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COOLING OF A MASSIVE BODY BY HEATPROOF GEL-FORMING COMPOSITION

Statement of the problem. For the protection of building structures during fires from its thermal impact it is proposed gel-forming systems are used, which ensure the application of the protected surfaces resistant layer of the gel. The objective of the research is to study the dynamics of cooling of a massive body with a layer of the gel.

Results. A mathematical model describing the dynamics of a cooling structure to be protected is designed. For this, the process of cooling of a massive body is broken into two consecutive stages: 1) warm-up of the wet gel to the boiling temperature, with the subsequent «boiling» of the liquid phase of the gel; 2) cooling of a massive body with a tap of the heat into the environment through the heat-insulating layer of the formed dry gel. The formula was obtained for calculating the temperature of the surface to be cooled after formation of a layer of the wet gel on it.

Conclusions. The effectiveness of this mechanism was identified as well as cooling advantages of this method of cooling compared with the cooling by water.

Keywords: gel-forming systems, gel coating, cooling of building structures, mathematical model.

Introduction

Protection of building structures from fire heat that occurs during a fire is one of the main activities fire & rescue services are involved in. Unlike regular fire protection, this kind of fire protection will be called temporary or quick response.

Quick response fire protection commonly uses the same fire retardants as for fire suppression. In most cases it is water. It is known to have one drawback and this is that it drips down oblique and vertical surfaces. This makes it necessary to treat the same object with water on numerous occasions, which undermines the opportunities of quick response fire protection.

Previously fire retardants and fire retardant gels were suggested for improving fire safety [1—3]. They are two separately stored and separately or simultaneously supplied compositions. The first composition is a solution of a gel-forming component and the second one is a solution of gel-formation catalyzer. When both solutions are supplied simultaneously, they are mixed on burning or protected surfaces. Both interact and that results in the formation of a solid gel. The gel generates a non-fluid fire protection layer which safely remains on vertical and oblique surfaces.

The advantage of fire retardant gels over water is that they allow a significant reduction of fire retardants associated with them dripping down oblique and vertical surfaces. A significant reduction of losses caused by film boiling effect is also typical of the components of fire retardant gels. These allow not just a reduction in the consumption of fire retardants but also losses incurred in the process of flooding of the lower-level floors.

The dynamics of cooling the objects treated with fire retardant gels has not been addressed. In order to estimate the parameters of cooling bodies using gel-containing layers, the process should be mathematically modelled.

1. Designing a model of cooling a massive body using gel-like layers

In the paper this is looked at as a problem of cooling a massive body (a subspace) which is equally heated up to t_0, which is over some critical level t_c, which is the temperature of the balance of the water steams and solid gel. In order for the body to be cooled, a solid gel film is applied at the temperature $t_{g0} < t_c$. As a result of a heat impact of a body being cooled, the gel is first heated up to t_c, and then (in case the resulting steam can be diverted) is "dried": the liquid component of the gel becomes gaseous as the steam is removed. In the process of cooling a massive body, the two subsequent stages are followed: 1) heating up a wet body up to t_c followed by "boiling out" of the liquid phase of the gel; 2) cooling of a massive body with the heat being diverted into the environment through a heat-insulating layer of the resulting dry gel. Let us consider these stages in more detail.

1. First, the wet gel generates a flat film with the thickness h_g on the flat surface of a massive body. Then, due to the heat coming from a massive body, there is heating of the wet gel up to

t_c. It has the following dynamics: first, over a negligibly small time, the temperature of the gel in the contact plane of the gel film and massive body (the spatial coordinate $x = 0$ in Fig. 1) reaches t_c. Then the critical heating (up to t_c) travels along the wet gel from the right to the left (in Fig. 1) with an increase in the temperature of the wet gel on the right from the flux being negligibly small. At this stage the evaporation is obstructed by no chance of diverting the steam As the critical heating flux reaches the outer boundary of the gel film (the coordinate $x = -h$ in Fig. 1), the gel starts to dry on the surface with the resulting steam being diverted into the environment (to the left). Then the corresponding critical heating flux with the same temperature t_c travels towards a massive body (from the left to the right) with the steam being diverted through a resulting film of the dry gel. The process is over when the flux of the boundary of a massive body dries with the temperature remaining the same through the entire first stage t_c. At the same time the thickness of the film B h can change due to shrinkage as the gel dries.

