CPAP Machine

Mid-Semester Report

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Abstract

Respiratory Distress Syndrome (RDS) is a condition characterized by a lack of surfactant production on lungs. RDS occurs in infants whose lungs have not fully developed and is one of the leading causes for preterm death, especially in developing countries where health care is severely limited. Continuous Positive Airway Pressure (CPAP) machines are commonly used to assist preterm infants in breathing by providing a continuous air flow to the infant. Our goal this semester is to design and fabricate a CPAP machine that can be used in developing countries and at a cost significantly less than today's CPAP machines without sacrificing the safety, efficiency, and reliability of the machine.

Background

A CPAP machine is a commonly used medical instrument in the health industry that delivers pressurized air to a patient through the nose. The general components of a CPAP machine include a flow generator, a hose to connect to the flow generator, and a mask interface to fit on the patient's face. Many CPAP machines will also contain a humidifier, data logging, and exhalation relief for extra comfort and function. Although originally meant for sleep apnea patients, CPAP machines are now used to treat a variety of illnesses.

In today's world, a large number of pregnancies end with preterm birth. 9.6 percent of births in 2005 were preterm according to the World Health Organization or WHO [1]. A majority of these preterm births occur in developing countries with a large percentage occurring in African countries. Of the 115.3 million births recorded by WHO, 12.9 million were preterm births with 11.8 million occurring in African, Latin American, and Caribbean countries. Research also showed that 30 percent of preterm infants are born with RDS [1]. RDS is a condition where a newborn does not produce enough surfactant in their lungs [2]. Surfactant maintains the shape of the alveoli within the infant's lungs, which are responsible for allowing oxygen to enter the body [2]. Without enough surfactant, an infant's alveoli will not inflate enough for the infant to breathe normally (Figure 1) [2]. RDS can commonly cause rapid heartbeat and breathing in infants. In order to prevent the alveoli from collapsing, CPAP machines are used.

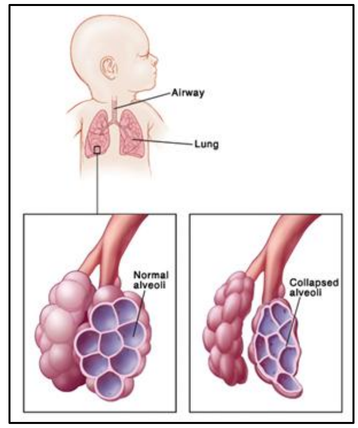

Figure 1. Effects of RDS

Infant CPAP machines are the most common treatment for RDS. A CPAP machine works by providing a steady flow of pressurized air to a patient. This air is also humidified and heated to improve the comfort of the patient using the CPAP. Infant CPAP machines are designed specifically to re-inflate the alveoli in an infant suffering from RDS. The pressurized air from the CPAP machine forces the alveoli to form into the proper shape to allow oxygen to enter the body easily. CPAP machines can be used to effectively treat patients in the United States where they are easily found, but this is not the case in many developing countries.

A large number of developing countries around the world lack formalized healthcare. These countries lack the materials and funds to obtain any type of modern-day medical technology. Because of this, many preterm infants suffering from RDS do not get the medical treatment they need which proves fatal.

Problem Statement

The goal for the this project is to design a CPAP that will be significantly less than current CPAPs and be able to be used in developing areas by untrained workers. The device needs to be made of resources that are found in the region that it is being implemented in or be easily accessible to those regions. It also needs to be reliable and user-friendly so that anyone can operate the machine.

Design Specifications

Our infant CPAP is designed for premature infants born 30 to 33 weeks after conception. These pre-mature infants are the most common infants born without sufficient surfactant to fully support their lungs. Targeting this range of premature infants optimizes the amount of premature infants our infant CPAP can save. For these infants certain physiological parameters are necessary to meet in order to save their lives.

It is vital that the pre-determined specifications of the air that is continuously pumped into the infant are under tight control. First, the infant CPAP must supply a continuous stream of air for up to 2 weeks. Infants born after 30-33 weeks after conception usually require a CPAP for 3 days to allow their lungs to recover. Anything longer than that is for precautionary measures. Air pressure from the infant CPAP must between 4-10 cmH_2O. Anything below 4 cm H_2O will not have an effect on the infant. Anything above 10 cm H_20 may do more harm to the infant than good since their lungs most likely won't support pressures this high. The infant CPAP must also be able to 100% humidify the air and heat it to 35°C. All of the specifications of the air entering the lungs must also be able to be regulated based on the circumstances of the birth.

