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Particularities of flame propagation and ignition mechanisms

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Abstract

In this paper, starting from correlations and data for methane existing in literature, was established a correlation for thermal diffusivity coefficient and was calculated the diameter hydraulic equivalent for channel arrester, triangle type. The values calculated for the diameter hydraulic equivalent were compared with those found in literature, therefore was set up the optimum for this type of channel arrester.

Key word: *Pecle, deflagration, detonation, critical diameter, quenching velocity, thermal diffusivity, thermal conductivity, specific heat.*

Particularities of flame

The worldwide requirement of improved technical performances of industrial installation for burning imposed an accentuated development of studies flame dedicated. The numerous experiences, the studies and research materials related to burning processes are found today in books and fundamental books many of them already classic bibliography. Against these impressive amounts of publications presenting the scientific basics of the flame, this article intends to show the theoretical bases of particular issues of propagation of laminating, turbulent flame.

Should we think that burning include- in widest meaning of the word- any quick exothermic chemical reaction, in gas phase, running through radical chains, in neutral or electronic excitation (ions, electrons and photons too) then the flame is a burning reaction accompanied by light having as specific characteristics the self-propagation in a convenient environment.

This self-propagation characteristic of the flame makes the first distinction between the chemical reactions with flame and other reactions. A common chemical reaction is confined to the initiation place while the flame once started propagates until the depletion of the reacting system.

There are two types of "self propagation" one of the normal flame (common, deflagrating having a propagation speed comparable to the sound speed) and the detonator flame having a supersonic propagation speed. The normal flame propagates successively, by heat transfer and by diffusion of active centers (radicals and free atoms) while the detonator flame is a shock wave whose propagation is supported by the reaction chemical energy liberated at the high temperatures and pressures arising in this wave.

Another singularity of the flame is that talking about a burning chemical reaction between the two reactants, the combustible and the oxidant, the contact between these reactants is the first condition required such as the reaction takes place.

There are two possibilities:

- the contact between molecules of the two reactants takes place long time previously ignition such that the duration of the flame equals the duration of the burning reaction;

- to produce burning, the contact follows to take place, needing the real time τ_f to mix the reactants even if they are both gases.

Once initiated, a flame stops only after the reaction has depleted all combustible mixture. Sometimes the flame is not welcome; there are many situations when the flame arises accidentally in the gas transport installations, in technological installations incurring significant damages.

The flame appears under three conditions existing simultaneously:

- combustible gas presence;

- oxidant (air) presence;

- certain temperature (ignition sources, sparks).

The self-propagation characteristic of the flame requires utilization of the previously generated heat.

The flame may be stopped only in absence of one of the three factors above. The temperature is the only factor that supports a control. If during the flame propagation, the flame is decelerated and the heat is transferred to a metallic body, it is possible to draw out the temperature from the combustible mixture. This operation is possible by means of the technical procedure named flame lamination.

The heat is transferred from the hot body (flame) to the cold body by thermal convection and conductivity.

For the assessment of this heat transfer the specialized literature shows many dimensionless criteria used for the heat transmission [12].

The Peclet number is the dimensionless criteria used for the study of the possibilities to stop the flame (drawing out the heat from the flame). The definition of this criterion consists of the ratio between the heat flow transmitted by convection, conduction respectively at the same temperature Δt and defined by the expression [1,3,12]:

$$Pe = \mathrm{Re} \cdot \mathrm{Pr} = \frac{w_f \cdot d_{crt}}{a} \tag{1}$$

Where: P_e - is Peclet number for critical passages;

w_f - the speed of the laminating flame of the gas and air mixture, [m/s]

a - the thermal diffusivity of gas and air mixture, in [m^2/s][12];

$$a = \frac{\lambda}{\rho \cdot c_p}[m^2 / s] \tag{2}$$

λ - the thermal conductivity of gas and air mixture $\left[\frac{W}{m \cdot {}^o C}\right]$;

c_p - specific heat at constant pressure$\left[\dfrac{j}{kg \cdot {}^{o} C}\right]$;

ρ - density$\left[\dfrac{kg}{m^3}\right]$;

d_{crt} - the critical diameter of the canal.$[m]$.