We assume that the temperature field $t\ (x,\tau)$ in a massive body through the cooling stages is described with a linear equation of non-stationary heat conductivity:

$$\frac{\partial t(x,\tau)}{\partial \tau} = a_* \frac{\partial^2 t(x,\tau)}{\partial x^2}, \quad 0 \le x < \infty; \tag{1}$$

where $a_* \equiv \frac{\lambda_*}{c'_*}, \quad \frac{м^2}{c}$ is the temperature conductivity coefficient, while λ_* and c'_* are heat conductivity coefficient respectively, Watt·m^{-1}·K^{-1} and the specific volumetric isobar heat capacity, J·m^{-3}·K^{-1} of the body being protected.

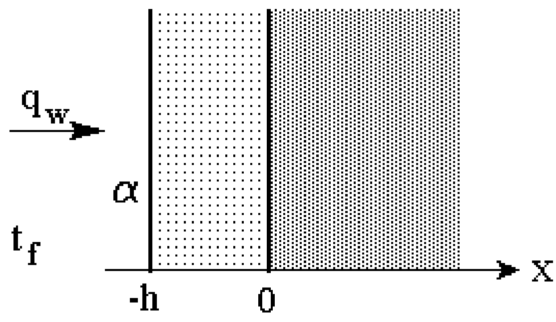

Fig. 1. Spatial scheme of cooling

The boundary condition of the equation (1) during the process is the limit of the temperature of a body away from the boundary:

$$t(x,\tau)\big|_{x=\infty} < const\,. \tag{2}$$

The key factor which allows an analytical description of a temperature field in a massive body throughout Stage 1 is no changes in the temperature of a body in the boundary with the gel. It specifies the boundary condition typical of Stage 1 only:

$$t(x,\tau)\big|_{x=+0} = t_c\,. \tag{3}$$

The initial condition of the problem (1)—(3) is even distribution of the temperature in the body being protected ($0 < x$):

$$t\,(x,\,-\Delta\tau) = t_0, \tag{4}$$

where t_0 is the initial temperature being known; $\Delta\tau$ is the duration of Stage 1 starting (at $\tau = -\Delta\tau$) with the formation of the film of the wet body on the surface of a massive body and ending (at $\tau = 0$) when the gel completely dries.

The problem (1)—(4) is a known first order boundary condition. Its solution is (see, e.g., [4]):

$$t(x,\tau) = t_0 + \Delta t_c \cdot \operatorname{erfc}\left(\frac{x}{2\sqrt{a_* \cdot (\tau + \Delta\tau)}}\right), \tag{5}$$

where $\Delta t_c \equiv t_c - t_0$ and the symbol erfc(Z) designates an extra Gauss error function for an argument Z.

In order to identify a missing $\Delta\tau$ we will keep an energetic balance in mind. All the changes occurring in the gel film suring Stage 1 will be assumed to be due to the heat of a massive body.

The heat ΔE_s, J·m^{-2} that travels from a massive body to the gel in 1 m^2 of the contact area during Stage 1 according to the major Fourier conductivity law (considering the formula (5)) is

$$\Delta E_s = \left|\int_{-\Delta\tau}^{0} \lambda_* \frac{\partial t(x,\tau)}{\partial x}\bigg|_{x=0} d\tau\right| = \left|\int_{-\Delta\tau}^{0} \frac{\lambda_* \cdot \Delta t_c \cdot d\tau}{\sqrt{\pi \cdot a_* \cdot (\Delta\tau + \tau)}}\right| = \frac{2 \cdot \lambda_* \cdot |\Delta t_c| \cdot \sqrt{\Delta\tau}}{\sqrt{\pi \cdot a_*}}\,. \tag{6}$$

This heat is for heating the wet body up to t_c and for drying it therefore

$$\Delta E_s = h_g \cdot \left[c'_{p.g} \cdot (t_c - t_{g0}) + k_m \cdot \rho_g \cdot \Delta H_g\right], \tag{7}$$

where $c'_{p.\,g}$ is a specific volumetric isobaric heat capacity of the wet gel, J·m^{-3}·K^{-1}; ρ_g is the density of the wet gel, kg·m^{-3}; k_m is the mass concentration of the wet gel that converts into steam when the gel has completely dried; ΔH_g is the heat, J·kg^{-1} for 1 kg of the wet gel steam at t_c.

