Distribution and Influence of Radiant Heat Transfer at Cars

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***Abstract**: Heat radiation at fires of cars, especially in parking and garages is a main factor in their distribution. The high power which is emitted by the burning of cars and their proximity to each other define the radiant heat transfer as a dangerous source of ignition of a large number of cars.*

This provides the foundation to pay particular attention to this type of heat exchange

***Key words:** fires, fire danger in motor vehicles, mathematical models*

INTRODUCTION

For fires in open space characteristic feature is the transmission of heat by radiation. When temperature is increase radiation also increases because of increases of internal energy of the body. Together with the radiation of body of its own energy it consumes radiant energy emitted by other bodies and falling over each body.

At open fires does not accumulate heat in the space around the burning zone. The size of the combustion process is determined by the fire load in space and emerging from it convective gas flows. Heat exchange is performed in unrestricted environment. (Fig.1)

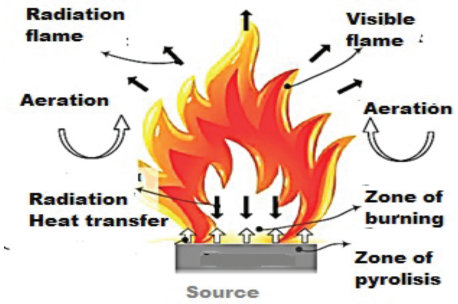

Fig.1

The peculiarity of such a heat exchange concluded that the brief impact of radiant heat can lead to ignition of closed objects with combustible load (house, garage, car, etc.). The continued impact of radiant heat from a burning car on parked cars in the neighbourhood, often occurs with fire

For magnitude of the radiating ability is applying the law of Stefan - Boltzmann. Quantity of radiant heat emitted by the black body is proportional to its absolute temperature raised to power of 4:

$$E_0 = \sigma_0 T^4 \tag{1}$$

where: σ_0 - constant radiation numerically equal to $5{,}67 \times 10^{-8}, W / m^2 \times K^4$. For convenient σ is increase to 10^8 and it is defined with C_0. Eq (1) takes the forms:

$$E_0 = C_0 \left(\frac{T}{100} \right)^4 \tag{2}$$

where: E_0 - is the broadcasting capability of blackbody, $W / m^2; C_0 = 5{,}67 W / \left(m^2 K^4 \right)$- constant of radiation of absolute blackbody.

T_1- maximum temperature developed during combustion of a substance, T_2–

invitation temperature of exposure substance, ε_1- degree of blackness of the torch of the flame of burning substance, ε_2– degree of blackness of exposure substance, $a_1, b_1, r,$ - geometrical sizes of the model, calculated on the maximum size of the torch.

Equation (2) gives the relation between the integral radiation of all wavelengths and temperature. The whole amount of radiant energy emitted by all wavelengths is as follow:

$$E = \int_{\lambda=0}^{\lambda=\infty} E_{\lambda T} d\lambda = \sigma \cdot T^4 \tag{3}$$

For all the energy emitted by $1m^2$ surface of the blackbody analytical may be obtained from the equations of Planck:

$$E = \int_{\lambda=0}^{\lambda=\infty} \frac{c_1 \lambda^{-5}}{e^{\frac{c_2}{\lambda T}}} d\lambda \tag{4}$$

It is applied: $\lambda = \frac{c_2}{xT} \Rightarrow d\lambda == -\frac{c_2}{x^2 T} \Rightarrow dx$

Boundary conditions: $\lambda = 0$, $x = 0; \lambda = \infty$, $x = 0$

$$E = \int_{x=\infty}^{x=0} \frac{c_1}{\left(\frac{c_2}{xT}\right)^5 \cdot e^x - 1} \frac{c_2}{x^2 T} dx \tag{5}$$

$$E = \frac{c_1}{c_2^4} T^4 \int_{x=0}^{x=\infty} \frac{x^3}{e^x - 1} dx \tag{6}$$

It is solving e^x in row of the form:

$$E = \frac{c_1}{c_2^4} T^4 \int_0^{\infty} x^3 \left(e^{-x} + e^{-2x} + e^{-3x} + ...\right) dx \tag{7}$$

$$E = \frac{c_1}{c_2^4} T^4 \left[\int_0^{\infty} x^3 e^{-x} dx + \int_0^{\infty} x^3 e^{-2x} dx + \int_0^{\infty} x^3 e^{-3x} dx + ... \right] \tag{8}$$

but:

$$\int_0^{\infty} x^3 e^{-X} dx = \left[-e^{-x} \left(x^3 - 3x^2 + 3 \cdot 2x - 3 \cdot 2 \cdot 1 \right) \right]_0^{\infty} = 1 \cdot 2 \cdot 3, \tag{9}$$

