

# PRELIMINARY DESIGN AND DEVELOPMENT OF A MEDICAL HUMIDIFIER

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**Abstract** - Breathing assistance required to patient can be caused by multiple reasons. Assistance to breathing can be required for new-born child or can be matured adult. Thus, this makes impossible to make one standard ventilation system which can treat both and results in high cost and demand of ventilator.

The human natural way of heating and humidifying the inhaled air is replaced by endotracheal tube(ETT) when they go through invasive type mechanical ventilation. Thus, results in complications to patient's airways as they become cold and dried by dry gases that provided by the ventilator and that too severe complications if patient is kept for longer period of time, as will happen in invasive mechanical ventilation and hence, system is needed which can provide proper humidification to the patient airway. Such system exists and that too with various functionality but results in high cost.

In this research we will undergo the study of humidifier, its working and how we can reduce its pricing. Main study is to make an alternative way to reduce price and not expected to be ready for mass production.

**Key Words:** Humidifier, Nebulizer, breathing, Endotracheal tube (ETT), Ventilator, conductivity, temperature.

## 1. INTRODUCTION

### 1.1 HUMIDIFIER

It is the device which adds water vapours and heat to gas which comes from ventilator, in our case from AMBU bag. The amount of water present in gaseous or molecular form in air or gas mixture is termed as **Humidity**. It can be measured in numerous units, but the two majors are **Absolute Humidity(AH)** and **Relative Humidity(RH)**.

AH, the quantity of water in a given volume of gas and expressed in terms of milligram per litre(mg/L).

$$AH = \frac{m_w}{V} \dots\dots\dots 1$$

RH, the quantity of water vapor in a given volume of gas or partial pressure of water to the saturation vapour pressure at atmospheric temperature and expressed as percentage(%)

$$RH = \frac{P_{H_2O}}{P_{H_2O}^s} \times 100\% \dots\dots 2$$

## 1.2 PRINCIPLES / FACTORS GOVERNING HUMIDIFIER FUNCTION

The performance or to say design of humidifier depends on the following four factors<sup>[1]</sup>

- Temperature
- Surface Area
- Contact Time
- Thermal mass

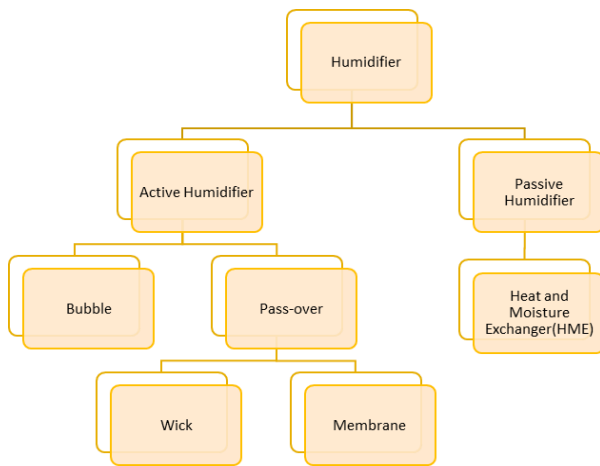
**1. Temperature** - Temperature being the important factor affecting the performance of a humidifier. More the temperature or more we heat the gas it will hold the water vapour in highest quantity.

**2. Surface Area** - Water and gas coming out from ventilator should be in contact for long time. This results in designing the humidifier of larger surface area. Pass over humidifier is one of the example which is having large surface area.

**3. Contact Time** - Contact time is directly proportional to surface area, more the surface area more will be the contact time which helps the gas to carry enough humidity.

**4. Thermal Mass** - The amount of water should be sufficient or must be more than the normal line resulting in greater thermal mass. Increase in thermal mass result in increase of to hold and transfer heat to gases coming from ventilator.

