Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2014, 39(111) pp. 63–66
ISSN 1733-8670

2014, 39(111) s. 63–66

Safety aspect of handling and carriage of solid bulk cargoes by sea

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Key words: flow moisture point, transportable moisture limit, ore concentrates, dangerous goods, transportation, solid bulk cargoes

Abstract

The increasing needs for carrying solid bulk cargoes by means of marine transport have increased interest in the subject of safe carriage of these cargoes by sea. One of them are ore concentrates. During the transport by the sea, the cargo tends to liquidate and shift toward the sides which may increase the inclination when rolling and leads to loss of stability of the ship. There has been presented the results of researches on moisture content and flow moisture point of copper ore concentrate. Furthermore, transportable moisture limit for this concentrate was determined. The researches are of practical importance, because of the liquefaction phenomenon of concentrates that are transported by the sea. This phenomenon is the cause of many accidents and even may lead the vessel to capsize.

Introduction

Maritime transport is one of the links in the supply chain of various cargoes, including solid bulk cargoes consisting of a combination of non-cohesive particles. These include fine-particle goods, such as ore concentrates that occur in maritime transport mostly in the form of solid bulk. According to the criterion of classification of goods they are classified as special cargoes otherwise known as specific cargoes belonging to a group of burdensome goods. Considering their high density, ore concentrates are included in a group of heavy goods and they are subject to classification as dangerous goods class MHB (Hazardous Materials in Bulk).

Ore concentrates, as loose free-flowing bulk cargoes are transported by the sea. Marine transport of those goods is associated with many risks due to the self-heating processes, particularly in concentrates containing impurities of sulfur compounds, misconduct during transport and reduction or loss of stability due to the cargo shifting which under certain conditions can go into a state of semi-fluid. This process is initiated by exceeding the limit of acceptable, transportable moisture content. This situation can cause movement of cargo inside holds as a result of the ship's lists on the waves and as a consequence loss of its stability.

Liquefaction phenomenon of mineral concentrates can occur even when goods are conveyed at a relative humidity below transportable moisture limit.

Sea transport of solid bulk cargoes

In the literature solid bulk cargoes are determined as bulk goods which are neither liquid nor gas. Ore concentrates are included in group of solid bulk cargoes transported in bulk by the sea.

These concentrates due to their inherent properties are dangerous fine-particle goods with considerable degree of fragmentation. This feature qualifies them as being able to liquidate. Additionally, the characteristic feature is that strongly absorb water.

Extreme conditions caused by phenomena occurring in this type of cargo, despite of following

IMO' recommendations, caused the need to look for other possibilities to limit the ability to liquidate these goods.

One of such solutions is the introduction of polymeric materials to goods which are hygroscopic [1]. According to M. Popek, starch materials absorb water from the space between the particles of the concentrate, thus reducing its moisture content and increasing value of transportable moisture limit. The use of polymeric materials limits the ability of copper ore concentrates to liquidate, which increases the safety of their transport [1].

Safety during maritime transport of solid bulk cargoes is defined by the rules contained in the code IMSBC[1].

The Code also discusses the relevant terminology closely related to moisture content in mineral concentrates [2]:

- **cargoes which may liquefy** – goods, in which moisture movement can occur in pores between particles and as consequence liquefaction, in case of cargo shipment with moisture content in excess of their transportable moisture limit;
- **flow moisture point** – the percentage of moisture content in the concentrate, as defined in relation to the wet concentrate at which a flow state develops under the prescribed method of test in a representative sample of the material;
- **flow state** – a state occurring when a mass of granular material is saturated with liquid to an extent that under the influence of prevailing external forces, such as vibration, shock or ship's motion, it loses its internal shear strength and behaves as a liquid;
- **moisture content** – portion of a representative sample consisting of water, ice or other liquid, expressed as percentage of the total wet mass of that sample;
- **moisture migration** – the movement of moisture contained in bulk materials caused by process of settling and consolidation of the cargo due to the vibration and ship's motion. Water is progressively displaced in some part or in whole cargo, which becomes the reason for the state of liquidity;
- **transportable moisture limit** (TML) – the maximum moisture content of the cargo, which is considered safe for carriage in ships not complying with the special provision of subsection 7.2.2 and 7.2.3 of the Code IMSBC. It is determined based on moisture limit (method using vibrating table) or based on the results obtained by the other methods approved by the relevant authorities of the port State and recognized as being parallel.