The thermal transmission coefficient *a* defines the possibility of equalization in an uneven heated body.

The cause of flame extinction in the narrow channels, namely capillary is mainly thermal. The assessment of the extinction capability of the dry flame dry, mainly intended for discharge (not for communication) rely upon the invariability of the Peclet criteria (Pe) at the flame extinction limit (Pe =65)[1,11]

The diagram of the thermal diffuzivity depending of temperature, determined by means of the regression method for methane we obtained the following relation, use to determine the values of the extinction critical diameter:

$$a(t) = 0.0901 \cdot t^2 + 1.1702 \cdot t - 0.658 \tag{3}$$

Is used to determine the values of the extinction critical diameter.

Thermal transmissibility *a,* is a physical property of the material and arises in the transitory thermal; processes and defines the temperature variation with the time. As the general equation of the thermal conduction shows, the gradient of the temperature in time in a certain point of a body is proportional with a, the thermal transmission being in this case a measure of the thermal inertia of that body. The higher the temperature speed variation of a body, the higher thermal transmission is and the lower thermal inertia. The liquids and the gases have a low thermal transmissibility respectively a decreased thermal inertia

That means that due to the high thermal inertia of gases a short time heat transfer requires a decrease of the thermal inertia of the gas. The only possibility to reduce the thermal inertia is to decrease as much as possible the volume of the gas reducing the mass flow. Forcing the gas and the flame through narrow outlets until the heat from the reaction is less than the heat transferred to the cold body by convection and conduction enables reduction of gas volume. A value of extinction critical diameter will be determined for each gas, according to the physical characteristics. Onward we present a study for methane to determine the values of the critical diameter according to the physical properties.

Study of case

In order to make a comparative analysis as corect as possible of what has been previously stated, I have studied the parameters obtained by using methane as combustible gas, since it has the largest area of usage in installations and technological processes. In this respect, we used the calculus relations for the thermical conductivity coefficient λ_T, the density ρ_T, the specific heat at constant pressure c_p, and the thermical diffusion a for methane. The values of the critical quenching diameter were determined in accordance with the temperature and the propagation velocity of the flame by applying the relation(2):

$$d_{crt} = \frac{Pe \cdot a}{w}[m]. \tag{4}$$

The results are presented in table 1.