### 1.3 TYPES OF HUMIDIFIERS



Humidifier are classified into two types,

- Active Humidifier
- Passive Humidifier

**1. Active Humidifier** - Active humidifier is the one in which we can provide external heat, water or both. Active humidifier can be further classified into,

- Bubble Humidifier
- Pass-over Humidifier

**a. Bubble Humidifier** - In bubble humidifier inlet pipe extended deep inside the humidifier below the level of water to make the gas mixture coming from ventilator finitely mix with sufficient humidity as shown in figure 1.

**b. Pass-over Humidifier** - In pass-over humidifier the gas hovers over the surface of water. There are three types in pass-over humidifier,

- Simple Reservoir** - In this reservoir gas passes or hovers over the surface of water. This type of reservoir is commonly used in invasive mechanical ventilation.
- Wick Humidifier** - In this humidifier we use the absorbent material by which we can increase the surface area (as surface area is affecting parameter discussed earlier).
- Membrane Humidifier** - In this humidifier the membrane is placed on the surface of water, by doing this, as we heat water from below the heated water vapours can only pass-through pores of membrane and not liquid water.

**2. Passive Humidifier** - Passive Humidifier is the one which uses the patients' exhaled air heat and humidity in humidifier. Typical example of passive humidifier is,

- Heat and Moisture Exchangers

**a. Heat and Moisture Exchanger** - It is also termed as "artificial nose". Same as the function of nose, HME provides up to 70% of heat and humidity during the next cycle when patient inhale air.

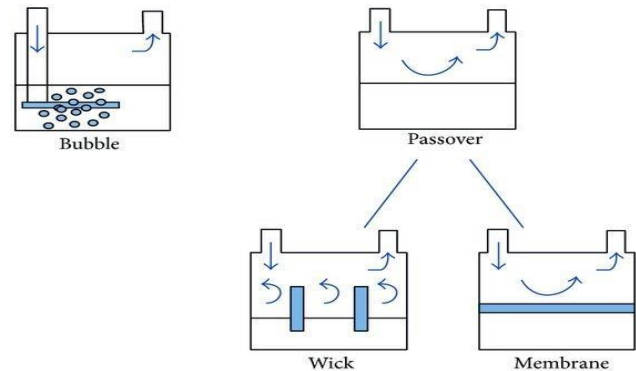


Fig - 1 : Primary Types of Active Humidifier<sup>[1]</sup>

## 2. PHYSIOLOGY

### 2.1 NATURAL PHYSIOLOGY OF HUMAN AIRWAY

Atmospheric air is inhaled by nose and the air passing through trachea increases the surface area contact between the inhaled air and mucosa. The nose heats and humidifies the inhaled air, it can warm the inhaled air up to 28.5°C<sup>[3]</sup>. According to studies, the inhaled air achieves body temperature and pressure saturated(BTPS) condition (i.e., body temperature, 37°C; at 100% RH)<sup>[1]</sup> as it arrives to lungs, see figure 2. The region at which BTPS condition occurs approximately nearly 5cm below carina is termed as ISOTHERMIC SATURATION BOUNDARY(ISB). Above and below the ISB, the temperature and humidity decreases during inspiration and increase during exhalation respectively and RH remains constant.

There are numerous factors or reasons that can shift ISB deeper into lungs, this condition can occur when person breathes via mouth ; inspired cold and dry air; or the airway is bypassed by ETT. This happens to get or provide the necessity humidification to lungs. These shifts of ISB can lead to complications.

