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Design and Development of a Wastewater Treatment Plant System for Improved Ammonia Removal at Metro Medika Hospital

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Abstract: Hospital wastewater contains various pollutants, including ammonia, which may contaminate receiving water bodies and threaten environmental health if not adequately treated. The existing wastewater treatment plant (WWTP) at Metro Medika Hospital, Mataram, was unable to consistently reduce ammonia concentrations to comply with the regulatory limit of 10 mg/L, with the latest effluent concentration reaching 58.1 mg/L. Therefore, this study aimed to redesign the hospital WWTP to improve ammonia removal through the optimization of an integrated anaerobic-aerobic biological treatment system. A laboratory-scale experimental study was conducted using actual hospital wastewater in a modified treatment system consisting of anaerobic and aerobic biofilters, a bioball reactor, and a disinfection unit. The novelty of this study lies in integrating sequential anaerobic-aerobic biological treatment with a combination of attached-growth biofilter media, including DD-01 media, honeycomb media, bioballs, gravel, silica sand, zeolite, and plastic media, to enhance nitrification performance while maintaining a simple and practical treatment configuration. Data were analyzed using descriptive analysis by comparing influent and effluent ammonia concentrations, while treatment performance was evaluated through ammonia removal efficiency calculations. The redesigned WWTP reduced ammonia concentration from 58.1 mg/L to 10.0 mg/L, corresponding to an ammonia removal efficiency of 82.77%, thereby meeting the applicable wastewater quality standard. These findings demonstrate that the proposed WWTP design offers a feasible approach for improving ammonia removal and a promising strategy to support sustainable hospital wastewater management and regulatory compliance.

Keywords: Ammonia Removal; Hospital Wastewater; WWTP Redesign.

Introduction

Hospitals are among the healthcare facilities that play an important role in improving public health. On the other hand, hospital operational activities generate wastewater with high potential to pollute the environment because it contains organic substances, hazardous chemical compounds, pathogenic microorganisms, and nutrients such as nitrogen and phosphorus [1]. If not properly treated, wastewater may degrade water quality, disrupt aquatic ecosystems, and pose risks to public health in the vicinity of wastewater discharge.

One of the major pollutants in hospital wastewater is ammonia (NH_3-N). This compound is toxic and relatively difficult to degrade naturally [2][3]. Ammonia in hospital wastewater generally originates from patient urine, laboratory waste, pharmaceutical residues, and various other medical service activities. If discharged directly into the environment without proper treatment, ammonia may reduce dissolved oxygen levels, trigger eutrophication, and endanger aquatic organisms as well as public health[4][5]. These conditions indicate that effective hospital wastewater management is essential for supporting environmental sustainability and protecting public health.

As an effort to control environmental pollution, hospitals are required to operate a Wastewater Treatment Plant (WWTP) capable of treating wastewater before it is discharged into the environment [4][6][7][8]. Hospital WWTP systems are generally designed to reduce organic matter, suspended solids, pathogenic microorganisms, and nitrogen compounds through physical, chemical, and biological treatment processes[9]. The effectiveness of wastewater treatment is strongly influenced by the suitability of the design capacity, the selection of treatment technology, operational conditions, and the efficiency of the applied biological processes[10]. However, in practice, many hospital WWTP systems still fail to comply with regulatory wastewater quality standards due to limitations in system design and operational performance.

This problem was also identified in the WWTP system at Metro Medika Hospital, Mataram, particularly in the ammonia (NH_3-N) parameter, which still exceeded the wastewater quality standard established by the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. 68 of 2016 [11]. Laboratory test results showed that the ammonia concentration in the WWTP effluent reached 53.2 mg/L in 2021, decreased to 12 mg/L in January 2025, but increased again to 58.1 mg/L in April 2025, while the permitted quality standard is 10 mg/L. These findings indicate that the existing WWTP system has not been able to operate optimally and consistently in reducing ammonia concentration.

In addition to the high ammonia concentration, the increasing number of patients and healthcare service activities at the hospital have led to increased wastewater generation, potentially exceeding the existing WWTP treatment capacity [12]. On the other hand, the treatment system is still dominated by simple biological processes

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using biofilter media with relatively low efficiency in ammonia removal. These conditions indicate the need to evaluate and develop a more effective treatment system to ensure that effluent quality consistently meets environmental quality standards [13].

