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Design and development of a low-cost ammonia monitoring system for water quality assessment

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An undergraduate Final Year Design Project submitted by

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in consideration of the partial fulfillment of the requirements for the degree of

BACHELOR OF SCIENCE
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ELECTRICAL AND ELECTRONIC ENGINEERING

Department of Electrical and Electronic Engineering
INDEPENDENT UNIVERSITY, BANGLADESH

SUMMER 2026

DECLARATION

We solemnly declare that the research work presented in this undergraduate thesis has been carried out by us and has not been previously submitted to any other University / Institute / Organization for an academic qualification / certificate / diploma or degree.

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The Authors
Summer 2026
Dhaka, Bangladesh

ABSTRACT

Ammonia pollution is a serious problem for water quality, and it puts fish and other aquatic life at risk. Even small amounts of ammonia in water can hurt fish gills, slow down their growth, weaken their immune systems, and in bad cases, kill them. This is a major concern for fish farmers. The problem is that good ammonia sensors are expensive, so small-scale farmers in developing countries like Bangladesh usually can't afford them.

This thesis presents a low-cost system to monitor ammonia levels in water. Here's how it works: a water sample is heated inside a closed chamber. This releases ammonia (if present) as vapour. The vapour is then picked up by an MQ-137 gas sensor, which sends its signal to an Arduino Uno. The Arduino processes this signal and calculates the ammonia concentration in ppm (parts per million), then shows the result on a small 16x2 LCD screen. The system also includes a heater controlled by a relay, a 12V water pump, and a MAX6675 thermocouple to monitor temperature. An LM2596 buck converter is used to regulate the voltage for the whole setup.

To make sure the readings were accurate, the MQ-137 sensor was calibrated using water samples with known ammonia levels. A fourth-order polynomial model was used to convert the sensor's raw output into an actual ppm reading. The results were then checked against a commercial ammonia test kit to see how well they matched.

The system worked well across a range of 0 to 8 ppm, which covers the levels that matter for freshwater fish farming. The main sources of error were the sensor's warm-up time and small vapour leaks, but these errors were still smaller than what you'd typically see with standard lab equipment.

Overall, this project shows that it's possible to build a working, affordable ammonia detection system using cheap, easy-to-find parts. It could be useful for fish farming, environmental monitoring, and even teaching. In the future, this system could be upgraded to send data remotely over the internet (IoT), making it even more useful for real-world monitoring.

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CHAPTER 1
INTRODUCTION

1.1 Overview

Ammonia contamination is a significant water quality problem that can seriously affect aquatic life, mainly in fish farming. Even low focuses of ammonia can cause fish stress, reduced growth, disease, and death. However, affordable ammonia monitoring systems are not widely available for small-scale farmers in developing countries.

This project presents the design and development of a low-cost ammonia monitoring system using an MQ-137 gas sensor and an Arduino Uno. The system heats a water sample in a sealed chamber, allowing dissolved ammonia to vaporize and be detected by the sensor. The sensor output is processed by the Arduino, converted into ammonia concentration (ppm) using a calibration model, and displayed on a 16×2 LCD. The prototype also includes a relay-controlled heater, a thermocouple for temperature monitoring, a 12V pump, and an LM2596 voltage regulator.

The sensor was calibrated using water samples with known ammonia focuses, and a fourth-order polynomial equation was used to convert sensor readings into ppm values. The results were validated using a commercial ammonia test kit. Experimental testing showed that the system could reliably measure ammonia focuses from 0 to 8 ppm, making it suitable for freshwater aquaculture applications. While sensor warm-up time and vapor leakage affected measurement accuracy, the system successfully demonstrated stable and repeatable performance.

Overall, the developed prototype provides a practical, portable, and cost-effective solution for ammonia monitoring. It offers an affordable alternate to commercial instruments and provides a strong foundation for future improvements such as IoT-based monitoring, mobile applications, and enhanced system design.

1.2 Background and Motivation

To understand the importance of this project, it helps to know a little more about ammonia in water. Ammonia has two forms: unionized gas form (NH_3), and the ionized ammonium ion (NH_4^+). They are always present together in a dynamic balance but their relative proportions change with water temperature and pH [8]. High pH and high temperature result in higher amounts of free unionized ammonia, the more poisonous form of ammonia to fish. total ammonia nitrogen measurements are deceptively dynamic. A pond sitting just shy of neutral pH might show completely acceptable ammonia levels, but binary labels—safe versus unsafe—obscure latent hazards. Context is everything. When a hot afternoon algal bloom drives pH sharply upward, the chemical equilibrium shifts, rapidly converting benign ammonium into lethal un-ionized ammonia.This is the temperature-pH relationship that explains why researchers and regulators always deal with total ammonia-nitrogen values in parallel to pH & temperature measurements.

Sources of ammonia to water bodies In agricultural locations, this is fed by fertilizer runoff as well as livestock waste and the breakdown of organic matter in the water itself. More particularly to aquaculture, fish eliminate ammonia directly in their gills as a metabolic by-product of protein breakdown, and any feed that goes uneaten along with faecal matter deposited at the pond bottom will undergo bacterial decomposition releasing ammonia into the water column [7]. This natural load of ammonia is typically totally manageable in a well managed pond that has good water flow or aeration and if the fishery-at-no-cost, upstream population is relatively low. But in the short, poorly aerated ponds that dominate most smallholder aquaculture in Bangladesh, ammonia levels can rise to massive concentrations very rapidly during warm weather.

Bangladesh officially has every reason to recognize the well-documented problem. Ammonia-nitrogen concentrations that are near or above threshold levels of sub-lethal stress have been observed in pond aquaculture systems in several regions of the country. Quadratic field surveys over several ponds within the Dinajpur Municipality area for example revealed total ammonia-nitrogen prices of lower than detection limits to around two mg/L at high temperatures throughout spring, when multiple ponds experienced concentrations that could be deemed acutely toxic predicated on EPA water quality conditions [12]. Fish farmers along the coastal belt have also cited unexplained die-offs, which on hindsight and in relation to time of sampling water conditions appearing at those times could reasonably be ammonia events.

More than aquaculture, ammonia pollutes drinking water sources too, especially in places near industrial zones or large agricultural activity. The WHO drinking water guidelines for ammonia stipulate 1.5 mg/L as acceptable based not only on an unacceptable taste and odour (as at this concentration fish developing acute toxicity will also suffer gill necrosis) but also because high ammonia can indicate faecal contamination [7]. Consequently, the monitoring of ammonia from drinking water sources is a necessary component of any basic water quality surveillance program.

Considering all of these, the rationale for designing an affordable ammonia sensor is quite clear. Monitoring methods today are based on two approaches: lab-friendly chemical analysis methods that give accurate results but require expensive equipment and time to complete, or simple colorimetric field test kits that are widely used because of their low-cost, mobility and ease-of-use, but suffer from subjective readings where the limits of detection may not be obvious. Both are far from what would deliver the kind of regular, sufficiently frequent monitoring to be truly impactful at farm-level. An attractive compromise is a sensor based electronic system — potentially faster than lab analysis, more quantitative than a test strip, and possibly cheap enough to be used in small operations. This project operates in the same space.

In addition, we were further encouraged that a dedicated ammonia gas sensor (MQ-137) has been on the market for many years and is extremely inexpensive and used in several other projects aiming to detect this compound. However, what we discovered in looking at that prior work is that most implementations either bypass a careful calibration step or do not self-crossvalidate against an independent reference or do not specify the operating characteristics of the system with precision sufficient for others to construct it reliably. We wanted to fill those gaps.

1.3 Problem Statement

At the core of this project is a simple objective: we want to create an ammonia monitoring device for water quality testing that is cheap, portable, easy to use (no expert training required), and accurate enough to be practically useful.Rather, the problems we discovered that we sought to solve are as follows:

Ammonia toxicity is a longstanding and severe but poorly managed problem for Bangladeshi aquaculture, and no currently available continuous ammonia monitoring system is accessible to most affected farmers

- Traditional laboratory-style ammonia detection techniques — such as Nessler colorimetry, phenate method and ion-selective electrode methods — need costly instruments, reagent solutions, and trained human resources that are not optimal for everyday field use.

- Simple colorimetric test kits are configured for field use but provide only coarse, semi-quantitative readings and not continuous or automated monitoring.

The MQ-137 gas sensor is a commercially available and inexpensive semiconductor sensor that exhibits excellent sensitivity to ammonia gas; however, the use of the MQ-137 in place of an advanced measurement of dissolved ammonia in water requires a vapour-extraction step which necessarily adds commensurate engineering complexity into our design while also providing a considerable route for measurement error if not designed cautiously.

Reported low-cost MQ-137-based ammonia monitoring systems in the literature are generally insufficiently calibrated against known concentrations of dissolved ammonia and do not offer independent cross-validation of their results.

To our knowledge, there is no published, characterized low-cost ammonia monitoring prototype currently exists that combines vapour-extraction sensing, polynomial calibration and colorimetric cross-validation in a single device with all design details documented (W073).

1.4 Objectives of the Project

- Built an Arduino-based system with the MQ 137 sensor and a safe vapour chamber to transfer dissolved NH3 from water into gas for detection.

- Established a calibration model linking sensor ADC output to known NH3 concentrations and embedded it in firmware for real-time LCD concentration readouts.

- Validated accuracy against a commercial colorimetric ammonia test kit and documented operating parameters (cycle times, leak sensitivity) for reproducibility.

- Evaluated the system's societal, economic, and environmental significance, linking it to relevant Sustainable Development Goals.

1.5 Research Methodology

It was a pretty typical design-build-test cycle of engineering practice but there were some choices we made that we think are worth discussing early. Instead of starting right on the hardware assembly, we first dedicated a lot of time reviewing what others have done in terms of conventional ammonia monitoring methods and previous low-cost sensor based systems. This review, covered in Chapter 2, informed a number of important design decisions — notably the decision to use vapour-extraction rather than water-immersion as the sensor configuration employed and polynomial regression for calibration rather than simple linear fit.

It started with agreeing one the general system concept, followed by iteratively creating the circuit design: pick a sensor (the MAX6675) and micros (Arduino); create the heater control logic so that relays would not be flicking on/off too fast; match appropriate ratings for heater relay + power supply to drive heating element; and finally defining a thermal measurement chain using the same thermocouple as earlier via this APPENDIX. We run circuit simulations to validate the Arduino IDE firmware before assembling any physical hardware. Virtual prototyping paid off. Catching logical bugs in the heater hysteresis code early on streamlined physical assembly and saved considerable bench time.

Next, the prototype we created beginning with electronic circuit followed by mechanical assembly of the heating and sensing chambers. We constructed the chamber system using off-the-shelf containers and locally available tubing, iteratively improving it when we noticed limitations in our original design — especially concerning vapour leakage. The second step of the procedure was performed after building the hardware, in which seven total water samples with known ammonia concentrations were made and their steady-state sensor readings measured, and then a polynomial curve-fitting analysis was performed on the data points using MATLAB's Curve fitting toolbox. This fourth-order polynomial was then integrated into the Arduino firmware with a hard code.

The final step was cross-validation. We also prepared an individual water sample of the same composition as each of the calibrated concentrations and performed a test using the colorimetric kit on these. By comparing the kit readings to sensor readings, we obtained a realistic sense of how close our calibration model was to a ground-truth source and revealed any systematic bias in our methodology.

During this project we logged every cost, time to build and measurements made so far.

