

Art Meets Lifestyle: Designing a Bio-Design Water Bottle with Purification and Cooling Features

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Abstract

With the advancement of countries and the industrialization of societies, the importance of water has become increasingly evident. Humanity has realized that water, besides quenching thirst, can serve as a source of clean energy and be effective in treating diseases. Population growth and the demand for clean water have led to water shortages and, ultimately, the issue of water scarcity. Many researchers, policymakers, and environmentalists have proposed and implemented solutions to address water scarcity, yet the conservation and maintenance of water remain major environmental challenges. Additionally, a significant concern for future generations is the issue of survival without access to clean water. Therefore, this project aims to propose a design that adequately addresses some of these problems. The goal is to suggest the production of a water bottle with purification and cooling features, which can be used as a portable, small reservoir of clean water.

Keywords: Drinking Water Bottle, Filter, Cooler, Bionic, Water Pump

1. Introduction

Water is essential for life, making up two-thirds of the human body and playing crucial roles in cell function, metabolism, temperature regulation, and toxin removal [1]. Thirst signals water loss, intensified by exercise, heat, and illness. Many countries face water shortages, and future conflicts over water are predicted. Thus, designing products to address water scarcity and safeguard public health is vital [2]. In this project, the goal is to provide individuals with easy access to clean and healthy water, especially in locations or specific urban and rural recreational areas where it may not be readily available. Additionally, the project aims to include a feature for cooling the water inside the bottle, enhancing the enjoyment of drinking refreshing water.

1.1. Problem Analysis

Where are these bottles needed?

Initially in water-scarce areas, potentially expanding nationwide in the future.

Where are they produced and sold?

Manufactured in Iran with specific technologies, sold in sports facilities and stores.

Where can't these bottles be used?

In salty water due to the need for separate filtration systems.

What happens to these bottles after use?

Mainly made from recyclable plastics and metals; proper disposal is crucial to avoid environmental harm.

What materials are used to make these bottles?

Seamless, lightweight aluminum with a hygienic inner plastic coating, and an outer layer of polyamide and nylon.

When will production costs decrease?

Costs will reduce with technological advancements and cheaper material alternatives.

Who uses these bottles?

Initially accessible to the military, athletes, and travelers, with potential future availability to the general public.

Who can use these bottles?

Initially affordable mainly to the middle and upper classes due to technological costs, but expected to diversify with advancements.

Why are these bottles needed?

Essential for providing accessible, cool, and purified water, especially in areas lacking clean water sources.

Why are designers interested in creating such bottles?

Lightweight and practical for purifying and cooling water swiftly and effectively, addressing the need for clean drinking water in various environments.

1.2 Initial Solutions

Historical Background:

Municipal water filtration systems were early urban advancements, evolving with science and industrial automation. Small industrial and home filtration systems are now viable solutions, with three-liter and 1.5-liter bottles offering convenience and faster filtration [3].

Recent Innovations:

New rapid water purification bottles can fully purify water but are more expensive [4].

Transportation and Storage Evolution: Initially, mineral waters were transported from mountains to cities for medicinal use, leading to container development. In the 18th century, glass bottles replaced clay vessels. Later advancements introduced plastic bottles, optimizing production and reducing environmental impact [5].

Advanced Packaging Techniques:

Using ozone to disinfect single-use bottle interiors and sanitize caps marks significant progress in water packaging [6].

Modern Sustainable Designs:

Designers are exploring renewable materials like paper for recyclable bottles and innovating in glass and plastic bottle technology [7].

2. History of Bottles Worldwide and in Iran

Etymology and Development:

The word "bottle" comes from English and entered Persian through the Persian Gulf. In Persian, it refers to a cylindrical container with a narrow mouth for holding liquids [8].

Cultural and Linguistic Context:

According to Persian dictionaries, a "bottle" is defined as a cylindrical container with a narrow mouth used for containing fluids, including beverages [9].

Historical Usage and Evolution:

Throughout history, humans have used various vessels for storing liquids, especially water. Earthenware pots were among the earliest containers, keeping water cool and potable [10]. Iranian pottery dates back to the 4th millennium BCE, with vessels such as unglazed jugs and large storage containers.

