

AD/A-001 187

**COMBUSTION OF GAS SUSPENSION OF METAL  
POWDERS AND EFFECT OF PARTICLE SIZE  
ON EXPLOSIBILITY PARAMETERS**

V. V. Nedin, et al

Foreign Technology Division  
Wright-Patterson Air Force Base, Ohio

13 November 1974

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UNCLASSIFIED  
Security Classification

AD/A-001187

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Foreign Technology Division Air Force Systems Command U. S. Air Force		20. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		25. GROUP	
3. REPORT TITLE COMBUSTION OF GAS SUSPENSION OF METAL POWDERS AND EFFECT OF PARTICLE SIZE ON EXPLOSIBILITY PARAMETERS			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Translation			
5. AUTHOR(S) (First name, middle initial, last name) V. V. Nedin, O. D. Neykov, et al			
6. REPORT DATE 1972	72. TOTAL NO. OF PAGES 13	70. NO. OF REFS 0	
80. CONTRACT OR GRANT NO.	82. ORIGINATOR'S REPORT NUMBER(S) FTD-HT-23-1873-74		
a. PROJECT NO.	83. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)		
c.			
d.			
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Foreign Technology Division Wright-Patterson AFB, Ohio	
13. ABSTRACT 21, 20			

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NATIONAL TECHNICAL  
INFORMATION SERVICE  
U S Department of Commerce  
Springfield VA 22151

## EDITED TRANSLATION

FTD-HT-23-1873-74

13 November 1974

CSP 73193384

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PARAMETERS

By: V. V. Nedin, O. D. Neykov, et al

English pages: 6

Source: Gorennye i Vzryv, Izd vo Nauka,  
Moscow, 1972, pp. 195-198

Country of Origin: USSR

Translated by: Marilyn Olachea

Requester: FTD/PDTN

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TRANSLATION DIVISION  
FOREIGN TECHNOLOGY DIVISION  
WP-AFB, OHIO.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	А а	A, a	Р р	Р р	R, r
Б б	Б б	B, b	С с	С с	S, s
В в	В в	V, v	Т т	Т т	T, t
Г г	Г г	G, g	У у	У у	U, u
Д д	Д д	D, d	Ф ф	Ф ф	F, f
Е е	Е е	Ye, ye; E, e*	Х х	Х х	Kh, kh
Ж ж	Ж ж	Zh, zh	Ц ц	Ц ц	Ts, ts
З з	З з	Z, z	Ч ч	Ч ч	Ch, ch
И и	И и	I, i	Ш ш	Ш ш	Sh, sh
Й я	Й я	Y, y	Щ щ	Щ щ	Shch, shch
К к	К к	K, k	Ъ ъ	Ъ ъ	"
Л л	Л л	L, l	Ы ы	Ы ы	Y, y
М м	М м	M, m	Ь ь	Ь ь	'
Н н	Н н	N, n	Э э	Э э	E, e
О о	О о	O, o	Ю ю	Ю ю	Yu, yu
П п	П п	P, p	Я я	Я я	Ya, ya

\* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ѣ in Russian, transliterate as yĕ or ě. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH  
 DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	sin <sup>-1</sup>
arc cos	cos <sup>-1</sup>
arc tg	tan <sup>-1</sup>
arc ctg	cot <sup>-1</sup>
arc sec	sec <sup>-1</sup>
arc cosec	csc <sup>-1</sup>
arc sh	sinh <sup>-1</sup>
arc ch	cosh <sup>-1</sup>
arc th	tanh <sup>-1</sup>
arc cth	coth <sup>-1</sup>
arc sch	sech <sup>-1</sup>
arc csch	csch <sup>-1</sup>
rot	curl
lg	log

### GREEK ALPHABET

Alpha	A	α	•	Nu	N	ν
Beta	B	β		Xi	Ξ	ξ
Gamma	Γ	γ		Omicron	Ο	ο
Delta	Δ	δ		Pi	Π	π
Epsilon	E	ε	•	Rho	Ρ	ρ ϑ
Zeta	Z	ζ		Sigma	Σ	σ ς
Eta	H	η		Tau	Τ	τ
Theta	Θ	θ	⚡	Upsilon	Υ	υ
Iota	I	ι		Phi	Φ	φ ϕ
Kappa	K	κ	κ	Chi	Χ	χ
Lambda	Λ	λ		Psi	Ψ	ψ
Mu	M	μ		Omega	Ω	ω