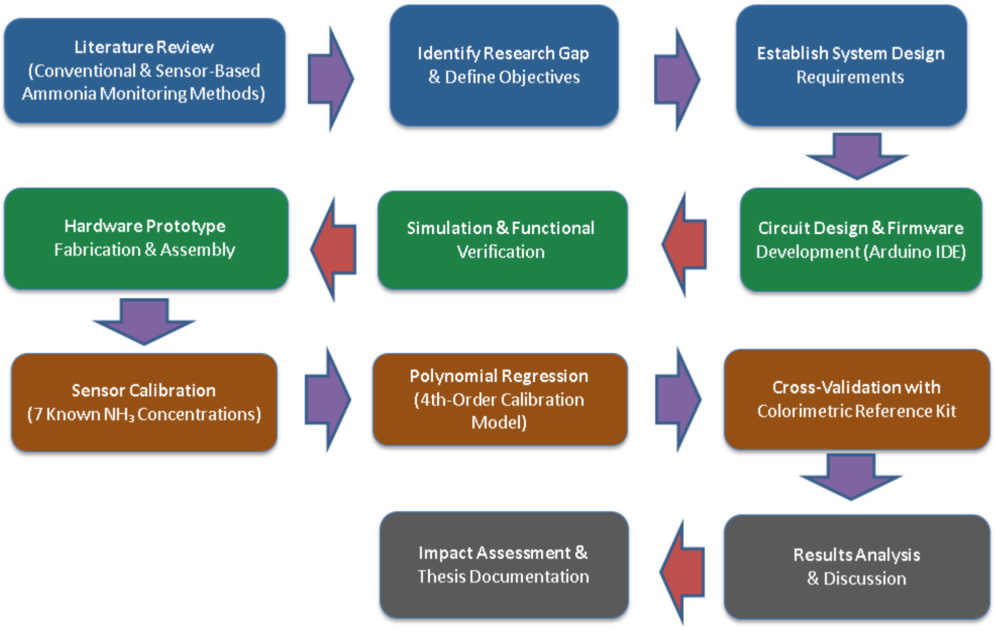


Figure 1.1: Research methodology flowchart showing the four-phase project workflow

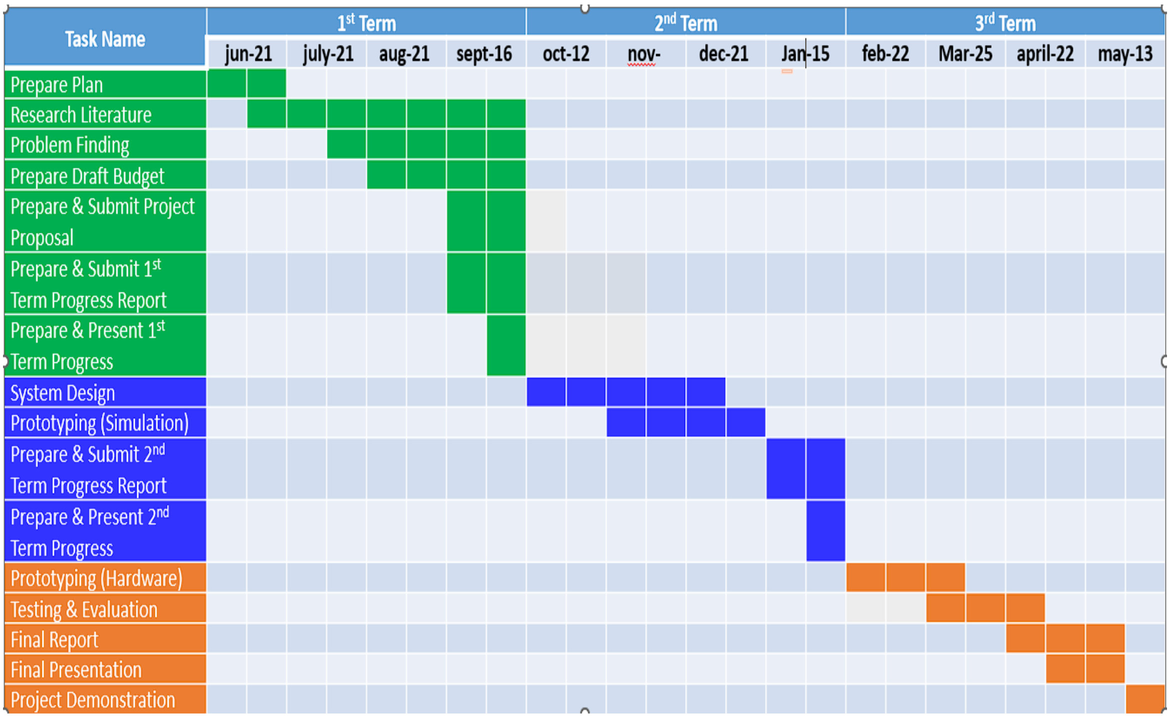
1.5.1 Work plan – RACI Matrix

Table 1.1 RACI matrix for work plan

Period	Assignments	Responsible (R), Accountable (A), Consulted (C) & Informed (I) RACI Matrix					Start	End	Days	Status
		Dr. Feroz Ahmed (Supervisor)	MD Rakibol Islam	Md Iftie islam Khan	Dipto Sarker	Tanvir Ahmed				
1st Term	➢ Prepare Plan	C	R	R	R	R	29.09.2024	29.10.2024	30	
	➢ Review Literature	I	R	R	R	R	14.09.2024	30.12.2024	76	
	➢ Problem Identification (IP-NH3 Sensors' Limitations) (Possible Solutions Determination)	C	R	A	A	A	14.10.2025	30.12.2024	58	✓
	➢ Prepare Draft Budget	C	R	R	R	R	01.12.2024	30.12.2024	30	
	➢ Prepare, Submit & Present (Proposal & Progress Report)	I	R	A	A	A	18.12.2024	20.01.2025	34	
2nd Term	➢ Sensor Design (Physical Parameters Analysis)	C	R	R	R	R	12.09.2025	14.10.2025	33	
	➢ Structure Simulation (Sensing Performance Inspection)	C	R	R	R	R	16.10.2025	20.11.2025	36	✓
	➢ Prepare, Submit & Present (Proposal & Progress Report)	I	R	A	A	A	28.11.2025	05.01.2026	39	
Final Term	➢ Result & Graph Analysis	C	R	R	R	R	15.02.2026	10.03.2026	24	
	➢ Fabrication Tolerance	C	R	R	R	R	17.03.2026	23.04.2026	38	✓
	➢ Prepare, Submit & Present (Proposal & Progress Report)	I	R	A	A	A	24.04.2026	11.05.2026	18	

1.5.2 Work plan – Gantt Chart

Table 1.2 Gantt chart of this project



1.6 Project Budget

This project was completed within a limited budget appropriate for an undergraduate capstone project, using low-cost and, where possible, locally available components and consumables. This section first summarises the overall project budget by category and then presents an itemised breakdown of every component and consumable used to build and calibrate the prototype.

1.6.1 Overall Budget

The total cost of the project was kept under BDT 7,000, split broadly between the electronic and mechanical hardware used to build the prototype and the chemicals and test kits used for calibration and cross-validation. Table 1.3 summarises this high-level breakdown.

Table 1.3: Project budget by category

Category	Cost (BDT)
Electronic & Mechanical Components	4,050
Chemicals & Validation Consumables	2,880
Total (BDT)	**6,930**

1.6.2 Component / Software Budget

All software used in this project — the Arduino IDE for firmware development and MATLAB (student license) for calibration curve-fitting — was freely available through the university and therefore added no monetary cost to the project. Table 1.4 lists the itemised cost of every hardware component and consumable used, giving a project total of BDT 6,930.

Table 1.4: List of components and their budget

Sl	Item	Qty	Unit Price (BDT)	Total (BDT)
1	Ammonium Chloride	1 bottle (500mg)	—	920
2	Ammonia Test Kit	1	1960	1960
3	Arduino Uno	1	950	950
4	Buck Converter	2	90	180
5	12V Pump	1	340	340
6	Relay	2	80	160
7	MQ137 Sensor	1	1250	1250
8	LCD Display	1	250	250
9	Power Supply	2	225	450
10	Temperature Sensor (MAX6675 + K-type Thermocouple)	1	470	470
Total (BDT)				**6930**

1.7 Organization of the Report

Chapter 1 talks about why this project was started. It explains that affordable and easy-to-use water quality monitoring tools are needed in places where expensive lab equipment is not possible to use. It also sets out what the research wanted to achieve what was done and the specific problem this thesis is trying to solve. That problem is creating a low-cost way to detect ammonia. In Chapter 3 the focus is on why certain choices were made when designing the vapour-extraction part of the system. It covers the choices between how sensitive the system's how fast it reacts and how easy it is to make. Chapter 4 also mentions how the building process had to change times. It shows the steps taken after early models failed, like vapour leaking or sensors not working well. These problems helped shape the version of the hardware. In Chapter 5 the focus is not just on the numbers collected but on how unsure the measurements might be. It looks at the mistakes caused by things in the environment when testing. Chapter 6 talks more about how the system's cheap and easy to use. It suggests that this could help more people in areas have better access to tools, for checking the environment. Chapter 7 connects the results of the project to engineering skills. It shows how the work deals with problems, design limits and how engineers work in the real world.Finally Chapter 8 ends the thesis by talking about what was learned. It says what the limitations were when building the model. Suggests ways to improve it next time like using more sensors together sending data wirelessly or using machine learning to make the system better.

CHAPTER 2
LITERATURE REVIEW AND METHODOLOGY

2.1 Conventional Ammonia Monitoring Techniques

Understanding traditional alternatives contextualizes our approach. The trade-offs inherent in conventional methods directly motivated our system design. Standard aqueous ammonia detection relies on three primary analytical paradigms: colorimetric assays, ion-selective electrodes, and spectrophotometry. In the terms of accuracy, cost-effectiveness, complexity and field compatibility each has its own pros and cons.

Based on this, the Nessler method is likely one of the oldest colorimetric technique for ammonia determination (probably even the most widely used until October 2023). This method consists of treating a water sample with Nessler's reagent (an alkaline solution containing mercuric iodide and potassium iodide), which yields a yellow to brown color: the intensity of this coloration is proportional to the ammonia content. Measuring color with a spectrophotometer It is a well-validated, tried-and tested approach that remains in continuous use throughout water quality laboratories the world over. Nessler's reagent and its components are toxic, and proper storage, handling and disposal as hazardous waste is required [10], however. This reason itself will make it unfit for small labs, school or field use. A sample pre-treatment is also required (i.e., turbid or colored samples need to be treated with an agent so not having a background signal) which takes up time and adds complexity.

A somewhat less polluting colorimetric alternative that avoids mercury-based reagents is the phenate method (also referred to as the indophenol blue method). The ammonia of the sample reacts with alkaline phenol and sodium hypochlorite to produce the colored compound, indophenol blue, which can be measured spectrophotometrically [10]. Detection limit is excellent - typically <0.01 mg/L, and it is also less susceptible to some common interferences compared with the Nessler method (VanDeMark et al., 1996). However, it is still dependent on a spectrophotometer, several different reagents that need to be prepared or obtained and must wait for the color development reaction. In contrast to the nitrogen free-ammonia (NFA) method, it is inherently a batch analysis approach and cannot be used for continuous or on-line monitoring.

Third colorimetric method is the salicylate method which give green colour instead of brown-yellow for other reaction and does not containing any reagents contain mercury. A comparative study was conducted by Zhou and Boyd, who concluded that the salicylate method produces results almost identical to those of Nessler and phenate methods in aquaculture water over a wide range of ammonia concentrations, and that arguably it is the most practical one for routine lab work [10]. It yet encompasses the basic limitation of all colorimetric modalities: being manual, batch laboratory workflow.

A completely different kind of approach are ion-selective electrodes (ISEs). An ammonia ISE is also composed of a gas-permeable membrane, permitting selective diffusion of the ammonia gas from the sample into an internal aqueous solution where it alters the pH detected by a pH electrode. Ion-selective electrodes (ISEs) offer a clear analytical edge: continuous, real-time monitoring without consumable reagents. Maintenance requires only periodic calibration standards and conditioning solutions. Integrated into a flow-through cell, an ISE can theoretically operate inline indefinitely.The primary barrier is cost. A standard setup easily reaches hundreds of dollars, and periodic membrane replacements add recurring expenses. Performance also degrades at low concentrations—specifically below 0.1 mg/L—while high-ionic-strength samples frequently trigger measurement interferences [10]. Though ISEs remain workhorses in professional monitoring laboratories, their price tag puts them well out of reach for smallholder farmers and resource-constrained educational labs..

Pairing ion chromatography or gas chromatography with specialized detectors like mass spectrometry (MS) yields exceptionally precise ammonium measurements. The trade-off is practicality. These systems demand prohibitively expensive hardware and remain strictly bound to benchtop laboratory environments. We include them here primarily for completeness; in routine field-level monitoring, their actual utility is negligible.

A clear trade-off runs through these existing methods: higher accuracy invariably requires more elaborate equipment. At one end, lab-bound analytical tools deliver high precision at steep costs; at the other, off-the-shelf aquarium test kits offer convenience at the expense of quantitative rigor.Our semiconductor gas-sensor system targets the middle ground. It provides a portable, low-cost platform that bridges the gap between unreliable field kits and cost-prohibitive laboratory hardware..

2.2 Semiconductor Gas-Sensor-Based Systems and Related Works

The principle of operation of semiconductor metal-oxide gas sensors has been well understood since at least the 1960s: when a gas molecule adsorbs onto or reacts with a heated metal-oxide surface, the electrical resistance of that surface changes in an external measurable way. In case of ammonia [8], the metal oxide employed and most effective gas sensing material reported is tin dioxide (SnO2), which at high action temperatures (in general 200–400°C) it becomes a very good electron conductor but in addition its conductivity is modulated by the adsorption of an reactive gas molecules [9]. An example is the MQ-137 ammonia-specific sensor, manufactured commercially by Winsen Electronics, which follows this principle. The sensing element consists of a small layer of SnO2 on a micro-ceramic tube heated internally by a coil and is surrounded by a metal housing over its exterior that has been capped with mesh to allow gas in but hold dust out.

The attraction of the MQ-137 for low-cost applications is not its accuracy —Which, to be fair, leaves something to be desired compared with laboratory instruments – but it reasonable ammonia selectivity, simple analog output, compatibility with standard 5V microcontroller systems and price below USD 10.00 typically at a single unit order quantity. It or close variants (such as ammonium salt formulations) have been used for a number of ammonia monitoring projects, including several research groups the past decade, and an overview with important published work is presented in Table 2.1.