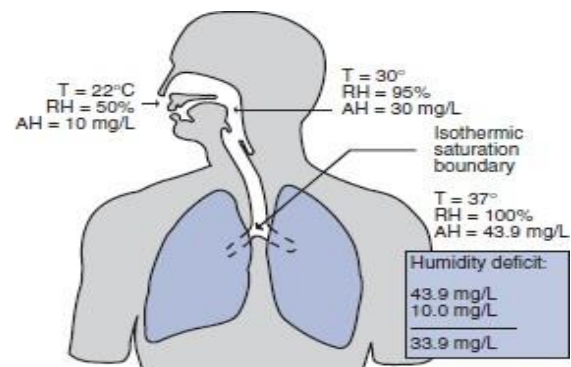


Fig - 2 : Natural Breathing Humidification

## 2.2 PHYSIOLOGICAL COMPLICATIONS – OVERHUMIDIFICATION

This complication may occur when humidifier provide humidity at higher temperature than BTPS condition. Exposing internal trachea at this higher temperature will cause thermal injury. The estimated temperature in which trachea remain unharmed is up to 43 to 45 °C<sup>[2]</sup>. This can be reduced by increasing the water content without changing the temperature but will result in below complication i.e., Underhumidification

## 2.3 PHYSIOLOGY COMPLICATIONS – UNDERHUMIDIFICATION

This complication frequently occurs due to improper humidity provided by humidifier. If we delivered the air with less temperature and humidity or below BTPS condition, the condition of mucor-mycosis, pneumonia, etc. will occur. This situation can be overcome by heating the air in extended pipe after outlet of humidifier.

## 3 EXISTING HUMIDIFIERS

The two most commonly used humidifiers in today's generation are Heated Humidifier(HH) specifically pass-over and Heat and Moisture Exchanger(HME).

### 3.1 Heated Humidifier

Heated Humidifier comes under active humidifier that too in pass-over humidifier. The humidifier of Fisher & Paykel MR850 is studied which is shown in figure 3. It consists of a bowl of water mounted on hotplate.

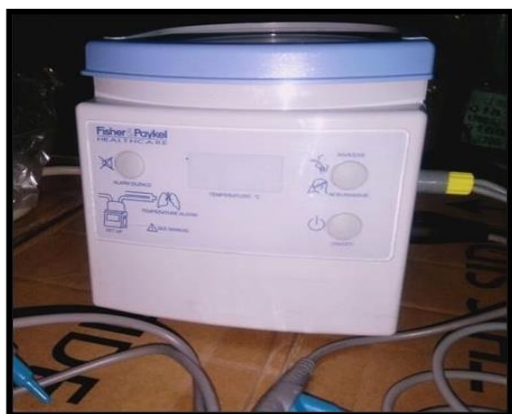


Fig - 3 : The Fisher & Paykel MR850 Heated Humidifier

The gas mixture coming out from AMBU bag will go through humidification chamber. The various types of condition for temperature and humidity can be controlled digitally as shown in figure and also humidifier can run automatically according to the condition specified, this can be achieved by feedback mechanism provided at the end of tube close to the patient.

Providing the desired 37 °C and 100% RH is way easy in HH and to reach this condition the temperature inside the humidification chamber must be higher than 37 °C and then passing through tube condensation will help to reach to desire condition but condensation in tube will create water droplets inside tube and if this remains for longer duration can generate bacteria inside tube. This is the main disadvantage in HH.

### 3.2 HEAT AND MOISTURE EXCHANGER

HME comes under passive humidifier and working is same as explained earlier.

In this type of humidifier, the temperature and humidity of inhaled air is always less, and it is not possible to reach BTPS condition using HME. Modifications done in HME results in widely usage of this humidifier when patient receiving assistance via endotracheal tube(ETT) or for short-term humidification.



Fig - 4 : The Servo Humidifier 162

## 4. IDEAS FOR FINAL SELECTION

### 4.1 MODULES FOR HEATING

The heater in humidifier performs the task to warm the water in bowl which is placed on hotplate to create the vapours of liquid water so that the gas mixture can take humidity as required by patient. But we all know that the energy required to change the phase of water will be more than just to heat water in same phase.

Therefore, three heaters were studied that how we can make a design that will heat water in vapour phase to reduce workload and energy. Described as follows,

#### Heater from a Heat Gun

The product of Leister, COTS air heater was studied<sup>[2]</sup>. This heater provides more than sufficient heat because of its high ratings i.e., 450 W at 230 V and this is the only product available at its lowest ratings.

