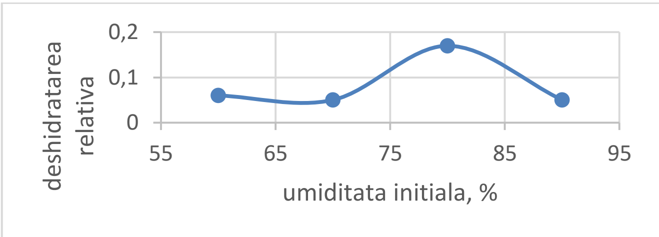


Fig. 5. 51. Distribution of Experimental Data on Relative Sludge Dewatering as a Function of Initial Moisture Content.

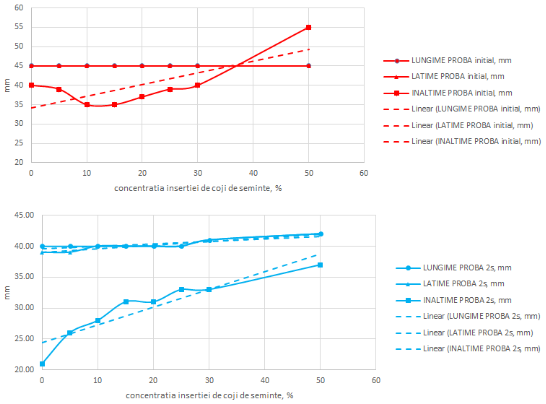
Figure 5.49 shows that pressing-based dewatering in the process of forming pure sludge bricks results in positive values, meaning that the difference between initial and final moisture content is positive (e.g., for an initial moisture of 60%, the final moisture is below 60%; for an initial moisture of 70%, the final value is also below 70%, etc.). This behavior is more clearly illustrated in **Figure 5.50**, where dewatering—defined as in **relation (5.3)** — is positive, ranging from 2% to 14%. The same phenomenon is observed in **Figure 5.51**. Therefore, press-based dewatering (using conventionally selected values for pressure or pressing force) is effective, with its role in the brick formation process being to remove water rather than to dry; in practice, drying occurs after the forming process is completed.

5. 3. 3. 5. Behavior of Composite Materials Over Time Under Standard Storage Conditions

Figure 5.59 shows the variation in the dimensions of composite sludge bricks with seed shell inserts as a function of seed shell concentration. It can be observed that length remains constant, width varies negligibly, while height varies significantly.

Figure 5.60 graphically represents the variation of the ratio between each dimension (after two weeks of storage) and the initial dimension (at the end of the manufacturing process). The curves lie below the line with ordinate equal to one, indicating that the ratios are subunitary. This demonstrates that the bricks contract during storage, at least within the two-week period following fabrication and under the specified storage conditions.

The same behavior is studied for composite material with a sludge matrix and sawdust insert.



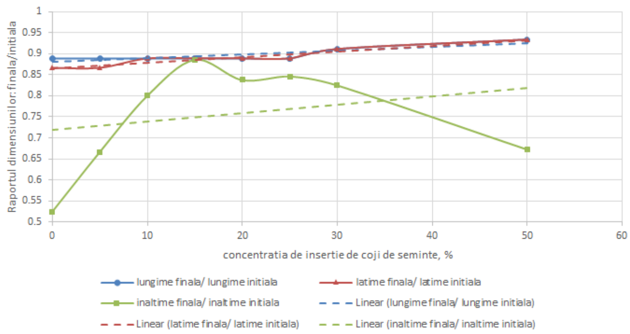


Fig. 5.59. Variation in Brick Dimensions with Seed Shell Concentration During Storage (2 Weeks)

Fig. 5.60. Ratio Between Final (After 2 Weeks of Storage) and Initial Values of Dimensions for Composite Bricks (Sludge Matrix with Seed Shell Insert)

5. 3. 3. 6. Proprietăți mecano-termice ale materialelor compozite obținute

5. 3. 3. 6. 1. Proprietăți termice

a b

Fig. 5. 66. Measuring Surface Temperature on Bricks **[53]**
a - brick placement b - temperature measurement

To determine the heat transfer properties of sludge bricks with seed shell or sawdust inserts, a fire-resistant box was used. The upper wall of the box includes a slot where the bricks are tightly inserted. Inside the box, a heat source raises the internal temperature to 100 °C **[54**

]. The ambient temperature and the distance from which the measurements are taken remain constant.
The surface temperature of the bricks is measured using a digital infrared thermometer. For each material concentration, three temperature readings are taken—one per brick **(see Figure 5.66)**. The thickness of the brick must be measured, and the average density of the three bricks calculated.