Then:

$$\int_0^{\infty} x^3 e^{-2X} dx = \int_0^{\infty} \frac{(2x)^3 e^{-2x} d(2x)}{2^4} = 1 \cdot 2 \cdot 3 \cdot \frac{1}{2^4}, \tag{10}$$

$$\int_0^{\infty} x^3 e^{-3X} dx = \int_0^{\infty} \frac{(3x)^3 e^{-3x} d(3x)}{3^4} = 1 \cdot 2 \cdot 3 \cdot \frac{1}{3^4} \tag{11}$$

Expression is obtained:

$$E = \frac{c_1}{c_2^4} T^4 \cdot 1 \cdot 2 \cdot 3 \left(1 + \frac{1}{2^4} + \frac{1}{3^4} + ... \right) \tag{12}$$

$$E = \frac{6{,}494 c_1}{c_2^4} T^4 \tag{13}$$

Or

$$E = \sigma \cdot T^4 \tag{14}$$

Using the laws of radiant heat transfer can be obtained computational formulas for the radiant heat exchange between bodies. Starting from this that heat exchange by radiation between two bodies the amount of heat energy is determined by the difference between the amount of energy which is absorbed by it in transmissions of another body.

For the application of the results of the study of fires in cars in practice the main interest is the process of fire spread from a burning car located close to other cars. Distribution of the combustion from one object to another (vehicle) can be effected by direct impact of flames or through the effects of convective and radiant heat exchange flows.

The radiant heat exchange passes through ambient air to locations adjacent to another vehicle or object. The surfaces of adjacent objects absorb part of the radiant heat and its start heated. Temperature rising following this mechanism leading up to the temperature of ignition of combustible parts of adjacent objects (car) and ultimately to the spread of fire.

Fig. 2

Three experiments were conducted on ordinary midsize cars manufactured in the end of 1970 [2]. Degree of heat release is determinate using oxygen calorimetric, loss of mass, heat flow, carbon monoxide, carbon dioxide and the production levels of smoke, gas temperatures of over car and the temperatures inside the car. Vehicles are allowed to burn to quench the fire.

The aim of the experiments of cars fire is to obtain a curve of heat release. For this purpose is used source of ignition in heptane tray with very high output power about 160 kW to ensure self-sustaining fire and develop a fully developed fire in the car. The windows are open before the experiments starts, which also helps to achieve the objective. The cars were ignited by the cabin in first case and under the engine in two other cases. The study does not address any flammability of cars, nor the role of any phase of smoulder.

All combustible materials in cars are consumed, the peak levels of heat generation in the range 1,5-2,0 MW. The total heat released in the experiments is 3.0-3.9 GJ. Rate curves of heat release contain several rapidly rising peaks which after that are slowly decreased. This corresponds to the ignition and combustion of various parts of the car, confirmed by observations during the experiments. Figure 3 shows the curve of heat from first experiment where arrows show two different peaks corresponding to growing fire in the cabin and the ignition of gasoline from the entrance of the filling tube and the rear of the car. Arrow 1 shows the time for destroying the windshield and escalating fire in the cabin, Arrow 2 shows the time of ignition tube filling and rear of the vehicle.

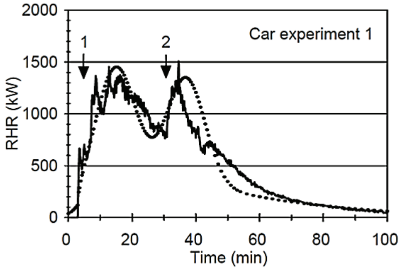

Fig. 3. Measured (with thick) and calculated (dashed) curves of heat in the fire experiment in car 1.

Car is encapsulated structure with openings where may occur flames. Temperatures measured within the car are increase to levels of post-detonation internal fire, or about 800°C. Gas temperature over the opening like front and rear windscreen reach 600^0-800°C. Except these peaks, the temperatures directly above the openings are in the range of 200^0-300°C. The gas temperature above the closed parts of the car like hood or roof rising to 200^0-400°C. Fire behaviour of the car can be described as local fire with fire various waves that come out of the openings [2].

Example for distribution of heat flow is given in [4,5].Fire is occurred on 03.12.2011. at 03.30 hours and the car is "Toyota." During the inspection is established the following: the left side of the car was with molten plastic of indicators, bumper covers of the front and rear wheel, front door and rear doors. The plastic of the rear side view mirror on the left side is also melted. It is molten also the left headlight and bumper underneath. There was a fumigation of paint on both left doors. The fire started around 03.30 hours in the adjacent car BMW 740. Both cars were located at a distance of 1,20 m apart {Figure 3) because of that there is melting paint and plastic on the left side of the car "Toyota". The whole left side of the car is affected.

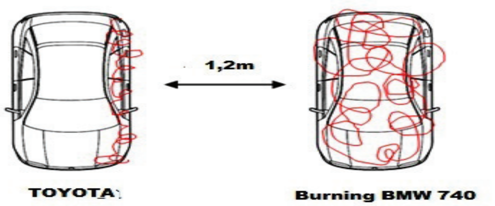

Fig. 3

The impact of the flame of burning BMW on "Toyota" was short-lived, and therefore damage on it is small and superficial. It can be concluded: the damage at car "Toyota" are caused by the fire in the car "BMW 740" spaced from each another about 1,20 m.

