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Investigation of Polish lead ore concentrates regarding their safe transport by sea

SUMMARY

In this paper a results are presented of estimation of the critical (FMP) and permissible (TML) moisture content in floatation and sedimentary galena concentrates obtained by different test methods. The applicability of Japanese Penetration Test for determination of critical moisture content in these cargoes is discussed from the point of view of their safe shipment.

INTRODUCTION

Main factors influencing safe sea shipment of lead ore concentrates are a.o. : **their Pb content, moisture content and grain size distribution.**

Lead ore concentrates produced in Poland by „Trzebionka" Mining Works, Trzebinia and „Bolesław" Mining-Metallurgical Works, Bukowno are of two kinds : sedimentary galena and floatation galena, composed mainly of PbS.

Pb content

Pb content in the galena concentrates was gradually increasing in the years 1973÷1996. In 1973 in the sedimentary galena it was of 71% and in 1995,1996 it increased to 80%. In the floatation galena Pb content was smaller and increased from 64% in 1973 to 74% in 1995,1996 [1].

Moisture content

Moisture content in the sedimentary galena concentrates was about 1÷2%, and in the floatation galena concentrates 8÷9% in 1973÷1992, and about 5% from 1993. The concentrates of 8÷9% moisture content were not suitable for shipment by sea because of the danger of their passing into liquid state [2]. The necessary reduction of their moisture content was first performed by means of vacuum filtering, and from 1993 – by means of capillary filtering, and this way the thermal demoisturing process used up to 1992 became unnecessary.

Grain size content

Grain size content (distribution) is of crucial importance for assessment of proneness of the concentrates to liquefaction in sea transport conditions [3].

The grain size content of the galena concentrates in question was gradually changing in 1973÷1996 due to deepening the grinding process of the lead rock material, demonstrated by increasing content of smaller grains. In the floatation galena concentrates the content of the grains smaller than 0.2 mm was 30%, that of the grains from 0.06 mm to 0.3 mm was 40÷50%, and that of the grains greater than 1 mm – only 6÷8%.

In the sedimentation galena concentrates the content of the grains from 0.06 mm to 0.2 mm was 15% to 25%, that of the grains from 0.06 mm to 0.3 mm – over 30%, and that of the grains greater than 1 mm – over 40%.

The content greater than 10% of the grains from 0.06 mm to 0.2 mm makes the sedimentary galena concentrates able to liquefy, especially if they are shipped by rather small ships of shallow and long holds. Moreover a high content (over 40%) of the grains greater than 1 mm makes it impossible to assess Flow Moisture Point (FMP) of the concentrate by means of Flow Table Method (see comments below).

Assessment methods of safe moisture content

The appropriate assessment of the critical moisture content (Flow Moisture Point – FMP) and its permissible limit (Transportable Moisture Limit – TML) is an important issue for sea transport of ore concentrates and other fine-grained bulk cargoes. Therefore International Maritime Organisation (IMO) approved, in its Code of Safe Practice for Solid Bulk Cargoes, the following assessment methods of safe moisture content in the fine-grained bulk cargoes [4] :

➔ Flow Table Method – (valid since 1965)
➔ Japanese Penetration Method
➔ Proctor C / Fagerberg Method.

In the Code it is also stated that choice of an adequate method for testing given cargo samples is left to the interested parties.

In the Chemistry Department, Gdynia Maritime Academy also F.Guerra's Method [5] is used for testing of such cargo samples to which Flow Table Method is not applicable.

All the above specified assessment methods yield similar TML values [2,6], except of Proctor / Fagerberg Method which provides greater values than those given by the remaining ones.

Japanese Penetration Method can be applied for testing both fine-grained and coarse-grained materials such as e.g. sedimentary galena concentrates.

Conditions for FMP and TML assessment by means of Japanese Penetration Method

Determination of FMP and TML by using Japanese Penetration Method, in accordance with the above mentioned IMO Code, should be carried out with obeying the following testing conditions :

- ✓ maximum value of vibration acceleration : a_{max} = 3 g (equivalent to a_{rms} = 2.13 g)
- ✓ vibration frequency : 55 Hz
- ✓ vibration sample testing time : 6 min
- ✓ penetrating bit pressure : 10 kPa - for samples of concentrates, 15 kPa - for coal samples
- ✓ sample consolidation pressure : 40 kPa.

