International Journal of Scientific & Engineering Research, Volume 7, Issue 11, November-2016 1148
ISSN 2229-5518

Design of a Low cost Non Electrical Type Baby Incubator for Developing Country

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Abstract— A large number of infants in the developing world die due to prematurity complications arising due to non availability of Infant Incubators. These deaths are often caused due to heat loss and dehydration as the prematurely born babies cannot regulate the temperature as the temperature of the environment changes, this can be prevented by medical care with the help of an incubator. Unfortunately, this infant incubator is relatively expensive and for this reason many health care centers especially at rural areas of developing countries like Bangladesh can't afford to buy. The other problem is that most incubators run on electricity, therefore countries like ours where there is an acute shortage of electricity, this existing expensive baby incubator is of no use. The major challenge, therefore, has been to design a low-cost incubator that will run without the use of electricity. The hot water is used as a prospective non-electric heating source in the proposed incubator. The humidity level at 70% RH and above is also maintained non-electrically. In the proposed incubator system special type of dust and air particulate masks are placed at the windows of the incubator to remove dust and air particulate. We have shown that a 12v 100 Ah standard battery available in the market can supply 20 days for sensors and fan drive system. In designing the incubator we tried to reduce the cost by using locally available materials. We believe that our proposed non electrical type infant incubator will be a great help in reducing the death of premature babies at rural areas in Bangladesh where portability, cost and electricity are primary concerns.

Index Terms— Infant Incubator, Infant Physiology, Infant Incubator Controller, Temperature Sensor, Humidity Sensor, Temperature Controlling, Heat Transfer Mechanism.

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1 Introduction

Every year 20 million babies are born premature with low birth weight and they struggle to survive because they cannot regulate their body temperature and they don't have enough fat on their tiny bodies to keep warm. Over 4 million infants are died within a month of birth worldwide, of which 99% belongs to the developing country [1]. The incubator environment provides a homogeneous and stable temperature, a relative humidity (RH) level and oxygen gas concentration that are needed especially for intensive care of the premature baby [2-4]. Most incubators run on electricity and are rendered worthless in regions without electricity, or in those that suffer frequent power cuts. In developing country, there is a limited access to high-tech incubators due to cost as well as lack of electricity. The challenge therefore, has been to design a low cost infant incubator that will run independent of electricity or minimum use of electricity.

For designing this device, our main aim has been to engineer a simple solution to a complex problem in the developing world while keeping the user minimally dependent on Western resources for sustainability of the device. The distinguished feature of our proposed infant incubator is that the heat energy required regulating the temperature inside the incubator supplied from hot water flow rather than a conventional electrical heating system. The humidity level at 70% RH and above is also maintained non-electrically. However, temperature and humidity sensors as well as low power fan drive systems are powered and controlled by an electrical source. We have shown that a 12v 100 AH standard battery available in the market can supply 20 days for sensors and fan drive system. In designing the incubator we tried to reduce the cost by using locally available materials.

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2 Physiology of Premature Infants

Premature infant incubator system is a vital and critical area because it deals with premature infant or illness baby. It is essential to detect any abnormal conditions occur in the premature infant incubator system as soon as possible.

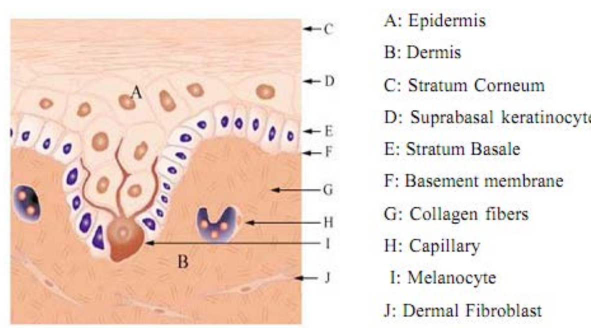

Fig. 1. Skin surface [7].

Temperature, humidity, and oxygen concentration are the main parameters must be control in the premature infant in-

ISSN 2229-5518

cubator system [5,6].

Premature infants are babies born prior to the normal 36 or 37 weeks of gestation within the womb. As a result, their physiological systems are underdeveloped, making them vulnerable to a number of health complications [8]. The inadequate thermoregulations, wherein their physiology is unable to compensate for the loss of heat and water from the body are the leading causes of death in premature infants [9-13]. Heat is lost via evaporative, conductive, convective and radiative means. Furthermore, in the first days of life, premature infants suffer extremely high transepidermal water loss due to their immature skin causing a considerable evaporative heat loss and a potentially fatal imbalance of salts and acids in the infant's system.