This may be remarkable to use because of its low thermal mass and the wire housing is open to atmospheric air but due to very high power rating this heater is in doubt that how to control its end temperature.

### Aluminum Heater with Cartridge Heating Element

This heater model will consist of a pair of aluminum rods having pores for atmospheric air to pass confined in cartridge / skeleton heater. It is studied to replace the Heat gun with preferable power rating. But aluminum rod can melt surrounding plastic tube though it has good thermal conductivity.

Main finding in this heater study is that control on temperature was accurate but heat gun provides lesser or no risk of melting of surrounding plastic.

### Heater Made of Heating Wires and Plastic Housing

Below figure 5 shows the heater designed by considering the advantages of two previously described heater. A heating wires are exposed to air stream which are confined in skeleton housing and material used is having low thermal mass, by choosing wire and its length had made us confident to conclude that it having low power rate and also low voltage.

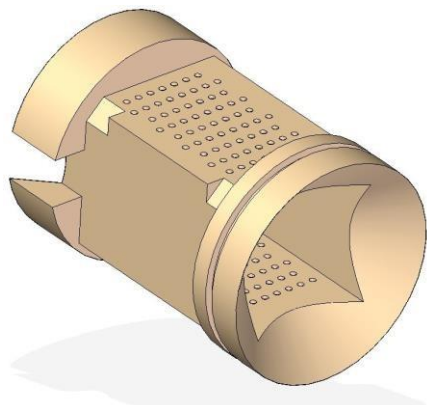


Fig - 5 : An Image from CAD-design of the Heater

## 4.2 HUMIDITY ACTUATORS

Now we had made the system to heat vapour but how to convert water into its vapour form. This work is done solely in HH, heating water and converting water into vapour. The phase transition from water to vapour can be done using Ultrasonic Nebulizer.

Nebulizers is used to create aerosol as shown in figure 6.

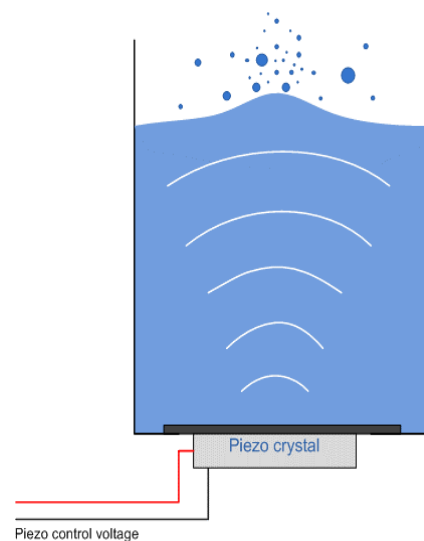


Fig - 6 : Schematic Diagram of Ultrasonic Nebulizer Driven with a Piezo element

## 5. PROTOTYPE DESIGN

The focus of this project is to determine an alternative and cost-efficient way of ventilation. The design that has been proposed can have some modifications and we do not claim to be ready for mass production.

### 5.1 DESIGN USING CAD-SOFTWARE

The rough design of Humidifier is made on Auto-CAD shown in figure to give an insightful view of how the design will be look like. The four factors affecting the performance of humidifier is taken into consideration during the design of a humidifier.

