# Reusable Hydrometer for Specific Gravity Measurements

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**ABSTRACT**

**Specific gravity is an approachable method to monitor daily outflow of urine for the purpose of preventing kidney stone formation. However, most specific gravity measurement devices are clinical research grade equipments and are not commercially available due to cost and technical experience to operate. Here described is our method for adapting a commercially available fish tank hydrometer to be utilized for human urine specific gravity measurements by fabricating an adapter attachment that not only increases the ease of use for our device but also increases the accuracy of it.**

## Introduction

Kidney stone formation has become a prevalent problem facing the onset of the obesity epidemic. It was found Ahmed et al. that epidemiologic studies have shown that incident renal stone risk increases with a body mass index[1]. A simple preventative to kidney stone formation is increased fluid intake. Studies have shown that increased intake of fluids decreases the concentration and acidity of urine[2]. Other studies have found that changing the pH of urine reduces kidney stone formation[3]. Our client, Dr. Jhagroo, a nephrologist at the University of Wisconsin – Madison Hospital and Clinic, has found a methodical way to approximate a patient's previous 24-hour urine volume output by measuring the specific gravity of the patient's urine. He currently uses a fish tank hydrometer to measure specific gravity and a prevalent problem for him is the bubble formations. Bubbles in urine cling on the hydrometer needle and gives inaccurate readings. He requests a reusable device that can easily read specific gravity while reducing bubble formation, is easy to use for patients, and can be cleaned easily.

Hydrometers are instruments that measure the specific gravity of different solutions, or, the ratio between the density of the solution and the density of water[4]. Commercially, they are used to test the specific gravity of fish tanks or car batteries. Hydrometers provide information such as the identification of a solution or the concentration of the solution. In our case, the client will be

[1] Ahmed, M; Ahmed, H; Khalil, A. *Ren. Fail.* **2012**, 34, (10)
[2] Vaamonde, Carlos et al. *J. App. Phys.* **1974**, 36.4, (434 – 439)
[3] Lu, Xiuli et al. *Urology Annals.* **2011**, 3.2, (71-74)
[4] Stuempfle, KJ et al. *J Athl Training* **2003**, 38.4 (315-19)

using the hydrometer to test the concentration of the urines.

There are two basic types of hydrometer: the standard hydrometer and the swing arm hydrometer. The standard hydrometer is composed of a sleek, glass instrument that is filled with a reference solution, which is calibrated to be the density of water. The instrument is placed into a container filled with the solution and, once the buoyant force is equal to the weight of the instrument, it provides the specific gravity (Figure 1). At equilibrium, the buoyant force is equal to the pressure on the object multiplied by the surface area of the instrument:

$F_B$ / SA= Pressure = $\rho_{sol}$ x h x g

$F_B = F_w = \rho_{sol}$ x h x g x (SA) =mg

h=m/ ($\rho_{sol}$ x SA)

SA = surface area of object

This gives us an inverse relationship between the height of object in the solution and the density of the solution. Analytically, this relationship agrees with what we would see. For example, if we place the object in syrup the height device will not sink very far in the solution and the height will be small.

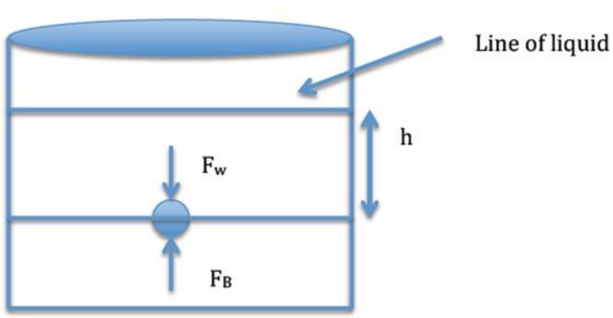


**Figure 1**: Standard hydrometer at equilibrium. The weight of the instrument is equal to the buoyant force acting on it.

The swing arm hydrometer is composed of a container that holds a needle, which is calibrated to be the density of water. When liquid is poured in, the needle rotates on a pin in a circular motion until the buoyant force is equal to the weight of the needle. This instrument works using moment: the density difference between the solution and the needle forces the needle to go up while the density difference between the weight and the solution forces it to go down (Figure 2).

ΣMoment= $\rho V_1 g$ x lcos(α+ θ) + $\rho V_2 g$ x lcos(α) - $m_1 g$ x lcos(α+ θ) – $m_2 g$ x lcos(α)=0

ρ= ($m_1$cos(α+ θ) + $m_2$gcos(α))/($V_1$gcos(α+ θ) +$V_2$cos(α))

Commercially, these are used to test the specific gravity of fish tank water.