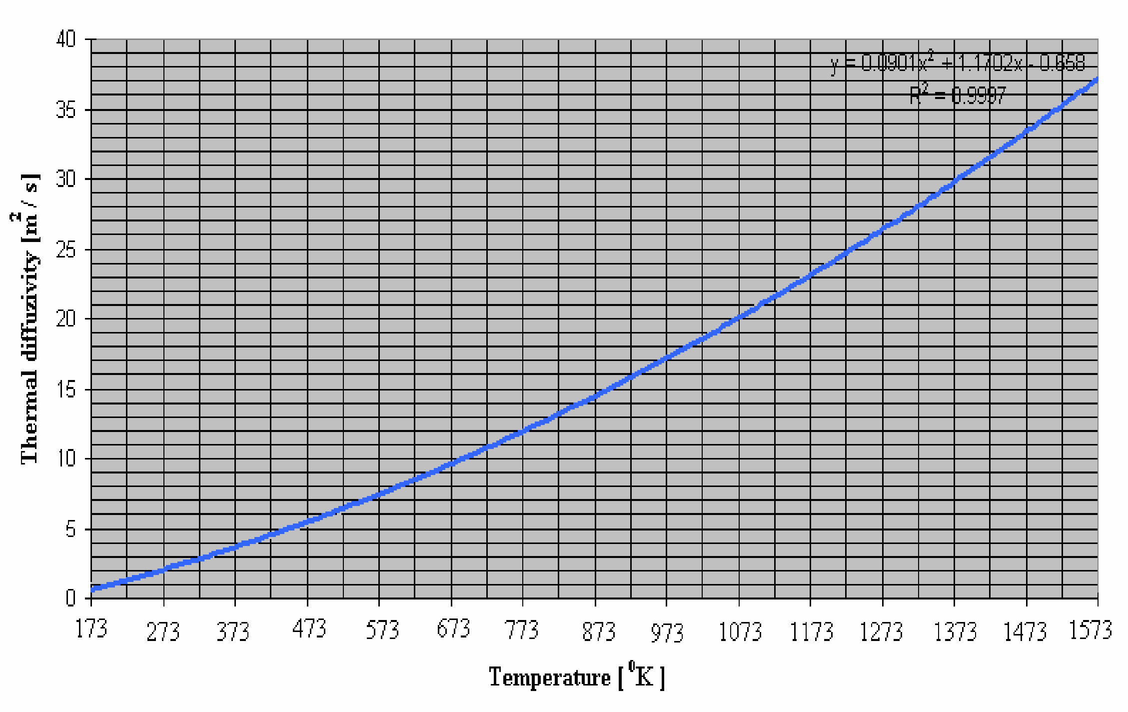

Fig.1. Diagram of variation the thermal diffuzivity

As compared to the results presented within the first part and obtained by Mendoza and his co-workers, a study has been made over the influence of the temperature and the propagation velocity of the flame on the values of the critical diameter for methane.

By analyzing the results presented in the table, one can draw the following conclusions:

- the value of the critical diameter decreases once the burning velocity increases. This phenomenon may be explained by the fact that a certain amount of time is needed in order to accomplish the heat transfer from the flame to the walls of the time. By diminishing the critical diameter, the time needed to maintain the flame in the channals increases, thus ensuring the heat transfer until the temperature drops under that of autoignition;

- at the same value of the burning velocity, the value of the critical diameter increases at the same time with the temperature. This observation can be explained by the fact that, once the heat that must be taken over by the metallic mass of the quenching channel during the same period of time, the surface needed to transfer the heat between the flame and the channel must be enlarged.

- at low temperatures, the gas density has a maximum value, and the critical quenching diameter has a minimum value at the same flame propagation velocity. This can be explained by the fact that there are more molecules that will burn and will produce a higher amount of heat at high density on the same length unit. In order to ensure the same ratio of 65 (the Pecle Number) between the flows of heat transmitted through convection, and through conduction respectively, at the same difference of temperature, the transfer surface, namely the critical quenching diameter, must be diminished.

Table 1. The analytical calculation of the critical quenching diameter in accordance with the temperature of the methane.

Weight[kg/kmol]	16
ρ_o[kg/m^3]	0.71
λ_o[j/m·s·^{0}grad]	3.06

Metan											
t [°C]	T [°K]	T_{calcul} [°K]	ρ_T [kg/m^3]	$\lambda_T \cdot 10^{-2}$ [j/kg·°K]^1	$c_p \cdot 10^3$ [j/kg·°K]^1	a · 10^{-5} [m^2/s]	The critical quenching diameter d_{crt} [mm] Flame propagation velocity w_f [m/s]				
							0.35	0.4	0.5	0.6	0.66
-50	223	0.744	0.88	2.42	2.08	1.31	2.44	2.14	1.71	1.42	1.29
0	273	0.911	0.72	3.05	2.18	1.93	3.60	3.15	2.52	2.10	1.91
20	300	1.000	0.65	3.30	2.23	2.24	4.18	3.65	2.92	2.44	2.21
227	500	1.667	0.39	5.90	2.59	5.75	10.69	9.35	7.48	6.23	5.67
327	600	2.001	0.32	7.16	2.76	7.84	14.57	12.75	10.20	8.50	7.73
427	700	2.334	0.28	8.41	2.93	10.14	18.84	16.48	13.19	10.99	9.99
527	800	2.667	0.24	9.67	3.10	12.62	23.44	20.51	16.41	13.67	12.43
627	900	3.001	0.21	10.92	3.25	15.26	28.36	24.81	19.85	16.54	15.04
727	1000	3.334	0.19	12.18	3.40	18.07	33.56	29.37	23.49	19.58	17.80
927	1200	4.001	0.16	14.69	3.69	24.12	44.81	39.21	31.37	26.14	23.76
1227	1500	5.001	0.13	18.46	4.08	34.28	63.67	55.72	44.57	37.14	33.77

