

ULTRASONIC ACOUSTIC STANDING WAVES FOR EFFICIENT MICROPLASTIC REMOVAL: A SCALABLE AND SUSTAINABLE APPROACH TO WASTEWATER TREATMENT

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ABSTRACT

Microplastic contamination poses severe environmental and public health risks due to their persistence, bioaccumulation, and potential toxicity. Existing removal methods are limited by inefficiency, clogging, or by-product generation [1]. This project introduces an ultrasonic-based system for microplastic removal that leverages acoustic standing waves to concentrate particles for continuous filtration. The system integrates three main components: a controlled water circulation pump, an AD9833-driven ultrasonic transducer for frequency sweeps, and a turbidity sensing module for real-time performance evaluation. Two experiments were conducted to assess performance. Frequency sweeps identified 1.20 MHz as the optimal resonance for focusing, while pump testing revealed 50% duty as the best balance between residence time and throughput. Compared to prior methodologies that relied on degradation, aggregation, or microfluidics, our approach provides a scalable, low-maintenance, and environmentally sustainable solution [2]. The results confirm the promise of acoustics for practical wastewater treatment and set the foundation for further development.

KEYWORDS

Ultrasonic, Environmental engineering, Water filtration, Water pollution, Microplastics

1. INTRODUCTION

The contamination of water by microplastics represents a pressing environmental and public health challenge that demands innovative solutions. Microplastics-plastic particles smaller than five millimeters-have become ubiquitous pollutants in freshwater and marine ecosystems worldwide [3]. Their persistent presence in water bodies threatens aquatic life, disrupts ecosystems, and poses potential risks to human health through bioaccumulation and chemical exposure. Addressing the effective removal of microplastics from contaminated water is therefore critical to safeguarding environmental and human well-being.

The problem of microplastic pollution has intensified in recent decades, paralleling the exponential increase in global plastic production and consumption [4]. Microplastics originate from the fragmentation of larger plastic waste and from primary sources such as microbeads in personal care products and synthetic fibers released during laundering. These particles accumulate in freshwater systems, where slow water flow facilitates their persistence. Scientific studies have documented alarming levels of microplastic contamination; for instance, Illinois-Indiana Sea Grant funded research (Miles, 2018) has found that approximately 85% of fish

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sampled from certain rivers in the United States contained microplastics within their digestive tracts. Furthermore, microplastics have been detected in human placental tissues, underscoring their infiltration into the food chain and raising concerns about human exposure.

The importance of addressing microplastic contamination lies in the multifaceted threats these particles pose. Microplastics serve as carriers for toxic chemicals, including endocrine-disrupting compounds such as bisphenol A and phthalates, which have been linked to reproductive disorders, developmental abnormalities, and cancer. Additionally, microplastics can harbor pathogenic microorganisms, further exacerbating ecological and health risks. When ingested or inhaled, microplastics may trigger inflammatory and immune responses, potentially contributing to chronic diseases such as cardiovascular and respiratory conditions. The persistence and bio-accumulative nature of microplastics endangers biodiversity, food safety, and water quality, making their removal from water sources a matter of urgent concern.

The long-term impact of microplastic pollution affects a broad spectrum of stakeholders, including aquatic organisms, ecosystems, and human populations. Aquatic species ingest microplastics, which then bioaccumulate through the food web, ultimately reaching humans. Studies (Myers, 2025) have revealed microplastics in 98.9% of seafood samples in regions such as Oregon, USA, and estimates suggest that humans may ingest hundreds of thousands of microplastic particles annually through drinking water and food. The United Nations Environment Program reports that approximately 19-23 million tons of plastic waste enter aquatic systems each year, perpetuating the cycle of contamination and exposure.

The application of ultrasound waves presents a promising approach to this problem. Ultrasound technology utilizes high-frequency sound waves to generate acoustic forces that can manipulate and concentrate microplastic particles within flowing water. This enables the separation of microplastics by size and density, facilitating their efficient removal. Additionally, ultrasonic cavitation produces shock waves that can degrade organic contaminants and improve water clarity, enhancing overall purification.