The variation in thermal conductivity of the composite with a sludge matrix and seed shell insert as a function of seed shell concentration is shown in **Figure 5.67**. According to the trendline, thermal conductivity increases gradually with the insert concentration. The minimum conductivity value is 0.4089 W/m·K, and the maximum is 0.59989 W/m·K.

The variation in thermal conductivity of the composite with a sludge matrix and sawdust insert as a function of sawdust concentration is shown in **Figure 5.68**. Similarly, according to the trendline, thermal conductivity increases with the insert concentration. The minimum value is 0.430946 W/m·K, and the maximum is 0.674512 W/m·K.

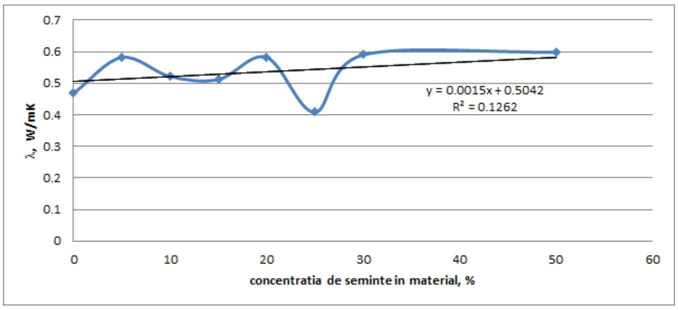


Fig. 5. 67. Thermal Conductivity Variation of the Composite Material (Sludge Matrix with Seed Shell Insert) as a Function of Seed Shell Insert Concentration

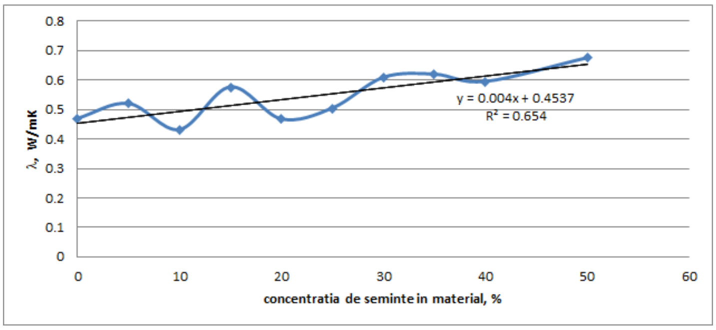


Fig. 5. 68. Variația conductivității termice a materialului compozit (matrice de nămol cu inserție de rumeguș) cu concentrația inserției de rumeguș

5. 3. 3. 6. 2. Mechanical Properties

***Compression Test* [67]**

Fig. 5. 67. Positioning and Alignment of the Specimens on the Mechanical Testing Machine Support

a. b.

Fig. 5.68. Brick After Compression:
a – Applied Force; b – Brick After Compression

The variation in compressive strength as a function of seed shell insert concentration in composite bricks with a sludge matrix is graphically represented in **Figure 5.69**.

The compressive strength of bricks made from composite material with a sludge matrix and seed shell insert decreases as the seed shell concentration increases. This decrease is non-linear. The trendline, as well as the regression equation, confirms that compressive strength diminishes with the increasing seed shell content in the composite material. The compressive strength values for the composite variants range between 0.375 MPa and 2.292 MPa.

