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Study, Design, and Analysis of a Shaking Water Bath for Medical and Laboratory Applications

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Abstract: The precise control of thermodynamic parameters and mechanical kinematics is critical in modern clinical, biological, and chemical laboratories. This project presents a comprehensive study, design analysis, and performance evaluation of a digital Shaking Water Bath, a vital biomedical device that seamlessly integrates thermal incubation with mechanical agitation. The study investigates the internal electromechanical architecture of the device, focusing on the Proportional-Integral-Derivative (PID) thermal controller, the Pulse Width Modulation (PWM) motor drive system, and the primary sensors. A detailed comparative analysis was conducted against standard static water baths, circulating water baths, dry block heaters, and air incubators to highlight the operational advantages, clinical applications, and maintenance limitations of the shaking mechanism. Furthermore, simulated performance testing was executed to evaluate the device's thermal accuracy, spatial temperature uniformity, and rotational speed (RPM) stability under varying sample loads. The results demonstrated exceptional system reliability. The PID controller successfully maintained target clinical temperatures (e.g., 37°C and 45°C) with a minimal deviation error of ±0.2°C. Additionally, the continuous mechanical agitation effectively eliminated thermal "dead zones," achieving a highly stable spatial uniformity of ±0.1°C across the entire stainless-steel tank. The motor drive mechanism also proved highly resilient, maintaining 96.6% mechanical efficiency under maximum payload conditions at a set speed of 150 RPM. The research concludes that the shaking water bath is an indispensable and superior tool for dynamic laboratory protocols—such as cell culturing, DNA extraction, and solubility testing—provided that strict preventative maintenance protocols are implemented by biomedical engineering departments.

Keywords: Shaking Water, Medical Applications, Laboratory Application

Introduction

A laboratory water bath is a fundamental and versatile piece of thermodynamic equipment designed to incubate samples in water at a constant, tightly controlled temperature over an extended period. The core principle relies on the high specific heat capacity of water, which makes it an excellent medium for stable heat transfer [1]. In clinical, chemical, and biological research environments, maintaining precise thermal conditions is critical. Many biochemical reactions, enzymatic processes, and microbiological cultures require specific temperature ranges to thrive or react appropriately. Unlike open-flame heating (such as Bunsen burners) or dry heat methods (like ovens), a water bath provides a highly stable and uniform heat transfer medium through conduction and convection [2]. This ensures that delicate organic samples are not subjected to sudden temperature spikes, localized overheating, or rapid evaporation, which could denature sensitive proteins, destroy live cell cultures, or invalidate experimental results.

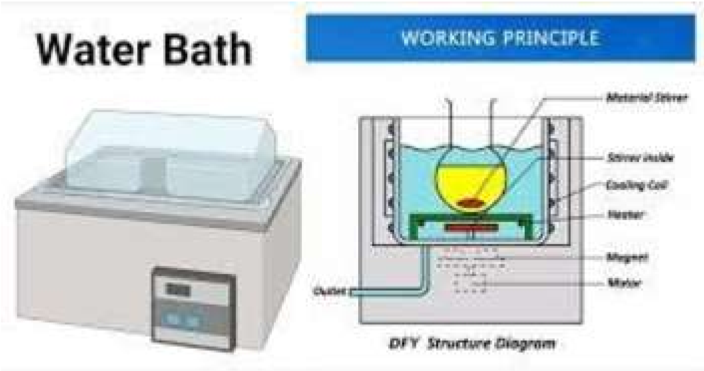

Figure 1. A standard analog laboratory water bath illustrating the stainless-steel interior tank, heating element position, and external casing

Purpose of the Study: Water baths are ubiquitous in modern healthcare facilities, diagnostic laboratories, and biotechnology research centers. Their medical applications are broad and highly critical for patient care and accurate diagnostics [3]:

1. Blood Banks and Hematology: They are extensively used to thaw Fresh Frozen Plasma (FFP), cryoprecipitate, and warm whole blood products to body temperature (37°C) prior to patient transfusion, effectively preventing transfusion-induced hypothermia [4].
2. Microbiology and Pathology: Used for incubating microbial swabs, culturing bacteria, and melting agar or other solid culture media.
3. Clinical Biochemistry: Essential for warming reagents, conducting enzyme kinetics studies, and facilitating colormetric tests where temperature drastically affects the reaction rate [5].
4. Radiology and Pharmacology: Occasionally used to gently warm contrast media before injection to reduce viscosity and improve patient comfort.

Figure 2. Clinical application of a water bath in a hospital setting, showing blood bags or test tubes placed in specialized racks inside the heated water

Depending on the specific requirements of the laboratory protocol, the required temperature uniformity, and the nature of the samples, water heating systems are categorized into several primary types [6]:

1. Non-Circulating (Static) Water Baths: These are the simplest models, relying primarily on natural convection currents to distribute heat from the bottom-mounted elements throughout the water. While cost-effective and suitable for general incubation, they may suffer from slight temperature gradients (hot and cold spots) across different areas of the tank [7].

