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The calculation of the parameters of the crimped ribbon for Flame Arresters

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Abstract

The work puts forward solutions to establish the parameters of the reference rack which generates the gears which crimped ribbon . Presenting the calculation formula for the parameters of the trap grid offers the possibility to establish some functional characteristics for the grid of flame arrester such as: the equivalent hydraulic diameter, the length of the ribbons which make up the grid, the weight of the grid, the obstructing ratio of theflame arrester, the number of channels per area unit.

Key words: flame arrester, hydraulic diameter, critical diameter, the length of the crimped metal ribbon

General considerations

In order to execute quenching channels, there are used devices which crimped metal tapes (stamping) of aluminium or stainless steel, thus obtaining an involute profile (resembling the gear teeth). The diameter of the channels (ports) which are technologically achieved in production, by means of corrugating the metal tape, is not a circular diameter. The quenching channels, obtained as a result of winding the crimped metal ribbon together with a bar tape, have their section similar to that of an isosceles or equilateral triangle. In order to characterize these channels, there was introduced the notion of equivalent hydraulic diameter d_{ech} .

In order to obtain the flame trapping function, the area of these channels must have a certain value for the parameter called equivalent hydraulic diameter d_{ech} . This value, established out of purely technological reasons, must be less than or equal to the critical quenching diameter d_{crt} .

The value of the critical diameter is influenced by the chemical properties of the substance that is burning, being a function of the flame propagation, of thermal diffusivity of the substance that is burning, and is calculated with the relation:

$$d_{crt} \leq \frac{32.5 \cdot R \cdot T_c \cdot \lambda_c}{w_f \cdot c_{pc} \cdot p_c \cdot M_c} = \frac{270.216 \cdot T_c \cdot \lambda_c}{w_f \cdot c_{pc} \cdot p_c \cdot M_c} \left[m\right] \tag{1}$$

where: Re - Reynolds' criterion;

Pr - Prandtl' s criterion;

w_f - the normal speed of the flame $\left[\frac{m}{s}\right]$;

d_{crt} - the calculation diameter of the channels of flame arrester elements (grids) $[m]$;

c_{pc} - the mass caloric power at constant pressure of the given fuel mixture $\left[\frac{N}{m^2}\right]$;

T_c - the initial temperature of the inflammable mixture $[{}^oK]$;

λ_c - thermal conductivity of the inflammable mixture $\left[\frac{W}{m\cdot{}^o K}\right]$;

R - gas constant per mole $\left(R = 8314.34\frac{j}{mol\cdot{}^o K}\right)$;

M_c - gram-molecular weight of the gas inflammable mixture $\left[\frac{Kg}{mol}\right]$.

For non-circular flow channels or cross sections, the equivalent hydraulic diameter is established with the relation:

$$d_{ech} = \frac{4S}{P}[m], \tag{2}$$

where: S – is the flow cross section, [m^2];

P – the perimeter wetted by the fluid, [m].

In order to calculate the equivalent hydraulic diameter d_{ech}, it is necessary to establish the relations to determine the values of the perimeter wetted by the fluid and for the flow cross section.

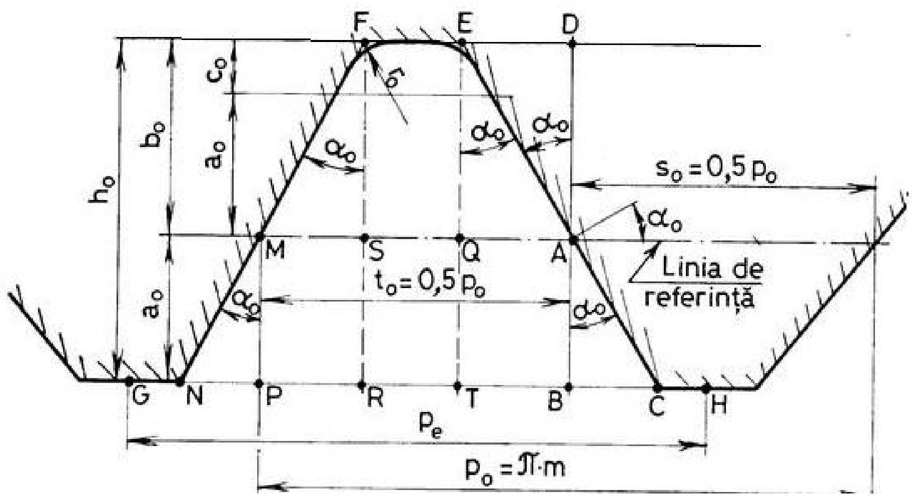

Fig 1. Geometric elements of the reference rack

The calculation of the perimeter wetted by the fluid

In order to establish the calculation relation of the wetted perimeter, we shall use the notations from Fig.1, where it is represented the geometry of the reference rack.