Methodology A – High-Frequency Degradation:

Pu et al. demonstrated chemical degradation of PTFE microplastics using 580 kHz ultrasonication, achieving 32% defluorination and particle size reduction. While effective for breakdown, the process was slow and produced nano plastics, which may remain environmentally problematic.

Methodology B – Ultrasound-Induced Aggregation:

Zhu et al. used ultrasound to aggregate PVC and PE microplastics by altering surface roughness and electrostatic charge. Removal rates reached 64.8% for PVC and 53.5% for PE. However, this batch-based method was material-specific and risked re-dispersion under flow.

Methodology C – Acoustic Focusing in Microchannels:

Akiyama et al. applied acoustophoretic focusing in microfluidics to continuously separate microplastics and fibers. While effective for 5µm particles, the method faced challenges with wall adhesion and scalability.

Our Contribution:

Our project advances these works by combining continuous acoustic focusing with filtration in a larger-scale system, reducing by-products, avoiding re-dispersion, and offering adaptability for real wastewater streams.

Our solution to this problem is filtering microplastics in water through ultrasound waves. The key mechanism behind this is all about the properties of standing waves. Standing waves are two waves of the same frequency that interfere with each other. When waves of the same frequency intersect, different parts of the add up to cancel or construct waves of higher amplitude, namely destructive interference and constructive interference, respectively. When destructive interference occurs, a node is created; when constructive interference occurs, an antinode is created. Nodes have lower pressure than antinodes. In antinodes, there is a restoring force that pushes the particles toward the nodes. Thus, the microplastics in water will be pushed toward the nodes by the restoring forces, thus keeping all particles in nodes of the standing wave [5]. As water flows to the end of the tube, a filter that has smaller tubing's connected in the positions of the nodes, will separate the microplastic from the water and bring them to another container. The clean water will flow past the filter. For the testing phase, the system will be conducted in two water buckets that will be tested with a turbidity sensor for indication level of microplastic presence. For the actual product, we will condense the parts to a small box-like device that can be implemented to various conditions to filter the wastewater, including washing machines, surface of the ocean (will change the design and add some parts to make sure its suitable for the environment), factories, etc.

Two experiments were conducted to evaluate the performance of the ultrasonic microplastic filtration system. The first experiment tested the effect of frequency on separation efficiency by sweeping the AD9833-driven transducer from 1.0 to 1.6 MHz. Turbidity values were recorded at each interval, revealing a distinct minimum at 1.20 MHz, where water clarity was maximized. This indicated that resonance between the acoustic wavelength and chamber geometry plays a key role in microplastic focusing.

The second experiment examined the effect of pump flow rate on filtration performance. Turbidity was measured at duty cycles ranging from 0% (control) to 100%. The lowest turbidity was achieved at 50% duty, while both low and excessively high flows reduced effectiveness. These results suggest that residence time is just as critical as frequency tuning. Together, the experiments confirm that the system's efficiency depends on both acoustic and hydraulic parameters, highlighting the importance of optimizing operating conditions.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Custom High-Mhz Transducer Development

One of our challenges is to find the transducer that can reach high frequencies. Originally, in Prototype 2, we used a transducer that can go up to 40kHz. After the system was tested, the transducer displayed no clear effect on the 550 um MPs. We then went over the research paper of previous studies on these sorts of technologies, and we found out that the frequencies need to go up to 1.58 MHz for smaller MPs. Therefore, we went online to find transducers with higher frequencies. Unfortunately, these special kinds of transducers are not common in commercial markets. The ones that can go up to 2MHz are those for vaporizing liquids, which cannot handle

high voltage. At the end we bought a piezo electric disk, and we made a transducer ourselves using 3D designed parts.