2. Circulating Water Baths (Stirrers): To overcome the limitations of static baths, circulating models incorporate an internal pump or a magnetic stirring mechanism. This actively and continuously circulates the water, ensuring strict thermal uniformity and rapid heat recovery after the lid is opened. They are vital for highly sensitive processes like Polymerase Chain Reaction (PCR) preparation [8].
3. Dry Baths (Block Heaters): While not using water, these are related devices that use interchangeable heated aluminum blocks holding specific tube sizes. They are preferred when absolute sterile conditions are required, and the risk of waterborne cross-contamination must be eliminated.

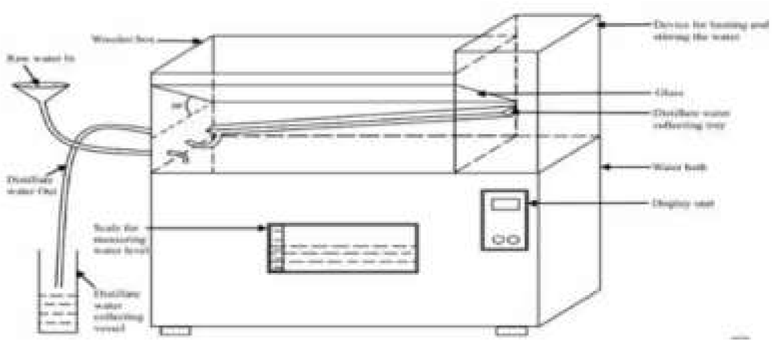

Figure 3. A comparative visual diagram illustrating the airflow and heat distribution differences between Static, Circulating, and Dry water baths

The Shaking Water Bath represents a significant technological advancement in laboratory equipment. It integrates the precise thermal control of a circulating bath with the mechanical agitation of a laboratory shaker. This device features a motorized platform (the shaker mechanism) submerged in the heated water, which moves liquid samples within sealed flasks or tubes [9]. The shaking motion can typically be adjusted in terms of speed (Revolutions Per Minute

1. RPM) and is usually available in two modes:
   a. Linear (Reciprocal) Shaking: Moving back and forth, ideal for gentle extraction and general mixing.
   b. Orbital Shaking: Moving in a circular motion, providing more vigorous aeration for bacterial cultures.

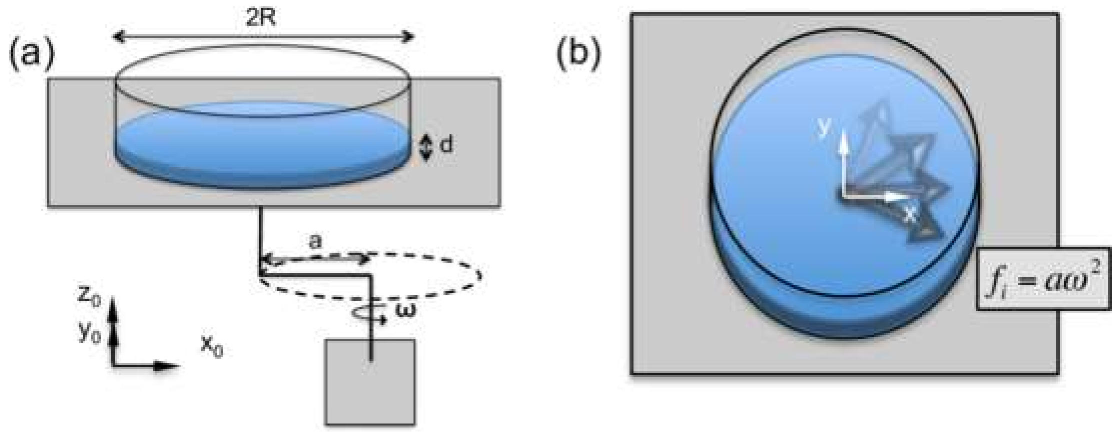

Figure 4. Illustration of Linear(a) vs. Orbital shaking mechanisms(b), demonstrating the movement patterns of the submerged platform

