ESE 2025
Main Examination

UPSC ENGINEERING SERVICES EXAMINATION

Topicwise

Conventional Practice Questions

Civil Engineering

PAPER-I

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E-mail: infomep@madeeasy.in
Contact: 9021300500

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CONTENTS

01 Building Materials

1. Cement

Level-1

1.1 Write short notes on the following:

(a) Hydraulic cement and Non Hydraulic cement.

(b) Flash set and false set of cement.

[10 Marks]

Sol:

(a) **Hydraulic Cement :** It sets and Hardness extremely fast in the presence of water and results in water resistant product which is stable. This allows setting in wet condition or under water and further protects the hardened material from chemical attack e.g. - Portland cement.

Non Hydraulic Cement: These are derived from calcination of gypsum or limestone because their products of hydration are not resistant to water. However the addition of pozzolanic materials can render gypsum and lime cement hydraulic. Thus it will not set in wet conditions or under water, rather it sets as it dries and reacts with carbondioxide in the air. Eg. - Plaster of Paris.

(b) **Flash set:** It is defined as the rapid development of permanent rigidity of the portland cement paste, mortar or concrete along with high heat evolution. This rigidity cannot be dispelled and plasticity can not be regained by further mixing without addition of water.

False set : It is rapid development of rigidity (Premature stiffening or hardening) in freshly mixed portland cement paste, mortar or concrete with no appreciable evolution of heat. Remixing (large amount of heat is produced in this process) the cement paste without addition of water restores the plasticity of the paste.

1.2 Describe the various factors on which the hydration of cement depends and also show the relationship between rate of hydration of Bogue compounds.

[10 Marks]

Sol:

Hydration of cement depends on following factors :

(i) **Temperature at which hydration takes place :** It is for this reason that in cold weather, sometimes the aggregates are heated before they are used for making concrete.

(ii) **Fineness of cement :** Finer the cement, rapid is the hydration because finer cements have larger surface areas. However a very fine ground cement is susceptible to air set and deteriorates earlier.

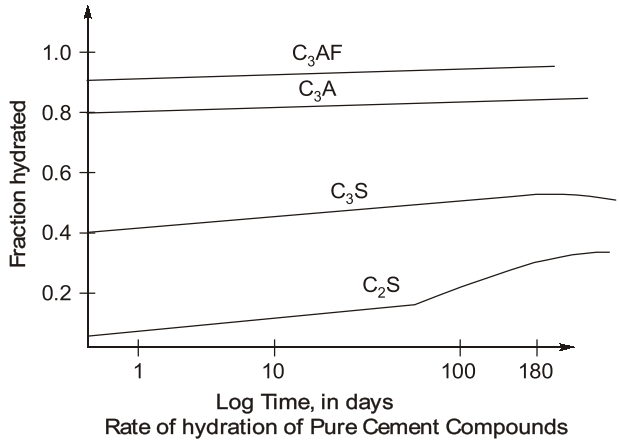
(iii) **The ingredients of cement :** The reaction can be made rapid or slow by changing the proportions of the ingredients of the cement.

Rate of hydration of Bogue compounds :

Bogue compounds of cement are C_3S, C_2S, C_3A and C_4AF. The rate of hydration is increased by an

increase in fineness of cement however, total heat evolved is same. The rate of hydration of the bogue compounds is shown in figure and will be in the following descending order.

$C_4AF > C_3A > C_3S > C_2S$



Rate of hydration of Pure Cement Compounds

1.3 Explain Pozzolanic action.

[5 Marks]

Sol:

Pozzolanic action

Pozzolana is a siliceous or siliceous and aluminous material which as such does not have cementitious properties. It reacts with calcium hydroxide in the presence of water at room temperature through a reaction called pozzolanic reaction to form insoluble calcium silicate hydrate and calcium aluminate hydrate compounds possessing cementitious properties. The reaction can be written as

$$\text{Pozzolana} + Ca(OH)_2 + H_2O = \text{C-S-H (gel)}$$

It is firstly slow and hence heat of hydration and strength development will be accordingly slow. The reduction of $Ca(OH)_2$ improves the durability of cement paste by making the paste dense and impervious. It also reduces the expansion caused by alkali-aggregate reaction in concrete.

