

A Temperature Monitoring Apparatus, System and Method for
Monitoring the Temperature of a Reactant System

Technical Field

5 The present invention generally relates to a temperature monitoring system, apparatus and method for monitoring the temperature of a sample reactant undergoing a reaction.

Background

10 It is often important to monitor the temperature changes of a reactant system as it undergoes chemical reaction. One example is the temperature rise during the setting and hardening of concrete, which is very important for concrete structures because it determines the structures ultimate
15 strength. The properties of concrete and cementitious materials are solely determined by the composition of its ingredients and the conditions during the setting and hardening process. Should the concrete or cement be damaged during its setting and hardening, the set product may be weak
20 and subject to cracking, necessitating the concrete having to be replaced, thereby significantly increasing construction costs.

Information about the properties of early age concrete and its development in time is therefore very important.
25 Furthermore, it is desirable that the information about the early age of the concrete be obtained on-site to enable real time remedial action to be taken at the constructions site if necessary.

One property that is important to monitor for early age
30 concrete is the adiabatic temperature rise of the concrete as it undergoes hydration.

The adiabatic temperature rise of concrete has been a topic of interest for the control of thermal-related cracking of concrete to many civil engineers and chemists. This is
35 because an excessive increase in the differential temperature

across the concrete core may lead to the development of undesired thermal stresses during the hydration process, leading to cracks and casting doubts on the integrity of the concrete. Most commercial devices available for monitoring
5 the adiabatic temperature within the concrete, hitherto, employ either (i), a reactor chamber placed within a controlled environment of an oven or (ii) a reactor chamber and/or an oven which is being hot-guarded by a re-circulating fluid at controlled temperatures.

10 The adiabatic conditions of a reactor are usually effected by a single "hot-guard" (an insulated heater), using only single point measurement on the sample or its surface and hot-guard control is performed with an appropriate control algorithm. One known apparatus handled hazardous
15 runaway reactions with external heat addition to simulate an explosion of the reactants.

Another known apparatus utilized a medium jacket where the medium was circulated to the reactor vessel and or the external oven to achieve adiabatic conditions. The oven
20 environment is controlled by external firing of the electrical heaters which in turn controlled the re-circulating air medium, flowing over the reactor vessel. This approach enables the reactor vessel to be guarded with minimal heat loss however the need to have an externally
25 controlled oven environment makes it cumbersome and expensive to operate on-site.

Another proposed solution incorporated an additional measurement of pressure to the reactor. The temperature scheme was essentially that of a medium jacket. Another
30 apparatus used a vacuum guard placed over a single hot-guard vessel to minimize convective heat losses. The incorporation of a vacuum chamber made the design fairly clumsy.

There is a need to provide a temperature monitoring apparatus, system and method for monitoring the temperature

of a reactant system that overcomes, or at least ameliorates, one or more of the disadvantages described above.

Summary

5 According to a first aspect there is provided a temperature monitoring system for monitoring the temperature of a sample reactant undergoing a reaction, said temperature monitoring system comprising:

10 a housing having at least one inner wall defining an enclosed chamber;

 at least one first temperature sensor provided on said inner wall of said housing capable of sensing the temperature of said inner wall of said housing;

15 a sample container provided within said chamber for containing said sample reactant therein;

 at least one second temperature sensor capable of sensing the temperature of an external surface of said sample container;

20 a heat pump capable of transferring heat to or from said chamber; and

25 a controller capable of monitoring the temperature of said sample reactant and capable of operating said heat pump based on the output from said first and second temperature sensors to substantially maintain thermal equilibrium therebetween.

30 One embodiment may comprise at least one third temperature sensor capable of sensing the temperature of said sample reactant as it undergoes a reaction within said sample container. In use, the controller may use the output of said third temperature sensor to monitor the temperature of said sample reactant.

35 Advantageously, in use, the temperature monitoring apparatus may monitor the adiabatic temperature rise of a sample reactant undergoing a reaction, such as endothermic reactions or an exothermic pozzolanic reaction of concrete or

cementitious reactants, without the use of a heat sink such as a water jacket.

In one embodiment, the heat pump is a heater for heating said chamber.

