Density patterns of the inhomogeneous liquids in the industrial pipe-lines measured by means of radiometric scanning *

by Miss A. Michalik

Institute of Nuclear Techniques
Academy of Mining and Metallurgy, Krakow, Polland

Introduction

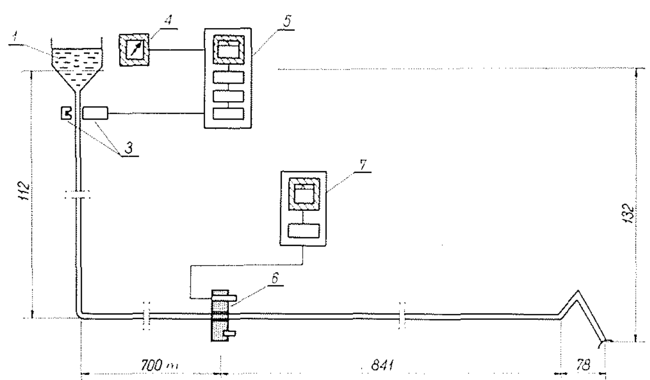
Radiometric methods were found to be most useful in measurements of the flow parameters of the unhomogeneous hydromixtures [1]. The radiometric method for determining a spatial distribution of concentration was developed a few years ago. This method is based on the recording of the changes in radiation intensity of the gamma-ray beam continuously penetrating a pipe-line cross-section [2]. The scanning device applied for this purpose is a special type of density meter which enables the determination of the density of the flowing medium at any point of its cross-section. The scanning head is applicable to the industrial pipe-lines of D_p = (200-220) mm.

This paper deals with a preliminary analysis of the results of measurements carried out at the "Sosnowiec" coal-mine stowing installation.

Experimental procedure

The hydrotransport installation at the "Sosnowiec" coal-mine is used to convey the stowing mixture, which consists of sand and water and is used to fill up worked-out cavities.

A simplified diagram of this installation is shown in Figure 1. From the in-flow filling funnel the stowing mixture flows along a vertical pipe-line (122 m length) and a horizontal pipe-line (1,620 m length) to the worked-out cavity. A radioistotope density meter placed just under the pipe-line inlet, enables a continuous measurement of the mean density of the flowing mixture [3]. The scanning device was placed on the horizontal pipe-line section at the distance of 700 m from the shaft. The flow of the measured mixture is enforced by the gravitation, which causes a regulation of the mean flow velocity impossible. The mean flow velocity was measured independently [4]. Its values varied in a range between 3.85 m/s and 4.25 m/s, depending on the actual mean density of the mixture. It was thus assumed on the basis of these measurements that $\bar{v}$ = 4.00 ± 10% m/s. The mixture under investigation consists of sand (γ=2.65 g/cm³) and water (γ=1.00 g/cm³). The granulometric composition of sand is shown in Figure 2. In the measurements the only changing parameter was the mean density of mixture continuously controlled



1/ Simplified scheme of industrial installation.
1: inlet of pipe-line; 3: measuring head of radioisotope gauge; 4 and 5: electronic assembly of the radioisotope densimeter; 6: head of radiometric scanning device; 7: electronic assembly of radiometric scanning device.

(*) The work was done within the framework of I.A.E.A. Research contract n° 1175/RB.

Article published by SHF and available at http://www.shf-lhb.org or http://dx.doi.org/10.1051/lhb/1973003

during the measurement in the range from 1.10 to 1.90 g/cm^3.

