# NONTHERMAL HYDRATOR FLOWABILITY IN CURING CONCRETE

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**Abstract**

Apart from water other liquids having hydrating capabilities have been tested in vapourised form for the first time in the world to impart strength to concrete progressively and continuously at a first rate. Results of these experiments are analysed which yields some important conclusions about the flowability of hydrating liquids in the process of curing. These conclusions also pave a new way for rapid curing in prefabrication concrete industry.

**Keywords:**hydrators; accelerated curing; cement concrete; viscosity; vapourisation; prefabrication industry; hydrator consumption; concrete temperature.

## 1. INTRODUCTION

Cement is the binding material in concrete. Its binding property enhances with the degree of hydration it achieves. Basic raw materials for cement are lime and clay which form complex compounds in the form of silicates of calcium and aluminium in its manufacturing process hydroxyl ions of water gets combined with these compounds leading to the formation of hydrates of calcium silicates, aluminium silicates and calcium hydroxide out of which calcium silicates are responsible for imparting strength to concrete. In addition to this carbon di-oxide gas if allowed to react with calcium hydroxide calcium carbonate is produced thereby imparting a little earlier hardening to concrete. This reason prompted many inventors to pass carbon dioxide into concrete under sub-atmospheric pressure [1,2]. This gas is generated by burning oil fuels, coal and other carbonaceous materials. The heat produced at the place of its generation is carried and keeps concrete warm. Trials to strengthen concrete quickly for reasons of early occupancy and commercial benefits to prefabrication industry became successful with curing by warm and hot water. Further improvements in strength occurred with passing of steam on concrete. All these led to the belief that warm temperature and moisture are favourable for curing of concrete. This belief also got reinforced by the fact that concreting is almost impossible in extreme cold conditions.

Keeping this notion in mind prefabrication concrete industry started providing temperature to concrete products in various ways. Steam is applied in a closed kiln to preserve heat for a very long time. Carbon dioxide is also applied along with steam to reduce humidity and to maintain temperature after steam condenses to fog [3,4,5]. Emphasis is given on further increase of temperature by using autoclaves [6,7] which are nothing but bigger versions of pressure cookers to quicken the curing process. Other ways of application of heat was made possible

by use of alternating electric current [8], infrared [9] and microwave heaters [10]. While heating, concrete members are kept covered by moulds or electrode plates and rubber sheets to prevent loss of moister from them due to evaporation. This way it is felt that the objective of getting both warm temperature and moisture is fulfilled.

However, a technique provided by patent application 1182/k02/2015 of this author [11] firmly establishes that 'warm temperature and moistere favouring curing' is just a notion but not the reason of fast curing. Rather faster the rate of curing as stated in the document lower becomes the temperature of concrete. Thus, the technique is found to be just the reverse of artificial heating of concrete. It is also found that neither temperature nor moister is part of the curing process, still hydration occurs at a faster rate.

The patent document manifests effectiveness of the technique in the form of a statement on the strength gained by concrete after a certain curing duration. Elaborate experimentation and in-depth analysis are not presented in the document. This paper provides the scope to fulfil that lacuna and establish the factor that control the rate of curing.

## 2. EXPERIMENTAL STUDY

### Science behind the experimental technique

The theory underlying the technique found in the patent invention [8] and adopted here can be understood if mechanism of existing practices of curing is analysed. Hydration of cement grains binds the aggregates and imparts strength to concrete. Thus, more the number of cement grains get hydrated more is the strength of concrete. But with the progress in the formation of hardened structure capillary pores or microchannels leading to the inner cores of concrete mass gets choked. Hence it takes a very long time for water to make its way to all the grains of cement in a concrete block even though it is kept immersed in water. This is

the reason for which though initial gain of strength is very fast it slows down later but continues indefinitely even beyond a year indicating towards the fact that the speed of water in the channels is very slow. Therefore, the flow can be termed as laminar or viscous, which is governed by the viscosity of the flowing liquid. This fact is further established from our knowledge about the relation between viscosity and temperature. Rise in temperature reduces viscosity of liquids. Once viscosity is reduced less resistance is offered to flow of liquids. This is the reason for which when concrete is submerged in warm water, warm water moves faster in the capillaries inside concrete and produces more strength by hydrating more number of cement grains than normal water. Further with the increase in temperature from warm to hot condition there happens further increase in the rate of hardening of concrete. Exactly opposite phenomenon occurs for concreting in extremely cold conditions requiring the use of insulated formworks. This formwork keeps the inside temperature of concrete intact, which help water left in concrete during mixing to move and hasten the hardening process a little bit. Otherwise water gets converted into snow halting its movement completely and making concreting work almost impossible. In methods adopting direct heating of concrete products with adequate cover to check evaporation during heating water left in concrete during mixing operation vaporizes inside concrete but cannot escape out because of the covering. Hence this vapour is bound to move inside concrete to all its parts at a very fast pace as viscosity of water vapor is much less than water in liquid form.