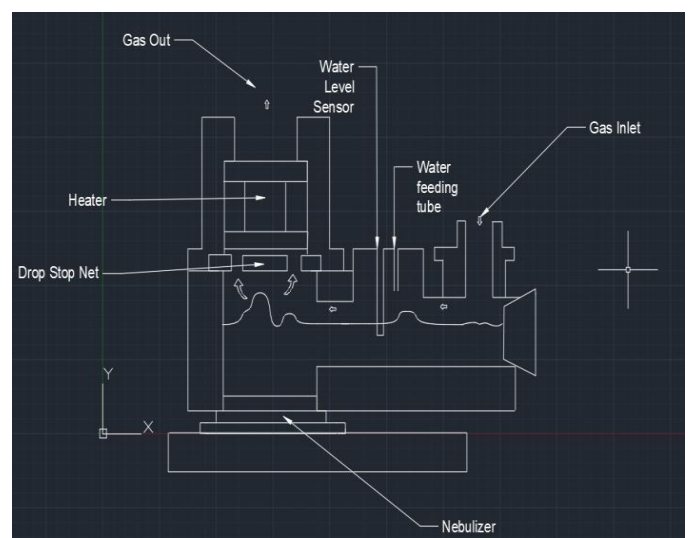
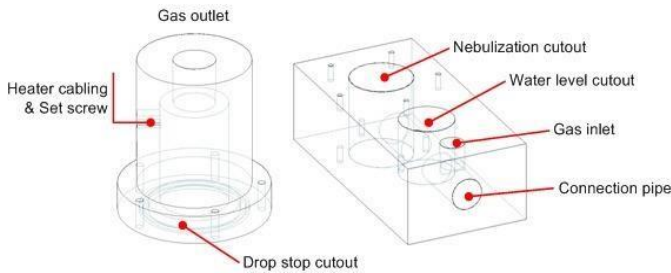


Fig - 7 : A Half-sectional view in 2D Sketch of the Final Prototype

The design can be broken into two major parts: heater pipe and water container. The SolidWorks CAD software is used to make a rough 3D model to show the inferior view.

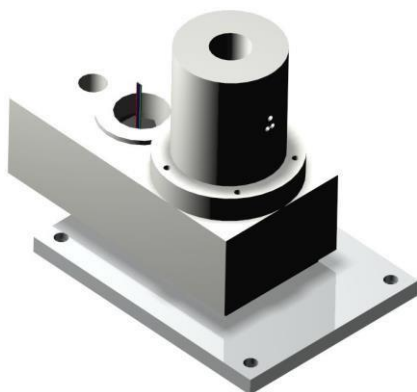


**Fig - 8 :** The prototype’s two main parts, Heater Chamber and Water Container

The heater chamber (left in figure 8) is the one which hold the heater in vertical position. The gas mixture will pass through heater which will absorb heat from heater and will go out of the heater chamber. A minor cutout near the bottom is provided for drop stop net so that the water droplets should not reach up to heater wires as it may cause short-circuit.

The water chamber (right in figure 8) in which at bottom a nebulizer will be fitted. The two holes made vertical are, one for the inlet of gas that will come from AMBU bag and second is to be provided to check the water level as nebulizer work efficiently up to 40 to 50 mm of water above it. Apart from that a connection pipe is provided for easy removal of water if not in use where the knob will be fitted during working operation.

Below figure 9 of 3D Model of the Humidifier that we had design.



**Fig - 9 :** Assembly from CAD

## 6. Choice of Materials

The material has to be chosen for development of humidifier is very difficult task, we didn't only have choose material, but which is cost effective, easy to manufacture and can

withstand the requirements of humidifier. The material which we'll be used is already used in medical equipment.

The heater skeleton will be exposed to very high temperature because of the heater wires that are wrapped back and forth through holes. The area of wire which will pass through the skeleton walls, temperature can reach up to ~200 °C. The outlet of humidifier will be exposed to temperature of around ~90 °C and the remaining parts are not that exposed to high temperature.

Therefore, the material PEEK(Polyetheretherketone) is to be chosen for the designing of heater skeleton. PEEK is the material that is been used in medical equipment because of its good characteristics; it has high transition temperature up to 275 °C and its melting point is of around 300 °C<sup>[4]</sup>. Alternatively, the choice can be metal, but it will short circuit the wires and also the danger of electric shock.

The other material which are not that exposed to high temperature can be made of PMMA(poly(methyl methacrylate)). It is in doubt will it be withstanding or not because its characteristics tells us that it has melting temperature of around 100 °C<sup>[4]</sup>. Earlier stated the outlet of humidifier can reach up to 90 °C.