The dimensions characteristic to the reference profile are:

- the angle of the reference profile α_0;
- the reference pitch p_0;
- the height of the reference head a_0;
- the height of the reference foot b_0;
- the bottom reference backlash c_0;
- the height of the reference tooth h_0;
- junction radius r_0.

Out of the notations in the figure, we obtain:

- out of Δ ABC there results :

$$\cos(\alpha_o) = \frac{\overline{AB}}{\overline{AC}} \Rightarrow \overline{AC} = \frac{\overline{AB}}{\cos(\alpha_o)} \tag{3}$$

- out of Δ ADE there results:

$$\cos(\alpha_o) = \frac{\overline{AD}}{\overline{AE}} \Rightarrow \overline{AE} = \frac{\overline{AD}}{\cos(\alpha_o)} \tag{4}$$

where:

$$\overline{AD} = a_o + c_o = (f_o + w_o) \cdot m \tag{5}$$

$$\overline{AB} = a_o = f_o \cdot m \tag{6}$$

Introducing (6) in (3) there results:

$$\overline{AC} = \frac{f_o}{\cos\alpha_o} \cdot m \tag{7}$$

Introducing (4) in (3) there results:

$$\overline{AE} = \frac{f_o + w_o}{\cos\alpha_o} \cdot m \tag{8}$$

Adding (7) to (8) we obtain:

$$\overline{EC} = \overline{AE} + \overline{AC} = \frac{f_o + w_o}{\cos\alpha_o} \cdot m + \frac{f_o}{\cos\alpha_o} \cdot m = \frac{2 \cdot f_o + w_o}{\cos\alpha_o} \cdot m \tag{9}$$

Out of Δ ABC there results:

$$tg\alpha_o = \frac{\overline{BC}}{\overline{AB}} \Rightarrow \overline{BC} = \overline{AB} \cdot tg\alpha_o = a_o \cdot tg\alpha_o = f_o \cdot m \cdot tg\alpha_o \tag{10}$$

because: $$\overline{NP} = \overline{BC} = f_o \cdot m \cdot tg\alpha_o \tag{11}$$

and side $$\overline{NC} = \overline{NP} + \overline{PB} + \overline{BC} \tag{12}$$

Introducing (11) in (12) and taking into account that:

$$\overline{PB} = t_o = 0.5 \cdot p_o = 0.5 \cdot \pi \cdot m \tag{13}$$

we obtain: $$\overline{NC} = t_o + 2 \cdot f_o \cdot m \cdot tg\alpha_o = 0.5 \cdot \pi \cdot m + 2 \cdot f_o \cdot m \cdot tg\alpha_o \tag{14}$$

Out of Δ EQA there results:

$$\overline{QA} = b_o \cdot tg\alpha_o = (f_o + w_o) \cdot m \cdot tg\alpha_o \tag{15}$$

and: $$\overline{SQ} = \overline{EF} = t_o - 2 \cdot \overline{QA} = [0.5 \cdot \pi - 2 \cdot (f_o + w_o) \cdot tg\alpha_o] \cdot m \tag{16}$$

Out of the figure, there results that the perimeter P has the expression:

$$P = \overline{EC} + \overline{EF} + \overline{FN} + \overline{NC} \tag{17}$$

Taking into account that $\overline{EC} = \overline{FN}$ and introducing the relations (19), (14) and (16) in (17) we obtain:

$$P = \{2\frac{2f_o + w_o}{\cos\alpha_o} + \left[0.5\pi - 2(f_o + w_o) \cdot tg\alpha_o\right] \cdot +0.5\pi + 2 \cdot f_o \cdot tg\alpha_o\} \cdot m \tag{18}$$

