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Determination of critical and permissible moisture content in coarse-grained plumbous galena concentrates and coal samples

SUMMARY

In the paper applicability of different methods to determination of critical (FMP)and permissible (TML) moisture content in coarse-grained ore concentrates are discussed from the point of view of safe shipment in bulk of such cargoes.

Test results for three different coarse-grained materials, obtained with the use of four various methods, are presented.

INTRODUCTION

Ore concentrates and other similar fine-grained materials shipped by sea are mostly loaded in bulk without packing and considered as bulk cargoes.

Additionally ore concentrates belong to heavy cargoes due to their high specific weight. To ensure sea transport of the cargoes The Sub-committee on Containers and Solid Bulk Cargoes of International Maritime Organization (IMO) issued "Code of Safe Practice for Solid Bulk Cargoes" (CSP) in 1965 [1]. The next six editions of the code appeared during the years 1968-1991. In Poland the CSP Code was established as obligatory in 1974.

According to the CSP Code, deterioration or loss of ship's stability is one of three basic hazards which are bound with sea shippment of ore concentrates and other fine-grained cargoes. Too high humidity of cargo leading to its liquefaction may cause shift of the cargo and in consequence ship's heel and even its capsizing and sinking.

To better illustrate liquefaction mechanism three-phase structure of ore concentrates and similar materials is considered, which consists of:

- solids (mineral grains),
- water and
- air

Mineral grains are very small; they are from 0,001 mm to several milimetres large. Often as much as 90% of all particles are smaller than 0,05 mm. Disintegration level and percentage of particular size fractions may differ depending on concentrate type.

In the three-phase structure, shown in Fig.1, air and water fill the pores between mineral grains.

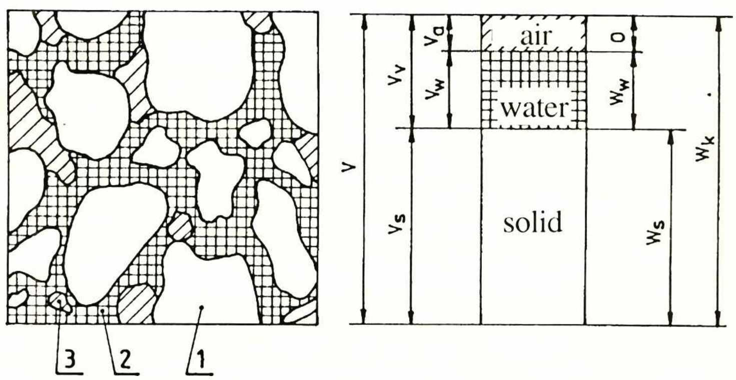

Fig. 1. Scheme of the concentrate three-phase structure and its characteristic magnitudes: 1 - mineral particles, 2 - water, 3 - air, V - concentrate volume, V_s - solid phase volume, V_v - pore volume, V_w - water volume, V_a - air volume, O - air weight, W_w - water weight, W_s - solid phase weight, W_k - concentrate total weight.

The inter-grain pores are contracted in sea transport conditions due to ship rolling and vibration. The air, permeability coefficient of which is about 500 times greater than that of water first escapes, thus full water saturation of the pores is effected.

Full compressive stress is thus applied to the incompressible water in the pores between mineral grains which causes drop of inter-grain friction, i.e. ore liquefaction and in consequence possible shift of cargo. Many cases are reported of large heel of a ship or even her sinkage due to cargo liquefaction. Such accidents happened yet in the 1970s.

Details of two accidents are described in IMO reports of 1978 [2]. The consequence of the first which happened in January 1975 was ship's sinkage and toll of 11 out of 13 crew members. The ship was loaded with coarse-grained anthracite. In the second case, which took place in 1977, a ship carried too humid zinc - lead concentrate. Liquefaction of it caused serious heel of the ship which was forced to call at the nearest port.

In 1986 Maritime Safety Committee (MSC) of IMO reported 107 serious ship accidents which happened in 1981-1984 [3]. 12 of the ships sunk. A number of the accidents were caused by cargo liquefaction.