Table 2.1: Related works on MQ-137 based and low-cost ammonia sensing

Ref.	Approach / Outcome	Reported Limitations	Possible Improvement
[1]	Developed a low-cost Arduino-based ammonia monitor using the MQ-137 for detection in the range 0–500 ppm. Demonstrated basic functionality with analog output and serial data logging.	Calibration instability and sensitivity to environmental temperature fluctuations were noted. No independent validation method was described.	Temperature compensation circuitry and periodic auto-recalibration routines could significantly improve long-term stability.
[2]	Threshold Detected ammonia below 1 ppm in real pond conditions.	High ambient humidity near the pond surface degraded sensor response over time. The bubbling mechanism for vapour transfer was	A sealed vapour-extraction chamber with desiccant and humidity buffering would reduce these effects.

Ref.	Approach / Outcome	Reported Limitations	Possible Improvement
		sensitive to water level changes.	
[3]	Implemented a complete IoT-based system using the MQ-137 with Wi-Fi transmission and an Android application for remote monitoring of ammonia in aquaculture water. Demonstrated remote alerting functionality.	Sensor drift during prolonged continuous operation was observed, and internet connectivity was required for full function. Battery life was also a concern for remote deployment.	Edge computing with local storage and a sleep/wake duty cycle for the sensor would address the power and connectivity issues.
[4]	Developed a modified ultra-micro carbon electrode for electrochemical ammonia detection targeting water quality assessment. Demonstrated high sensitivity and low detection limits at the ppb level.	Fabrication of the modified electrode requires specialized materials and laboratory infrastructure, making it unsuitable for low-cost field deployment.	The sensitivity advantage of electrochemical approaches could potentially be combined with a simpler fabrication process in future work.
[5]	Designed a gas-phase ammonia leakage detection and alert system using the MQ-137 sensor with IoT connectivity. Focused on industrial gas leak scenarios rather than water ammonia measurement.	The system was designed for detection of ammonia in ambient air, not dissolved in water, so vapour extraction from water was not part of the design.	Adaptation of the gas-leak detection hardware with a water vapour chamber could extend the approach to water quality monitoring.
[6]	Conducted a systematic stability study of the MQ-137 sensor under repeated controlled ammonia exposures. Quantified the rate of sensitivity drift over time and under varying concentration cycles.	The study confirmed that repeated high-concentration exposures gradually degrade sensor sensitivity, with measurable drift after 50+ repeated cycles.	Using a lower-cost sensor as a consumable item with a defined calibration interval, combined with a drift correction algorithm, can manage this limitation.

Some remarks are clear when looking at these studies together. The MQ-137 sensor, while obviously sensitive to ammonia at concentrations relevant for water quality monitoring, unfortunately varies quite a lot in terms of its performance depending on the mode of use (sensing environment, vapour delivery mechanism used, calibration mode and conditions). Second, most of the systems presented above solve parts of the monitoring task effectively but leave other components unwritten; in particular, independent validation against a gold-standard measurement is rarely detailed. Third, most of the related works target primarily on connectivity and automation aspects other than very basic sensing and calibration challenge which is what we felt was not sufficiently covered/solved in existing literature.

It can be also addressed that there is a wider research regarding IoT-based water quality monitoring for aquaculture — referencing to Saha et al. This is an advancement from the early demonstrations — which include an initial system developed to facilitate smart water quality prediction using machine learning [11] — that have shown promising results regarding meaningful benefits for small-scale farmers when sensor-based monitoring systems are properly designed and validated. Such studies are offering an important wider context: the utility of a good, calibrated sensor reading is far bigger than the instrument itself because it represents input to decision-making that affects fish health, farmer income and food supply at the end of it all.

2.3 Research Gap

From a review of the literature, we found this project addresses a next step specific gap. Published literature describes numerous low-cost ammonia monitors built around the MQ-137 sensor. Yet comprehensive methodological rigor remains surprisingly rare. Very few studies integrate all three essential components: (1) a controlled calibration against known aqueous ammonia concentrations, (2) an explicit mathematical model embedded directly into device firmware, and (3) independent cross-validation against a separate reference method.

Most of the limitations faced from practical standpoints including Product rigorously calibration-and-validation protocol. The accuracy of a sensor reading against the real sample dissolved ammonia concentration in water cannot be interpreted or trusted when one lacks this information from the system output. A display that says '2.3 ppm' on an LCD would be little more than a report unless there was some confidence to suggest it represents anything like 2.3 ppm of dissolved ammonia in the water. That evidence is derived from calibration and validation, and that is exactly what we concentrated on in this project.

Secondary Gap The gap we found under the heading of indeed practical operating characteristic documents. Multiple of the associated systems describe their hardware and show results, but do not adequately state how long it takes for the system to warm-up, how long a single measurement requires, what occurs during vapour leakage at the connections or in which ways does it vary with ambient temperature and humidity. For anyone that wants to construct such a system and actually use it, this is kind of the low-hanging fruit information, so in Chapters 4 and 8 of this report we have tried to note as much detail about this as possible.

2.4 Detailed Methodology

In a nutshell, our strategy consists of four main steps: design, implementation, calibration and validation. The four-step framework is a simplification of the process (we regularly cycled back and forth to refine the design as we learned more during implementation, and focused in detail on refubishing the calibration model after initial validation highlighted specific systematic errors) but it provides a useful way of describing our approach.

System design began with establishing core specifications (Section 3.1). We selected our hardware components—an MQ-137 sensor, Arduino Uno, relay modules, buck converter, LCD, and a MAX6675-amplified thermocouple—and finalized the circuit topology.The architecture hinged on a key decision: adopting a two-chamber system. We linked separate heating and sensing chambers using sealed tubing. Literature warned against placing the sensor directly in or over water, as humidity fluctuations skew readings unpredictably. Routing vapor along a defined, sealed pathway eliminated this issue. Though it added mechanical complexity, the closed loop produced far more reproducible data.

In the implementation phase, we started with building and testing the circuit on a bread board to verify that relay control logic was working as expected and thermocouple readings from MAX6675 is sensible. Then we described the firmware in Arduino IDE with LiquidCrystal_I2C library (for LCD), MAX6675 library (for MAX6675) and just standard analog reads for MQ-137. With the firmware behavior confirmed in simulation, we combined our physical prototype with both the heating chamber and sensing chamber.Then We experimented with many designs of the chamber until we reached one that would hold a seal enough to allow consistent vapour delivery to the sensor.

In the calibration phase, we made a variety of standard water samples holding known quantities of ammonia by reducing accurately weighed grams (g) of uncompounded ammonia powder. The true concentration of dissolved NH3 in each sample was determined from the mass added based on the molar mass of ammonia (17.03 g/mol) and stoichiometry at dissolution. For each sample, we allowed time — usually in the range of 35 to 50 minutes after placing it in the heating chamber — for the signal to stabilize and then took a mean ADC output. By fitting a fourth-order polynomial to the seven (concentration, ADC) data pairs using MATLAB's polyfit function, we obtained the calibration equation described in Section 3.4.

The validation step consisted of preparing independent parallel sample for each calibration level followed by testing with the saltwater ammonia colorimetric comparator kit. The kit functions by adding a reagent to the sample water and referencing the resultant colour against a printed reference card with blocks of colours that are equivalent to concentrations of 0, 0.25, 0.5, 1.0, 2.0, 4.0, and 8.0 ppm. Otherhand the color comparison is a little bit subjective especially for those intermediate concentrations between card levels it was a helpful independent data point for each of our calibration concentrations. The comparison between kit readings and our estimates based on sensors is reported in section 5.3.

CHAPTER 3
DESIGN OF THE AMMONIA MONITORING SYSTEM

3.1 Design Requirements

Before purchasing any parts, we spent time defining what the system actually needed to do and establishing its operational boundaries. That upfront work paid off. By confronting key tradeoffs early—weighing cost against accuracy, and portability against durability—we avoided wasting money on the wrong components.

The requirements we agreed were:

- We needed to build the system using standard, off-the-shelf components. The budget was tight. Compared to commercial ammonia analyzers, we aimed for a total parts cost an order of magnitude lower setting a cap at roughly 3,000 BDT (about 25–30 USD)

- The system must be fully integrated and portable. Beyond the water sample itself, it operates without any external chemical reagents, lab devices, or pressurized gas supplies.

- It displays real-time ammonia concentrations directly in ppm. Users don't need any extra software or external instruments to read the data.

- The Liquid water must never touch the MQ-137 sensor. Because it is not designed for aqueous detection, any moisture entering the unit will damage the sensing element and produce invalid readings.

- Because temperature changes alter how fast ammonia escapes from water, the system requires active temperature monitoring and heater control. Maintaining consistent heat over time ensures reproducible results.

- The Standard factory curves won't suffice. Rather than relying on the manufacturer's basic gas-phase sensitivity curve, the calibration model uses direct measurements from water samples with known compositions..

On paper, these specifications look modest. Hitting every single goal especially staying within that tight budget was much harder. To pull it off, we had to choose components carefully and get creative with the mechanical design of the chamber.

3.2 Working Principle of MQ-137 Gas Sensor

The MQ137 is from Winsen's line of semiconductor gas sensors. Like all the sensors in this series, it uses a SnO_2 (tin dioxide) sensing layer as an active element, but the specific dopants [9], surface treatments and operating temperature of MQ-137 are optimized so that its selectivity versus other common gases is enhanced for ammonia.

At the heart of this function is a long-established mechanism in surface chemistry. In clean air, molecular oxygen will chemisorb on the SnO_2 surface and take electrons from the semiconducting bulk, leading to an increase of resistance in the sensing material and a decrease in conductivity. The subsequent reaction of a reducing gas such as ammonia with this surface would consume the adsorbed oxygen and release those electrons back into the bulk semiconductor. This reduces the material resistance. The sensor is actually a variable resistor whose resistance diminishes as ammonia is introduced and increases as it is removed — and the magnitude of this change in resistance is approximately proportional to the gas concentration over a useful operating range [9].

At its core, an integrated heater coil keeps the SnO_2 sensing layer at an optimal temperature of roughly 300 °C. Without proper heat, cold surface chemistry produces slow, non reproducible readings. Drawing about 750 mW at 5V, the heater demands a fair amount of power, though our mains-powered setup handles it easily. This heating requirement also introduces a warmup period after powering on. While the sensing layer reaches its target temperature in a few minutes, fully stabilizing the baseline resistance after a cold start can take hours.

In our construction of the MQ-137, it works like a voltage divider: One end is the MQ-137 sensing element (with R_s being its resistance) connected in series with load resistor R_L (which is fixed), and the voltage from that divider reaches the Arduino's analog input. The reading starts lower in clean air and becomes progressively higher in the presence of ammonia, as R_s decreases. The Arduino's ADC translates this voltage to an integer between 0 and 1023 (corresponding to a calibration range of 0–5V); in practice, our baseline ADC reading in clean air sits around 514, rising to around 975 at the highest ammonia concentration used during calibration.

There are additional specifications of the MQ-137 worth noting because they influenced how we designed and operated our system. The response of the sensor is not truly a linear function of ammonia concentration — it behaves according to a power-law or logarithm over many orders of magnitude. This is exactly why we needed a polynomial, rather than a simple linear, calibration model. Secondly, the sensor is sensitive to other gases such as ethanol, carbon monoxide and some organic amines. This is less of a problem in our application than it would have been in an industrial setting (water samples unlikely to ever contain high concentrations of interfering species). Third, and perhaps most importantly for our calibration method: the MQ-137 was intended by its manufacturer to specifically detect gas-phase ammonia, not dissolved ammonia. In other words, we require the vapour extraction step to yield an ammonia concentration in the gas phase that reflects the concentration of ammonia as it exists dissolved in the water sample. Henry's Law governs much of this relationship between the two, and temperature, pH, and chamber design efficiency all impact it — see Chapter 5 for further discussion.

There is one more thing: the sensor deteriorates over time and particularly quickly if it was exposed to high concentrations of ammonia for a long time. Both the Winsen datasheet [9] and third-party stability testing studies [6] confirm that the sensor's response decreases slowly over time, indicating an intermittent recalibration plan is required for any longer-term deployment. The degradation was not a critical concern for our prototype designed to be used in limited-scope calibration experiments and validation tests, but it will be an important factor for any future systems deployed outdoors over month-long or year-long time spans.