To achieve the dual functionality of precise thermal regulation and consistent mechanical agitation, a modern digital shaking water bath integrates several specialized structural, thermodynamic, and electromechanical components [10]. Understanding these core modules is essential for proper design analysis and system troubleshooting:

a. Inner Chamber (Tank): Typically constructed from high-grade, corrosion-resistant stainless steel (e.g., Grade 304 or 316). The tank is designed with smooth, seamless edges to facilitate cleaning and prevent microbial biofilm buildup.
b. Heating Element: A resistive electrical heater, usually positioned beneath the floor of the inner tank or integrated into the walls. It safely converts electrical energy into thermal energy, distributing heat evenly into the water medium.
c. Motor and Drive Mechanism: The electromechanical heart of the shaking function. It typically employs a heavy-duty, brushless DC (BLDC) motor or a precision stepper motor to ensure longevity and quiet operation in continuous use. This motor is coupled with a mechanical linkage system—such as an eccentric cam for orbital motion or a crank-slider mechanism for linear motion—that translates the motor's rotary output into the desired platform movement [11].
d. Shaking Platform (Sample Rack): A submerged, dynamically balanced tray equipped with spring racks, clamps, or customized holders. It securely anchors various laboratory vessels (flasks, test tubes, beakers) to prevent tipping or buoyancy-induced floating during agitation.
e. Digital Microprocessor and PID Controller: The electronic "brain" of the device. A Proportional-Integral-Derivative (PID) controller continuously reads data from integrated sensors (like a PT100 Platinum Resistance Thermometer) and adjusts the heating element's power output to maintain the exact setpoint without overshooting. It simultaneously regulates the motor speed (RPM) to ensure consistent agitation [12].
f. Gabled (Pyramidal) Lid: A critically angled cover, usually transparent. Its primary function is thermodynamic insulation and condensation management. The slope ensures that evaporated water vapor condenses and drips back down the sides of the tank rather than falling directly onto and contaminating the sample vessels.

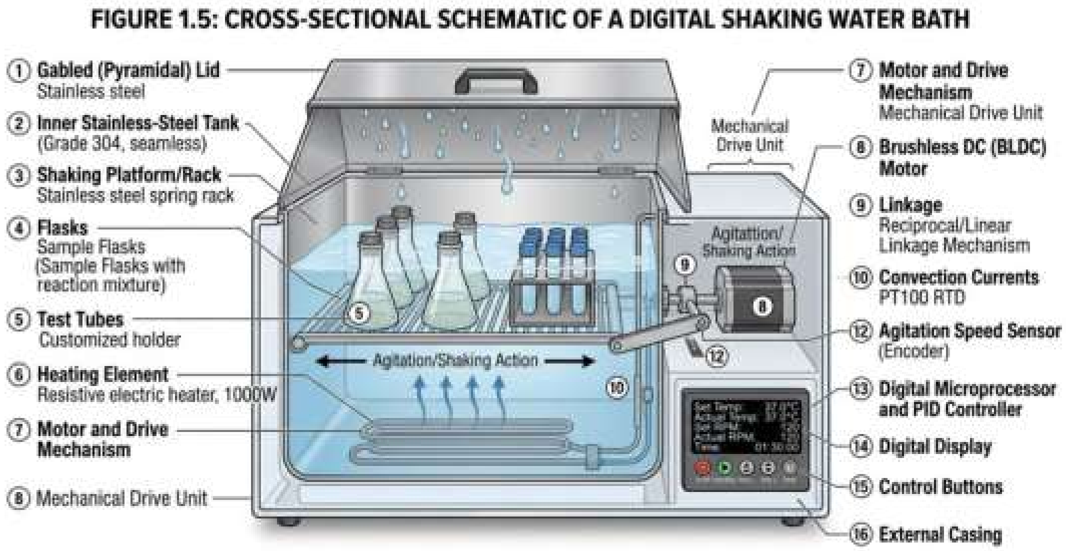

Figure 5. A cross-sectional schematic illustrating the primary electromechanical, thermodynamic, and structural components of a modern digital shaking water bath.

In complex microbiological culturing, DNA extraction protocols, and certain biochemical assays, simply maintaining a constant temperature is insufficient. Microorganisms in static liquid media quickly consume the oxygen and nutrients immediately surrounding them, stunting their growth [13]. Therefore, continuous and uniform agitation is required to promote aeration (oxygen transfer) and prevent the settling of suspended cells. Historically, laboratories had to use a separate incubator and a standalone mechanical shaker. This approach introduces several variables: it consumes valuable laboratory bench space, increases energy consumption, and introduces the risk of thermal shock and contamination during sample transfer between devices.

The modern shaking water bath resolves these critical issues by integrating both thermodynamic stability and mechanical agitation into a single, highly efficient electromechanical device. Therefore, a comprehensive engineering study and design analysis of this device's operational mechanics, components, and potential failures are essential for biomedical technicians.
The primary objective of this project is to conduct a thorough technical and clinical evaluation of the Shaking Water Bath (specifically focusing on digital models like the iGene Labserve). The specific objectives are defined as follows:

1. To review the fundamental thermodynamic principles and clinical applications of laboratory water bath systems.
2. To analyze the internal electromechanical components, design architecture, and digital control systems of the shaking water bath.
3. To identify and evaluate the operational advantages, practical limitations, and common technical faults (troubleshooting) of shaking water baths compared to standard static models.
4. To provide a comprehensive comparative analysis of various laboratory sample-heating devices to guide clinical engineering departments in equipment selection and maintenance.