1.4 Describe briefly the air permeability method and Wagner turbidimeter test to check the fineness of cement.

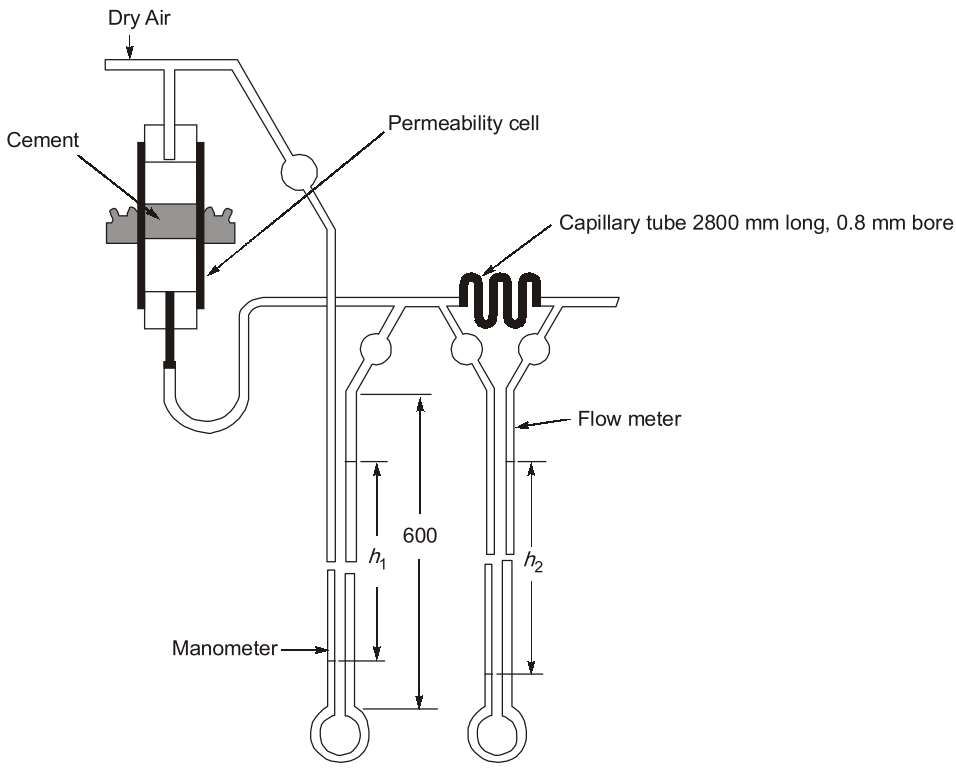
[10 Marks]

Sol:

Air Permeability Method : The fineness of cement is represented by specific surface, i.e. total surface area in cm^2 per gram or m^2 per kilogram of cement and is measured by Lea and Nurse apparatus or by Wagner turbidimeter.

The Lea and Nurse apparatus shown in figure essentially consists of a permeability test cell - where cement is placed and air pressure is applied, flow meter - to determine the quantity of air passing per second through its capillary tube per unit difference of pressure and manometer - to measure the air pressure.

Wagner Turbidimeter Method : L.A. Wagner developed a turbidimeter to estimate the surface area of one gram of cement. The cement is dispersed uniformly in a rectangular glass tank filled with kerosene. Then, parallel light rays are passed through the solution which strike the sensitivity plate of photoelectric cell. The turbidity of the solution at a given instant is measured by taking readings of the current generated by the cell. By recording the readings at regular intervals while the particles are falling in the solution, it is possible to secure information regarding the grading in surface area and in size of particle. Readings are expressed in sq. cm per gram.



Permeability Apparatus

Level-2

1.5 Name the four important constituents of cement and state the role of each in achieving its properties. [15 Marks]

Sol:

The four important constituents of cement are:

(i) Lime (CaO) – 60 to 67%
(ii) Silica (SiO_2) – 17 to 25%
(iii) Alumina (Al_2O_3) – 3 to 8%
(iv) Iron oxide (Fe_2O_3) – 0.5 to 6%

All these oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxides compositions are responsible for influencing the various properties of cement in addition to rate of cooling and fineness of grinding. The complex compounds which are formed due to the combination of these oxides are called **Bogue's compounds** and four of them are usually regarded as major compounds. They are tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetra calcium aluminoferrite (C_4AF).