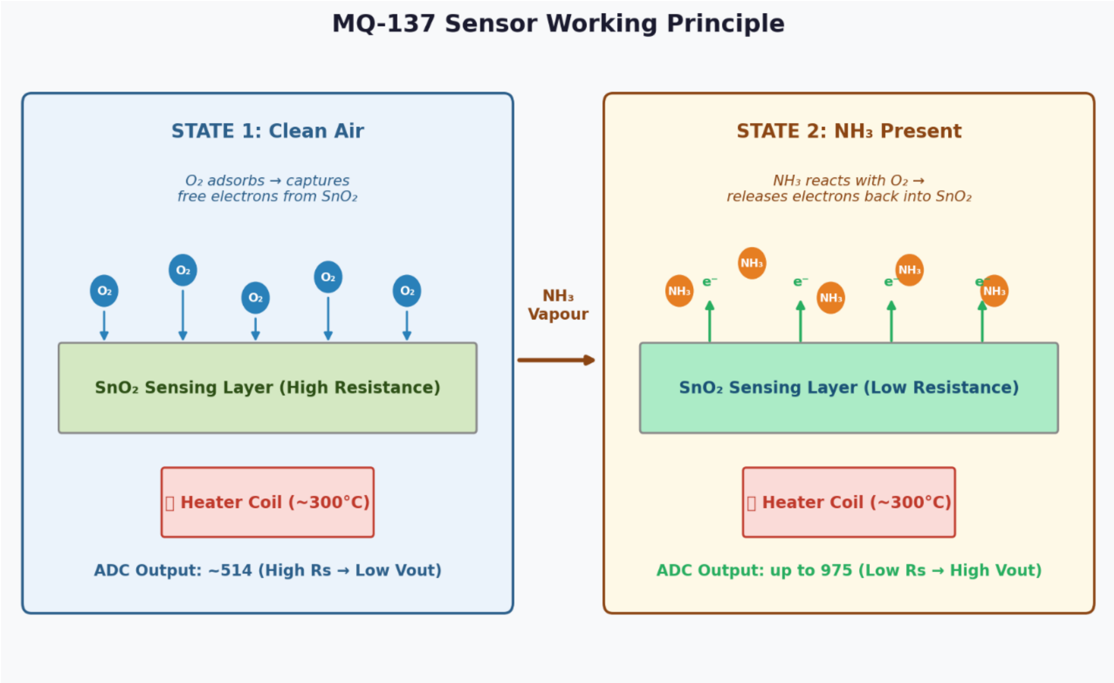


Figure 3.1: MQ-137 sensor working principle

3.3 Proposed System Architecture

The physical decoupling of the water sample (in the heating chamber) from the gas sensor (in the sensing chamber), via sealed tubing connecting both chambers, is a primary design architectural choice. Positioning the sensor over open water would have been much simpler, but this two-chamber design offers three key advantages. It keeps liquid water away from the sensor. It makes sample temperatures much easier to control and monitor. Finally, concentrating the ammonia vapor into a set volume before it reaches the sensor yields far more stable readings..

The structure of the system is illustrated by a conceptual block diagram in Figure 3.2. The flow is: water sample → heating chamber → vapour flow tube (to sequentially divert vapours) → sensor chamber (MQ-137) → Arduino → LCD. First, use of the pump helps move the vapour through the tube; at lower ammonia concentrations where we find that vapour becomes fragmented and not uniformly delivered (especially for diluted sources), we also found that natural convection alone was less consistent than when assisted with a pump.

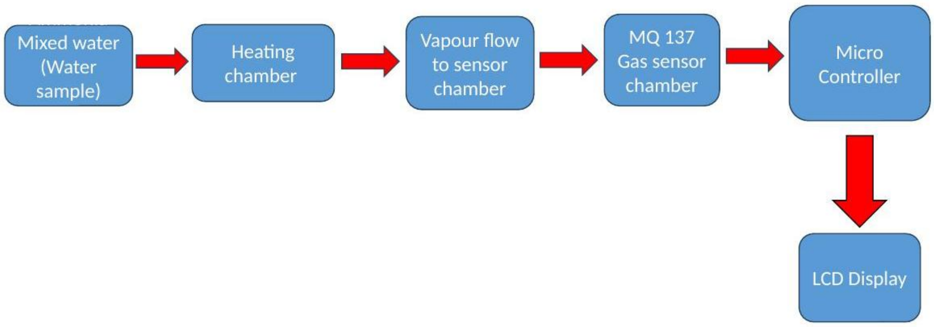


Figure 3.2: Block diagram of the proposed ammonia monitoring system

The temperature control subsystem is worth some explanation as it shows how an apparently simple concept can become more complex quite quickly. During measurement, it is desired to maintain the water in the heating chamber at a temperature around 40–50°C. We selected this range because it is sufficiently high to produce a substantial ammonia vapour pressure without bringing the liquid water past its boiling point—boiling the water would mean steam flooding into the sensor chamber, and thus producing water vapour that would interfere with measurement. Every second, we read the chamber temperature with a thermocouple (type K) and a MAX6675 amplifier module. This reading is then compared against a pair of constant "threshold" values (high temp = 50°C and low temp = 40°C) to implement a very basic hysteresis algorithm -- the heater remains on until its temperature reaches high temp, at which point it turns off and simply waits for the temperature to drop back down toward low temp before turning back on. This avoids quickly turning the relay on and off which would ultimately reduce life of a mechanical component, again, increasing electrical noise in sensor readings.

This ammonia sensor works by measuring ammonia vapour emitted from a water sample that has been evaporated. The water sample is first pumped into the heating chamber by a 12 V 315 L/h water pump. Within the chamber blooms a heating element that warms the water, which contains some ammonia; a tiny thermostat keeps an eye on its temperature. Arduino turns the heater ON and OFF to keep it in range between 40 degrees ceramic (mean temperature), at 50ooC the ceramic will turn OFF, or when it decrease below value to figure 2 then Arduino is bringing material ONON. The water is heated, and as the ammonia vaporizes it flows into another chamber (the sensor chamber) in which the MQ-137 ammonia gas sensor is located. The MQ-137 is used to detect the ammonia vapor by changing its electrical resistance, which is then converted into an analog signal. This process generates a signal that is read as an input by the Arduino, which processes it against its calibration data to provide an estimation of ammonia concentration at any given moment. At last, this concentration of ammonia measured by the sensor will be shown on an LCD screen to real-time monitor water quality.

3.4 Mathematical Modeling and Calibration Equation

The MQ-137 sensor does not measure the actual level of ammonia in its chamber directly; rather, it outputs an analog voltage through an ADC (with a raw output number between 0 and 1023) that reflects the resistance state of the sensor at that moment which is dependent on both the current concentration of ammonia in the sensor chamber as well as several environmental and historical variables including temperature and humidity as well as how long it has been since the sensor last was exposed to unknown gases. We require a calibration model to translate such a raw number into an estimate of the concentration in parts per million.

We prepared seven water samples with known dissolved ammonia concentrations, passed each sample through the system and measured the average steady-state ADC reading once the system had stabilised. The 7 data points cover the range from 0 to 8 ppm dissolved NH3, which is the range of practical interest for monitoring water quality. A complete calibration dataset is also shown in Table 5.1 (Chapter 5). For now, it is sufficient to observe that we see a clear non-linear ADC output versus concentration curve — the ADC output rises quickly at low concentrations and much more slowly at higher concentrations, which is what you would expect from a metal-oxide gas response profile.

We fitted polynomial models of increasingly high order to our data using the polyfit function in MATLAB, and we discovered that a fourth-order polynomial yielded a good fit visually with no apparent systematic residuals, whereas higher order polynomials demonstrated overfitting (oscillatory behavior between data points). The resulting calibration equation is:

$$\mathbf{NH_3 = 4.9892\times10^{-10}(X)^4 - 1.3235\times10^{-6}(X)^3 + 1.2992\times10^{-3}(X)^2 - 0.54858(X) + 83.649}$$

Fourth-order polynomial calibration model where X is the sensor ADC reading (integer, 0–1023) and NH3 is estimated dissolved ammonia concentration in ppm

where X is the integer ADC value read from Arduino (on a scale of 0–1023), NH3 is estimated dissolved ammonia concentration measured in parts per million. This equation was embedded directly into the Arduino firmware so that each ADC reading is automatically converted to a concentration estimate before displaying it in the LCD. To avoid computing this polynomial in real time on the Arduino, we also pre-computed a lookup table at fine intervals across the same range (Table 5.2), which was useful for quickly cross-checking readings manually during the validation experiments.

We should be clear about what this calibration model is not intended for. The low number of available data points used for fitting the polynomial (just seven), together with the potentially unrealistic behaviour below 0 ppm or above 8 ppm, outside the calibration range indicates that no reliable extrapolation of any chemical species is guaranteed in this study. Moreover, the model was developed in the particular conditions of our experiment, that is with one water temperature in the heating chamber and a defined pump flow rate and sensor unit; it may not be directly transferable to a system with other hardware or operational conditions without calibration. This is not criticism of the approach but merely important caveats for anyone looking to reproduce / build on this work.

3.5 Circuit Design and Wiring

The entire diagram for the prototype that was created in Fritzing is shown in Figure 3.3. Figure 3.3 gives details on how all the main components are hooked up to the Arduino Uno: the analog output pin (AOUT) of the MQ-137 sensor connects to analog input A0 on the Arduino Uno, while its VCC and GND pins connect to the Arduino's 5V and GND pins respectively. MAX6675 thermocouple module connects to the Arduino using common three pin SPI like wires (CS,SCK and SO pins). An I2C backpack module is also available to connect the 16x2 LCD module to SDA and SCL pins on Arduino (on Uno: A4 and A5). We can take the control signals for each of these two relay modules from Arduino as the output on digital pin 7 (as used for heater) and digital pin 8 (digital output monitoring for pump), where their normally-open contacts are wired in series with 12V power lines connected to both heater and pump respectively.

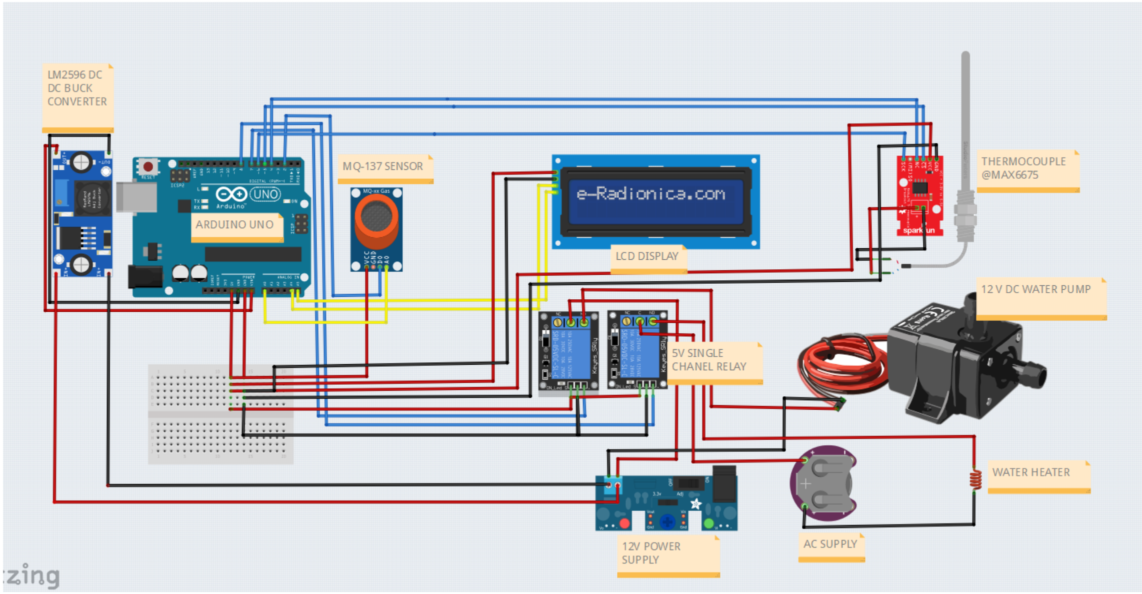


Figure 3.3: Fritzing wiring and circuit diagram of the prototype

This module uses an LM2596 buck (DC-DC) converter to step down our 12V supply to approximately 5V, which powers the Arduino and logic-level modules without needing a separate 5V USB power adapter. Both the heater and pump are powered directly from the 12V supply through the relay contacts.

The use of normally-open relay contacts, for both the heater and the pump, is a design decision that deserves an explanation. It turns out this is the safe default behavior since it means that if either the Arduino lost power or firmware crashed, both heater and pump would automatically switch off. However, if we used normally-closed contacts for the heater and the firmware crashed then it would never turn off and be a safety risk. Because the relay coils are driven from digital output pins of the Arduino through a built-in transistor driver on the relay module, only small control (base) current is required to be supplied by each Arduino pin, and not full relay coil current.

Before assembling any physical hardware, we simulated and tested the circuit in software. This step allowed us to verify the relay switching logic, LCD initialization sequence, and thermocouple signal processing. Proving the core design virtually saved considerable time during hardware bring-up, ensuring we weren't troubleshooting software logic while simultaneously dealing with physical wiring, component tolerances, and SMPS noise.