The comparative investigations [7] demonstrated that the proposed penetrating bit pressure was not appropriate for testing coarse-grained ore concentrates. It was possible to assess FMP values of such concentrates only when mass of the penetrating bit was increased to 352 g, and thus also the pressure exerted by the penetrating bit – up to 20 kPa.

Moreover, FMP assessment of Carol iron ore concentrate appeared ineffective due to too low consolidation pressure of the sample in the penetration vessel.

It was hence justified to initiate investigations aimed at assessment of optimum conditions of testing FMP and TML values of various granular bulk cargoes by means of Japanese Penetration Method.

In this paper results of the following considerations, are presented :

- ♦ study of changes of FMP and TML values of the sedimentary galena, observed in the years 1988÷1996
- ♦ investigation of FMP and TML values of the lead ore concentrates by means of different methods
- ♦ investigation of influence of changing the testing condition parameters of Japanese Penetration Method on the FMP and TML values.

COURSE AND RESULTS OF EXPERIMENTAL INVESTIGATION

Study of changes of FMP and TML values of the sedimentary galena, observed during the years 1988÷1996

FMP and TML values of sedimentary galena samples, determined by means of Proctor C / Fagerberg Method, Guerra's Method and Japanese Penetration Method, were compared. During testing by using the last method the penetrating bit of 20 kPa pressure load was applied instead of the commonly used 10 kPa bit. Results of the investigations are presented in Tab.1 and Fig.1.

Tab.1. *Results of determination of the critical and permissible moisture content values of sedimentary galena concentrates in 1988÷1996 years*

Sample taking date	TML values equivalent to Sw = 70% moisture level in samples consolidated acc. to Proctor C Fagerberg Method	Moisture content determined by using F.Guerra's Method		Moisture weight content [%] determined by using Japanese Penetration Method	
		TML values, equivalent to Sw = 70%	Critical moisture content values, equivalent to Sw = 100 %	Equivalent to TML values	Equivalent to FMP values
„Trzebionka" Works					
January 1988	5.00	-	-	-	-
October 1988	5.30	-	-	-	-
April 1990	5.30	-	-	-	-
October 1990	5.26	-	-	-	-
March 1991	5.37	-	-	-	-
September 1991	5.77	-	-	-	-
October 1991	5.37	-	-	-	-
February 1992	5.15	-	-	-	-
September 1992	5.35	2.78	3.90	3.20	3.56
February 1993	5.43	3.08	4.37	3.61	4.01
March 1993	5.62	2.43	3.44	4.14	4.60
July 1993	5.32	3.58	5.03	3.92	4.35
January 1994	5.7	3.38	4.90	4.32	4.80
May 1994	5.57	3.80	4.95	4.41	4.90
November 1994	5.59	3.50	4.91	4.05	4.50
April 1995	5.97	3.25	4.57	4.32	4.80
July 1996	5.14	3.84	5.4	3.76	4.18
„Bolesław" Works					
February 1988	4.9	-	-	-	-
July 1996	8.83	4.76	6.66	4.39	4.88

Note : *The mean TML value of the sedimentary galena concentrates produced by „Trzebionka" Works during 1992÷1996 amounts to 3.97 %*