This discussion makes it clear that it is not concrete but water, the hydrating liquid whose temperature is responsible for controlling the rate of curing. Temperature reduces the viscosity of liquids. Any liquid possessing hydroxyl ion ($OH^-$) is capable of hydrating cement and hence can be called as hydrator. Increase in temperature goes on reducing viscosity of liquid and cause phase transformation into vapour. The role played by temperature can be taken by pressure. If pressure is reduced to sub-atmospheric or suction or vacuum or negative gauge boiling point of liquid also reduces. Alcohols possess hydroxyl ions. Those having boiling point lower than water are less viscos and hence when converted into vapour under suction created in the curing chamber act as excellent hydrators. As there will be no air in the voids of concrete cubes due to vacuum condition in the curing chamber this vapor of hydrators enter easily the capillary and cause curing of interior cement grains. This is the technique provided in the patent document which is adopted here for the experiments.

**Equipment for experiment:**

The setup as shown in Figures 1 and 3 for creating vacuum condition inside the curing chamber consists of (1) Rectangular curing chamber of 50×25cm and height 30cm, (2) Support grid to accommodate concrete cubes, (3) Tray to contain hydrator,(4)Vacuum pump, (5) Suction pipe, (6) Pressure gauge, (7)Top cover for curing chamber, (8) Accessories for maintaining air-tight condition.

**Experimental procedure**:

Viscosity is just the opposite of flowability of a liquid. More the flowability less is the viscosity. If viscosity is the lone determining factor of the rate of hydration then gain of strength by concrete should happen in the increasing order of viscosity of the hydrators. For this purpose five liquids with different viscosity, all containing hydroxyl ions are used as hydrating agents in the experimentations carried out here. These are methanol ($CH_3OH$), ethanol ($C_2H_5OH$), 2-propanol ($C_3H_7OH$), water (HOH) and 0.1N sodium hydroxide solution (NaOH). From here onwards these are referred as HI, H2, H3, H4 and H5 respectively. They are converted into vapour form by application of suction pressure instead of increased temperature to keep the effect of temperature isolated from the process and to show that temperature is not the key to curing. Liquids of low boiling point are less viscos. Boiling points of methanol, ethanol and propanol are $65^0$C, $75^0$C and $99^0$C respectively at normal atmospheric pressure. Boiling point of sodium hydroxide is more than water as it is a solution of salt in water .Three cubes of side 15cm are prepared with water-cement ratio of 0.5 for each set of experiment using M-53 grade cement, sand and coarse aggregates of amount 384kg, 687kg and 1200kg respectively per cubic meter of concrete with physical properties, finess modoulus and size etc. complying the relevant Indian standards (IS). The moulds were opened after 24 hours. A tray filled with hydrator is kept under the support grid on which concrete cubes after being taken out from the mould are placed. Top cover is to be screwed air-tight on the thick but flexible rubber belt surrounding the margin of the box. The chamber is then deaired completely. After the gauge reading shows complete vacuum the pump should be switched off. Strength of the cubes after every 24 hours of curing are measured by rebound hammer test before they are finally test-crushed at the end of 3-days of cuing. In the same way tests are also conducted for compressive strength values resulting from normal curing for different durations of 1,3,7,14,21 and 28 days. Quality of the cubes are assessed by using Ultra Sound Pulse Velocity (USPV).

## 3. RESULTS AND DISCUSSION

The results of normal curing are given in Table 1 whereas those for average strength of concrete cubes obtained from rebound hammer test and the amount of hydrator consumed by them at the end of every 24 hours of curing using H1, H2, H3, H4, and H5 are arranged in Tables 2(a), 3(a), 4(a), 5(a) and 6(a) respectively. Quality of individual concrete cubes and their temperature are recorded in the same order in Tables 2(b), 3(b), 4(b), 5(b) and 6(b).