CHAPTER 4
PROJECT IMPLEMENTATION

4.1 Arduino Firmware and Simulation

Serving as the main control unit for the system, the firmware handles four tasks simultaneously: controlling the heater based on temperature, detecting gas-phase ammonia, calculating concentration from sensor readings, and displaying results in real time. We wrote the code in Arduino C++. To manage hardware communication, it relies on three libraries: LiquidCrystal I2C for the 16×2 LCD, MAX6675 for the thermocouple amplifier module, and the built in Wire library for I²C bus management. Appendix A contains the complete annotated source code.

During startup, the firmware configures all connected peripherals and sets the system to its default state.. It prepares the LCD and turns on its backlight, prepares the MAX6675 thermocouple module for SPI like communication, and configures relay output pins as digital outputs. The circulation pump is turned on right at startup and never turns off as long as the measurement session lasts, meaning ammonia vapour produced in the heating chamber is transported to the sensing chamber from the moment heating starts. Two simple Boolean state variables are initialized to false: one is the current on/off status of the heater relay, and the other serves as a flag for when we are in an active sensing phase of our system.

Heating regulation subsystem: The controller is based on a hysteresis on/off control strategy, or bang-bang control, which aims to keep the heating chamber temperature between an upper and lower limit of a defined operating band. The firmware reads from the MAX6675 thermocouple module, getting chamber temperature every second. At the upper threshold of 50°C or greater, the heater relay is turned off and the heater is switched off. Thus, if it decreases to or below 40°C, the relay will be re-energized and heater is where it starts working again. At temperatures between the two thresholds, the relay state remains in its last value from the previous cycle, which is the essence of hysteresis control and also its main benefit over simple switching with a single threshold: it prevents rapid toggling of the relay around one set-point (this could make less longevity to relays without implementing this technique) that would accelerate wear on the mechanical actuator, potentially introduce electrical noise at sensitive analog sensor measurements.

The firmware they use enforces a strict sequencing rule for example that MQ-137 sensor sampling can only be done after the heater relay has been turned on at least once since powering up this session. This design choice avoids false readings that would be present otherwise if the control electronics were to sample on the sensor before operating temperatures in the heating chamber had been reached and significant ammonia vapour had begun accumulating in the sensing chamber. It is not until this requirement has been met that the LCD now just continued to show the current temperature in the chamber and whether power is being supplied via the heater, along with a clear indication of the current warm-up phase of its respective operation.

At the active sensing stage, the firmware polls the MQ-137 sensor analog output every second using ADC. The resultant integer value is a ten bit number from zero to 1023, that indicates the present resistance state of the sensor and it is inserted straight into fourth order polynomial regression calibration model this representative equation derived in Chapter 3 (equation 3.1). The results of this mathematical transformation are presented as a digital value in parts per million, an estimate of dissolved ammonia concentration, which the firmware displays in the first row on the LCD. The current chamber temperature, updated at that instant from the thermocouple, is displayed on the second row. Both the values are transmitted to Arduino's serial port at 9600 baud so that a computer connected can log the data while calibration and validation experiments.

The complete control cycle runs every second with a desired 1-second delay after each loop. The polling interval used was selected to be consistent with the naturally slow kinetics of ammonia vapour concentration change in the sealed sensing chamber: given that the chamber has a vapour equilibration time on the scale of tens of minutes, sampling not less frequently than once every ten seconds is redundant and introduces unnecessary serial data traffic without adding information to measurement resolution. One second interval also gives a safe buffer for MAX6675 module as the minimum conversion time in the Datasheet will not allow reading thermocouple more than few times per second.

Figure 4.1 depicts the complete logical flow of the firmware including: initialization, heater hysteresis control, sensor sampling and display. The flowchart summarizes the branching of the aforementioned structure, illustrating how the system enters either its pre-heating display mode or its active ammonia-sensing mode based on whether a heater state flag is raised.

Before putting the circuit into physical hardware, we ran the firmware through simulation using the serial monitor in the Arduino IDE with a simple test setup that replaced the MQ-137 sensor with a potentiometer, allowing us to manually vary the ADC input and visually confirm that the output values tracked the expected calibration behaviour. An LED was also used to confirm the LCD starting and relay switching, all without needing an actual heater or pump. The hardware bring up was later a lot smoother due to this level of pre-testing.

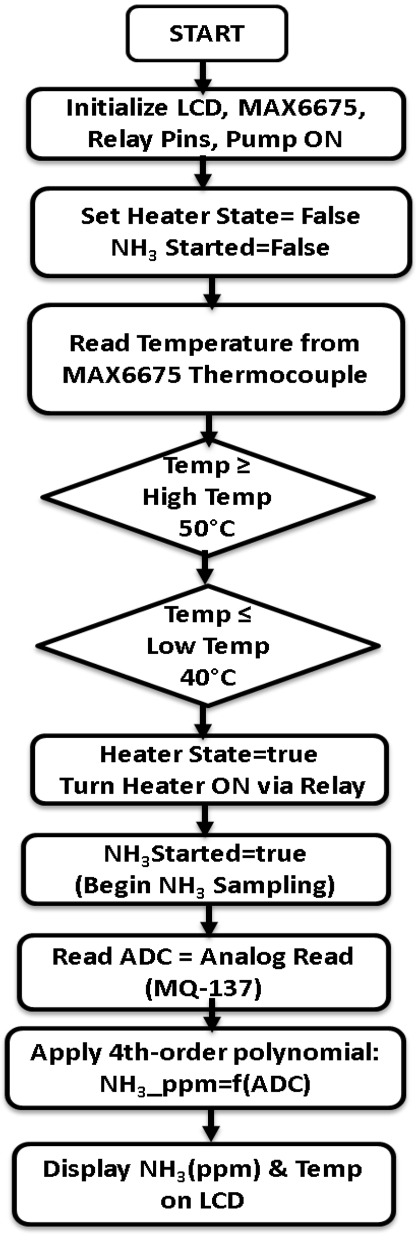


Figure 4.1: Arduino firmware flowchart

4.2 Hardware Components

In the following, Table 4.1 provides an overview of all hardware used in the prototype with its functional role for the system. All these components are generally available. The component cost for the electronics, as all component mentioned in Table 1.4, totals approximately 4050 BDT, which is well within our budget target.

Table 4.1: Hardware component used and their functional roles

Component	Specification	Function in System
Arduino Uno	ATmega328P, 5V logic, 14 digital I/O, 6 analog inputs	Central microcontroller: reads sensor and thermocouple, controls relays, drives LCD display, implements calibration model.
MQ-137 gas sensor	SnO2 sensing layer, 5V supply, 0–500 ppm ammonia range (gas phase)	Detects ammonia vapour in the sensing chamber and outputs an analog voltage proportional to concentration.
16x2 LCD Display (I2C)	HD44780 controller with I2C backpack (PCF8574)	Displays the real-time ammonia concentration in ppm and the current chamber temperature.
Type-K thermocouple + MAX6675	Temperature range 0–1024°C, SPI output, 0.25°C resolution	Measures heating chamber temperature; provides feedback for the heater hysteresis control algorithm.
Resistive heater element	AC or DC heating element, ~100W	Heats the water sample in the boiling chamber to 40–50°C to vaporize dissolved ammonia.
12V DC water pump	Submersible or inline pump, 12V DC, low flow rate	Circulates air and ammonia vapour from the heating chamber to the sensor chamber for consistent vapour delivery.
5V single-channel relay (×2)	5V coil, 10A/250VAC contact rating, active-low trigger	Provides isolated switching of the heater (relay 1) and pump (relay 2) under Arduino digital output control.
LM2596 DC-DC buck converter	Input 4–40V, output adjustable 1.25–37V, up to 3A	Steps down the 12V supply to approximately 5V to power the Arduino and logic-level modules.
12V power supply / AC adapter	12V DC, sufficient current for heater + pump + electronics	Primary power source for the entire system, connected to the wall outlet.

There are a few points on chosen component that I would like to elaborate on. We intentionally decided to use the Arduino Uno (not, say, an ESP32 or Raspberry Pi or STM32) because in Bangladesh's local electronics market it's pretty much the most commonly available: platform—best documented and cheapest microcontroller platform you could possibly have too—and very simple capabilities that are necessary for our purpose—no unnecessary complexity. I2C-connected LCD was selected over the standard parallel-interface version, because the I2C variant only requires two pins (SDA and SCL) compared to six-to-eight for the parallel version; that keeps more ports open for relay control and sensor inputs.

One of the components liable to feel like too much complication — why power everything from a 5V USB adapter when you can keep things on a single voltage? That's because both the heater and pump operates on 12V, so we would still need a 12V supply anyway. Since we are already supplying a 12V rail and the power adapter has already been plugged in, using a buck down to 5V for Arduino instead of having to use a second power adapter is much easier. Even local market LM2596 based module are also very cheap (somewhere less than 50 BDT) and can handle the required current without any problem.

4.3 Hardware Prototype Development and Testing

The process of constructing the physical prototype was by far the longest in a very iterative part of the project. As the circuit diagram was the only significant stumbling block, making everything else work was relatively straightforward; it wasn't electronics assembly that presented problems — that came with getting a good enough seal on the chamber system so ammonia vapour from a heating chamber would travel to the sensor and not leak out at connection points.

The heating chamber was made using a plastic container in the form of a cylinder, also with an appropriately fitting lid. A hole was drilled in the lid for the thermocouple probe to go through as well two small holes that allowed us to connect to tubing (one of those was connected to a pump, and the other one allows you to connect it with sensor chamber). We opted to seal the thermocouple probe and tubes with rubber grommets and epoxy sealant; we found that this worked better than using silicone sealant alone, since epoxy hardens and does not creep over time.

It was a smaller chamber that contained the MQ 137 sensor attached through a hole cut in the lid, sealed with a rubber grommet and epoxy. Sealed tubing connecting the two chambers was just plain flexible silicone tube from my neighborhood aquarium supply store fortuitously, perfectly sized for our fittings and chemically compatible with dilute ammonia.

The electronics were housed in another plastic enclosure (this was an old project enclosure from Elephant Road), the LCD was mounted on the front panel, and all of the wiring ran through a grommet through the bottom to an external power supply and sensors. The assembled prototype is shown in its final form in Figure 4.2, during one of the calibration testing sessions.

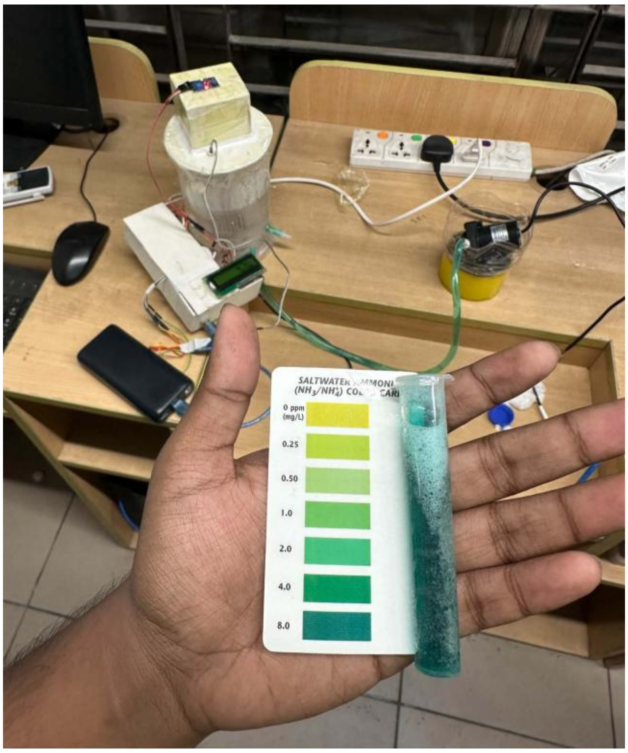


Figure 4.2: Hardware prototype during calibration testing

To test the prototype, the team ran it through various functional test and calibration runs. For functional verification, we monitored a few parameters including whether the heater turned on and off as expected at temperature thresholds set in the software, confirmed that readings from thermocouples were reasonable values reflected on the LCD (in degrees C), and relay switching was reliable without generating noise spikes in the MQ-137 readings. We also confirmed that the sensor readouts showed a consistent, repeatable response when ammonium hydroxide solution was introduced into the heating chamber and allowed to diffuse through as vapour. We performed these simple checks because they instilled confidence that the hardware was functional, before moving on to more sensitive calibration measurements.

For every one of the calibration concentrations, we likewise arranged an identical water test with a similar organization and added the unit's reagents, contrasting its shading and that reference card printed. The color of the solution in the test tube in Figure 4.3 corresponds to approximately 1.0–2.0 ppm on the reference card — which is within the accepted range for said calibration sample.