5 According to a second aspect there is provided a temperature monitoring apparatus for monitoring the temperature of a sample reactant undergoing a reaction, said temperature monitoring apparatus comprising:

10 a housing having at least one inner wall defining an enclosed chamber;

 at least one first temperature sensor provided on said inner wall of said housing;

 a sample container provided within said chamber for containing said sample reactant therein;

15 at least one second temperature sensor provided on an external surface of said sample container;

 a heat pump capable of transferring heat to or from said chamber; and

20 a controller capable of monitoring the temperature of said sample reactant and capable of operating said heat pump based on the output from said first and second temperature sensors to substantially maintain thermal equilibrium therebetween.

25 One embodiment of said second aspect may comprise at least one third temperature sensor capable of sensing the temperature of said sample reactant as it undergoes a reaction within said sample container. In use, the controller may use the output of said third temperature sensor to monitor the temperature of said sample reactant.

30 One embodiment relates to an adiabatic calorimeter comprising:

 a housing having at least one inner wall defining an enclosed substantially thermally insulated chamber;

35 at least one first temperature sensor provided on said inner wall of said housing;

a sample container provided within said chamber for containing, in use, a sample reactant therein;

at least one second temperature sensor provided on an external surface of said sample container;

5 at least one third temperature sensor provided within said sample container;

a heater capable of heating said chamber; and

a controller capable of operating said heater based on the output from said first and second temperature sensors and
10 capable of monitoring the output of said third temperature sensor,

wherein in use, said controller operates said heater to substantially maintain thermal equilibrium between said inner wall of said chamber and said external surface of said sample
15 container while monitoring the temperature of said sample reactant undergoing a reaction.

According to a third aspect there is provided a method for monitoring the temperature of a sample reactant undergoing a reaction, said method comprising the steps of:

20 providing a sample reactant in a sample container contained within an enclosed chamber;

monitoring the temperature of said sample reactant as it undergoes a reaction;

monitoring the temperature differential between an
25 external surface of said sample container and the surface of an inner wall of said enclosed chamber, wherein said temperature of said inner wall is monitored using a temperature sensor provided on said inner wall; and

maintaining substantially thermal equilibrium between
30 said external surface of said sample container and said inner wall of said enclosed chamber.

In one embodiment, there is provided a temperature monitoring apparatus for monitoring the temperature of a cementations or concrete material undergoing a reaction, the
35 monitoring apparatus comprising:

a housing having at least one inner wall defining an enclosed substantially thermally insulated chamber;

at least one first temperature sensor provided on said inner wall of said housing;

5 a sample container provided within said chamber for containing, in use, said cementations or concrete material therein;

at least one second temperature sensor provided on an external surface of said sample container;

10 at least one third temperature sensor provided within said sample container;

a heater capable of heating said chamber; and

a controller capable of operating said heater based on the output from said first and second temperature sensors and
15 capable of monitoring the output of said third temperature sensor,

wherein in use, said controller operates said heater to substantially maintain thermal equilibrium between said inner wall of said chamber and said external surface of said sample
20 container while monitoring the temperature of said cementations or concrete material as it undergoes a reaction.

According to a fourth aspect there is provided a portable apparatus for monitoring the adiabatic temperature rise of a concrete or cementitious material undergoing a
25 reaction, the apparatus comprising:

a thermally insulated housing having a chamber defined between at least one inner side wall, a bottom and a top;

at least one first temperature sensor provided on at least one of inner side wall, said bottom and said top for
30 monitoring the surface temperature thereof;

a sample container disposed within said chamber for containing said concrete or cementitious material undergoing said reaction therein;

at least one third temperature sensor provided within said sample container capable of sensing the temperature of said concrete or cementitious material undergoing said reaction;

5 at least one heater foil capable of heating said chamber; and

a controller capable of operating said heater foil based on the output from said first and second temperature sensors and capable of monitoring the output of said third
10 temperature sensor,

wherein in use, said controller operates said heater foil to substantially maintain thermal equilibrium between said inner wall of said chamber and said external surface of said sample container while monitoring the temperature of
15 said concrete or cementitious material undergoing said reaction.

Definitions

The following words and terms used herein shall have the meaning indicated:

5 The term 'reaction' is to be interpreted broadly to include a process involving a change in the arrangement of atoms or molecules of one, two or more reactants to yield one or more product(s) which are different from the reactant(s). The change in the arrangement of the atoms or molecules of said reactant(s) may include a dissociation, recombination, 10 or rearrangement of the atoms of the reactants. The reaction may include hydration reactions and pozzolanic reactions, silification reactions involving hydrolysis reactions, recombination reactions and geopolymeric reactions or any other physical or chemical reaction.

