Extinguishing system, fire protection, spraying, water mist system, jet stream, sprinkler, stream-whirl nozzle

Jerzy GAŁAJ[1]
Tomasz DRZYMAŁA [2]

ANALYSIS OF WATER DROPLETS SPECTRUM ON A PLANE IN SPRAY GENERATED BY MIST NOZZLES AND THE SPRINKLER FROM EXTINGUISHING EFFECTIVENESS POINT OF VIEW

The main purpose of this work is analysis of perimeter and radial distribution of droplets in the spray generated by two mist nozzles: stream-whirl and whirl designed in The Main School of Fire Service, and the typical sprinkler. The extinguishing effectiveness of the nozzle is mainly dependent on three parameters: spraying angle, average volumetric diameter of droplets and sprinkling intensity. Either radial functions or perimeter functions of average volume diameter of droplets and sprinkling intensity were obtained on the basis of the measurements of droplets spectrum in selected points positioned symmetrically on the horizontal plane. Using criteria defined by the authors obtained characteristics were compared from extinguishing effectiveness point of view, and the conclusions concerning applicability of the nozzles and sprinkler in fire protection area were formulated.

ANALIZA PORÓWNAWCZA PARAMETRÓW ROZPYLONYCH WYTWARZANYCH PRZEZ DYSZE MGŁOWE I TRYSKACZ Z PUNKTU WIDZENIA ICH SKUTECZNOŚCI GAŚNICZEJ

Celem pracy jest analiza porównawcza rozkładu promieniowo-obwodowego kropel w strumieniu rozpylonym wytwarzanym przez dwie zaprojektowane w SGSP dysze mgłowe: strumieniowo-wirową i wirową oraz typowy tryskacz pod kątem ich skuteczności gaśniczej. Jest ona zależna przede wszystkim od trzech parametrów: kąta rozpylenia, średniej średnicy objętościowej kropel oraz intensywności zraszania. Na podstawie pomiarów widma rozpylenia kropel w kilkudziesięciu równomiernie rozłożonych punktach na płaszczyźnie otrzymano zarówno promieniowe jak i obwodowe rozkłady średniej średnicy objętościowej kropel i intensywności zraszania. Posługując się przyjętymi kryteriami porównano własności mające wpływ na ich skuteczność gaśniczą i na tej podstawie sformułowano wnioski dotyczące przydatności zaprojektowanych dysz mgłowych i tryskacza w stałych urządzeniach gaśniczych.

[1] The Main School of Fire Service, Faculty of Fire Safety, POLAND, Warsaw 01-692, Slowackiego 52/54. Phone: +48 22 561-75-70, Fax: +48 22 407-40-62, E-mail: galaj@sgsp.edu.pl
[2] The Main School of Fire Service, Faculty of Fire Safety, POLAND, Warsaw 01-692, Slowackiego 52/54. Phone: +48 22 561-76-54, Fax: +48 22 561-76-54, E-mail: tomasz.drzymala@sgsp.edu.pl

1. INTRODUCTION

This work is the last of a series of the papers connected with the investigations of the sprays generated by self-constructed stream-whirl and whirl nozzles from extinguishing point of view [2,3,4,5,6,7,8]. The characteristics were compared with the ones obtained for typical bulb sprinkler produced in 2000, which catalogue number was 80LA and operating temperature was 79˚C [15]. Heat sensitive element was not mounted, what gave the possibility of immediate initialization of measurement procedure after switching on of water supply system. Nominal diameter of tested sprinkler was 15 mm and the size of thread was ½ inch. According to the standard, its capacity coefficient was 80±4 $dm^3 \cdot min^{-1} \cdot bar^{-1/2}$, what coincided with the values obtained during experiment (K=79 $dm^3 \cdot min^{-1} \cdot bar^{-1/2}$ at 0.4 MPa and K=82,73 $dm^3 \cdot min^{-1} \cdot bar^{-1/2}$ at 0.6 MPa) [15]. The bottom, top and side views of tested sprinkler are shown in fig. 1.

