Energy Efficient Water Cooling
A Competent Cooling Technique

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***Abstract*— Water is an elemental need in every facet of life, be it for survival or industrial purposes. Since few years there has been an increasing demand for cold water that led to the invention cooling water systems. The majority of the demand for cold water comes from the common households. Many households have water purifiers. Most of the water purifiers aim just at purifying the water. People have a delusion that cold water can only be found in a refrigerator and also to obtain cold water in a water purifier, they need to purchase those big bulky machines that consume a lot of power, area and obviously money. The term 'energy efficient' signifies negligible losses during the cooling process. This paper discusses the designing, construction and working of the prototype that would be an accession to the existing water purifiers. This accession would aid in efficiently fulfilling the need for cold water from water purifiers. It can also be scaled up to replace the existing water cooling techniques in various industries. For understanding purposes, this paper discusses considering a small scale setup.**

***Keywords*— Water Cooling, Coolant Fluid, Plate and Frame Heat Exchanger, Endothermic Reaction**

I. Introduction

Every year engineers are taking a step towards developing efficient and effective water-cooling systems. The world needs more water-cooling systems, which utilize the least of energy and provide better outputs. Cold water is required in various sectors. These sectors may vary from individual needs to industrial needs.

Some industrial processes where cold water is required are as follows:

1. ***Oil and Gas Industry***: In heat exchangers, to cool the hot fluids coming from different units in a refinery

2. ***Vessel Jackets***: Certain storage vessels have cold water jackets surrounding them.

3. ***Air Conditioning Systems***: There are some air conditioning systems that use chilled water. The chilled water is pumped through an air handler that extracts the heat from the air and then spreads this air throughout the space to be cooled.

4. ***Nuclear Power Plants***: Nuclear reactors can be categorized into two types, Boiling Water Reactor (BWR's) and Pressurized Water Reactors (PWR's). In both these reactors, water is boiled to produce steam that has to be cooled after it passes the turbine to produce electricity. This task is achieved with the help of cold water.

5. ***Automotive***: The cooling systems present in automobiles are pressurized (usually up to 15 psi) which reduces the evaporation of the coolant by raising its boiling point.

II. Prototype Features

The prototype prepared promises the following:

1. Cold Water
2. Negligible power consumption
3. Minimal cost of construction
4. Easy maintenance
5. User Friendly

The prototype works on the basic principle of conduction during endothermic reactions. When an endothermic reaction takes place, it seeks a source of heat from its surroundings. It attains the heat required by different modes of heat transfer like conduction, convection and radiation. There is no use of electricity in the process of cooling water. However a minimal amount of electricity would be utilized during the functioning of the electrical circuit.

III. Coolant Fluid

This is the heart of this entire process. The chemicals proposed to prepare the coolant fluid are, Ammonium Chloride [(NH_4Cl)] and Urea [$(NH_2)_2CO$]. There are many alternatives for the chemicals to be chosen, but we choose those, which are economically efficient. These chemicals would be stored inside a container and released when required and in required amount. Mixing these chemicals in water would result in an endothermic reaction. Since endothermic reactions require heat for absorption, the only source of heat present would be the drinking water. It would obtain the heat from the drinking water by conduction thereby cooling the drinking water. It is obvious that this coolant fluid is not suitable for consumption. It is being kept in complete isolation from the purified water.

Table I: Comparative analysis of coolant salts

Property	*Urea*	*Potassium Chloride*	*Ammonium Chloride*	*Ammonium Nitrate*
Molecular Formula	$(NH_2)_2CO$	KCl	NH_4Cl	NH_4NO3
Molar Mass	53.491 g/mol	74.5513g/mol	60.06g/mol	80.052 g/mol
Density	1.5274g/cm3	1.984 g/cm3	1.32g/cm3	1.725g/cm3 (20 °C)
Boiling Point	520 C	1420 °C	150 C	~210 °C
Melting Point	338 C	770 °C	133-135 C	169.6 °C
Solubility	372 g/L	344 g/L (20°C)	391.8 g/L (25 °C)	150g/100ml(20 °C)
pH Value	9.2	~7	0.18	4

IV. REACTIONS INVOLVED

A. Ammonium Chloride

$NH_4Cl + H_2O = NH_3 + HCl + H_2O$

NH_4Cl is fully ionized, even in solid state. Hence

NH_4 (s) + H_2O = NH_3 (aq.) + H_3O+(aq.)