15 The term "heat pump" is to be interpreted broadly to include any device or means capable of transferring heat to or from the chamber. In one embodiment, the heat pump may only be capable of heating the chamber, or only cooling the chamber, or it might be capable of heating and cooling the 20 chamber. In one embodiment, the heat pump may be a thermoelectric heater for heating the chamber. In one embodiment, the heat pump may be an air conditioner for cooling the chamber.

25 Unless specified otherwise, the terms "comprising" and "comprise", and grammatical variants thereof, are intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, unrecited elements.

30 As used herein, the term "about", in the context of concentrations of components of the formulations, typically means +/- 5% of the stated value, more typically +/- 4% of the stated value, more typically +/- 3% of the stated value, more typically, +/- 2% of the stated value, even more typically +/- 1% of the stated value, and even more typically 35 +/- 0.5% of the stated value.

Throughout this disclosure, certain embodiments may be disclosed in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible
5 limitation on the scope of the disclosed ranges. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be
10 considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

Detailed Disclosure of Embodiments

Exemplary, non-limiting embodiments of a temperature monitoring apparatus for monitoring the temperature of a sample reactant undergoing a reaction, will now be disclosed.

20 The temperature monitoring apparatus comprises a housing having at least one inner wall defining an enclosed chamber. At least one first temperature sensor is provided on the inner wall of said housing. The apparatus also comprises a sample container provided within the chamber for containing
25 said sample reactant therein and at least one second temperature sensor provided on an external surface of said sample container. At least one third temperature sensor is also provided within the sample container. The apparatus also comprises a heat pump capable of transferring heat to or
30 from said chamber and a controller capable of operating said heater based on the output from said first and second temperature sensors and capable of monitoring the output of said third temperature sensor. Advantageously, in use, said controller operates said heat pump to substantially maintain
35 thermal equilibrium between said inner wall of said chamber

and said external surface of said sample container while monitoring the temperature of said sample reactant undergoing a reaction.

5 In one embodiment, the heat pump is a heater. In one embodiment, the controller determines the temperature differential between said first and second temperature sensors and adjusts the differential by turning the heater on or off to substantially maintain thermal equilibrium between said inner wall of said chamber and said external surface of
10 said sample container.

In one embodiment, the heater is turned on when the temperature output of said first temperature sensor is less than said temperature output of said second temperature sensor.

15 In one embodiment, the heater is turned off when the temperature output of said first temperature sensor is greater than said temperature output of said second temperature sensor.

Advantageously, the output temperature of said third
20 temperature sensor is used to monitor the temperature of the sample reactant as it undergoes a chemical reaction.

In one embodiment, the controller comprises a two-channel temperature controller. In another embodiment, the controller comprises:

25 a temperature controller connected to said first and second temperature sensors and said heater; and

a monitoring controller connected to said third temperature controller for monitoring the temperature of said sample reactant as it undergoes a reaction.

30 The controller may be connected to a graphical user interface for output of said third temperature sensor.

In one embodiment, said inner wall is spherical to define said enclosed chamber. The inner wall may comprise a removable cover for allowing access to said enclosure. In
35 another embodiment, the inner wall is cylindrical and extends

between a top wall and a bottom wall. The top wall may be removable from said cylindrical inner wall. In yet another embodiment, said chamber is defined between four inner walls that extend between a top and a bottom.

5 The housing may be covered with an primary insulation layer. The housing primary insulation layer may be covered with a secondary insulation layer. The primary insulation layer may comprise cork material while the secondary insulation layer may comprise polystyrene.

10 The heater may be disposed between the primary insulation layer and the housing. The heater may be a heater foil disposed between the primary insulation layer and the housing.

15 The heater may comprise one or more foil heaters that are mounted to the at least one inner wall of the housing.

In one embodiment, the heater may comprise:

a first foil heater that extends around and substantially covers the surface of, said at least one inner wall that defines the enclosed chamber; and

20 a second foil heater that substantially covers at least one of the top cover and the bottom base of the housing.

