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Determination of critical and permissible moisture content in fine-grained ore concentrates and similar materials

SUMMARY

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

Test results of several floatation and sedimentation ore concentrates and coal samples of Polish as well as foreign origin, obtained with the use of four various methods, are presented. Results of earlier tests of ore concentrates and coal samples are also given for comparison.

On this basis the methods are critically evaluated and the ranges of applicability of each of them stated.

INTRODUCTION

Ore concetrates due to their high specific weight are classified as heavy cargoes, shipment of which may be associated with several hazards. One of these hazards is deterioration or loss of ship's stability [1] which may be a result of:

- surface lateral shift of a loose cargo, dry or moist, with moisture content less than it would be necessary to liquefy it;
- lateral shift of an excessively wet loose cargo which can pass into liquid state in sea transport conditions.

Cargoes of such properties are composed of very fine grains.

Moisture content allowing for passing of a bulk cargo from solid into liquid state in given conditions is called critical moisture content. One of its possible measures is the flow moisture point (FMP). On its basis permissible moisture limits for shippment conditions are determined.

Transportable Moisture Limit (TML) is such a moisture content at or below which a loose cargo can be transported in bulk on ships, not specially adapted to such cargoes, without danger of passing of the cargo into liquid state. It is usually calculated as 90% of FMP.

The specific behaviour of ore concentrates, when being transported by sea, makes it necessary to establish a reliable method, giving exact, repeatable results for determination of critical moisture content in ore concentrates and similar materials.

Safe transport of such materials is a responsible task. Ships which carry excessively wet ore concentrates are endangered with possible liquefaction of the cargo leading in consequence to a heel or even capsize of the ship.

SCOPE OF INVESTIGATIONS

Since 1976 the Institute of Mathematics, Physics and Chemistry, presently Chemistry Chair of the Academy, has carried out investigations concerning determination of FMP and TML values for Polish ore concentrates (galena, zinc blende, copper ore, flue dust) from Polish mine works in Bukowno, Trzebinia, Lubin and Żukowice, prior to loading the concentrates on ships; some samples from Japan and Norway have also been tested.

In the last years the Chemistry Chair conducted comparisons of FMP and TML values of ore concentrates determined with the use of the following methods:

- Flow Table Method
- Japanese Penetration Method
- Proctor C/ Fagerberg Method
- F. Guerra's Method (a modification of Proctor C Method)

The Chair took also part in three international research projects aimed at evaluation of methods for FMP determination conducted in 1978, 1989÷1990 and 1992÷1993 years [2], [3], [4].

FMP determination with the use of Flow Table Method

Initially, particle size analysis is carried out as the method is not applicable for coarse-grained concentrates, e.g., floatation galena. Application of the method is not possible if fractional content of particles with size within 0,02 and 0,3 mm is not greater than 10%.

Particle size analysis of the tested materials has been carried out in compliance with PN-66/Z-04007 standard: „ Screen analysis of dusts of particle size over 63 μm".

Volumetric density of a concentrate has been determined at the same moisture content as it was at the material delivery for testing. The value is necessary for calculation of a force for sample consolidation prior to its testing with the Flow Table Method.

The sample consolidation is performed with a rammer of 0,36 kg mass in a brass cylinder of 1000 cm³ capacity.

Moisture content in concentrates not entering into chemical reactions with oxygen was determined by drying material sample in 105°C up to constant weight.

FMP and TML values were determined in compliance with provisions of the Code of Safe Practice for Solid Bulk Cargoes [1]. The tested samples were divided into sub-samples the first of each was used for the preliminary determination of FMP.