Fig. 1. Bottom, side and top views of sprinkler

It is well known, that mist streams consisting of the droplets which diameter is of the range 0.1÷1 mm, are very effective in fire extinguishing process [1,9,10,11,17]. Many investigations were conducted in USA and other countries to estimate appropriate diameter of the droplets which is the best from majority of fires suppression point of view [9,10,17]. This size should be small enough to ensure a larger evaporation surface, but simultaneously should be big enough to reach a flame zone before evaporation. A general conclusion is as follows: “This value depends on many factors, especially type of fire, should exceed 200 µm and be less than 600 µm”. The average value of droplet diameter equal to 350 µm, optimal for extinguishing process, was taken for the purpose of this work. Furthermore, the sprinkling intensity above 6 mm/min should be provided to extinguish small and medium fire effectively. The droplets spectrum and sprinkling intensity on the horizontal plane 180 cm away from nozzle axis was obtained to check, if designed stream-whirl sprinkler meets above criteria. The experiment was done using the special stand consisting of: water supply unit, pipes system, nozzle and measurement system. It was described in [6,12,13,14]. The results were presented in the form of graphs showing the perimeter and radial functions of average volume droplets diameter and sprinkling intensity. They were included separately for stream-whirl nozzle in [2,3,4,5,6,7] and for whirl nozzle in [6,8]. The several mathematical criteria like: homogeneity and distortion of sprinkling, index of closeness to optimal droplets diameter and others defined in [7] were assumed to evaluate extinguishing effectiveness of tested nozzles. The comparison of these parameters obtained for mist nozzles and the sprinkler enables to choose the most suitable equipment for application in fixed extinguishing systems.

2. RESULTS

2.1 Average volumetric droplets diameter

The values of average volumetric diameters of droplets D_v obtained for three types of sprayers (two nozzles and sprinkler) in measurement points located were included in tab. 1. Every cell of the table contain six values in two lines corresponding to different supply pressure: 0.4 MPa for upper line and 0.6 MPa for lower line. The values are separated by semicolon.

Tab. 1. The values of average volumetric diameter of droplets D_v in μm for sprinkler, whirl and stream-whirl nozzles (pressure 0.4 MPa – upper line, pressure 0.6 MPa – lower line)

β [deg]	**Radius r [cm]**				
	0	**20**	**40**	**60**	**80**
0	369;140;186 467;164;297	344;179;198 407;201;299	312;226;228 362;284;341	302;325;295 550;362;411	244;434;261 550;383;336
45	-	273;134;145 512;180;301	287;191;140 528;267;325	323;255;158 579;362;390	294;262;175 550;393;363
90	-	284;172;216 363;192;320	276;245;240 360;269;363	281;321;260 394;375;421	274;312;221 350;370;412
135	-	144;137;147 401;180;210	149;192;166 401;241;235	175;290;202 406;356;263	234;310;200 440;340;225
180	-	203;191;230 521;215;333	219;260;255 502;278;410	229;333;294 534;394;456	229;285;254 567;367;405
225	-	250;134;156 524;158;190	255;184;181 501;223;228	288;272;190 473;314;263	241;304;185 443;374;186
270	-	252;153;251 492;229;358	258;191;288 447;273;434	247;262;310 357;335;448	207;255;233 291;363;250
315		238;149;164 522;179;221	224;183;186 499;219;262	226;247;237 451;294;338	230;316;197 474;380;238

The graphs of perimeter $D_v=f(\beta)$ and radial $D_v=f(r)$ functions for r=20 cm and β=0˚C respectively, at 0.6 MPa as pressure supply, are shown in fig. 2 and 3.

Taking into account values included in tab. 1, average values of radial volumetric diameter of droplets were calculated based on the algorithm given in [7]. The resulting values for two different supply pressures are included in tab. 2. The graphs of functions $D_{va}(r)$for p=0.4 MPa and p=0.6 MPa are shown in fig. 4 and 5 respectively.