Based on these problems, improvement efforts are required, including redesigning the WWTP system to adopt a treatment approach better suited to the characteristics of hospital wastewater. The redesign aims not only to improve ammonia removal efficiency but also to enhance the operational stability of the treatment system. Previous studies on hospital wastewater treatment have primarily focused on WWTP performance evaluation, hydraulic redesign, or physicochemical methods for ammonia removal. However, most WWTP redesign studies have emphasized hydraulic optimization rather than improving biological ammonia removal, while ammonia-specific treatment studies often rely on more complex and costly technologies. Consequently, limited research has investigated the integration of anaerobic-aerobic biological treatment with multiple biofilter media to enhance ammonia removal from hospital wastewater. To address this research gap, the present study redesigns the existing WWTP by incorporating an integrated anaerobic-aerobic biofilter system with multiple biofilter media and evaluates its performance using actual hospital wastewater. This approach is expected to provide a practical, technically feasible solution to the limitations of the existing treatment system, particularly by improving the biological nitrogen removal process.

Research Methods

Research Location and Object

This study was conducted at Metro Medika Hospital, Mataram, West Nusa Tenggara Province, Indonesia. The research object consisted of hospital wastewater generated from inpatient and outpatient services, laboratories, laundry facilities, kitchens, pharmacies, radiology units, and other supporting activities. Based on the Technical Approval Document (PERTEK), the average wastewater discharge was approximately 19.3 m³/day, corresponding to approximately 80% of the hospital's clean water consumption. It was calculated from 120 hospital beds and the standard water demand of 200 liters/person/day. The WWTP redesign was based on this wastewater flow rate and a combination of anaerobic and aerobic biological treatment processes.

Experimental Design

The study employed a laboratory-scale experimental design to evaluate the redesigned WWTP's effectiveness in removing ammonia from hospital wastewater. A laboratory-scale mini WWTP with a total working volume of approximately 40 L was constructed, consisting of four treatment units: an anaerobic biofilter, an aerobic biofilter, a bioball reactor, and a disinfection unit. Each treatment unit had an effective working volume of approximately 10 L.

The anaerobic unit was filled with DD-01 biofilter media, whereas the aerobic unit contained honeycomb media and was continuously aerated using a mini air blower. The bioball unit served as an additional attached-growth reactor to enhance nitrification, while the final unit was used for disinfection before effluent sampling. Wastewater was continuously pumped through all treatment units to simulate the hydraulic conditions of the proposed WWTP system.

The experiment was conducted for 7 days using actual hospital wastewater collected from the outlet of the existing WWTP. Influent and effluent samples were collected only at the beginning of the process and at the last day of the process. Subsequently, the collected samples were analyzed for the specified water quality parameters at the STTL Mataram Laboratory.

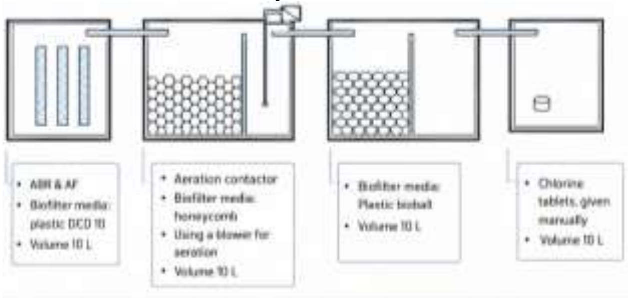


Figure 1. Laboratory Scale Mini Wastewater Treatment Plant Design Scheme

Ammonia Analysis

Ammonia concentration in influent and effluent wastewater samples was determined using the Phenate Method (APHA Standard Methods for the Examination of Water and Wastewater, Method 4500-NH_3 F) with spectrophotometric measurement (SNI 06-6989.30-2005). The analytical procedure included sample preservation, reagent addition, color development, and absorbance measurement at the specified wavelength according to APHA procedures. Ammonia concentrations were expressed as mg/L NH_3–N.