**Effect of viscosity on compressive strength**

It is found that vacuum curing by methyl alcohol is producing slightly better result than ethyl alcohol. Value of compressive strength after 1-day curing produced by methyl alcohol is also above 28 days normal curing strength. This is also true for a period of two days of curing by ethyl alcohol. However, after 3 days of curing by ethyl alcohol the result is better than the 28 days moist cured strength. Boiling point and viscosity of methanol is the least of all hydrators

so also viscosity of its vapors. Low boiling point enables it to produce amount of vapor which is the highest of all hydrators. Because of these two reasons, i.e. I ) production of maximum amount of vapour and 2) lowest viscosity enough number of cement grains residing even in the remotest part of concrete gets hydrated and therefore strength of concrete cured by methanol for any curing duration become the highest of all. As is seen these two reasons also cause the gain in strength in the order of the rate of vaporization of the hydrators or in the order of viscosity. As such H5 gets the least amount of strength in all the three days of curing. Further it is to be noted here that gain in strength is much more in the first day for all the hydrators which gradually has slowed down.

The value of compressive strength was found to be 25.11 MPa after the 3rd day of curing by water under vacuum which is slightly more than the 21 days normal curing strength. These results show that the same water when gets vapourised causes hydration at a rate much higher than it in liquid state. The interesting fact is that though in the first case when the cubes are not even in contact with water gets more strength than when they remain completely submerged under it. In artificial heating technique vapor of water is also produced. But that vapour is produced inside concrete by application of heat. Thus, as soon as this water in the form of vapour is consumed in the hydration reaction further application of heat rather causes retrogression in strength as only thermal dilatation of concrete prevails, in the absence of further supply of vapour. To avoid dilatation process parameters like temperature and humidity inside the kiln are to be adjusted based on physical characteristics of concrete [5] and data acquisition and feedback control are also devised for infra-red curing [12]. Because of excess and unnecessary heating Walter [13] has demonstrated that microwave curing degrades the product quality more than autoclave curing. In electrical heating after a certain number of days and beyond a certain amount of voltage strength retrogression is manifested [14]. But in this new technique as neither the hydrator nor the concrete cubes are heated thermal dilatation does not happen. Rather as the hydrator from the tray continuously evaporates under vacuum, curing becomes a continuous process like that when concrete gets completely submerged under water. Thus, it is clear that this technique of vacuum successfully couples availability and accessibility of hydrator to make hydration very fast and continuous only by reducing viscosity of the hydrator, which has happened never before. But as availability of hydrator or production of vapour of the hydrating liquid also depends on the viscosity of the hydrator, viscosity stands to be the lone factor in determining the rate of gain of strength. At this point it is worth elaborating the two important parameters like availability and access of hydrator. In direct heating availability of hydrator is limited due to lack of further supply once the limited amount of water left in concrete during mixing operation is exhausted in hydration of cement. Hence hydration does not continue after a certain duration. It means that the case of artificial heating is just the reverse of the case of submergence of concrete blocks in water, where availability of hydrator is in plenty but access is poor whereas in the former case availability is less or limited but access is excellent.

**Effect of viscosity on consumption of hydrator**

The rate of hydration is also indicated by the amount of hydrator consumed by concrete cubes which gives an account of the mass of hydrator getting involved in the chemical reaction. Consumption of hydrator has also happened in a manner which is directly related with gain in strength provided by the different hydrators i.e., to say in case of methanol which has provided maximum strength to concrete has been consumed to the maximum amount and H5 providing least amount of curing has been consumed insignificantly. Because of the poor rate of vaporization of H4 and H5 owing their high value of viscosity, there happened a poor rate of hydration which is indicated by the insignificant amount of its consumption by the concrete cubes. In this respect ethanol stands 2$^{nd}$ succeeded by propanol. Further like the case of gain in strength consumption of hydrators happens to be the maximum for the first day of curing which has gradually reduced.

**Effect of viscosity on temperature reduction of concrete**

Another indication of the rate of hydration is the lowering down of the temperature of the cubes. Temperature of the cubes during curing process is noticed to be decreasing, because when the hydrator vapourises the latent heat of vaporization is extracted from them. This lowering down of temperature in the first day of vacuum curing is more than the second and third day by any hydrator, indicating faster rate of hydration in the beginning which gradually slows down due to choking of paths through the capillaries. Further this loss of temperature is maximum for methanol followed by ethanol and then by propanol. For that reason, cubes cured by methanol give an extremely cooling sensation when touched. This is because more the vapours produced more is the extraction of latent heat from the cubes. Loss of temperature by cubes cured by H4 and H5 is insignificant because of their low rate of evaporation or high value of viscosity. It should be note here that temperature of each of the cubes before keeping them in the curing chamber was almost equal to 33.55$^0$C.