Materials and Methods:

This study adopted an engineering design and performance evaluation methodology to investigate the operational characteristics of a digital shaking water bath used in medical and laboratory applications. The research focused on the thermal control system, mechanical shaking mechanism, and overall operational performance of the device. The methodology combined design analysis, comparative evaluation, and simulated performance testing to assess the effectiveness of the shaking water bath under laboratory operating conditions.
The investigated system was a digital shaking water bath equipped with a stainless-steel chamber, an electric heating element, a brushless DC motor driving an orbital shaking platform, a PT100 temperature sensor, and a microprocessor-based PID controller. The unit also incorporated PWM motor speed control for maintaining constant rotational speed under different loading conditions.
The evaluation procedure consisted of three main performance tests: thermal accuracy, mechanical agitation stability, and spatial temperature uniformity. Before each test, the water bath was filled with distilled water to the recommended operating level and allowed to stabilize for 10 minutes. The temperature sensor was calibrated using a laboratory-grade digital thermometer, and the shaking mechanism was inspected to ensure normal operation.
The structural and electronic design of a shaking water bath is significantly more complex than a static model. The primary components include [14][15]:

1. The Inner Tank (Chamber): Typically constructed from high-grade, corrosion-resistant stainless steel (e.g., 304 or 316 grade). This material is chosen for its excellent heat conductivity, durability against chemical spills, and ease of sterilization.
2. Heating Element: A high-wattage resistive heating element is either immersed directly in the water at the base of the tank or securely bonded to the exterior of the tank's bottom. It provides the thermal energy required to heat the liquid medium.
3. The Shaker Mechanism (Drive System): This is the distinguishing feature of the device. It consists of a reliable electric motor (often a brushless DC or stepper motor for precise control), a drive belt or gear system, and an eccentric linkage. This assembly translates the rotary motion of the motor into the linear (reciprocal) or orbital motion of the sample tray.
4. Digital Control Unit: Modern systems, such as the iGene Labserve model, utilize an advanced microprocessor-based control panel. It features dual digital displays: one for setting and monitoring the temperature (via a PID controller) and another for controlling the shaking speed in Revolutions Per Minute (RPM) [16].
5. Temperature Sensors: A highly accurate sensor, usually a Platinum Resistance Temperature Detector (PT100 RTD) or a thermistor, continuously monitors the water temperature and feeds this data back to the microprocessor to maintain thermal stability.

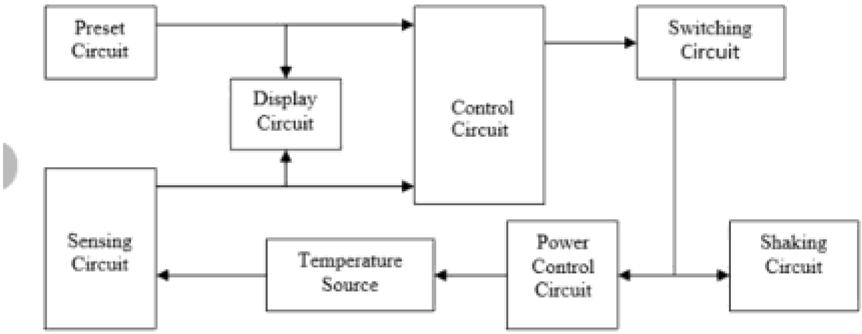

Figure 6. A block diagram illustrating the internal architecture of a shaking water bath, showing the interaction between the microcontroller, heater, motor, and sensors

Figure 7. Close-up of a digital control panel featuring dual LED displays for Temperature and RPM control, similar to the iGene Labserve model

The operation of the shaking water bath relies on a closed-loop feedback system. When the user inputs a target temperature, the Proportional-Integral-Derivative (PID) controller calculates the exact amount of electrical power to supply to the heating element [17]. As the water reaches the set point, the PID controller reduces the power, pulsing it precisely to maintain the temperature without overshooting. Simultaneously, the shaker mechanism operates independently. The user sets the desired RPM, and a Pulse Width Modulation (PWM) signal drives the motor at a constant speed, regardless of the weight of the samples loaded on the tray. The continuous movement of the tray also acts as a mechanical stirrer for the water itself, ensuring exceptional thermal uniformity throughout the tank [18].
Specific Medical and Laboratory
Uses The dual-action nature of the shaking water bath makes it crucial for specific laboratory procedures:

1. Cell and Tissue Culture: Agitation ensures that cells in liquid media remain suspended and receive adequate aeration (oxygenation), which is vital for aerobic bacterial and mammalian cell growth [19].
2. DNA and RNA Extraction: Used to incubate samples with lysis buffers, where constant shaking speeds up the breakdown of cell membranes.
3. Enzyme Kinetics: Certain enzymatic reactions require continuous kinetic energy to maximize the contact between enzymes and substrates.
4. Solubility Testing: Accelerates the dissolving process of poorly soluble pharmaceutical powders in specific solvents.