At least one of the primary and secondary insulation layers advantageously eliminates heat flow through said inner wall of the housing, thus minimizing thermal noise and errors that may arise due to undesired heat conduction paths. The insulation material may be any material that has a high thermal impedance such as cork or polystyrene.

The housing may be made from a relatively strong metal material such as aluminum, copper, brass or steel.

30 The temperature monitoring apparatus may comprise a plurality of first temperature sensors provided on the inner wall of the housing. The plurality of temperature sensors may be mounted to the inner wall.

The temperature monitoring apparatus may comprise a plurality of second temperature sensors provided on the

external surface of the sample container. The plurality of second temperature sensors are preferably mounted on the external surface of the sample container.

5 The third temperature sensor may be mounted within the sample container and preferably, is in direct contact with the material undergoing the reaction. The third temperature sensor may be mounted in the center of the sample container. The apparatus may comprise a plurality of third temperature sensors.

10 The sample container may be supported within the enclosed chamber on a pair of container supports. The container supports are preferably made of an insulation material such as cork, to inhibit thermal conductance between said container and said container supports.

15 In one embodiment, at least one of the controller, first temperature sensor, second temperature sensor, third temperature sensor and heater is powered by the mains power supply. In another embodiment, at least one of the controller, first temperature sensor, second temperature
20 sensor, third temperature sensor and heater is powered by a portable power supply such as a battery power supply.

In one embodiment, the housing comprises at least one side wall that extends between a top cover and a base. The top cover may be removable from said at least one side wall.
25 The at least one side wall, base and top cover may be made from aluminium or steel to form, when combined with a heater, a "hot-guard vessel", that is an insulated heater. The first and second temperature sensors may be parallel-series temperature sensors. The controller may be a two-channel
30 temperature controller which minimizes the error signal or reading of the first and second temperature sensors. The third temperature sensor may also be disposed within the sample container such that it records the core temperature of the sample reactant.

In another embodiment, there is provided a tandem arrangement of the two sets of parallel-series temperature sensors, each of said two sets of parallel-series temperature sensors respectively providing a comparison of the average readings of all the surfaces of the housing and container. Said readings from said respective sets of first temperature sensors and second temperature sensors may be either subtracted from each other and input to at least one controller. The controller may utilise the output from said first temperature sensors and second temperature sensors to achieve near zero temperature differences between them at all times.

Advantageously, the design of a preferred embodiment of a monitoring apparatus is light-weight and portable. The process of monitoring and tracking of the adiabatic temperature rise of a sample reactant, such as a concrete sample, can be easily performed on-site as there is no external encumbrance such as a heat sink (ie in the form of an associated medium jacket or the like). Advantageously, in one embodiment where the reactant is concrete or a cementations material undergoing curing. The simple arrangement of one preferred embodiment of a monitoring apparatus permits the use of portable batteries as a power source to thereby provide immunity from frequent power failure on-site and hence provide assured quality monitoring while a concrete material undergoes curing.

The operator of the apparatus is able to install electrical connectors between the housing and power source to facilitate quick equipment set-up time and portability.

Brief Description Of Drawings

The accompanying drawings illustrate a disclosed embodiment and serve to explain the principles of the disclosed embodiment. It is to be understood, however, that

the drawings are designed for purposes of illustration only, and not as a definition of the limits of the invention.

Fig. 1 is a schematic diagram of a cross-sectional view of a disclosed embodiment of an apparatus for monitoring the
5 adiabatic temperature rise of a concrete sample undergoing curing;

Fig. 2 is a picture of the housing used to house a container containing a concrete sample undergoing curing, showing the position of the temperature sensors;

10 Fig. 3 is a picture of the housing of Fig. 1 covered with a cork insulation layer;

Fig. 4(A) shows a picture of a round-shaped heater foil used in the apparatus of Fig. 1;

15 Fig. 4(B) shows a picture of a rectangular-shaped heater foil used in the apparatus of Fig. 1;

Fig. 5 is a schematic control diagram of the control algorithm used in the operation of the apparatus of Fig. 1;

Fig. 6 is a graph showing the results of a calibration test of the apparatus of Fig. 1; and

20 Fig. 7 shows a graph of the core temperature of a concrete sample undergoing curing in the apparatus of Fig. 1.

Detailed Description

Fig. 1 discloses a temperature monitoring apparatus 10
25 for monitoring the adiabatic temperature rise of a sample of concrete 12 undergoing curing. The apparatus 10 comprises an aluminium housing 14 consisting of a cylindrical side wall 16 that extends between a top cover 18 and a bottom plate 20 to define a chamber 17. The cylindrical side wall 16, top cover
30 18 and bottom plate 20 are respectively insulated with cork insulation layers (16A,18A,20A). The cork insulation layers (16A,18A,20A) are 10 mm thick and encapsulate the external surfaces of the housing 14.