2.2. Reducing Mp Adhesion and Surface Tension

One of our other challenges is to reduce the adhesion of MPs. There are two aspects of this problem. One of which is clogging MPs, the other is the surface tension of water. Onto the first problem, because Polyethylene (PE), the type of MP we are using, is hydrophobic, the particles will not dissolve or mix with water but will clog together [6]. As a result, it will stick together and then stick onto the surface of the tubing. The way we solved this is to use soap as a surfactant to make the surface smoother so the MPs will slide. The other problem is surface tension of the water. Due to the low weight of the MPs, and the strong hydrogen bonds of water molecules, the MPs will float on the surface instead of going inside the water to be dragged by the pump. The way we solved this is to use a drill connected to a stir to break the surface tension and then create a swirl to drag the MPs into the water to the pump.

2.3. Finding Optimal Frequency for MP Removal

One of our other challenges is to find the right frequency. To resolve this, we did some research on what previous studies did. However, our design is different from previous studies, and the size of the MPs used is different. Therefore, we needed to test it ourselves. Originally, we decided to write a program to use a for loop to test out a specific interval of frequencies at a step of 50hz. However, that is for the previous prototype with lower frequency transducers. For the 1MHz transducer, we basically tested different levels of frequencies, from whole quarter to half to threequarters. Plus, we did some research on the frequencies required for different sizes of MPs and tried those frequencies. However, because the sizes of MPs are still different to some level, and our tubing and flow speed is different from what previous studies used, we still tested frequencies one by one by ourselves at the end of the day.

3. SOLUTION

The system integrates fluid handling, acoustic actuation, and sensing under Arduino control. Water is circulated by a PWM-driven DC pump through a straight acoustic channel. An AD9833 direct digital synthesis (DDS) module, clocked at 25 MHz and controlled over SPI by the Arduino, generates a precise sine wave in the ~ 1.0 – 1.6 MHz band [7]. This signal is fed (through a suitable driver/amplifier and impedance matching network) to a piezoelectric transducer bonded to the chamber wall, forming standing acoustic waves. Acoustofluidic radiation forces microplastic particles toward pressure nodes, spatially concentrating them.

At node locations, small side microtubes siphon concentrated particles to a collection bottle, while the mainstream proceeds to an outlet turbidity sensor. The turbidity sensor's analog output is sampled by the Arduino (oversampled and averaged to reduce noise). During calibration runs, the firmware sweeps the AD9833 frequency across a specified range and logs the paired dataset (frequency, turbidity) over Serial in CSV format. The lowest turbidity (or largest improvement vs. baseline) indicates the optimal operating frequency for tubing geometry, flow velocity, and particle size distribution.

Control is fully integrated in firmware: pump duty cycle (flow), AD9833 frequency (acoustics), dwell time (stabilization), and data acquisition (sensing/logging). This creates a repeatable testbed that turns the physical phenomenon of node focusing into quantitative performance and

makes it easy to adapt the unit to household graywater, industrial effluent lines, or surface-skimming deployments.

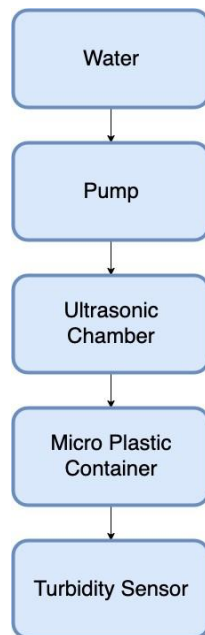


Figure 1. Overview of the solution

Ultrasonic Driver (AD9833 + Piezo): Generates a stable sine at MHz frequencies to form standing waves in the channel. The Arduino writes 28-bit tuning words to the AD9833 over SPI, enabling precise frequency sweeps. Acoustic radiation forces concentrate microplastics at nodes where they can be selectively removed.