Premature infants have a thin, underdeveloped stratum corneum or the rough, outer layer of the epidermis which protects the skin from external agents that enables excess of water to diffuse out [14]. Evaporative heat losses make up a significant fraction of the total heat loss of a premature infant [15].

3 Design of the Non Electric Incubator

Temperature and humidity are two very important parameters that need to be maintained and monitored continuously in the infant incubator chamber so that similar to their mother's womb environment can be replicated for the pre-term infant or new born baby. The preterm baby is particularly vulnerable because of increased heat loss and immature or absent thermoregulatory mechanisms. Even with modern methods of temperature control the increased metabolic demands caused by thermal stress can result in insufficient energy left over for good growth. The body attempts to maintain a constant central temperature within narrow limits. To do this there must be a balance between heat production and heat exchange with the environment. This exchange with the surroundings occurs by conduction, convection, radiation and evaporation. The effect of these four modes will depend on gestation, postnatal age, the characteristics of the environment such as temperature and humidity, the importance of high humidity to prevent evaporative heat losses, thereby maintaining the required body temperature of infants' body.

3.1 Design Requirements

The design requirements for the infant incubator are to provide the infant with the bare necessities, these are [2]:

- An ambient temperature of 34°C -37°C
- A humidity greater than 70% RH
- A sterile air supply

With these in mind, our important design elements are:

- An heat source/sink to maintain the ambient temperature in the 34°C – 37°C range for as long as possible- ideally 24 hours, with minimal monitoring.
- An effective air purification system that will circulate enough oxygen to the infant.
- A simple incubator design that will enable easy access to the infant when needed.
- An effective air filtration system that will remove bacteria and air particulate from the atmosphere.

3.2 Complete Diagram of The Proposed Incubator

The figure 2 shown below shows the complete design and functional components of different parts or subsection of our proposed non electrical infant (baby) incubator. The different main functional components are:

1) A hot water reservoir and flow control subsystem for heat transfer
2) A temperature sensor subsystem
3) Humidity sensor and control subsystem
4) Incubator case and other support system

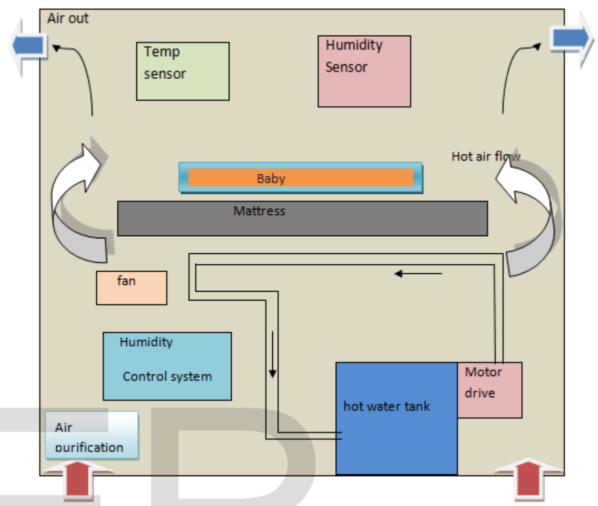

Fig. 2. Complete Functional diagram of the Non-electrical incubator.

3.2.1 Hot Water Reservoir and Flow Control Subsystem

The hot water reservoir and water flow subsystem is the important functional part of the proposed non electric incubator. A heat insulated reservoir holds a large amount of hot water (~100) and works as source of heat energy to be supplied to the incubator. Water from the tank is allowed to flow through a tube made from aluminium which is placed below the bed support of the baby.

However, the bed support is made from heat insulator and separated from the heat flow pipe (as shown in the figure 2) for the safety of baby in case of accident. The heat energy radiated from the hot water tube is driven in by a fan through holes into the main chamber of the incubator.

The heat energy required in the main chamber is fed from the lower chamber where the tube is directly exposed. The temperature and hence heat energy in the lower chamber is strongly dependent on the temperature difference and flow rate of the water through the tube from the hot water reservoir. The flow rate of hot water is controlled by a valve as shown is figure 3. A low power motor drive is used to circulate the hot water through the pipe. Diaphragm pumps are low power consumption pumps runs on 12v, with power requirement of approximately 5W. If the temperature of water falls below the desired level then the flow rate of water will be increased. To do this an automatic system with micro controller may be proposed.