Ship loss tragedy did not miss Polish ships. In 1956 motor ship STALOWA WOLA carrying zinc concentrates sank in the Bay of Biscay. Leakage to cargo holds occured in stormy weather and flooding water caused liquefaction of cargo which led to serious heel of the ship and to her capsizing 15 hours later. Another Polish ship, WROCŁAW II, sank in 1973 in the Mediterranean Sea when carried lead ore concentrates from Polish mining works in Chrzanów and Bukowno.

According to the sentence of the Polish Maritime Court [4] excessive cargo humidity which liquefied the cargo in heavy weather was the primary cause of the accident. The ship heeled on port by 10° and in spite of pumping ballast water from port side tanks the heel increased to 19°; in result of that the crew abandoned the ship which sank 25 min later.

The described facts have been incentive to many publications and research investigations on safe transport conditions of solid bulk cargoes [5]. The problem is still being thoroughly considered by the above mentioned special IMO Sub-committee (BC).

CRITICAL AND PERMISSIBLE MOISTURE CONTENT IN ORE CONCENTRATES AND SIMILAR CARGOES

Many methods can be found in the scientific literature dealing with determination of the moisture content which stimulates transition of fine-grained bulk cargo from solid into liquid state in sea trade conditions. The best known measure of that is Flow Moisture Point (FMP).

The FMP (called also "critical moisture") is such a moisture content in a fine-grained bulk cargo at which the cargo is able to transit from soft-plastic state into the liquid one. This is the basis of many methods for determination the Transportable Moisture Limit (TML).

The TML is such a moisture content at which a bulk cargo may be carried in bulk by a ship, not specially adapted to the purpose, without any risk of its transition into the liquid state. The following relationship between the two magnitudes holds:

$$TML = 0{,}9\ FMP.$$

Other measures for determination of the critical and permissible cargo moisture are also known.

METHODS FOR DETERMINATION OF CRITICAL AND PERMISSIBLE MOISTURE CONTENT IN FINE-GRAINED BULK CARGOES

Institute of Mathematics, Physics and Chemistry and recently Chemistry Chair of Merchant Marine Academy in Gdynia have been engaged since 1973 in research on the properties of solid bulk cargoes connected with their safe sea shipment, in particular, on evaluation of methods used for determination of critical and permissible content of moisture in ore concentrates, coal and other fine-grained cargoes. The Institute and recently the Chemistry Chair has participated in three international research projects under auspices of the IMO BC Sub-committee, namely:

❖ In 1977-1978 - in the project of evaluation of the then known methods of determination of critical and permissible moisture content, coordinated by Dr Kvalheim from Norges Geologiske Undersoekelse in Trondheim [6].

❖ In 1989-1990 - in the research: „ Program of International Cooperated Experiments" together with scientific centres of Australia, Norway, Great Britain and Japan, coordinated by Prof. Tamaki Ury from Industrial Sciences Institute, University of Tokyo [7].

❖ In 1991-1993 - in the research: „Second Program of International Cooperated Experiments" together with the same countries, coordinated by Prof. Tamaki Ury [8].

Results of these research works effected in the IMO-MSC decision to introduce into CSP Code the following methods recommended for critical moisture evaluation:

● Flow Table Method which has been already recommended since 1964 in the Code as a method for FMP evaluation [9]

● Japanese Penetrating Method recommended since 1993 (BC 32 session) for FMP evaluation

● Proctor c/Faberberg Method recommended also since 1993 for TML evaluation of some fine-grained bulk cargoes [9]

For coarse-grained plumbous galena concentrates and coal only the Japanese Penetrating Method is useful from among the three enumerated methods; but for investigation of ore concentrates - the Proctor c/Fagerberg Method.

Flow Table Method, in particular after introduction of recent modifications consisting in more precise estimation of sample consolidation energy, is very useful but only for very fine-grained ore concentrates of floatation type.

Flow Table Method limitations come from its measurement method which consists in forming a truncated cone from moist sample material and shocking it on a special device called the Flow Table. Such a cone can hardly be built from coarse-grained plumbous galena concentrates or coal, or it breaks down just under the first shock applied which makes any measurement impossible.

Japanese Penetrating Method

In principle, this is the only FMP determination method recommended by IMO for coarse-grained ore concentrates such as sedimentation galena, floatation concentrates and coal samples. Testing set consists of:

- a vibrator with vibration frequency and acceleration control, fitted with measuring gauges;
- a PVC container of 150 mm diameter, 200 mm height and 1700 cm^3 capacity;
- a depth indicator of penetrating bit, fixed at the upper edge of the container;
- a penetrating bit, weight of which differs depending on sample type;
- a rammer which enables to regulate applied pressure during sample consolidation.