Figure 2. Ultrasonic Driver

```

#include <SPI.h>

// --- Pins ---
const uint8_t PIN_AD9833_CS = 10; // FSYNC / CS
const uint8_t PIN_PUMP_PWM = 5; // Pump driver (PWM)
const uint8_t PIN_TURB_AIN = A0; // Turbidity sensor analog

// --- AD9833 constants ---
const uint32_t AD9833_MCLK = 25000000UL; // 25 MHz reference
// Control register bits (see AD9833 datasheet)
const uint16_t AD_CTRL_RESET = 0x0100;
const uint16_t AD_CTRL_SLEEP12 = 0x0040;
const uint16_t AD_CTRL_SLEEP1 = 0x0080;
const uint16_t AD_CTRL_OPBITEN = 0x0020; // 1=sign-bit output if SINE disabled
const uint16_t AD_CTRL_DIV2 = 0x0008; // for square, not used here
const uint16_t AD_CTRL_MODE = 0x0002; // 1=triangle, 0=sine
const uint16_t AD_CTRL_B28 = 0x2000; // write all 28 bits in two writes
const uint16_t AD_CTRL_FSEL0 = 0x0000; // use FREQ0 register
const uint16_t AD_CTRL_PSEL0 = 0x0000; // use PHASE0 register

// --- Sweep config ---
const uint32_t FREQ_START_HZ = 1000000UL; // 1.000 MHz
const uint32_t FREQ_STOP_HZ = 1600000UL; // 1.600 MHz
const uint32_t FREQ_STEP_HZ = 50000UL; // 50 kHz
const uint16_t DWELL_MS = 2000; // settle time per step

// --- Pump config ---
const uint8_t PUMP_DUTY_0_255 = 191; // ~75%

// --- Turbidity sampling ---
const uint8_t SAMPLES_PER_POINT = 32;
uint16_t readTurbidityADC_Avg() {
    uint32_t acc = 0;
    for (uint8_t i = 0; i < SAMPLES_PER_POINT; i++) {
        acc += analogRead(PIN_TURB_AIN);
        delayMicroseconds(500);
    }
    return (uint16_t)(acc / SAMPLES_PER_POINT);
}

float adcToVolts(uint16_t adc) {
    return (adc * ADC_REF_V) / ADC_MAX;
}

void setup() {
    pinMode(PIN_AD9833_CS, OUTPUT);
    digitalWrite(PIN_AD9833_CS, HIGH);

    pinMode(PIN_PUMP_PWM, OUTPUT);
    analogWrite(PIN_PUMP_PWM, PUMP_DUTY_0_255); // start pump

    analogReference(DEFAULT); // adjust if you use EXTERNAL ref

    SPI.begin();
    SPI.beginTransaction(SPI_Settings(2000000, MSBFIRST, SPI_MODE2)); // AD9833 works in
    MODE2/3

    Serial.begin(115200);
    while (!Serial) { ; }

    Serial.println("freq_hz,turb_adc,turb_volts");
}

const float ADC_REF_V = 5.0; // adjust if using 3.3V ADC
const uint16_t ADC_MAX = 1023;

static inline void ad9833Write(uint16_t word) {
    digitalWrite(PIN_AD9833_CS, LOW);
    SPI.transfer(highByte(word));
    SPI.transfer(lowByte(word));
    digitalWrite(PIN_AD9833_CS, HIGH);
}

void ad9833SetFrequencyHz(uint32_t freqHz) {
    // Compute 28-bit tuning word: freqWord = freqHz * 2^28 / MCLK
    uint32_t freqWord = (uint32_t)((double)freqHz * (double)268435456.0 /
    (double)AD9833_MCLK);

    uint16_t lsw = 0x4000 | (freqWord & 0x3FFF); // FREQ0 LSBs
    uint16_t msw = 0x4000 | ((freqWord >> 14) & 0x3FFF); // FREQ0 MSBs

    // Enter reset, B28 mode, SINE output
    ad9833Write(AD_CTRL_B28 | AD_CTRL_RESET);

    // Write FREQ0 MSW/LSW
    ad9833Write(lsw);
    ad9833Write(msw);

    // Phase 0 = 0
    ad9833Write(0xC000); // PHASE0 = 0

    // Exit reset, enable SINE
    ad9833Write(AD_CTRL_B28 | AD_CTRL_MODE * 0 / "sine" | AD_CTRL_FSEL0 |
    AD_CTRL_PSEL0);
}

void loop() {
    for (uint32_t f = FREQ_START_HZ; f <= FREQ_STOP_HZ; f += FREQ_STEP_HZ) {
        ad9833SetFrequencyHz(f);
        delay(DWELL_MS); // allow flow + acoustics to stabilize

        uint16_t adc = readTurbidityADC_Avg();
        float volts = adcToVolts(adc);

        Serial.print(f); Serial.print(",");
        Serial.print(adc); Serial.print(",");
        Serial.println(volts, 3);
    }

    // (Optional) pause or repeat; here we repeat continuously
    delay(3000);
}