In the reported tests the rammer acording to a Japanese proposal [5] was used. According to [6], the sample consolidation force is dependent on volumetric density of a concentrate and its stowing height in ship's holds. Consolidation pressure P [N/m²] for a concentrate is calculated from the following expression (1):

$$P = h\,d\,g \qquad (1)$$

where:

h - cargo stowing height in a ship's hold
h = 10 m is usually taken
d - volumetric density of a concentrate [kg/m³]
g - gravity acceleration (9,8 m/s²)

Force F [kG] which should be applied to the rammer is calculated from the expression (2):

$$F = \frac{P\,s}{g} \qquad (2)$$

where:

P - from (1)
s - rammer area equal 7 x 10^{-4} [m²]

FMP was determined using a conical sample, consolidated in the above described way, which was subjected to 25 shocks on the shock table. If a sample moisture content is lower than FMP then the sample appears brittle and scattered. If sample moisture content is greater than FMP then the sample, after being subjected to 25 shocks, plastically deforms which is manifested in a change of its conical shape.

FMP was calculated as the mean value of maximum moisture content at which sample deformation is still brittle and of minimum moisture content at which the deformation is already plastic. The difference between these measured values should not be greater than 0,5%. TML value can be calculated from so calculated FMP value as:

$$TML = 0{,}9\ FMP. \qquad (3)$$

Application of the Japanese Penetration Method

5 kg sample of the tested concentrate was put in three layers into a container made of polymethacrylate resin, of 200 mm height and 1700 cm³ capacity. Sample consolidation was performed with a rammer applying pressure of 0,4 kG/cm². The container with the consolidated sample was fixed on a vibrator platform and subjected to vibrations of 55 Hz frequency and maximum acceleration of 2,8 g, lasting 6 min. A depth indicator was placed at upper edge of the container and a penetrating bit - on the sample surface.

After preliminary testing of the sample distilled water was added to it in 1 to 1,5% amount of the entire sub-sample weight and the test was repeated. This procedure was repeated until liquefaction of the sample was obtained. When the penetrating bit immerses more than 50 mm at a given moisture content it means that the sample at this moisture content will liquefy.

A sample moisture content, at which the penetrating bit immersion is just 50 mm in a given test conditions, is taken as the Flow Moisture Point. FMP is calculated as the mean value of maximum sample moisture content value slightly less than FMP and minimum moisture content value just after sample liquefaction.

Application of Proctor C / Fagerberg Method

At the beginning a 50 g amount of a tested material was dried to constant weight at 105°C to determine a preliminary sample moisture content.

About 2000 cm³ of the tested material was taken and distilled water added to obtain an assumed moisture content. A part of the sample was put into the measuring cylinder of the Proctor apparatus and consolidated by 25 drops of the rammer from 0,2 m height, layer by layer, repeating the procedure 5 times and finally weighing the cylinder with the moist sample.

Then volumetric density of the wet concentrate γ_{ob} and of the dry consolidated concentrate γ_{objs} were calculated and a consolidation curve γ_{objs} = f(w) drawn, where „w" stands for moisture content percentage in relation either to dry or wet concentrate weight. A permissible moisture content can be determined from a cross point of the consolidation curve and a line of 70% volumetric moisture level theoretically calculated from an expression for actual moisture level in relation to wet material during its consolidation, knowing its volumetric density value in dry condition.

Application of the Canadian F. Guerra's Method

This method introduces a conversion factor equal 1,3197; due to that volumetric density of a concentrate dynamically consolidated at 70% moisture level can be calculated, if only its minimum volumetric density in dry and loose condition, γ_{min}, is known. A dynamic volumetric density value can be obtained as $\gamma_D = 1{,}3197\ \gamma_{min}$. The conversion factor calculated in this way is the mean value corresponding to a volumetric density value taken in ship's hold during cargo unloading and a minimum volumetric density value of a concentrate sample in completely loose condition determined in laboratory tests.

A minimum volumetric density value is determined from a material sample dried in 105°C. Then, permissible dynamic moisture content is determined entering with the calculated γ_D to „Tables of Tranportable Moisture Limits" [4],[5].