The comparison of the ratios (6), (7) gives the estimation of the whole duration of Stage 1:

$$\Delta\tau = \frac{\pi \cdot a_*}{4} \cdot \left\{ \frac{h_g \cdot \left[c'_{p.g} \cdot (t_c - t_{g0}) + k_m \cdot \rho_g \cdot \Delta H_g \right]}{\lambda_* \cdot (t_0 - t_c)} \right\}^2 . \tag{8}$$

Formula (8) finishes Stage 1. Let us move on the second stage happening at $\tau \geq 0$ and involving cooling of the cooled massive body through a heat-insulating film of the wet gel.

At this stage in the area of a massive body ($x > 0$) the equation (1) with a boundary condition stays the same (2) and initial distribution of the temperature determining the expression (5) at $\tau = 0$:

$$t(x,0) = t_0 + \Delta t_c \cdot \operatorname{erfc}\left(\frac{x}{2\sqrt{a_* \cdot \Delta\tau}} \right). \tag{9}$$

In the area of wet gel ($-h < x < 0$) the temperature field is governed by the non-stationary heat conductivity equation:

$$\frac{\partial t(x,\tau)}{\partial \tau} = a \frac{\partial^2 t(x,\tau)}{\partial x^2}, \quad -h \leq x \leq 0; \tag{10}$$

where $a \equiv \dfrac{\lambda}{c'}, \ \dfrac{м^2}{c}$ is the coefficient of temperature conductivity; λ and c' are the coefficients of heat conductivity respectively, Watt·m^{-1}·K^{-1} and specific volumetric isobaric heat capacity, J·m^{-3}·K^{-1} of the dry gel.

The boundary conditions for equation (10) are known. Therefore, in the boundary of the gel with the exterior environment ($x = -h$) the boundary condition is expressed the continuity of a complete heat flux:

$$-\lambda \left. \frac{\partial t(x,\tau)}{\partial x} \right|_{x=-h} = q_w - \alpha \cdot \left[t(-h,\tau) - t_f \right], \tag{11}$$

where q_w is a resulting density of the radiation source falling onto the surface, Watt·m^{-2};

α is the coefficient of convective heat transfer off the surface into the air, Watt·m^{-2}·K^{-1}; t_f is the temperature of the environment, ^{0}C.

The conditions in the boundary of the dry gel with a massive body ($x = 0$) are the continuity of the temperature and specific heat flux respectively:

$$t\,(-0, \tau) = t\,(+0, \tau),$$

$$-\lambda \left.\frac{\partial t(x,\tau)}{\partial x}\right|_{x=-0} = -\lambda_* \left.\frac{\partial t(x,\tau)}{\partial x}\right|_{x=+0}. \quad (12)$$

The initial condition of the problem (10)—(12) can be even distribution of the temperature in the coating ($-h < x < 0$):

$$t\,(x, 0) = t_c. \quad (13)$$

Let us note straightaway that the initial distribution of the temperature in the dry gel does not really have an influence on the type of the field $t(x,\tau)$ at times τ exceeding a typical time of heating the surface:

$$\tau_0 \equiv \frac{h^2}{a}. \quad (14)$$

The problem (1), (2), (9)—(13) if a, a_*, λ, λ_*, q_w, α, t_f and t_0 are stable is solved using the Laplace transformation for a time variable of a non-stationary field $t\,(x, \tau)$ separately in the ranges $-h < x < 0$ and $x > 0$ (see, e.g., [4]).