Technological Advancements:

The use of clay evolved to include animal skins and eventually, metal vessels like amphorae, copper, and gold, reflecting advancements in metallurgy and craftsmanship [11].

Discovery and Modernization:

In the 19th century, technological advances and reduced costs popularized glass bottles for potable water, addressing concerns about contaminated municipal water supplies [12].

PET Plastic Bottles

Invented in 1973 by chemist Nathaniel Wyeth, PET (Polyethylene Terephthalate) plastic bottles revolutionized beverage packaging with their clarity, durability, and lightweight nature. A redesign in 1978 made them 29% lighter, significantly boosting efficiency in storage and transport [13].

Consumer Needs:

Consumers need bottled water that ensures hygiene and safety, accessible in any situation with easy, ergonomic design. The bottle material must be health-safe, with adjustable cooling systems and lightweight, efficient purification filters. Transparency is essential for visibility [14].

Buyer and Seller Needs:

Buyers prefer attractively packaged bottles that are easy to transport, display, and store in minimal space, with accessible storage conditions [15].

Manufacturer Needs:

Manufacturers need access to raw materials, testing equipment, and suitable factory conditions. Consumers want hygienic, ergonomic bottles with replaceable purification systems and adjustable cooling. Sellers benefit from easy transport and attractive packaging [16].

Objectives of our project

Primary Objectives:

1. Use safe materials for the bottle that do not harm users.
2. Preserve the natural taste of water without altering it.
3. Ensure recyclability or minimal environmental impact.
4. Design for easy user handling and transport.
5. Include a reliable water purification system.
6. Create an attractive and aesthetically pleasing bottle design.
7. Incorporate a built-in water cooling system.

Secondary Objectives:

1. Provide a replaceable filtration system for user convenience.
2. Allow adjustable cooling settings to suit different preferences.
3. Ensure lightweight components for ease of use.
4. Keep the filtration and cooling systems compact to maximize water capacity.

Design Constraints:

1. Avoid large components to control production costs.
2. Minimize space occupied by cooling and filtration systems.
3. Consider limitations in manufacturing capabilities.
4. Maintain consistent bottle capacity after use.
5. Limit graphical designs due to material constraints.
6. Adhere to specific storage temperature requirements.

Final Objectives:

1. Guarantee user safety with non-toxic materials.
2. Preserve the natural flavor and quality of water.
3. Design for environmental sustainability beside to Ensure user-friendly handling and transport.
4. Create an appealing and visually pleasing bottle design.
5. Provide effective water purification for safe drinking.
6. Integrate a cooling system within the bottle and Allow detachable cooling for convenience.
7. Offer replaceable and repairable filtration options.
8. Optimize filtration and cooling systems for compactness and lightness.

3. Specialized Information

3.1 Market Analysis:

Marketing is a process where goods meet needs through exchange. It focuses on identifying customer needs, communicating expectations to businesses, and ensuring satisfaction through market research and long-term strategies. Effective marketing uses accurate data and insights from social sciences to seize opportunities and address dissatisfaction [17].

Marketing Decision Variables: Key marketing variables include product (goods/services), promotion (advertising), pricing, and distribution, all crucial for market success and customer satisfaction [18].

Product: Product management involves defining specifications and features that meet customer needs and desires [18].

Promotion (Advertising): Includes all promotional activities and incentives to enhance product visibility and brand awareness [18].

Pricing: Involves setting competitive prices that reflect product value and appeal to target customers [18].

Distribution: Ensures efficient delivery of products from production to customers, minimizing intermediaries to maintain competitive pricing.

This product addresses environmental and health concerns with its technology but may face price sensitivity. Direct distribution and attractive packaging can enhance its market appeal and sales performance.

3.2 Aesthetic Analysis: Product design must balance aesthetics for user satisfaction and sales effectiveness. Users expect products to be functional and visually appealing, meeting their psychological and sensory needs. Aesthetics are crucial for manufacturers to enhance marketability and maintain production cycles, especially for mass-produced items [19].

Form and Packaging: Packaging design's three-dimensional shape and form are crucial, communicating the product's essence and leaving a lasting impression. Simple shapes convey formality, while geometric designs suggest modernity and allure. Familiar shapes suit everyday items, but innovative designs can captivate attention, particularly for luxury goods [20].