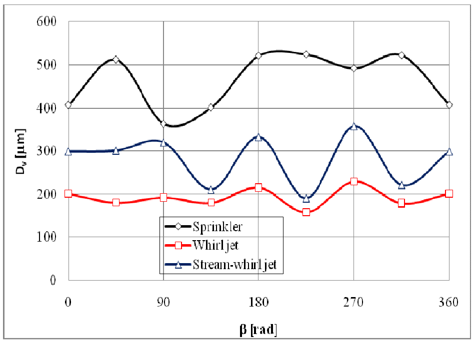

Fig. 2. Perimeter function $D_v(\beta)$ for r = 20 cm and p=0.6 MPa

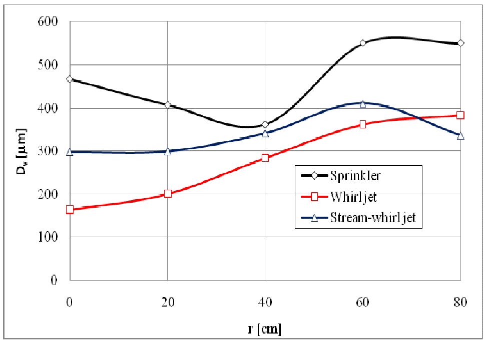

Fig. 3. Radial function $D_v(r)$ for β = 0°C and p=0.6 MPa

Tab. 2. The values of average radial volumetric diameter of droplets $D_{va}(r)$ in μm for two nozzles and sprinkler

Sprayer	Pressure [MPa]	Radius r [cm]				
		0	**20**	**40**	**60**	**80**
Sprinkler	0.4	369.2	249.0	247.9	259.5	244.5
	0.6	467.2	468.1	450.4	468.4	458.5
Whirl jet	0.4	140.4	156.4	209.6	288.4	310.3
	0.6	164.3	191.8	257.0	349.4	371.7
Stream-whirl jet	0.4	186.4	189.1	210.9	243.9	216.2
	0.6	297.3	279.3	325.1	374.2	302.4

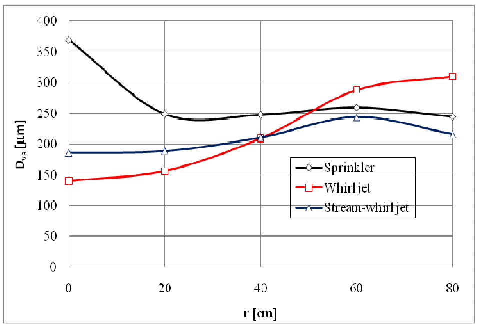

Fig. 4. Radial function $D_{va}(r)$ for p=0.4 MPa

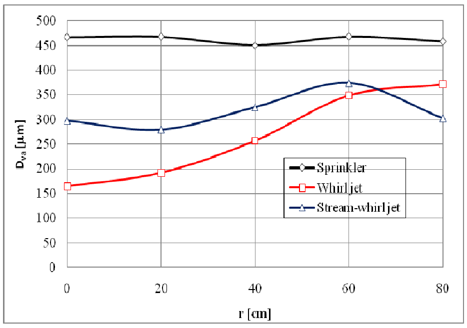

Fig. 5. Radial function $D_{va}(r)$for p=0.6 MPa

2.2 Sprinkling intensity

The values of sprinkling intensity *I* calculated on the basis of the algorithm given in [7] for three tested sprayers and two supply pressures p=0.4 MPa and 0.6 MPa are included in tab. 3.

Tab. 3. The values of sprinkling intensity I in mm/min for sprinkler, whirl and stream-whirl nozzles (pressure 0.4 MPa – upper line, pressure 0.6 MPa – lower line)