Hence it is now seen here that despite lowering down of the temperature, concrete cube attains hydration at a very fast rate. Finally, it can also be said that boiling point, rate of vapourisation, reduction of temperature, rate of hydration and consumption of hydrator all depend on viscosity. Thus, it can be inferred that instead of temperature and moisture the governing factor for curing of cement grains is viscosity of the concerned hydrator only.

**Effect of viscosity on gain in quality**

It may be mentioned here that though UPSV is usually used to check the workmanship of concreting it is utilized here to just get an indication of compactness achieved by the concrete cubes with the progress of hydration. As per IS 13311 Part-1:1992 classification out of 45, 19 cases of concrete quality are found to be medium, from which 9 cases are from vaccum curing by H4, 9 by H5 and 1 by propanol. Rest 26 cases of quality as per the I.S code are found to be good. Whereas in case of complete immersion under water none of the cube's quality become good before the 14 days of curing. It may be mentioned here that as per the above cited code the quality of cubes is medium for USPV within the range of 3-3/5Km/sec, good between 3.5 and 4 Km/sec and excellent beyond 4Km/sec.

## 4. Conclusions

Discussions in the previous section have led us to the following conclusions.

1. Viscosity of hydrator is the sole factor at any temperature and pressure governing the rate of hydration of concrete of a given physical charecteristic.
2. More is the viscosity less is the consumption of hydrator by concrete and vice versa.
3. More is the viscosity less is the loss of temperatuere by concrete in vacuum curing and vice versa.
4. More is the viscosity less is the improvement in quality of concrete and vice versa.
5. Viscosity of hydrator is exploited to ensure enough production of vapours with high penetrating ability by the technique of vacuum curing.

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**Table**

**Click here to download Table: Table 1.docx**

Table 1: Results of curing of concrete by immersion in water at normal room temperature

| Curing duration (days) | Average rebound hammer value (MPa) | Average compressive strength (Mpa) | USPV (Km/sec) |
|---|---|---|---|
| 1 | --------- | 8.33 | C1=3.0<br>C2=3.1<br>C3=3.2 |
| 3 | 21.79 | 22.19 | C1=3.2<br>C2=3.3<br>C3=3.3 |
| 7 | 24.08 | 23.42 | C1=3.2<br>C2=3.3<br>C3=3.3 |
| 14 | 24.29 | 23.66 | C1=3.5<br>C2=3.7<br>C3=3.6 |
| 21 | 24.84 | 24.5 | C1=3.5<br>C2=3.7<br>C3=3.6 |
| 28 | 25.62 | 26.11 | C1=3.98<br>C2=4.10<br>C3=3.92 |

* In the first day minimum value for rebound hammer reding is not attained

**Table**

**Click here to download Table: Table 2 .docx**

Table 2(a): Results of strength and liquid consumption by cubes cured by H1 under -760mm of Hg

| Curing duration (days) | Average rebound hammer value (MPa) | Average compressive strength (Mpa) | Liquid consumed (ml) |
|---|---|---|---|
| 1 | 27.99 | | 350 |
| 2 | 28.34 | | 250 |
| 3 | 28.39 | 28.42 | 240 |

Table 2(b): Results of quality and temperature of concrete cured by H1 under -760mm of Hg

| Curing duration (days) | Temperature of cubes ($^0$C) | USPV (Km/sec) |
|---|---|---|
| 1 | 32.21<br>32.22<br>32.19 | 3.543<br>3.540<br>3.548 |
| 2 | 32.16<br>32.17<br>32.14 | 3.543<br>3.538<br>3.543 |
| 3 | 32.15<br>32.15<br>32.12 | 3.643<br>3.683<br>3.593 |

**Table**

Click here to download Table: Table 3.docx

Table 3(a): Results of strength and liquid consumption by cubes cured by H2 under -760mm of Hg

| Curing duration (days) | Average rebound hammer value (MPa) | Average compressive strength (Mpa) | Liquid consumed (ml) |
|---|---|---|---|
| 1 | 25.55 | | 250 |
| 2 | 26.11 | | 150 |
| 3 | 27.55 | 27.13 | 146 |