When we have flame burning of vehicles with flame exceeds 1m, the flame temperature is above 900^0 - 1000°C. The flashpoint of paints is about 250^0, rubber, 340°C, fiberglass 250^0C. Flue gas Temperature of flue gas at a distance of 1-2 m is between 2500^0 - 3000^0C. In the first case, the flame heated the combustible material and ignites the products of the destruction, in the second - the products of destruction must be heated at a higher temperature of self-ignition and then fire may occur. In this current case we have directly heated by radiant heat transfer to "PASAT" on vehicle. The temperature of the flame of the burning car is over 950^0C, with which each elements of standing near vehicle were burning for 1-2 min. Car is burning strongly at the rear part and that indicates that combustion has begun backwards. First paint, tires are ignited and finally the interior of the cabin. Burning in the cabin began after breaking the glazing. Engine compartment is ignited last. Combustion of light trucks was about 10-15 min.

RESULTS OF NUMERICAL INVESTIGATION

Numerical results are presented for the distribution of the density of radiation in their bodies not only of the burning one and also a heated one which falling on other bodies which transform heat (Figure 4)

Initial conditions under which decision was implemented:

Time is determinate from start of the fire to start burning standing near car - $n-2$ (windows), with size 1m, length -2m, distance between ground and window - 1m, r = 2m from the burning car K_f = 0.7;

Determine the size of the torch: $H_{fl} = h_{op.} \times K_t = 1 \times 07 = 0{,}70m$ length of the flame $L_{fl.} = L_{window.} = 1 \times 2 = 2m$. The position of the irradiated critical point will be lower than at the lower section of the flame: $x = -0.5m$

For case with radiation are selected sizes of irradiation of the first type modules (rectangles) with dimensions:

$$H = H_{пл.} + abs(X) = 0{,}70 + 0{,}5 = 0{,}35m; \quad L_{пл.}/2 = 1{,}6/2 = 1m \tag{15}$$

$$b = \max\{H \times L_{пл.}/2\} = 0{,}7m \tag{16}$$

$$a_1 = \min\{H \times L_{пл.}/2\} = 0{,}42m \tag{17}$$

$$b_1 / a_1 = 0{,}35; \quad r / a_1 = 1 \tag{18}$$

The second type modules (rectangles), with dimensions $H = abc(X) = 0{,}5m; \quad L_{пл}/2 = 0{,}5m$, in their capacity of greater magnitude, $b_1 = \max\{H \times L_{пл}/2\} = 1m$ and at lesser value $a_1 = \min\{H \times L_{пл.}/2\} = 0{,}5m$; $b_1 / a_1 = 2; \quad r / a_1 = 1$

Interstices values are define using interpolation values by applying the schedule [1], are receives 0,067 and ψ_2 = 0,011. For case with radiation the ratio of private ψ and public total $\psi\sum$, are determine with following equation:

$$\psi\sum = 2(\psi_1 - \psi_2) = 0{,}106$$

Degree of blackness of the torch flame - $\varepsilon_{изт}.0{,}98$; degree of blackness of material - $\varepsilon_м = 60$

$$C_{ПР} = C_O \cdot \varepsilon_{пр} = \frac{C_O}{\frac{1}{\varepsilon_{изт}} + \frac{1}{\varepsilon_м} - 1} = 153 \tag{19}$$

At $(T_м = T_{доп})$

$$q_{1-2} = C_o \varepsilon_{пр} \Psi_{1,2} \left(\left(\frac{T_U}{100} \right)^4 - \left(\frac{T_M}{100} \right)^4 \right) = 45{,}52 kW / m^2 \tag{20}$$

With interpolation determining the ignition interval [3] q_{1-2} falls within the range of ignition of 5 to 15 min. Ignition timing is calculated by, by linear interpolation:

$$q_{възп.} = 5 + (5-15) \cdot (7800 - 4552)/(7800 - 4650) \approx 15{,}37 \min \tag{21}$$

At distance 0,7 m and 26,66 kW/m^2, the time for initiation is 8 min

CONCLUSION

Main external source of ignition is appears radiant heat transfer which represents electromagnetetic wavelengths from 0.4 to 800 micrometres which are emitted from their bodies (not just burning, and also heated). Results which are obtained from the radiation heat transfer in car fires show that brief effect of radiant heat may cause ignition of adjacent neighbouring cars, the temperature field of the radiation from external sources of ignition showed the following: the density of heat flux of 25 kW /m^2, the individual elements of the vehicle starting to burn during the 1 -2 minutes.

The sequence of ignition of combustible materials in the car is the following:

- Outer layer of paint of exposed materials;
- Rubber seal on the glass;
- Inner layer of paint and door seals;
- The materials of the interior,
- Motor and luggage compartment.

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This paper has been reviewed.