β [deg]	**Radius r [cm]**				
	0	**20**	**40**	**60**	**80**
0	2.89;0.13;0.92 4.27;0.39;4.39	2.89;0.45;1.28 6.22;0.75;4.79	2.45;0.93;1.66 5.05;2.76;7.14	2.31;2.97;2.75 9.1;5.56;10.47	1.26;3.94;1.29 12.63;2.78;3.16
45	-	2.79;0.17;0.19 7.34;0.51;4.89	2.97;0.48;0.16 7.62;2.18;4.82	4.27;0.99;0.22 9.53;4.84;8.26	3.29;0.63;0.18 9.00;2.13;4.31
90	-	2.63;0.37;1.75 3.85;0.62;6.07	2.67;1.14;1.89 3.85;2.13;5.11	3.07;2.33;2.03 5.82;6.13;8.88	3.29;1.13;0.92 4.53;1.64;3.51
135	-	0.88;0.19;0.34 5.17;0.48;1.64	0.99;0.57;0.44 5.59;1.50;2.12	1.29;1.85;0.63 6.58;4.98;2.67	2.57;1.17;0.44 8.73;0.97;1.02
180	-	1.66;0.36;1.75 8.78;0.76;2.26	1.94;1.14;1.99 6.19;2.22;6.18	2.17;2.09;2.74 12.34;6.41;3.41	1.94;0.69;1.35 17.14;1.18;2.62
225	-	2.75;0.17;0.34 9.67;0.14;1.10	3.38;0.48;0.48 7.73;0.89;1.53	5.51;0.99;0.51 6.36;3.01;2.34	3.46;0.63;0.28 5.50;1.64;0.62
270	-	2.88;0.14;2.50 9.54;1.03;7.18	3.37;0.37;3.21 7.51;1.92;12.96	3.18;0.97;3.36 3.8;3.82;10.34	2.04;0.44;1.21 2.25;1.86;1.23
315	-	2.18;0.20;0.50 6.19;0.31;2.20	1.94;0.41;0.70 6.51;0.74;3.21	2.01;0.94;1.21 5.41;2.28;4.79	2.28;1.47;0.47 10.13;2.64;1.07

The graphs of perimeter *I=f(β)* and radial *I=f(r)* functions for r=20 cm and β=0˚C respectively, at 0.6 MPa as pressure supply, are shown in fig. 6 and 7.

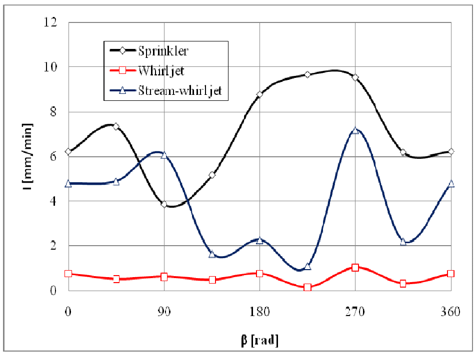

Fig. 6. Perimeter functions I=f(β) for three tested sprayers at p=0.6 MPa

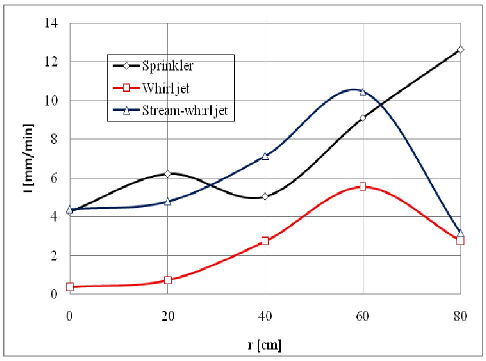

Fig. 7. Radial functions I=f(r) for three tested sprayers at p=0.6 MPa

Taking into account values included in tab. 3, average values of radial sprinkling intensity were calculated based on the algorithm given in [7]. The resulting values for two different supply pressures are included in tab. 4. The graphs of functions I_a for p=0.4 MPa and p=0.6 MPa are shown in fig. 8 and 9 respectively.

Tab. 4. The values of average radial sprinkling intensity I_a in mm/min for two nozzles and sprinkler

Sprayer	**Pressure [MPa]**	**Radius r [cm]**				
		0	**20**	**40**	**60**	**80**
Sprinkler	0.4	2.89	2.33	2.46	2.98	2.52
	0.6	4.27	7.09	6.26	7.37	8.74
Whirl jet	0.4	0.13	0.38	0.80	1.57	1.20
	0.6	0.39	0.57	1.79	4.63	1.86
Stream-whirl jet	0.4	0.92	1.08	1.32	1.68	0.76
	0.6	4.39	3.77	5.38	6.40	2.19