Since we are designing this infant CPAP for developing countries the entire infant CPAP machine must be portable in case the infant CPAP needs to travel from village to village. The entire infant CPAP includes its own power supply. The goal for the sum of the cost of each of these components of this infant CPAP must be under $150. This goal was given to us by the EWH national organization.

Overview of Design

The design that is being modified to function in developing country environments is the Bubble CPAP (Figure 2). The Bubble CPAP operates in the same way as a traditional CPAP. A blower generates air flow that passes through a heater/humidifier [3]. This heats the air to the desired temperature and humidifies it to provide comfortable air to the patient and to prevent the nasal passages from drying out [3]. Once the air is heated and humidified, it passes by a temperature sensor which monitors the temperature of the air to determine if the heater is functioning properly. The air then travels into the patient via nasal prongs that are inserted into the infant's nose [3].

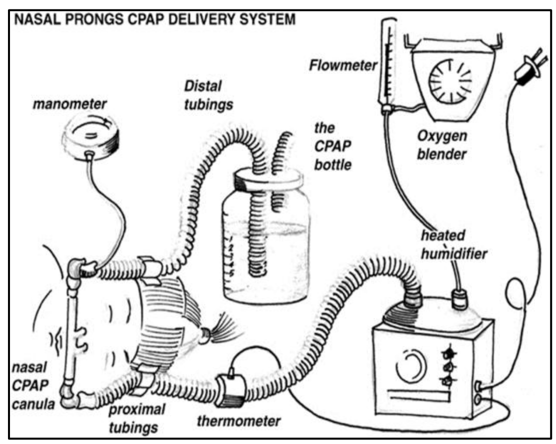

Figure 2. Bubble CPAP

When the infant exhales, the air travels through an exhalation tube whose end is submerged in a bottle filled with sanitized water [3]. This maintains the air pressure in the whole system. The pressure can be changed by moving the tubing deeper or shallower in the water [3]. A pressure sensor is attached to the exhalation tube to monitor the pressure of the air in the system. A one way exit valve is attached to the bottle to release pressure from the bottle along with water exit and entrance tubes to release or add water as needed [3].

This design was split into four different parts, with each group member taking the lead on a part. These parts were the blower, the heater/humidifier, the pressure sensor, and the power supply. Several designs were brainstormed for each part in order to determine the most effective, reliable, and cost-efficient design.

Designs

Blower

Two different fan designs to act as the blower in our infant CPAP machine were researched. The two designs were the centrifugal fan (Figure 3) and the axial fan (Figure 4). Centrifugal fans include a fan wheel and a housing unit [4]. Air is brought into the side of the fan wheel which rotates and blows a flow of air out of the housing unit [4]. An axial fan contains a group of blades attached to a rotating shaft [4]. An example of an axial fan is a basic household fan. The centrifugal fan costs $27.24 dollars which is slightly more than the axial which costs $21.21 dollars. In terms of portability, the centrifugal fan was much smaller than the axial: 39 cm^3 compared to 160 cm^3. Both fans are able to produce the required flow rate range of 20 to 60 liters per minute making them both good candidates, but the centrifugal fan's max output was much closer to the maximum output needed. We ultimately decided that the centrifugal fan was a better choice because of its lower volume.