The two silicates namely C_3S and C_2S which together constitute about 70 to 80 per cent of the cement control the most of the strength giving properties. Upon hydration, both C_3S and C_2S give the same product called calcium silicate hydrate ($C_3S_2H_3$) and calcium hydroxide. C_3S giving a faster rate of reaction accompanied by a greater heat evolution develops early strength. On the other hand, C_2S hydrates and hardens slowly and provides the ultimate strength. But the hydration of C_3S liberates nearly three times are much calcium hydroxide as compared to C_2S. That's why C_2S provides more resistance to chemical attack.

The compound tricalcium aluminate (C_3A) is characteristically fast reacting with water and may lead to an immediate stiffening of paste, and this process is termed as **flash set**. The role of gypsum added in the manufacture of cement is to prevent such a fast reaction. The hydrated aluminates do not contribute

anything to the strength of concrete. On the other hand, their presence is harmful to the durability of concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates fast it may contribute a little to the early strength.

On hydration, C_4AF is believed to form a system of the form $CaO–Fe_2O_3–H_2O$. A hydrated calcium ferrite of the form C_3FH_6 is comparatively more stable. This hydrated product also does not contribute anything to the strength. The hydrates of C_4AF show a comparatively higher resistance to the attack of sulphates than the hydrates of calcium aluminate.

- The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide.
- These oxides when subjected to high clinkering temperature combine with each other to form complex compounds.
- The identification of major complex compounds is based on R.H. Bogue's work and hence these are called Bogue's compound.

  There are 4 Bogue's compounds:

  1. **Tricalcium Silicate (C_3S)**

     Chemical formula : $3\,CaOSiO_2$

     Percentage : 30 - 50%

     - It undergoes hydration within a week and is responsible for development of early strength in cement.
     - It is the best cementing material and is well burnt.
     - Increases resistance to freezing and thawing.
     - Renders the clinker easier to grind.
     - Its proportion can be increased where early gain of strength is required.

     Example : Emergency repair work, cold weather concreting, prefabricated construction, etc.

  2. **Dicalcium silicate (C_2S)**

     Chemical formula : $2CaOSiO_2$

     Percentage : 20-45%

     - It hydrates and hardens slowly and takes long time to add to strength (1 year or more).
     - Imparts resistance to chemical attack.
     - Proportion is increased when early strength is not required and higher heat of hydration should not be there.

     Example : Dam or Bridge construction.

  3. **Tricalcium Aluminate (C_3A)**

     Chemical formula : $3CaOAl_2O_3$

     Percentage : 8-12%

     - Responsible for flash set of cement as it undergoes hydration within 24 hours after water addition.
     - Highest heat of hydration and tendency to volume changes causing cracking.
     - If present in higher amount, resistance to sulphate attack decreases.

  4. **Tetracalcium Alumino Ferrite (C_4AF)**

     Chemical formula : $4CaOAl_2O_3Fe_2O_3$

     Percentage : 6-10%

     - Responsible for flash set but generates less heat.
     - Poorest cementing value.
     - Raising its content reduces the strength slightly.

1.6 Write short notes on the following :

(i) High Alumina Cement

(ii) Quick Setting Portland Cement

(iii) Portland Slay Cement

(iv) Low Heat Portland Cement

[20 Marks]

Sol:

(i) High Alumina Cement :

- The raw material used for its manufacture consists of 40% bauxite, 40% lime and 15% iron oxide with a little percentage of ferric oxide and silica, magnesia etc. ground finely at a very high temperature.
- Since C_3A is not present, the cement has good resistance against attack by sulphate and some dilute acids and is particularly suitable for sea and under water work.
- High Alumina Cement has very high early compressive strength and has high heat of hydration in comparison to OPC 43 grade.
- High Alumina Cement has initial setting time of about 3.5 - 4 hours and final settling time of 5 - 5.5 hours.
- It should not be used in places where temperature exceeds 18°C and it is extremely resistant to action of fire, chemical attack, sea water, acidic water and sulphates.
- It is preferred for use in cold region due to high heat of hydration.