**COMBUSTION OF GAS SUSPENSION OF METAL  
POWDERS AND EFFECT OF PARTICLE SIZE  
ON EXPLOSIBILITY PARAMETERS**

V. V. Nedin, O. D. Neykov,  
A. G. Alekseyev, G. I. Vasil'yeva,  
and Ye. S. Kostina

The processes in which metal powders are obtained and used involves the formation of gas suspensions which ignite under certain conditions. This endangers human life and can result in considerable material loss. The original data used in developing the technology of explosion prevention in the production and use of powders are the main characteristics of ignitability and explosibility of the gas suspension.

In the Institute of the Problems of Material Science of the AS USSR methods have been developed and a complex of equipment created to study the ignitability and explosibility characteristics of dispersed metal powders.<sup>1</sup> These devices make it possible to obtain a gas suspension with a sufficiently uniform concentration and to monitor the concentration in time and space and register thermal explosion parameters. The minimal ignition

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<sup>1</sup>V. V. Nedrin et al. Explosion Prevention for Metal Powders. Kiev, "Naukova dumka", 1971.

temperature, explosion pressure, the rate of its increase, and the lower and upper concentration levels of explosibility, ( $lcl$  [ $г/л$ ] and  $ucl$  [ $г/л$ ]) are determined. The concentration limits are determined by establishing the moment of admission and the concentration of particles in the initiator zone of the gas suspension which accompanies it.

In the present work we examine the results of studies on the above characteristics for pyrophore and explosive powders of reduced iron and electrolytic titanium.

Table 1 shows the lower concentration level [ $lcl$ ], maximal pressure  $\Delta p$ , and the rate of increase in explosion pressure  $V_p$  of iron commodity powders of brand PZhM and fractions smaller than  $50 \mu m$  separated from them.

The study showed that maximal explosion pressure in a gas suspension of powders smaller than  $50 \mu m$  does not exceed  $2.5 \text{ kgf/cm}^2$ , while the maximal rate of increase in explosion pressure reaches  $30 \text{ kgf/cm}^2 \cdot s$ . For commodity powders explosion pressure and the rate of increase in explosion pressure do not exceed  $1.8 \text{ kgf/cm}^2$  and  $10 \text{ kgf/cm} \cdot s$ , respectively. In the range of concentrations close to the  $lcl$  we observe a significant scatter in explosion pressure. However, the obtained maximal values indicate that as the concentration is increased up to  $2-3 \text{ g/l}$  explosion pressure increases intensively, while further increasing the concentration results only in an insignificant increase in explosion pressure.

The explosibility characteristics depend on the concentration of iron, carbon, and oxygen in the powder. For example, for powders of brand PZhM of the Sulinskiy Metallurgical Plant with the same dispersion content and iron concentrations of 98 and 97.5% the  $lcl$  is 110 and  $287 \text{ g/m}^3$ , respectively.