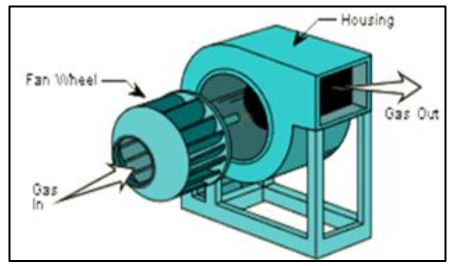

Figure 3. Centrifugal Fan

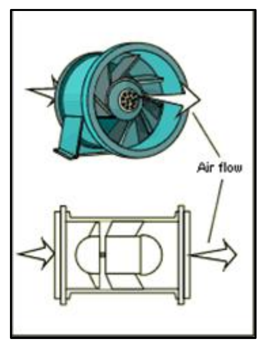

Figure 4. Axial Fan

Heater/Humidifier

Steam Humidifier

The steam humidifier uses a heat source to heat up a container of water to produce water vapor (Figure 5) [5]. The air that is generated from the blower is humidified as it passes through the water vapor and this air is sent to the infant. The steam humidifier has many pros. It is very effective and it provides clean air for the infant. It also provides the user with control over the humidity of the air. Depending on the temperature of the heat source, the air will become more or less humid. It is also able to be used in developing countries as many of the materials needed can be found in developing countries. A con of the steam humidifier is its need for a heat source. Typically steam humidifiers use an electric hot plate to heat the water, but since that would not be applicable for a developing country, a different heat source will have to be designed.

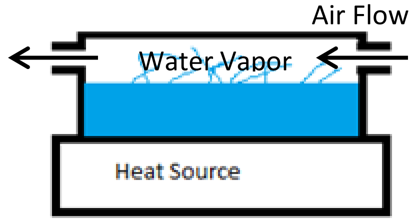

Figure 5. Steam Humidifier

Wick Humidifier

The wick humidifier utilizes a water reservoir and a water absorbent material (Figure 6) [5]. Depending on the humidity outside, the water is absorbed into the wick from the reservoir [5]. The fan then blows air through the wet wick and this humidifies the air. This technique is beneficial as it is easy to set up and it requires no energy for it to operate. However the wick humidifier has bacteria concerns, lacks control over humidity, and is not very comfortable for


Figure 6. Wick Humidifier

the user. The wick absorbs water and will constantly be damp. This damp environment is great for bacteria to thrive and the bacteria would be picked up by the air and flow into the infant. The wick would have to be changed periodically to prevent these harmful bacteria concerns. The wick also self-regulates itself, meaning depending on the humidity of its surroundings it makes the air more or less humid. If the air outside is very humid the wick will absorb less water making the air that flows into the infant not that humid. Lastly, the wick is not comfortable for the user because it lacks warm air.

Pressure Sensor

Piezoresistive Sensor

A piezoresistive pressure sensor uses the piezoresistive effect of formed strain gages to detect strain due to applied pressure [6]. The strain gages, made of a semiconductor material, have a certain resistivity at a particular pressure. As the pressure induced on the strain gages increases or decreases, the resistivity of the strain gages increases or decreases respectively [6]. This change in resistivity affects the current passing through the circuit which in turn affects the total output voltage of the sensor. An increase or decrease in output voltage indicates an increase or decrease in pressure. The strain gages are arranged in a Wheatstone bridge to maximize the output of the sensor (Figure 7).

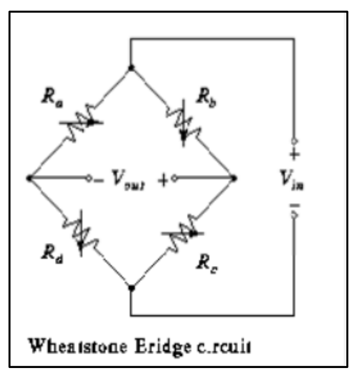

Figure 7. Wheatstone bridge circuit

Piezoresistive pressure sensors have many pros over the other pressure sensors. The first is that they have low power consumption. This is beneficial because allows the power supply to provide less voltage, which will increase the life of the power supply. They are also very accurate at low pressure operations and are commonly used in many biomedical applications. Piezoresistive pressure sensors are very cost-effective and because of their simple circuitry, they require a smaller area and can therefore be used in more applications. However piezoresistive pressure sensors are sensitive to environmental temperature changes and require Silicon to achieve high-performance.

Capacitive Pressure Sensor

A capacitive pressure sensor utilizes two parallel metal plates that are aligned facing each other to create a capacitor [6]. One plate is fixed to provide a reference pressure and the other plate is allowed to move freely back and forth. As the pressure on the free-moving plate increases or decreases, the plate moves closer or further away from the other plate which affects the capacitance of the circuit [6]. This change in capacitance affects the current flowing through the sensor which affects the output voltage of the circuit. An increase or decrease in output voltage indicates an increase or decrease in pressure.