## 7. Choice of Wire for Heater

The wire which chosen is Nikrothal 80 having the diameter of 0.5 mm. The usage of 1mm wire is decided but it is very hard to bend 1 mm wire and when bend around holes of heater skeleton can damage the product. That's why we will use a pair of 0.5mm wire. These wires can be taken as resistors in parallel and having resistance of  $2 \cdot 5.55\Omega = 11.1\Omega$

$$R_w = \frac{11.1 \cdot 11.1}{11.1 + 11.1} = 5.55\Omega \quad \text{---- 3}$$

Assuming maximum power to be 100 W, the voltage required would be

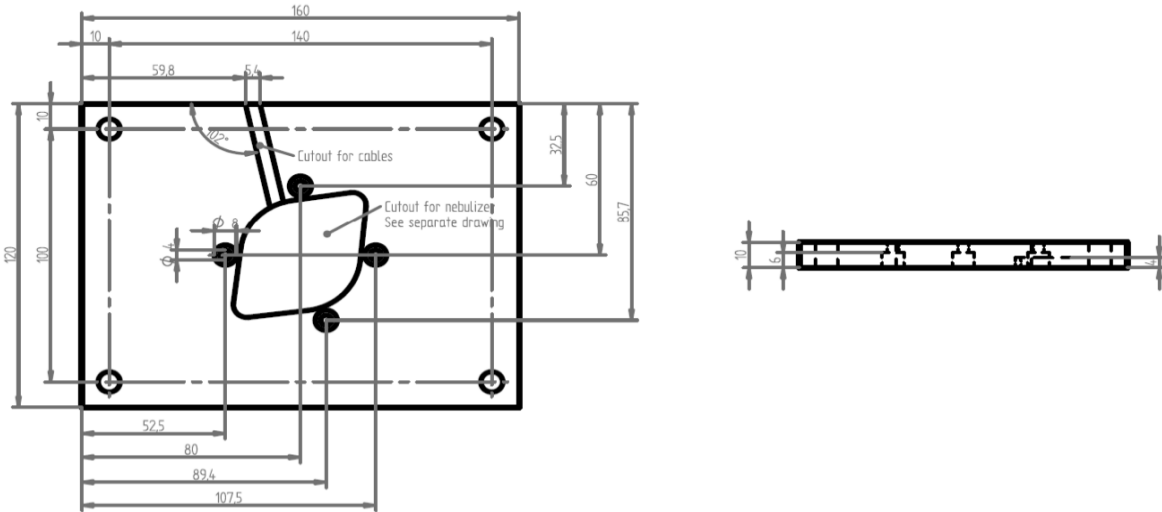
$$V = \sqrt{P \cdot R} = \sqrt{100 \cdot 5.55} = 23.6V \quad \text{---- 4}$$

A 24 V will be capable to provide more than 100 W.