Size and Volume: The dimensions of packaging convey a product's identity and target audience. Small packages suggest delicacy, while large packages imply bulk usage.

Structure: The method of creating a three-dimensional form impacts the design, varying based on the material used (e.g., plastic, metal).

Color: Color is a powerful tool in attracting attention and conveying messages. It competes with form and logo for visual impact in packaging.

Material: The use of plastic and polymer materials in packaging is widespread due to their versatility, cost-effectiveness, and recyclability.

3.3 Ergonomic Analysis: Ergonomics studies human-environment interaction to improve efficiency, productivity, and safety by applying scientific data to design for better user experiences [21].

Product Design Considerations: A well-designed product must be safe and perform well. Ergonomics is crucial for products requiring a good grip, focusing on hand anthropometry.

Bottle Ergonomics:

Weight and Dimensions: A portable water bottle should hold enough water for individual use, with uniform weight distribution.

Body Stability: The bottle must remain stable under all conditions.

Grip and Handling: The design should accommodate both right- and left-handed users, ensuring a comfortable grip.

Drinking Ease: The distance from the bottle's mouth to the user's lips should be minimized for ease of use, with an acceptable angle for drinking [21].

3.4 Environmental Analysis

When designing a water bottle, it's crucial to consider its usage environment, its impact on the environment, and how environmental factors influence its design [22].

Usage Environment: Consider where and how the bottle will be used, addressing factors like temperature, sunlight exposure, and durability.

Environmental Impact: Evaluate the entire life cycle, from material extraction to disposal, aiming for materials with lower carbon footprints, efficient manufacturing processes, and recyclability [23].

Impact of Environment on the Product: Account for environmental conditions affecting performance, such as UV exposure and water quality, by selecting appropriate materials and features like UV resistance and water filtration [24].

3.5 Material and Manufacturing Methods Analysis

Material Analysis:

Aluminum: It is a lightweight yet strong metal, resistant to corrosion and oxidation, making it ideal for various industrial applications. It is non-magnetic, durable, and suitable for aerospace and transportation due to its weight-to-strength ratio. Aluminum products are becoming more common due to their lower environmental impact, improved quality, and reduced production costs [25].

Benefits of Aluminum in Manufacturing: Aluminum canteens are favored in the military over steel due to easier production and enhanced value. This shift was prompted by steel production challenges and the need for lighter, more efficient products. Aluminum canteens are manufactured as single pieces, improving durability and production efficiency compared to two-part steel canteens [25].

Plastic Inner Layer: Plastics and rubbers are cost-effective and often superior to metals in daily use. Recyclable thermoplastics and bio-plastics with additives help reduce environmental impact, but concerns remain about chemicals like BPA in food packaging. Designers should prioritize recyclable materials and easy disassembly to address environmental and health risks linked to plastic use [26, 27].

4. Selected Plastic: Polyether Ether Ketone (PEEK)

Specifications:

- **Temperature Resistance:** High and low.
- **Abrasion Resistance:** Good.
- **Electrical Properties:** Excellent.
- **Chemical Resistance:** High.
- **Hydrolysis Resistance:** Good.
- **Ease of Processing:** Easy.
- **Purity:** High.
- **Radiation Resistance:** Good.
- **Flame, Smoke, Toxicity Resistance:** Good [28].

Applications: Thermoplastic, known as Ketron or Victrex PEEK.

Properties:

- **Monomer:** Bisphenolate.
- **Solubility:** Insoluble.
- **Density:** 1.31 to 1.32 g/cm³.
- **Melting Temperature:** 335 to 340°C.
- **Glass Transition Temperature:** 140°C.

Flammability:

Burns with a yellow flame, does not drip, produces black smoke, self-extinguishes when the flame is removed.

Copper and Nickel

Copper:

- Flexible and malleable.
- Used in plumbing and water heaters.

Nickel [29]:

- Silvery-white, shiny, hard, and flexible.
- Conducts electricity, resists oxidation.
- Used in coins, brass, iron alloys, and chemical tools.
- Common oxidation state: +2.

Manufacturing Methods for Bottle Components

Die Casting Process:

Definition: Producing parts by injecting molten metal under pressure into a mold.