Evaluation of Ammonia Removal Efficiency

The effectiveness of the redesigned WWTP was evaluated by comparing influent and effluent ammonia concentrations. Ammonia removal efficiency was calculated using the following equation:

$$\text{Removal Efisiensi (\%)} = \frac{C_i - C_e}{C_i} x\ 100$$

where:
C_i= influent ammonia concentration (mg/L)
C_e= effluent ammonia concentration (mg/L)

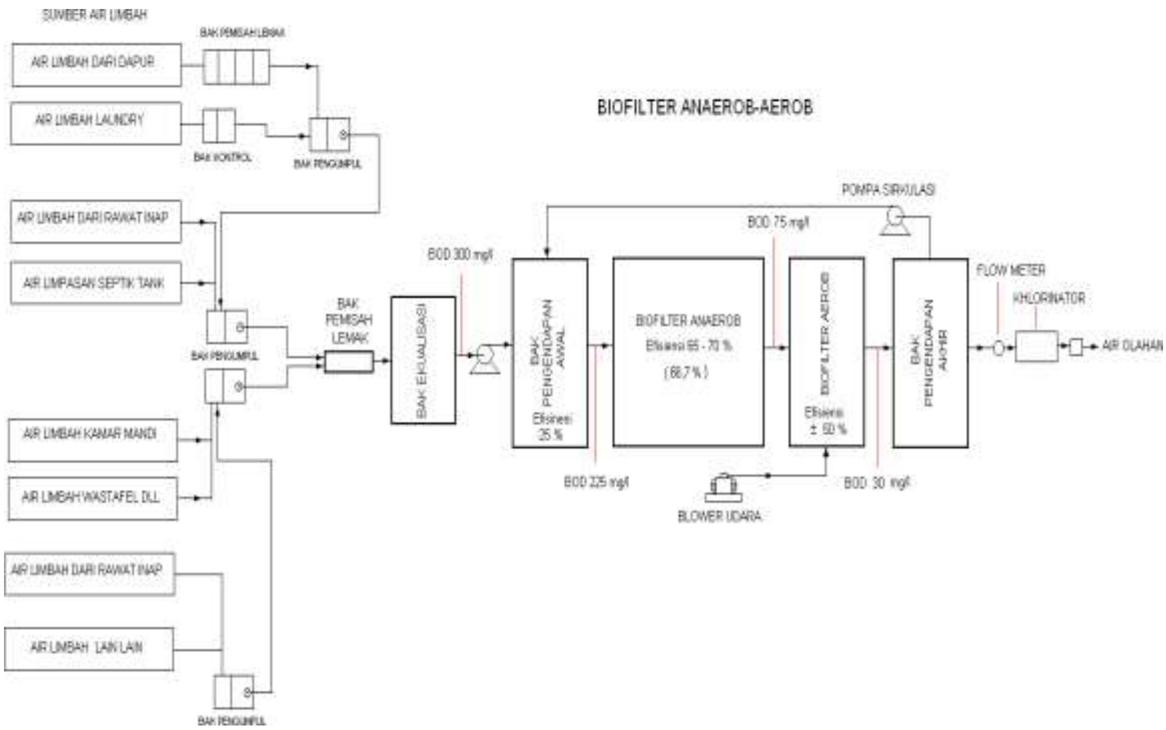
The measured influent ammonia concentration of the existing WWTP was 58.1 mg/L, while the effluent concentration after treatment using the redesigned laboratory-scale WWTP was 10.0 mg/L, corresponding to an ammonia removal efficiency of 82.77%.

Results and Discussion

Existing Condition of the Metro Medika Hospital WWTP

The Wastewater Treatment Plant (WWTP) at Metro Medika Hospital, Mataram, was designed to treat hospital wastewater using a combined biological treatment system comprising anaerobic and aerobic processes. The anaerobic treatment process employed Anaerobic Baffle Reactor (ABR) and Anaerobic Filter (AF) technologies, while the aerobic process utilized a contact aeration system. This technology was selected due to its advantages, including simple operation, resistance to load fluctuations, and relatively low sludge production [14][15].