A container used by the authors of this paper consisted of three parts: a base, a cylindrical vessel and a cover with opening of the same diameter as the cylinder. The measurement container was assembled of these parts and then bolted with 4 screws. This solution makes taking-out samples after testing very easy. This container was used without difficulties for different samples.

A sample is put into the container in four layers if it is an ore concentrate or in five layers if it is coal sample. Each layer is consolidated with the use of the rammer to reach 0,4 kg/cm^2 pressure. Ramming should be uniform all over the sample surface to make it completely flat. The minimum depth of the consolidated sample in the container is 100 mm for ore concentrates and 150 mm for coal samples. Penetrating bit pressure is to be 10 kPa for ore concentrates and 5 kPa for coal investigation. The container with the consolidated sample, depth indicator and penetrating bit, touching the sample surface, is fixed to the vibrator platform and subject to vibration at 55 Hz frequency and 2,8g maximum acceleration (2g effective acceleration) for 6 min.

The investigated sample with a given moisture content will liquefy if the penetrating bar immerses more than 50 mm deep at this moisture. Flow Moisture Point is such moisture content in a sample at which the penetrating bit reaches exactly 50 mm deep immersion.

The measurment is carried out in two stages. Preliminary measurements are made at first which enables to determine a relatively narrow band of moisture values containing FMP of the sample. Proper measurments are carried out applying distilled water addition of 0,4 to 0,5% of sample mass. FMP is calculated as the mean of the maximum moisture content somewhat less than FMP and the minimum moisture content just after liquefaction. The measurement results obtained with the use of the penetrating method are usually presented as a function of sample moisture content.

INVESTIGATION RESULTS

The investigations carried out by the Chemistry Chair in 1991-1993 within the Second Program of International Cooperated Experiments [8] concerned critical and permissible moisture content in coarse-grained plumbous galena concentrates from „Trzebionka" Mining Works in Trzebinia and coal samples taken in the Port of Gdańsk. Ore samples were taken in September 1992 and February 1993, but coal samples in 1989. The investigations were made using the Japanese Penetrating Method and the Proctor c/Fagerberg Method (however other methods were also used for comparison). Their results are collected in Tab. 1 and 2. Disintegration level and particle size distribution may differ depending on concentrate type.

Coarse-grained concentrates and 0-10 mm fine coal have greater percentage of larger particles than e.g. floatation galena. FMP investigation with the Flow Table Method is not possible to be done if fraction of particles ranging from 0,02 to 0,3 mm is not much greater than 10% [10]. The numbers are assumed as a criterion to conventionally distinguishing coarse-grained from fine-grained ore concentrates.

The grain analysis of ore concentrates and other fine-grained materials is carried out by their screening through an appropriate set of screens, in wet or dry condition. Fig. 2 to 4 illustrate grain composition of sedimentation galena, fine coal and, for comparison, floatation galena, where grain percentages are presented as ordinates in the uniform scale, but grain size (mm) as abscissae in the logarithmic scale.

Tab. 1. Critical and permissible moisture content (weight percentage in relation to wet concentrate) determined by several methods

No Concentrate type	Flow Table Method		Japanese Penetrating Method		Proctor c/Fagerberg Method		Canadian Method acc. to F.Guerra	
	FMP	TML	FMP	TML	TML	-	equivalent to 100%moist.	equivalent to 70% moist.
1. Sedimentation galena (taken in Sept.1992)	undeterminable	undeterminable	3.56	3.2	5.35	-	3.90	2.78
2. Sedimentation galena (taken in Feb.1993)	undeterminable	undeterminable	4.01	3.61	5.43	-	4.37	3.08
3. Coal sample (taken in Port of Gdańsk,1989)	undeterminable	undeterminable	16.09	14.18	15.58	-	-	-

Tab. 2. Investigation results for concentrates from the „Trzebionka" Mining Works, obtained by applying the Japanese Penetrating Method