A polystyrene insulation layer (16B,18B,20B) covers the
35 cork layers insulation layers (16A,18A,20A), which are 48 mm

thick and provide added insulation for any heat transfer between the housing 14 and the ambient environment. The layers (18A,18B) and top cover 18 are respectively removable from insulation layers (16A,16B) and cylindrical side wall 16 to allow access to the chamber 17.

Four sets of parallel-series temperature sensors (22A,22B,22C,22D) are mounted such that temperature sensors (22A,22B) are on the wall of the cylindrical side wall 16 oppositely facing each other and temperature sensors (22C,22D) are respectively on top cover 18 and bottom plate 14. A sample container in the form of container 30 is provided within the chamber 17 for containing the concrete sample 12 that is undergoing curing. Four sets of temperature sensors (24A,24B, 24C, 24D) are provided on the external surface of the container 30.

The temperature sensors (22A,22B,22C,22D,24A,24B,24C,24D) are connected to a controller in the form of two-channel temperature controller 28 so that one channel can monitor and calculate an average temperature of the set of temperature sensors (22A,22B,22C,22D) and the other channel can monitor and calculate an average temperature of the set of temperature sensors (24A,24B,24C,24D).

A temperature sensor 26 is also provided within the sample container 30. The apparatus 10 also comprises a heater in the form of heater foils (7A,7B,7C). The heater foil 7A is disposed between the cylindrical side wall 16 and the cork insulation layer 16A. The heater foil 7B is disposed between the base plate 20 and the cork insulation layer 20A. The heater foil 7C is disposed between the top cover 18 and the cork insulation layer 18A. The heater foils (7A,7B,7C) are flexible and have a heating capacity up to $2\text{W}/\text{cm}^2$.

The temperature controller 28 is connected to the heater foils (7A,7B,7C) and is able to turn them on or off based on

the output from the temperature sensors (22A, 22B, 22C, 22D, 24A, 24B, 24C, 24D).

The temperature controller 28 is also connected to the temperature sensor 26 so that it can record the temperature data of the concrete sample 12 as it undergoes curing. The data from temperature sensor 26 is output to a graphical user interface in the form of display interface 36. The display interface 36 allows the average temperature readings from temperature sensor set (22A, 22B, 22C, 22D) temperature sensor set (24A, 24B, 24C, 24D).

The container 30 is mounted within the chamber 17 on a pair of supports 34 which are made from a material that has relatively low thermal conductance—to thereby minimise the thermal bridge between the cylindrical wall 16 and the container 30. The container 30 and cylindrical wall 16 are dimensioned such that a relatively small air gap exists between the external surface of the container 30 and the cylindrical side wall 16 to thereby minimise any temperature differential. Furthermore, the air gap between the external surface of the container 30 and the cylindrical side wall 16 should be minimised to reduce sluggish response times between the temperature sensors (22A, 22B, 22C, 22D) mounted to the cylindrical wall 16 and the temperature sensors (24A, 24B, 24C, 24D) mounted to the external wall of the container 30. In this embodiment, the air gap is only as big as to allow the container to be removed from the chamber 17.

Fig. 2 is a picture of the housing 14 without the top cover 18, the insulation layers (16A, 16B, 18A, 18B, 20A, 20B), or the container 30. Fig. 2 does show one of the pair of container supports 34, the cylindrical side wall 16, and the position of the temperature sensors (22A, 22B). Fig. 3 is a picture of the housing 14 covered with cork insulation layers (18A, 22A) and with the leads of the temperature sensors (22A, 22B, 22C, 22D, 24A, 24B, 24C, 24D 26) and the heater foils (7A, 7B, 7C) protruding from the cork layer 18A. The leads of

the temperature sensors (22A, 22B, 22C, 22D, 24A, 24B, 24C, 24D, 26) are connected to the controller 28.