The WWTP has a treatment capacity of 19.3 m³/day, which is adjusted to the volume of wastewater generated from various hospital activities at Metro Medika Hospital, including inpatient units, the emergency department, laboratories, kitchens, laundry facilities, and other supporting units. Wastewater entering the WWTP is collected through a piping network and passes through several treatment units, starting from the control tank, equalization tank, screening unit, anaerobic unit, sedimentation unit, aerobic unit, and finally a disinfection process before being discharged into the environment through an infiltration well. The existing WWTP system, as illustrated in the process flow diagrams, is shown in Figure 2. A proper WWTP system should be capable of reducing pollutant concentrations to meet the quality standards established by government regulations[14].



Source: Metro Medika Hospital

Figure 2. Process Flow Diagram of the Metro Medika Hospital Wastewater Treatment System (WWTP)

All wastewater generated from various operational activities at Metro Medika Hospital is conveyed via drainage channels or piping systems to the collection tank, except for wastewater containing heavy metals and chemical solvents, which is treated separately.

Table 1. Result of Wastewater Quality Test Results of the Metro Medika Hospital WWTP Effluent in 2025

No	Parameter	Result	Unit	Quality Standard
1	Total Suspended Solid (TSS)	2,500	mg/L	30
2	pH	7.46	-	6.0–9.0
3	BOD	2.65	mg/L	30
4	COD	4.81	mg/L	100
5	Amoniak (NH_3-N)	58.1	mg/L	10
6	Minyak dan Lemak	1	mg/L	5

Based on the evaluation results of the existing WWTP performance, it was found that the current treatment system has not been able to reduce ammonia concentrations to meet the required wastewater quality standard. The latest laboratory test results showed that the ammonia concentration in the effluent reached 58.1 mg/L, which is significantly higher than the permitted standard of 10 mg/L according to the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. 68 of 2016[11]. The laboratory test results are presented in Table 1.

Several factors contributed to this ineffectiveness, including the mismatch between the WWTP capacity and the actual wastewater discharge [14][15], inadequate infrastructure maintenance, and the low efficiency of the treatment technology in reducing pollutant concentrations such as ammonia[15]. In addition, the nitrification-denitrification biological processes had not operated optimally, while the biofilter media used had a relatively low surface area, limiting microbial growth and treatment performance. The lack of routine maintenance and monitoring [14] of operational parameters such as dissolved oxygen (DO), pH, and temperature, as well as the limited availability of skilled technical personnel for WWTP operation, also affected system performance. These conditions indicate that the existing WWTP system has been ineffective at treating hospital wastewater. Furthermore, the presence of pharmaceutical compounds and antibiotics in hospital wastewater poses an additional challenge, as these substances are difficult to degrade with conventional treatment methods, allowing them to persist and potentially contaminate the environment [12].

Overall, the WWTP system at Metro Medika Hospital has generally fulfilled its function in treating wastewater in accordance with applicable standards. However, to maintain consistent effluent quality, improvements to the monitoring system are still required, including the use of automatic flowmeters and better supervision of the disinfection system. In addition, sludge management is performed every 6 to 12 months, and the WWTP is operated by personnel within the hospital's general affairs subdivision. Therefore, although the WWTP system at Metro Medika Hospital has been operating adequately, further improvements in operational quality and supporting equipment are still necessary to ensure sustainable, environmentally friendly hospital wastewater management.

Redesign of the Metro Medika Hospital WWTP

The redesign of the WWTP system was required to improve the effectiveness of wastewater treatment and ensure that the treated effluent discharged into the environment complied with applicable quality standards. This redesign included improvements in treatment technology, enhancement of WWTP capacity, and optimization of biological, physical, and chemical treatment processes within the system [16][17]. The redesign concept for the Metro Medika Hospital Wastewater Treatment Plant (WWTP) focused on improving the efficiency of ammonia (NH_3-N) removal, which had consistently been the primary pollutant parameter exceeding the quality standard. Various alternative technologies can be applied to remove ammonia before wastewater is discharged into the environment. One of the most commonly used methods is the nitrification-denitrification process, a biological process that converts ammonia into nitrate via nitrifying bacteria, followed by the conversion of nitrate into harmless nitrogen gas via denitrification[1][18][19]. This method has been widely implemented in modern WWTP systems because it has been proven effective in significantly reducing ammonia concentrations.