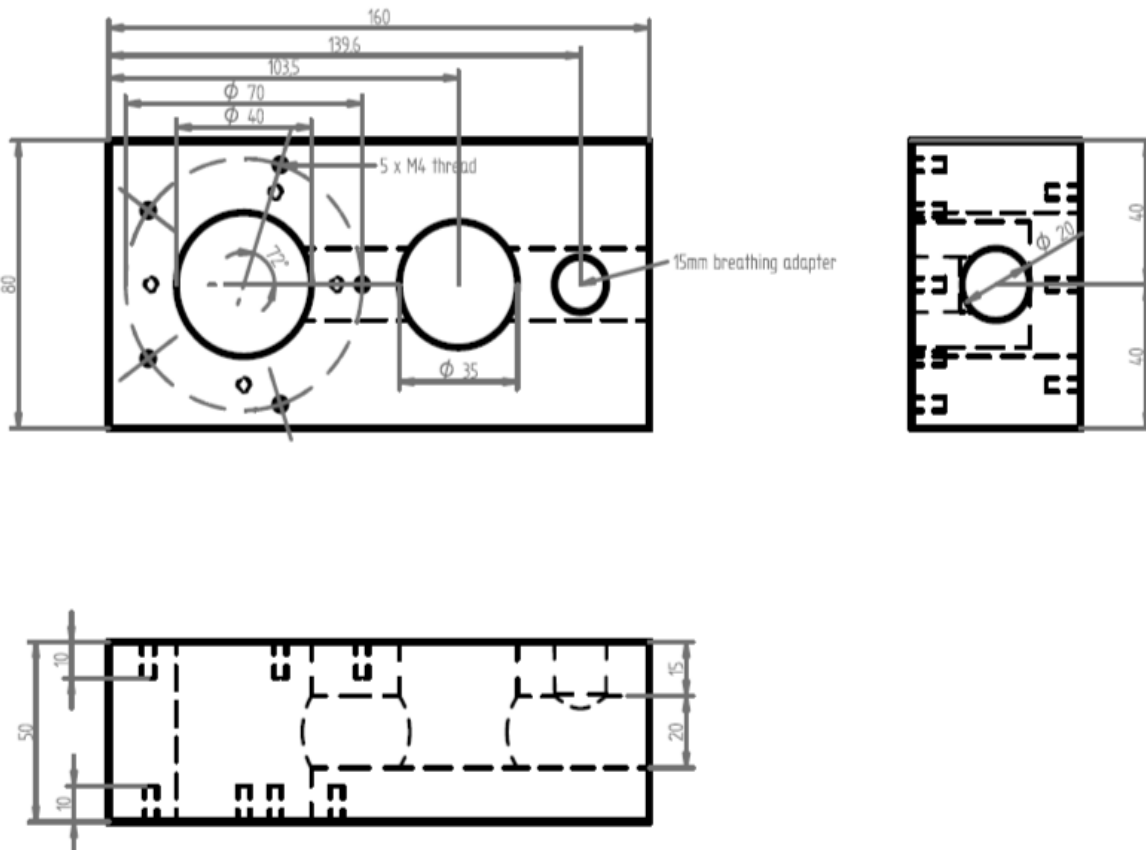
## 8. CONCLUSION

The main idea behind this project is to provide an alternative and cost-effective way for humidification though as far as design is concerned it is subjected to minor changes. The material that chosen for prototype can be replaced which may result in lower cost.

