An Eco-friendly and Reusable Heat Source for Self-Heating Food Packaging

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Abstract— **Self-heating food packaging have a heating module inside it which helps to heat the ready to eat food or beverage in it. Exothermic reaction is used as heat source. Such product can be very useful for military operations, during natural calamities, for mountaineers, and whenever conventional cooking is not possible. It also proves useful in daily life as one can get hot food anywhere without need of microwave oven to reheat the packed food.**

Chemicals used for exothermic reaction makes it difficult to recycle the Can and also pollute the environment. Chemicals used adds up to high cost of such Food Can. An attempt has been made to find an alternate heat source which is environment friendly, recyclable, cheap and readily available. Phosphorous pent-oxide with water and zeolite are explored for alternate heat source. Heat liberated from the reaction of Phosphorous pent-oxide with water in presence of calcium oxide and heat of adsorption of zeolite is measured and a comparative analysis is done for an alternate heat source.

Keywords—Heat of Adsorption, Zeolites, heat of reaction , heat of hydration

I. INTRODUCTION

Self-heating Food Can is usually a two chambered Can, one for food and one for heating unit. The heat is generated by an exothermic chemical reaction, water. The heating unit is contained in either an outer chamber surrounding the food, or an inner compartment immersed in the food or drink. It is activated by pressing a button or poking holes to break the seal between the water and quicklime. The reaction heats up within a few seconds, and heats the food inside the can in minutes.

Heinz manufactured self-heating beverages with a cordite stick down the center that heated the contents when lit, but they were not always reliable. Some of the cans even exploded when tried to light the cordite stick. In 2002, Nescafé tested a self-heating coffee can in the United Kingdom, but found that the can did not heat the liquid to a consistent temperature and even they failed to heat evenly.

Recent development in these product includes use of solid fuel technology which includes heat release from oxidation of aluminum where silica act as source of oxidation. The drawbacks of the technology are first it is not completely recyclable and second is that it is costlier. Hence there is need of new alternate heat source which can even make self-heating Can a commercially viable product.

Different ways to store heat energy are:

- Heat of dilution
- Heat of hydration
- Heat of solution
- Heat of reaction
- Heat of adsorption

Since heat of dilution and heat of solution is usually very less as compared to requirement for this application, these two ways are discarded. Heat of reaction is liberated when two reactants combine together to form a new compound which is chemically different. Heat of hydration is liberated is liberated when water molecules are added to slat crystal and can cause change in the crystal structure of salt. Heat adsorption is liberated during adsorption phenomena and there is no change in crystal structure of sorption material.

Reaction of quicklime (calcium carbon dioxide) and water is commonly used.

$$CaO + H_2O \rightarrow Ca(OH)_2 + Heat \quad (1)$$

Heat liberated from the reaction is 62.3 kJ/mol. The basic drawback of this reaction is calcium-oxide is fairly insoluble in water. This inhibits the proper mixing of calcium-oxide with water. Due to improper mixing of the two reactants, the heat is not liberated at uniform rate. The non-uniform rate of heat liberation results in uneven heat distribution in food can, which is not favorable. Thus an alternate is needed to replace quicklime and water. For alternate two heat source, Phosphorous pent-oxide with water in presence of calcium oxide and zeolite, are studied and best alternate is selected for self-heating packaging.

II. PHOSPHORUS PENT-OXIDE AND WATER

Phosphorous pent-oxide is white amorphous powder having melting point at 3400ºC. It is Corrosive in nature to metals and tissue. It is highly hygroscopic. It reacts vigorously with water resulting in formation of phosphoric acid. To neutralize the acid formed during reaction, calcium oxide is added with reactants.

$$P_2O_{5(s)} + 2CaO_{(s)} + 5H_2O \rightarrow 2CaHPO_4.2H_2O + \text{Heat} \quad (2)$$

A. *Heat of reaction*

To determine heat of reaction of Phosphorous pent-oxide and water in presence of calcium oxide, 15.32 g of Phosphorous pent-oxide and 9.54 g of calcium-oxide is added with water in a beaker. Then beaker is placed in water bath to obtain rise of temperature rise of water bath. From temperature rise, heat of reaction can be easily calculated.

Fig. 1. Reaction of Phosphorus pent-oxide with water in presence of calcium oxide

Temperature rise, Δt= 120-30= 90°C

The heat of reaction calculated, ΔH=176 kJ/mol. The heat of reaction calculated is inaccurate due to escape of water vapor and heat loss by radiation.