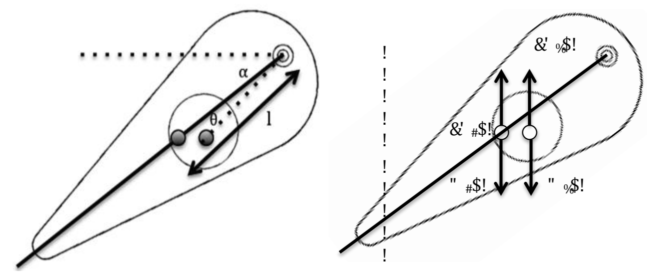


**Figure 2**: Swing arm hydrometer at equilibrium. The forces acting on the need occur at the center mass of the needle and the counterweight.

**Design Process**

Our group came up with three hydrometer designs for the purpose of testing the specific gravity of human urine: syringe, tube (swing arm), and funnel (swing arm).

The syringe hydrometer (Figure 3), involves two dynamic pieces: a simple syringe, and a pre-calibrated counter weight, which is the component that actually would determine the specific gravity of the solution. The syringe hydrometer works by the patient pulling in the desired liquid into the inner compartment of the syringe. At this point, the pre-calibrated weight would bob up and down until equilibrium is reached. Basically, it works on Archimedes Principle. The principle states that the weight of the counterweight equals the weight of the fluid that it displaces at equilibrium. In this case, with fluids of different densities drew into the syringe, the counter weight will displace different amount of solutions. To be more precise, the counter weight displaces less solution, thus floating higher if the solution has higher specific gravity.

**Figure 3**: Syringe Hydrometer. Includes pre-calibrated counter weight, and syringe components. Liquid is pulled in the syringe and the internal component would

Some benefits of using this design are ease of portability, the ease of not needing a large volume of urine for testing, and easy cleaning. However, an inherent problem with the design is the difficulty associated with manufacturing the counterweight. Calibrating the internal piece to have water as a reference liquid would be incredibly difficult. Also, properly designating particular gradations on the counter weight is problematic. Lastly, having two separate pieces increases the possibility of losing one or the other, preventing any further measurements.

Our next design, the tube adapter hydrometer, utilizes a commercially available fish tank hydrometer (Figure 4).

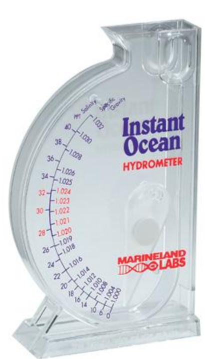


**Figure 4**: Commercially available fish tank hydrometer for specific gravity measurements.

To prevent urine from splashing and generating bubbles (disrupts data collection), we postulated fabricating a tube that runs the length of the hydrometer, until the bottom, allowing the flow to proceed at a leisurely pace (Figure 5).

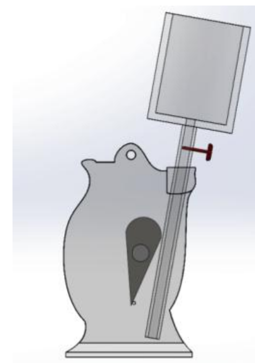

**Figure 5:** Tube-adapter hydrometer. Fabricated funnel and tube would be inserted into hydrometer to facilitate easier pouring and prevent bubble formation.

This design would work by urine being poured into the top portion. Once the funnel is filled to a particular line (which would be calculated), the stopcock is opened at the base of the funnel, allowing urine without bubbles to flow into the hydrometer. Once enough urine has filled the hydrometer, the stopcock would be closed, and the adapter would be removed from the hydrometer.

A positive aspect of this design is when used correctly, this design will minimize bubble formations drastically. However, this design still has two assembly pieces which complicates its use, and the act of closing the stopcock to prevent bubbles entering the hydrometer may prove difficult for some patients. Lastly, another drawback with this design is the potential for urine spilling when removing the adapter.

Our final design is known as the funnel adapter (Figure 6) also uses the commercially available fish tank hydrometer. This design is an extension of the previous design and incorporates similar aspects.

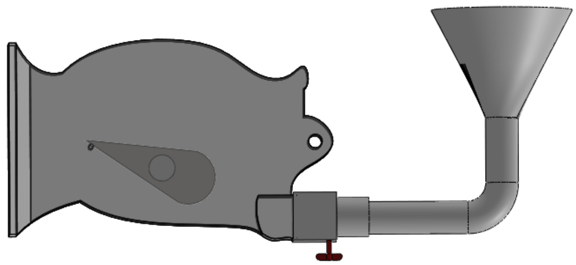

**Figure 6:** Funnel adapter design. Funnel is attached to hydrometer and urine is poured in this state. When finished pouring, the hydrometer is turned upright and measured.