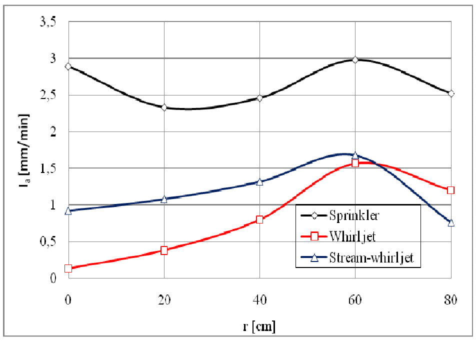

Fig. 8. Radial function I_a for p=0.4 MPa

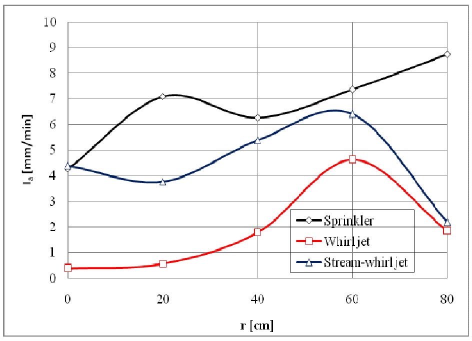

Fig. 9. Radial function I_a for p=0.6 MPa

2.3 Index of deviation from optimal droplet diameter

Index of deviation from optimal droplet diameter taken as 350 μm WSO is the parameter, which can be used for analysis of extinguishing effectiveness. It was defined in earlier works [7]. Generally it was assumed, that less value of WSO corresponds to better efficiency of extinguishing process. The values of radial function *WSO(r)* for three tested sprayers are given in tab. 5. The graphs of this function for p=0.4 MPa and 0.6 MPa are shown in fig. 10 and 11 respectively.

Tab. 5. The values of radial function WSO(r) in µm for two nozzles and the sprinkler

Sprayer	**Pressure [MPa]**	**Radius r [cm]**				
		0	**20**	**40**	**60**	**80**
Sprinkler	0.4	19.2	114.9	12.6	101.2	108.6
	0.6	117.2	121.7	118.7	140.5	142.9
Whirl jet	0.4	209.6	68.83	50.63	24.54	23.10
	0.6	185.7	56.42	33.93	10.87	9.30
Stream-whirl jet	0.4	163.6	58.5	51.9	41.8	48.5
	0.6	52.7	32.5	27.1	27.0	33.5

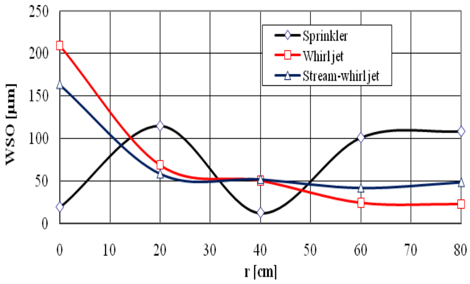

Fig. 10. Radial function WSO(r) for p=0.4 MPa

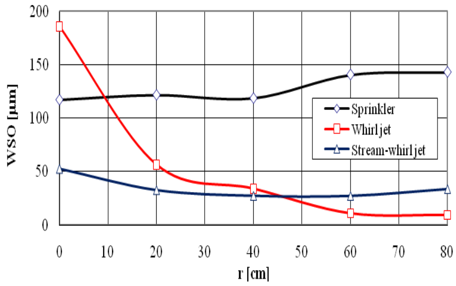

Fig. 11. Radial function WSO(r) for p=0.6 MPa

2.4 Index of sprinkling intensity distortion

Even distribution of droplets in the spray is important from extinguishing effectiveness point of view. This property can be characterized by index of sprinkling intensity distortion WNZ, which was earlier defined in [7]. Generally it was assumed, that less value of WNZ corresponds to better efficiency of extinguishing process. The values of radial function *WZN(r)* for three tested sprayers are given in tab. 7. The graphs of this function for p=0.4 MPa and 0.6 MPa are shown in fig. 12 and 13 respectively.