B. *Phophorous pent-oxide and water as Heat Source*

- Phosphorous pent-oxide is very hygroscopic in nature and can cause severe burns when comes in contact with skin. This can cause harm to consumer if reactants leak out of container.
- Large amount of water vapors are produced which can cause high pressure to build up in Can and can result into explosion.
- Heat liberated is very high compared to requirement and can burn the food in Can.
- It is difficult to handle Phosphorous pent-oxide and control the reaction.
- It is not recyclable, costly and corrosive to metals
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III. ZEOLITES

Zeolites are alumino-silicate minerals which have open channels containing water molecules and extra-framework cations. They have high cation-exchange capabilities and molecular sieve capabilities. Their structure is characterized by a framework of Si- and Al-centered tetrahedral arranged to form 2-10 Å channels that contain water molecules and extra framework (charge-balancing) cations. The general chemical formula for natural zeolites is (Li, Na, K) a (Mg, Ca, Sr, Ba) d [Al (a+2d) Si n-(a+2d)O_2n]·mH_2O,

Where the portion in square brackets represents the framework and rest of the species reside within the channels.

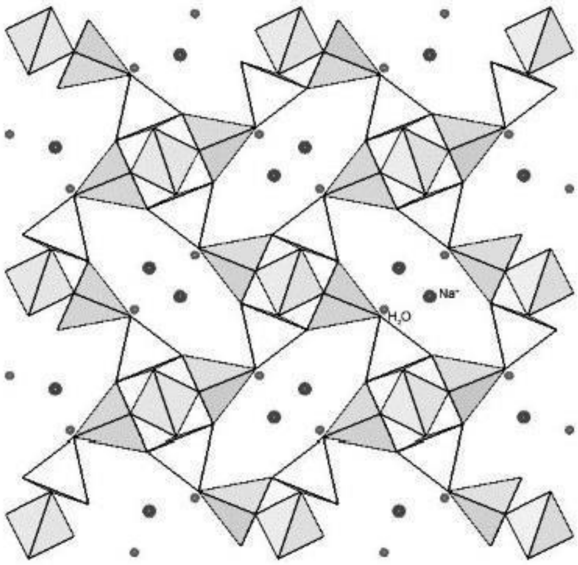

Fig. 2. Crystal Structure Zeolite (natrolite)

Equilibrium between a zeolite and water vapor can be represented by a reaction of the form

$$\text{Zeolite} + H_2O \leftrightarrow \text{Zeolite}.H_2O + \text{Heat Energy} \quad (3)$$

Where Z·nH_2O and Z are homologous hydrated (water sites occupied) and dehydrated (water sites vacant) components of a zeolite and n is the number of moles of H_2O in the fully hydrated zeolite. When zeolite is dehydrated, it stores energy in form of chemical bond and on hydration the same stored energy is released. Thus zeolite act as thermal energy storage system. Synthetic zeolites are classified on basis of molecular sieve size, they are: 3A, 4A, 5A, 13X. For experimentation purpose synthetic zeolite 3A in granules form is used.

A. *Heat of hydration of Zeolite 3A*

First known quantity of zeolite 3A is dehydrated in the furnace to remove the moisture completely.Five samples of were taken in the bowl and they were heated to different temperatures.After heating them to the different temperatures in the furnace,Zeolite was allowed to cool in air tight container to ambient temperature.Then known quantity of water was added in the zeolite.Temperature after hydration was noted by inserting thermometer to water bath which contained the zeolite beaker.

Fig. 3. Zeolite 3A sample

Fig. 4. Muffle Furnace

TABLE I. OBSERVATION TABLE

Sample	Weight of zeolite(g)	Furnace Temp(°C)	Quantity of water added (ml)
1	28.92	100	20
2	28.59	125	18
3	28.55	150	16.98
4	27.8	175	18.22
5	28.46	200	12.25
6	28.34	500	16

TABLE II. TEMPERATURE RISE TABLE

Sample	*Initial temperature(°C)*	*Final temperature(°C)*	*Temperature raise Δ°C*
1	31	41	10
2	31.8	47	15.2
3	32.5	53	20.52
4	31	50	19.2
5	33	60	27
6	30	99	69