Fig. 4(A) shows a picture of a round-shaped heater foil that is used for the heat foils (7B, 7C). The round heaters foil fit adjacent to the top cover 18 and the bottom plate 20. Fig. 4(B) shows a picture of a rectangular-shaped heater foil (7A), which hugs the outer surface of the cylindrical wall 16 of the housing 14.

For accurate operation, a calibration of the total power input to the heater foils (7A, 7B, 7C) should be conducted, ensuring a uniform rise of wall temperatures during a heating-up period. Fig. 5 shows a schematic control diagram of the control algorithm used in the operation of the apparatus 14. As an example of a time-based thyristor firing method Table 1 below indicates exemplary voltage levels of individual heater foils (7A, 7B, 7C) employed in a "blank" run in which the container 30 is not charged with any sample. The maximum temperature differences across all sensors was less than 0.3°C.

Table 1 Parameter settings for the heaters foils and controller

Item description	Adjusted Voltage
Supply voltage for heater 7A	51 Volts
Supply voltage for heater 7B	35.5 Volts
Supply voltage for heater 7C	31.2 Volts
Proportional band for the Temperature Controller	0.25
Integral Time for the Temperature Controller	120 seconds

5 Fig. 6 is a graph showing the results of a calibration test of the apparatus of Fig. 1 showing the measured core temperature and calculated theoretical temperature overlapping each other throughout the 1500 minutes. This shows that the apparatus 10 maintained adiabatic conditions during heating and that the controller 28 maintains the temperature within the chamber 17.

In use, the controller 28 receives input temperature signals from the temperature sensors (22A,22B,22C,22D,24A,24B,24C,24D). The controller 28 calculates an average temperature (T_{sw}) of the cylindrical side wall 16 from the temperature output from the sensors (22A,22B,22C,22D) and average temperature (T_c) of the container 30 from the temperature output from the sensors (24A,24B,24C,24D). The controller 28 then calculates the differential (E) between T_{sw} and T_c as follows:

$$[E = T_{sw} - T_c]$$

If $E < 0.02$, the controller 28 activates the PID thyristor 29 to turn the heater foils (7A,7B,7C) on. If $E \geq 0.2$, the controller 28 de-activates the PID thyristor 29 to turn the heater foils (7A,7B,7C) off. Accordingly, the controller 28 operates the heater foils (7A,7B,7C) based on the average temperature (T_{sw}) of the cylindrical side wall 16 and the

average temperature (T_c) of the container 30 to maintain thermal equilibrium between the cylindrical side wall 16 and the container 30 as the sample concrete 12 undergoes hydration.

5

Example

The apparatus 10 was used to test a sample of concrete being used in an actual construction site. The concrete for use in the construction site was prepared according to the composition shown in Table 2 below.

10

Table 2 Constituent materials per cubic meter of concrete sample

Cement	OPC	133 kg
	GGBFS	247 kg
Coarse Aggregate		1000 kg
Fine Aggregate		780 kg
Water		160 kg
Admixture (Mid range WRA - Mira 99)		3.42 litres

Where "OPC" is Ordinary Portland Cement and "GGBFS" is Ground Granulated Blast Furnace Slag.

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A sample of the admixture of Table 2, after being well mixed, was placed into the container 30 of the apparatus 10. The container 30 was placed into the chamber 17 of the apparatus 10. The temperature of the concrete sample residing in container 30 was measured by the temperature sensor 30 and recorded by the controller 28 over a 6 day (8640 minute) period. The adiabatic temperature rise was recorded by the controller 28 and is shown in Fig. 7, showing that the temperature differential between the temperature sensors (24a, 24b, 24c, 24d) of the container 30, the temperature sensors (22a, 22b, 22c, 22d) and temperature sensor (26) of the concrete core temperature were all close to each other. That is, adiabatic conditions were maintained during

20

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the curing of the concrete. The container was found to be 67.3° C at day 3 (after 72 hours), while the actual maximum recorded temperature of a 3m thick concrete raft foundation with insulation all round concrete measured in-situ while being cured at the constructions site was 66.9°C. This confirms the accuracy of the apparatus.