During the maritime transport due to the vibration of ship's hull associated with ship's motion, rolling and to the engines work, compaction of cargo (increasing of density) takes place in ore concentrates, which is related to the change in its characteristics affecting the formation of the liquefaction hazard and displacement.

The mechanism of transition of ore concentrate in semi-liquid state at vibrations is associated with a phenomenon called thixotropy. This phenomenon can occur even at relatively dry cargo.

During the thixothropy phenomenon, water contained in the concentrate as a result of previously discussed vibrations, moves the free spaces between the particles upwards. Water may appear on cargo surface. The upper layer of cargo which are saturated by moisture, become susceptible to liquefaction and may move along with ship's heeling. At gravitational falling of water, the lower layers of cargo can also be liquefied. Then the liquidation of both the upper and lower layers of cargo may also cause the loss of stability of the vessel [3].

Considering the safety aspect, it is important to determine the performance characteristics of ore concentrates, which determine their ability to liquidate. These include [1]:

- basic characteristics: density, bulk density, grain composition, humidity;
- the characteristics of derivatives: density volume of dry concentrate, porosity, degree of humidity, relative density, permeability.

Lack of the information and cargo data, i.e. moisture content, flow moisture point or transportable moisture limit, contributes to many accidents and hazards in maritime transport. A set of principles and rules for dealing with this type of cargoes is included in the code IMSBC. Then, a crucial parameter for the proper handling of cargo during transport by sea is flow moisture point.

Safety of cargo carriage in the logistic chain of that cargo handling is the most important element. Parameter, which is a guideline for accepting of a concentrate to maritime transport, is transportable moisture limit. In addition, the other important parameters are moisture content of concentrate and flow moisture point.

In the proper cargo handling, a good practice and awareness of people responsible for safe carriage of ore concentrates by the sea, are very important. The provisions and rules contained in the Code include research methodology for deter-

[1] Kodeks IMSBC – Code IMSBC. International Maritime Solid Bulk Cargoes Code.

mining flow moisture point, and guidance for accepting cargo by vessel. The ship's master may accept ore concentrate when the average current moisture content is below transportable moisture limit [4].

The behavior of ore concentrate during sea transport depends on a various factors. This will include: external forces, type of concentrate, size and shape of particles and type of substances filling intermolecular spaces.

An excessive amount of moisture in concentrate ore poses a threat to liquidation and transition into a liquid state. It generates muddy and fluid mass which has ability to shift towards ship's sides inside the holds which may increase displacement / list and lead to loss of the ship's stability.

Due to the safety of maritime transport of ore concentrates it is important to determine whether the moisture content in cargo does not exceed transportable moisture limit. This is a criterion for classification of concentrates to its loading to vessels. Units, such as cargo transport, should have a certificate specifying the level of moisture during transport of the cargo ship.

Experimental Section

The subject of researches were fractions of copper ore concentrate.

In order to determine the susceptibility to liquefaction of this concentrate, the grain composition were determined. The researches that have been carried out, took into account determination of water content and flow moisture point in copper ore concentrate.

All designations were conducted in six parallel repetitions.

Methodology and results of researches

Water content was determined by "Drier Method" (metoda suszarkowa) at temp. 105°C according to ISO 6496:2002. Flow moisture point was determined by "Flow Table" method consistent with the Code of IMSBC.

1. Water content determination method was based on examination of moisture content by "Drier Method", by drying the examined concentrate at 105°C to constant weight. Current, the actual moisture content of the test samples was calculated from the bellowed formula [5] and the results are given in table 1:

$$W = \frac{m_2 - m_3}{m_2 - m_1} \cdot 100 \ [\%] \qquad (1)$$

where:

m_1 – mass of vessel [g];

m_2 – mass of vessel with the examined concentrate [g];

m_3 – mass of vessel with the examined concentrate after drying in temp. 105°C [g].

Table 1. Determination of moisture content in copper ore concentrate [own study]

O.N.	Water content in hygroscopic sample [%]	Average value of water content in hygroscopic sample [%]
1.	10.33	10.08
2.	10.42	
3.	9.92	
4.	10.39	
5.	9.51	
6.	10.08	

The actual water content in the tested copper ore concentrate was 10.08%.

2. To carry out an analysis of the results of flow moisture point there was necessary to perform sieve analysis. Particle size composition, ie fragmentation was determined according to PN-ISO 4701:2001, by mechanical sieving.