Critical and permissible moisture content values can also be calculated from a formula if only actual moisture content in relation to wet material, its dynamic volumetric density and inherent density is known.

EXPERIMENTAL TESTS AND THEIR RESULTS

The research on evaluation of methods for critical moisture determination was carried out by the authors in two stages. In 1990 the following samples were tested:

- a floatation zinc blende concentrate from Mining-Metallurgical Works „Bolesław" in Bukowno, (Poland) sample taking in September 1990
- a floatation galena concentrate of the same manufacturer and time of sample taking
- a floatation iron ore concentrate from Canada, sample taking in December 1990
- a coal sample of 0÷20 mm grade from Port of Gdańsk taken in April 1989

The tests were performed with the application of three methods: of the Flow Table, Japanese Penetration and Proctor C/Fagerberg Method. Results of that research stage are given in Tab. 1.

Tab. 1. Critical and permissible moisture contents (determined in 1990).

Concentrate type Origin Sample - taking date	Weight percentage in respect to wet concentrate				
	Flow Table Method		Japanese Penetration Method		Proctor C Fagerberg Method
	FMP	TML	FMP	TML	TML
Floation zinc blende "Boleslaw" Works, IX 1990	9,96	8,96	9,83	8,84	9,85
Floation galena "Boleslaw" Works, IX 1990	8,87	7,98	8,70	7,80	8,53
Floation iron ore Canada	8,36	7,52	8,63	7,76	7,52
Coal sample Port of Gdańsk, 1989	undeter-minable	undeter-minable	16,09	14,48	15,58

In years 1992÷1993 the second stage of research was performed using the following materials:

- an ore concentrate from Canada, sample taking in 1991
- an ore concentrate from Norway, sample taking in 1990
- a barite concentrate from Japan, sample taking in 1992
- a sedimentation galena concentrate from Mining-Metallurgical Works „Trzebionka" in Trzebinia (Poland), sample taking in 1990
- a coal sample of Mikke grade from Japan, sample taking in 1992
- a floatation galena, a zinc blende, and a sedimentation galena - all three concentrates from „Trzebionka" Works, sample taking in February 1993
- a sedimentation galena from „Trzebionka" Works, sample taking in September 1992

The tests were carried out using the same methods as applied earlier and additionally the Guerra's Method. The results of the tests are collected in Tab. 2 and 3.

Tab. 2. Critical and permissible moisture contents (determined in 1992).

Concentrate type Origin	Weight percentage in respect to wet concentrate			
	Flow Table Method		Japanese Penetration Method	
	FMP	TML	FMP	TML
Barite concentrate Japan	10,35	9,31	10,31	9,27
Coal of 0÷20 mm grade Japan	-	-	13,02	11,70
Iron ore concetrate Norway	5,20	4,68	4,45	4,00
Iron ore concetrate Canada	8,36	7,52	7,40	6,66
Sedimentation galena concetrate	-	-	4,72	4,24

Tab. 4. Particle size fractional contents of ore concentrates.

Ore type Origin Sample-taking data	Screen analysis - fractional content of sandy grains [%]				
	0,06 - 0,15mm	0,15 - 0,25mm	0,25 - 0,43mm	0,43 - 1,5mm	1,5mm and more
Zinc blende "Bolesław" Works , IX 1990	4	76	9	11	-
Iron ore Canada, XII 1990	-	19	53	28	-
Floation galena "Bolesław" Works, IX 1990	3	21	7	69	-
Barite Japan, 1992	51	2	44	3	-
Coal Mikke Japan, 1992	3	2	3	24	68
Iron ore Norway, 1992	26	9	20	23	22
Iron ore Canada, 1991	-	19	54	27	-
Sedimentation galena "Trzebionka" Works, 1990	4	31	22	36	7
Floation zinc blende "Trzebionka" Works, II 1993	8	8	29	50	5
Floation galena "Trzebionka" Works, II 1993	22	10	28	35	5
Sedimentation galena "Trzebionka" Works, IX 1992	13	16	10	44	17
Sedimentation galena "Trzebionka" Works, II 1993	9	15	25	41	10

The critical moisture contents determined with the use of various methods are given in Fig. 1, 2 and 3, comparing two of them in each case. Results of the particle size analysis are presented in Tab. 4.

