CHAPTER I
INTRODUCTION

1.1 Background

Tofu is a traditional Indonesian food that is widely consumed by the public. It contains a complete set of amino acids and is easily digestible. The relatively low price makes tofu a popular choice for daily meals. This has led to the rapid growth of the tofu industry, which has expanded across various regions using conventional methods (Cahyani et al., 2021). According to Wahyuningsih et al. (2024) Household-level consumption of tofu, tempeh, and soy sauce in Indonesia during the 2002–2023 period exhibited a fluctuating trend. The average per capita consumption of tofu was 7.53 kilograms per year. The consumption of soybeans in the form of tofu in 2024 is projected to increase by 1.14% compared to that in 2023, and is expected to continue rising until 2026, reaching 8.09 kilograms per capita.

During production, tofu industry generates two types of waste, solid and liquid waste. The solid waste is the residue from soybeans and is often repurposed, while the wastewater is typically discarded into rivers. The liquid tofu waste contains high levels of protein, fat, and carbohydrates, resulting in high levels of BOD and COD in waters (Cahyani et al., 2021).

Wastewater from tofu industry is known to cause eutrophication in water bodies. To manage this problem, BRIN (*Badan Riset dan Inovasi Nasional*) constructed a wastewater treatment plant in Giriharja Village, Sumedang Regency, using a multistage fixed-bed reactor anaerobic digester treatment system. However, this treatment system is only able to reduce the concentration of ammonium and phosphate to 178 ± 13 mg NH_4^+-N/L and 79 ± 13 mg P/L, respectively, which is then disposed of directly to the water body. This concentration exceeded the environmental standards and does not fulfill the Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management in class 3 water bodies, which are 0.5 mg/L and 1 mg/L, respectively. Therefore, further treatment is necessary (Ha et al., 2024).

The removal of ammonium employs various methods, showcasing a wide array of biological, physicochemical, and innovative technological approaches. Biological technology relies on microbial activity to transform ammonia into safer, less harmful compounds. Physicochemical technologies (e.g., adsorption, membrane filtration, ion exchange, chemical precipitation, and ammonia stripping) encounter challenges related to operating conditions and costs, requiring specific environmental parameters, and incurring expenses for chemicals and energy-intensive processes (Farghali et al., 2024). Physicochemical methods for ammonia removal require high operating costs ranging from approximately US $1.12 to $13.00 per m^3 of feed. For example, conventional chemical precipitation for ammonia removal using commercial magnesium salts can cost about US $13/$m^3$, while ion exchange costs around US $9.30/$m^3$, primarily due to the need for ultrafiltration, pre-treatment, and zeolite regeneration (Zarebska et al., 2015). Phosphate, on the other hand, can be extracted through three traditional methods: adsorption, chemical treatment, and activated sludge processing. Adsorbents come with certain limitations, such as low phosphate selectivity, limited capacity, high acid and base consumption during material production, and diminished performance after cycles. Environmental factors affect the efficiency of the activated sludge method, requiring significant investment in sludge management during the initial stages (Li et al., 2024).

When applied specifically for nutrient recovery as struvite, chemical precipitation can be relatively simple, energy-efficient, and potentially low-cost, particularly when low-cost magnesium sources such as seawater or bittern are used. Struvite, chemically known as magnesium ammonium phosphate hexahydrate ($MgNH_4PO_4 \cdot 6H_2O$), is a crystalline compound that commonly precipitates from aqueous solutions rich in magnesium (Mg^{2+}), ammonium (NH_4^+), and phosphate (PO_4^{3-}) ions. Chemical precipitation of struvite occurs under alkaline pH conditions (typically between pH 8 – 10), which favor the low solubility of the compound (Le Corre et al., 2009). Struvite is a slightly soluble, odorless mineral that gradually releases nutrients (Mg, N, and P) and can be regarded as a high-quality fertilizer (Ha et al., 2024). Struvite precipitation is a sustainable approach for extracting ammonium from wastewater. It can produce nearly or entirely insoluble compounds that are easily separated from the solution, and has become widely adopted as an affordable method for producing fertilizers (Farghali et al., 2024). Struvite crystal consists of ions in equimolar concentrations and can be found on pipe walls and reactor vessels after an anaerobic digestion process in wastewater treatment (Kim et al., 2016).

Struvite crystal formation is highly influenced by pH of the solution, molar ratio, interfering ions, reaction time, types of chemicals added, types of reactors used, and temperature. The main factors in struvite precipitation, however, are the pH level and magnesium source. The pH of the solution can significantly affect the amount of struvite produced and also its purity. Struvite can be precipitated at a pH range from 7.0 to 11.5, with the most suitable pH range being from 8.0 to 9.5 (Kim et al., 2016). Struvite reaches minimum solubility at pH values between 9.0 and 10.7. Increasing the solution pH to around 10 in struvite precipitation processes enhances nutrient removal efficiency but demands higher doses of alkaline and magnesium reagents. Since the magnesium source alone can contribute up to three-quarters (75%) of the total treatment cost, this pH adjustment significantly elevates overall operational expenses (González-Morales et al., 2021).