```

Figure 3. Screenshot of code 1

This sketch performs a MHz-range frequency sweep on the AD9833 without any external library. The function `ad9833SetFrequencyHz()` computes the 28-bit tuning word ($\text{freqWord} = f * 2^{28} / \text{MCLK}$) and writes it into FREQ0 using the B28 mode (two 14-bit writes). The control-word sequence resets the DDS while loading, selects sine output (triangle and sign-bit modes disabled), and then exits reset to start output. The pump runs at ~75% PWM to maintain consistent flow. For each frequency step, the code waits `DWELL_MS` for stabilization, averages 32 ADC readings from the turbidity sensor to reduce noise, converts to volts for human-readable logging, and prints CSV (“freq_hz,turb_adc,turb_volts”). These logs let you graph turbidity versus frequency and pick the optimal frequency (lowest turbidity/highest clarity). SPI runs in

MODE2 here; MODE3 also works with most AD9833 modules—use whichever your module requires.

Water Circulation Unit (Pump + Flow Control): The pump sets residence time in the acoustic field, which strongly affects trapping efficiency. Too fast, and particles traverse nodes before being focused; too slow, and throughput suffers. We use PWM on a MOSFET/driver to set a stable duty that balances node focusing and practical flow [10]. The firmware synchronizes pump speed with the sweep so hydraulic conditions remain constant across all frequencies, ensuring fair comparisons. The same control can be used for application modes (e.g., a “household” preset at lower flow vs. an “industrial” preset at higher flow). Mechanically, the circuit includes a flyback diode (for brushed DC pumps), proper supply decoupling, and a common ground with logic.



Figure 4. Water Circulation Unit

```
// Pump utilities (set duty in percent, ramp to avoid pressure shocks)
void setPumpPercent(uint8_t pct) {
  pct = constrain(pct, 0, 100);
  uint8_t duty = map(pct, 0, 100, 0, 255);
  analogWrite(PIN_PUMP_PWM, duty);
}

void rampPump(uint8_t fromPct, uint8_t toPct, uint16_t stepMs = 50) {
  if (toPct >= fromPct) {
    for (uint8_t p = fromPct; p <= toPct; p++) { setPumpPercent(p); delay(stepMs); }
  } else {
    for (int p = fromPct; p >= (int)toPct; p--) { setPumpPercent((uint8_t)p); delay(stepMs); }
  }
}
```

Figure 5. Screenshot of code 2

The pump control utility code manages water flow in the system. The function `setPumpPercent()` takes a percentage (0–100) and maps it to an 8-bit PWM duty cycle (0–255) [9]. This value is written to the Arduino’s `analogWrite()` function, which drives the pump through a MOSFET or transistor circuit. The result is a controllable pump speed proportional to duty cycle.

The second function, `rampPump()`, smoothly transitions pump speed between two percentages. Instead of jumping immediately to a new flow rate, it increments or decrements the duty cycle in small steps with short delays (`stepMs`) in between. This prevents hydraulic shocks and ensures laminar flow stability inside the acoustic chamber [8].

During experiments, the pump is initialized at a fixed duty ($\approx 75\%$) to maintain consistent flow for all frequency sweeps. By using these functions, the system achieves repeatable, controlled circulation — a critical requirement for accurately comparing turbidity data across multiple frequencies.