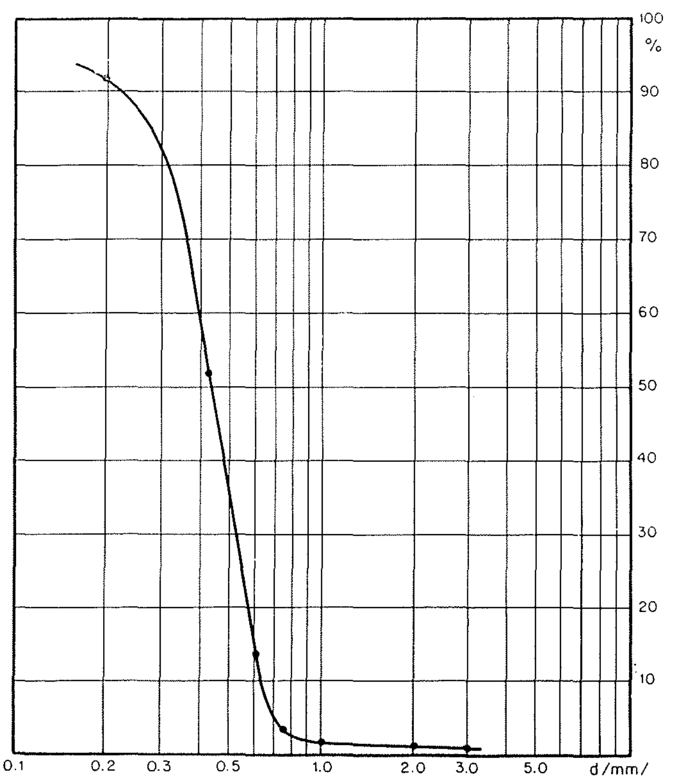
The duration of one measuring run is 3 mn. It is the time in which the flow conditions are sufficiently constant. In practice, it was possible to keep constant flow conditions for the period of several scanning runs. e.g. the spatial distribution of concentration was measured 30 times for density $\bar{\rho} = 1.3$ g/cm^3, 15 times for $\bar{\rho} = 1.5$ g/cm^3 and 4 times for $\bar{\rho} = 1.9$ g/cm^3.

Results of measurements

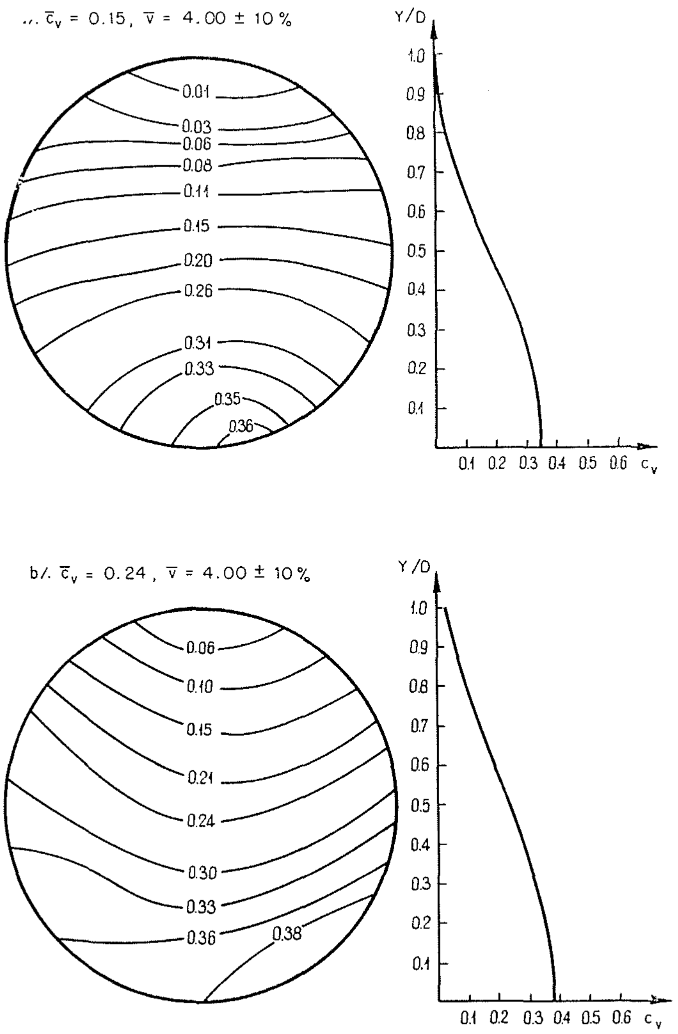
The direct results of the measurement are obtained as the records of gamma radiation intensity from the scanning of the mixture stream cross-section. About 100 records were obtained altogether for various mean sand concentrations. They enable the calculations of density diagrams on the basis of the theoretical approach presented in the paper [5]. The final results of the computer calculations have the form of maps of local density distributions in the mixture stream cross-section (an example: density diagram n° 1).