Tab. 7. The values of radial function WNZ(r) in mm/min for two nozzles and the sprinkler

Sprayer	**Pressure [MPa]**	**Radius r [cm]**				
		0	**20**	**40**	**60**	**80**
Sprinkler	0.4	0.31	1.27	0.77	1.33	0.73
	0.6	3.00	1.99	1.64	2.57	4.68
Whirl jet	0.4	0.81	0.69	0.39	1.01	1.11
	0.6	1.77	1.61	0.75	2.83	0.67
Stream-whirl jet	0.4	0.28	0.81	0.99	1.21	0.62
	0.6	0.04	2.21	3.52	3.78	2.59

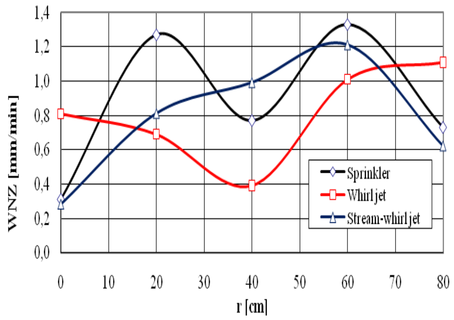

Fig. 12. Perimeter function WNZ(r) for p=0.4 MPa

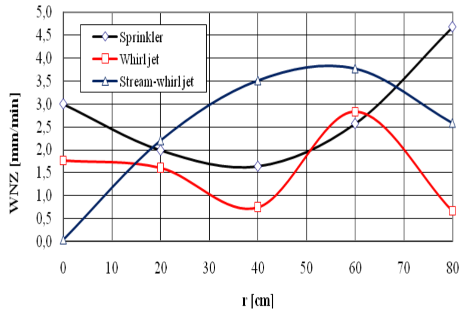

Fig. 13. Perimeter function WNZ(r) for p=0.6 MPa

2.4 Other parameters

There are also other parameters described in earlier papers [12,13,14], which can be generally characterized properties of the spray generated by the tested sprayers. Their values for all tested sprayers are given in tab. 8.

Tab. 8. The values of other spray parameters obtained for tested sprayers

Parameter	Unit	Type of sprayer		
		Stream-whirl jet	Whirl jet	Sprinkler
Mean value of volumetric droplets diameter	µm	315	267	462.5
Mean value of surface output	m^2/min	5034	4093	4397
Output	dm^3/min	69.3	41.7	158
Mean value of sprinkling intensity	mm/min	1.20	0.93	2.15
Mean value of WSO	µm	34.56	59.24	128.2
Mean value of WNZ	mm/min	2.43	1.53	2.8
Approximate angle of spraying	deg	70	90	140
Approximate surface of spraying	m^2	6	9	12

3. CONCLUSIONS

On the basis of the curves representing average sprinkling intensity I_a shown in fig. 8 and 9 can be concluded, that the values of I_a obtained at supply pressure p=0.4 MPa for all tested nozzles are significantly smaller than minimal assumed value of 6 mm/min. Hence only characteristics obtained at p=0.6 MPa were taken for further considerations.

Basing on the analysis of the spray parameters, the following general conclusions can be formulated:

1. The highest sprinkling surface and intensity for the sprinkler were obtained. The surface of approximately 12 m^2 was covered by the spray in this case, while it was only approximately 6 m^2 in the case of stream-whirl nozzle.

2. Considering average value of index WSO, the best result (WSO=34.56 μm) for the stream-whirl jet was obtained. A higher value (WSO=59.24 μm) for the whirl jet was calculated. In turn, WSO for the sprinkler was significantly the highest and equal to 128.2 μm.
3. The lowest value of index WNZ (the best from extinguishing effectiveness point of view), which determines distortion of sprinkling, for the whirl nozzle was obtained (WNZ=1.53 mm/min). These values for the stream-whirl nozzle (WNZ=2.43 mm/min) and the sprinkler (2.8 mm/min) were considerably higher.
4. The highest average value of sprinkling intensity was obtained for the sprinkler (I_a=6.75 mm/min), while the lowest for whirl jet (I_a=1.85 mm/min). The value of I_a for stream-whirl was equal to 4.43 mm/min. Taking into consideration initial condition $I_a \geq 6$ mm/min for effective internal fire suppression, we can conclude, that only the sprinkler meets this requirement. Other tested nozzles generate the sprays with too low sprinkling intensity.

