DEVELOPMENT AND TESTING OF A REGENERATIVE RECHARGEABLE SOLAR STOVE SYSTEM

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ABSTRACT

To be able to use solar energy for cooking purposes, a radically different solution has been used wherein the heat liberated by the reaction of quicklime with water would be utilized and the subsequent conversion of hydrated lime back to quicklime by the usage of solar radiation in a paraboloid concentrator. The other salient feature of this stove is that it can be used for cooking Ethiopian staple diet, INJERA, inside one's own kitchen. This paper reports the development, production and test results of this regenerative, rechargeable solar stove system. All the stove components have been manufactured, assembled, tested and their performance characterized. The solar concentrator forms part of the community facility that can be jointly shared by a number of families. Heat retention, heat liberation rates, cooking pan surface temperature and efficiency of the stove have all been exhaustively assessed and encouraging results have been obtained. This stove has the potential to significantly contribute towards environmental protection through smokeless cooking, conservation of precious forest resources, improvement of economic and health standards of the rural, people leading to sustainable development.

***Key Words**: Solar Energy, Regenerative Rechargeable solar stove, Solar Cooker*

1.INTRODUCTION

Global warming is at large the result of deforestation, desertification and incessant environmental pollution. While most of the environmental pollution is caused by the burning of fossil and biomass based energy resource, deforestation is largely attributed to the extensive use of biomass for various applications, mostly for cooking. Ethiopian has lost 98% of her forest coverage in the last 40 years, a situation which left us with no option but to experience a series of droughts and exposure of the land for desertification. It is known that 90% of the population uses firewood stove with the wood coming from the forest. When people did not find trees, they tend to seek for other alternatives like cow dung which might have been used in order to maintain the fertility of the soil.

The traditional firewood stoves are smoky and very inefficient considering fuel economy, having only 5-10% efficiency. Taking all the wood a woman can carry no an average 20kg, it is not even enough for two days for one family. Taking this into consideration, different types of stoves were developed, like. Fuel-efficient stoves, Gasifies stoves, Biogas stoves and solar stoves. All solutions have been introduced in our country, but none prevailed and solved the problem to any extent.
Environmental protection, future energy security and sustainable developmental calls for extensive use of renewable

energy resources like solar, wind, etc. Which are economically viable.

Fuel-efficient and gasifier stoves still use biomass while biogas stoves need cow dung. As far as conventional solar cookers are concerned they did not takeoff and penetrate to any appreciable extent, mainly because of the following inhibiting factors.

i) Cooking need to be done as and when sunshine is available and not when required.
ii) Cooking need to be done outside the kitchen affecting not only the hygiene but also the convenience, bringing in some sort of apathy.
iii) Ethiopian staple diet, Injera cannot be cooked
iv) It takes unusually longer time for cooking with box type cookers
v) Tracking is required for dish cookers
vi) Cooking is highly inconvenient and especially in windy conditions with dish type cookers

Having stated these basic facts, this paper presents the development and testing of new idea.

2. THE CONCEPT OF RECHARGEABLE REGENERATIVE SOLAR STOVE

The conceptual and design details have been explained and elaborated in an earlier study [1]. To remedy some of the inhibiting factors preventing the adoption of solar cookers, Chemical energy storage has been selected considering stability, conservation and ease of extraction. Storing energy in a chemical form can enhance the performance of ordinary solar cookers than using solar energy directly for cooking [2-4]. This can be achieved by using $Ca(OH)_2$ to take up the energy and convert it into the energy rich form CaO. We can extract the energy from CaO by reacting with water. The whole system is based on the reversible reaction of Calcium oxide with water.

$$CaO + H_2O \rightleftharpoons Ca(OH)_2$$
(+ Heat (64.8kJ/mole)

We can use the forward reaction to gain heat for cooking and the reverse reaction (to convert $Ca(OH)_2$ back to CaO for cooking next time) to store solar energy. Obviously we can obtain the forward reaction at any time of the day or night. The present stove design conceived is also in the form where we can prepare injera, a

Feature, which was totally impossible with the previous solar cookers

3. STRUCTURE OF THE STOVE SYSTEM

3.1 Components

The stove (given in Fig.1) therefore will have the following components in the operation, namely a) reactor vessel b) cooking pan integral with heat conducting fins underneath c) water injection arrangement including the holding cup d) thermal insulation e) container housing box.