No	Sample type	Measured FMP values [moisture weight %]		FMP mean value $\overline{X}_i$	FMP standard deviation [s]	FMP confidence interval $\overline{X}_i \pm 3s$
1.	Floatation galena (Feb.1993)	5,65 5,72 5,95 6,69	5,77 5,95 6,14 6,64	6,06	0,35	6,06 ± 1,05
2.	Sedimentation galena (Feb.1993)	3,97 4,20 4,20 3,66	4,10 3,70 3,99 4,24	4,01	0,22	4,01 ± 0,66
3.	Sedimentation galena (Sept.1992)	3,39 3,56 3,60 3,71	3,41 3,52 3,72 3,60	3,56	0,11	3,56 ± 0,33

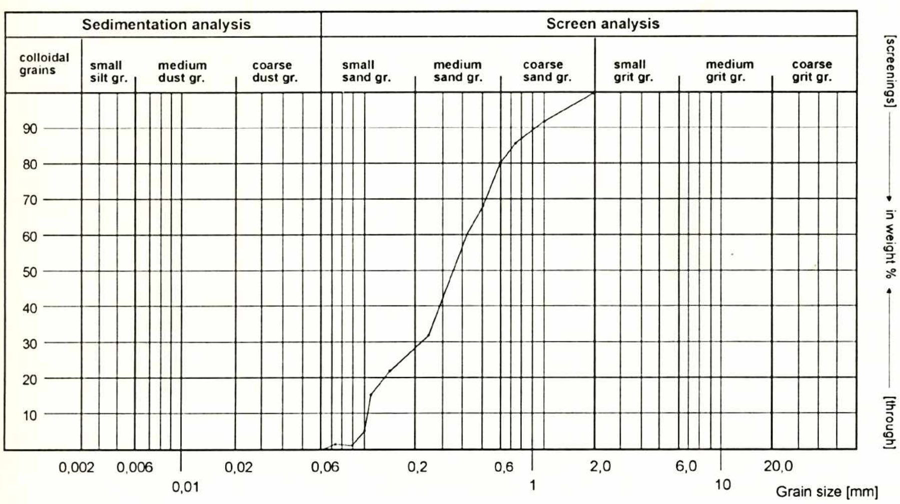

Fig. 2. Particle size distribution diagram for the floatation galena sample from Trzebionka Mining Works (Feb.1993).

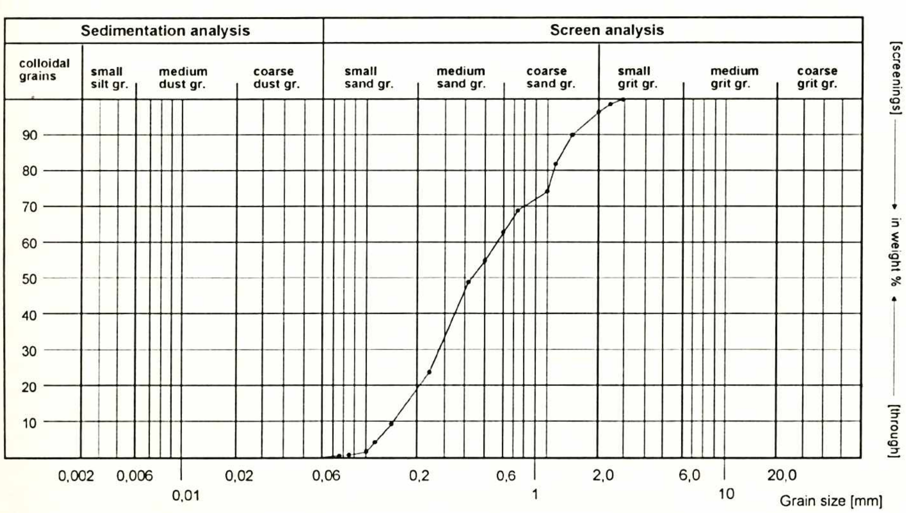

Fig. 3. Particle size distribution diagram for the sedimentation galena from Trzebionka Mining Works (Feb.1993).