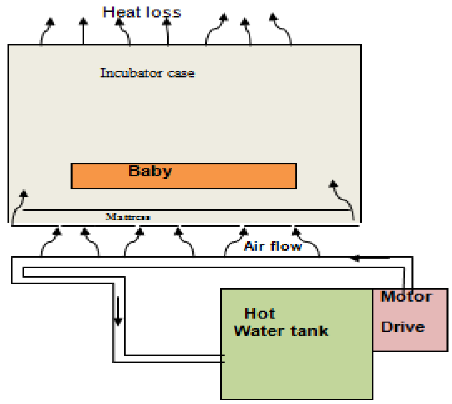

Fig. 3. Heat transfer mechanism in incubator.

3.2.1.1 Heat Transfer Modeling and Calculation

To increase the temperature of the incubator, first we have to supply heat for the baby and the air inside the incubator case.

So to know the amount of heat required in the incubator we have to know the amount of air in the case. The standard size of an incubator case used now a day is approximately:

Height h between 40 and 80 cm
Width w between 50 and 100 cm
Length l between 70 and 150 cm
Wall width d between 5 and 10 mm
For our calculation we took the parameters as:
Height of the case = 40cm
Length of the = 50cm
Width of the case = 43cm

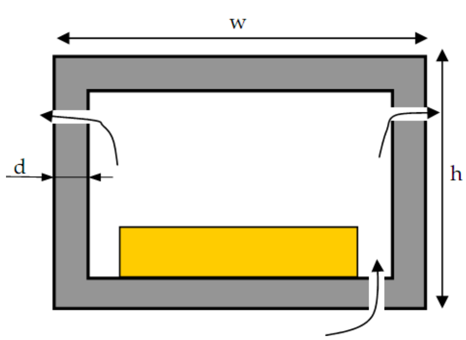

Fig. 4. Simplified cross section of chamber where babies are lied down.

The mass of the air inside the incubator can be found from the volume of the incubator and the density of the air:

$$m = \rho \times V = 1.29\ kgm^{-3} \times (0.4 \times 0.5 \times 0.43)m^3 = 0.11094\ kg$$

Here, ρ = air density = $1.29\ kgm^{-3}$

The amount of heat required to raise the temperature from room temperature to 37°C can be found by finding the heat required for /°C temperature change of the air of the incubator.

The heat required for /°C increase in temperature can be found from the equation given below:

$$Q = mC\Delta T = 0.11094 \times 1050 \times 1 = 116.487\ J$$

Here

$$C = \text{specific heat of air} = 1050\ \text{Jkg}^{-1}\text{K}^{-1}$$

We also need to increase the temperature of the infant from its normal body temperature to 37°C. Let the specific heat of the baby is same as the specific heat of the water, since 80% of the baby's body is water. So the heat required for the baby to raise the temperature per can be found by

$$Q_{baby} = mC\Delta T = 1.814 \times 4200 \times 1 = 7618.8\ J$$

Here m= average baby's mass = 4lb = 1.814 kg

Let us consider that the temperature of the premature baby is below 37°C, say 32°C. So the total amount of heat required to raise the temperature from 32°C to 37°C is

$$Q_{baby} = 5 \times 7618.8 = 38094\ J$$

Three types of losses occur from the incubator, namely: conduction, convection and radiation. Radiation losses occur from all sides of the incubator, we can neglect the loss from the bottom side, since we apply heat from this side. Convection loss occur from the top side only, losses from the other sides due to convection can be neglected. In our model we use Plexiglas, a transparent type of plastic which have very low thermal conductivity 0.17 $wm^{-1}K^{-1}$ for the incubator case. So we can neglect conduction losses. Now we have to calculate these losses to get the proper amount of heat required for the incubator.

Radiation loss can be found from the equation

$$Q_{rad} = \varepsilon\sigma A_s(T_s^4 - T_{surr}^4)$$

Here the area A_s is the total area of the incubator walls, considering the five walls we have the total area

$$A_s = 40 \times 50 + 40 \times 43 + 50 \times 43 + 40 \times 43 + 50 \times 40$$
$$= 9590cm^2 = 0.959m^2$$

We use Plexiglas a transparent plastic as the material of the incubator wall. The emittance of the Plexiglas is 0.86.