(ii) Quick Setting Portland Cement :

- In the manufacture of this cement, gypsum content is reduced to get the quick setting property. Also small amount of aluminium sulphate is added.
- It is ground much finer than OPC.
- It sets quickly but does not hardens quickly.
- Initial setting time = 5 minutes.
- Final setting time = 30 minutes.
- It is used when concrete is to be laid under water or in running water.

(iii) Portland Slag Cement :

- It is made by intergrinding portland cement clinter $(\lesssim 35\%)$ and granulated blast furnace slag (which is a waste product in the manufacture of pig iron) and gypsum.
- Properties of these slag cements are similar to those of OPC but they have a lower lime and higher silica and alumina content.
- Blast furnace slag cement is less reactive than OPC and gain strength a little more slowly during the first 28 days. It has high percentage of C_3S.
- It has high sulphate resistance rendering it suitable for use in environments exposed to sulphate.
- Due to low heat of hydration, it can also be used for mass concreting e.g. dams, foundations etc.

(iv) Low Heat Portland Cement :

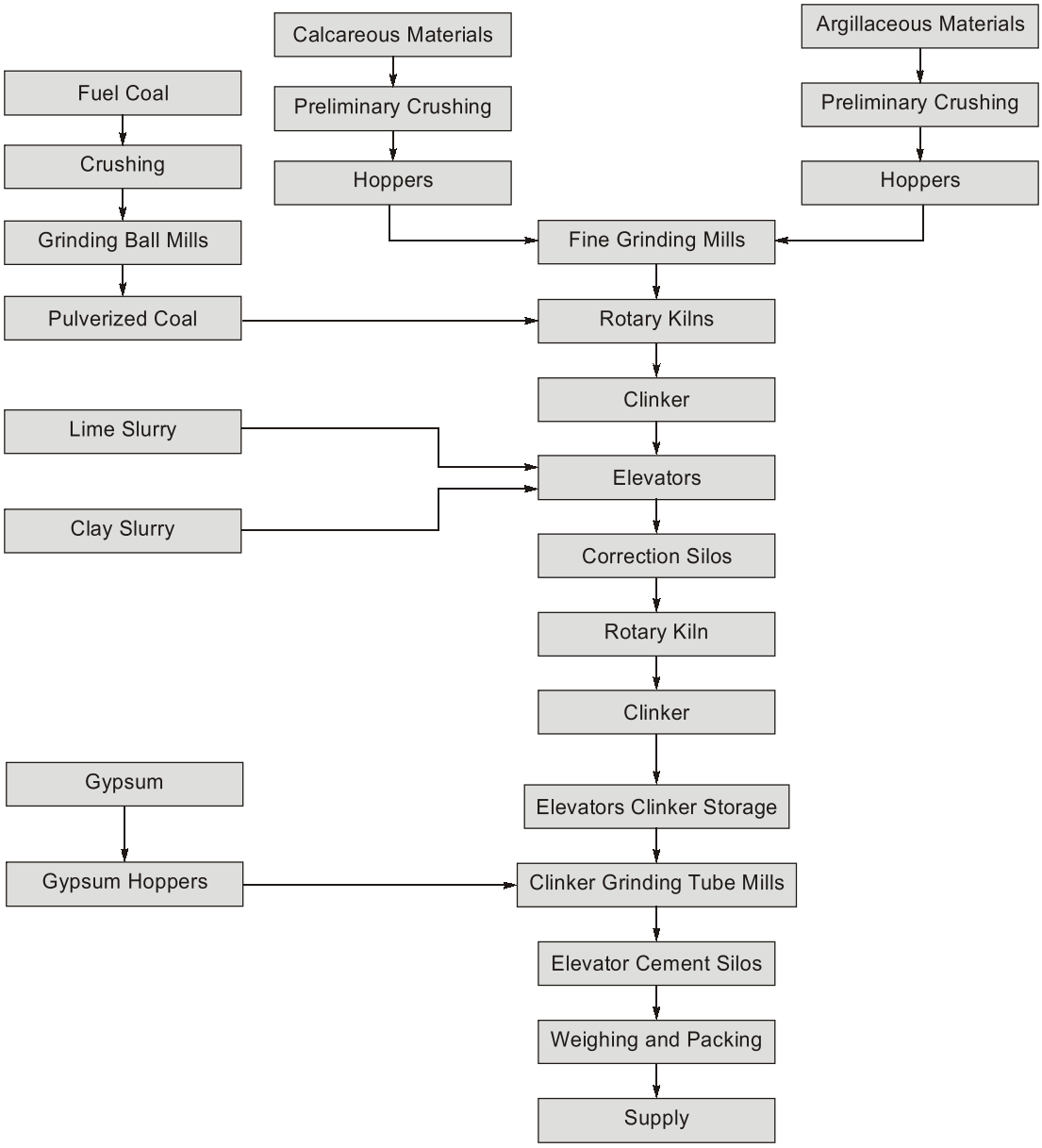
- It is a Portland cement with relatively lower contents of the more hydrating compounds C_3S and C_3A and more content of C_2S.
- This is desirable in mass concreting of gravity dams.
- It is helpful in preventing shrinkage at higher temperature.
- Rate of development of strength is slow but the ultimate strength is same as that of OPC.