Where 'Cl^-' is a spectator ion. NH_4^+ is a weak acid

B. Urea

$CO(NH_2)_2$ (s) + H_2O = $2NH_3 + CO_2$

V. ENERGY BALANCE

A. Ammonium Chloride

Solubility of NH_4Cl = 5 g in 100 cm^3 (25 °C)
Specific Heat Capacity of Water = 4.18 kJ kg^{-1}°C^{-1}
Density of Water = 1 g cm^{-3}
Resultant Temperature Difference = ΔT °C.

$\Delta H = m*c_p*\Delta T$

Mass of water = Volume*Density = 0.1 x 1 = 0.1 kg
ΔH^{AC} = Heat of Solution of Ammonium Chloride
$\Delta H^{AC} = 0.1*4.18*\Delta T = 0.418*\Delta T$ kJ
Temperature Drop Found Experimentally = 3°C.
$\Delta H^{AC} = 0.418*3 = 1.254$ kJ

1 mole of NH_4Cl contains 53.5g

For 5g of NH_4Cl, ΔH^{AC} = 1.254 kJ
By unitary method we can find ΔH^{AC} for 53.5g of NH_4Cl.

ΔH^{AC} for 53.5g of NH_4Cl = 1.254*53.5/5 = 13.42kJ

ΔH^{AC} for 1 mole of NH_4Cl = 13.43kJ Urea

B. Urea

Dissolving 5 g in 100 cm^3 (25 °C)
Specific Heat Capacity of Water = 4.18 kJ kg^{-1}°C^{-1}
Density of Water = 1 g cm^{-3}
Resultant Temperature Difference = ΔT °C.

$\Delta H = m*c_p*\Delta T$

Mass of water = Volume*Density = 0.1 x 1 = 0.1 kg
ΔH^{U} = Heat of Solution of Urea
$\Delta H^{U} = 0.1*4.18*\Delta T = 0.418*\Delta T$ kJ
Temperature Drop Found Experimentally = 2°C.
$\Delta H^{U} = 0.418*2 = 0.836$ kJ

1 mole of $(NH_2)_2CO$ contains 60.06g

For 5g of $(NH_2)_2CO$, ΔH^{U} = 0.836 kJ
By unitary method we can find ΔH^{U} for 60.06g of $(NH_2)_2CO$.
ΔH^{U} for 60.06g of $(NH_2)_2CO$ = 0.836*60.06/5 = 10.042 kJ

ΔH^{U} for 1 mole of $(NH_2)_2CO$ = 10.042kJ

The heat of solution (ΔH) of Ammonium Chloride is more than that of Urea under constant conditions. Hence Ammonium Chloride is more effective coolant salt than urea.

VI. DETAILED WORKING AND CONSTRUCTION

There are two different setups that would help achieve the desired output:

A. Cooling With The Help Of Heat Exchanger

The setup shown below consists of the following sections:

- Reactants Storage
- Coolant Tank (MIDDLE)
- Exchanger Block (BOTTOM)
- Electronic Circuit Section (TOP)

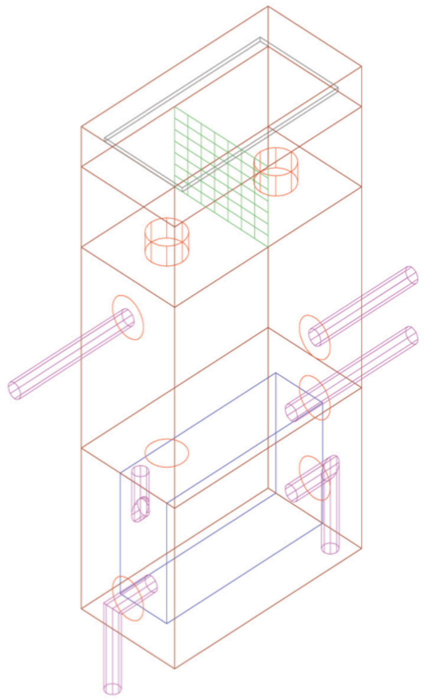

Figure 1: AUTOCAD Simulation of Prototype A

1. CONSTRUCTION

Table II: Material of construction of Prototype A

Section	*Material of Construction*	*Function*	*Comments*
Reactants Storage	Fiberglass	Stores the chemicals required for the preparation of coolant fluid	The volume of the container is variable.
Coolant Tank	Fiberglass	Holds the coolant fluid and feeds it to the plate and frame heat exchangers.	A non-corrosive material of construction is chosen due to acidic nature of Ammonium Chloride.
Exchanger Block	Fiberglass	The exchanger block holds the plate and frame heat exchanger	
Plate and Frame Heat Exchanger	Stainless Steel	He coolant fluid enters the frame side and the drinking water enters the plates where conduction takes place.	The number of plates can be determined experimentally according to the volume available in the exchanger block.