The components of solar concentrator, which is used to concentrate solar energy (for converting hydrated lime to quicklime), will have the following components, namely a) concentrator b) vessel seat c) manual arrangement for tilting the dish and d) base

3.2 Method of operation of the stove

The reactor vessel will be containing CaO with the water injector under it. The water injector will be connected to a holder from which distilled water (amount determined by the mass of CaO in reactor vessel and as per reaction stoichiometry) is let through and gradually controlled by a valve. The water will react with the CaO after injection and then it will produce heat. Further, when more water is injected it will evaporate and it will react with the un reacted CaO producing more heat. This heat will be picked up and delivered to the cooking pan by the integral heat conducting fins. We can get the desired heat for cooking by controlling the rate of water injection. To make the process more efficient and to protect users from burning hazards, insulation is provided around the reactor vessel, which is contained in side a wooden box container.

3.3 Method of operation of solar concentrator

After all the CaO has been consumed (cooking completed) and had changed in to $Ca(OH)_2$, the reactor vessel is taken out separately from the cooking pan and water holder. It is put into the vessel seat of the solar concentrator, which is fixed to the focal point of a paraboloid concentrator. The paraboloid concentrator is a point focus dish which is laminated with aluminum foil .The foil reflects solar radiation to the focal point and produce the required heat that will recharge $Ca(OH)_2$ to CaO and water. This water can be collected for reuse. The solar concentrator will be able to follow the sun during the day using a tracking mechanism, which can be set or easily adjusted by manually. The tracking need not be continuous, at least during recharging (in minutes) by a single family. The whole system will be seated on the base, which is not fixed to the ground for mobility purpose.

3.4 Calcinations

Quicklime is the market name given to CaO. Quicklime is produced by heating limestone ($CaCO_3$) above 900^0C. Above this temperature $CaCO_3$ dissociates in to CaO (quicklime) and carbon dioxide (CO_2). The process is known as calcination. In manufacturing companies, limestone is heated up to 954-1066^0C in kilns. Since quicklime could not be located in the local market, it has been obtained by calcining the limestone (available locally) in an electrical furnace in our laboratory.

4.DESIGN OF STOVE

The design of the stove starts from the determination of the capacity of the stove, which is in turn determined by the energy required for cooking, which again depends on family size. It was very difficult to get precise data on the amount of fuel used by rural people. But based on the fact that both rural and urban people eat similar cultural foods, we were able to calculate the energy consumption for cooking by each family as 1.7 kWh based on our demographic survey conducted. Hence the design of the stove was made for 1.7kWh size, as per the design methodology reported earlier [1, 5].

4.1 Calculation of amount of reactants

Mass of CaO= 5.296kg.
Mass of water = 1.7 kg
Volume of CaO = mass of CaO/density of CaO
Volume of CaO = 5.296kg/3320kg/m3
Volume of water = 1.6* 10-3 m3

4.2 Heat Conducting Fins attached to Cooking Pan

In this part different alternatives were considered with regard to shape, size and material selection. The fins' shape and size were optimized using the standard analytical methods. Based on high thermal conductivity, formability, cost and mechanical strength , Aluminum (k= 237W/mK in the temperature range of interest)) was selected as the fin material. The length of each fin was fixed based on the requirements of compactness, heat retention and convenience for cooking. From the reaction temperature, the heat transfer rate that could be affected by each fin was estimated and for the stove capacity the total number of fins was selected to be 16.

4.3 Water injection- Dripper System

While injecting water into a bed of CaO, there will be resistance to flow. The flow resistance may be due to the $Ca(OH)_2$ and head loss and some minor losses. Taking these considerations the minimum head required between the bottom of the water tanker and the dripper holes was estimated to be 40cm.

4.4 Insulation

To affect energy conservation, personal protection and comfort from hot reactor vessel surface as well as corrosion protection from oxidation, thermal insulation is necessary around the reactor vessel. Towards this effect, a wooden box with insulation has been used with sawdust as the insulating material (k=0.05W/mK). To retain the insulation permanently a wire mesh has been used forming a cylindrical hole in to which the reactor vessel could be simply inserted.