Steps:

1. **Injection:** Molten metal is injected into the mold cavity under pressure.
2. **Pressurization:** Pressure is maintained as the metal cools.
3. **Ejection:** The mold opens, and the part is ejected.
4. **Cleaning:** The mold is cleaned and prepared for the next cycle.

Bottle Components:

Aluminum Wall, Internal Insulation, Copper Base with Nickel Insulation, TEC (Thermo Electric Cooling), Heat Pipe, Electrical Generator.

Filters:

Polypropylene Filter: Removes large particles [30] and **UV Filter:** Eliminates microorganisms [31].

TEC [32]

Advantages:

No mechanical parts, compact size, no harmful chemicals, precise temperature control, long lifespan (100,000+ hours).

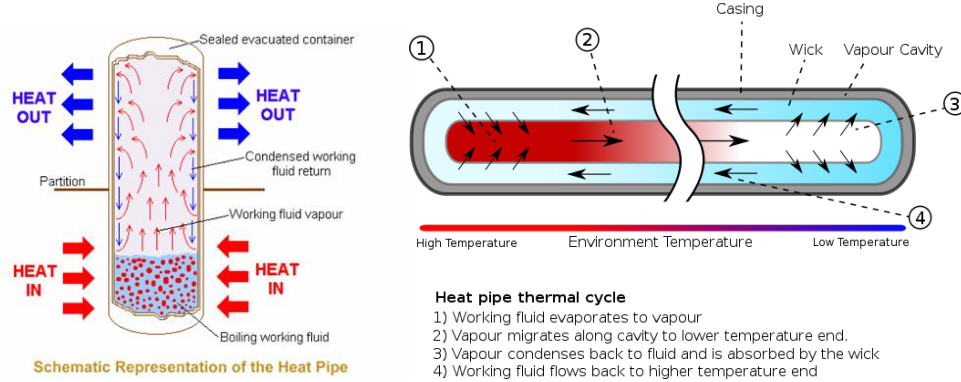
Drawback: High cost for efficiency.

Heat Pipe:

- High-conductivity tube in a vacuum with a volatile liquid.
- **Operation:** Liquid vaporizes at the hot end, moves to the cold end, condenses, and repeats (Fig 1).

Cooling Cycle:

1. Copper belt at the bottom cools the liquid inside the bottle.
2. TEC cools the copper belt; heat pipe dissipates excess heat.
3. Movement generates electricity powering the TEC, cooling the liquid inside (Fig 1).



Water Filtration Stages [33]:

1. **Polypropylene Filter:** Removes sediments and rust.
2. **Granular Carbon Filter:** Eliminates chlorine and bad tastes.
3. **Carbon Block Filter:** Filters larger particles.
4. **Reverse Osmosis:** Removes microbes and dissolved solids.
5. **Final Carbon Filter:** Enhances taste.
6. **Mineral Filter:** Adds essential minerals.

Enjoy freshly filtered mineral water!

Filtration in Bottles

Reduced Filtration System:

- Traditional six-stage filtration is reduced to one polypropylene filter and a UV radiation inlet.

Polypropylene Filter [34]:

- Made from pure polypropylene fibers, meeting FDA requirements.
- Uses melt-blown technology for micro-level filtration.
- Three-layer structure removes sediments, rust, and particles.

UV Filter:

- Uses UV radiation to destroy bacteria and microorganisms [35].
- **Advantages:** No chemical transport, unaffected by pH changes, no by-products, quick disinfection.
- **Disadvantages:** No residual disinfection, less effective on organic materials, limited on certain surfaces.

Filter Characteristics:

- High contaminant capacity, long life, low pressure drop, high cleaning efficiency, good chemical resistance.
- **Operational temperature:** 75°C, pressure drop: 5 kg/cm².
- **Filtration rates:** 1, 5, 10, 20, 30, 50, 100 microns.

National Standards for Packaged Drinking Water (Iran)

Bottle Design and Usage [36]:

- Handheld bottle with twist-off cap and integrated dual-filter system.
- Mechanical pumping system for water filtration and cooling.
- Cooling system at the base, using a motor and heat transfer pipe.

Water Refill Process:

- Twist-off cap for refilling.
- Plastic cover for better grip in various temperatures.

Standard Compliance:

- Set by the Institute of Standards and Industrial Research of Iran.
- Applies to packaged drinking water, excluding mineral waters.
- Ensures safe collection, transportation, and treatment of groundwater.