As a result there is a shift to Laplace mapping:

$$t_L(x,s) = \int_0^\infty \left[t(x,\tau) - t_0\right] \cdot \exp(-s\,\tau)\,d\tau.$$

The latter agrees with a linear system of ordinary differential equations in respect with a spatial variable x.

The technology of solving the systems of ordinary linear differential equations is well developed so we can skip the calculations.

The result for a Laplace mapping in question of the temperature in the boundary of a massive body with the coating ($x = 0$) is as follows:

$$t_L(0,s)=\frac{\Delta t_{ef}+\Delta t_c\cdot\left[1-e^{s\cdot\Delta\tau}\cdot\operatorname{erfc}\left(\sqrt{s\cdot\Delta\tau}\right)\right]\cdot K\cdot\left(\dfrac{\phi}{Bi}\cdot\operatorname{ch}\phi+\operatorname{sh}\phi\right)}{s\cdot\left[\left(1+K\cdot\dfrac{\phi}{Bi}\right)\cdot\operatorname{ch}\phi+\left(K+\dfrac{\phi}{Bi}\right)\cdot\operatorname{sh}\phi\right]}. \tag{15}$$

In writing the ratio (15), we introduced the variable $\phi=\sqrt{s\cdot\tau_0}$ using the following designations: $\Delta t_{ef}\equiv t_f+\frac{q_w}{\alpha}-t_0$ is an effective temperature of the environment; $K\equiv\sqrt{\frac{\lambda_* c'_*}{\lambda c'}}$ is a criterion of a relative heat activity of the environments; $Bi\equiv\frac{\alpha\cdot h}{\lambda}$ is the Biot criterion of cooling the coating with the environment.

In this coating the criterion K is not small and the criterion $Bi \ll 1$ therefore the summands with shφ can be neglected in the formula (15) can be neglected so we have the estimation:

$$t_L(0,s)=\Delta t_{ef}\cdot I_{L.f}(s)+\Delta t_c\cdot I_{L.c}(s), \tag{16}$$

where

$$I_{L.f}(s)\equiv\frac{1}{s\cdot\left(1+K\cdot\dfrac{\phi}{Bi}\right)}\cdot(\operatorname{ch}\phi)^{-1}=\frac{1}{s\cdot\left(1+\sqrt{s\cdot\tau_*}\right)}\cdot\left(\operatorname{ch}\sqrt{s\cdot\tau_0}\right)^{-1}, \tag{17}$$

$$I_{L.c}(s)\equiv\frac{1-e^{s\cdot\Delta\tau}\cdot\operatorname{erfc}\left(\sqrt{s\cdot\Delta\tau}\right)}{s\cdot\left(1+K\cdot\dfrac{\phi}{Bi}\right)}\cdot K\cdot\frac{\phi}{Bi}=\frac{1-e^{s\cdot\Delta\tau}\cdot\operatorname{erfc}\left(\sqrt{s\cdot\Delta\tau}\right)}{\sqrt{s}\cdot\left(1+\sqrt{s\cdot\tau_*}\right)}\cdot\sqrt{\tau_*}\,. \tag{18}$$

Writing (17), (18) the parameter is used

$$\tau_*\equiv\left(K\cdot\frac{\sqrt{\tau_0}}{Bi}\right)^2=\frac{\lambda_*\cdot c'_*}{\alpha^2},$$

which is a typical heat removal of a massive body into the environment, sec.

The first summand in the formula (16) corresponds with cooling of an evenly heated massive body with the dry gel coating (if there is no Stage 1), the second summand accounts for prior cooling of the system at Stage 2.