4.5 Paraboloid Solar Concentrator

The use of solar energy is to help the dissociation of Ca $(OH)_2$ (calcium hydroxide) into the original substance CaO and water vapor. This is achieved by placing the reactor vessel containing the hydrated lime at the focal point. The design of this and its parametric sensitivity predictions vis-à-vis conversion time has been dealt in great detail elsewhere [1, 5-6]. Based on reaction temperature of CaO with water [7] calculations at the core of the reactor vessel, the dish has been designed (Aperture diameter = 2.4 m and focal length=72 cm) and manufactured for testing.

5. MANUFACTURING

5.1 Solar Stove

The reactor vessel (diameter=16cm, height=25cm), water-holding cup and injector were manufactured using MS sheet metal. The cooking pan (diameter=18cm) with integral fins (height=2ocm,width=30mm,thickness=5 mm for sufficient strength) underneath were made using Aluminum and this entire piece was produced by casting in our laboratory. The insulating box was constructed using wood and a ¼" standard valve has been employed for water injection control.

5.2 Manufacturing of paraboloid solar concentrator

The paraboloid solar collector (dish) is the main part of the rechargeable regenerative solar stove that is used for collecting the solar radiation and reflecting to the reactor vessel containing the hydrated lime (obtained after cooking) by concentrating it at one point. The paraboloid surface of revolution was formed in steps using circularly bent steel rods held in appropriate elevation by plywood retaining plates. Steel strips were welded to the circular rods reinforcing the formation of circular cross sections at different elevations. After obtaining a rigid parabolic structure, the ply wood plates were cut and removed. To obtain a smooth paraboloid surface, wire mesh was tied on the outer surface of the paraboloid structure. Then on the interior surface of the dish white paper was glued all over. Finally on top of this, the aluminum foil was attached giving a fine reflecting surface. This entire assembly was fixed to a base (made out of angle iron) with a mechanism to raise or lower the dish giving one-way tracking that can be adjusted manually. Using steel plate and steel rod a reactor vessel seat was made, and, located at the focal point of the paraboloid concentrator. Arc welding machine, Oxyacetylene welding equipment, Rolling machine, Bench drilling machine, Shearing machine, Grinding machine, and different types of accessories were employed during the entire fabrication process. Photographs of all the manufactured parts are attached.

6.EXPERIMENTAL TESTING AND TEST RESULTS

Different tests was conducted to evaluate the performance of the stove system, like Heat retention test, Surface temperature test and Water injection and heat liberation test

6.1 Heat retention efficiency test

The purpose of this test is to calculate the heat retention efficiency of the stove. A known mass of hot water at a known temperature (close to the actual temperatures to be encountered) is put in the reactor vessel placed in the insulating box. Then transient temperature history was recorded. For reproducibility 3 such tests were carried out and the data are given in the Fig.2. From this data the average heat loss from the stove was found to be 0.1156 KW. Using this value the heat retention efficiency of the stove was found to be 90.6%, which indicates that the stove has a high performance for insulation.

6.2 Surface temperature test

Purpose of this test is to determine the maximum temperature that can be attained on the surface of the cooking pan and in this aspect a value of 98^0C has been recorded.

6.3 Heat liberation test

To determine the heat liberation rate vis-à-vis water injection rate, three tests were conducted at different water injection rates. In each of the tests, water injection rates and cooking pan surface temperatures were recorded and the results are presented in Fig.3

Detailed testing of the conversion of hydrated lime back to bunt lime is still to be completed and as such no problems are foreseen on this front.

7. CONCLUSION AND RECOMMENDATION

The test results have proved that the innovative concept involving CaO can be feasibly implemented in reality and used to liberate a large amount of energy, which can be used even for the cooking of Injera. The maximum surface temperature of 98^{0}C recorded shows that required temperatures could be easily attained by further modification and development. The response of heat liberation rate vis-à-vis water injection rate points to the controllability of this solar stove, which is missing in other designs. Heat retention noticed for substantial period of time after the completion of water injection proves the high efficiency of this stove Materials used have insignificant cost and Manufacturing is simple that locally available materials and least sophisticated machines make it possible to be operated by any person with a little technical skill. Manufacturing is simple that locally available materials and least sophisticated machines make it possible to be operated by any person with a little technical skill. Operation is simple that any unskilled person can maneuver it by controlling the rate of water through a simple valve. Since CaO is cheap and can be used and reused again it makes the operating cost negligible. Finally assuming 3 minutes for installation and about 20 minutes of charging time for the stove where the sun shined on average for 8hrs\day at least 25 families can use the concentrator where by the establishment cost will never be a problem since it is shared with in the villagers. This type of stove is capable of cooking even during the nighttime with out the assistance of the Sun.