1.7 Draw flow diagram of dry process and wet process of manufacturing of cement.

[20 Marks]

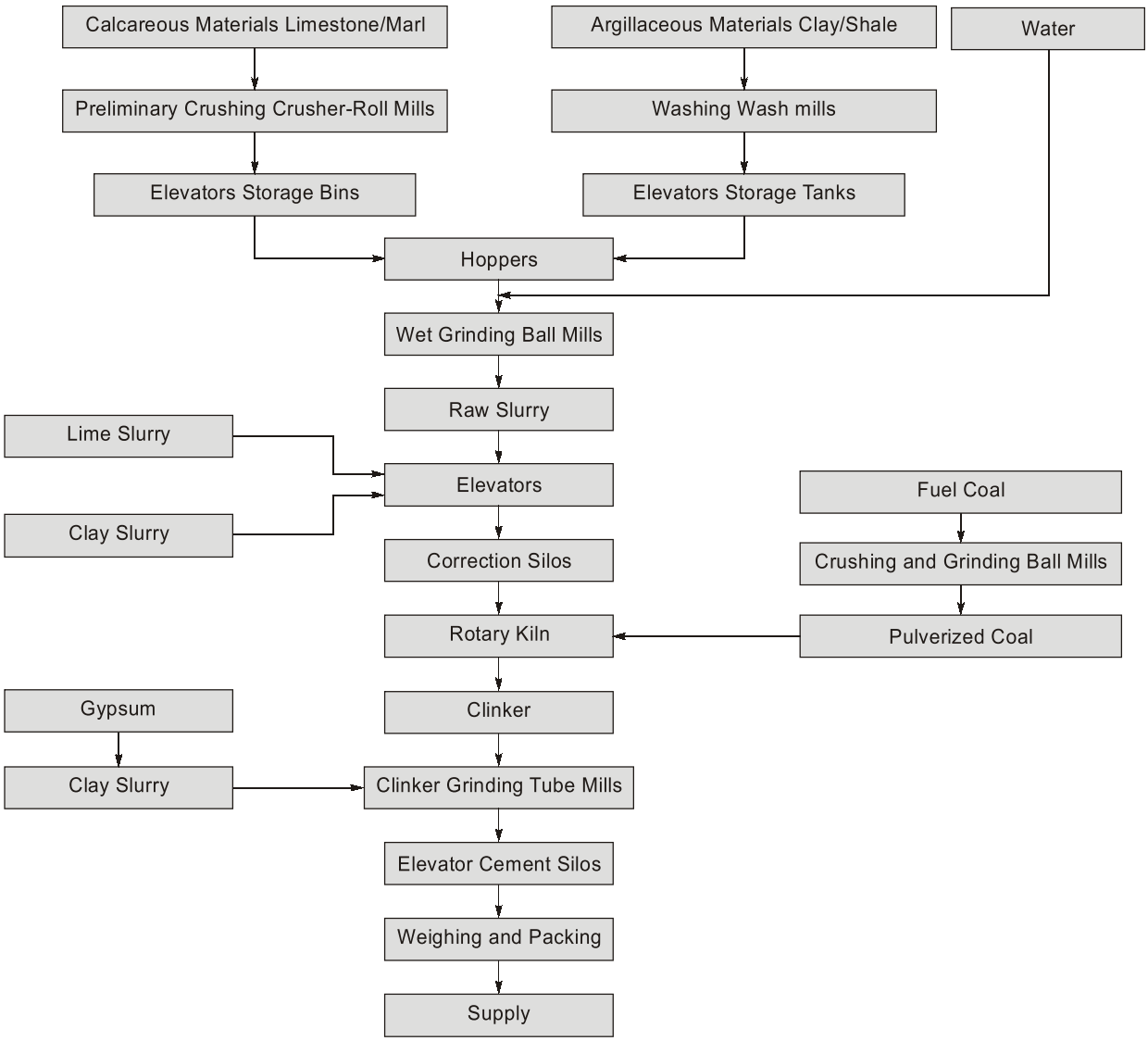
Sol:

Dry Process:



Flow Diagram of Cement Manufacture - Dry Process

Wet Process:



Flow Diagram of Cement Manufacture - Wet Process

1.8 List the various laboratory tests for assessing the quality of cement and their importance.

[15 Marks]

Sol:

The various tests done to determine the quality of cement are as follows:

A. Fineness test

1. The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence faster the development of strength.
2. Increase in fineness of cement is also found to increase the drying shrinkage of concrete.
3. Fineness of cement is tested in two ways :
   (a) **By sieving :** The principle is that, we determine the proportion of cement whose grain size is larger than specified mesh size.

(b) **By determination of specific surface area** (total surface area of all the particles in one gram of cement) by air-permeability apparatus. Expressed as cm^2/gm or m^2/kg. Generally, Blaine Air permeability apparatus is used.

4. Maximum number of particles in a sample of cement should have a size less than about 100 microns. The smallest particle may have a size of about 1.5 microns. By and large an average size of the cement particles may be taken as about 10 micron.

B. Setting Time Test

1. The significance of initial and final setting times is in the construction industry. There are various time bound factors involved in cement work such as mixing, transportation, laying, compacting and finishing, which will be facilitated only if cement or concrete is in plastic condition. For this purpose the initial setting time of concrete is determined.
2. Simultaneously, it is also very important that once the concrete is compacted and finished, it attains its firmness as soon as possible to avoid damages from external forces, bringing final setting time into the picture.
3. Vicat's apparatus is used to find these parameters.

C. Compressive Strength Test

1. The compressive strength of hardened cement is the most important and most specified of all the properties.
2. Therefore cement is always tested for this strength before employing it for important works.
3. Before starting any project, concrete mix designs are prepared in the lab in accordance with the properties of available materials. For checking the applicability and suitability of these designs, this test is used.
4. It is also employed to check the strength of concrete ready for dispatch from the batching plant.

D. Soundness Test

1. It is very essential that the cement after setting shall not undergo any appreciable change in volume, because change in volume after setting of cement causes :
   - Cracks
   - Undue expansion which results in disintegration of concrete
   - Adverse effect on durability
2. It can be tested with Le-Chatelier method or by autoclave method.
3. Le-Chatelier method is used in case of unsoundness due to free lime only as it does not indicate the presence and after effects of excess of Magnesia.
4. For magnesia content exceeding 3%, Autoclave test has to be used as it is sensitive to both free lime and magnesia.

E. Heat of Hydration Test

1. It is estimated that exothermic reaction of cement with water generates about 120 calories of heat for 1 gram of cement.
2. A temperature rise of about 50°C is observed in the interior of mass concrete dam. This can cause serious expansion of the body of the dam and subsequent cooling will cause shrinkage which can lead to serious cracking of concrete.
3. So test of heat of hydration is essentially required for low heat cements.
4. This is carried out over a few days by vacuum flask methods, or over longer periods in adiabatic calorimeter.

F. Chemical Composition Test

1. Cement mainly consists of lime, silica, alumina and iron oxide.
2. Their relative proportions greatly influence the various properties of cement.
3. So it is of vital importance to carry out chemical composition tests in laboratory.