Tab. 3. Critical and permissible moisture contents (determined in 1993).

Concentrate type sample taking date	Weight percentage in respect to wet concentrate						
	Flow Table Method		Japanese Penetration Method		Proctor C Fagerberg Method	Canadian Method acc. to F. Guerra	
						equivalent	
	FMP	TML	FMP	TML	TML	to 100%	to 70%
						moisture level	
Floation galena II 1993	7,03±0,089	6,75	6,06±1,05	5,45	8,00±0,66	8,21	5,89
Floation blende II 1993	9,05±0,22	8,15	8,43±0,57	7,59	10,45±0,15	13,54	9,87
Sedimentation galena IX 1992	undeter-minable	undeter-minable	3,56±0,33	3,20	5,35±0,12	3,90	2,78
Sedimentation galena II 1993	undeter-minable	undeter-minable	4,01±0,66	3,61	5,43±0,10	4,37	3,08

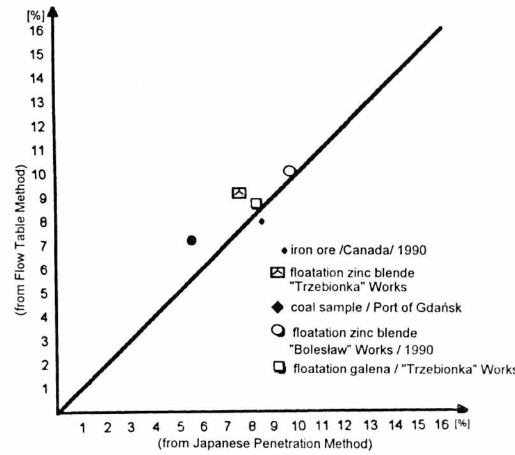

Fig. 1. Comparison of critical moisture contents (weight percentage in relation to wet concentrate) determined with Flow Table Method and Japanese Penetration Method.

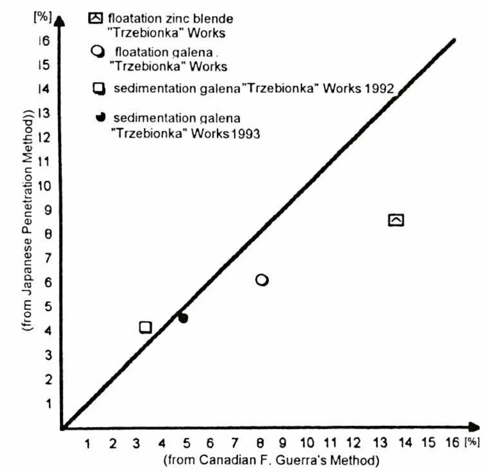

Fig. 2. Comparison of critical moisture contents (weight percentage in relation to wet concentrate) determined with Japanese Penetration Method and Canadian Method acc.to F.Guerra.

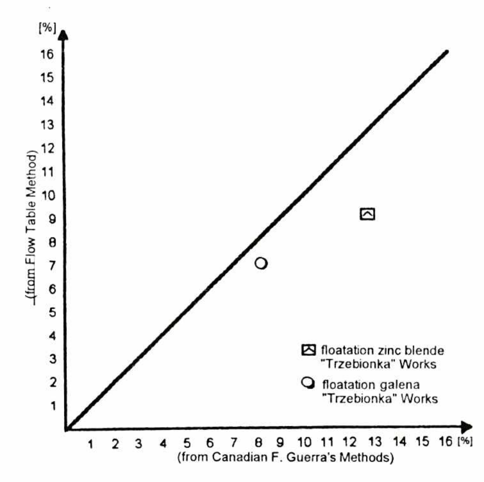

Fig. 3. Comparison of critical moisture contents (weight percentage in relation to wet concentrate) determined with Flow Table Method and Canadian Method acc.to F.Guerra.