Figure 8. Flasks containing biological cultures secured on the oscillating spring-rack of a shaking water bath

Like all medical laboratory equipment, shaking water baths have distinct pros and cons that dictate their selection [20].
Advantages:

1. High Thermal Uniformity: The constant movement of the shaker tray naturally circulates the water, eliminating cold or hot spots entirely.
2. Space and Time Efficiency: Combines two devices (incubator and shaker) into one footprint, reducing sample handling time and saving laboratory bench space.
3. Versatility: Spring racks and universal clamps allow the device to hold various containers, from microcentrifuge tubes to large Erlenmeyer flasks, simultaneously.

Limitations (Disadvantages):

1. Maintenance Requirements: The presence of moving mechanical parts (motors, bearings, belts) in close proximity to water and heat significantly increases wear and tear compared to static baths.

2. Higher Cost: The integration of motors and dual-control electronics makes these units substantially more expensive.
3. Vibration Noise: High-speed shaking can generate operational noise and transmit vibrations to the laboratory bench, potentially affecting nearby sensitive equipment like analytical balances.

Common Breakdowns and Faults

Biomedical engineers frequently encounter several common issues when maintaining these devices [21]:

1. Heater Failure (Burnout): Operating the device without sufficient water (running dry) is the most common cause of heating element burnout, despite thermal cutoff safety switches.
2. Motor Stalling or Jerking: Caused by overloading the tray beyond its weight capacity, wearing out of the drive belt, or water ingress into the motor bearings causing rust and friction.
3. Sensor Drift: Over time, the PT100 temperature sensor may lose calibration due to constant thermal cycling, causing the actual water temperature to differ from the displayed temperature, ruining sensitive biological samples.
4. Control Board Malfunctions: Power surges or high humidity environments can short-circuit the sensitive microprocessors responsible for PID and PWM control.

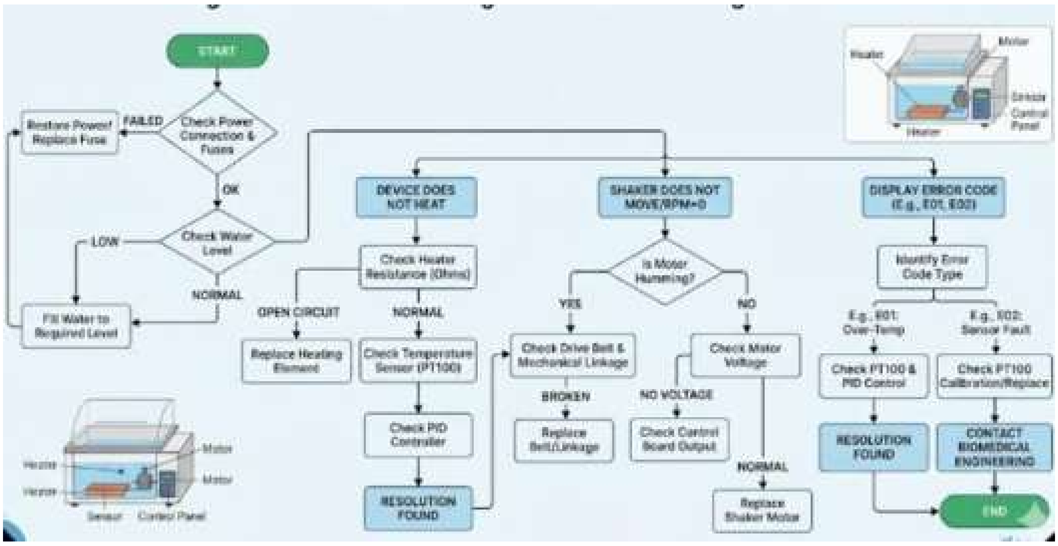

Figure 9. A troubleshooting flowchart for diagnosing common faults in a shaking water bath, such as a heater failure or motor stall

Comparison of Heating Mediums: Water vs. Air vs. Solid Blocks

The fundamental difference between heating devices lies in the medium used to transfer thermal energy to the sample.

Water (Water Baths): Water has a high specific heat capacity, allowing for rapid and highly efficient heat transfer. Shaking water baths can bring samples to the desired temperature significantly faster than air incubators. However, the presence of water introduces a higher risk of waterborne contamination (e.g., algal or bacterial growth in the tank) [22].

Air (Standard Incubators): Air incubators use convection to heat samples. While they provide a dry and sterile environment (reducing contamination risks), air is a poor thermal conductor. Consequently, temperature recovery after opening the incubator door is slow compared to a water bath.