In Figures 3, 4, 5 and Figure 6 eight local concentration distributions of sand for some chosen mean densities were exemplified. They are the transformations of local density distributions obtained from computer calculations. Also a volumetric concentration profile along the vertical diameter of the cross-section was shown for each case. Such a profile can be described as follows:

$$c_v = f(\eta)$$



2/ Grain composition of applied sand.



3/ Distributions and profiles of volumetric concentration in researched cross-section of pipe:
a) for mean concentration $\bar{c}_v = 0{,}15$;
b) for mean concentration $\bar{c}_v = 0{,}24$.

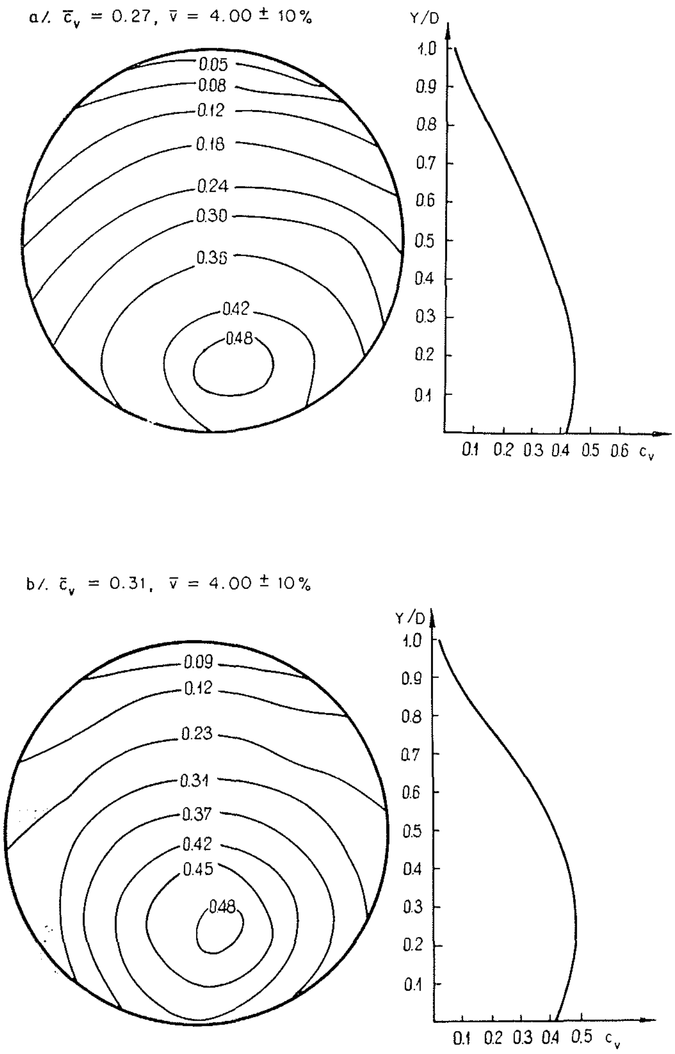
where:

$$c_v = \frac{\bar{\rho}_m - \rho_w}{\rho_s - \rho_w}, \quad \eta = y/D,$$

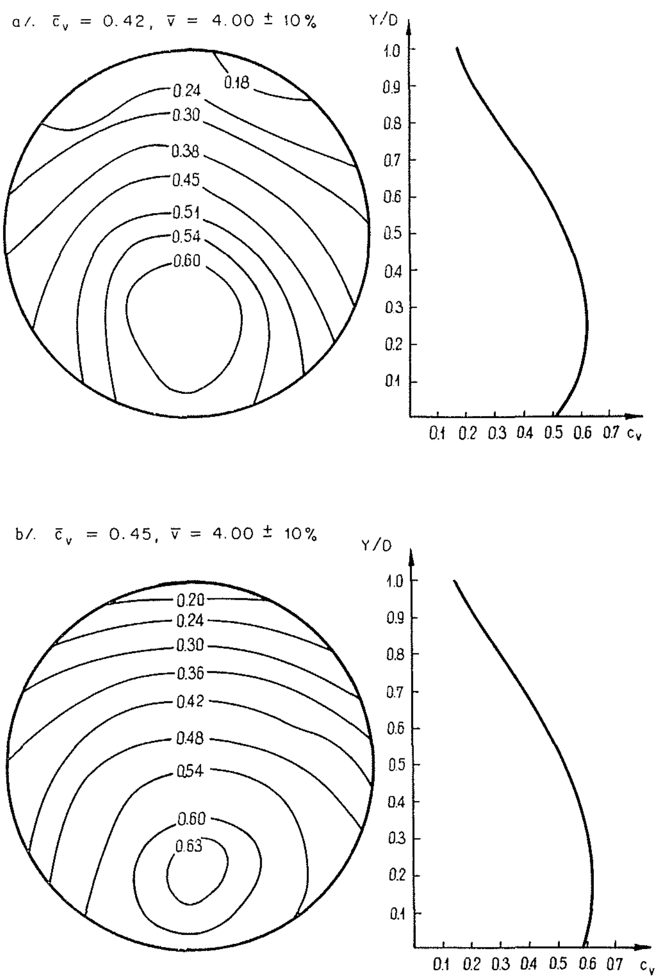
ρ_m is the mean, "in-line" density of mixture; ρ_s, ρ_w are the densities of sand and water respectively, y is the vertical distance from the bottom, D is the internal pipe diameter.

The obtained results are also interpreted by means of the relation $c_v/\bar{c}_v = f(\eta)$, where $\bar{c}_v$ is the mean volumetric concentration in the investigated cross-section. This form of presentation of the results is more precise than that: $c_v/c_{v0} = f(\eta)$, usually applied by many authors [6 and 7], where c_v is related to the chosen value of concentration c_{v0}, e.g. $c_{0.05}$. The above relation is presented in Figure 7 in form $c_v/\bar{c}_v$ versus η.

The accuracy of the measurements performed has been estimated at a level of the relative error equal to 5%. Independently, measurement results have been checked as far as their reliability is concerned by comparing concen-



4/ Distributions and profiles of volumetric concentration in the researched cross-section of pipe:
a) for mean concentration $\bar{c}_v = 0{,}27$;
b) for mean concentration $\bar{c}_v = 0{,}31$.



5/ Distributions and profiles of volumetric concentration in the researched cross-section of pipe:
a) for mean concentration $\bar{c}_v = 0{,}42$;
b) for mean concentration $\bar{c}_v = 0{,}45$.

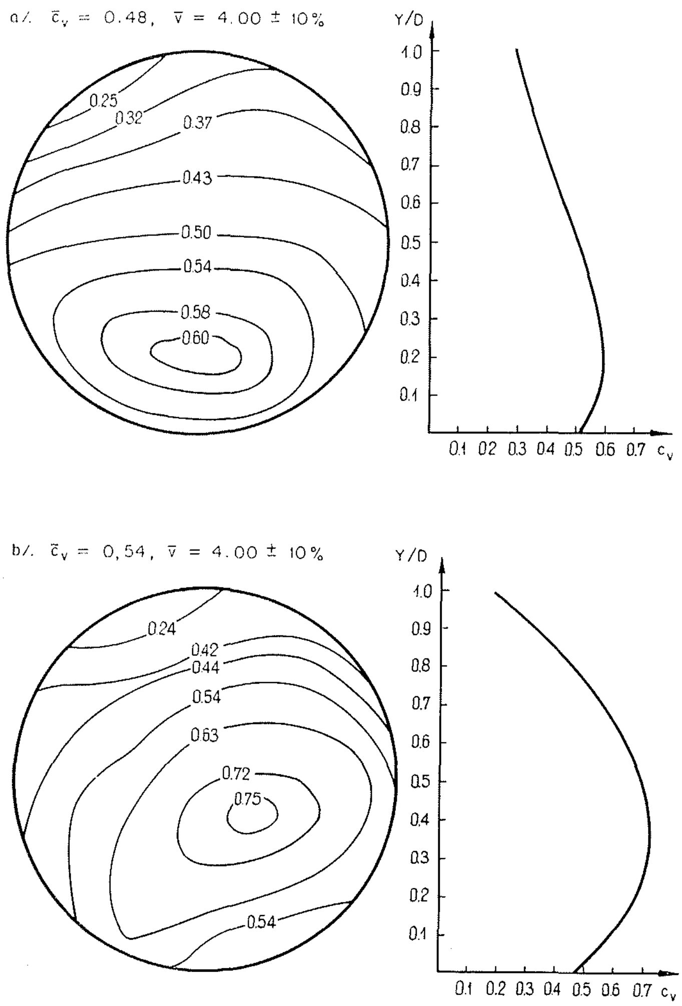
tration profiles obtained in the identical flow conditions. Figure 8 shows three concentration profiles obtained from six measurements of concentration distribution for mean density $\bar{\rho} = 1.30\ \mathrm{g/cm^3}$. The analysis proves that the error of the results of several distribution measurements does not exceed 5%.