Replacing in (18) the values for f_o, w_o, α_o, established in STAS 821-63, we obtain the relation to determine the perimeter wetted by the fluid:

$$P = 7.746 \cdot m \tag{19}$$

The calculation of the channel flow cross section

Out of fig.1.there results the area of the trapeze NCEF:

$$S = \left(\overline{NC} + \overline{EF}\right) \cdot \frac{h_o}{2} \tag{20}$$

because: $\overline{NC} = 2 \cdot \overline{NR} + \overline{SQ}$ and $\overline{EF} = \overline{SQ}$ the relation (20) becomes

$$S = \left(2 \cdot \overline{NR} + \overline{SQ} + \overline{SQ}\right) \cdot \frac{h_o}{2} = 2 \cdot \left(\overline{NR} + \overline{SQ}\right) \cdot \frac{h_o}{2} = \left(\overline{NR} + \overline{SQ}\right) \cdot h_o \tag{21}$$

Out of Δ NRF there results:

$$tg\alpha_o = \frac{\overline{NR}}{h_o} \Rightarrow \overline{NR} = h_o \cdot tg\alpha_o = \left(2 \cdot f_o + w_o\right) \cdot m \cdot tg\alpha_o \tag{22}$$

Introducing (16) and (22) in (21) we obtain

$$S = \{(2 \cdot f_o + w_o) \cdot m \cdot tg\alpha_o + [0.5 \cdot \pi - 2 \cdot (f_o + w_o) \cdot tg\alpha_o] \cdot m\} \cdot \left(2 \cdot f_o + w_o\right) \cdot m$$

or

$$S = \{ (2 \cdot f_o + w_o) \cdot tg\alpha_o + [0.5 \cdot \pi - 2 \cdot (f_o + w_o) \cdot tg\alpha_o]\} \cdot \left(2 \cdot f_o + w_o\right) \cdot m^2 \tag{23}$$

Replacing in (22) the values of the parameters $f_{o,} w_o, \alpha_o$ in STAS 821-63 we obtain the relation for the calculation of the channel flow cross section:

$$\mathbf{S = 3.328m^2} \tag{24}$$

The calculation of the equivalent hydraulic diameter

For non-circular flow channels or cross sections, the equivalent hydraulic diameter d_{ech} is established with the relation:

$$d_{ech} = \frac{4S}{P}[m] \tag{25}$$

Introducing (18) and (23) in (24) we obtain:

$$d_{ech} = \frac{4 \cdot 3.328 \cdot m^2}{7.746 \cdot m} = 1.718 \cdot m \tag{26}$$

The value of the hereby diameter must be less than the value of the critical diameter, being only a function of the m module which was used in generating the geometry of the drums used in corrugating the metal tape.

The calculation of the pitch at the peak of the toothing

Out of fig.1. , there results that the pitch at the peak of the toothing p_e is calculated with the relation:

$$p_e = \overline{GN} = 2 \cdot \overline{GN} + 2 \cdot \overline{NP} + t_o \tag{27}$$

Because: $2 \cdot \overline{GN} = \overline{EF} = \overline{SQ}$ (28)

and: $\overline{NP} = f_o \cdot m$ and $t_o = 0.5 \cdot \pi \cdot m$ (29)

Taking into account (15) and introducing (28) and (29) in (12) we obtain:

$$p_e = [0.5 \cdot \pi - 2 \cdot (f_o + w_o) \cdot tg\alpha_o + 2 \cdot f_o + 0.5 \cdot \pi] \cdot m \tag{30}$$

By adding up the similar terms, the relation (30) becomes:

$$p_e = [\pi - 2 \cdot (f_o + w_o) \cdot tg\alpha_o + 2 \cdot f_o] \cdot m \tag{31}$$

Introducing the standard values for f_o, w_o and α_o relation (31) becomes:

$$p_e = 4.23 \cdot m \tag{32}$$

With the notations for the characteristic dimensions of the reference profile, we establish:

- D_e - the peak diameter of the toothing calculated with the relation:

$$D_e = m \cdot (z + 2 \cdot f_o) \tag{33}$$

- D_d - the pitch diameter of the toothing calculated with the relation:

$$D_d = m \cdot z \tag{34}$$

- D_i - the minor diameter of the toothing calculated with the relation:

$$D_i = m \cdot [z - 2 \cdot (f_o + w_o)] \tag{35}$$

In table 1. there are established the parameters of the reference rack according to the equivalent hydraulic diameter d_{ech}. The equivalent diameter must be less than or at most equal to the critical quenching diameter d_{crt} established as per relation (1). As the module was set up in accordance with the equivalent diameter, there can be calculated the geometry of the drums used in corrugating the metal tape which make up the trap grid. The drums are generated with the help of the reference rack.