Capacitive pressure sensors have many pros. They are very accurate and are not as affected by temperature change as piezoresistive sensors. They are most commonly used in low pressure environments because of their sensitivity. Although they are more expensive than piezoresistive sensors, they still are relatively cost-efficient. They also are made of simpler materials than the other pressure sensors. However capacitive pressure sensors are relatively larger than other pressure sensors, sensitive to electromagnetic fields, sensitive to particles and humidity, and have more complex circuitry.

Potentiometric Pressure Sensor

Potentiometric pressure sensors utilize a Bourdon tube, capsule, or bellows to drive a wiper arm along a resistive element (Figure 8) [6]. As the pressure on the wiper arm increases or decreases, the wiper arm is raised or lowered along the resistive element [6]. The resistance of the element is dependent on where the wiper arm is located. The higher up the arm is the more resistive the element is and vice versa [6]. The change in resistance affects the current flowing through the circuit which affects the output voltage of the circuit. An increase or decrease in the output voltage indicates an increase or decrease in pressure.

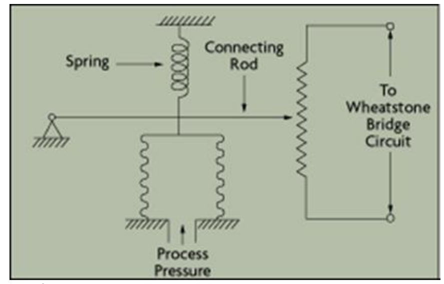

Figure 8. Potentiometric Sensor

The pros of potentiometric pressure sensors are that they are very low cost, can be small, and are relatively simple. However in order to obtain a reliable operation, the wiper arm must bear on the resistive element with some force, which leads to repeatability and hysteresis errors. They are also prone to mechanical wear which makes them unreliable over long periods of time. Overall, we decided that the piezoresistive pressure sensor was the best option to implement in our system because of their accuracy and their low power consumption.

Power Supply

If the design of the infant CPAP utilizes a blower and pressure sensor, voltage and current are needed to power the machine. We have obtained an adult CPAP which requires 100 W in order to run it properly. The goal wattage for our power supply is 100 W since this is enough to power an adult CPAP that has unnecessary components. This means our infant CPAP most likely requires less wattage. Once each component of the infant CPAP is determined, the resistance of each one will be calculated. From here, the wattage of which it runs at will be determined.

In order for the infant CPAP to run for a couple weeks the power supply must deliver 100 W continuously. Many power sources were taken into account. Solar panels and wind turbines are very expensive, and water turbines are unreliable. All these ideas also depend on factors that may not be available in a certain region. Deep cycle marine batteries work the best for our design (Figure 9). Deep cycle marine batteries are designed to be discharged down as much as 80% time after time [7]. They are designed to supply a constant supply of voltage and current and made to last longer than car batteries. However, for the infant CPAP to run continuously for 2 weeks, these batteries must still be recharged after a certain amount of time.

Figure 9. Deep cycle marine battery

Recharging the marine batteries efficiently is the largest problem associated with this design. Some ideas to recharge these batteries is to use a Stirling motor with a hand crank generator, man or animal power to constantly turn a hand crank generator or solar, wind and water power to recharge them. In order to charge a deep cycle marine battery, the voltage delivered to the battery must be more, about 15 V, than the voltage the battery produces, 12 V. More tests need to be conducted to determine which method is the most efficient to charge a deep cycle marine battery.

Future Work

Given that creating a new pressure sensor and a new blower would be design projects on their own, buying a blower and pressure sensor needs to be done. Inexpensive models have been found online which allows the team to focus on creating a functional humidifier and an efficient power supply. Implementing the steam humidifier means an efficient heat source will need to be designed. The heat source needs to be safe and controllable to insure that the air the infant breathes in is not harmful. Past design groups have used fire as the heat source because of its ability to be used anywhere in the world. However, having a flame near an infant is a big safety hazard so we will be looking for alternative methods.

The other big challenge is finding a method for recharging the marine batteries. The power supply we create needs to last for at least two weeks as the infant develops its own lungs. With rough calculations it was discovered that our system would be able to run off of a marine battery for about three hours before the battery dies. This means a quick and efficient way to recharge the battery needs to be discovered. One possible solution is a hand crank generator. Our team has a hand crank generator, but it will need to be modified so it can recharge a car battery faster. Additional gears may make this possible, but further exploration and testing is needed.