2. WORKING

The process unfolds in steps mentioned below:

i. Certain amounts of chemicals (to be calculated experimentally) are dropped inside the coolant tank after certain pre-calculated intervals of time. This is the time taken for the coolant properties to fade out.

ii. The tap water enters the coolant tank up to a certain preset level. The level transmitter present in the tank sends signal for the valve to shutdown after the tank has reached the set level.

iii. Now the coolant fluid is prepared and an endothermic reaction would occur in presence of a heat source.

iv. Then it is sent into the frames of the heat exchanger along with the feed drinking water.

v. The heat required for the endothermic reaction to occur will be gained by absorbing the heat of the feed drinking water thereby cooling the feed drinking water.

vi. The cool drinking water is then sent for storage in the insulated chamber and the hot (relatively) coolant fluid is either expelled out or reused for another pass (depends on the temperature of coolant fluid).

vii. The time required to cool, time required to drain and to fill, all such activities depend on the area, volume and material of construction. These are calculated experimentally and preset in the electronic circuits

The second approach is quite a miniature version of the above-discussed method. In this method there is just a requirement of a chamber below the feed drinking water storage to store the coolant fluid.

It consists of the following sections:

- Chemical Storage
- Coolant Storage
- Cooled Water Storage
- Electronic Circuit

1. WORKING

The process takes place as mentioned:

i. Certain amounts of chemicals (to be calculated experimentally) are dropped inside the coolant tank in certain pre-calculated interval of time. This is time taken for the coolant properties to fade out.

ii. The tap water enters in the coolant tank up to a certain preset level. The level transmitter present in the tank sends signal for the valve to shutdown.

iii. Now the coolant fluid is prepared and an endothermic reaction would occur in presence of a heat source.

iv. The coolant fluid now acquires heat from the feed drinking water just by conduction through the metal. Metal with high conductivity is to be used for effective heat transfer.

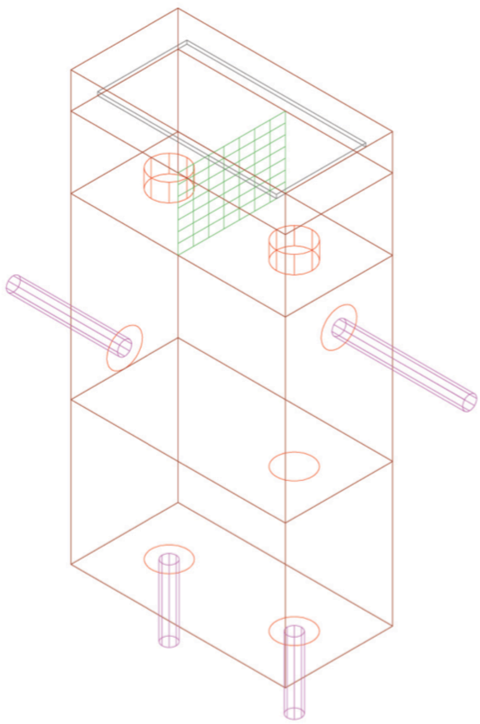

Figure 2: AUTOCAD simulation of Prototype B

2. CONSTRUCTION

- The cost of construction of this prototype is almost half the cost of construction of the previous method

- The quality of insulators is enhanced to keep the drinking water chilled for a long duration

Table III: Materials of construction of Prototype B

Section	*Material of Construction*	*Function*	*Comments*
Reactants Storage	Fiberglass	Stores the chemicals required for the preparation of coolant fluid	The volume of the container is variable.
Coolant Tank	Fiberglass on the surroundings 'excluding the top'. Carbon Steel on the top	Holds the coolant fluid and feeds it to the plate and frame heat exchangers.	A metal with high thermal conductivity is selected for efficient heat transfer.
Cooled Water Storage	Expanded Polystyrene Foam (EPS) or Extruded Polystyrene Foam (XPS)	Finally holds the cooled drinking water.	The cooled water storage is heavily insulated on the outer surface to avoid any heat transfer to occur. Polystyrene foam is used for insulation.