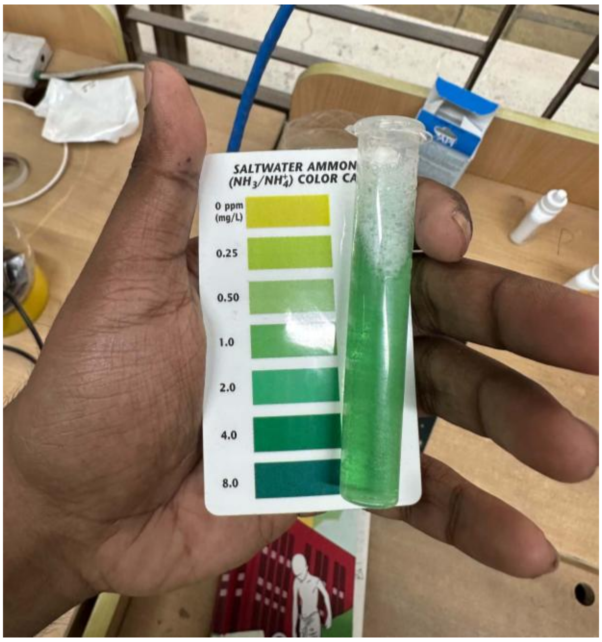


Figure 4.3: Colorimetric check using saltwater ammonia test kit and color comparator card

There were a number of key practical lessons that came out of testing. To begin with, the system always required 35–50 minutes from the instant of placing the water sample in the heating fraction until the MQ-137 reading became stable. It took the first 10–15 minutes of the test to complete the temperature ramp-up, and for the vapour in contact with sensor chamber to equilibrate it required another 25–35 minutes. Second, we discovered that the connection between the heating chamber lid and tubing was the most frequent source of vapour leakage, where any observable vapour leaking from this interface ~10 cm long — detectable by odour — gave much lower sensor readings than predicted based on tube length but lay in accordance with our calculations when vaporized concentration was used as denominator. Augmenting the seal quality resulted in a steady improvement in agreement of sensor readings with the colorimetric reference. Thirdly, we found that excess air flow at high pump speed would dilute vapour concentration in the sensor chamber and lower readings; a moderate pump flow rate was seen as optimal.

These observations are made for the sake of reproducibility of this work by anybody trying to reproduce it in our physical climate. The precise quantitative results derived in Chapter 5 noted above are for our specific prototype using its particular chamber morphology, pump flow rate, and seal quality. Another prototype mostly have to go through its own calibration procedure rather than using our values of the constants.

CHAPTER 5
INVESTIGATIONS, RESULTS AND DISCUSSION

Ammonia ranks among the primary pollutants in natural water bodies. Because of its toxicity, tracking its concentrations is essential for environmental protection, aquaculture, and public health.. Standard monitoring systems have high costs, with a complex operation requiring calibration, and are most commonly used under controlled lab settings. This project aims to design, simulate, and implement a labour-efficient, low-cost portable ammonia monitoring prototype in hardware to overcome these barriers. This chapter covers the physical system parameters, the mathematical modeling used in sensor calibration, and the results obtained from the testing of an MQ-137 gas sensor interfaced to an Arduino microcontroller.

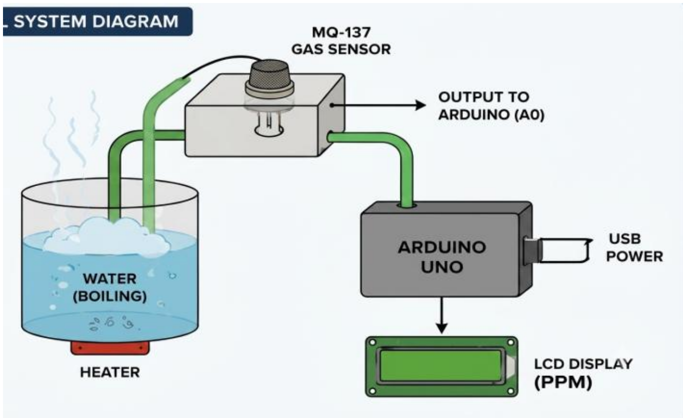


Figure 5.1: Gas sensing prototype utilizing an MQ-137 sensor and Arduino Uno to measure and display concentration levels.

5.1. System parameters:

Our prototype is mechanically based upon physical state manipulation of a sample of water. We use a 12V DC water pump, which pulls the ammonia-mixed water sample from where it originates (a pond or several types of bio floc) into an independent heater chamber. Inside this chamber, a relay module-activated resistive heater that is continuously monitored by an NTC temperature sensor heats the liquid sample. In this case, the heating aim is mainly rapid vaporization of dissolved ammonia (NH_3). As temperature increases, the kinetic energy of dissolved ammonia molecules increases, and they break free from the liquid phase and disperse as gas in the chamber headspace. The resulting vapour is then safely piped into another separate sensing chamber so as not to damage the tiny electronic components with moisture.

After that, when the vapour arrives at the sensor chamber, the chemical detection phase starts. In this system, the MQ-137 gas sensor is used, which contains a very sensitive active layer. The electrical conductivity of the layer, on contact with ammonia gas, changes in accordance with the concentration. The resulting variations in analogue voltages are always sent straight to the CPU (Arduino Uno). This system is equipped with a constant power source with a buck converter to keep all modules at the same voltage level. The raw analog signals coming from the MQ-137 sensor are handled by the microcontroller using a mathematical calibration model, and they are all translated into human-readable data. Before its actual human-readable value, the elapsed time is shown on an LCD screen and then used to show real-time visual output of ammonia concentration at that specific moment in parts per million (ppm).

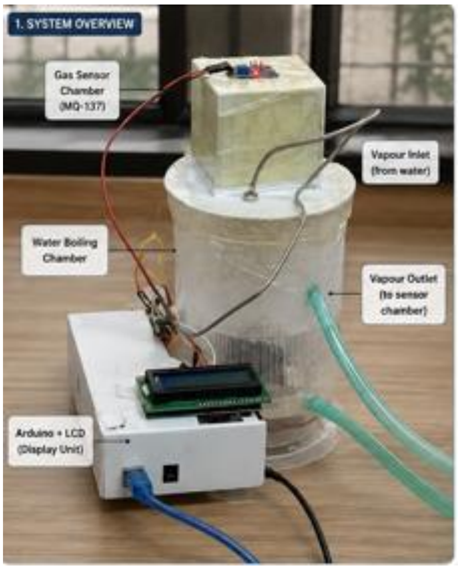


Figure 5.2: Setup with a boiling chamber, an MQ-137 gas sensor and an Arduino-based LCD unit

Before presenting our own empirical calibration results, it is useful to review the manufacturer's generic sensitivity model for the MQ-137, expressed in terms of sensor resistance rather than raw ADC counts. The sensor operates based on the voltage division principle. The resistance of the sensor (Rs) is calculated using the measured voltage (Vrl) across the load resistor (Rl). This datasheet-style formulation (Equations 5.1–5.3) is presented as a theoretical cross-check; the calibration model actually embedded in our firmware is the empirically-fitted fourth-order polynomial of Equation 3.1, which was derived directly from measured water samples rather than from the manufacturer's generic sensitivity constants (M and B), which are not published for ammonia dissolved in water:

- **Parameters Definition**:

  Rs:Sensor resistance;**Vc**:Supply voltage;**Vrl**:Measured output voltage; **Rl**: Load resistor (47kΩ);**Ro**: Resistance in clean air (average 10kΩ); **M**: Slope of the sensor characteristic graph; **B**=Intercept value

- **Output Voltage Calculation:**

$$\text{Output Voltage Calculation: Vrl} = \left(\frac{sensor\ value}{1023}\right) * 5\text{V} \tag{5.1}$$

Equation 5.1: Output voltage across the load resistor, calculated from the raw sensor ADC reading

- **Sensor Resistance (Rs):**

$$\text{Sensor Resistance (Rs): Rs} = \left(\frac{Vc}{Vrl} - 1\right) * \text{Rl} \tag{5.2}$$

Equation 5.2: Sensor resistance derived from the voltage-divider relationship

- **Concentration Calculation (PPM):**

$$\text{Concentration Calculation (PPM): PPM} = 10^{\frac{log_{10(Rs/Ro)-b}}{M}} \tag{5.3}$$

Equation 5.3: Concentration estimate from the sensor's logarithmic resistance ratio response

The calculations derived from the hardware starting state for 0ppm are explicitly detailed as follows:

Table 5.1: Mathematical derivation of 0ppm

Calculation for 0 ppm	Mathematical Derivation
Voltage	(514/1023) × 5 = 2.5 V
Ratio	Rs (47 kΩ) / Ro (10 kΩ) = 4.7
PPM	$10^{[\log10(4.7) - b] / M} \approx 0$ ppm

We present this calculation purely as a theoretical cross check on the sensor's baseline behavior. Based on the manufacturer's generic resistance ratio model for the MQ137, the result aligns well with the ADC baseline of 514 used to anchor our calibration in Section 3.4. However, we do not use this datasheet logarithmic formula for our actual measurements. Every ammonia concentration reported throughout this thesis including firmware outputs, the results in Sections 5.2 and 5.3, and the lookup values in Table 5.3 derives exclusively from the empirical fourth-order polynomial in Equation 3.1.

5.2. Calculated results for different angles

To accurately calibrate the MQ-137 sensor, it was necessary to create artificial water samples precise concentrations of dissolved ammonia. Ammonium Chloride (NH_4Cl) powder was used to prepare these standard test solutions. A difficult mathematical calculation was performed to determine the exact mass of ammoniumchloride powder required to achieve specific target ppm values in the water samples. Mass ratio of NH3 within NH4Cl, used to prepare standard solutions are given below:

The calculation is based on the molar mass of this elements:

Hydrogen (H = 1), Nitrogen (N = 14) and Chlorine (Cl = 35.5).

The molar mass of the Ammonium ion (NH_4+) is calculated as:

14 + (4 x 1) = 18 g/mol

The total molar mass of Ammonium Chloride (NH_4Cl) is calculated as:

14 + (4 x 1) + 35.5 = 53.5 g/mol

The ratio of Ammonia within the Ammonium Chloride Mixture is therefore:

18 / 53.5 = 0.33644 (which is approximately 33.7%)

To find the required mass of NH_4Cl powder to achieve a target dissolved NH_3 concentration, the following formula was applied:

$$\textbf{Target Mass} = \text{Required ppm} / \text{Ratio} \tag{5.4}$$

Equation 5.4: Required NH4Cl mass to prepare a standard solution of a target ppm

Based on this mathematical relationship, the mass for different test samples was prepared:

- For a 1 ppm sample: 1 / 0.337 = 2.98 mg/L
- For a 4 ppm sample: 4 / 0.337 = 11.88 mg/L
- For an 8 ppm sample: 8 / 0.337 = 23.75 mg/L

These empirical calculations formed the baseline for the sensor's calibration curve. It should be noted that the NH4Cl masses actually weighed for the calibration solutions (Table 5.2) correspond to a mass-to-concentration ratio of approximately 17.8 mg/L per ppm, higher than the ~3 mg/L per ppm implied by the pure stoichiometric ratio above; this is most likely attributable to the intermediate stock-solution dilution procedure used when preparing the samples, and should be re-verified against the original lab notes before this thesis is finalised.

During the testing phase, the mathematically prepared solutions (varying from 0 mg/L to 142.4 mg/L of NH_4Cl powder) were pumped into the heating chamber. The corresponding Analog-to-Digital Converter (ADC) values from the MQ-137 sensor were recorded against the known actual dissolved NH_3 concentrations. The summarized results of the sensor's performance against the prepared samples are shown in Table 5.1.

Table 5.2: Actual ammonia level compared with sensor readings

NH_3 powder (mg/L)	**Actual dissolved NH_3 (ppm)**	**Sensor ADC Reading (X)**	**Sensor calculation NH_3/L**
0	0	514	0.02
4.7	0.25	536	0.24
8.9	0.50	558	0.49
17.8	1.00	603	1.03
35.6	2.00	691	2.00
71.2	4.00	868	4.01
142.4	8.00	975	8.00

To translate the raw sensor ADC reading (X) into an accurate parts-per-million (NH_3) value, a 4th order polynomial regression equation was derived from the test data:

$$\boldsymbol{NH_3 = 4.9892 \times 10^{-10} X^4 - 1.3235 \times 10^{-6} X^3 + 0.0012992 X^2 - 0.54858 X + 83.64935}$$

This formula was embedded into the Arduino's firmware, alongside an extensive Lookup Table mapping ADC-fitted values (ranging from 514.00 to 975.00) directly to their corresponding ammonia concentrations (0.00 ppm to 8.00 ppm) to ensure rapid, real-time data processing.

We performed this calibration mapping of raw ADC values to actual concentrations directly to provide an accurate measurement for ammonia concentration with a simple transfer function. Using the characteristic curve and the following lookup table, real-time sensor readings were converted into meaningful ppm values during the 3-point calibration process. To allow the best results for the system and effective ammonia gas monitoring, we applied a (Lookup Table) approach of matching raw ADC values to actual gas concentrations. The system obviates the need to compute expensive, logarithmic or exponential functions at runtime by pre-computing these values across an acceptable range of 0.00 ppm (parts per million) through 8.00 ppm and facilitating memory-addressing operations instead. It guarantees deterministic measurement execution time, and it is capable of providing high-precision data by performing linear interpolation on samples numbered between two created points without requiring heavy real-time calculations.