Table 1. Establishing the mode of the reference rack as per the equivalent diameter

Parameters		$b_o=m\cdot(f_o+w_o)$						
		$h_o=m\cdot(2\cdot f_o+w_o)$						
f_o	1	$r_o=(w_o\cdot m)/(1-\sin(\alpha_o)$						
w_o	0.25	$r_o=0.38\cdot m$						
α_o	20^o	$aria=\pi\cdot D_e\cdot h_o/z$						
sin α_o	0.342	MESG=2.25m						
m	$p_o=m\cdot\pi$ (mm)	b_o (mm)	h_o (mm)	r_o (mm)	z (tooth)	area (mm^2)	perimeter (mm)	d_{ech} (mm)
0.18	0.57	0.23	0.41	0.068	32	0.431	1.39	0.31
0.2	0.63	0.25	0.45	0.076	33	0.532	1.55	0.34
0.22	0.69	0.28	0.50	0.084	34	0.644	1.70	0.38
0.25	0.79	0.31	0.56	0.095	35	0.832	1.94	0.43
0.28	0.88	0.35	0.63	0.106	36	1.044	2.17	0.48
0.3	0.94	0.38	0.68	0.114	37	1.198	2.32	0.52
0.35	1.10	0.44	0.79	0.133	38	1.631	2.71	0.60
0.4	1.26	0.50	0.90	0.152	39	2.130	3.10	0.69
0.45	1.41	0.56	1.01	0.171	40	2.695	3.49	0.77
0.5	1.57	0.63	1.13	0.190	41	3.328	3.87	0.86
0.55	1.73	0.69	1.24	0.209	42	4.027	4.26	0.95
0.6	1.88	0.75	1.35	0.228	43	4.792	4.65	1.03
0.7	2.20	0.88	1.58	0.266	44	6.522	5.42	1.20
0.8	2.51	1.00	1.80	0.304	45	8.519	6.20	1.37
0.9	2.83	1.13	2.03	0.342	46	10.782	6.97	1.55
1	3.14	1.25	2.25	0.380	47	13.311	7.75	1.72
1.125	3.53	1.41	2.53	0.427	48	16.847	8.71	1.93
1.25	3.93	1.56	2.81	0.475	49	20.798	9.68	2.15

The calculation of the winding diameter

When calculating the length of the flat tape (bar) we shall use the notations in fig. 2.

For the winding of the tape sheet, there shall be used a bushing with the exterior diameter d on which there shall be wound the tape sheet made out of a bar tape and a corrugated one. Considering the thickness of the bar and corrugated tape as being equal to g and the corrugations of the height tape h, the diameters D_i after each winding shall be calculated with the expressions:

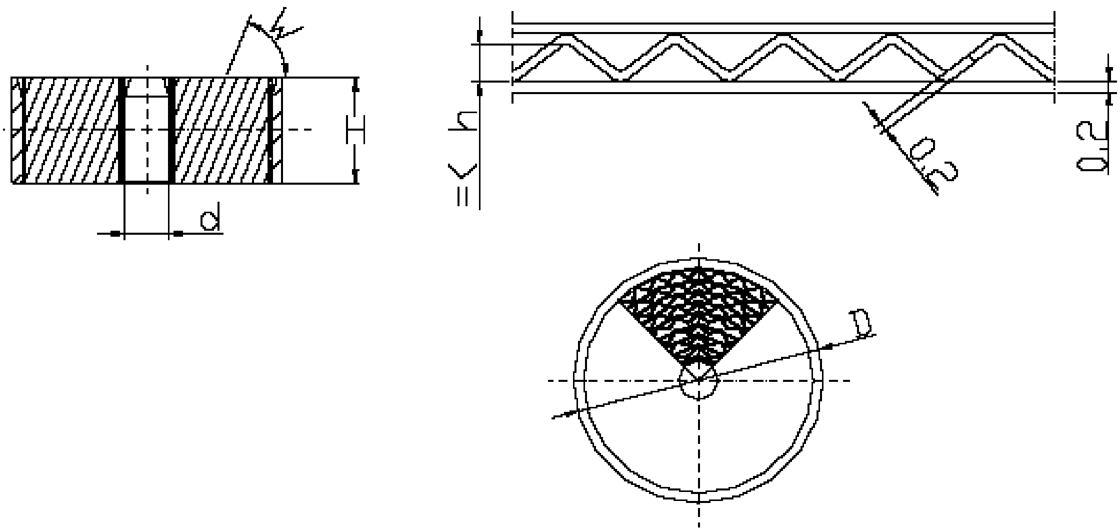

Fig. 2. Geometric elements of the crimped matal ribbon

$$D_1 = d + 2\cdot(h+g)$$
$$D_2 = D_1 + 2\cdot(h+g) = d \;\; + 2\cdot(h+g) + 2\cdot(h+g) = d + 2\cdot(2\cdot(h+g)$$
$$D_3 = D_2 + 2\cdot(h+g) = d \;\; + 2\cdot[2\cdot(h+g)] + 2\cdot(h+g) = d \;\; + 3\cdot[2\cdot(h+g)]$$
$$\vdots$$
$$D_i = d + i\cdot[2\cdot(h+g)] \tag{36}$$

Out of relation (36) there results the expression for the calculation of number i for the tape windings:

$$i = \frac{D_i - d}{2\cdot(h+g)} \tag{37}$$

The calculation of the winding length for the flat ribbon

In order to establish the calculation relation of the length of the metal tape which is wound on a bushing of *d* exterior diameter, using the notations in fig.2, there shall be written the relation for each winding, starting with winding 1 up to winding *i*. Firstly, there shall be established the relation for the length of the flat ribbon:

$$L_1 = \pi\cdot D_1 = \pi\cdot[d \;\; + 2\cdot(h+g)] = \pi\cdot d \;\; + \pi\cdot 1\cdot[2\cdot(h+g)]$$
$$L_2 = \pi\cdot D_2 = \pi\cdot\{d \;\; + 2\cdot[2\cdot(h+g)]\} = \pi\cdot d + \pi\cdot 2\cdot[2\cdot(h+g)]$$
$$L_3 = \pi\cdot D_3 = \pi\cdot\{d + 3\cdot[2\cdot(h+g)]\} = \pi\cdot d + \pi\cdot 3\cdot[2\cdot(h+g)]$$
$$\vdots$$
$$L_i = \pi\cdot D_i = \pi\cdot\{d \;\; + i\cdot[2\cdot(h+g)]\} = \pi\cdot d \;\; + \pi\cdot i\cdot[2\cdot(h+g)] \tag{38}$$

The total winding length L shall be calculated by summing up the interjacent windings, as per the relation:

$$L = \sum_i L_i = \sum_i \{\pi\cdot d \;\; + \pi\cdot i\cdot[2\cdot(h+g)]\} \tag{39}$$

Introducing relation (37) in relation (39) we obtain the relation for the length of the flat ribbon:

$$L = \pi \cdot \frac{D_i - d}{4 \cdot (h+g)} \cdot [D_i + d \;\; + 2 \cdot (h+g)] \tag{40}$$

The calculation of the length of the crimped ribbon

By means of the notations in fig.2. there shall be calculated the length of the crimped ribbon, noticing the fact that for a pitch to peak $p_e = 4.23 \cdot m$ given by the relation (32) there corresponds a developed length of the crimped ribbon l_{ond} equal to:

$$l_{ond} = 2 \cdot \overline{EC} \tag{41}$$

Introducing relation (8) in relation (41) we obtain:

$$l_{ond} = 2 \cdot \frac{2 \cdot f_o + w_o}{\cos \alpha_o} \cdot m \tag{42}$$

To the total length L of the flat ribbon there correspond $\frac{L}{p_e}$ pitches to the peak . If for a pitch to the peak there corresponds a length of crimped ribbon l_{ond} given by the relation (42), then for the $\frac{L}{p_e}$ pitches to the peak there corresponds a length of crimped ribbon:

$$L_{ond} = L \cdot \frac{l_{ond}}{p_e} \tag{43}$$

Introducing relations (32) and (42) in relation (43) we obtain:

$$L_{ond} = L \cdot \frac{2 \cdot \frac{2 \cdot f_o + w_o}{\cos \alpha_o} \cdot m}{4.23 \cdot m} = L \cdot \frac{2 \cdot \frac{2 \cdot f_o + w_o}{\cos \alpha_o} \cdot}{4.23} = 2 \cdot L \cdot \frac{2 \cdot f_o + w_o}{4.23 \cdot \cos \alpha_o} \tag{44}$$