Discussion

On the ground of the obtained concentration distributions an analysis was carried out. It was made to check well-known theories dealing with a concentration distribution [6]. First of all, Makkaveev diffusion theory [6] and Velikanov gravitational theory [7] were taken into consideration. These theories mainly apply to very low concentrations of solid phase, although there were some suggestions applying them to the concentration distributions for higher concentrations [8]. According to both theories the concentration profile should have an exponential character. On the ground of the carried-out investigations a high discrepancy between the theoretical and experimental curves have been observed. Even for the mean volumetric concentration $c_v = 0.06$ the concentration profile is not exponential one (Fig. 7).

Pechenkin's theory [8] seems to be much closer to the obtained results but in a small range of the mean concentrations from $c_v = 0.06$ to $c_v = 0.17$. While comparing the theories with the experimental data a certain apprcximation was adopted since in many cases it was impossible to find any data corresponding to the conditions of the measured flow. The concentration profiles presented in Figure 7 deal with the range of highly concentrated mixtures.

For $\bar{c}_v = 0.15$ and $\bar{c}_v = 0.19$ the profiles have a similar shape and are included in a local concentration interval from $c_v = 0$ to $c_v = 0.40$. Similar results in this concentration region were obtained by Ayukava [9]. However the present results are not in agreement with the results of



6/ Distributions and profiles of volumetric concentration in the researched cross-section of pipe:
a) for mean concentration $\bar{c}_v = 0{,}48$;
b) for mean concentration $\bar{c}_v = 0{,}54$.

Silin's research [10] dealing with high concentrations of solids phase. Starting from $\bar{c}_v = 0.25$ the profile shape changes towards a more homogeneous concentration distribution with a gradual shift of the concentration maximum towards the top.

In the case of concentration $\bar{c}_v = 0.25$ the concentration maximum is at the relative distance $\eta = 0.15$ from the bottom. At greater mean concentrations a further shift of the maximum is observed: for the concentration $\bar{c}_v = 0.48$ from the distance $\eta = 0.20$ to $\eta = 0.30$. For $\bar{c}_v = 0.54$ the greatest concentration occurs at the relative height $\eta = 0.30$ to $\eta = 0.45$.

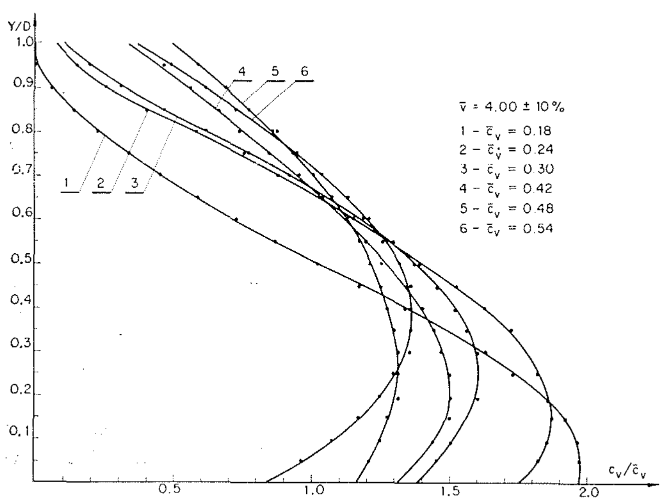
In this range of mean concentrations a distinct flattening of the distribution of solid phase concentrations is observed.

The presented measurements are only a preliminary part of much wider research programme, since they were carried-out in a very small velocity range.