The value of the critical diameter is a limit value. Normally, the flame should not propagate through the channel under this value. The analysis of the data presented in Table 1 shows that a channel can no longer stop the flame if at the same temperature for the same type of combustible misture there are conditions for the flame to accelerate because the value of the critical quenching diameter decreases at the same time with an increase in velocity. Highlighting these particularities regarding the flame propagation through channels enables taking technical measures on the technological development of the critical diameter.

Since the flame represents a characteristic of each combustible mixture, its propagation through oriffices is of major importance. Its importance is revealed by practice, especially for those devices operating in explosive environments which must be inserted in protective boxes and which must not have oriffices smaller than a certain value. The characterization of these oriffices is made by the means of the Maximum Experimental Safety Gap - MESG, which represents the dimension under which the flame no longer passes through the oriffice. The experimental determinations have established the value MESG of 1.12 mm for methane, three times smaller than the value of the critical diameter for methane d_{crt}=3.15mm[3]. Taking into account the observations presented above, one may reach the conclusion that, in order to characterize the means of propagating the flame, the real parameter that analyzes the possibility to stop the flame is not the critical diameter, but the MESG of the combustible mixture. This observation is based on the results of the study presented in Table 1. The conclusions show that this parameter d_{crt} is a variable that varies depending on the flame velocity and the temperature, so it depends on the conditions of the development of the process. Since MESG is a variable which depends on the chemical explosive properties of the combustible substance, it has great stability. As a result of the study over the possibility to stop the flames by the channels within the wavy band, we have organized the obtained data in Table 2. For the non-circular channels, the critical diameter is replaced by the hydraulic diameter equivalent d_{ech},, calculated with the relation[12]:

$$d_{ech}=\frac{4\cdot S}{P} \tag{5}$$

where: S – the surface of the channel crossed by the flame [m^2];
P – the perimeter covered by the flame [m].

For the non-circular channels having their section shaped as an isosceles triangle, the hydraulic equivalent diameter can also be calculated by using the relation (5). The results, calculated for diffrent values of module *m* , are presented in table 2.

Table 2. The determination of the hydraulic equivalent diameter depending on the module *m*

Dimensionless Parameters STAS 821-63							
$b_o=m\cdot(f_o+w_o)$		$r_o=(w_o\cdot m)/(1-\sin(\alpha_o))$			$f_o = 1$; $\alpha_o = 20^o$; $w_o = 0.25$		
$h_o=m\cdot(2\cdot f_o+w_o)$		$r_o=0.38\cdot m$			$\sin a_o = 0,342$		
m	$p_o=m\cdot\pi$ (mm)	b_o (mm)	h_o (mm)	r_o (mm)	aria (mm^2)	perimetru (mm)	d_{ech} (mm)
0.3	0.94	0.38	0.68	0.114	0.300	2.32	0.52
0.35	1.10	0.44	0.79	0.133	0.408	2.71	0.60
0.4	1.26	0.50	0.90	0.152	0.532	3.10	0.69
0.45	1.41	0.56	1.01	0.171	0.674	3.49	0.77
0.5	1.57	0.63	1.13	0.190	0.832	3.87	0.86
0.55	1.73	0.69	1.24	0.209	1.007	4.26	0.94
0.6	1.88	0.75	1.35	0.228	1.198	4.65	1.03
0.7	2.20	0.88	1.58	0.266	1.631	5.42	1.20
0.8	2.51	1.00	1.80	0.304	2.130	6.20	1.37
0.9	2.83	1.13	2.03	0.342	2.696	6.97	1.55
1	3.14	1.25	2.25	0.380	3.328	7.75	1.72
1.125	3.53	1.41	2.53	0.427	4.212	8.71	1.93
1.25	3.93	1.56	2.81	0.475	5.200	9.68	2.15
1.375	4.32	1.72	3.09	0.522	6.292	10.65	2.36
1.5	4.71	1.88	3.38	0.570	7.488	11.62	2.58
1.75	5.50	2.19	3.94	0.665	10.192	13.56	3.01
2	6.28	2.50	4.50	0.760	13.312	15.49	3.44
2.265	7.11	2.83	5.10	0.861	17.073	17.54	3.89
3	9.42	3.75	6.75	1.140	29.952	23.24	5.15