Table 2. Redesign plan

Design parameter	Value
Flow rate	19.3 m^3/day
Peak hour flow rate	1.206 m^3/hour
Hydraulic retention time (HRT)	24 hour
Biofilter Anaerobic HRT	4 hours
Biofilter Aerobic HRT	4 hours
Biofilter media	DD-01, honeycomb, bioball
Media filling ratio	50%
Influent NH_3	58.1 mg/L
Efluent NH_3	10 mg/L

In addition, the system was designed using a biofilter approach that combines anaerobic and aerobic biological processes, which was further enhanced by additional filtration using bioball media and finalized with a disinfection process. The treatment units were arranged sequentially to support gradual biological reactions and to ensure that the treated wastewater complied with environmental quality standards.

Ammonia Removal Performance

The redesigned WWTP concept was subsequently evaluated through a laboratory-scale effectiveness simulation. The laboratory test used actual wastewater collected from the outlet of the Metro Medika Hospital WWTP, with an initial ammonia concentration of 58.1 mg/L. The mini WWTP system consisted of four main treatment units, each with a capacity of 10 liters and equipped with a combination of gravel, silica sand, zeolite, plastic media, and bioballs [16]. All treatment units were operated continuously using a pump to ensure a stable flow between units.

To assess the effectiveness of the mini WWTP system in reducing ammonia concentration, an efficiency analysis was conducted by comparing the initial (influent) and final (effluent) ammonia concentrations. Based on laboratory test results from April 29, 2025, the ammonia concentration at the outlet of the existing WWTP was 58.1 mg/L. Meanwhile, the laboratory analysis conducted on June 28, 2025, after treatment using the laboratory-scale mini WWTP system, showed that the ammonia concentration decreased to 10 mg/L.

Table 3. Wastewater Quality Test Results of the mini WWTP (redesign) Laboratory scale

No	Parameter	Result	Unit	Quality Standard
1	Ammonia (NH_3-N)	10	mg/L	10

Laboratory test results and efficiency calculations show that the laboratory-scale mini WWTP system reduced ammonia levels by 82.77%, from an initial concentration of 58.1 mg/L to 10 mg/L. This reduction indicates that the WWTP redesign concept using a combination of anaerobic units (ABR-AF), aerobic units (aeration contact), and bioball biofilters is possible to optimize the nitrification-denitrification process. The nitrification process occurs in the aerobic unit, where ammonia is converted into nitrite and nitrate, which are then processed into free nitrogen (N_2) under anaerobic conditions through the denitrification process [1].

The observed reduction in ammonia concentration is consistent with the expected performance of attached-growth biological treatment systems reported in previous studies. The incorporation of additional biofilter media such as honeycomb and bioball likely increased the available surface area for nitrifying microorganisms, thereby improving ammonia oxidation. Nevertheless, because dissolved oxygen, nitrite, nitrate, microbial biomass, and biofilm development were not monitored during the experiment, the proposed biological mechanism remains inferential and should be confirmed in future studies.

Furthermore, the final result of 10 mg/L meets the quality standard threshold according to Ministerial Regulation No. 68 of 2016, which sets the maximum ammonia limit for hospital wastewater at 10 mg/L. The laboratory-scale redesign demonstrated promising ammonia removal performance under the experimental conditions of this study. Thus, the redesigned mini-wastewater treatment plant system tested has been experimentally shown to provide a viable solution to the ammonia waste problem at Metro Medika Hospital in Mataram. However, Further pilot-scale investigations with replicated experiments and operational monitoring are recommended before full-scale implementation.