In addition to finding an efficient way to recharge the battery, a way to connect the battery to the CPAP needs to be looked into. The battery needs to be able to safely power the blower, pressure sensor, and possibly the heat source. Air filtration also needs to be looked into more. Because our blower is drawing air from the environment, the air may contain particles and pathogens that could cause the infant harm. A filter will need to be placed in the tubing before it enters the humidifier to ensure that the quality of the air is safe for the infant.

Compressed air is an option that our team recently thought of implementing. This would eliminate the need for a blower and potentially the power supply. Instead of having to power a fan, an air tank would be used to push air through the tubing similar to the portable life support systems that elderly people use. Compressed air would also make maintaining a constant air pressure easier. However this option would need to have a method for refilling the air tanks. Further research is needed to determine this.

We have completed our mid-semester presentation and have presented it to our advisors. We are pleased with the progress that we have made thus far and we hope to continue developing a useful prototype. Finally, as we move to the fabrication and testing stages of the design process, we hope to collect valuable data and information that will guide us towards the most viable and practical solution.

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Appendix

Product Design Specifications:
Infant CPAP Machine

Team Roles:
Team Leader: Nick Shiley
Communicator: Drew Pierce
BSAC: Brad Lindevig
BWIG: Mike Kapitz
Last Update: October 19, 2010

Function: Preterm Infants are generally born with less surfactant in their lungs than full-term infants, resulting in more difficulty in keeping their lungs expanded. This can lead to chronic lung diseases which are often fatal for the infants, especially in developing countries where health care is severely limited. Continuous Positive Airway Pressure (CPAP) machines are commonly used to assist preterm infants in breathing, giving them a chance at a normal life. Our goal is to design and fabricate a CPAP machine that can be used in developing countries and at a cost significantly less than today's CPAP machines.

Client Requirements:
- Must cost no more than $150
- Must provide a continuous power supply for up to two weeks
- Must provide continuous pressurized air (4-10cmH_2O)
- Must supply 100W to system
- Must have a heater/humidifier to create safe air for the infant to breathe
- Must have an air-filter
- Must have a temperature and pressure sensor to measure values during treatment
- Must have an air exit valve to prevent air from recirculating after exhalation

Design Requirements:
1. **Physical and Operational Characteristics**

a. **Performance Requirements:** The CPAP machine must provide continuous pressurized air and continuous power supply of 100W for up to two weeks.

b. **Safety:** It must provide air that is at the correct pressure for the infant, at body temperature, humidified and filtered; otherwise the machine may be fatal.
c. **Accuracy and Reliability:** The air temperature must be measured continuously and be between 36-37^{o}C. The air pressure must be measured continuously and be between 4-10cmH_2O.
d. **Life in Service:** Power Supply must last for up to two weeks.
e. **Shelf Life:** Storing the product will have no effect on its ability to perform.
f. **Operating Environment:** This device will be used in developing countries around the world, mostly in Africa and South America. It should be operable in any environment, including patients' homes.
g. **Ergonomics:** The device should be able to be operated by an untrained adult, but settings should be determined by a professional.
h. **Size:** The device should be compact and easily portable. The Bi-Nasal prongs should have a diameter between 2mm-3.5mm and separated between 6mm-7mm.
i. **Weight:** The device should be light enough to be lifted by a child.
j. **Materials:** The device should utilize materials that can be found in the area it is used in.
k. **Aesthetics, Appearance, and Finish:** Not applicable.

2. **Production Characteristics**

a. **Quantity:** Our team will be developing one CPAP.
b. **Target Product Cost:** The cost should be significantly less than current CPAPs. Our device should cost $150 as compared to $500.

3. **Miscellaneous**

a. **Standards and Specifications:** The device should utilize the same concept as current CPAPs, but with cheaper material.
b. **Customer:** The client wants the design to cost significantly less than current devices and utilize rechargeable batteries, making it operable in any environment.
c. **Patient-related concerns:** The device should be sterilized when switching patients. The device should be comfortable for the patient. Pressure and temperature readings should be carefully monitored.
d. **Competition:** CPAPs are a common instrument used in developed countries, but not where health care is severely limited. Our device will be able to be used anywhere.