This stove has the innate potential to contribute significantly to sustainable development. Its smoke free operation resulting from the use of solar energy gives relief from health hazards and respiratory ailments as well as raising the income that is unproductively lost through the time spent in collecting the firewood. It also mitigates the problems arising out of deforestation due to excessive use of firewood for cooking and the resultant ill effects like climatic changes, drought etc. Considering the all pervading benefits associated with the large scale adoption of this stove both in rural and urban areas, all out efforts must be made for the development and improvisation of this stove by governmental and non-governmental agencies.

9. REFERENCES

1. A. Venkata Remayya and Ato Melesse, design of a rechargeable regenerative solar stove for Ethiopian staple diet Ethiopian Journal of Technology, Education and sustainable development, (EJTE& SD) VoL. 2, No. 2, August 2004, Bahir Dar, page 37-47.
2. Matsuda H., et. al. Kagaku Kagaku Ronbunshu, Vol.12. 1986, p542.
3. Lee. S.K. et.al Kagaku Kagaku Ronbunshu, vol.12, 1986,p165
4. Punya Chowdary, Report of process Improvement System (prims), Sweden, 1999.
5. Abera Melesse, Destalem Hailu, Mesfin Kassa and A.Venkata Ramayya, Design of a regenerative rechargeable solar stove, project report of Department of Mechanical Engineering. Jimma University, Jimma, 2003.
6. Tewodros Eshetu, Shimelis Desalegn, Desta Abraham, Abera Melesse and A.Venkata Ramayya, Development, fabrication and testing of a regenerative rechargeable solar stove, Project report of Dept. of Mechanical Engg, Jimma

University, Jimma, 2005.
7. Robert H. Perry and Don W. Green (Ed), Chemical Engineers Hand Book
8. Friedr. Vieweg & Sohn Braunschweig, Fuel-Saving Cook Stoves, 1984