Water Sources:

- Includes underground water, springs, artesian water, well water, and natural glacier meltwater.
- Packaged water can be naturally mineral-rich or enhanced, without sweeteners or flavorings.

Treatment and Handling:

- Safe physical, thermal, chemical, or antimicrobial treatments allowed.
- Maintains original water composition without harmful additives.

Physical and Chemical Properties:

- Must meet national standards for safety and quality.

5. Library study on plastic types used in packaging [37]:

LDPE: Offers good resistance to tensile stress and water vapor permeability but not to oils. LDPE is used for large nylon bags, thin films for various plastic bags, and thicker bags for liquid and semi-solid food packaging.

HDPE: Has high density, tensile strength, toughness, crystallization, friction resistance, and heat resistance. HDPE is used for rice and frozen food bags, milk bottles, and transport containers.

PP: Known for clarity and strength, impermeable to oils, but with half the tensile strength of HDPE. Used in plastic bags and textiles.

OPP: Modified PP for flexibility and resistance, used in packaging chocolate, chips, and pasta.

P.S: Offers clarity and toughness, used in injection-molded cups. Variants include impact-resistant and high-temperature types for margarine packaging.

P.V.C: Neutral taste, very transparent, and used in cost-effective packaging to prevent gas and water vapor penetration. Available in flexible and rigid forms.

P.V.D.C: Impermeable to gases, water vapor, and aromas, used for packaging meat, cheese, and poultry.

PET: Chemically resistant and stretchable, used in vacuum-packed food packaging for low gas permeability.

P.E.T.f: PET film with excellent tensile and impact strength, impermeable to water vapor. Used for fresh meat or fermented packaging.

P.C: Very transparent, high heat resistance. Used for multi-use bottles, liquid detergents.

P.A: Strong resistance to stretching, used for high-tensile strength plastic strips.

Composite Films: Used extensively in food packaging systems for their special properties like high gas barrier, moisture resistance, and printability.

Manufacturing Plastic Containers: Techniques include injection molding, blow molding, thermoforming, compression molding.

These plastics serve various packaging needs from food to industrial applications, each offering specific advantages depending on the requirements for barrier properties, strength, and clarity.

Mineral Water Production: Mineral water production includes sourcing, sterilizing, and filling natural spring or well water to maintain its chemical composition, followed by container preparation for packaging [38].

PEEK Polymer: PEEK, polymerized from bisphenolate salts, boasts high mechanical strength and heat resistance (up to 260°C). It excels in stiffness, dimensional stability, and chemical resistance but is costly and has lower UV resistance than metals. Used widely in aerospace, automotive, and medical industries for durable parts in harsh conditions [39].

Biodesign: Biodesign mimics natural organisms to create sustainable products aligned with natural principles, aiming to surpass current technological limitations in meeting ecological demands [40].

In this project, we are designing a filtration and cooling bottle inspired by the function of kidneys in blood purification and the heart's role in pumping. The heart, a muscular organ situated between the lungs and tilted slightly leftward, pumps blood through rhythmic contractions, averaging 70 beats per minute. It is nourished by coronary arteries and operates through the cardiac cycle, beginning with an action potential in the sinoatrial node. This cycle includes diastole (filling with blood) and systole (contraction). Divided into four chambers, the heart functions as two pumps: the right side receives deoxygenated blood from the body, sending it to the lungs for oxygenation; the left side receives oxygenated blood from the lungs, pumping it through the aorta to the rest of the body [41, 42].

The lungs, weighing approximately 1200 grams in men and 900 grams in women, facilitate blood purification through alveoli, which provide a surface area of 200 square meters. Deoxygenated blood from the heart is oxygenated in the lungs, with gas exchange occurring in the alveoli. Breathing expands alveoli during inhalation and expels used air during exhalation, a continuous automatic process that can also be consciously controlled. Lung capacity averages 4.5 liters, varying by individual, with inhaled air containing 20% oxygen and exhaled air containing 16%, demonstrating efficient gas exchange [43] (Fig 2).