The procedue to utilize this design is similar to the previous, tube design. The hydrometer, with the associated adapter, is tilted 90° towards the horizontal. The patient then pours urine into the adapter until a certain line, designated by the funnel, is reached. The stopcock is now opened and the urine proceeds into the hydrometer. Once a state of equilibrium is reached, the stopcock is closed and the hydrometer is tilted up 90° until it is vertical. The urine that is on the funnel's side after equilibrium will then collect in the long horizontal tubing, preventing urine spillage.

This design is the most beneficial to the patient. It allows the hydrometer and the adapter to be fitted together as one individual piece, rather than two separate pieces, and it allows the patient to easily pour in urine without having to worry about closing the stopcock. Furthermore this design takes more preventative measures against bubble formation. Having the hydrometer vertically assembled with the adapter allows for the passive flow of urine into the hydrometer at a slower rate than in the previous design.

With these design in mind, and after talking with our client, we constructed our design matrix (Figure 7).

| | Fish-tank hydrometer design I (Adapter) | Fish-tank hydrometer design II (tube) | Syringe hydrometer |
|---|---|---|---|
| **Cost (20%)** | 5 | 5 | 5 |
| **Accuracy (20%)** | 5 | 5 | 4 |
| **Portability (15%)** | 4 | 3 | 5 |
| **Durability (15%)** | 5 | 5 | 3 |
| **Ease of use (15%)** | 5 | 3 | 4 |
| **Fabrication (10%)** | 4 | 4 | 5 |
| **Safety (5%)** | 5 | 5 | 5 |
| **Total score (out of 100)** | **95** | **86** | **87** |

**Figure 7:** Design matrix. The choice of our final design was based on seven different categories, placing cost and accuracy as the most important considerations.

After much deliberation, our group decided on the funnel adapter design for the fish tank hydrometer. As the table shows, three alternative designs of hydrometer are compared through seven different categories: cost, accuracy, portability, durability, ease of use, fabrication, and safety. A total score of 100 is assigned into seven categories with different weights. The "cost" and "accuracy" both have the highest weights (20% each) since it is required to design a cheap hydrometer for patients to measure the specific gravity of their urines reliably. More specifically, a cheap design of urine specific gravity measurement system allows for more fabrications of prototypes to test the accuracy for different patients within the limited budget. The desirable cost for each hydrometer system is estimated to be less than 30 dollar. There are specific requirements for the accuracy for the specific gravity measurement. The design is aim to precisely measure the specific gravity to 0.001 and with a total range from 1.000 to 1.032. Since the design is used to monitor the specific gravity of patient's urine sample variation within a day, the device must remain accurate after multiple uses. It is also important for the design to be portable, easy to operate, and effective for certain duration; thus each of these categories has a 15% weight. The hydrometer system should be convenient for patients to carry with daily; therefore the size of the device is restricted to be no bigger than 25 cm by 15 cm by 5 cm and the optimal weight is roughly 1 kg. In this case the hydrometer system could be easily transported in a suitcase or luggage. The device is designed to be easy to operate and clean for patients. The patients would like to put less effort into using the hydrometer and getting the measurement results of urine quickly. The "fabrication" and "safety" categories both have a lower weights (10% and 5% respectively) than the rest since the fabrication process of each design is believed to be easy and all the potential hydrometers we are going to incorporate into the designs have smooth finishes.

In general, a score from 1 to 5 is assigned to each of design alternatives in each category. The fish tank hydrometer with tube has a low cost (scores 5), high accuracy (5), and is considered to be use for long time (5) while it is not portable (3) with the loose tube inside it. For the syringe hydrometer, it is the most portable (5) one among the three due to its small volume. Also, with the syringe being available, there is not much work of fabrication (5). However, its accuracy (4) largely depends on the calibration of counterweight and it has to change the syringe quite often. Lastly, the design of swing arm hydrometer incorporating adapter shows the advantage of being low cost (5), high accuracy (5), easy to use (5), and safe (5). It also achieves a balance of being portable (4) as well as durable (5). Overall, the swing arm hydrometer with adapter scored the highest (95) among the three, with the syringe hydrometer coming in second (87) and the swing arm hydrometer with tube coming in last (86). So at this stage, the swing arm hydrometer with adapter is the ideal one among all potential designs.