Table 3(b): Results of quality and temperature of concrete cured by H2 under -760mm of Hg

| Curing duration (Days) | Temperature of cubes ($^0$C) | USPV (Km/sec) |
|---|---|---|
| 1 | 33.20<br>33.00<br>32.72 | 3.540<br>4.380<br>3.590 |
| 2 | 32.39<br>32.50<br>32.67 | 3.654<br>3.543<br>3.543 |
| 3 | 32.39<br>32.39<br>32.33 | 3.650<br>3.680<br>3.593 |

**Table**

Click here to download Table: Table 4 .docx

Table 4(a): Results of strength and liquid consumption by cubes cured by H3 under -760mm of Hg

| Curing duration (Days) | Average rebound hammer value (MPa) | Average compressive strength (Mpa) | Liquid consumed (ml) |
|---|---|---|---|
| 1 | 23.76 | | 100 |
| 2 | 24.25 | | 80 |
| 3 | 26.22 | 26.89 | 80 |

Table 4(b): Results of quality and temperature of concrete cured by H3 propanol under -760mm of Hg

| Curing duration (days) | Temperature of cubes ($^0$C) | USPV (Km/sec) |
|---|---|---|
| 1 | 33.55<br>33.54<br>33.49 | 3.543<br>3.540<br>3.548 |
| 2 | 33.46<br>33.47<br>33.44 | 3.543<br>3.438<br>3.543 |
| 3 | 33.45<br>33.45<br>33.42 | 3.643<br>3.683<br>3.593 |

**Table**

Click here to download Table: Table 5 .docx

Table 5(a): Results of strength and liquid consumption by cubes cured by H4 under -760mm of Hg

| Curing duration (days) | Average rebound hammer value (MPa) | Average compressive strength (Mpa) | Liquid consumed (ml) |
|---|---|---|---|
| 1 | 22.73 | | 5 |
| 2 | 23.11 | | 4 |
| 3 | 25.11 | 24.88 | 4 |

Table 5(b): Results of quality and temperature of concrete cured by H4 under -760mm of Hg

| Curing duration (days) | Temperature of cubes ($^0$C) | USPV (Km/sec) |
|---|---|---|
| 1 | 33.55<br>33.55<br>33.55 | 3.463<br>3.460<br>3.447 |
| 2 | 33.55<br>33.55<br>33.55 | 3.343<br>3.478<br>3.465 |
| 3 | 33.55<br>33.55<br>33.55 | 3.464<br>3.468<br>3.493 |

Table

Click here to download Table: Table 6.docx

Table 6(a): Results of strength and liquid consumption by cubes cured by H5 under -760mm of Hg