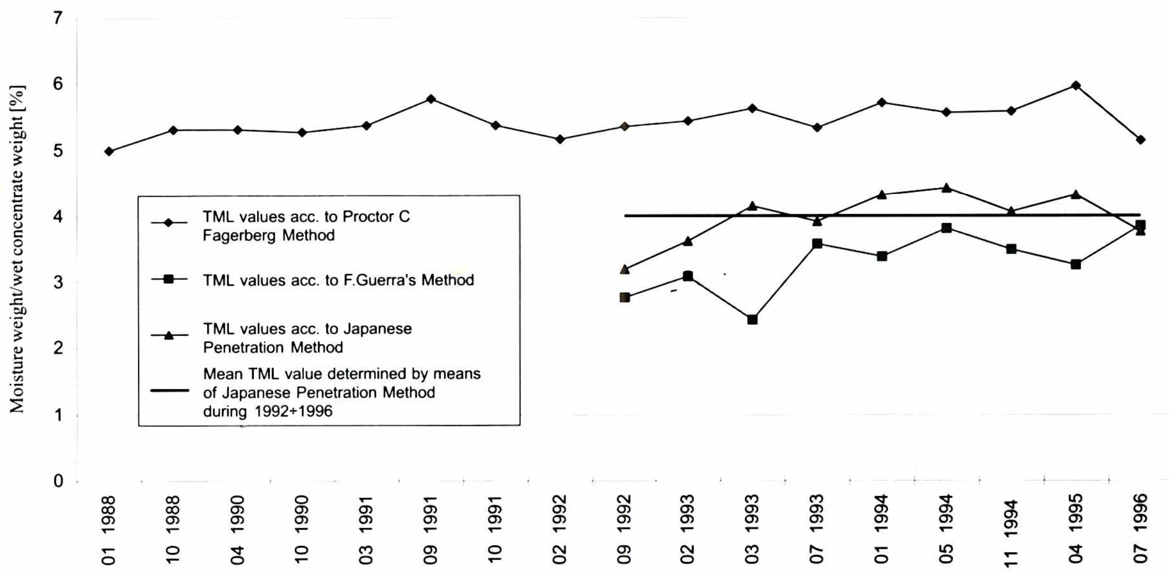

***Fig.1.** Changes of TML values of the sedimentation galena samples from „Trzebionka" Works, observed during 1988÷1996*

***Tab.2.** FMP and TML values of the plumbous ore concentrates determined by means of different testing methods*

Place and date of sample taking	Flow Table Method		Japanese Penetration Method		Proctor C Fagerberg Method	F.Guerra's Method	
	FMP values [%]	TML values [%]	FMP values [%]	TML values [%]	Permissible moisture content (TML) values [%]	Critical moisture content values [%], equivalent to Sw = 100 %	Permissible moisture content (TML) values [%], equivalent to Sw = 100 %
Floatation galena from „Trzebionka" Works, 1996	7.13	6.42	7.23	6.51	7.75	9.88	7.13
Floatation galena from „Bolesław" Works, 1996	7.22	6.50	7.46	6.71	8.42	10.37	7.49
Sedimentary galena from „Trzebionka" Works, 1996	-	-	4.18	3.76	5.14	5.50	3.84
Sedimentary galena from „Bolesław" Works, 1996	-	-	4.88	4.39	8.83	6.66	4.76

Investigation of FMP and TML values of the lead ore concentrates by using different testing methods

Four samples were tested of both floatation and sedimentary galena concentrates from „Trzebionka" Works and „Bolesław" Works. At first grain-size screening analysis of the samples was performed, and then FMP and TML values of the samples were determined by applying : Japanese Penetration Method, Flow Table Method, Proctor C / Fagerberg Method as well as Guerra's Method. Results of this phase of investigation are presented in Tab.2.

Investigation of the influence of changing the testing condition parameters of Japanese Penetration Method on FMP and TML values

Finally, investigations were carried out aimed at assessment of influence of :

- pressure exerted by the penetrating bit
- pressure applied to consolidate concentrate samples within the penetration vessel
- vibration acceleration applied during testing
- duration time of vibrations applied to tested samples

on results of assessment of FMP and TML values of coarse-grained sedimentary galena.

Testing condition parameters were systematically changed as follows :

- Values of the pressure exerted by the penetrating bit were changed from 10 kPa through 15, 20, 25 up to 30 kPa by increasing mass of the bit from 176 g up to 528 g. Results of this investigation phase are presented in Fig.2.
- Values of the consolidation pressure were systematically changed from 0 kPa (loose sample) through 10, 20, 30, up to 40 kPa, and even to 50 kPa for the concentrate from „Trzebionka" Works. Results of the investigation phase are shown in Fig.3.
- The investigations were carried out at different duration times of vibrations, namely : 3, 6 and 9 min, and corresponding results are given in Fig.4.
- Vibration acceleration values applied during testing were as follows : 1 g, 2 g, 3 g and 4 g. Results of this phase are presented in Fig.5.