The explosibility parameters of fractions with particles



Table 1

Powder	Composition, %										Particle content, wt. %						Explosibility parameters		
	Fe	C	S	P	Mn	Si	O <sub>2</sub>	0-20 μm	20-50 μm	50-100 μm	100-160 μm	160-210 μm	210-280 μm	280-350 μm	350-500 μm	g/l	kg/m <sup>3</sup>	V <sub>max</sub> m/sec	
Novosibirsk plant	98.1	0.09	0.02	0.01	0.33	0.1	1.0	0.3	12.5	36.2	27.9	17.3	1.8	4.0	0.875	0.1	1.0		
	PZhM																		
Novosibirsk plant	97.5	0.22	0.02	0.01	0.23	0.09	H	0	7.6	23.0	49	8.0	12.4	0.13	0.6	3.0			
	PZhM																		
Novosibirsk plant	97.5	0.22	0.03	0.01	0.23	0.09	H	0	0	0	0	0	0	100	0.066	1.7	18.0		
	PZh fin- er than 50 μm																		
Novosibirsk plant	97.5	0.11	0.01	0.01	0.40	0.25	1.5	0	1.6	23.2	25.4	12.6	11.8	25.4	0.287	1.3	13.2		
	PZhM																		
Novosibirsk plant	98.0	0.12	0.01	0.08	0.33	0.25	H	0	2.6	23.3	37.6	12.4	24.1	0.110	0.9	18.0			
	PZhM																		
Novosibirsk plant	97.5	0.12	0.01	0.01	0.40	0.25	1.7	0	0	0	0	0	0	100	0.114	2.3	16.5		
	PZh fin- er than 50 μm																		
Novosibirsk plant	98.1	0.07	0.02	0.03	0.30	0.19	1.0	0	0.6	17.6	32.8	12.8	11.3	24.9	0.35	1.45	13.0		
	PZhM																		
Novosibirsk plant	98.1	0.07	0.02	0.03	0.30	0.19	1.0	0	0	0	0	0	0	100	0.146	2.4	18.0		
	PZh fin- er than 50 μm																		
Novosibirsk plant	98.6	0.08	0.01	0.01	0.31	0.05	0.4	0	16.6	41.5	23.0	5.9	1.9	8.1	0.46	0.75	2.0		
	PZhM																		
Novosibirsk plant	97.1	0.05	0.02	0.02	0.30	0.16	1.5	3.6	0.6	24.9	27.5	9.3	5.4	28.7	0.20	1.8	10.0		
	PZhM																		
Novosibirsk plant	98.5	0.06	0.02	0.62	0.35	0.18	0.9	0	0	0	0	0	0	100	0.13	2.5	30.0		
	PZh fin- er than 50 μm																		

Note. N - not determined.  
 Abbreviation: кг/см<sup>2</sup>=kgf/cm<sup>2</sup>; смк=μm.

smaller than 40  $\mu\text{m}$  isolated from commodity PZhM brand powder of the Dnepr' Aluminum Plant, in which the concentration of oxygen varies from 0.2 to 2.1%, showed that when the concentration of oxygen is increased about 1.2% the activity of the powders is significantly reduced. Figure 1 describes the effect of the degree of oxidizability of the powders on the lcl n. As the result of studies on artificially oxidized powder it was established that powders containing 5% oxygen do not explode.

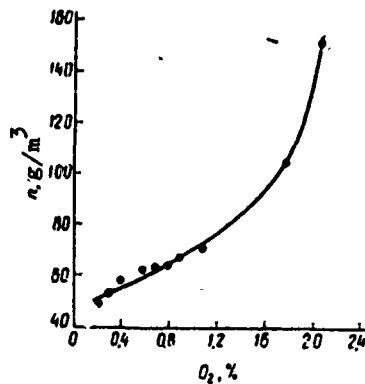


Figure 1. Effect of oxygen concentration in iron powders on lower concentration limits of explosibility.

The degree of dispersion of the powders has a substantial effect on the explosibility parameters: for a more active powder with particles of less than 50  $\mu\text{m}$  the lcl is 66  $\text{g}/\text{m}^3$ , while for PZhM powders of the Vrovarskiy Powder Metallurgical Plant, containing only 4% of fractions smaller than 50  $\mu\text{m}$ , the lcl is 875  $\text{g}/\text{m}^3$ , and still larger PZhS powders did not explode at all.

Powders of electrolytic titanium have a greater tendency to explode as compared to powders of reduced iron: they have lower lcl values and higher developed pressure levels.

The concentration of titanium in all studied powders was above 99%, oxygen - 0.4%. Polydispersed powders were studied (commodity powders smaller than 560  $\mu\text{m}$  and fractions smaller than 40  $\mu\text{m}$ ) along with various powder fractions obtained by sifting through a sieve with mesh openings up to 15  $\mu\text{m}$ .

The polydispersed powder had the following dispersion composition: 160-560  $\mu\text{m}$  - 3.85%; 100-160  $\mu\text{m}$  - 6.4%; 80-100  $\mu\text{m}$  - 2.36%; 71-80  $\mu\text{m}$  - 18%; 50-71  $\mu\text{m}$  - 36%; 40-50  $\mu\text{m}$  - 13%; 30-40  $\mu\text{m}$  - 19%; 15-30  $\mu\text{m}$  - 3.99%; smaller than 15  $\mu\text{m}$  - 1.4%.