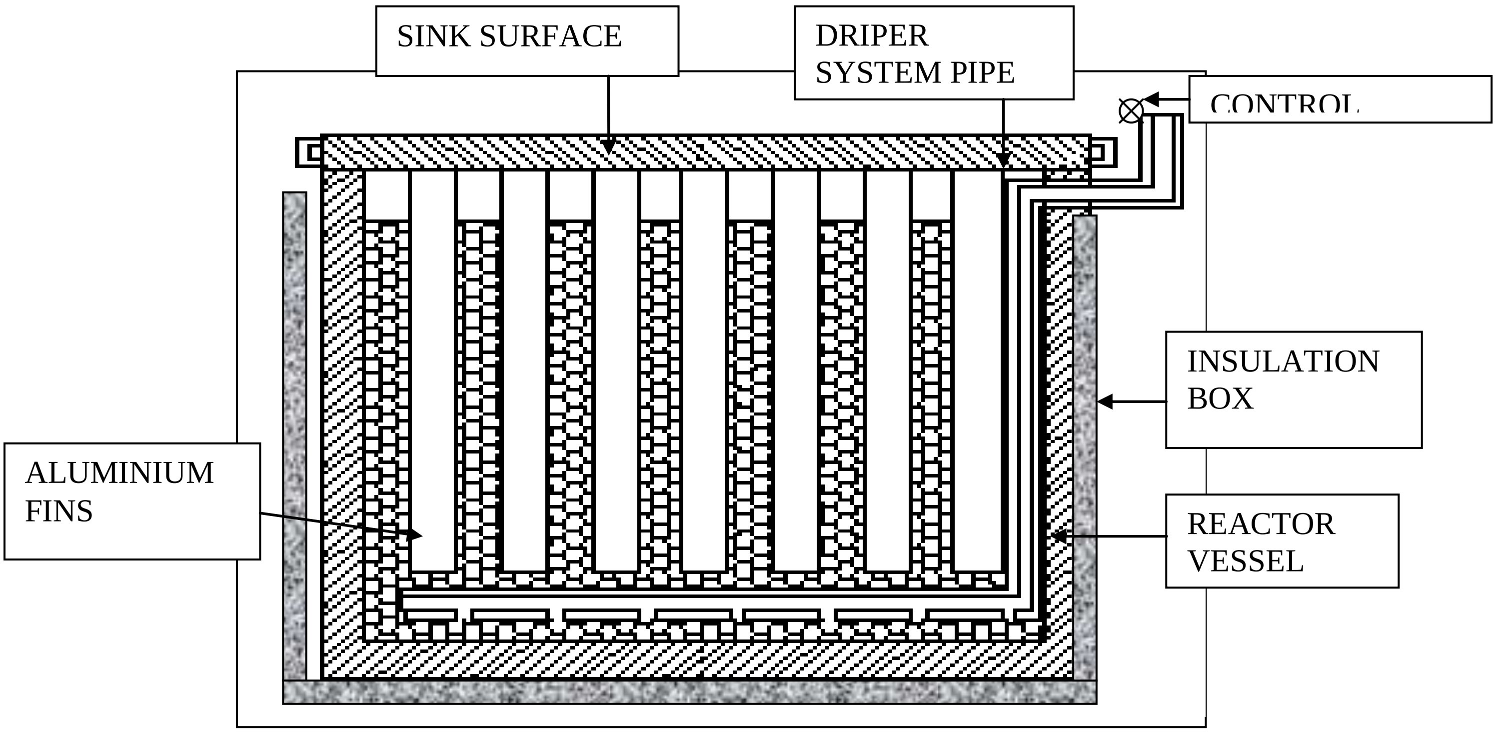
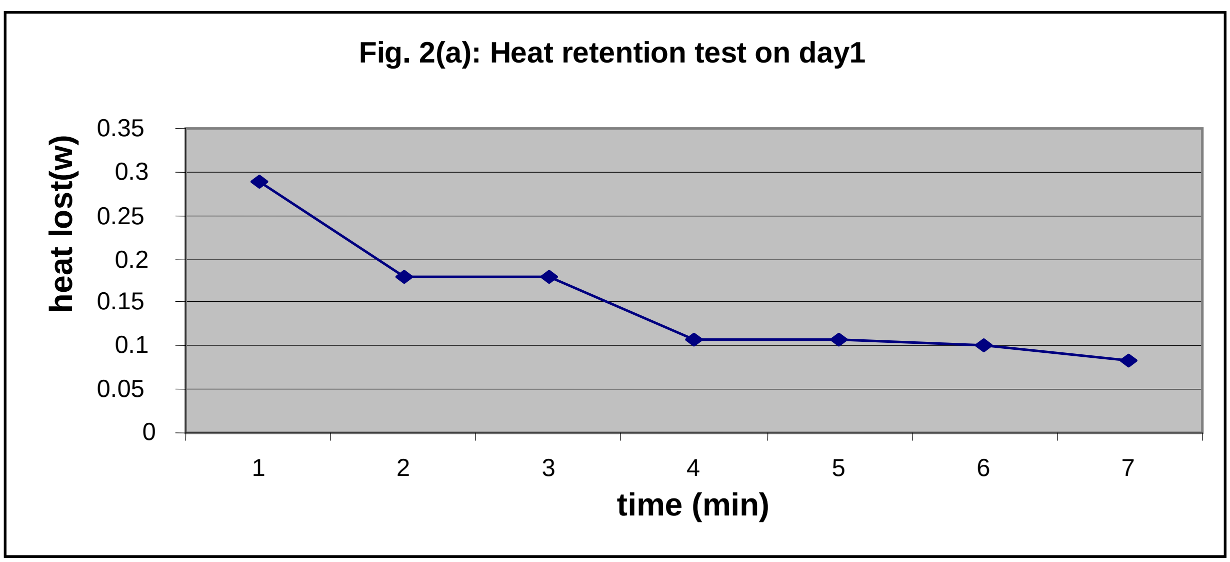


Fig. 1: cut sectional view of regenerative rechargeable solar stove.