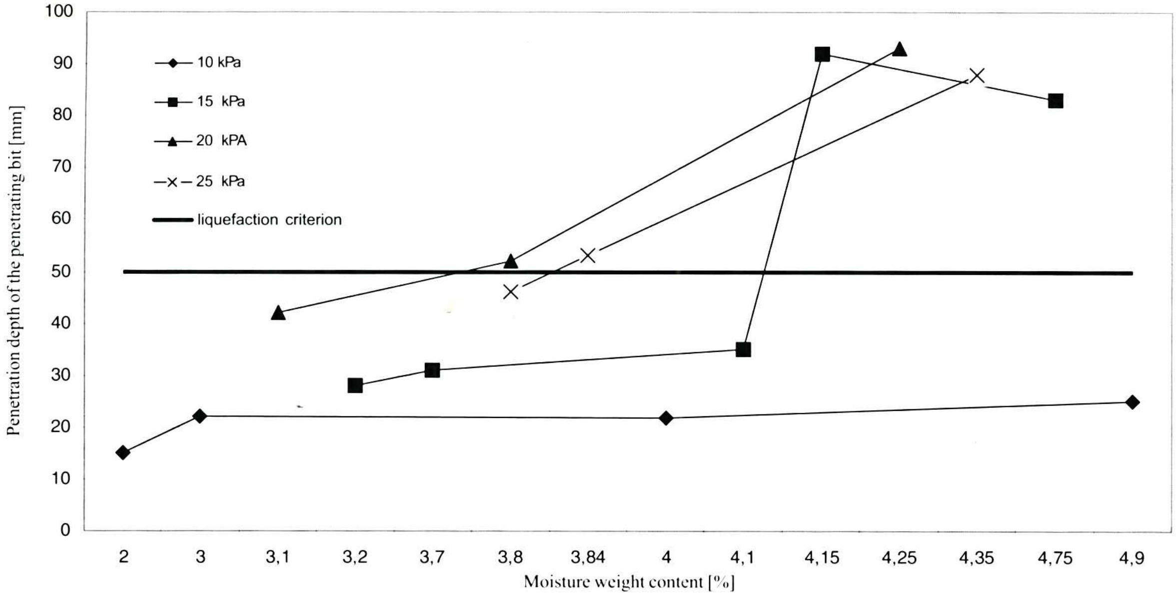

Fig.2. Penetration depth of the penetrating bit in function of its pressure load onto the galena concentrate samples from „Trzebionka" Works, and of their moisture content