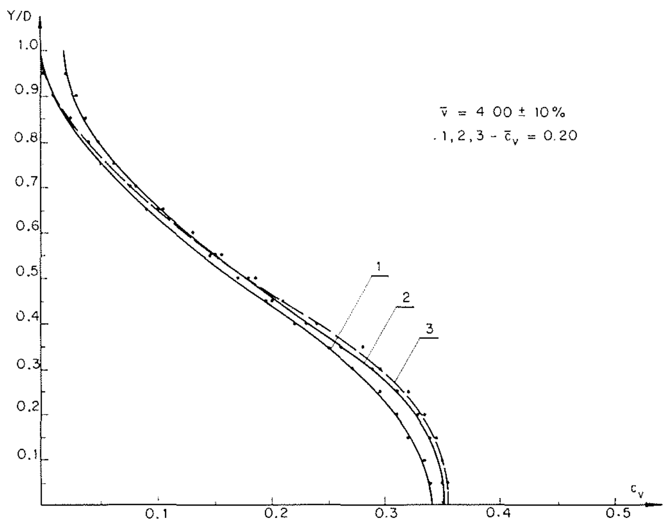
The developed programme includes measurements at several mean velocities in the superterminal velocity range for mixtures of various mean densities. Since it is impossible to regulate the flow in industrial installations, the research will be continued at the hydraulic laboratory.

Acknowledgements

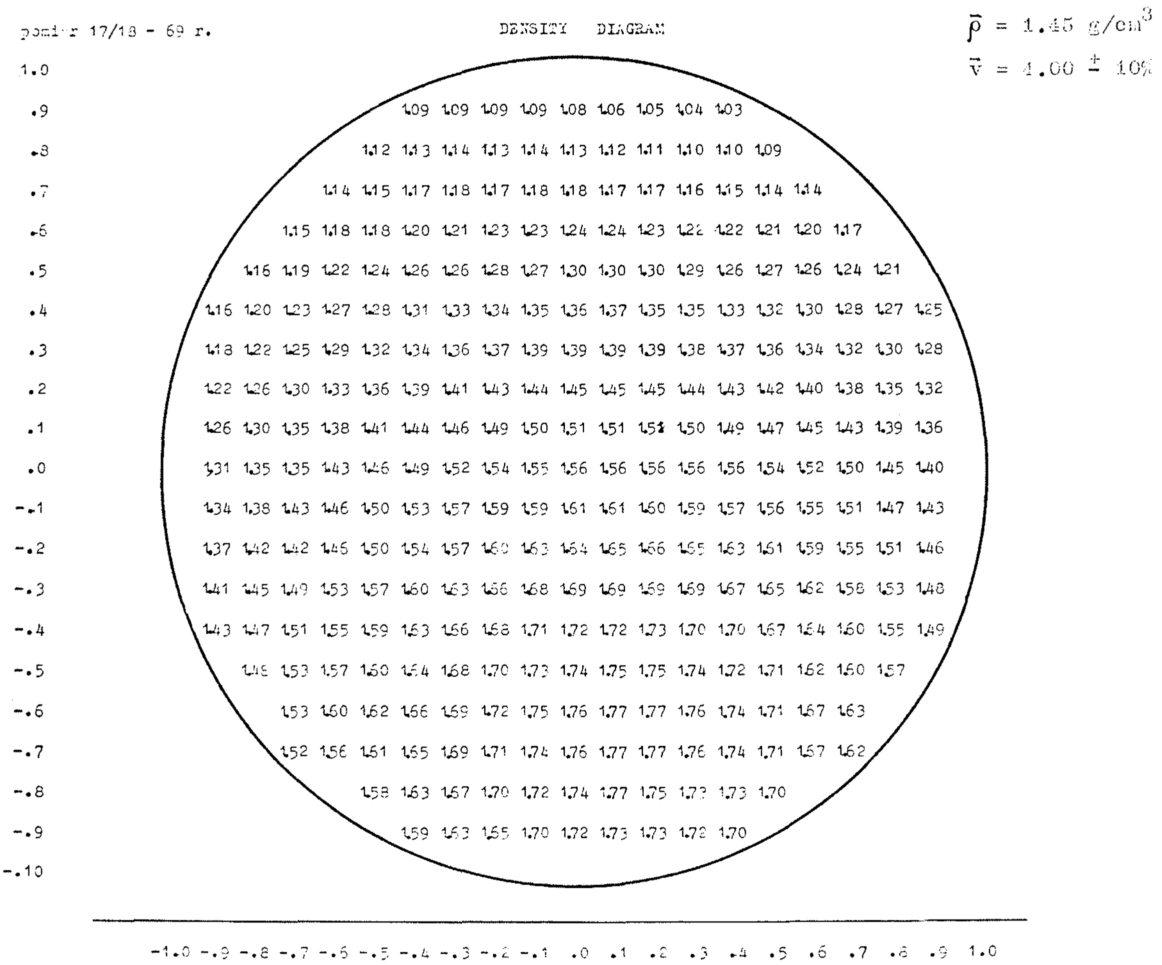
The author is greatly indepted to Mr. K. Korbel and Mr. K. Przewlocki for their valuable remarks and discussions during preparing this paper for publication. The participation of the scientific and technical staff of the Laboratory of Nuclear Instruments at the Institute of Nuclear Techniques in Cracow, and especially of Mr. L. Kalemba in perfoming the radiometric in-field measurements is also gratefully acknowledged.