So the total radiative loss in /°C temperature change is

$$Q_{rad} = \varepsilon\sigma A_s(T_s^4 - T_{surr}^4) = 0.86 \times 5.67 \times 10^{-8} \times 0.959 \times 1$$
$$= 4.6763 \times 10^{-8}W$$

Convective heat loss from the top wall of the incubator for /°C temp change is found from the equation

$$Q_{conv} = KA(T_1 - T_2)$$

Here

K= Free Convection Over Various Shape - Air
$= 2 - 20\ W/m^2K$ (Take2 W/m^2K)
$A = 0.5 \times 0.43 = 0.215m^2$
T_1= incubator temp at saturation
T_2= surrounding temperature
$T_2 - T_1 = 1K$

So $Q_{conv} = 2 \times 0.215 \times 1 = 0.43\ W$

So the total heat loss is found easily by

$$Q_T = Q_{rad} + Q_{conv} = 4.6763 \times 10^{-8}W + 0.43\ W$$
$$= 0.430000046\ W = 0.43\ J/s$$

So we have total heat loss 0.43J per second.

Now, we consider that for 6 hours (=21600s) how much total heat we need. From this we can found the amount of water needed to supply the required heat.

Total heat loss in 6 hours is

$$Q_{T(6hours)} = 0.43 \times 21600 = 9288\ J$$

ISSN 2229-5518

Now we can find the total heat required (including loss) for the incubator to increase the temperature/°C. It can be found by adding the heat losses.

So

$$Q_{req} = Q + Q_{baby} + Q_T$$
$$= 116.487 + 38094 + 9288 = 47498.487\ J$$

In the winter temperature may fall up to 5°C in rural areas of Bangladesh. So in that case the temperature difference for the incubator is (37-05) °C =32°C. For per ℃ increase in temperature heat required for the incubator is 47498.487J So for 32°C increase, required heat is (47498.487×32)=1519951.584 J

Now we can find the maximum amount of water required to obtain this amount of heat. We use hot water of temperature in the range 90°C-100°C. As time goes the temperature may fall. We will use the water until its temperature falls to 60°C. So how much water required can be found from the equation:

$$Q = mC\Delta T$$

Or, $m = Q/C\Delta T$

Or, m = 1519951.584/ 4200 (100-60) = 9.04733 kg ≈ 9 kg

So we need approximately 9kg water to deliver the required heat for the incubator. If the temperature of water reduces then we have to increase the flow of water for the desired heat.

Now since we know the amount of water we can find the volume of water. Once we know the volume of water we may have the volume of the reservoir. We know density of water is 1000 kgm^{-3}, amount of water is 9 kg. So the volume of water is

$$V = m/\rho = 9/1000 = 0.009\ m^3 = 9000\ cm^3$$

So we need a tank of dimensions 20 cm length, 20 cm width and 22.5 cm height to accommodate 9 kg water. We may use some bigger tank for accommodate the desired amount of water easily.

3.2.2 Temperature Sensor Subsystem

Sensor is the front end device which comes directly in contact with the quantity being measured. The choice of transducer or sensor to measure the temperature of baby, temperature of incubator air, temperature of water reservoir is very critical. So we require temperature sensor.

The requirements of the temperature measurement are given below:

1) Temperature Sensor (T_1) for measurement of body temperature of an infant and air temperature in the incubator within the range of 35°C-38°C.

2) Temperature Sensor (T_2) for measurement of temperature of water reservoir should measure temperature within range of 42°C-95°C for humidity control water tank and for hot water tank within range of 60°C-100°C.

Despite being capable of measuring temperature in the range of 28°C-38°C and 42°C-45°C and 60°C-100°C, the transducer should have following properties [15]:

i) Accuracy
ii) High Output
iii) Repeatability
iv) Long term stability
v) High Input Impedance
vi) Linearity
vii) Self Heating
viii) Temperature Compensation
ix) Small Size

For this work LM35 is selected as temperature sensor [16]. The temperature sensor is chosen on basis of its characteristics of nonlinearity, accuracy, low self heating capability, range as required for application and lastly it gives output in terms of degree Celsius (°C). The sensors selected on basis of study have temperature range of -55°C -150°C.