It will be observed from Fig. 7 that the rapid heat generation due to the hydration reaction of the concrete sample as it cures was observed to commence after 6 to 7 hours and this is reflected by a steady rise in the concrete core temperature, initially at ambient temperature of 30°C to about 60°C within the next 18 hours. The heat release was observed to slow down during the next 24 hours and leveling off during the third day (~4320 minutes) to reach its adiabatic maximum temperature of 67.3°C.

The surface temperature of the sample container 30 was tracked with respect to the temperature of the cylindrical side wall 16 by the monitoring and control system to within $\pm 0.1^\circ\text{C}$ at all times. Once past the peak temperature, it was observed that the concrete core dropped in temperature at a rate of less than 0.02°C per hour over the subsequent three days (72 hours). This temperature holding capability is a unique feature of apparatus 10.

Applications

Advantageously, it has been demonstrated that the unique design of the apparatus 10 provides near zero heat loss from the concrete reactant system. Furthermore, the temperature drop within the concrete core was less than $0.02^\circ\text{C}/\text{hour}$ or about $0.5^\circ\text{C}/\text{day}$ after attaining the maximum adiabatic temperature.

It will be appreciated that the apparatus 10, having a relatively simple design, provides a highly convenient device by which to monitor the adiabatic rise of a material undergoing a reaction, such as concrete undergoing hydration.

The apparatus 10 is also highly portable in that its dimensions are such that it is able to be transported in a vehicle such as a van or lightweight truck. Other embodiments may be dimensioned to be transported by hand.

5 The apparatus 10 also does not requires an external oven unit for environmental control, thereby providing a significant advantage over the prior art.

Advantageously, the apparatus 10 does not require a re-circulating fluid system for maintaining the adiabatic
10 conditions within the chamber 17. This significantly reduces the capital and operating costs of the apparatus.

Advantageously, the low power rating of the apparatus 10, which may be powered simply by a portable power source, such as a chargeable battery unit.

15 As the integrity of the adiabatic conditions is assured, the temperature of reactants, such as concrete undergoing hydration, is able to be accurately and constantly monitored. Furthermore, the portable power source protects the apparatus 10 from any undesirable effect of power outage. This is a
20 significant advantage for applications that require the apparatus to monitor the hydration of concrete as the device can be taken on-site, such as a construction site, to monitor the adiabatic temperature rise of a sample of concrete.

The portability of the apparatus 10 offers an
25 alternative to the need for site temperature measurement of concrete cores. As on-line site temperature measurements are known to be laborious and expensive, the apparatus 10 provides a substantial savings in obtaining the adiabatic temperature rise data of concrete or cementitious materials.

30 It will be apparent that various other modifications and adaptations of the invention will be apparent to the person skilled in the art after reading the foregoing disclosure without departing from the spirit and scope of the invention and it is intended that all such modifications and
35 adaptations come within the scope of the appended claims.

Claims

1. A temperature monitoring system for monitoring the temperature of a sample reactant undergoing a reaction, said temperature monitoring system comprising:

5 a housing having at least one inner wall defining an enclosed chamber;

at least one first temperature sensor provided on said inner wall of said housing capable of sensing the temperature of said inner wall of said housing;

10 a sample container provided within said chamber for containing said sample reactant therein;

at least one second temperature sensor capable of sensing the temperature of an external surface of said sample container;

15 a heat pump capable of transferring heat to or from said chamber; and

a controller capable of monitoring the temperature of said sample reactant and capable of operating said heat pump based on the output from said first and second temperature sensors to substantially maintain thermal equilibrium therebetween.

2. A system as claimed in claim 1, comprising at least one third temperature sensor capable of sensing the temperature of said sample reactant as it undergoes a reaction within said sample container.

3. A system as claimed in claim 2, wherein in use, said controller uses the output of said third temperature sensor to monitor the temperature of said sample reactant.

4. A system as claimed in claim 1, wherein said heat pump is a heater.

5. A system as claimed in claim 4, wherein said heater is a heater foil.

6. A system as claimed in claim 1, wherein the controller determines the temperature differential between said first and second temperature sensors and adjusts the differential by turning the heater on or off to

substantially maintain thermal equilibrium between said inner wall of said chamber and said external surface of said sample container.

7. A system as claimed in claim 2, wherein the
5 controller is connected to a graphical user interface for output of at least one of said first, second and third temperature sensors.

