NorthStandard

Bulk Cargo Liquefaction and Dynamic Separation

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Contents

Introduction

There have been a number of very serious incidents over recent years where vessels have experienced liquefaction or dynamic separation of cargo. These issues have sometimes led to a loss of stability and capsize. Cargoes such as iron ore fines, nickel ore, mineral concentrates, bauxite fines and others have all given rise to liquefaction or dynamic separation associated problems.

The International Maritime Solid Bulk Cargoes (IMSBC) Code provides definitions, tests and precautions for cargoes that may liquefy or dynamically separate. Liquefication risk has historically been associated with ore fines and metal ore concentrates, for which the IMSBC Code tests and recommendations are relatively straightforward to apply. However, any cargo containing fine material and moisture has the potential to liquefy or separate and the properties of such cargoes should be determined by the shipper.

Intense pressure from shippers, mis-description of cargoes, inadequate testing methods, lack of shipper knowledge and lack of crew awareness over the potential for liquefaction and dynamic separation in some cargoes have all contributed to recent incidents. The purpose of this briefing is to inform and advise members of the problems associated with liquefaction and dynamic separation in general.

What is Liquefaction?

The IMSBC Code defines cargoes which may liquefy as *"Cargoes which contain a certain proportion of fine particles and a certain amount of moisture. They may liquefy if shipped with a moisture content in excess of their transportable moisture limit."*

What actually happens?

In such a cargo composed of fine particles and containing moisture, the spaces between the particles are filled with both air and water. Whilst at sea the cargo is subject to forces due to the vibration and motions of the vessel. These forces cause the particles to move closer together and reduce the size of the spaces (voids) between the particles, which is known as consolidation. The water in the spaces between the particles is subject to a compressive force due to consolidation. As it is a liquid, the water between the particles cannot be compressed and is therefore driven to flow into nearby void spaces. However, if there is nowhere for the water to flow to, it becomes pressurised and exerts a force back against the particles. This has the effect of reducing the frictional force between the particles that would typically give the cargo its strength and stability. Where enough water is present and the pressure is allowed to increase without have the ability to dissipate, the resulting reduction in inter-particle friction can be sufficient to cause the cargo to flow like a liquid.

What is Dynamic Separation?

The IMSBC Code defines cargoes which may liquefy as *"Cargoes which contain a certain proportion of fine particles and a certain amount of moisture. They may liquefy if shipped with a moisture content in excess of their transportable moisture limit."*

What actually happens?

Dynamic separation occurs during a voyage where the moisture in the cargo rises to the surface of a stow as the cargo consolidates due to vibration and vessel motion. This is caused by a mechanism similar to liquefaction, but the cargo contains enough fine particles such that the void spaces between particles are very small and impedes the moisture flowing through the cargo. As the water becomes pressurised and begins to flow, fine particles are carried with it and create a slurry.

Unlike liquefaction where a portion of the cargo in its entirety flows like a liquid, dynamic separation generates a slurry of water and fine particles which is driven away from the consolidating portion of the stow to areas of lower pressure and collects on the top of the denser (consolidated) portion of the stow. In response to vessel motions, this slurry has a free surface effect causing incremental shifting of the centre of gravity in the hold, leading to a reduction of the vessels' metacentric height (GM) negatively effecting the ship's stability.

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The Australian Maritime Safety Authority (AMSA) produced a video explaining dynamic separation and its effects on the vessel, this can be viewed here. (Dynamic separation of bauxite (aluminium ore) in bulk cargo - YouTube)

What are the Consequences?

Cargoes that lose stability and flow due to liquefaction or dynamic separation have similar negative consequences as far as the ship is concerned. The effects may produce dangerous angles of list and in some instances the resulting loss of stability can be such that the vessel and the lives of those onboard are lost. It is therefore imperative that crews are aware of the types and condition of cargo prior to loading commencing that may give rise to either phenomenon.

How are these cargoes classified?

In the IMSBC Code cargoes that can liquefy or dynamically separate are classified as a **Group A** cargo. The IMSBC Code 2022 definition of a Group A cargo is:

"Group A consists of cargoes which possess a hazard due to moisture that may result in liquefaction or dynamic separation if shipped at a moisture content in excess of their transportable moisture limit."

SOLAS Requirements

The International Convention for the Safety of Life at Sea (SOLAS) Chapter VI – Carriage of Cargoes – provides the general framework for the carriage of all cargoes.