Table 2 presents the results of a study on the effect of powder dispersion on the lcl and explosion pressure at different powder concentrations. As we see in the table, as the particle size changes from 7.5 to 53  $\mu\text{m}$  the lcl changes slightly, but rises rapidly with a further increase in particle diameter. Explosion pressure at different powder concentrations declines as particle diameter increases. Maximal explosion pressure is observed at concentrations of 1000-1200  $\text{g}/\text{m}^3$ .

Table 2

Powder fraction of titanium, $\mu\text{m}$	$d_{cp}$ , $\mu\text{m}$	lcl, $\text{g}/\text{m}^3$	Explosion pressure ( $\text{kgf}/\text{cm}^2$ ) for concentration, $\text{g}/\text{cm}^3$							
			100	200	400	600	800	1000	1200	
Polydispersed smaller than 40	63.5	64	1.0	1.5	2.5	3.2	3.5	3.75	3.75	
	29.4	40	1.5	2.3	3.0	3.5	3.75	3.9	3.9	
- 15	7.5	34	1.35	2.1	3.0	3.6	4.0	4.2	4.0	
+15- 30	22.5	36	1.35	2.0	2.8	3.5	3.8	3.9	3.8	
+30- 40	35.0	38	1.2	1.8	2.6	3.2	3.4	3.6	3.6	
+40- 50	45.0	49	1.15	1.7	2.4	2.75	3.2	3.4	3.6	
+50- 56	53.0	36	1.1	1.75	2.6	3.25	3.5	3.7	3.7	
+56- 63	59.5	56	1.1	1.7	2.6	3.25	3.4	3.5	3.5	
+56- 71	63.5	53	1.0	1.4	2.1	2.5	2.6	3.0	3.0	
+71- 80	75.5	80	0.5	1.2	1.8	2.5	2.7	3.2	3.5	
+80-100	90.0	90	0.3	0.9	1.7	2.2	2.6	2.9	3.2	
+100-160	130.0	194	0.0	0.2	0.3	0.5	1.2	1.5	1.8	
+160-250	205.0		Not exploded							
Polydispersed	63.5	20	1.0	1.5	2.5	3.4	3.5	3.75	3.8	

Figure 2 shows the maximal explosion temperature, rate of pressure increase, minimal ignition temperature<sup>1</sup> and lcl as a function of particle size.

Air suspensions with a fraction of 160-250  $\mu\text{m}$  were not exploded by a powerful ignitor of the pyrophore mixture. When particle

<sup>1</sup>A. P. Kuzub and A. F. Shapoval participated in determining minimal ignition temperature.

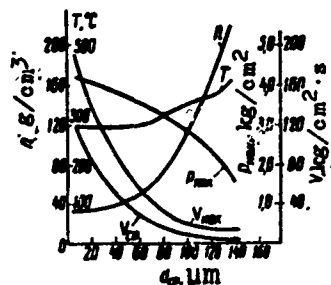


Figure 2. Effect of particle size of titanium powders on main explosibility characteristics.

size is reduced explosion pressure and the rate of pressure increase rise up to the smallest particles. The minimal ignition temperature, just as the lcl, remains practically constant for particles smaller than 50-60  $\mu\text{m}$ . For larger particles the ignition temperature and the lcl increase, respectively.

As particle diameter increases so does the explosion-proof concentration of oxygen in the inert medium. Thus, for particles with diameters of 7.5, 35, 53, and 63.5  $\mu\text{m}$  dispersed in gas the explosion-resistant concentration of oxygen in the argon is equal to 1.7, 1.8, 3.0, 4.1%, respectively.

The lcl of the explosibility of titanium is influenced by the initial concentration of oxygen in the powder. Increasing the concentration of oxygen from 0.12 to 0.194% increases the lcl of powder smaller than 71  $\mu\text{m}$  from 44 to 67  $\text{g}/\text{m}^3$ . Polydispersed powder ( $d_{cp} = 63.5 \mu\text{m}$ ) containing 0.1% oxygen had an lcl of 20  $\text{g}/\text{m}^3$ .