VII. DESIGNING

A. MATERIAL PROPERTIES

1. FIBERGLASS

It is often referred to as Glass Reinforced Plastic (GRP) or Fiber Reinforced Plastic (FRP). Currently FRP is excessively used in he designing of storage vessels and tanks. Due to its strong, light and non-corrosive nature, it competes in replacing other materials of construction like steel and aluminum.

BS 4994:1987 – Specification for design and construction of vessels and tanks in reinforced plastics.

Table IV: Comparative analysis of types of Polystyerene

Property	*GFRP*	*Units*
Density	107-120	Lb./ft^3
Tensile Strength	30,000 (LW*) – 7,000 (CW*)	Psi
Flexural Strength	30,000 (LW) – 10,000 (CW)	Psi
Thermal Conductivity	4	BTU in./(hr. ft^2 F)
Thermal Expansion	7-8	X 10^{-6} in./in./F

*LW = Lengthwise
*CW = Crosswise

It has been selected due to its following properties-

- Lightweight - Weighs 30% less than aluminum and 70% less than steel. Hence it permits ease in transportation and installation.

- Corrosion Resistant - Resistant to a broad range of chemicals. Moisture and water immersion do not influence its characteristics.

- Long Life – 15 Years or more

- Less Maintenance - Not being exposed to corrosion decreases the need for maintenance. However a timely check must be carried out to check for scaling, which may occur while handling certain fluids.

- Environment Friendly

- Good Insulator - It is a good insulator with thermal conductivity of 4 BTU in./(hr. ft2 F)

- Easy Fabrication - Can be fabricated using simple tools like carbon or diamond tip blades. It does not require any torches or welding activities.

2. CARBON STEEL

Carbon steel is that kind of steel whose properties mostly rely on its carbon content. The addition of carbon increases the strength and resistance to wear and abrasion. By far carbon steel is the most widely used kind of steel. It is widely used in boilers, pressure vessels, heat exchangers and other moderate temperature systems where strength and ductility is desired.

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Table V: Properties of Carbon Steel

Property	*Value*	*Units*
Carbon Content	0.2%	
Density	7.86	103 kg/m3
Thermal Conductivity	50	W/mK
Thermal Expansion	11.7	10-6 K-1
Tensile Strength	350	MN/m2
Sulphur Content	0.050% (Max.)	
Manganese Content	0.30-0.60 %	
Phosphorous Content	0.040%(Max.)	

It has been selected due to its following properties-

- Malleable and Ductile - The prototype in Case 2 uses a sheet of carbon steel for separation. Carbon steel can be used here, as it is malleable.

- Good Conductor - Carbon steel with 0.02 percent of carbon content has a thermal conductivity of 50 W/mK. Thereby providing excellent heat transfer.

- Economical
- Favorable operating temperature range

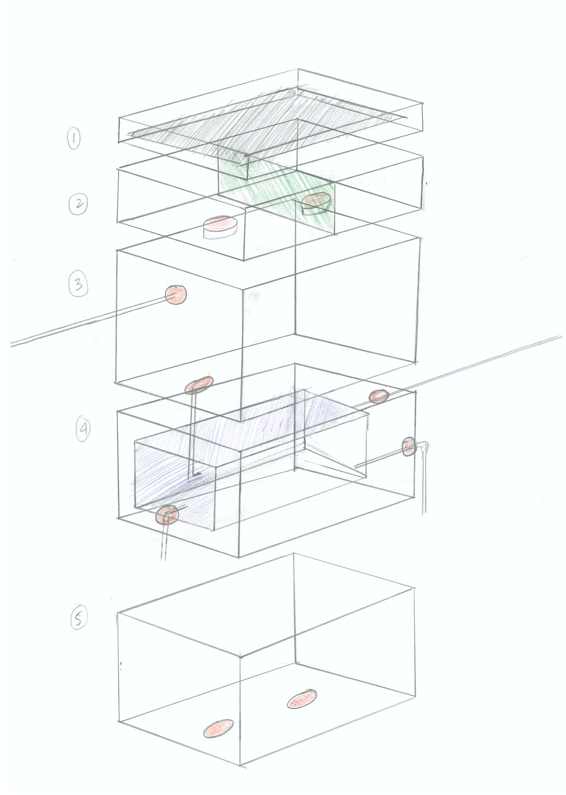
3. Plate and Frame Heat Exchanger

Plate and frame heat exchangers are used in this prototype as they provide greater surfaces areas for heat transfer as compared to the conventional heat exchangers, This facilitates the rate of heat transfer and hence the change in temperature occurs at a faster rate. The plates are generally made of stainless steel due to its wide range of operating temperature and its ability to withstand corrosion.