In order to return to the initial temperature t (0,τ) the reverse Laplace transformation should be used for $t_L(0,s)$. If it is designated $L^{\wedge -1}$, according to (16)

$$t(0,\tau)-t_0 = L^{\wedge -1}\left[t_L(0,s)\right] = \Delta t_{ef}\cdot I_f(\tau)+\Delta t_c\cdot I_c(\tau),$$

where $$I_f(\tau)\equiv L^{\wedge -1}\left[I_{L.f}(s)\right],\quad I_c(\tau)\equiv L^{\wedge -1}\left[I_{L.c}(s)\right].$$

For transforming the expression (17) $\left(ch\,\phi\right)^{-1}$ will be presented as

$$\left(\mathrm{ch}\,\phi\right)^{-1} = \left(e^{\phi}\cdot\left[1-\frac{1-e^{-2\cdot\phi}}{2}\right]\right)^{-1} = e^{-\phi}\cdot\sum_{n=0}^{\infty}\left(\frac{1-e^{-2\cdot\phi}}{2}\right)^{n}, \tag{19}$$

which is more consistent for small φ than a row with the degrees $e^{-2\cdot\phi}$.

Further on, the known binomial split is used

$$\left(\frac{1-e^{-2\cdot\phi}}{2}\right)^{n} = \frac{1}{2^n}\cdot\sum_{k=0}^{n}(-1)^k\cdot\frac{n!}{k!\cdot(n-k)!}\cdot e^{-2\cdot k\cdot\phi}$$

and the ratio (see, e.g., [1])

$$L^{\wedge -1}\left[\frac{e^{-(1+2\cdot k)\cdot\sqrt{s\cdot\tau_0}}}{s\cdot\left(1+\sqrt{s\cdot\tau_*}\right)}\right] = Ib\left(\tau,k\right),$$

where $$Ib\left(\tau,k\right)\equiv \mathrm{erfc}\left(\frac{1+2\cdot k}{2}\cdot\sqrt{\frac{\tau_0}{\tau}}\right)-e^{(1+2\cdot k)\cdot\sqrt{\frac{\tau_0}{\tau_*}}+\frac{\tau}{\tau_*}}\cdot\mathrm{erfc}\left(\sqrt{\frac{\tau}{\tau_*}}+\frac{1+2\cdot k}{2}\cdot\sqrt{\frac{\tau_0}{\tau}}\right), \tag{20}$$

and k is a whole non-negative number.

As a result,

$$I_f(\tau)=\sum_{n=0}^{\infty}\Delta I(\tau,n), \tag{21}$$

where $$\Delta I(\tau,n)=\frac{1}{2^n}\cdot\sum_{k=0}^{n}(-1)^k\cdot\frac{n!}{k!\cdot(n-k)!}\cdot Ib(\tau,k).$$

A summand with $n = 0$ is the most important one in the row (21). At $\tau >> \tau_0$ it dominates.

If it is necessary to consider the time $\tau_0 \geq \tau > 0$ as well, as the analysis suggests, in this range the initial summand provides 50 % accuracy, for maintaining 20 % accuracy two summands are necessary, for 10% - three summands, for 5% - four summands of the row.

In order to transform the expression (18) the ratio (see [4]) can be used

$$L^{\wedge -1}\left[\frac{\sqrt{\tau_*}}{\sqrt{s}\cdot\left(1+\sqrt{s\cdot\tau_*}\right)}\right] = e^{\frac{\tau}{\tau_*}}\cdot \operatorname{erfc}\left(\sqrt{\frac{\tau}{\tau_*}}\right), \quad (22)$$

and the formulas

$$L^{\wedge -1}\left[\frac{\sqrt{\tau_*}}{1+\sqrt{s\cdot\tau_*}}\right] = \frac{1}{\sqrt{\pi\cdot\tau}} - \frac{1}{\sqrt{\tau_*}}\cdot e^{\frac{\tau}{\tau_*}}\cdot \operatorname{erfc}\left(\sqrt{\frac{\tau}{\tau_*}}\right), \quad (23)$$

$$L^{\wedge -1}\left[\frac{e^{s\cdot\Delta\tau}}{\sqrt{s}}\cdot \operatorname{erfc}\left(\sqrt{s\cdot\Delta\tau}\right)\right] = \frac{1}{\sqrt{\pi\cdot(\tau+\Delta\tau)}}, \quad (24)$$

in conjunction with a compression equation

$$L^{\wedge -1}\left[F_{L.1}(s)\cdot F_{L.2}(s)\right] = \int_0^{\tau} f_1(\tau-\theta)\cdot f_2(\theta)\cdot d\theta,$$

where $f_1(\tau) \equiv L^{\wedge -1}\left[F_{L.1}(s)\right]$, $f_2(\tau) \equiv L^{\wedge -1}\left[F_{L.2}(s)\right]$ used for the formulas (23), (24).