Our bottle model has two filters under the cap inspired by human lungs and a manual pump inspired by the heart. Pressing a button on the outside pumps water through the filters, making it drinkable. The cooling system at the bottom converts mechanical energy to kinetic energy. Shaking the bottle cools the water via a thermal transfer tube. To refill, twist open the top cap and add water. The bottle has a plastic-coated aluminum body for a better grip and the filters are replaceable.

After selecting designs of the bottle, a list of requirements and restrictions are needed which include:

- Ergonomic and comfortable grip, attractive design, and designed according to Iranian anthropometry
- Lightweight with standard dimensions, creating an impression of abundant water inside
- Sunlight protection for water with a stable base and suitable dimensions
- Easy-to-open cap with an audible click seal, addressing transport issues
- Made from recycled and specialized plastics, featuring transparent or blue color appropriate for drinking water
- Replaceable filters and compact design for mass storage and transport
- Designated area for branding without covering the entire bottle
- Conveys freshness with moderate production costs, making it affordable for consumers
- Inner material is galvanized, anti-sediment aluminum, with lightweight extruded aluminum components
- Appropriately placed pump button and impact-resistant cooler motor at the bottom

- Main detachable parts are screwable for ease of maintenance

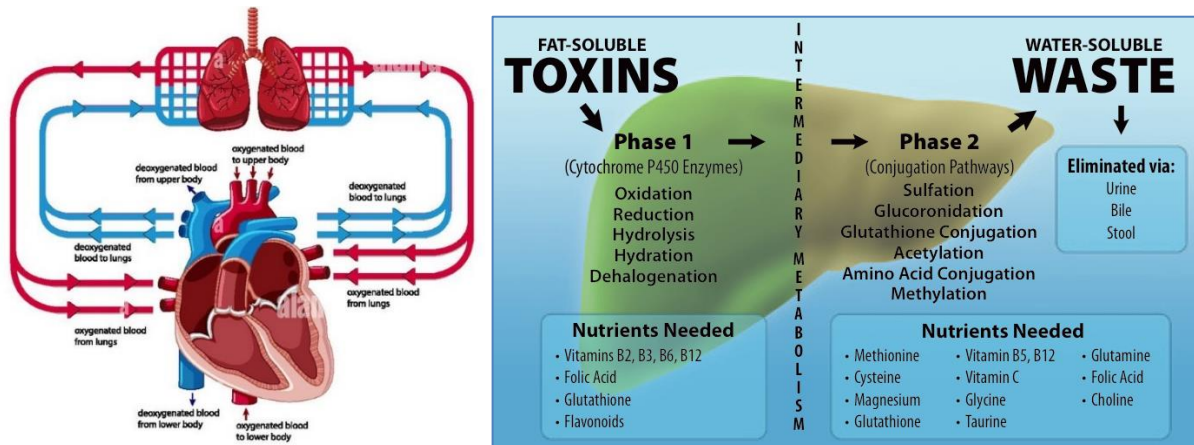


Figure (2) The process of blood circulation/heart pumping and blood purification by the white liver

6. Interview and Questionnaire

- What material do you think is suitable for a reusable filtered water bottle?
 - ☐ Plastic
 - ☐ Lightweight anti-scale aluminum
 - ☐ Stainless steel
- In your opinion, what is the most important factor in a filtered water bottle?
 - ☐ Form
 - ☐ Size
 - ☐ Weight
 - ☐ Color
 - ☐ Price
- How much do you estimate the price of a filtered and cooling water bottle?
 - ☐ Below 5 Dollars
 - ☐ Between 5 to 10 Dollars
 - ☐ Above 10 Dollars
- What color do you suggest for a filtered and cooling water bottle?
 - ☐ Blue
 - ☐ White
 - ☐ Black
 - ☐ Gray
 - ☐ Another
- Considering the filtration feature, how often would you like to replace the filter?
 - ☐ Every month
 - ☐ Every three months
 - ☐ Every six months
 - ☐ Every year
- What do you think is the most suitable capacity for the bottle?
 - ☐ 500 milliliters
 - ☐ 600 milliliters
 - ☐ 700 milliliters
 - ☐ 800 milliliters

The analysis found that price is the most critical factor for water bottle buyers, favoring a lightweight, blue aluminum bottle of 700 milliliters, priced below \$5, with a six-month filter replacement cycle.