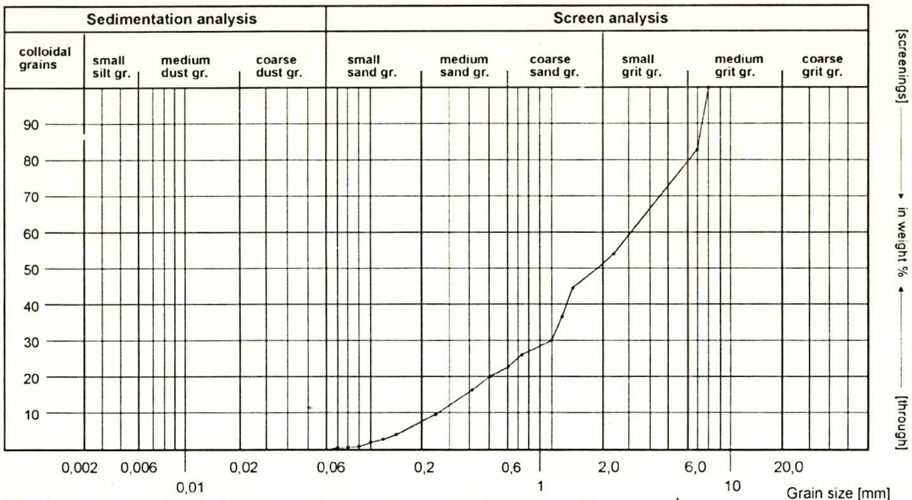

Fig. 4. Particle size distribution diagram for the fine coking coal taken in the Port of Gdańsk (1989).

The coarse-grained materials are the following:

- sedimentation galena with content of grains
  - smaller than 0,25 mm - 24%
  - from 1 to 3 mm - 26%
- fine coking coal with content of grains
  - smaller than 0,25 mm - 9%
  - from 1 to 6 mm - 68%.
- whereos flotation galena contains grains
  - smaller than 0,25 - 32%
  - from 1 to 2 mm - 8 % only

In principle coarse-grained materials are characterized by a higher content of grains greater than 1 mm in size.

CONCLUSIONS

● It comes from Tab. 1 , where Tranportable Moisture Limits determined with the use of the above mentioned methods are compared, that lower TML values are obtained when the Japanese Penetrating Method is applied.

● Moreover the method allows to determine the FMP which is not possible when the Proctor c/Fagerberg Method is applied.

● The lowest FMP and TML values are obtained also for fine-grained concentrates when the Japanese Penetrating Method is applied [9].

● There is a very good correlation between results for floatation concentrates obtained with the use of the Flow Table and Japanese Penetrating methods [8]. A weaker correlation was revealed for coarse-grained ore concentrates and coal samples to which the Japanese Penetrating and Proctor c/Fagerberg methods were applied (see Fig. 5).

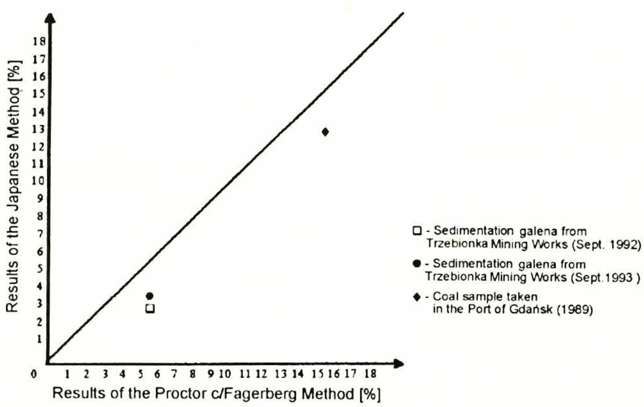

Fig. 5. Correlation of TML and FMP values determined with the use of the Japanese Penetrating Method and the Proctor c/Fagerberg Method.

● Investigation of the Polish floatation galena with the use of the Japanese Penetrating method showed that the pressure exerted by the penetrating bit (10 kPa for ore concentrates) was too low. The bit did not reach 50 mm depth in spite of a high sample moisture content. It was only possible when the penetrating bit weight was doubled (which corresponded to 20 kPa pressure).

In spite of the limitation the Penetrating Method seems to be of good repeatability and accuracy of measurements, which is confirmed by the FMP statistical parameters given in Tab. 2.

● The low FMP value of floatation galena obtained with the use of the Penetrating Method speaks for the method. The result is of great importance for safe shippment of such bulk cargoes.

● However, having practically only one FMP determination method recommended by IMO for coarse-grained concentrates, continuation of searching for new methods and improving existing ones applicable to the considered type of bulk cargoes seems to be necessary.

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