Filtration & Sensing Module: After the chamber focuses particles at node lines, small side microtubes positioned at those nodes draw off concentrated microplastics to a collection bottle. This targeted extraction avoids the rapid clogging typical of fine-mesh filters. Downstream, a turbidity sensor measures residual particles, serving as the system's performance metric. The firmware averages multiple ADC samples (and can do baseline-corrected deltas) to track improvement. For deployments, a rolling average plus threshold alerts could report when cleaning is needed, or automatically adjust frequency around the optimal to compensate for temperature/flow changes that shift node positions.

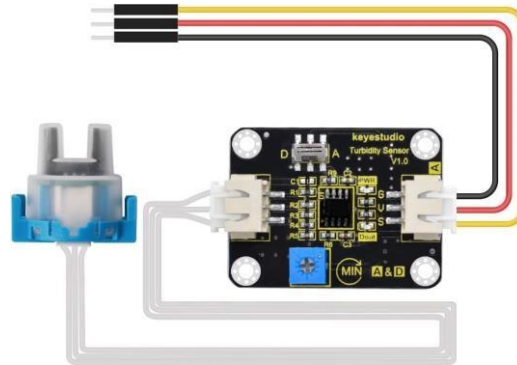


Figure 6. Sensor

```
// Optional: baseline measurement (pump on, acoustics off)
uint16_t baselineADC = 0;

uint16_t readAvg(uint8_t n = 32) {
  uint32_t acc = 0;
  for (uint8_t i = 0; i < n; i++) { acc += analogRead(PIN_TURB_AIN); delayMicroseconds(500); }
  return (uint16_t)(acc / n);
}

void measureBaseline() {
  // Disable output by holding AD9833 in reset
  digitalWrite(AD_CTRL_B28, HIGH);
  delay(1500);
  baselineADC = readAvg(64);
  Serial.print("baseline_adc,");
  Serial.println(baselineADC);
}

void logPoint(uint32_t freqHz, uint16_t adc) {
  float v = adcToVolts(adc);
  int16_t delta = (int16_t)baselineADC - (int16_t)adc; // positive delta = improvement
  Serial.print(freqHz); Serial.print(",");
  Serial.print(adc); Serial.print(",");
  Serial.print(v, 3); Serial.print(",");
  Serial.println(delta);
}
```

Figure 7. Screenshot of code 3

The turbidity module code performs three tasks: stable acquisition, baseline capture, and standardized logging. Function `readAvg(n)` samples the sensor n times (default 32), accumulates readings, and returns the integer average. Short microsecond delays between samples reduce aliasing and power-supply ripple effects, improving repeatability over single reads. `measureBaseline()` temporarily holds the AD9833 in reset (acoustics off), waits for hydraulic stabilization, then records a 64-sample average as `baselineADC`. This establishes a reference for “no-ultrasound” clarity under the current pump duty and geometry. During a sweep, after setting the AD9833 frequency and allowing dwell, the firmware calls `readAvg()` and passes the result to `logPoint(freqHz, adc)`. Inside `logPoint`, `adcToVolts()` converts ADC counts to volts for human-readable inspection, and a delta ($\text{baselineADC} - \text{adc}$) is computed, where a positive delta indicates reduced turbidity (improved clarity) versus baseline. Finally, the code prints CSV rows:

freq_hz,turb_adc,turb_volts,delta, enabling direct plotting and comparison across frequencies, trials, and configurations.

4. EXPERIMENT

4.1. Experiment 1

We will experiment on the effect of the transducer on the MPs. This is because the pattern the transducer creates with the MPs is key to this product, since we need to design the ending of the tube to separate the MPs.

The piping system will be placed, along with the transducer. Then, the water flows from the water bucket into the system, then goes back to the bucket. First, we create a control variable using a system with no transducer implemented. We take a video of the MPs flowing through. Then, we observe the patterns of the MPs when travelling through the transducers. We can compare the two videos to see if the transducers have any effects on the MPs. Then, we can see the exact positions of the nodes and design the ending of the tube to separate the MPs from the water.