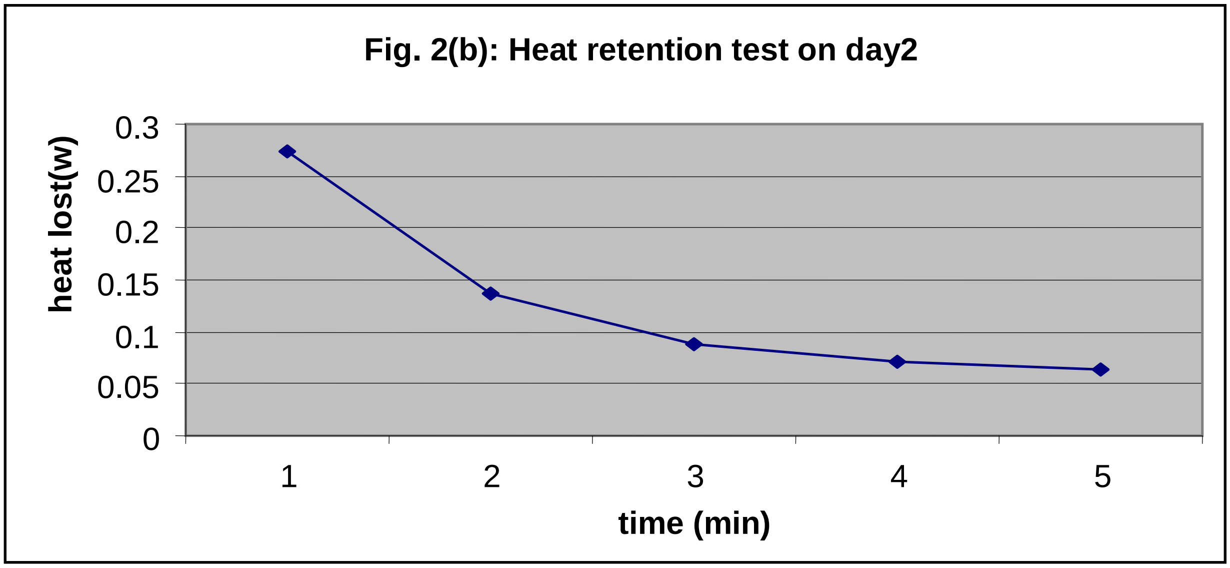


Fig. 2(b): Heat retention test on day2
heat lost(w)
0.3
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
time (min)

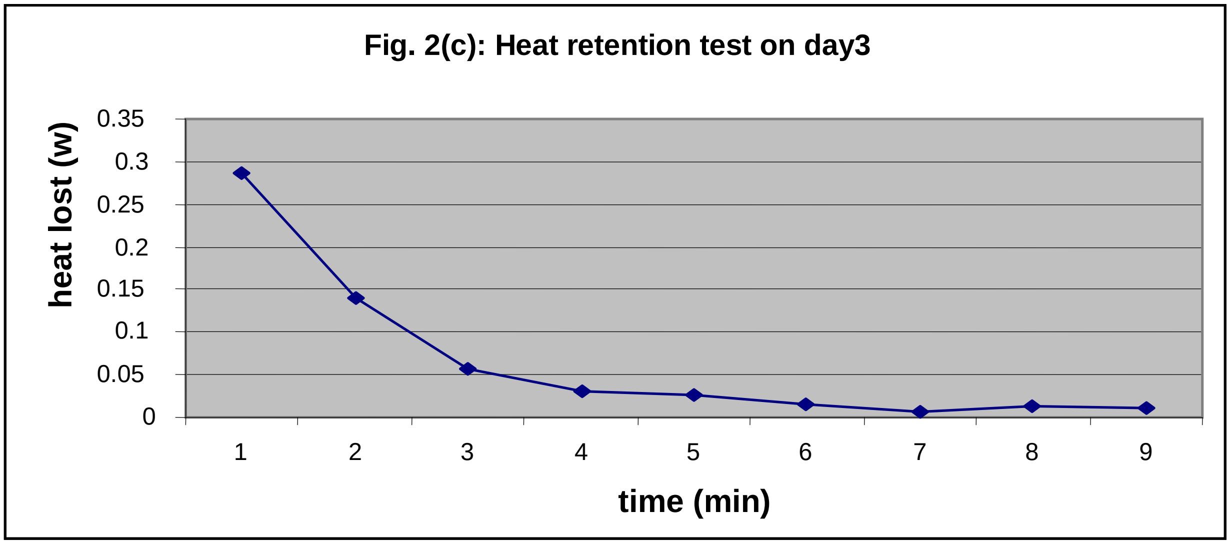


Fig. 2(c): Heat retention test on day3
heat lost (w)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
6
7
8
9
time (min)