Shipper's duties

In respect of cargoes with particular hazards, such as liquefaction or dynamic separation, SOLAS is explicit in requiring the shipper to provide the master, or his representative, with the appropriate cargo information sufficiently in advance of loading to enable the necessary precautions for safe carriage to be put into effect. The format of such information is provided in the IMSBC Code 2022 Section 4.2.3. A typical form for the shipper's declaration is also included in IMSBC Code 2023 Appendix 5.

Additionally, there are specific provisions for additional information to be supplied for Group A cargoes in the form of a certificate of moisture content and transportable moisture limit (TML).

As such, shippers are obliged to provide appropriate cargo information to the master prior to loading commencing. To obtain this information, the shipper must arrange for the cargo to be properly sampled and tested.

Physical property tests on the cargo are meaningless unless they are conducted prior to loading commencing on truly representative samples. If such information is not given the master should **not** accept the cargo for loading.

Master's duties

Section 7.3.1.1 of the IMSBC Code, states that:

"Group A cargoes shall only be accepted for loading when the actual moisture content of the cargo is less than its TML."

Therefore, a master should not accept such a cargo for loading without first receiving the appropriate documentation certifying the moisture content and TML of the cargo with the moisture content shown to be less than the TML.

Terminal representative's duties

SOLAS Chapter VI, Part B, Regulation 7 deals with the loading, unloading and stowage of bulk cargoes and introduces the Code of Practice for the Safe Loading and Unloading of Bulk Carriers (BLU Code). The BLU Code is included as a supplement of the IMSBC Code.

The BLU Code, although primarily concerned with arrangements between the terminal and the ship to ensure safe and efficient cargo operations in port, does under Section 3.3.3 state that:

"The terminal representative should be satisfied that the ship has been advised as early as possible of the information contained in the cargo declaration as required by chapter VI of SOLAS 1974 as amended."

Terminal representatives bringing commercial pressure on masters to load their vessels before receiving the shipper's cargo declaration are acting in contravention of the BLU Code and therefore SOLAS. Masters are urged to resist such pressures.

It is a master's responsibility to ensure that the vessel is safely loaded: where the shipper's cargo declaration has not been received, the master has no visibility on the likely hazard properties of the cargo to be loaded.

If such declaration is not forthcoming a master should not commence loading and should immediately notify owners. Members should contact us for advice in such circumstances.

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Group A Cargoes and the IMSBC Code

The main reference for any ship operator or master when considering whether or not a cargo is likely to liquefy or dynamically separate is the IMSBC Code. As mentioned earlier the dangers associated with commonly shipped cargoes are listed within the Code – Group A cargoes are those that are likely to liquefy. Any cargo listed as Group A should be carried strictly in accordance with the provisions of the IMSBC Code.

However, the Code itself warns in section 1.2.1 that the schedules for individual cargoes are not exhaustive. It may be that some cargoes which can liquefy are not included in the Code, for example - river sand. Ship operators and masters should not automatically assume there is no risk of liquefaction or dynamic separation simply because it does not appear in the Code as Group A. Any bulk cargo containing the correct proportion of fine particles and sufficient moisture may liquefy or dynamically separate.

It is essential that masters and ship operators are familiar with the IMSBC Code.

Sampling and Testing Group A Cargoes for Safe Carriage

Testing of cargoes which may liquefy is detailed in IMSBC Code at Appendix 2. Six test methods are presented in the current edition: four of the tests use the Proctor/Fagerberg methodology which actually measures the parameters of liquefaction (methods 1.3 to 1.6).

Flow Moisture Point (FMP)

Is the maximum water content, expressed as a percentage, at which a sample of cargo will begin to flow. Cargoes with moisture content close to, equal to or in excess of the FMP may liquefy or dynamically separate. The FMP is determined using the flow table test (method 1.1) or penetration test (method 1.2).

Loading a cargo above, at or near its FMP represents an unacceptably high risk for vessels and for this reason a safety margin is included in the test methods – this gives the TML.

Transportable Moisture Limit (TML)

This is defined as 90% of the FMP value when determined by the flow table test (FTT) and the penetration test. When determined by the Proctor/Fagerberg method, it is defined as the critical moisture content at 70% or 80% degree of saturation depending up which of the four tests is being used.

From the ship operators and master's perspective, the TML of a representative sample of the cargo to be loaded and its actual moisture content are the important figures for the shipper to declare. It is a requirement of SOLAS that the average moisture content of a Group A cargo in any cargo space must not be higher than the TML. This is an important point: it is of little use to the vessel if an average moisture content of all cargo is provided. This may lead to dry cargo in some holds and cargo liable to liquefy or dynamically separate in others which will put the vessel at risk.