3.2.3 Humidity Control and Sensor Subsystem

The humidification system is the last compartment in the incubator system, where water vapour is added to the air from the humidifier. The system comprises of a plastic container and a finned-aluminium block that is placed inside the container as shown in figure 4 and 5.

Heated air enters the water chamber via an opening in the lid of the chamber, which is also placed at the end of the duct of the heated air. The moist air leaves the water chamber from an opening at the far side of the chamber and past the aluminium block.

The purpose of the finned-aluminium block is to store heat and exchange it with the water and air. The finned-aluminium block is half-immersed in water, and the exposed parts of it exchange heat with the heated air by convection. There is also heat transfer within the aluminium block by conduction between the exposed and the immersed parts.

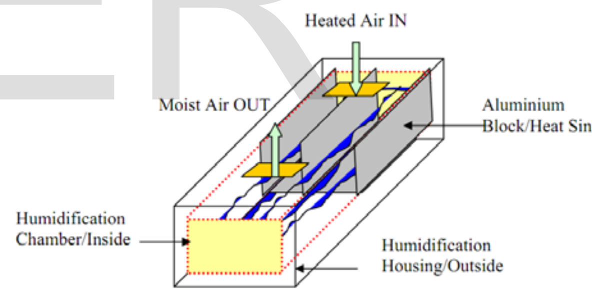

Fig. 5. humidification subsystem diagram.

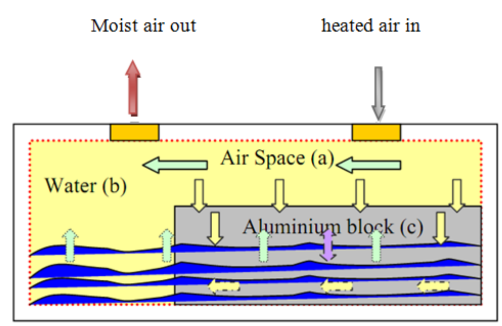

Fig. 6. Water chamber- heat exchange/ cross sectional diagram.

ged parts and vice versa with a high efficiency estimated at around 99.5%.

Therefore, it is reasonable to assume that the temperature gradient between the exposed parts of the aluminium block

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and the submerged parts is zero (i.e.$T_{al1} = T_{al2} = T_{al}$) and the finned-aluminium block acts as a heat sink. As a result, the heat energy of the heated air is accumulated in the aluminium block and within the mass of the water accordingly.

For this reason, the water in the container will constantly be warmed as the heated air continues entering the water chamber, and this will cause a mass flow of water vapour to the air in form of latent heat via evaporation. By using a fan the flow of humid air to the incubator case can be controlled. The value can be set to a point between 44 and 95%. Levels recommended in the literature are located between 65 and 90%. As till to now, this parameter needs not high precision, its adjustment is done sometimes manually. Humidity is linked to temperature. But the important point is to make sure that the fan is running. Otherwise, an alarm must sound. The alarm sounds also if water level in the tank is too low.

3.2.3.1 Humidity Sensor

The choice of transducer or sensor to measure the humidity of the incubator is very critical. So we require humidity sensor for monitoring the humidity of the incubator chamber.

Humidity sensor should provide humidity level in the incubator in terms of relative humidity (%RH) in the range of 0-100%RH.The humidity sensor must have the following properties [16]:

i) Accuracy
ii) Temperature Range
iii) Repeatability
iv) Long term stability
v) High Input Impedance
vi) Linearity
vii) Humidity Range

The Humidity Sensor chosen for the present work is HIH 3310. The humidity sensor is chosen on basis of accuracy, linearity, low power design, workable within required temperature range, repeatability and stability [17].

3.2.4 Incubator Case and Other Support System

Except the main heating and humidity subsystem there are many other considerable parts of the incubator. They include

1) Incubator case and mattress (room for the baby)
2) Fan for hot and humid air circulation
3) Battery
4) Air purification system

3.2.4.1 Incubator Case and Mattress

Our incubator will have two compartments, a main compartment that will hold the baby along with a small lower compartment. The lower compartment will be used to store the water container and heated air will rise up from here to the main compartment through openings along the inside bottom (figure 7).