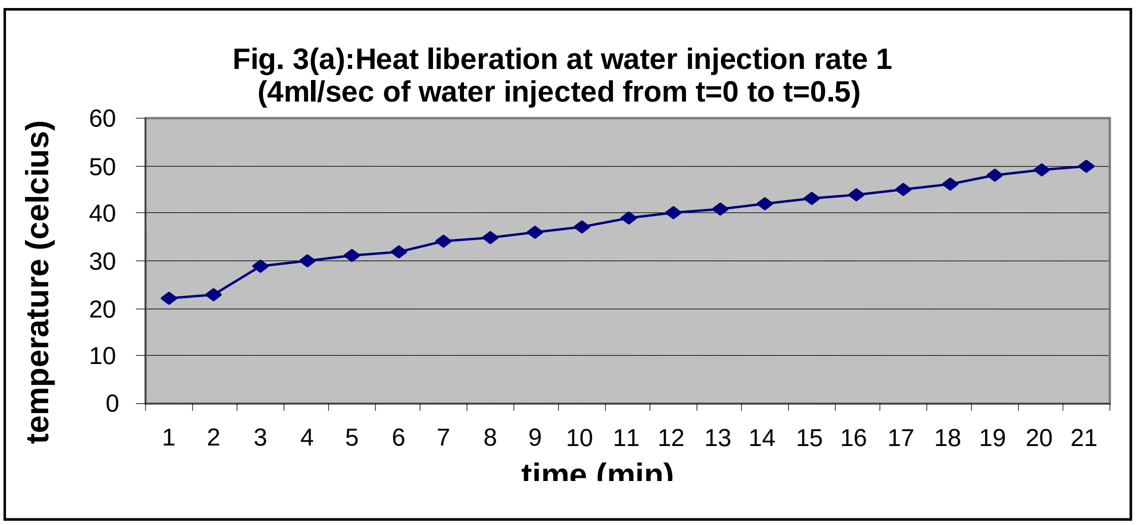


Fig. 3(a):Heat liberation at water injection rate 1
(4ml/sec of water injected from t=0 to t=0.5)
temperature (celcius)
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
time (min)

Fig. 3(b): Heat liberation at water injection rate 2
(2ml/sec of water injected from t=0.14 to t=1.54)

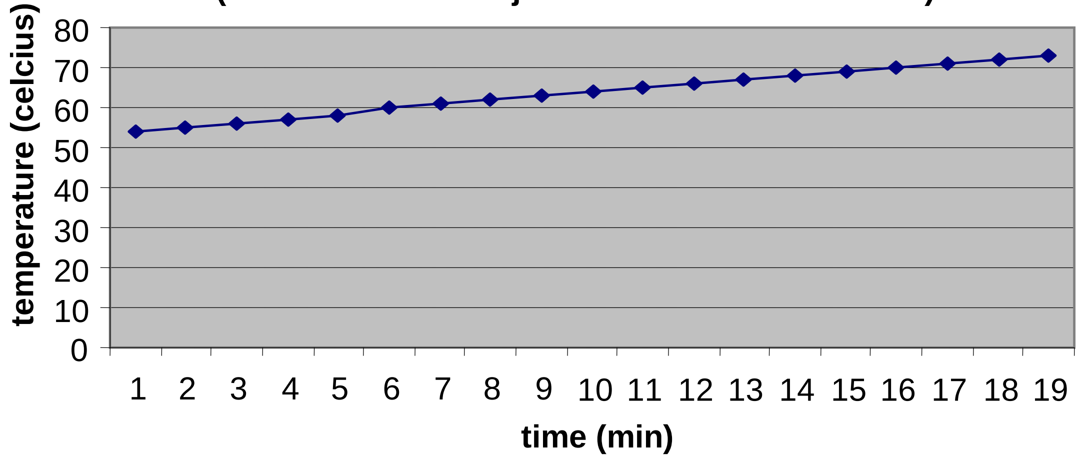


Fig. 3(c): Heat liberation at water injection rate 3
(3.5ml/sec of water injected from t=0.01 to t=0.058)