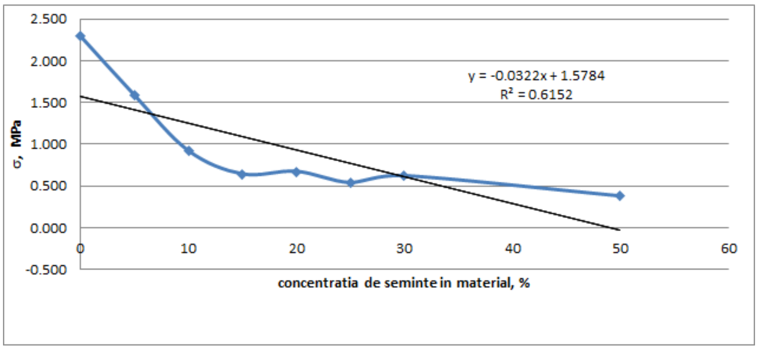


Fig. 5. 69. Variation in Ultimate Crushing Strength of the Composite Material with Sludge Matrix and Seed Shell Insert, as a Function of Seed Shell Concentration

Therefore, bricks made from composite material with a sludge matrix and seed shell insert fall within the lower strength range of conventional construction materials.

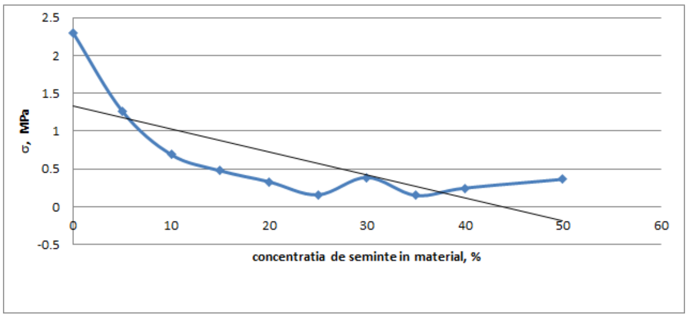


Fig. 5. 70. Variation in Ultimate Crushing Strength of the Composite Material with Sludge Matrix and Sawdust Insert, as a Function of Sawdust Concentration

The variation in compressive strength, as a function of the sawdust insert concentration in composite bricks with a sludge matrix, is graphically represented in **Figure 5.70**. Here too, the compressive strength of the bricks decreases as the sawdust concentration increases. This decrease is non-linear. The compressive strength values for the composite variants with sludge matrix and sawdust insert range between 0.149 MPa and 2.292 MPa.

5. 4. Conclusions

Following the experiments carried out, the following aspects were observed:

- No outlier values were identified, therefore no corrections or adjustments were necessary;
- Dewatering is more intense when the initial moisture content is lower and the sieve inclination angle is smaller;
- Dewatering is only slightly influenced by the sieve motor speed, with a low level of statistical significance; it increases with motor speed;
- The range of dewatering values varies between 1.0% and 18%;
- The relative dewatering variation, influenced by initial moisture and sieve angle, ranges between 1.0% and 25.7%;
- Power consumption depends linearly only on the rotation speed of the sieve drive motor, ranging between 18.15 W and 24.75 W;
- Energy consumption decreases as the sieve inclination increases and increases with motor speed;
- There is a decreasing trend in efficiency with the sieve angle and a slight increase with motor speed; a higher speed reduces drainage time of the batch, and the increased motor speed increases the surface flow velocity over the sludge during drying.

2. **Regarding dewatering by pressing:**

- Dewatering values range between 2.0% and 14%, with conventionally chosen pressing forces;
- The final moisture content is higher for pressing than for screening; therefore, vibratory screening results in more efficient dewatering.

3. **For composite materials with a sludge matrix and seed shell or sawdust insert:**

- Insert concentration has an insignificant effect on dewatering, as does pressing force;
- The pressing force is the most important input parameter for the relative densification of the composite material;
- Volume, density, and moisture content values of the bricks are lower after two weeks of storage compared to their initial values after fabrication;
- The thermal conductivity of the composite with seed shell insert increases gradually with insert concentration; the values range from 0.4089 W/mK to 0.59989 W/mK;
- The thermal conductivity of the composite with sawdust insert also increases with insert concentration; values range from 0.430946 W/mK to 0.674512 W/mK;
- The compressive strength of bricks with sludge matrix and seed shell insert decreases as the insert concentration increases; values range from 0.375 MPa to 2.292 MPa; hence, these bricks are at the lower performance threshold for common construction materials;

- Similarly, for composites with sawdust insert, compressive strength decreases with increased sawdust concentration, and this decrease is non-linear; the values range between 0.149 MPa and 2.292 MPa.