CONCLUSIONS

1. It may be concluded from the results given in Tab. 1 that all applied methods can be used for testing of fine-grained materials (floatation ore concentrates).

- The Flow Table Method is of very good repeatability and accuracy; its accuracy is however substantially influenced by particle fractional content. If the content of grains with the size within 0,02 and 0,03 mm is not greater than 10%, the use of the method is impossible [7]. However, full particle fractional content also decides whether the FMP is possible to be determined with the method or not possible at all. Therefore fine coal of 0÷20 mm grade not containing sufficient fraction of particles of size less than 0,3 mm cannot be tested with the method.
- The Japanese Penetration Method can be used without limitations for testing ore concentrates and fine-grained coal. Moreover a very good correlation between the Flow Table Method and Japanese Penetration Method was demonstrated (Fig.1).
- The Proctor C/ Fagerberg Method leads to high errors in testing of coal samples.

2. Results of FMP determination, obtained in 1992 [4] using the corrected Japanese Penetration Method and compared with those achieved with the Flow Table Method (Tab. 2.), indicate that this method is also reliable and of good repeatability and accuracy. Statistical parameters calculated for the measured values confirmed this conclusion.

3. Investigations of ore concentrates carried out in 1993 indicated that:

- The results obtained using the Proctor C / Fagerberg Method are higher in all cases than those given by the remaining used methods (Tab. 3.).
- The Japanese Penetration Method is good for determination of FMP and TML of fine-grained concentrates as well as coarse-grained ones. Moreover the results obtained in this way are consistent with those got from the Flow Table Method and the Canadian Method acc. to F. Guerra.
- The largest discrepancies appeared in the case of testing the floatation zinc blende where results obtained with each used method differed more than usually from those obtained with remaining ones.

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Appraised by Stefan Kawiak, Assist.Prof.,D.Sc.,Chem.E.

Miscellanea

BALTICA

Modern fishery research ship

Sea Fisheries Institute in Gdynia is known for many years owing to its scientific research works on biological phenomena in sea and changes in them due to human activity. The institute is a research establishment leading in creation of scientific background for an integrated management system of the Polish economic zone on the Baltic Sea. It implements in Poland the principles of a „responsible fishery" i.e. a rational sea life resources management, elaborated under the auspices of FAO/UN.

The institute carries, out together with American scientists, a comparative research on eco-systems of the Baltic Sea and the North Western Atlantic.

It also co-operates with other Baltic countries in developing pro-ecological activities, having support of UN and the World Bank.

Recently the research potential of the institute was substantially strengthened by a modern fishery research ship BALTICA (see foto).

The main particulars of the ship are: length overall - 41,08 m, moulded breadth - 9,00 m, moulded depth - 4,50 m, draught - 3,50 m/4,45 m, gross tonnage - 614 RT; the main engine rated power 1040 kW at 90 rpm enables the ship to reach speed of 11,5 knots. The ship with a crew of 10 and scientific staff of 12 persons can spend 30 days at sea without being supplied.

The scientific staff has to its disposal the following laboratories and research facilities:

- biological, chemical, ichtiological and physical laboratories
- computer network for measurements controlling, data recording and processing
- the most advanced measuring equipment for special researches

The ship is fitted with the following equipment for easy sample-taking and conducting measurements:

- a side ramp with portable davit
- a pivotable stern ramp
- a hoisting boom and 7 deck stands fitted with cable trawling winches for oceanographic investigations, and luffing type davits
- a towed underwater facility for in-motion simultaneous recording of more than ten various physical, chemical and biological parameters of marine environment

BALTICA is also able to carry out trawl fishing.