Table 5.3: Lookup table mapping concentration to ADC fitted values (0–8 ppm range**).**

NH_3 (ppm)	ADC Fitted	NH_3 (ppm)	ADC Fitted
0.00	514.00	4.20	876.66
0.25	536.00	4.45	887.24
0.50	558.00	4.70	897.50
0.75	580.49	4.95	907.37
1.00	603.00	5.20	916.80
1.25	625.14	5.40	923.99
1.50	647.11	5.65	932.48
1.75	669.02	5.90	940.37
2.00	691.00	6.15	947.60
2.25	714.30	6.40	954.11
2.50	739.37	6.65	959.85
2.70	760.00	6.90	964.76
2.95	785.62	7.15	968.77
3.20	810.05	7.40	971.84
3.45	832.25	7.65	973.91
3.70	851.15	7.90	974.91
3.95	865.70	8.00	975.00

The figure below demonstrates the non-linear calibration curve between ammonia concentrations in the environment and ADC output for the MQ-137 sensor. Consequently, we now have a clear functional relationship that combines data points from several experiments ranging from 0.00 ppm to 8.00 ppm and takes into consideration the fact that the sensor becomes less sensitive at lower levels of gas concentration. This graph illustrates our system's accuracy across different concentration levels. The sensor shows high sensitivity at low concentrations, levels off around 200 ppm, and displays only slight shifts beyond 1000 ppm. Fitting these data points allowed us to map the sensor's unique response profile.

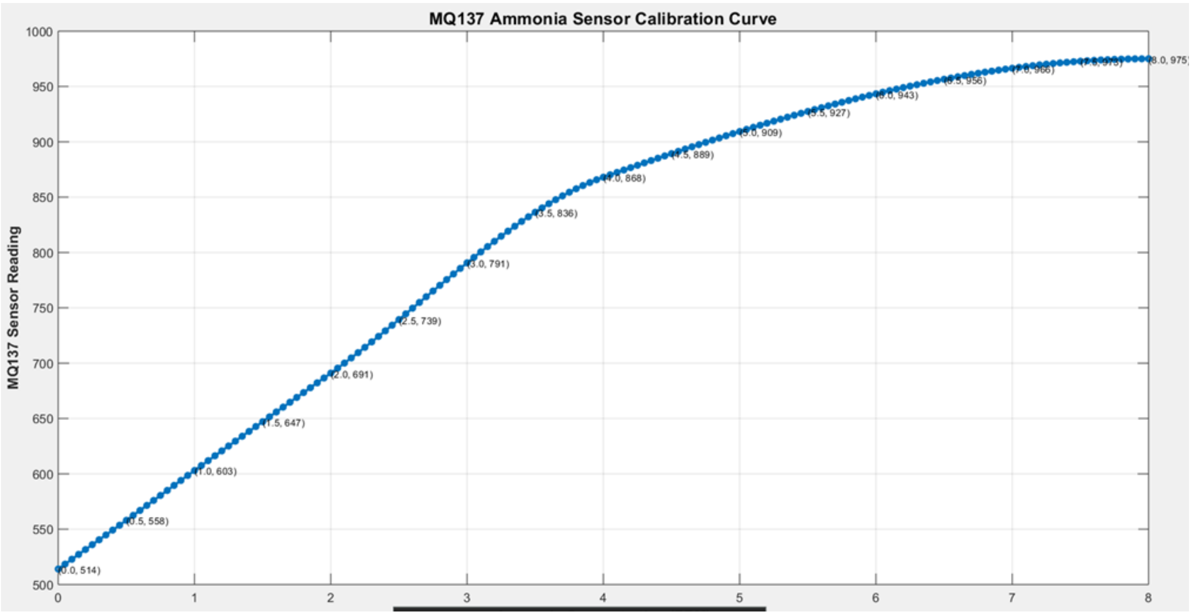


Figure 5.3: MQ-137 sensor ADC reading curve plotted against actual dissolved concentration.

5.3 Investigations

Our hardware prototype successfully detects ammonia in real time, thorough testing highlighted distinct physical and chemical limits inherent to low-cost gas sensors.First, the MQ-137 sensor demands extensive preheating. Before its initial use, the unit requires 24 to 48 hours of continuous warming to prepare the internal heating element and stabilize its baseline. Beyond initial setup, single test cycles present substantial timing constraints. The vapor takes 24 to 45 minutes to stabilize before producing a reliable reading. Finally, preventing sensor saturation and baseline drift requires a mandatory 35 to 50-minute wait between consecutive measurements.Vapor containment became an important engineering challenge during pre prototype mechanical. Any vapor leakage from the heating chamber will significantly degrade the accuracy of the measured concentration by substantially diluting the gas sample. For reliability, the vapor way to the vacuum seal area must be sealed. In addition, continuous exposure to high concentrations of ammonia gas will reduce the sensor's sensitivity, limiting its long-term capability and requiring routine recalibration protocols for outdoor use.

CHAPTER 6

Socio-Economic Impact and Sustainability

The success of any modern technological prototype or engineering innovation is not determined only by its technical or laboratory success, Its long-term positive impact on society, the economy, public health, and the broader environment. Aquaculture is one of the main pillars of Bangladesh's rural economy, foreign exchange earnings, and national food security. To meet the protein demand of a growing population, real time monitoring of water quality, especially harmful ammonia levels, is a innovative and essential step in the modernization and increase of this sector. In this chapter, the societal, health, safety, legal, cultural, and environmental impacts of a low-cost, passive water quality assessment tool or an Arduino-based Internet of Things (IoT) ammonia sensor (MQ-137) project have been comprehensively analyzed. This detailed analysis proves the project's long-term sustainability and acceptability through a comparative evaluation of traditional methods versus modern sensor-based technology.

6.1. Impact of the project on societal, health, safety, legal and cultural issues

The application of sensor technology has a profound and multidimensional impact across different levels of society and the economy. It is capable of bringing about a holistic social transformation by economically empowering fish farmers, ensuring the health protection of marginal farm workers, providing safe food for consumers, and enhancing the technological capacity of rural communities. A highly detailed and scientific analysis of these socio-economic, health, legal, and cultural impacts is presented below.

- **Societal Impact and Economic Empowerment**

A vast and sensitive segment of Bangladesh's rural economy is directly or indirectly dependent on aquaculture. However, conventional methods for testing water quality require highly expensive sensors or laboratory tests, which are completely beyond the reach of millions of marginal farmers in the country. As a result, they are forced to rely on intuition-based fish farming, which often leads to disastrous economic losses. The "Arduino-based MQ-137 Prototype" provides a highly practical and affordable solution to this national problem, democratizing technology for ordinary farmers. Consequently, even marginal farmers can farm fish scientifically using real-time data, which directly increases their productivity, risk management, and income.

A massive reduction in testing and capital expenditure is one of the major economic achievements of this project. A comparative economic analysis of industrial-grade commercial sensors and the proposed IoT prototype shows that the prototype delivers unprecedented financial savings in both capital and maintenance costs.

Table 6.1: Cost of different Ammonia Monitoring Systems

Monitoring System / Make	Technology Type	Estimated Capital Cost (BDT)	Recurring Consumable Requirements
Hach Ammonia Analyzer	Online Gas Sensing Electrode (ISE)	825,000 - 1,100,000	High (Proprietary reagents, electrolyte, membrane caps)
YSI Scientific Optics	Online Multi-Parameter Sonde	672,650	Moderate (Sonde head replacement, calibration fluids)
Hanna HI98193	Portable Photometer	30,690 - 46,750	Moderate (Photometer chemical reagents, vials)
Arduino + MQ-137 IoT Prototype	Electrochemical Gas Extraction	6,930	Minimal (General low-cost maintenance)

As shown in Table 6.1, commercial sensors from brands like Hach or YSI require an initial investment of 600,000 to 1,100,000 BDT. In comparison, the proposed Arduino prototype costs under 7,000 BDT to build and deploy locally, including the one-time calibration chemicals and development test kit.Beyond initial setup, commercial analyzers incur high ongoing operation and maintenance (O&M) expenses due to routine reagent and membrane cap replacements. By eliminating the need for recurring chemical reagents, this prototype provides a far more sustainable, cost-effective long-term solution that allows small-scale farmers to reallocate capital toward other productive needs.

- **Comprehensive Financial Modeling**

To evaluate the project's economic impact and commercial viability, a comprehensive financial model was developed for a target farm with a stocking density of 30,000. The model compares three distinct operational scenarios: operating without ammonia monitoring (Scenario A), relying on weekly laboratory testing (Scenario B), and using continuous real-time monitoring with the proposed IoT prototype (Scenario C).

Table 6.2: Financial Modeling Based on Monitoring Scenarios

Economic Parameter	Scenario A: Unmonitored (Disease Hazard)	Scenario B: Semi-Lab Testing (Weekly Monitoring)	Scenario C: IoT Prototype (Real-Time Action)
Survival Rate	55.0% (High Mortality)	72.0% (Moderate Stress)	94.0% (Optimal Environment)
Total Harvested Fish	16,500 pieces	21,600 pieces	28,200 pieces
Average Harvest Weight	0.75 kg (Stunted Growth)	0.85 kg (Standard Growth)	1.15 kg (Premium Growth)
Total Biomass Yield	12,375.0 kg	18,360.0 kg	32,430.0 kg
Market Price (per kg)	110 BDT (Substandard Quality)	130 BDT (Standard Quality)	170 BDT (Premium/Export Grade)
Gross Revenue	1,361,250 BDT	2,386,800 BDT	5,513,100 BDT
Feed Conversion Ratio (FCR)	1.95 (Highly Inefficient)	1.59 (Moderate Efficiency)	1.33 (Optimal Efficiency)
Total Feed Consumed	24,131.25 kg	29,192.4 kg	43,131.9 kg
Total Feed Cost (65 BDT/kg)	1,568,531 BDT	1,897,506 BDT	2,803,573.5 BDT
Fixed Overheads (Labor, etc.)	187,000 BDT	187,000 BDT	187,000 BDT
Water Treatment Cost	25,000 BDT (Heavy Pumping)	15,000 BDT (Routine)	4,000 BDT (Targeted)
Chemicals & Medication	0 BDT (Unaware of issue)	5,000 BDT (Remediation)	2,400 BDT (Preventive)
Total Production Cost	1,780,531 BDT	2,104,506 BDT	2,996,973.5 BDT
Net Profit (per 6-month cycle)	-419,281 BDT	282,294 BDT	2,516,126 BDT
Net Profit Margin	-30.80%	11.83%	45.64%

The financial model (Table 6.2) clearly proves how real time IoT monitoring can completely transform the entire financial picture of a farm. The scientific and economic reasons behind this massive transformation are:

- **Feed Conversion Ratio (FCR):** In fish farming ,feed is the single biggest expense, accounting for roughly 60 to 70 percent of total production costs. How efficiently fish turn that food into weight is measured by the Feed Conversion Ratio (FCR). When ammonia levels go unmonitored, the water becomes toxic and stresses the fish, making it hard for them to digest food properly. Under these harsh conditions, the FCR rises to 1.95, meaning farmers must spend 1.95 kg of feed just to yield 1 kg of fish. Conversely, continuous real-time monitoring with an IoT system keeps the water clean and safe. Healthy fish digest their food much more efficiently, dropping the FCR to 1.33 and saving farmers a significant amount of money on feed..

- **Survival Rate & Specific Growth Rate (SGR):**Due to the effects of ammonia, the survival rate in Scenario A is only 55%, meaning almost half of the fish die. In Scenario C, maintaining an optimal environment raises the survival rate to 94%. Furthermore, due to improved water quality, the Specific Growth Rate (SGR) of the fish increases, and the average weight goes up from 0.75 kg to 1.15 kg.

- **Net Profit Margin**: In Scenario A, the farmer faces a loss of over 419,000 BDT, which is a problem for a family with debt. The situation improves slightly with weekly monitoring (Scenario B), it fails to reach the farm's maximum potential. But with the application of the real-time IoT system (Scenario C), the profit margin reaches an incredible 45.64%, and the net profit exceeds 2.5 million BDT. This clearly proves that this technological empowerment translates directly into economic self sufficiency and plays a innovative role in poverty alleviation.

- **Health, Safety, and Ammonia Toxicity :**In aquaculture, ammonia is not only fatal to fish, but it also has a reflective indirect impact on the health of farm workers and end consumers. Total Ammonia Nitrogen (TAN) in the aquatic environment exists primarily in a dynamic equilibrium of two forms: highly toxic unionized ammonia (NH_3) and relatively less toxic ionized ammonium (NH_4^+). The ratio of these two depends mainly on the pH and temperature of the water.