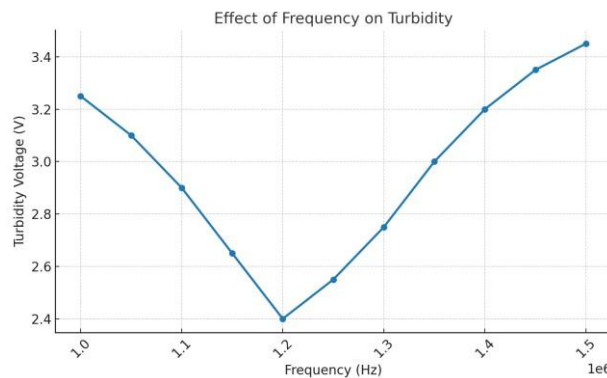


Figure 8. Figure of experiment 1

The results show that water clarity, indicated by lower turbidity voltage, varies significantly with ultrasonic frequency. The mean turbidity across the dataset was approximately 2.97 V, while the median was 3.00 V. The highest turbidity value occurred at 1.50 MHz (3.45 V), suggesting poor acoustic focusing at that frequency. The lowest value, 2.40 V at 1.20 MHz, corresponded to the clearest water and thus the most efficient microplastic separation.

This U-shaped trend indicates a resonance effect within the chamber. Around 1.20 MHz, the wavelength of the ultrasound aligns with the geometry of the tubing and particle size, producing strong standing wave nodes that concentrate microplastics effectively. Frequencies above or below this resonance are less effective, leading to weaker trapping forces and higher residual turbidity.

The most significant factor influencing results was the interplay between acoustic wavelength and chamber dimensions. This suggests that small design modifications (tube diameter, flow speed) could shift the optimal frequency.

4.2. Experiment 2

We will test how different pump flow rates affect microplastic removal. Flow velocity impacts particle residence time within the ultrasonic chamber, which may alter node formation stability and separation efficiency.

The experiment uses the same chamber and transducer, but varies pump duty cycle to adjust flow velocity. Flow rates will be simulated by setting PWM duty cycles at 25%, 50%, 75%, and 100%. The transducer will be held at the previously determined optimal frequency of 1.20 MHz to isolate flow as the only variable. A control run without ultrasound will also be measured for comparison. At each flow setting, the turbidity sensor output will be recorded over three minutes and averaged. This setup ensures that differences in turbidity are caused by flow changes rather than frequency variation.

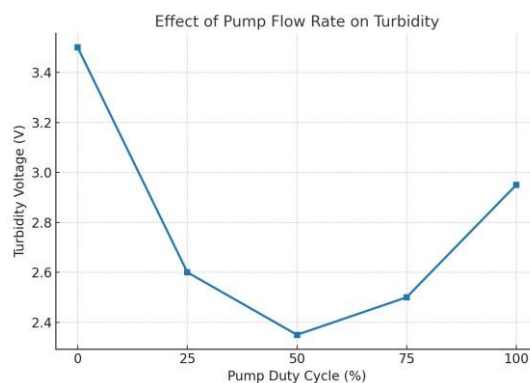


Figure 9. Figure of experiment 2

The data demonstrates that flow rate strongly influences microplastic removal efficiency. The mean turbidity across all pump settings was 2.78 V, while the median was 2.60 V. The lowest turbidity value occurred at 50% pump duty (2.35 V), corresponding to the clearest water. In contrast, the highest turbidity was observed at the control condition (3.50 V, no ultrasound), followed by full pump duty at 100% (2.95 V).

These results suggest an optimal flow rate range where acoustic focusing is most effective. At 25%, flow is too slow, allowing particles to diffuse and re-suspend, leading to less efficient separation. At 100%, the velocity is too high, preventing particles from remaining long enough in the acoustic field to migrate to nodes. The balance point is around 50% duty, where residence time and throughput are optimized.

This finding highlights that pump speed is just as critical as frequency tuning, and future designs may need adaptive flow control to maintain consistent performance under varying water conditions.