For the bottom part of the incubator we may use wood or plywood instead of plastic. In this wood frame small holes are made for hot air to enter the case. The holes are made to the side of the frame. For other side walls of the incubator case we

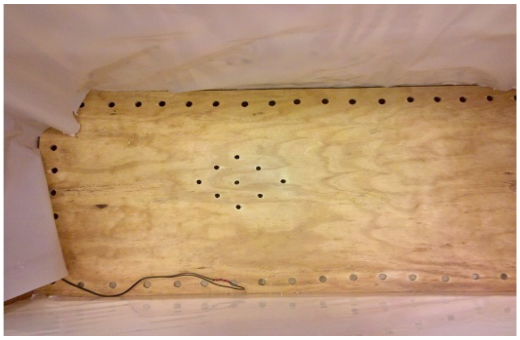

Fig. 7. Lower part of the incubator case with holes for hot air entrance.

may use transparent plastic materials. Plexiglas is a good choice for this purpose since it has a low thermal conductivity and has a better transparency. There is a window in one side of the incubator case through which the baby is entered into the case. The control system will be located at the bottom of the room. Sensors are placed on air inlets and outlet or tapped on the infant skin.

The mattress for the baby may be normal wool mattress. Now a days PCM (phase change materials) mattress are widely used in incubators. PCM materials can hold heat for long periods. To reduce the cost and for availability we may prefer wool mattress.

3.2.4.2 Fan for Air Circulation

For air circulation in our incubator, we believe that using old PC fans may be more cost efficient and locally available than other solutions. This is because the turnover rate for computers is extremely high, and there is an abundance of old computers that still contain perfectly working parts. As an additional plus, PC fans do not consume an excess of power, they run off 12 V, and should generally be free of cost, since most people find old computers (> 10 years old) useless.

3.2.4.3 Battery

A battery is needed for power supply of the electrical part. It has to supply power for the sensors, motor drive and PC fans. Our heating mechanism is non electric, so a small battery can serve our purpose. Also the sensors and PC fans runs on low power. The motor needed here does not need to run for a whole day, it runs occasionally when the temperature falls below the desired value. Many types of motor pumps are available now a days, from those diaphragm pumps consume low power and are suitable for battery operated systems. The diaphragm pumps runs at 12v and consume average 5w of power.

From the specification of the sensors we see that LM35 consume 0.3mw and the humidity sensor consume 1mw. The PC fans power consumption depends on its rpm. A PC fan operating at 12v runs at 2739 rpm draws 157.4 mA of current. So it consumes 1.9w.We have 2 fans in our system, so total power consumption is 3.78w.

Now we can calculate the total Amp-Hour load required per day from the following table:

TABLE 1
CALCULATION OF TOTAL AMP-HOUR LOAD

Load	Dc load power (w)	Daily duty cycle (Hr/day)		Nominal system voltage		Amp-Hr load(Ah/day)
Motor	5	×	5	÷	12	2.0833
Temp sensor	0.0003	×	24	÷	12	0.0006
Humidity sensor	0.001	×	24	÷	12	0.002
Fans	3.78	×	10	÷	12	3.148
Total load power (w)=	8.7813	Total Amp-Hr load(Ah/day) =				5.2339

So total load required per day for our system is 5.2339Ah. If we use a 12v battery of 100 Ah capacity then it can supply our system for up to 20 days.

3.2.4.4 Air Purification

Since a premature infant's immune system is very underdeveloped, it should be kept in a sterile environment to prevent infection. Most bacteria and other air borne particles can be prevented from entering the incubator by filtering the incoming air. The use of non-woven, spun bond polypropylene fabric used in physician's surgical masks is being looked into. Not only is this option light and hypo-allergic, but it also has 0.5micron filtration efficiency greater than 95%, while the average size of bacteria is between 1-2 microns. This component is still under study.
To make the system easily transportable we may add wheels to the lower side of the incubator. For ease of moving and safety the rolling part must consist of sufficient numbers of freely rolling wheels with tires of rubbers. The freely rolling wheels may require a brake for safety precaution.

4 CONCLUSION

We have designed a low cost non-electrical type baby incubator for rural health care centers, where there is a minimum electricity supply or nothing at all. We believe that our proposed non electrical type infant incubator will be a great help in reducing the death of premature babies at rural areas in Bangladesh. The complete system needs to be tested in real life clinical environment in the hospitals, before it is used as safe incubator. Sometime the newborn have jaundice and needs medical care by giving appropriate amount of ultra-violet ray in the incubator. We would be able to design and add the ultra-violet light control system in our proposed incubator to make it a complete incubator in future.

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