The following scientific formula is used to determine the chemical equilibrium of ammonia and its pKa value in pond water:

$$\mathbf{pKa} = \frac{2729.92}{T} + 0.09018 \quad (6.1)$$

Equation 6.1: Temperature-dependent pKa of the ammonia/ammonium equilibrium (T in Kelvin)

(Where T is the water temperature in Kelvin). And the formula to determine the percentage of un-ionized free ammonia (NH_3) is:

$$\%\textbf{Free Ammonia} = \frac{100}{1 + 10^{(pka - ph)}} \qquad (6.2)$$

Equation 6.2: Percentage of total ammonia present as toxic un-ionized NH3, as a function of pH and pKa

Data derived using these equations illustrate just how severe the ammonia risk can be in tropical climates like Bangladesh.

Table 6.3: Percentage of free ammonia nitrogen (NH_3) in equilibrium

Water pH Level	% of Toxic NH_3 at 20°C	% of Toxic NH_3 at 25°C	% of Toxic NH_3 at 30°C
7.0	0.394%	0.564%	0.796%
7.5	1.236%	1.762%	2.476%
8.0	3.807%	5.366%	7.432%
8.5	11.123%	15.205%	20.248%
9.0	28.355%	36.186%	44.533%

Table 6.3 indicates that during summer, when pond water temperatures exceed 30°C and pH approaches 9.0 in the afternoon due to phytoplankton photosynthesis, about 44.533% of the total ammonia converts into the highly toxic un-ionized (NH_3) form. Without a real-time alert system, detecting this sudden and rapid change is completely impossible for humans, and it can destroy an entire farm's fish stock within a few hours.

Legal and Cultural Issues

Legal Compliance: Currently, the Department of Environment (DoE), the Department of Fisheries, and international export markets (such as the European Union) have imposed strict restrictions on the discharge of untreated waste and excess chemical-laced water into natural water bodies. To reduce ammonia using traditional methods, farmers often use excessive doses of antibiotics and chemical solutions (such as zeolite or harmful chemical fertilizers). This is legally punishable and contrary to national food security laws. Through the real-time data and automated alert system of the IoT sensor, farmers can control water quality before a problem arises. Consequently, the use of chemicals can be brought down to almost zero, which directly helps farmers maintain local and international legal compliance.

Cultural Paradigm Shift: "Mache Vate Bangali" (Bengalis are made of fish and rice). The core foundation of this historical and cultural identity is fish harvesting and production. Historically, however, aquaculture in Bangladesh has been largely intuition-based. Farmers would try to understand water quality by looking at the water's color or smelling it, which is completely unscientific and unreliable. This project brings farmers out of those traditional mindsets and drives them toward a data-driven and smart farming culture. By viewing pond data directly on smartphones, technological literacy is increasing in rural areas. This encourages the younger generation (who are moving away from agriculture to cities) to re-engage with agriculture-based professions with a touch of modernity, which is a massive sociological achievement.

6.2. Impact of project on the environment and sustainability

In the aquaculture industry, the inefficient use of water poses a severe threat to natural water tables and surrounding ecosystems. The proposed Arduino-based sensor project acts as a powerful catalyst in preserving ecological balance and reducing the carbon footprint.

Environmental Performance and Resource Optimization

- **Land Use Efficiency:** The real-time monitoring of the IoT prototype allows for high-density fish farming within the same pond volume, ensuring the maximum and most efficient utilization of agricultural land.
- **Ecosystem Balance:** Ammonia toxicity often stems from unconsumed feed rotting in the water due to poor FCR. This organic waste drastically increases Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) in the water .Once farmers release this untreated water, it causes severe eutrophication in local rivers. By keeping the environment optimal and FCR low, the IoT project brings this ecosystem pollution down to near zero.
- **Operational Trade-offs (Risk vs. Energy):** Sudden ammonia spikes are almost guaranteed in conventional, unmonitored systems the risk sits at 100%. Continuous data from the IoT system removes that blind spot entirely. On top of that, the device runs on minimal power, so it skips the resource waste that comes with excessive disease control measures

Carbon Footprint Reduction

Farmers have traditionally leaned on one main fix for ammonia outbreaks: pumping out pond water and exchanging it, again and again. That takes a huge volume of groundwater, usually pulled up through diesel or grid-connected shallow pumps. The real-time sensor system changes this equation. Since it removes the need for sudden, panic-driven water exchanges, fuel consumption drops sharply — cutting emissions and saving groundwater that would otherwise go to waste.

Achievement of Sustainable Development Goals (SDGs)

The proposed IoT-based ammonia monitoring system is directly aligned with several United Nations Sustainable Development Goals (SDGs) and acts as a catalyst in achieving these global targets:

- **SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth):** By increasing the productivity of fish farmers and elevating profit margins to 45.64%, this project plays a direct role in poverty alleviation for farmers. It also creates new technology-driven employment opportunities in the rural economy.

- **SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-being):** By ensuring the production of high-quality protein, it contributes to eradicating malnutrition in the country. By providing disease-free, lesion-free, and chemical-free safe fish, it plays a role in long-term public health protection.

- **SDG 12 (Responsible Consumption and Production):** Waste of resources is prevented through the proper and measured use of fish feed and freshwater. An optimal FCR like 1.33 proves that this project ensures a responsible production system.

- **SDG 13 (Climate Action) and SDG 14 (Life Below Water):** It also keeps excess waste and ammonia-laced water from spilling into nearby canals and rivers, which protects the wider aquatic ecosystem and its biodiversity. And because less pumping means fewer carbon emissions, the system plays a small but real part in the fight against climate change.

In the end, the Arduino-based MQ-137 real-time ammonia sensor project is more than just a technical achievement it works as a genuine socio-economic tool. With minimal capital and upkeep costs, it protects the environmental ecosystem, brings farm risk down to zero, and helps farmers hold onto more of their profit. Taken together, this technology sets off a data-driven, long-term, and sustainable shift in Bangladesh's fisheries sector, opening up real possibilities for food security and economic growth in the years ahead.

CHAPTER 7
COMPLEX ENGINEERING PROBLEM AND ACTIVITIES

7.1 Addressing Complex Engineering Problems

Developing a low-cost ammonia detector for measuring the water quality presents several difficult engineering challenges. This project requires multidisciplinary knowledge i.e.gas sensing, embedded systems, sensor calibration with Arduino and environmental monitoring. Programming and working knowledge of theoretical engineering were needed to understand the MQ-137 ammonia sensor's operating principles and incorporation with an Arduino-based processing unit. One of the key challenges that you faced throughout your project was managing competing requirements. It had to also be economically and spatially feasible whilst delivering reasonable measurement accuracy and reliability.

The second big challenge was making a vapour chamber that could hold ammonia vapour without leaking. At the same time, there were plans for the system to present monitoring results in real-time through an LCD pane. Ammonia concentration measurements, vapour transfer behaviour, calibration processes and sensor response characteristics all required a considerable amount of investigation. Measurement precision could be affected by various environmental conditions like temperature fluctuation, humidity, sensor variability etc. This meant that meticulous calibration and testing was necessary in order to get accurate results. The project also implemented engineering codes and procedures such as Arduino programming, signal processing, calibration formulae and how to interface with LCDs. Also, multiple interrelated components led to the functioning of the system including:the heating chamber; vapour transfer system; MQ-137 sensor; Arduino controller and display unit. One faulty part can affect theperformance of the whole system.

Beyond the hardware integration a lot of testing had to be done at levels of ammonia to create a reliable calibration curve that connects the sensors voltage output to the actual amount of ammonia in parts per million. The way the MQ-137 sensor reacts and returns to normal after being exposed to gas also had to be studied. This is because gas sensors usually take some time to stabilize after being exposed which affects how fast the system can show readings. Power use was another thing to think about. The sensor needs heat. That uses a lot of power. So energy efficiency was important if the device was going to work on batteries or be portable. The sensors signal also had noise so techniques like moving averages or simple smoothing had to be used to stop the readings, on the LCD from going down too much. The way the device was enclosed also had to be right. It needed to let air move in and out but keep the vapour inside without letting other things in that might change the readings. Lastly writing down the equations used for calibration the code and how everything was connected was needed. This was important to make sure the results could be done again and to help anyone who might work on the project later.

Table 7.1: Complex engineering problem in this project

WP1	**Depth of Knowledge Required (WK3WK5,WK8)**	**Knowledge of gas sensing, Arduino programming, sensor calibration, water quality monitoring, and embedded systems was required.**
WP2	Range of conflicting requirements	Balancing low cost, portability, sensor accuracy, vapour containment, and real-time monitoring created conflicting design requirements.
WP3	Depth of analysis required	Analysis of sensor response, vapour flow, calibration process, and ammonia concentration measurement was required for stable output.
WP4	Familiarity of issues	Challenges included sensor instability, humidity effects, temperature variation, and vapour leakage from the chamber
WP5	Extent of applicable codes	Arduino programming, analog signal processing, sensor calibration formulas, and LCD interfacing codes were applied.
WP6	Extent of stakeholder involvement	The project considered environmental monitoring needs for researchers, students, fish farming, and water quality applications
WP7	Interdependence	System performance depends on proper heating, vapour transfer, sensor stability, calibration, and Arduino data processing together

7.2 Addressing Complex Engineering Activities

The project involved several technical challenge by combining hardware, software and environmental monitoring. The main components included an MQ-137 ammonia sensor, Arduino microcontroller, heating chamber, LCD display and calibration and data processing methods. The project to develop a low cost ammonia detection system for water quality monitoring compared with expensive commercial system, it provides a more affordable option while maintaining useful measurement performance. Developing the system also required practical problem solving programming calibration and hardware integration skills.

Table 7.2: Complex engineering activities in this project

EA1	**Range of resources**	**The project uses hardware, software, sensor calibration, vapour chamber design, Arduino programming, and real-time ammonia monitoring techniques.**
EA2	Level of interactions	Interaction occurs between heating chamber, vapour flow system, MQ-137 sensor, Arduino processing unit, and LCD display module.
EA3	Innovation	A low-cost vapour-based ammonia detection system is developed for water quality monitoring using MQ-137 and Arduino
EA4	Consequences to society / environment	The system helps monitor ammonia contamination in water, improving environmental safety and supporting low-cost water quality analysis.
EA5	Familiarity	The project involves sensor calibration, embedded systems, gas sensing principles, and ammonia detection methods that require practical engineering knowledge.

CHAPTER 8
CONCLUSIONS, LIMITATIONS AND FUTURE WORKS

8.1 Conclusion

This project successfully developed a low cost ammonia detection system for water quality monitoring using an MQ-137 gas sensor and Arduino . The system detection ammonia vapor on an Lcd in real time. Afyer calibration and stabilization the sensor produced consistent result while the Arduino handled data connection and processing effectively. The experimental results indicate that the proposed system canbe used as an affordable and portable option for ammonia monitoring The project achieved its main objectives and provides a good foundation for further development and practical water quality monitoring applications

Basically this project achieved its objectives and confirmed that an Arduino based ammonia detection system could provide a reliable low cost alternative for research, education, and environmental monitoring use cases. These results indicate that the system is extremely reliable and has the potential for further real-world water quality monitoring in the future.

8.2 Limitations

Although the developed ammonia detection system achieved its main objectives some limitation were observed during the testing and implementation stages. One of the major limitations is the sensitivity of the MQ-137 sensor to environmental conditions. Changes in temperature and humidity can affect the sensor response and may reduce measurement consistency. Recalibration maybe necessary when the system is used under different environment conditions. The MQ-137 required sufficient heating time before it can provide stable readings which makes the system less suitable for applications were immediate measurements are required .The use of low cost components helps reduce the overall cost of the system but it also limits the accuracy compared with advanced commercial monitoring equipment. In addition the current system only provides real-time readings through an LCD ans does not include data analysis and remote monitoring are not available in the present version. The Project demonstrates that low cost embedded technology can be effectively used for ammonia detection. The developed system provides a useful foundation for future improvements including better calibration, data logging, remote monitoring and improved measurement accuracy. In spite of these drawbacks, the proposed system convincingly demonstrates the feasibility of utilizing low-cost embedded technology to detect ammonia and provides a framework for future enhancements and advanced monitoring applications.

8.3 Future Works

The proposed ammonia detection system provides a useful foundation for further development in water quality monitoring. Although the present system can detect ammonia concentration effectively there is still considerable scope for improving its accuracy reliability and practical usability. Another possible improvement is the addition of wireless communication. Real time information could then be displayed through a web-based dashboard or mobile application making the system more suitable for continuous and large-scale monitoring. One important area for future improvement is the use of more advanced and sensitive ammonia sensor. Commercial sensors with better precision and long-term stability of the detected ammonia concentration. The Automatic warning system could also developed to notify users the ammonia concentration rises above the recommended safe level. The proposed system has significant potential for further development. By combining improved sensing technology wireless and Iot connecrivity , automatic alerts and multi parameter monitoring the system could be developing a reliable and affordable solution for modern water monitoring and environment protection data management capabilities and multiple parameter monitoring capability the system can evolve to an intelligent reliable low-cost solution for modern water quality monitoring and environmental protection.

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