Summarizing discussion on the tested sprayers, the general conclusion can be expressed in the following form: "Despite the lower values of indexes WNZ and WSO, which determine sprinkling quality, in the case of the mist nozzles, only the sprayer can be used in fixed extinguishing systems regarding suitable sprinkling surface and intensity. Only small or first-phase fires can be extinguished by either stream-whirl or whirl nozzles"

4. REFERENCES

[1] Bielecki, P.: *Podstawy taktyki gaszenia pożarów*, Kraków, SAPSP, 1996.

[2] Denczew, S., Gałaj, J., Kieliszek S., Drzymała T.: *Badanie wpływu zawirowania strumienia centralnego wybranej dyszy na parametry strumienia rozpylonego*. Gaz, Woda i Technika Sanitarna, vol. 5, Warszawa, 2006, s. 19-22.

[3] Gałaj, J., Drzymała, T.: *Investigation of the relation between central and whirl streams on extinguishing effectiveness of stream-whirl jet*. Proceedings of IX International Conference „TRANSCOMP 2006", Zakopane, 2006.

[4] Gałaj, J., Kieliszek S, Drzymała T.: *Badanie wpływu zawirowania strumienia centralnego wybranej dyszy na parametry strumienia rozpylonego*, Zeszyty Naukowe SGSP, vol. 35, Warszawa, 2007, s. 3-15.

[5] Gałaj, J., Drzymała, T.: *Investigation of the influence of degree of whirl stream on extinguishing effectiveness of stream-whirl jet.* Proceedings of XI International Conference „TRANSCOMP 2007", Zakopane, 2007.

[6] Gałaj, J., Drzymała, T.: *Analiza porównawcza strumieni rozpylonych generowanych przez strumieniowo-wirową i wirową dyszę mgłową z punktu widzenia ich skuteczności gaśniczej*. Proceedings of XII International Conference „TRANSCOMP 2008", Zakopane, 2008.

[7] Gałaj, J., Drzymała, T.: *Analysis of water droplets spectrum on a plane in spray generated by stream-whirl nozzle from extinguishing effectiveness point of view.* Proceedings of XIII International Conference „TRANSCOMP 2009", Zakopane, 2009.

[8] Drzymała, T., Gałaj, J.: *Analysis of water droplets spectrum on a plane in spray generated by whirl nozzle from extinguishing effectiveness point of view.* Proceedings of XIII International Conference „TRANSCOMP 2009", Zakopane, 2009

[9] Grant G., Drysdale D.: *The suppression and extinction of class 'A' fire using water*

sprays. FRDG 1;97.

[10]Grimwood P., Desmet K.: *Tactical Firefighting. A Comprehensive Guide to Compartment Firefighting & Fire Training. version 1.1*, Firetactics, Cemac, January 2003.

[11]Kaleta A.: *Wpływ rozdrobnienia strumienia wodnego na jego skuteczność gaśniczą*, BIT, Warszawa, 1985.

[12]KAMIKA Zakład Elektronicznej Aparatury Pomiarowej, *AWK System. Analiza wielkości cząstek,* KμK, Warszawa, 1999.

[13]Orzechowski Z., Prywer J.: *Wytwarzanie i zastosowanie rozpylonej cieczy*, WNT, Warszawa, 2008.

[14]Szkodziński M.: *Badanie płaskiego rozkładu promieniowo-obwodowego kropel w strumieniu rozpylonym generowanym przez dyszę strumieniowo-wirową*. Praca inżynierska, SGSP, Warszawa, 2009.

[15]Schab, S.: *Analiza porównawcza płaskiego rozkładu widma kropel w strumieniu wody rozpylonym przez wybrane rodzaje tryskaczy przy różnych ciśnieniach ich zasilania.* Praca inżynierska, SGSP, Warszawa, 2009.

[16]Stańczak, Ł.: *Badanie płaskiego rozkładu promieniowo-obwodowego kropel w trumieniu rozpylonym generowanym przez dyszę wirową*. Praca inżynierska, SGSP, Warszawa, 2009

[17]Tuomisaari M.: Suppression of Compartment Fires with a Small Amount of Water. VTT Finland, 1995.