**APPENDIX**



**Figure 10.** Nebulizer cut-out in Aluminum plate



**Figure 11a.** Water Chamber

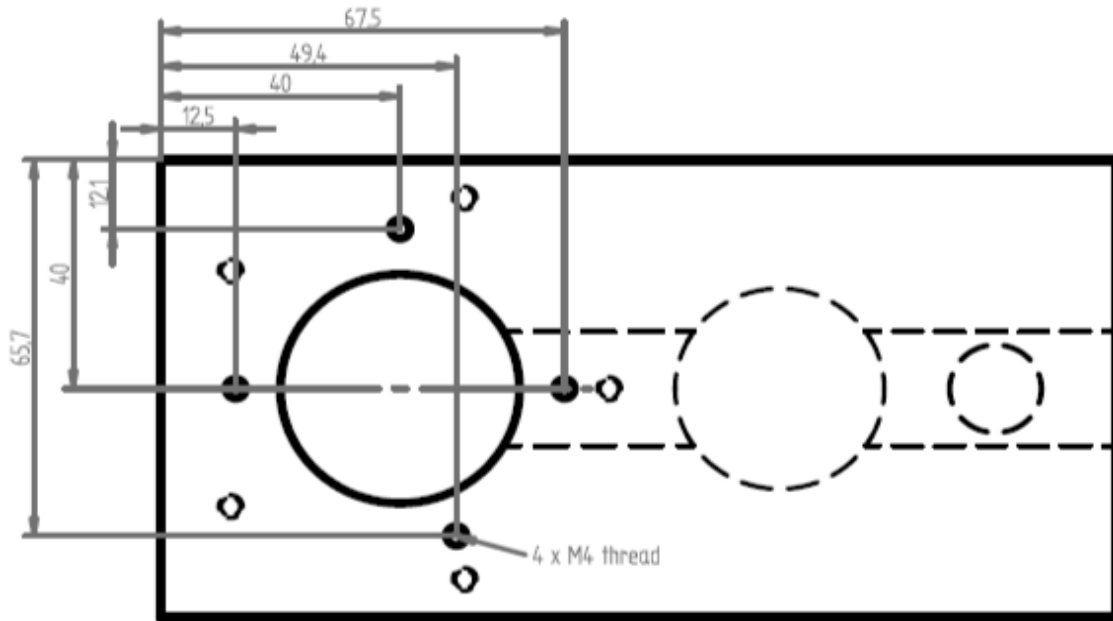


Figure 11b. Water Chamber from below

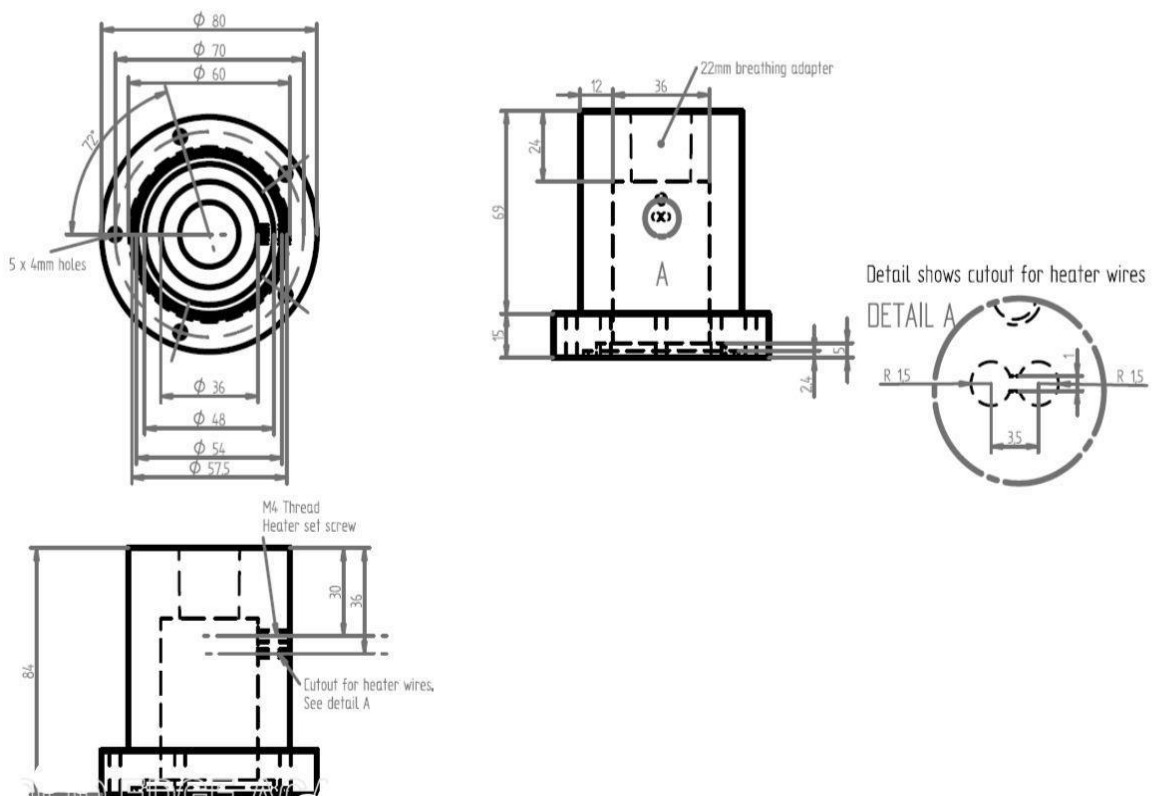


Figure 12. Heater Chamber





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