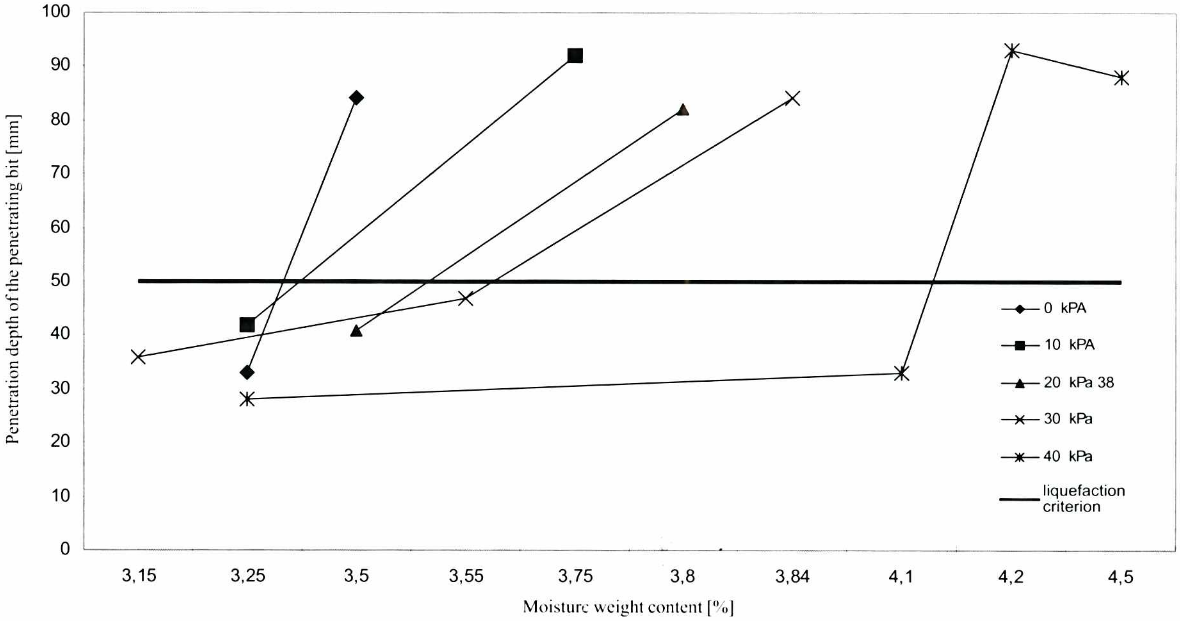

Fig.3. Penetration depth of the penetrating bit in function of consolidation pressure applied to the galena concentrate samples from „Trzebionka" Works, and of their moisture content

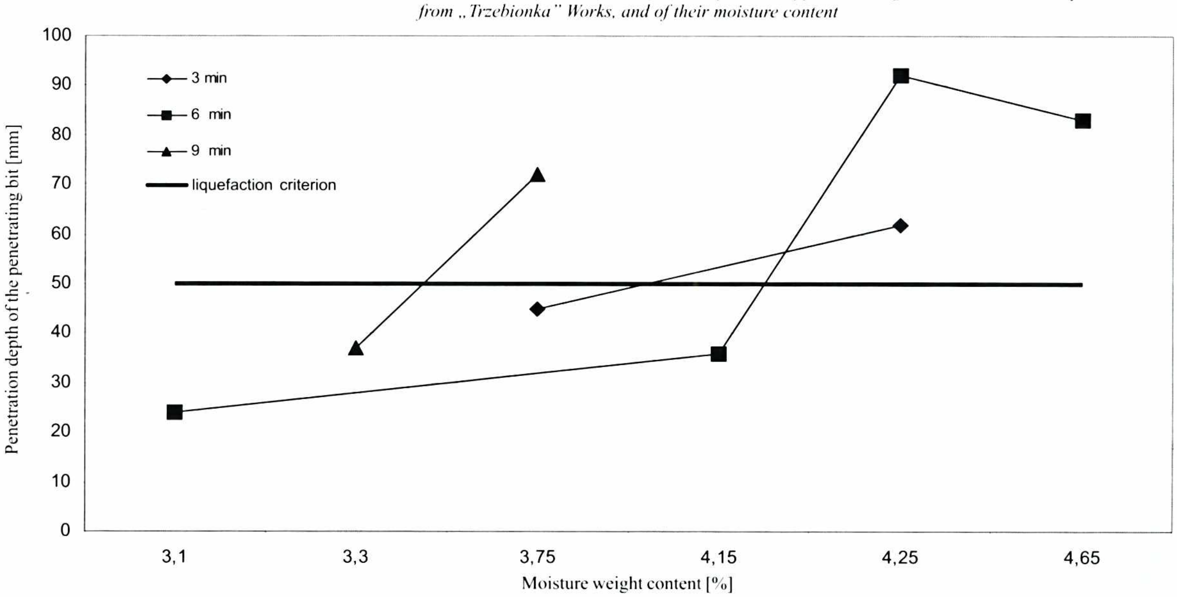

Fig.4. Penetration depth of the penetrating bit in function of duration time of vibrations applied to the galena concentrate samples from „Trzebionka" Works, and of their moisture content