8. A system as claimed in claim 2, wherein at least
10 one of the controller, first temperature sensor, second temperature sensor, third temperature sensor and heat pump are capable of being powered by a portable power supply.

9. A temperature monitoring apparatus for monitoring the temperature of a sample reactant undergoing a reaction, said temperature monitoring apparatus comprising:

15 a housing having at least one inner wall defining an enclosed chamber;

at least one first temperature sensor provided on said inner wall of said housing;

20 a sample container provided within said chamber for containing said sample reactant therein;

at least one second temperature sensor provided on an external surface of said sample container;

a heat pump capable of transferring heat to or from said chamber; and

25 a controller capable of monitoring the temperature of said sample reactant and capable of operating said heat pump based on the output from said first and second temperature sensors to substantially maintain thermal equilibrium therebetween.

30 10. An apparatus as claimed in claim 9, comprising at least one third temperature sensor provided within said sample container for sensing the temperature of said sample reactant as it undergoes a reaction.

35 11. An apparatus as claimed in claim 9, wherein said inner wall is cylindrical and extends between a top wall and a bottom wall.

12. An apparatus as claimed in claim 9, wherein the housing is covered with a primary insulation layer.

13. An apparatus as claimed in claim 12, wherein the primary insulation layer comprises cork material.

5 14. An apparatus as claimed in claim 12, wherein a secondary insulation layer covers the primary insulation layer.

15. An apparatus as claimed in claim 9, wherein the heat pump is a heater.

10 16. An apparatus as claimed in claim 12, wherein the heat pump is a heater and is disposed between the primary insulation layer and the housing.

17. An apparatus as claimed in claim 10, wherein at least one of the controller, first temperature sensor, second temperature sensor, third temperature sensor and heater are capable of being powered by a portable power supply.

18. A method for monitoring the temperature of a sample reactant undergoing a reaction, the method comprising the steps of:

20 providing a sample reactant in a sample container contained within an enclosed chamber;

monitoring the temperature of said sample reactant as it undergoes a reaction;

25 monitoring the temperature differential between an external surface of said sample container and the surface of an inner wall of said enclosed chamber, wherein said temperature of said inner wall is monitored using a temperature sensor provided on said inner wall; and

30 maintaining substantially thermal equilibrium between said external surface of said sample container and said inner wall of said enclosed chamber.

19. A temperature monitoring apparatus for monitoring the temperature of a cementations or concrete material undergoing a reaction, the monitoring apparatus comprising:

a housing having at least one inner wall defining an enclosed substantially thermally insulated chamber;

at least one first temperature sensor provided on said inner wall of said housing;

5 a sample container provided within said chamber for containing, in use, said cementations or concrete material therein;

at least one second temperature sensor provided on an external surface of said sample container;

10 at least one third temperature sensor provided within said sample container;

a heater capable of heating said chamber; and

a controller capable of operating said heater based on the output from said first and second temperature sensors
15 and capable of monitoring the output of said third temperature sensor,

wherein in use, said controller operates said heater to substantially maintain thermal equilibrium between said inner wall of said chamber and said external surface of said
20 sample container while monitoring the temperature of said cementations or concrete material as it undergoes a reaction.

20. A portable apparatus for monitoring the adiabatic temperature rise of a concrete or cementitious material
25 undergoing a reaction, the apparatus comprising:

a thermally insulated housing having a chamber defined between at least one inner side wall, a bottom and a top;

at least one first temperature sensor provided on at least one of inner side wall, said bottom and said top for
30 monitoring the surface temperature thereof;

a sample container disposed within said chamber for containing said concrete or cementitious material undergoing said reaction therein;

at least one second temperature sensor capable of
35 sensing the temperature of an external surface of said sample container;

at least one third temperature sensor provided within said sample container capable of sensing the temperature of said concrete or cementitious material undergoing said reaction;

5 at least one heater foil capable of heating said chamber; and

a controller capable of operating said heater foil based on the output from said first and second temperature sensors and capable of monitoring the output of said third
10 temperature sensor,

wherein in use, said controller operates said heater foil to substantially maintain thermal equilibrium between said inner wall of said chamber and said external surface of said sample container while monitoring the temperature of
15 said concrete or cementitious material undergoing said reaction.