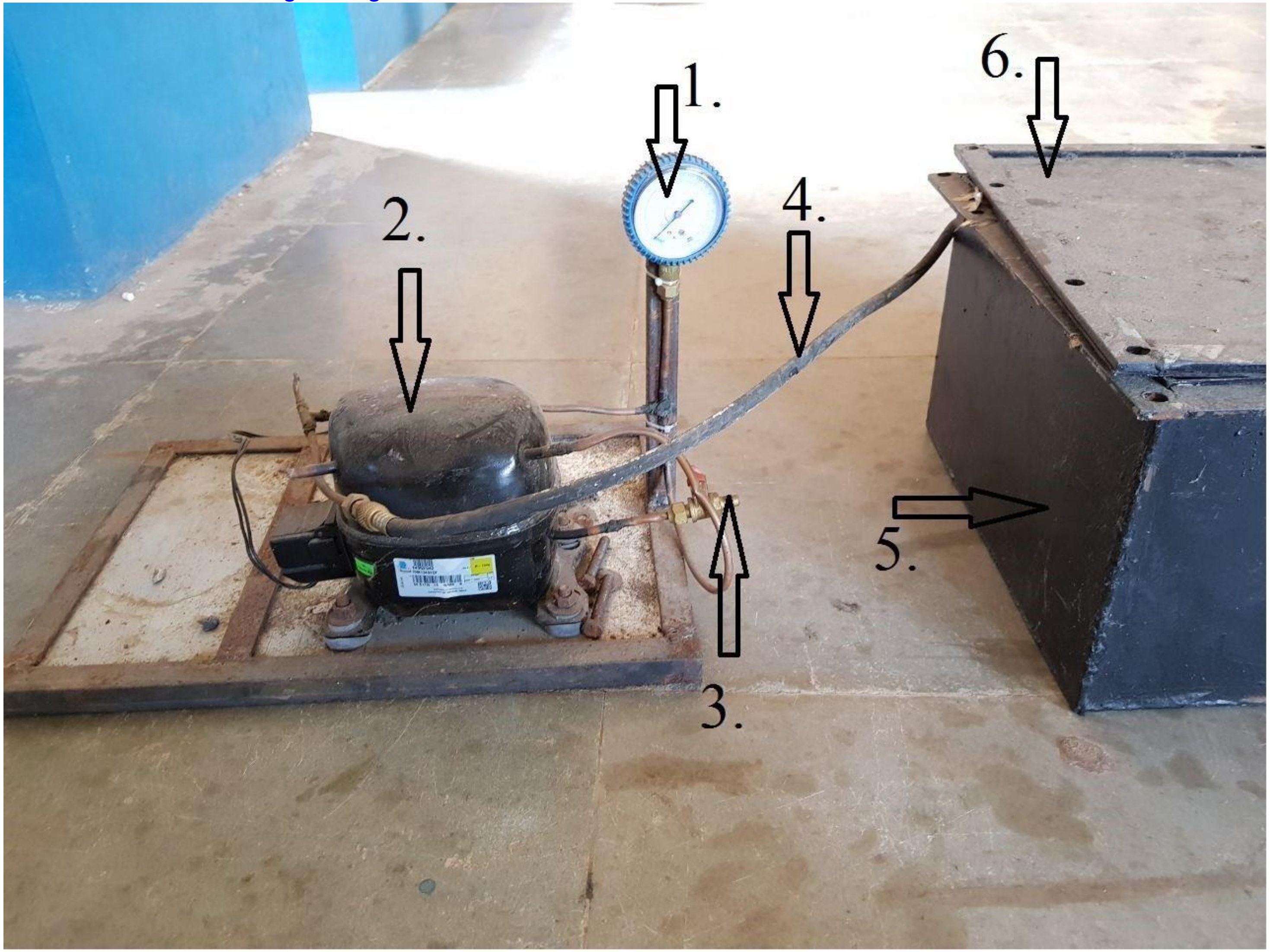
| Curing duration (days) | Average rebound hammer value (MPa) | Average compressive strength (Mpa) | Liquid consumed (ml) |
|---|---|---|---|
| 1 | 12.75 | | Negligible |
| 2 | 13.14 | | Negligible |
| 3 | 15.12 | 14.98 | Negligible |

Table 6(b): Results of quality and temperature of concrete cured by H5 under -760mm of Hg

| Curing duration (days) | Temperature of cubes ($^0$C) | USPV (Km/sec) |
|---|---|---|
| 1 | 33.55<br>33.55<br>33.55 | 3.363<br>3.360<br>3.357 |
| 2 | 33.55<br>33.55<br>33.55 | 3.363<br>3.378<br>3.365 |
| 3 | 33.55<br>33.55<br>33.55 | 3.364<br>3.389<br>3.395 |

**Figure**

**Click here to download Figure: Figure 1.docx**




1. Vaccume Guage
2. Vaccume Pump
3. Exhaust
4. Suction Pipe
5. Curing Chamber
6. Top Cover

Fig. 1: Experimental Equipment

Figure

Click here to download Figure: Figure 2 .docx

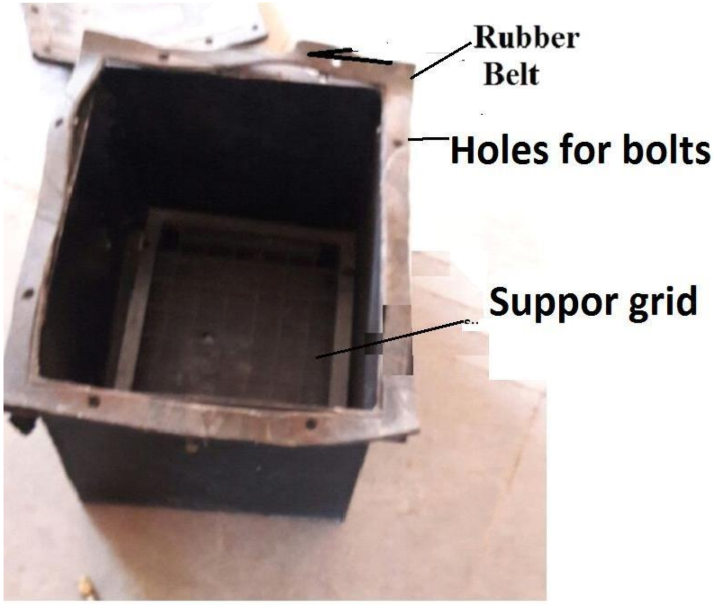



Fig. 3: Accessories