B. Graphs

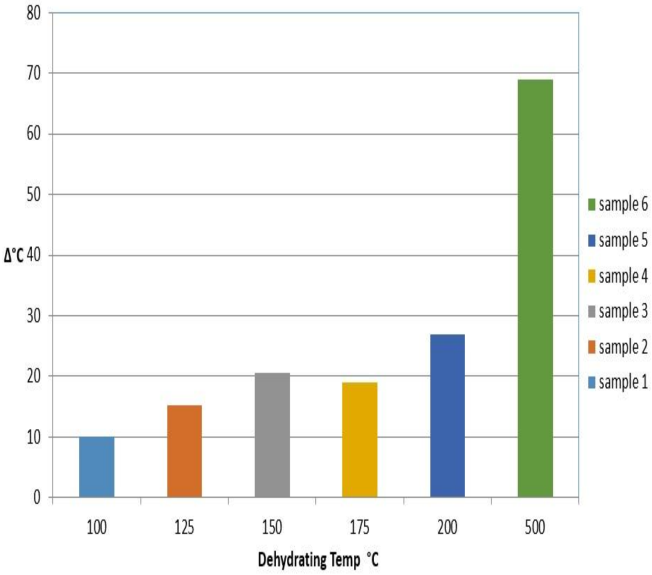

Fig. 5. Tepmerature rise for different samples

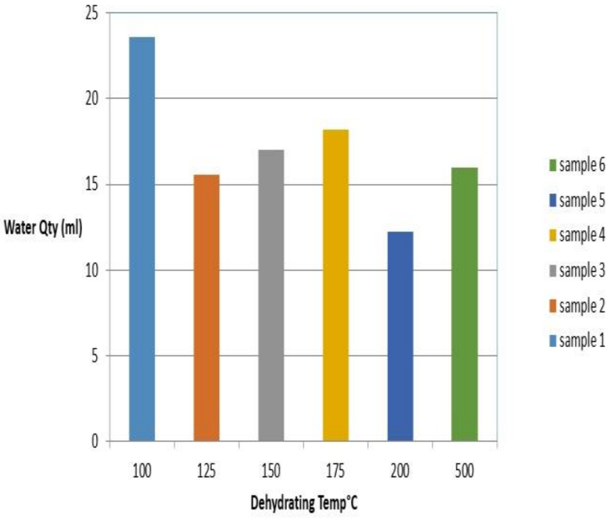

Fig. 6. Water quantity added to different samples

From graphs it can be inferred that heat of adsorption of zeolite increases as temperature at which it is dehydrated increases. Zeolite sample which is more dehydrated releases more amount of heat energy on hydration. Heat released also depends upon amount of water added to zeolite sample. If water quantity added increases above the absorption capacity, leads to decrease in temperature raised as extra water absorbs some amount of heat energy. Complete dehydration of zeolite can occur at 700°C. Dehydration of zeolite below this temperature takes longer time of heating.

C. Calculation of heat of hydration of Zeolite

Heat of hydration is determined by measuring the water in in water-bath and temperature rise of water in water-bath beaker. Heat of hydration can be determined by Formula:

$$\Delta H = m*Cp*(\Delta T) \qquad (4)$$

Where ΔH= Heat of Hydration

m=mass of water bath

Cp=Specific heat capacity of water= 4.18 kJ/kgK

Heat of hydration calculated for sample 5 zeolite 3A is 220 J/g.

D. Comparison between different synthetic zeolite

TABLE III. TYPES OF ZEOLITE

Zeolite type	***Cationic Form***	***Nominal pore diameter (Å)***	***Si/Al***
3A	K	3	1
4A	Na	3.9	1
5A	Ca	4.3	1
10X	Ca	7.8	1.2
13X	Na	8	1.2
Y	K	8	2.4
Mordenite	Na	7	8
ZSM-5	Na	6	31
Silicate	-	6	∞

Zeolites can be selected on basis of capacity, selectively, regenerability, kinetics, compatibility, and cost. Based on heat of hydration, bulk density, sieve size, zeolite 3A can be selected from other synthetic zeolites.

IV. CONCLUSION

From study of various properties of phosphorous pent-oxide with water in presence of calcium oxide and hydration zeolite, and experimentation to measure heat released by respective heat source, zeolite 3A can be selected as heat source for self-heating Food Can. Even though phosphorous pent-oxide with water releases high amount of heat energy, due to its corrosive nature to metals and hazardous to human skin, it is discarded as heat source. Zeolite 3A is eco-friendly as well as user friendly. Zeolite is also reusable. It can be dehydrated after use and thus can be activated again to make it reusable. This can make self-heating Food Can reusable and decrease its effective cost compared to onetime used self-heating Food Can. Zeolite even liberates heat energy instantaneously which will decrease time required to reheat the food. Zeolite is also completely recyclable. All this features makes zeolite better alternative over other heat sources and can make self-heating Food Can commercially viable product.

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