As a result,

$$I_c(\tau) = e^{\frac{\tau}{\tau_*}}\cdot \operatorname{erfc}\left(\sqrt{\frac{\tau}{\tau_*}}\right) + \frac{1}{\sqrt{\pi}}\int_0^{\frac{\tau}{\tau_*}} \frac{e^{y}\cdot \operatorname{erfc}(\sqrt{y})\cdot dy}{\sqrt{\frac{\tau+\Delta\tau}{\tau_*} - y}} - \frac{2}{\pi}\cdot \arcsin\left(\sqrt{\frac{\tau}{\tau+\Delta\tau}}\right). \quad (25)$$

Therefore the initial ratio which described the temperature of the surface of a massive body in the first approximation at Stage 2 is now

$$t(0,\tau)=t_0-\left(t_0-t_f-\frac{q_w}{\alpha}\right)\cdot\left[\operatorname{erfc}\left(\frac{1}{2}\cdot\sqrt{\frac{\tau_0}{\tau}}\right)-e^{\sqrt{\frac{\tau_0}{\tau_*}+\frac{\tau}{\tau_*}}}\cdot\operatorname{erfc}\left(\sqrt{\frac{\tau}{\tau_*}}+\frac{1}{2}\cdot\sqrt{\frac{\tau_0}{\tau}}\right)\right]+$$
$$-\left(t_0-t_c\right)\cdot\left[e^{\frac{\tau}{\tau_*}}\operatorname{erfc}\left(\sqrt{\frac{\tau}{\tau_*}}\right)+\frac{1}{\sqrt{\pi}}\int_0^{\frac{\tau}{\tau_*}}\frac{e^y\cdot\operatorname{erfc}(\sqrt{y})\cdot dy}{\sqrt{\frac{\tau+\Delta\tau}{\tau_*}-y}}-\frac{2}{\pi}\cdot\arcsin\left(\sqrt{\frac{\tau}{\tau+\Delta\tau}}\right)\right]. \quad (26)$$

If the calculations need to be made more accurate for small $\tau_0 \geq \tau > 0$, a number of the summands of the row (21) should be added in the first quadratic bracket of the formula (26).

2. Calculation of the temperature of the surface of a massive body cooled with a gel layer

The dependence graph $t(\tau)$ of the temperature of the surface of a massive body throughout the entire cooling process involving the gel (i.e. at $\tau > -\Delta\tau$) is presented with a solid line in Fig. 2.

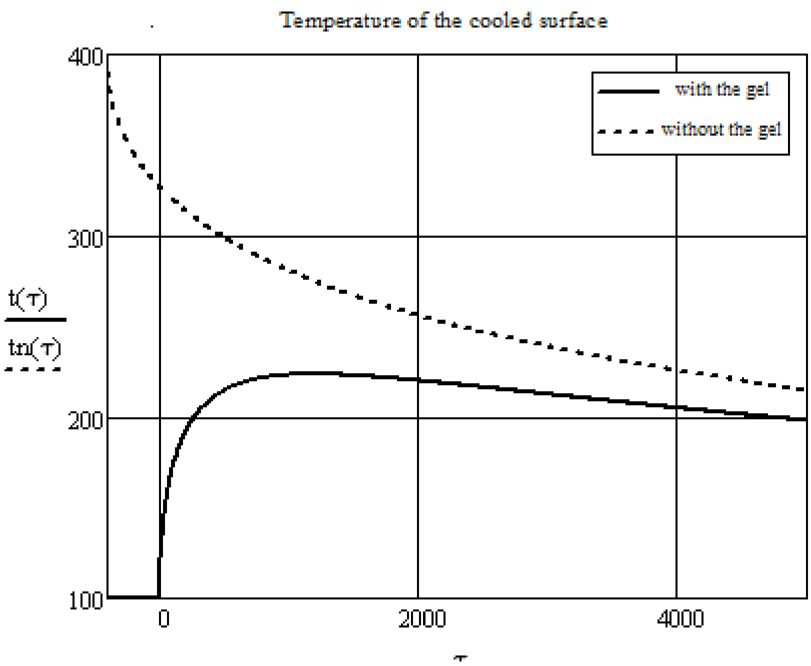

Fig. 2. Dependence of the temperature of a massive body on the time during cooling