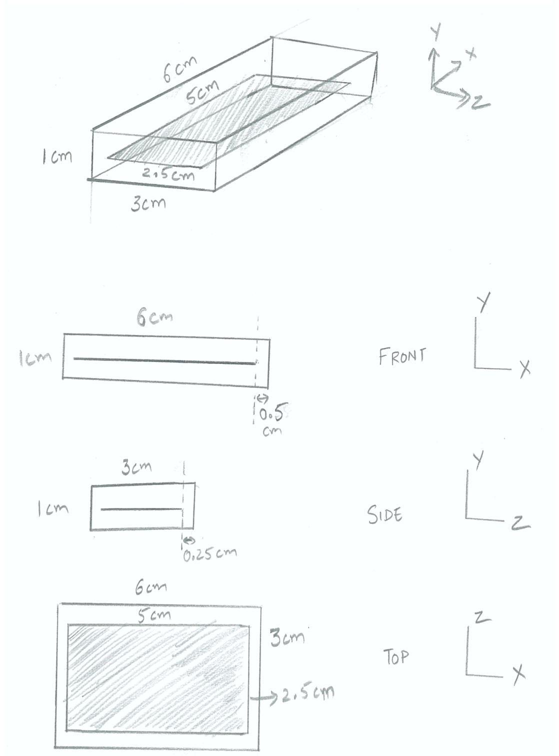
Plate and frame heat exchanger can attains similar level of heat transfer as a shell and tube heat exchanger by inhabiting less surface area.