Replacing in (44) the values stipulated in STAS 821-63 for f_o, w_o, α_o we obtain:

$$L_{ond} = 2 \cdot \frac{2 \cdot 1 + 0.25}{4.23 \cdot 0.9397} \cdot L = 1.131 \cdot L \tag{45}$$

The calculation of occupied area of the flat and crimped ribbon

The area occupied by the two ribbons S_{band} shall be calculated by multiplying the total length $L_t = L + L_{ond}$ with the thickness g of the tapes:

$$S_{band} = L_t \cdot g = (L + 1.131 \cdot L) \cdot g = 2.131 \cdot L \cdot g \tag{46}$$

The calculation of the gas flow section

For a diameter D_i of the roller of the trap grid, the efficient flow section S_{ef} of the gas is given by the difference between the area of diameter D_i and the area occupied by the two tapes S_{band} given by the relation (46):

$$S_{ef} = \frac{\pi \cdot D_i^2}{4} - 2.131 \cdot L \cdot g \tag{47}$$

where: L - is the length of the flat ribbon given by the relation (40); g - the thickness of the ribbon.

In table 2. it is presented the result of the calculation as a result of the implementation, in a program of table calculus, of the methodology to establish the geometric parameters which characterize the crimped ribbon used in executing the grid of dry flame arresters.

where:

d_o - the exterior diameter of the winding bushing;

d_i - the maximum winding diameter;

g - the thickness of the ribbon used in making up the trap grid;

l - the width of the trap grid;

h - the height of the wave of the tape.

Table 2. The calculation of the geometric parameters of the grid made out of corrugated tape

d_o(mm)	12
d_i(mm)	146
g(mm)	0.15
l(mm)	10

h	L_{bar}	L_{ond}	L_{total}	Area (mm^2)	Volume (mm^3)	Weight (g)	S_{tape}/S_{trap} coefficient	S_{tape}/S_{trap} %
0.69	19996.12	22615.61	42611.73	6391.76	63917.59	501.75	0.3820	38.20
0.75	18677.07	21123.76	39800.83	5970.13	59701.25	468.65	0.3568	35.68
0.8	17705.14	20024.51	37729.65	5659.45	56594.47	444.27	0.3382	33.82
0.85	16830.4	19035.18	35865.58	5379.84	53798.37	422.32	0.3215	32.15
0.88	16346.32	18487.69	34834.01	5225.10	52251.02	410.17	0.3123	31.23
1.13	13194.77	14923.29	28118.06	4217.71	42177.08	331.09	0.2521	25.21
1.25	12081.82	13664.54	25746.36	3861.95	38619.55	303.16	0.2308	23.08
1.41	10864.24	12287.45	23151.69	3472.75	34727.54	272.61	0.2075	20.75

The calculation of the number of channels in the composition of a grid

Knowing the flow cross section of a channel (24) and the effective flow section given by the relation (47) there can be calculated the number of channels per area unit n_c with the relation:

$$n_c = \frac{S_{ef}}{S} = \frac{\frac{\pi \cdot D_n^2}{4} - 2.131 \cdot L \cdot g}{\frac{\pi \cdot 1.71 \cdot m}{4}} \tag{48}$$

where: D_n - the nominal diameter of the grid case; L - the total length of the ribbon; g - the total thickness of the flat and of the crimped one; m - the mode of the reference rack.

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Calculul parametrilor grilei din bandă ondulată pentru opritorii de flăcări

Rezumat

Lucrarea prezintă soluții pentru determinarea parametrilor cremalierei de referință care generează angrenajele ce ondulează banda. Prezentarea formulelor de calcul pentru parametrii grilei opritoare, oferă posibilitatea determinării unor caracteristici funcționale pentru grila opritorilor de flăcări cum ar fi: diametrul hidraulic echivalent, lungimea benzilor ce alcătuiesc grila, greutatea grilei, raportul de opturare al opritorului, numărul de canale pe unitatea de suprafață.