The struvite precipitation process is significantly affected by chemical inputs, especially the magnesium source, which contributes up to 75% of the total treatment cost. Exploration of low-cost magnesium sources is currently ongoing to develop an effective and economical process. Some relatively inexpensive and conventional alternative sources of magnesium include seawater, seawater concentrate, bittern, and wood ash (Setiawan et al., 2022). In coastal urban regions, seawater, containing approximately 1,300 mg/L of Mg^{2+}, offers a promising and economically viable source of magnesium for struvite recovery (Battaz et al., 2024). The local availability of such alternative sources is a key factor influencing the operational feasibility of implementing struvite precipitation processes in wastewater treatment systems (Shaddel et al., 2020).

Although struvite precipitation has been widely studied for ammonium and phosphate removal, previous studies regarding tofu wastewater were conducted using artificial wastewater under controlled conditions (Marshal, 2024). Such approaches do not adequately represent the characteristics of actual tofu wastewater, which contains variable nutrient concentrations and competing ions that may influence struvite recovery and formation.

In addition, the use of seawater as a low-cost magnesium source that has been conducted generally focused on hydraulic retention time or crystal formation (Marshal, 2024) and did not systematically evaluate the influence of pH variation on recovery efficiency from real tofu wastewater effluent. Subsequently, the optimum pH condition that maximizes nutrient recovery rather than achieving high removal efficiency remains insufficiently understood, particularly for tofu wastewater treatment system in Indonesia.

This research aims to address this by evaluating the effect of pH variation on ammonium and phosphate recovery through struvite precipitation using an actual tofu wastewater effluent and seawater as the magnesium source. By focusing on recovery efficiency and crystal production, this study identifies the optimal operational pH that balances nutrient recovery performance and operational cost.

1.2 Aim and Objective

This research aims to analyze the recovery of ammonium and phosphate with struvite precipitation using seawater as the magnesium source in different pH conditions.

The objectives that will be obtained from this research are:

1. To analyze the recovery of ammonium in different pH variations of two different solutions.
2. To analyze the recovery of phosphate in different pH variations of two different solutions.
3. To analyze the effect of seawater addition on the solution after struvite precipitation is conducted.
4. To analyze the amount of crystal produced by each solution in different pH variations.
5. To determine the optimum pH level required to reach effective ammonium and phosphate recovery.

1.3 Research Benefit

The result of this research is expected to give benefit toward various aspects, as follows:

1. To discover the optimum pH condition to recover nutrients from tofu wastewater using seawater as a magnesium source.
2. To further improve and contribute to the innovation of tofu wastewater treatment in an effort to reduce its negative impact toward environment.

1.4 Scope

To ensure the research remains focused and aligned with its aims and objectives, the following scope has been established.:

a. The research will be conducted in the Microbiology Laboratory and Water Laboratory in the Department of Environmental Engineering, Andalas University, for five months from 14^{th} of July 2025 – 30^{th} November 2025.
b. Batch experiment is used in the struvite precipitation process.
c. Influent used is an effluent from the tofu production process taken from a tofu factory in Sumedang.
d. Seawater from Pantai Padang will be used as a magnesium source.
e. There are two solutions prepared: wastewater solution and wastewater + seawater solution.
f. Retention time used is 60 minutes with ambient temperature.
g. The variation of pH used are 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, and 10.0.
h. The experiment was conducted in triplicate.
i. The measurement method is using spectrophotometer to determine the ammonium and phosphate concentrations by calculating the efficiency of ammonium (SNI 06-6989.30-2005) and phosphate removal (SNI 06-6989.31-2005).
j. The struvite crystal ($MgNH_4PO_4 \cdot 6H_2O$) will be weighed to determined crystals productions.

1.5 Writing Systematics

The writing systematics of this Final Project are as follows:

CHAPTER I **INTRODUCTION**

This chapter outlines the research background, emphasizing nutrient pollution from tofu wastewater and limitations of the existing BRIN treatment system. It explains the rationale for using struvite precipitation with seawater as the magnesium source, the problem formulation, research objectives, benefits, scope, and the overall structure of the thesis.

CHAPTER II **LITERATURE REVIEW**

This chapter reviews relevant theories and previous studies on tofu wastewater characteristics, nutrient removal technologies, struvite chemistry and formation, effects of pH and hydraulic retention time (HRT), the use of alternative magnesium sources such as seawater, and concludes with related research from previous studies.

CHAPTER III **RESEARCH METHODOLOGY**

This chapter details the experimental procedures, including seawater and tofu wastewater sampling, sample analysis, and the struvite precipitation setup. It describes the variables tested (pH variation at fixed HRT of 60 minutes), measurement methods for ammonium and phosphate recovery, crystal production, and data analysis methods.

CHAPTER IV **RESULT AND DISCUSSION**

This chapter presents the results of the experiments, which include nutrient recovery efficiencies, the effect of seawater toward the solution, and struvite crystal yields. It analyzes the influence of pH on ammonium and phosphate recovery and compares findings to previous studies.

CHAPTER V CONCLUSIONS AND SUGGESTIONS

This chapter summarizes the main findings, highlighting the optimal pH for nutrient recovery from tofu wastewater, and also provides recommendations for process optimization, potential scaling, and future research directions.