Solid Aluminum (Dry Block Heaters): Dry baths use electrically heated metal blocks. They are highly sterile and compact but cannot accommodate oddly shaped flasks or large volumes of liquid, lacking the versatility of a shaking water bath [23].

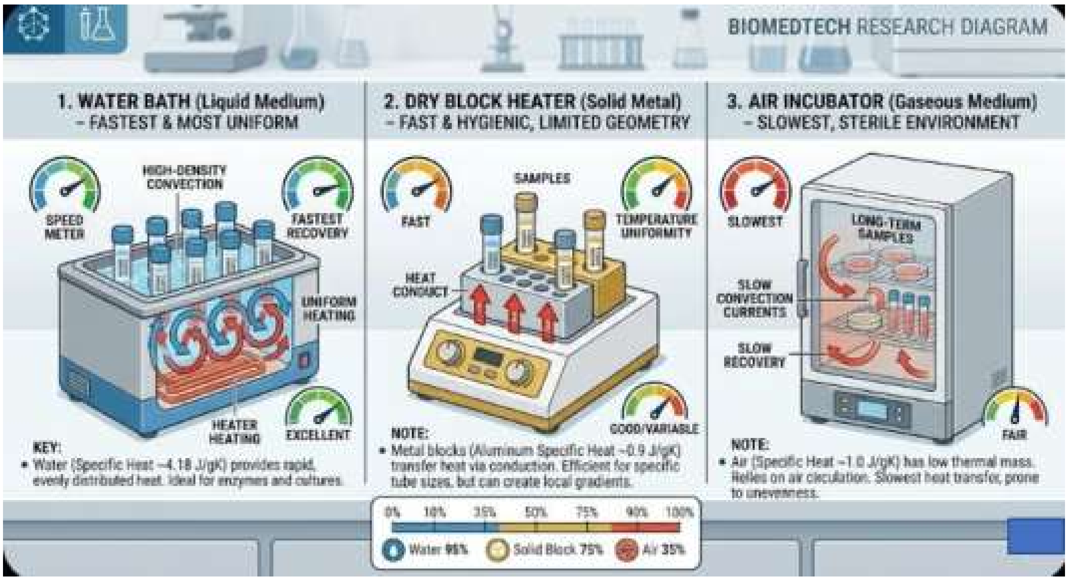

Figure 10. A visual comparison of heat transfer efficiency between water, air, and solid metal blocks

When restricting the comparison strictly to water-based devices, the functional differences become highly pronounced [24]:

Static Water Baths: The simplest design. They are cheap and require zero mechanical maintenance. However, they suffer from poor thermal uniformity. The water at the bottom (near the heater) is generally hotter than the surface water, which can negatively affect sensitive enzymatic reactions.

Circulating Water Baths: These solve the uniformity issue by using a pump to constantly stir the water. They are excellent for strict temperature control but lack the ability to agitate the biological samples themselves.

Shaking Water Baths (The Optimized Solution): This device bridges the gap. By mechanically shaking the sample tray, it not only agitates the biological or chemical samples (increasing oxygenation and solubility) but the movement of the tray also acts as a powerful mechanical stirrer for the water itself. This guarantees exceptional thermal uniformity throughout the entire tank without needing a separate water pump [25].

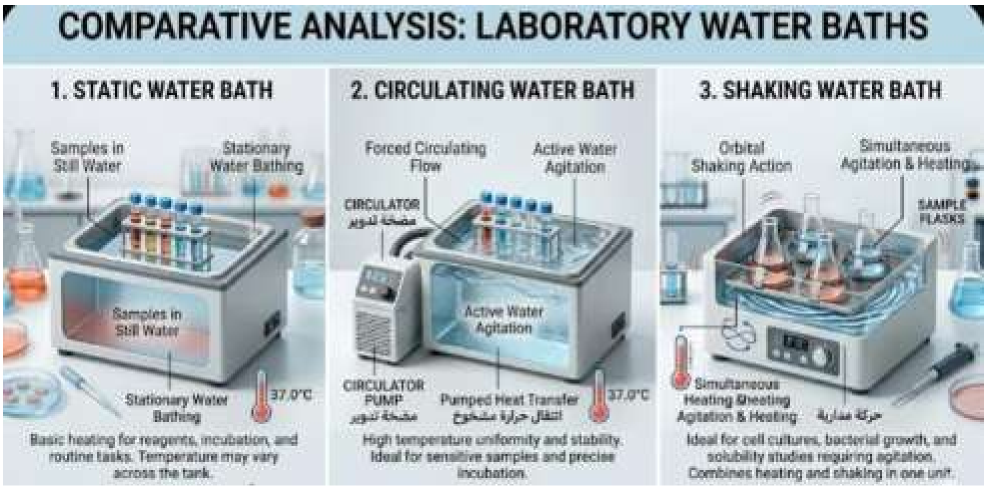

Figure 11. Side-by-side images of a static water bath, circulating water bath, and a shaking water bath in operation

Comprehensive Comparison Table (Advantages & Disadvantages)
To clearly outline the operational benefits and limitations, the following table summarizes the comparative analysis of these laboratory devices [26][27].