While designing it, the typical values of the parameters are

$$h = h_g = 3\cdot10^{-3}\ \text{m};\quad \rho_g = 1250\ \text{kg}\cdot\text{m}^{-3};\quad k_m = 0.75;$$

$$c'_{p.\,g} = 5\cdot10^6,\ \text{J}\cdot\text{m}^{-3}\cdot\text{K}^{-1};\quad \Delta H_g = 2\cdot10^6,\ \text{J}\cdot\text{kg}^{-1};\quad t_{g0} = t_f = 20\ {}^0\text{C};$$

$$t_0 = 400\ {}^0\text{C};\quad t_c = 100\ {}^0\text{C};\quad \lambda = 0.25\ \text{Watt}\cdot\text{m}^{-1}\cdot\text{K}^{-1};\quad c' = 2.5\cdot10^5,\ \text{J}\cdot\text{m}^{-3}\cdot\text{K}^{-1};$$

$$\lambda_* = 1.0 \text{ Watt}\cdot\text{m}^{-1}\cdot\text{K}^{-1}; \quad c'_* = 1.0\cdot10^6, \text{ J}\cdot\text{m}^{-3}\cdot\text{K}^{-1};$$

$$q_w = 0, \text{ Watt}\cdot\text{m}^{-2}; \quad \alpha = 10, \text{ Watt}\cdot\text{m}^{-2}\cdot\text{K}^{-1}.$$

The time of cooling and drying the gel film is $\Delta\tau \approx 400$ sec and the time of heating the dry gel film is typically $\tau_0 = 9$ c. Stage 1 has a time interval $\Delta\tau < \tau < 0$ and Stage 2 occurs at $\tau > 0$. The ratio of the temperature of the surface of a massive body tn(τ) if it cools without a gel coating is drawn in the same graph. The comparison of the lines is very indicative of the efficiency of wet gel for cooling the surface.

While comparing the suggested method of cooling with a traditional cooling of structures using water irrigation, it is necessary to remember that the gel consists of 70—96 % water. I.e. at Stage 1 of cooling its cooling capacity will be 70—96 % of the corresponding characteristics for water if there is a complete loss of it due to dripping down vertical and oblique surfaces. For fire suspension water losses are normally ~90 %, for fire retardant gels they are estimated to be 10 %. It can therefore be concluded that the total cooling effect of gel-forming layers is 6.3—8.5 times higher than that of water.

Conclusions

For the first time it has been suggested that gel-froming fire retardant and fire protection systems are used for quick response fire protection. They are two separately stored and separately or simultaneously supplied compositions. The first composition is a solution of a gel-forming component. The second composition is a solution of a gel-formation catalyzer. If they are both supplied simultaneously, they are mixed on burning or protected surfaces. Both interact causing a solid gel to form. The gel generates a non-fluid fire protection layer on the surface which safely stays on vertical and oblique surfaces.

Cooling of a thermally thick body with a layer of a gel-forming composition on it has been addressed. Cooling of a massive body is divided into two subsequent stages: 1) heating of wet gel up to the boiling temperature followed by "boiling" of the liquid phase of gel; 2) cooling of a massive body with the heat being diverted into the environment through a heat-insulating layer of a resulting dry gel. The formulas for the temperature of a cooling surface following the formation of wet gel were obtained. This cooling mechanism was shown to be effective. It was found that the total cooling effect of gel-forming layers is 6.3—8.5 times higher than that of water in similar cooling dynamics.

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