CHAPTER 6
CONCLUSIONS. PERSONAL CONTRIBUTIONS. PERSPECTIVES

6. 1. Conclusions

The aim of this thesis was to conduct an in-depth examination of the challenges related to the dewatering and utilization of sewage sludge, which are highly relevant topics in the context of the transition towards a circular and sustainable economy. Sewage sludge generated in wastewater treatment plants is both a valuable resource and a complex environmental challenge with implications for environmental protection, public health, and economic efficiency on a global scale.

Throughout the history of sludge management, technological developments have played a vital role—from primitive disposal methods to advanced solutions such as composting, incineration, and energy recovery. Furthermore, the analysis of the physico-chemical and biological properties of sludge provides a deeper understanding of its behavior in treatment processes.

The regulatory framework is another significant conclusion. While Directive 86/278/EEC and associated national and EU legislation provide a solid foundation for the safe use of sludge in agriculture and other sectors, implementation in Romania remains in its early stages.

This thesis also highlights the potential for reusing sewage sludge across various fields and supports the development of a circular economy. Thanks to its ecological safety potential, using sludge as fertilizer, alternative fuel, or building material contributes to waste reduction and resource conservation.

6. 2 Personal Contributions

This doctoral research integrates findings from specialized literature with original contributions, leading to the fulfillment of the research objectives. The main contributions are as follows:

1. A comprehensive literature review on the formation, classification, and physico-chemical and biological characteristics of sludge resulting from wastewater treatment
2. Analiza legislației pentru gestionarea și valorificarea nămolului la nivel european, și național, concentrată pe strategiile specifice economiei circulare
3. Prezentarea celor mai recente tehnologii moderne de tratare a nămolurilor cu avantajele și dezavantajele lor
4. Determinarea posibilităților de utilizare a nămolului în agricultură, industrie și generare de energie, în funcție de compoziția şi de potențialul caloric al lui.
5. Corelarea strategiilor optime de valorificare cu parametrii fizico-chimici, în funcție de tipul de nămol.
6. Formularea rezultatelor și recomandărilor pentru cercetări viitoare care sa vină în sprijinul progresului științific și al aplicabilitîții practice a soluțiilor propuse.

Conţinutul tezei reflectă unele contribuţii personale, după cum urmează:

6. 2. 1. 6.2.1. Theoretical Contributions

6. 2. 1. 1. 6.2.1. Theoretical Contributions

Chapter 1

- A study of the evolution of wastewater treatment systems and the formation process of sewage sludge, along with a description of the main wastewater treatment methods and how they generate sludge as a by-product.

- An overview of modern technologies for sludge valorization and recycling, emphasizing advancements in sustainable practices.

- A comprehensive analysis of the circular economy concept and the role of sewage sludge within this system, particularly in reducing waste and promoting resource efficiency.

Chapter 2

- A detailed breakdown of the stages of the sludge dewatering process, including the criteria for selecting the most appropriate method based on operational and technical requirements.

- A critical evaluation of the commonly used dewatering methods—such as drying beds, centrifugation, pressing, and thermal drying—considering factors like residual moisture, energy efficiency, and associated costs. The influence of sludge characteristics on process performance is also analyzed, with a focus on mechanical and thermal methods.

Chapter 3

- An analysis of the equipment used for sludge dewatering, highlighting construction features, operational principles, and performance indicators depending on the sludge type.

- A comparative discussion on the advantages and disadvantages of each equipment type, supported by practical examples of industrial application.

Chapter 4

- An in-depth study of equipment designed for particle size separation of solids in sludge, assessing their efficiency relative to sludge composition and the technological requirements of the processes in which they are used.