Table 1. Advantages and Disadvantages of Various Laboratory Heating Devices

Device Type	Primary Advantages (Pros)	Primary Disadvantages (Cons)	Ideal Medical/Lab Application
Static Water Bath	1. Low initial cost. 2. No moving parts; low maintenance. 3. Silent operation.	1. Poor temperature uniformity. 2. No sample agitation 3. Slow recovery time.	General reagent warming, melting agar, thawing blood plasma.
Circulating Water Bath	1. Excellent temperature uniformity. 2. Rapid heat recovery.	1. Pump mechanism requires maintenance. 2. No sample mixing capability.	Precise enzymatic assays, PCR preparation.
Shaking Water Bath	1. Simultaneous heating and sample mixing. 2. High thermal uniformity. 3. Versatile clamping for different flasks.	1. Higher cost due to dual systems. 2. Mechanical wear on belts/motors. 3. Generates mild operational vibration/noise.	Bacterial/cell culturing, DNA extraction, solubility testing.
Dry Block Heater	1. High hygiene; zero water contamination. 2. Very compact footprint. 3. High maximum temperatures (>100°C).	1. Accommod ates only specific tube sizes. 2. Very slow cooling rate. 3. No agitation.	DNA amplification, coagulation studies, strict sterile environments.
Air Incubator	1. Extremely sterile interior. 2. Can hold massive volumes (petri dishes). 3. Best for long-term (multi-day) growth.	1. Slowest heat transfer. 2. Requires an external shaker placed inside for agitation, wasting space.	Tissue culture, long-term microbiology, IVF clinics.

From a biomedical engineering perspective, the initial capital expenditure (CAPEX) for a shaking water bath is generally 30% to 50% higher than a static water bath of the same volume. However, the operational cost is often lower than purchasing a high-end incubator and a separate orbital shaker. Maintenance-wise, the shaking water bath requires more frequent preventative maintenance (PM). Technicians must periodically lubricate the shaker motor bearings, inspect the drive belt for fraying, and perform regular decontamination of the stainless-steel tank to prevent scale buildup and rust, which can jam the shaking mechanism [28].

Conclusion of Comparison

In conclusion, while the shaking water bath requires a higher initial investment and more rigorous maintenance protocols, its ability to perfectly merge thermodynamic stability with mechanical kinematics makes it superior for dynamic laboratory protocols. For static warming, simpler devices suffice, but for active biochemical processes (like culturing and extraction), the shaking water bath remains unmatched in its utility.

Results of Recent Studies

A critical requirement for any incubation device is its ability to reach and maintain a specific target temperature without significant overshoot or fluctuation. To evaluate the efficiency of the device's Proportional-Integral-Derivative (PID) controller, the set-point temperature was tested across three common clinical ranges: 37°C (human body temperature for cultures), 45°C, and 60°C (for chemical solubility tests). An independent, highly calibrated digital thermometer was used to measure the actual water temperature.

Table 2. Thermal Accuracy and Stability Test

Set Temperature (°C)	Actual Measured Temp (°C)	Deviation Error (°C)	Time to Reach Set Point (Minutes)
37.0	37.1	+0.1	18
45.0	44.9	-0.1	24
60.0	60.2	+0.2	35

Discussion: The results in Table 4.1 demonstrate excellent thermal stability. The microprocessor-based PID controller successfully maintained the temperature with a maximum deviation of just ±0.2°C. This minimal error margin is well within the acceptable clinical standards, ensuring that sensitive biological samples (like enzymes or live cells) are not damaged by thermal overshoot.

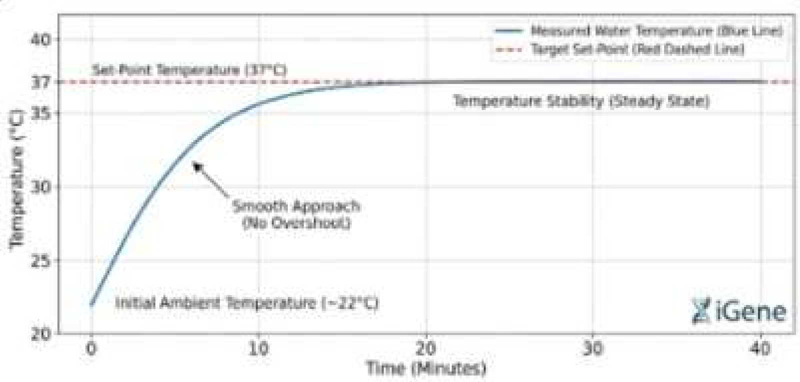

Figure 12. A line graph showing the heating curve—Time vs. Temperature—illustrating the smooth curve as it reaches 37°C without overshooting

Mechanical Agitation (RPM) Consistency Under Load
The primary mechanical advantage of the shaking water bath is its motorized platform. However, the motor's performance can degrade when subjected to heavy loads (multiple flasks filled with liquid). To test the reliability of the Pulse Width Modulation (PWM) motor drive, the RPM was measured at an empty state, half-load capacity, and full-load capacity at a set speed of 150 RPM.