## Experimetal Testing

After deciding on our design, our group researched various aspects of the hydrometer accuracy. We first tested temperature's effect on specific gravity measurement. When the temperature of a liquid is raised, the volume is also raised, causing the density to decrease. Since specific gravity is directly correlated to density, we expected increase in temperature would decrease specific gravity. We used tap water from the sink as our source and measured the specific gravity at room temperature, near boiling, and near freezing (Figure 8).

| Temperature | Trial 1 | Trial 2 | Trial 3 | Average |
|---|---|---|---|---|
| 21 Celcius | 1.003 | 1.004 | 1.003 | 1.003 |
| 90 Celcius | 1.000 | 1.001 | 1.001 | 1.001 |
| 1 Celcius | 1.000 | 1.000 | 1.000 | 1.000 |

**Figure 8:** Testing of water's specific gravity measurement at various temperatures.

At room temperature the specific gravity reading was on average 1.003. The reason it was not exactly 1.000 is due to the minerals in tap water which increases the overall mass and therefore density. The specific gravity measurements at room temperature and near-boiling matches the idea that higher temperature gives lower specific gravity readings. Therefore it is plausible that lower temperatures give higher specific gravity readings. The specific gravity measurements near freezing, however, measured lower than that of room temperature and near boiling. We believe that error in measurement results from water's peculiar trait of having a lower density solid than liquid. Since we used a mixture of ice and water for our near freezing experiment, the ice's lower density may have affected the measurements.

Another issue we want to pursue is whether crystallization of urine would affect specific gravity measurements. If the patients were to not adequately rinse out the hydrometer, it is possible that residue of urine will crystallize on the needle and affect specific gravity measurements. Our client, Dr. Jhagroo, has been using a hydrometer to measure urine specific gravity for a few months and he only needs to rinse it out before and after each use. We plan to take his hydrometer and a brand new hydrometer and compare the specific gravity measurement with a same liquid.

## Timeline

**Timeline (Tentative):**

| Task | September | | | | October | | | | November | | | | | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 14 | 21 | 28 | 5 | 12 | 19 | 26 | 2 | 9 | 16 | 23 | 30 | 7 |
| **Project R&D** | | | | | | | | | | | | | | |
| Lit. Research | X | X | X | X | | | | | | | | | | |
| Cost Estimation | | | | | X | X | X | | | | | | | |
| Manufacturing | | | | | | | | | | | | | | |
| Prototyping | | | | | | | | | | | | | | |
| **Deliverables** | | | | | | | | | | | | | | |
| Progress Reports | X | X | X | X | X | X | X | X | | | | | | |
| PDS | | X | X | X | X | X | X | X | | | | | | |
| Midsemester | | | | | | | X | | | | | | | |
| Final Poster | | | | | | | | | | | | | | |
| **Meeting** | | | | | | | | | | | | | | |
| Client | | X | | X | | | | | | | | | | |
| Team | X | X | X | X | X | X | X | X | | | | | | |
| Advisor | X | X | X | X | X | X | X | X | | | | | | |
| **Website** | | | | | | | | | | | | | | |
| Update | X | X | X | X | X | X | X | X | | | | | | |

**Figure 9:** Proposed timeline for our group project.

Our group as a whole has made a great effort staying close to the proposed timeline (Figure 9). Any deviations from the timeline can be seen specifically in not meeting with the client and a delay in beginning the cost estimation phase and manufacturing phase.

Our group has made a consistent effort to meet with our client when needed. The previous weeks have not needed a formal meeting with Dr. Jhagroo since all questions that our group had were answered via email.

The delay in the initiation of the cost estimation phase and the manufacturing phase is due to group member schedule difficulties. The past previous weeks have unforeseeably been busy for each member of our team and consequently have prevented our group as a whole from reaching the desired point in our research and development of our adapter.

## Budget

A formal budget has yet to be reached for our group. Our team suspects, however, that the main source of our expenditures would be involved in procuring the bulk plastics for fabricating the adapter. We would like to be able to purchase solid pieces of plastic that we can work and mold into the adapter. We do not need to purchase any more fish tank hydrometers since Dr. Jhagroo has provided us with enough fish tank hydrometers.

## Conclusion

Kidney stones are a prevalent problem in American culture, and the only real means of preventative measure is to increase daily urine outflow. Measuring the specific gravity of an individual's urine can be extrapolated to measure if daily urine outflow needs to be increased. Our team has been tasked with designing a reusable hydrometer for the purposes of testing the specific gravity of human urine. With the help of Dr. Jhagroo, we have found that a commercially available product exists, but it is not adapted to interface with the human body. This fish tank hydrometer has the required scale to measure human urine specific gravity but application of urine into the device can result in bubble formation around the needle, skewing data. Our team has consequently designed an adapter that will reduce bubble formation and thus give more accurate data.

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