6. 2. 1. 2. Original Theoretical Contributions

- A detailed analysis of the methods involved in sludge dewatering and particle size separation was carried out. The study also examined the correlation between the types of equipment used and the characteristics of the sludge. Numerous bibliographic sources related to sludge dewatering technologies and equipment were consulted in order to synthesize the information logically, coherently, and adapted to the Romanian context.

- The most commonly used types of vibratory screens in sludge treatment were identified and analyzed. Each construction type was assessed in terms of separation efficiency, throughput, and adaptability to different particle sizes. Additionally, comparative analyses were performed between square-mesh and circular-mesh screens.

- The probability of particle passage through screen openings of different geometries was also examined.

6. 2. 2. Original Experimental Contributions

The experimental analysis focused on sludge dewatering by pressing in a mold and by vibratory screening, using a vibrating sieve inclined at various angles and operated at different rotation speeds. The sludge was mixed with seed husks or sawdust to produce composite materials, potentially usable in the construction sector. The following investigations were conducted:

- Particle size analysis of the three materials using an analytical balance and a set of standard sieves from the Process Equipment Department of the Faculty of Mechanical Engineering and Mechatronics, National University of Science and Technology Politehnica Bucharest.

- Dewatering of sludge using the constructed vibratory sieve and necessary apparatus. The results were tabulated, mathematically modeled, and graphically represented..

- Sludge pressing in a fabricated mold. The results were interpreted and compared to those from vibratory screening, with graphical representations included.

- Production of composite materials, data processing, observation of performance over time under standard storage conditions, mechanical testing with equipment from the Faculty of Civil Engineering, specifically at the Laboratory for Construction and Thermal Material Testing, using the experimental stand of PhD candidate Elena Dobrițoiu. The data were further mathematically modeled and graphically presented.

6. 3. Future Perspectives

Based on the results obtained, several research directions were identified for further development and improvement of the current study:

- The use of multilayered sieves with openings of various sizes on the vibrating sieve, to achieve more precise fractionation and allow treatment adjustment for each material batch**;**

- The extension of the tested filler materials, including recoverable industrial residues, to develop optimal composite material formulations;

- Optimization of mixture recipes based on granulometry results and mechanical and thermal testing, to determine the most suitable combinations balancing strength, durability, and sustainability;

- A feasibility analysis for scaling up the process in a real production unit or an existing wastewater treatment plant, to assess technical and economic viability;

- Implementation of a monitoring system for product quality and traceability, ensuring the environmental safety and ecological integrity of the final materials.

LIST OF PUBLISHED ARTICLES

SCOPUS/WEB OF SCIENCE ARTICLES

1. FARCAŞ-FLAMAROPOL Dana-Claudia, Elena SURDU*, Radu I. Iatan, Petru CÂRDEI, Ramona MARE, *Preliminary research regarding the creation of a category of composite material based on a mud matrix and agricultural waste as filler materials* , INMATEH-Agricultural Engineering, vo. 71, no. 3, **2023**, p 205-214 (ISSN 2068-4215; 0n line ISSN 2068-2239), WOS : 001146897700001.

2. Elena SURDU, **Dana-Claudia FARCAŞ-FLAMAROPOL**, Radu I. IATAN, Petru CÂRDEI, Nicoleta SPOREA, Gheorghița TOMESCU, Ion DURBACĂ, *Heat transmission through walls of composite material with clay matrix (Transmiterea caldurii prin pereti de material compozit cu matrice de lut),* INMATEH-Agricultural Engineering, vo. 73, no. 2, **2024**, p 416-426 (ISSN 2068-4215; 0n line ISSN 2068-2239), WOS:001293857700035.

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2. Farcaş – Flamaropol Dana – Claudia. Surdu Elena, *Wastewater Purging. Case Study*, Hidraulica, nr. 1, **2020**, p. 109-113 (ISSN 1453 – 7303).

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CHAPTER 2

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CHAPTER 4

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CHAPTER 5

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