7/ The family of curves $c_v/\bar{c}_v = f\,(Y/D)$:
1 : for $\bar{c}_v = 0{,}18$; 2 : for $\bar{c}_v = 0{,}24$; 3 : for $\bar{c}_v = 0{,}30$;
4 : for $\bar{c}_v = 0{,}42$; 5 : for $\bar{c}_v = 0{,}48$; 6 : for $\bar{c}_v = 0{,}54$.



8/ Three profiles of volumetric concentration $\bar{c}_v = 0{,}20$ (obtained in six measurement runs).



References

[1] PRZEWLOCKI (K). — Investigations of the fluidized solids by radiometric methods in colliery stowing pipe-line. Scientific Bulletins n° 119, *Academy of Mining and Metallurgy,* Cracow (1965).

[2] MICHALIK (A.), PRZEWLOCKI (K), PRAXMAYER (T.). — A Radiometric method of determination of the spatial distribution of density in closed media. *Nukleonika* I, Warsaw (1968).

[3] KORBEL (K). — The Applicability of the radiogauges for measuring the density of the flow solids-liquids mixtures. *Isotopenpraxis,* 6 Jahrgang, Heft 7 (1970).

[4] KORBEL (K.), KRASOWSKI (R.), MICHALIK (A.), NIZEGORODCEW (P.), PRZEWLOCKI (K). — Determination of some kinematic characteristics of flow of stowing slurry by means of radiometric measuring methods. *Nukleonika,* XV, n° 3 (1970), 291.

[5] KORBEL (K.), MICHALIK (A.), NIZEGORODCEW (P.), PRZEWLOCKI (K). — Final report for International Atomic Energy Agency, according to the Research Agreement 465/CF, Cracow (1970).

[6] MICHAJLOVA (N. A.). — Pierenos tviordych castic turbulentnymi potokami vody. *Gidrotiechn. Izdat,* Leningrad (1966).

[7] VELIKANOV (M. A.). — Dinamika ruslovych potokov. *Gosudarsty. Izdat. Tiechn. Tieoret. Litieratury,* Moscow (1954).

[8] PECHENKIN (M. V.). — Experimental studies of flow with high solid particle concentrations. *Proc. of the XIII Congr. I.A.H.R.,* 2 (1969), Japan, 157-164.

[9] AYUKAVA (K). — Velocity distribution and pressure drop of heterogeneousty suspended flow in hydraulic transport through a horizontal pipe. I Int. Conf. Hydr. Transp. in Pipes (1970), F3.

[10] SILIN (N. A.), PICHTCHENKO (I. A.), OCHERETKO (V. F.). — Eksperimentalnoje issliedovanije raspriedielenije osriedniennych skorostiej, konsistiencij i krupnosti castic po sjeceniju truboprovoda pri dvizeni dvuchkomponentnych potokov. *Izdatielstvo,* An. S.S.S.R., Kiev, 1964.