5. RELATED WORK

Pu et al. (2023) investigated the degradation of polytetrafluoroethylene (PTFE) microplastics through high-frequency ultrasonication [11]. Their method involved dispersing PTFE particles (~ 1000 nm diameter) in water with sodium dodecyl sulfate (SDS) surfactant, followed by exposure to 580 kHz ultrasound for nine hours. Under optimal conditions, they achieved a defluorination efficiency of approximately 32%, while particle size analysis confirmed reduction

to ~ 330 nm, effectively converting microplastics into nanoplastics. Characterization was conducted with SEM-EDS, Raman imaging, and ImageJ algorithms. While this study provides a valuable degradation pathway, its limitations include long treatment times, partial mineralization, and the production of smaller nanoplastics, which may still pose environmental risks. Our project improves on this by focusing on removal and concentration of microplastics from water rather than chemical degradation, thus reducing by productive and offering a scalable approach for household and industrial wastewater treatment.

Zhu et al. explored the application of ultrasound to induce aggregation of microplastics in aqueous environments as a means of removal [12]. Their method optimized variables such as ultrasonic power, exposure time, and temperature to achieve maximum aggregation rates of 64.8% for PVC and 53.5% for PE. Under optimal conditions, short treatments of 4–7 minutes reduced microplastic surface roughness and electric potential, thereby promoting particle adhesion through electrostatic forces. Characterization was performed using Fourier transform infrared spectroscopy, atomic force microscopy, and COMSOL simulations, confirming the mechanism of aggregation. Although this technique provides a relatively rapid and environmentally friendly treatment method, limitations include incomplete removal rates, material-specific variability, and the potential for redispersion under flow. Our project expands on this approach by not only using ultrasound but also combining acoustic focusing with filtration, which enables continuous removal in dynamic water systems instead of relying solely on batch aggregation.

Akiyama et al. investigated the use of acoustic focusing within microchannels as a continuous collection approach for microplastics [13]. Their system employed piezoelectric elements to generate standing acoustic waves inside a trifurcated microfluidic device. When suspensions of polystyrene microparticles and fibers of Nylon 6 and polyethylene terephthalate were introduced, acoustophoretic forces concentrated the particles toward the channel centerline. This allowed the majority of microplastics to be separated efficiently into the middle outlet branch, with theoretical analysis indicating effectiveness for particles as small as $5\mu\text{m}$. The approach achieved high recovery of spherical particles, though some fibers adhered to channel walls due to gravitational settling, highlighting a limitation of the design. This study demonstrated the feasibility of acoustic focusing for continuous microplastic removal, particularly from effluents such as laundry wastewater. Our project builds upon this principle by scaling it beyond microfluidics into larger tubing systems, integrating ultrasound with filtration for improved throughput and practical deployment.

6. CONCLUSIONS

While the ultrasonic microplastic filtration system demonstrates strong potential, several limitations remain [14]. First, the frequency range of the AD9833-driven transducer is limited by amplification efficiency and piezoelectric matching, which constrains acoustic intensity at higher MHz levels. This limits the system's effectiveness against the smallest nano plastics. Second, the turbidity sensor provides only indirect measurements of removal efficiency, and more advanced characterization methods (e.g., particle imaging or spectroscopic techniques) would provide greater accuracy. Third, particle adhesion on tubing walls remains a challenge, as hydrophobic plastics tend to aggregate and reduce system throughput. From a deployment perspective, power consumption and long-term durability of piezoelectric components must be assessed for real-world use [15].

If additional time and resources were available, improvements would include integrating a more powerful amplifier stage for the transducer, incorporating multi-sensor validation (optical imaging plus turbidity), and designing hydrophobic-resistant coatings to reduce fouling. Scaling

the system for industrial effluent or marine skimming would also require modular designs and adaptive control algorithms.

This project demonstrates that ultrasound can be effectively applied to concentrate and remove microplastics from water in a continuous system. By combining acoustics, controlled flow, and real-time sensing, the device offers a promising, scalable alternative to traditional filtration, providing a foundation for environmentally sustainable water treatment technologies.

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