The data presented in the table show that the first value smaller than MESG = 1.12mm that can be technically accomplished for the quenching diameter is d_{ech}=1.03mm<1.12mm, and as compared to d_{crt} the first smaller value is d_{ech}=3.01<d_{crt}= 3.15mm. The big difference in value between the two parameters proves the importance of MESG as compared to $d_{crt.}$ In conclusion, since the critical diameter is a parameter that only depends on the physical properties of the combustible, it does not represent a solid criterion in analyzing the conditions of stopping the flame. Out of these reasons, one can state that, since MESG also characterizes the explosive properties of the gas and since it proves a certain stability under the conditions of the process development, it can also function as a parameter in analyzing the particularities in flame propagation.

Conclusion

- since the critical diameter is a parameter that only depends on the physical properties of the combustible, it does not represent a solid criterion in analyzing the conditions of stopping the flame; - out of these reasons, one can state that, since MESG also characterizes the explosive properties of the gas and since it proves a certain stability under the conditions of the process development, it can also function as a parameter in analyzing the particularities in flame propagation;
-the critical diameter is not useful to study the flame stop in combustible mixtures within industrial applications because the related flame accelerates reaching high speed and it is impossible to stop it for a ratio of heat transfer (convection and conduction) of 65.
- for any flame speed propagation will be used the equivalent hydraulic diameter compared to the safety experimental maximum admissible limit MESG.

References

1. Pavel, A., Paraschiv, M., Voicu, I., *Protecția antiexplozivă a instalațiilor tehnologice*. Ed. Tehnica. Bucureşti. 1993.
2. Vicente A. Mendoza P.E, Vadim G. Smolensky,. Chemical Engineering RP96-*3*. Arrest that flame May 1996
3. Mendoza V,A.V,G.Smolensky.*Chemical Engineering Progress*. Understand flame and explosion quenching speeds Philadelphia.May 1991
4. * * *, htpp:/www.nao.com/rp_93-77.htm
5. Langfurd. B. Palmer K. Fire Research Station. Borchain Wood.Hems. *UK* 1964
6. Palmer. K. *Symposion Chemical Process.* The Quenchings of Flames by Perforated Shecting.Ruchs.UK pp 51-57. 1961
7. Reid R.C, Pranznitr, Sherwood J.M, *The Properties og Gases and Liquid* pag. 544-601. New York 1977
8. Perry J. II, Chemical Engineers Handbook. Table 9-19 pag 9-32. New York 1983
9. http://www.enardo *Flame Arrestors Technology.* Tusla, OK 74145-4607
10. *** , *National Fire Protection*, Classification of Gases, Vapors and Dusts. Quinry Mast. 1991
11. Stanley, S. G. *Deflagration and Detonation Flame Arresters*.Center for Chemical Process Safety of the American Institute of Chemical Engineers. 3 Park Avenue New York, New York 10016-5991. 2002.
12. Carabogdan, I. G., Badea, A., Ionescu, L., Leca, A., Ghia, V., Nistor, I.,Cserveny, I., *Instalații termice industriale*. Ed. Tehnică, Bucureşti. 1978

Particularități ale propagării flăcării şi mecanisme de aprindere

Rezumat

În acest articol, pornind de la date şi relații existente în literatura de specialitate pentru metan, s-a stabilit o relație pentru calculul coeficientului de difuzibilitate termică şi s-a calculat diametrul hidraulic echivalent pentru canale de stingere de formă triunghiulară. Valorile calculate pentru diametrul hidraulic echivalent au fost comparate cu cele recomandate în literatura de specialitate, stabilindu-se valoarea optimă pentru acest tip de canale opritoare de flăcări.