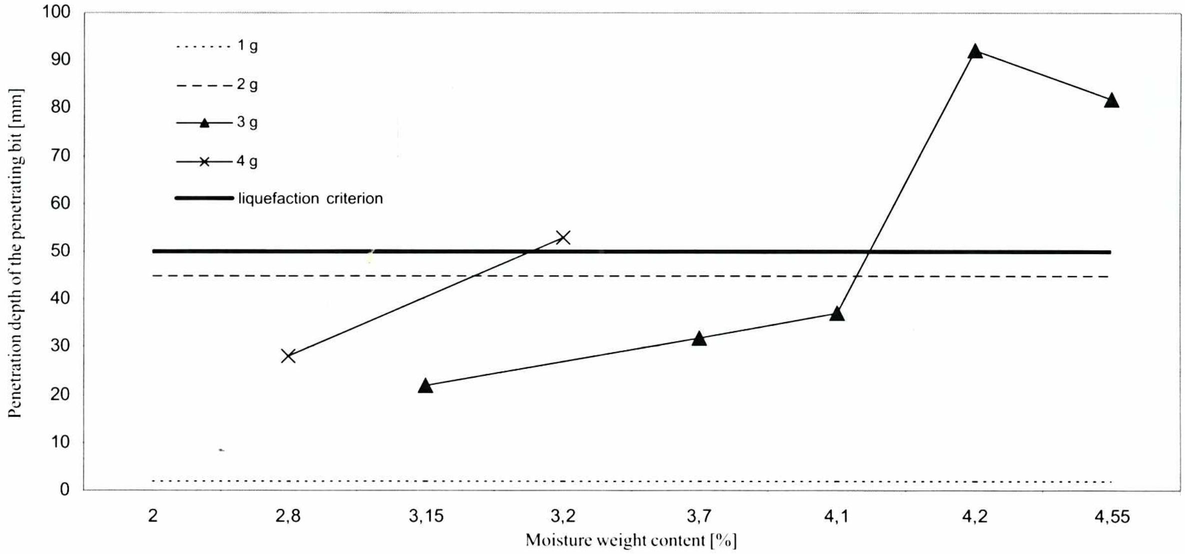

Fig.5. *Penetration depth of the penetrating bit in function of acceleration of vibrations applied to the galena concentrate samples from „Trzebionka" Works, and of their moisture content*

DISCUSSION AND CONCLUSIONS

- The results of TML assessment of the sedimentary galena concentrates in question (Tab.1., Fig,1.) greatly differ from each other depending on the applied testing method, namely : Japanese Petnetrating Method yields average TML values; The values obtained from Guerra's Method are the smallest both those concerning the critical (Sw = 100%) and the permissible moisture content (Sw = 70%). It can be explained by the fact that the so-called dynamic volumetric density [5] of the ore concentrate corresponds to the volumetric density of the sample taken from the bottom layers of the bulk cargo in the hold.
- The rather small increase of TML values observed in successive years is connected with increasing degree of concentrate grinding.
- The results of FMP and TML assessment of the floatation galena concentrates in question by means of Japanese Penetration Method and Flow Table Method are very close to each other. And, the values resulting from Proctor C / Fagerberg Method and Guerra's Method are greater than the latter.
- The grain size analysis revealed that both tested sedimentary galena concentrates can become flowable as their content of the grains greater than 1 mm in size is below 95%. The concentrates cannot be tested by using Flow Table Method. The results obtained from Japanese Penetration Method show good conformity to those from Guerra's Method, and lower conformity, however, to those from Proctor C / Fagerberg Method.
- Testing the sedimentation galena concentrates with the use of Japanese Penetration Method makes it necessary to carry out measurements at the penetrating bit pressure of 15 kPa or 20 kPa. The values resulting at 20 kPa pressure are smaller than the permissible moisture content values obtained from Guerra's Method, and the values at 15 kPa pressure are either over or within the permissible range determined by means of the latter method. The two values of the bit pressure should be deemed appropriate for the coarse-grained concentrates.
- Along with increasing the sample consolidation pressure the bit penetration depth in the tested sample exceeds the flow criterion value (50 mm) at increasing values of moisture content in the sample (Fig.3). The pressure of 40 kPa can be deemed the optimum for sample consolidation.
- 6 min duration time of test vibrations is optimum as 50 mm penetration depth is obtained at the moisture content equivalent to TML value determined by using Guerra's Method, or to a somehow greater value (Fig.4).
- 3 g vibration acceleration value is appropriate for carrying out measurements. At 1 g and 2 g acceleration value the penetrating bit does not immerse at all or less than 50 mm deep, and at 4 g value it does, but at moisture content values smaller than the permissible one determined by means of Guerra's Method (Fig.5).
- In conclusion we can state that the optimum conditions for testing FMP values of the sedimentary galena concentrates by applying Japanese Penetration Method are as follows :
  - the maximum testing acceleration : 3 g (equivalent to rms value of 2.13 g)
  - vibration frequency : 55 Hz
  - vibration duration time : 6 min
  - sample consolidation pressure : 40 kPa
  - penetrating bit pressure : 15 kPa.

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