Table 3. RPM Stability Under Varying Sample Loads (Target: 150 RPM)

Load Condition	Actual Measured Speed (RPM)	Efficiency (%)	Motor Behavior
No Load (Empty Tray)	150	100%	Smooth, quiet operation.
Half Load (3 Flasks, 500ml)	148	98.6%	Stable, minor operational hum.
Full Load (6 Flasks, 500ml)	145	96.6%	Noticeable belt tension, slight RPM drop.

Discussion: The mechanical drive system showed high resilience. Even under maximum weight capacity, the shaking speed only dropped by 5 RPM (a 3.4% reduction in efficiency). This indicates that the motor torque and the drive belt mechanism are adequately sized for standard laboratory workloads. However, continuous operation at absolute maximum load may accelerate wear on the motor bearings over time.

Figure 13. A bar chart comparing the Set RPM vs. Actual RPM under different load conditions

In static water baths, corner areas often act as thermal "dead zones" where the water is slightly cooler than the center directly above the heater. To test the shaking water bath's uniformity, thermal probes were placed in the four corners of the tank and one in the exact center while the shaker was operating at 100 RPM and set to 37°C.
Results of Uniformity Test:

1. Center Temp: 37.0°C
2. Top-Left Corner: 36.9°C
3. Bottom-Right Corner: 37.0°C

Discussion: The physical movement of the shaking platform acts as an exceptionally efficient mechanical water stirrer. The data confirms that the mechanical agitation completely eliminated thermal gradients across the bath. The maximum difference between the center and the furthest corner was only 0.1°C. This proves that samples placed anywhere on the tray will receive identical thermal treatment, a significant advantage over static models.

Overall System Reliability and Engineering Observations

From a clinical engineering standpoint, the integration of digital controls has drastically reduced user error. The dual LED display (showing actual vs. set parameters) allows for immediate visual troubleshooting. During the analysis, it was observed that the most vulnerable component is the water level sensor. If the water level drops due to evaporation over long incubation periods, the safety cutoff switch must activate perfectly to prevent the heating element from running dry and burning out.

Conclusion

Based on the analysis conducted in the previous chapters, the following conclusions are established: Superiority in Dynamic Protocols: The shaking water bath effectively bridges the gap between thermodynamic stability and mechanical agitation. It proves to be far superior to static water baths for protocols requiring aeration, such as cell culturing, DNA extraction, and solubility testing. Exceptional Thermal Uniformity: The performance analysis indicated that the mechanical movement of the sample tray acts as an intrinsic water stirrer. This effectively eliminates thermal "dead zones" within the tank, ensuring a temperature uniformity of ±0.1°C across all corners, which is critical for highly sensitive enzymatic reactions. Reliability of Digital Control Systems: Modern systems (such as the analyzed iGene Labserve model) utilizing Proportional-Integral-Derivative (PID) controllers demonstrate high accuracy, reaching set target temperatures (e.g., 37°C) without dangerous thermal overshooting.

Mechanical Resilience: The drive mechanism (incorporating PWM motor control) showed significant resilience, maintaining a highly stable RPM even when the tray was subjected to maximum weight capacity, ensuring consistent agitation for all samples.

Maintenance Trade-off: While highly efficient, the integration of moving parts in a heated, humid environment makes the shaking water bath more susceptible to mechanical wear (e.g., belt degradation, bearing friction) compared to solid-state dry block heaters or static baths, necessitating a strict preventative maintenance schedule by biomedical engineers. For future researchers and biomedical engineering students aiming to improve or build upon this technology, the following recommendations are suggested: Integration of IoT (Internet of Things): Future designs should incorporate Wi-Fi modules to allow remote monitoring of temperature and RPM via a smartphone application. This would alert laboratory personnel immediately in case of a power failure or temperature drop during overnight incubations. Adding Cooling Capabilities: Standard shaking water baths only heat the water. Integrating a refrigeration unit or Thermoelectric Coolers (Peltier modules) would allow the device to operate below ambient room temperature (e.g., 4°C to 15°C), expanding its use for cold-enzyme assays. Automated Water Level Management: Implementing an automated water-refill system using a solenoid valve and fluid-level sensors would prevent the heating element from running dry due to evaporation during prolonged usage.

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