Samples of concentrate with water content of 10.08% by a set of sieves with a mesh size of 4 mm; 1.2 mm; 0.75 mm; 0.3 mm using a mechanical shaker. The particle size fractions larger than 4 mm, within the ranges 1.2–4 mm, 0.75–1.2 mm, 0.3–0.75 mm and smaller than 0.3 mm were extracted from copper ore concentrate.

The fraction with particles larger than 4 mm was accounted for only 2 g, range 1.2–4 mm – 53 g, in the range 0.75–1.2 mm – 35 g, the fraction of 0.3–0.75 mm – 33 g, and the fraction having a particle less than 0.3 mm up to 60 g. The results are summarized in table 2.

Table 2. Particle size distribution of copper ore concentrate [own study]

Grain class [mm]	Mass of grain class [g]	Selection of [%]	
		Single class	Sumary
> 4	2	1.09	1.09
1.2 do 4	53	28.96	29.89
0.75 do 1.2	35	19.02	48.91
0.3 do 0.75	33	17.93	66.85
< 0.3	60	32.61	99.46
Sum	183	99.46	

Ore concentrates are not liquefiable, unless they contain at least 10% of particles of size less than or equal to 0.3 mm [6].

Copper ore concentrate contains a significant amount of fine fractions of size less than 1 mm (50.54%) for particles sizes from 0–0.75 mm which according to the Code IMSBC qualifies this cargo, as susceptible to liquefaction, if the humidity is above the TML (transportable moisture limit).

3. Determination of FMP (flow moisture point) for copper ore concentrate was made by method recommended by the Code IMSBC, that means by "Flow Table" method (Fig. 1).

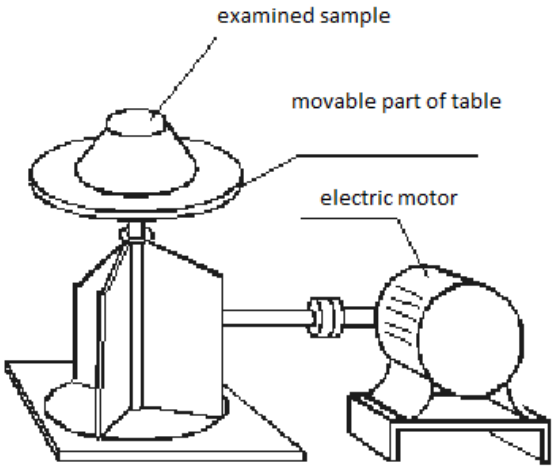

Fig. 1. "Flow Table" method for determining FMP in concentrates (own study based on [2])

"Flow Table" method is used for mineral concentrates and other solid bulk goods having a particle size smaller than 1 mm, designated for maritime transport [2]. The principle of the test is to determine the diameter of the cone after 25 strokes as a function of moisture content changes of the sample. Based on the results of researches and observations, FMP was adopted as a criterion for the occurrence of a muddy and smear weight of cargo, is adjacent to a vibration table after collection of the sample.

On the basis of performed six tests, as flow moisture point, was taken value 17.40% being the mean value of the final determinations.

$$FMP = 17.40\%$$

The moisture content in cargo, in the state assumed to be fit for sea transport in bulk should be in accordance with the IMSBC, less than 90% of moisture content corresponding to FMP.

Transportable moisture limit – TML was calculated by using the formula [2]:

$$TML = 90\% \; FMP$$

$$TML = 0.9 \cdot 17.40 = 15.66\%$$

Transportable moisture limit for copper ore concentrate was 15.66%.

Conclusions

Copper ore concentrate is solid bulk cargo with fine particles and considerable fragmentation. Maritime transport of that cargo is permitted at a given moisture content, in order to minimize the risk of hazards. Aspect of the safe transportation of ore concentrates is very important in the logistic chain and depends on correct assessment of cargo properties and on making appropriate decisions by personnel responsible for transport processes of that cargo.

The carried out researches allowed for determination of water content in a sample of copper ore concentrate, which was 10.08%. The fractions of less than 1 mm were 50.54% of the total, while the content of particles smaller than 0.3 mm was 32.61% of the total. This means that the presence of fine particle size fractions of less than 1 mm which were 50.54% and 10.08% water content does not pose the risk to liquefaction of the examined copper concentrate. This is due to the fact that its moisture content is below the limit of moisture transport which was 15.66%.

It should be recognized that, while transport by the sea this type of cargo liquefaction phenomenon may occur at humidity below transportable moisture limit. It may be caused due to the filtration capacity of water to the lower part of the holds, where the cargo slip may take place and uncontrolled movement.

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