Comparison with Previous Studies

Previous studies on hospital wastewater treatment generally fall into three categories. First, several studies have evaluated the performance of existing hospital WWTPs and reported that ammonia removal remains insufficient despite acceptable removal of other pollutants. These studies mainly recommend operational improvements, such as increasing aeration intensity or hydraulic retention time, rather than modifying the treatment configuration[9][20]. Second, numerous studies have focused on the planning or redesign of hospital WWTPs by determining wastewater flow rate, hydraulic loading rate, detention time, treatment unit dimensions, and construction costs. However, these studies primarily emphasize engineering design and hydraulic capacity, while experimental validation of ammonia removal performance is rarely conducted[21]–[23]. Third, recent studies specifically targeting ammonia removal have mainly employed physicochemical technologies, including electrolysis, adsorption, bio-adsorbents, nanofiltration membranes, and bioaugmentation. Although these methods have demonstrated high ammonia removal efficiencies, they generally require additional materials, energy input, or operational complexity, making their implementation less practical for many hospitals[25]-[26].

Therefore, a research gap remains regarding the development of a practical WWTP redesign that simultaneously integrates anaerobic and aerobic biological treatment with multiple attached-growth biofilter media, specifically to enhance ammonia removal from hospital wastewater. To address this gap, the present study redesigns the existing WWTP of Metro Medika Hospital by integrating anaerobic and aerobic biofilters with multiple biofilter media, including gravel, silica sand, zeolite, honeycomb media, plastic media, and bioballs. The redesigned system was subsequently evaluated using actual hospital wastewater under laboratory-scale continuous operation. The novelty of this study lies in combining WWTP redesign with an integrated multi-media biological treatment system and experimentally validating its effectiveness for ammonia removal, rather than focusing solely on hydraulic design or employing advanced physicochemical treatment technologies.

Study Limitations

This study has several limitations that should be considered when interpreting the findings. First, the performance evaluation was conducted using a laboratory-scale wastewater treatment system; therefore, the hydraulic and biological conditions may differ from those of a full-scale hospital WWTP. Second, the assessment focused primarily on ammonia (NH_3–N) removal efficiency, while other important wastewater quality parameters, such as total nitrogen, nitrate, nitrite, phosphorus, pathogenic microorganisms, pharmaceutical residues, and antibiotic-resistant bacteria, were not investigated. Third, the operational conditions, including hydraulic retention time, aeration rate, and media configuration, were maintained constant throughout the experiment; consequently, the influence of these operational variables on treatment performance was not evaluated. Finally, the study assessed treatment performance over a relatively short operational period and did not examine long-term biofilm development, media durability, sludge accumulation, or seasonal fluctuations in the characteristics of hospital wastewater.

Future studies should validate the proposed WWTP configuration under full-scale operating conditions and investigate the long-term stability of the integrated anaerobic-aerobic biofilter system while considering a broader range of water quality parameters and operational optimization.

Conclusion

The redesigned WWTP, incorporating an integrated anaerobic-aerobic biological treatment system with multiple biofilter media, effectively reduced ammonia concentrations in hospital wastewater from 58.1 mg/L to 10.0 mg/L, corresponding to an ammonia removal efficiency of 82.77%. These findings demonstrate that integrating sequential biological treatment processes with diverse attached-growth media can substantially enhance ammonia removal while maintaining a simple and practical treatment configuration. The proposed WWTP redesign offers a feasible alternative for hospitals seeking to improve environmental compliance and wastewater management, particularly where existing treatment systems cannot achieve satisfactory ammonia removal. Although the laboratory-scale results are promising, further validation through pilot-scale and full-scale implementation is recommended to evaluate long-term operational stability, maintenance requirements, hydraulic performance, and treatment efficiency under actual hospital operating conditions. Future studies should also investigate additional wastewater quality parameters, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen, nitrate, nitrite, total phosphorus, pathogenic microorganisms, pharmaceutical residues, and antibiotic-resistant bacteria, to provide a more comprehensive assessment of the redesigned WWTP and support the development of sustainable hospital wastewater management systems

Author's Contribution

H. Anwar: Drafted the conclusions and technical recommendations, ensuring alignment of research findings with environmental regulations and practical implementation. T. Abdullah: Collected primary and secondary data through field observations, interviews, and laboratory testing of wastewater quality parameters. Azwaruddin: Designed the research methodology, including defining variables, planning the IPAL redesign system, and calculating wastewater flow and unit dimensions. H. Susane: Conducted data analysis and discussion, evaluating the performance of the existing IPAL and calculating ammonia removal efficiency.

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