VIII. Modeling

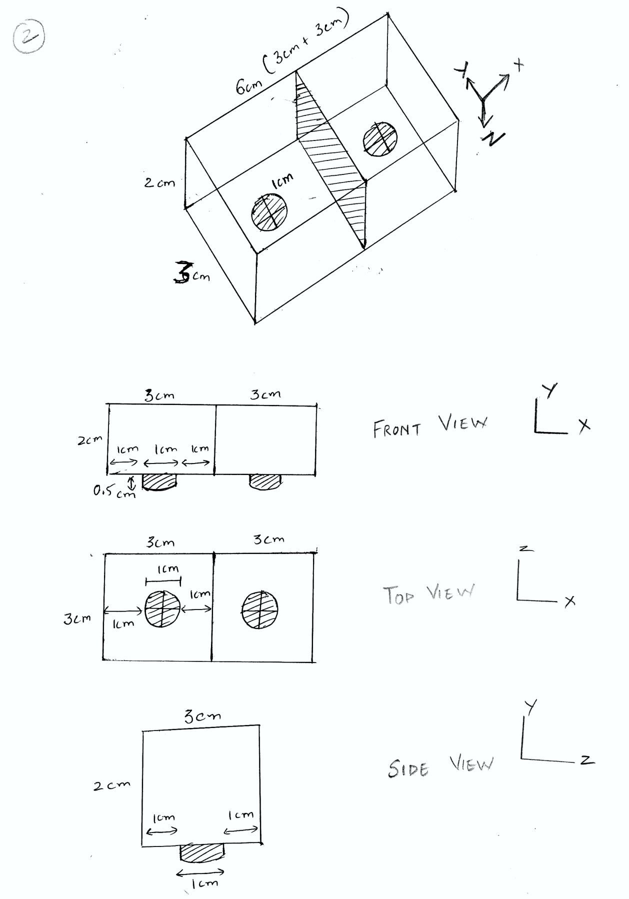
A. Various Sections Of Prototypes



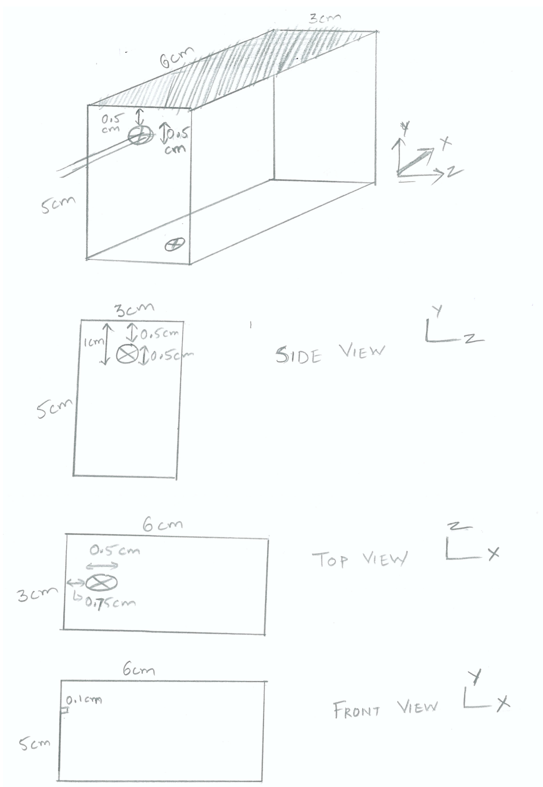
1. Electronic Circuit



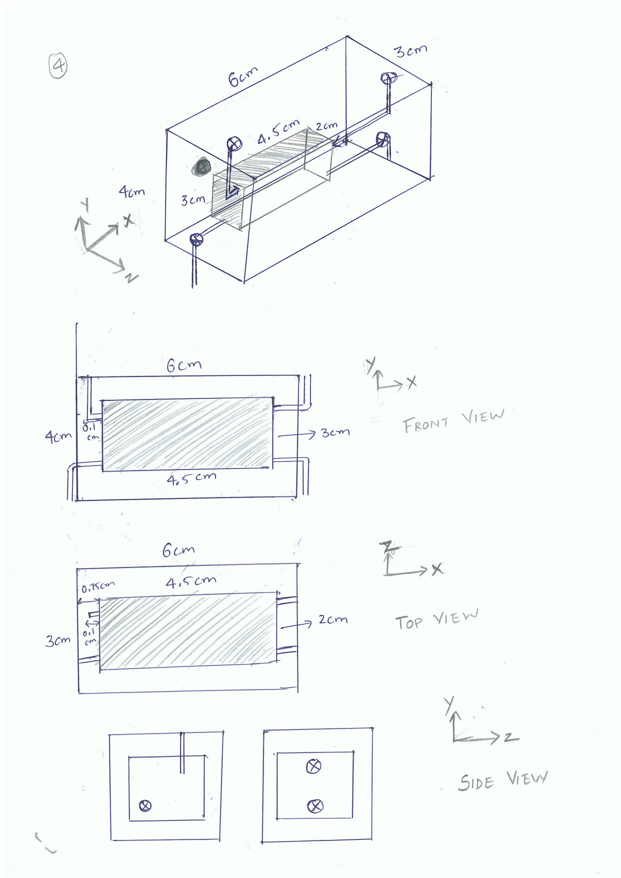
2. CHEMICALS STORAGE



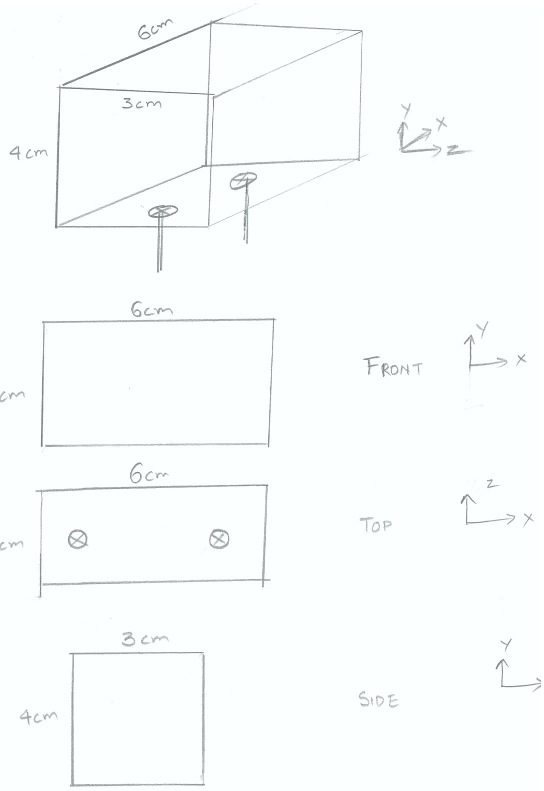
3. COOLANT FLUID TANK



4. EXCHANGER TANK



5. DRINKING WATER STORAGE



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