7. Product design steps

7.1 Ideation



Figure (3) A collection of initial ideas and etudes

7.2 processing



Figure (4) Secondary etudes

7.3 Final evaluation



Figure (5) Consider the Ergonomic Design of the Bottle in Hand



Figure (6) Etude and map of the third best plan and 3D image of the third best plan

7.4 Presentation of the plan Manual and software rendering

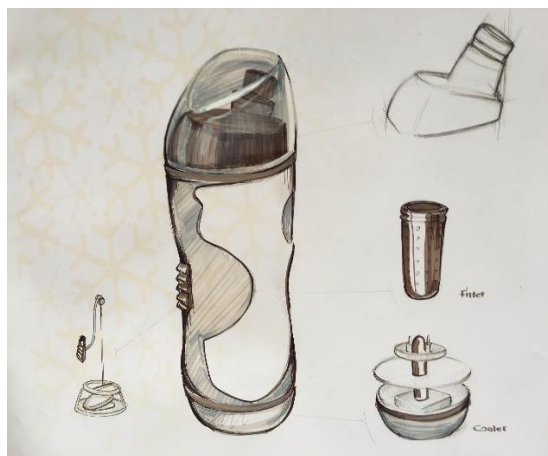


Figure (7) Manual and software rendering

7.5 Technical drawings Three views with measurements

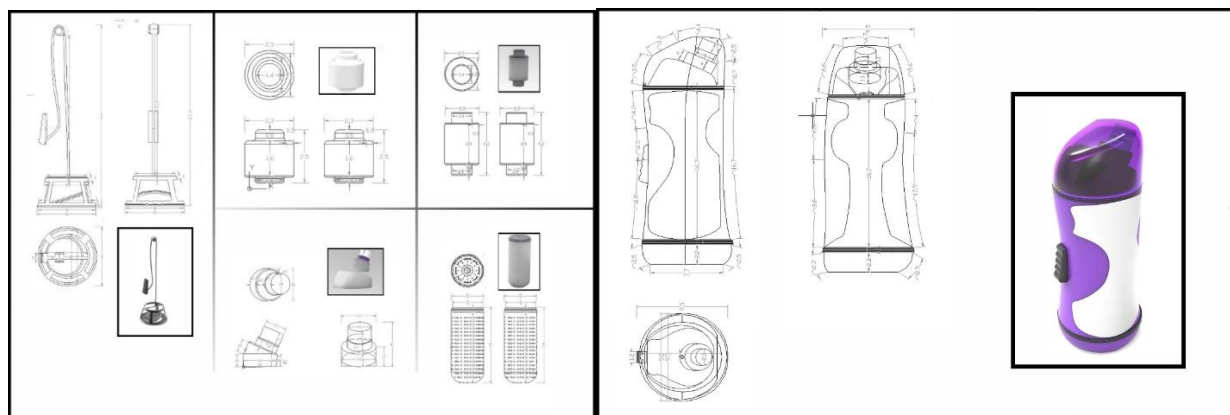


Figure (8) Map with measurements



Figure (9) Exploded-view drawing



Figure (10) Maquette

8. Advantages and disadvantages of the bottle design is as follow:

Advantages

- Durable aluminum construction
- Cost-effective for production and repair
- Efficient cooling system
- Enhanced grip
- Lightweight
- User-friendly caps
- Simple mechanism
- UV and rust-resistant

Disadvantages

- Relatively large size due to filtration and cooling systems
- Environmental incompatibility
- Relatively high final cost

9. Conclusions

Water scarcity and pollution are critical issues due to population growth. Designing attractive and functional water bottles for non-mineral waters is essential. Products should integrate ergonomic, aesthetic, and material science principles. As human health becomes more critical with medical advancements, precise lifestyle insights and safe materials are necessary. Petroleum-based plastics pose health risks and environmental threats. Therefore, using materials that reduce petroleum reliance, safeguard health, and preserve the environment is crucial. Lightweight aluminum water bottles with purification and cooling capabilities address these challenges. This innovation is vital amid global climate trends and future water scarcity predictions. Inspired by Biodesign technology, our innovative water bottle incorporates lung and heart functions for filtration and cooling. When shaken, an internal element converts mechanical energy into heat, heating the exterior while cooling the water inside. Future research may enable users to switch between cold and hot water with a button, useful in special conditions such as on top of a mountain.

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