The TML test certification is usually considered in date for 6 months.

Moisture Content

The moisture content of the cargo is obtained by drying samples of the cargo in accordance with Section 4.6 and Appendix 2 of the Code. It is taken from samples independent of those collected for TML determination purposes but must also be based upon samples representative of the cargo range to be loaded.

If the moisture content of the cargo sampled is below the TML then the cargo should be safe to load.

Figure 1: A flow table for determining FMP

The moisture content values are usually considered valid for seven days since the date of sampling. This however should be questioned if there are any changes to the condition of the cargo in those seven days, for example the stockpile has been exposed to heavy rain or snow.

Shipper's declaration

Section 4 of the IMSBC Code requires the shipper of the cargo to provide the master with appropriate cargo information sufficiently in advance of loading to enable the precautions which may be necessary for the safe carriage of the cargo to be put into effect. The minimum information to be provided is listed in Section 4.2.2.

Bulk Cargo Liquefaction and Dynamic Separation (cont.)

This information includes both the TML of the cargo and its moisture content at shipment.

The vessel should resist pressure from shipper or terminal representatives to begin loading in advance of receipt of the shippers declaration, moisture content and TML certification. It is better to delay loading whilst awaiting these documents than to have to discharge unsuitable cargo loaded without the appropriate documentation. Such a discharge may be highly problematic due to the lack of suitable equipment, berth or due to local customs or other regulations. Terminals and shippers may simply be unwilling to accept the discharged cargo. For cargoes tested in accordance with the provisions contained in Appendix 2 of the IMSBC Code, the shipper's cargo declaration should be accompanied by a signed certificate stating the cargo's TML and moisture content.

Unfortunately, there have been many instances where the information provided by the shipper has stated that the cargo has been within the TML but which cargo has later proven to be liable to liquefy or dynamically separate. This can come about through poor sampling and testing procedures, changes in circumstance since testing was carried out, such as heavy rain, or through lack of understanding by shippers' representatives of the potential dangers posed to the vessel by spurious test results.

As such, even where the certificate states that cargoes are safe to load, masters and their officers must always be vigilant in monitoring the condition of the cargo as it comes onboard. Stockpiles of cargo can have different characteristics so vigilance throughout the duration of loading operations is necessary.

In the event of a dispute arising over the properties of the cargo intended for loading we would recommend that members consider the employment of an independent surveyor/ expert to assist the master. In such circumstances members should contact us for advice.

Sampling and testing of cargo

It is incredibly important that cargoes are sampled correctly. Any samples taken for testing must be representative of the cargo to be loaded onboard the vessel, that way the master knows the TML and moisture content is for the cargo in the holds. The IMSBC Code states that sampling and testing procedures should be developed based upon the cargo's properties. These procedures should be approved by the competent authority in the country of origin (or port of loading).

If there is any doubt as to the sampling and testing procedures, the master should also be given evidence (usually in the form of approval certification) of the competent authority's approval.

Section 4.3.3 of the IMSBC Code states:

"When a Group A cargo is carried, procedures for sampling, testing and controlling moisture content to ensure the moisture content is less than the TML when it is on board the ship shall be established by the shipper, taking account of the provisions of this Code. Such procedures shall be approved and their implementation checked by the competent authority of the port of loading. The document issued by the competent authority stating that the procedures have been approved shall be provided to the master or his representative."

Can test

Figure 2: Before

Figure 3: During

Figure 4: After - on this occasion, the test indicates a higher risk of liquefaction.

In order that the vessel can make a "check test" on the condition of the cargo the IMSBC Code describes a shipboard method known as the "can test". Master's can refer to the IMSBC Code, Section 8, for details.

Bulk Cargo Liquefaction and Dynamic Separation (cont.)

The test involves filling a can with the sampled cargo and repeatedly banging it on a hard surface. The appearance of the material at the end of the test can be used to form an opinion regarding the suitability of the material for shipment.

This test should not be a substitute for proper laboratory testing using an appropriate methodology. However, if can tests carried out on a cargo presented for loading indicate free moisture or fluid conditions, this may be a major warning sign that the cargo as a whole may be unsafe for carriage, so expert advice should then be sought. If shippers present significant amounts of material that indicate free moisture or fluid conditions, this is an indication that the cargo as a whole may be unsafe and that the documentation provided may be incorrect. It should also be noted that an apparent low-risk result from the can test (no visible free moisture or fluid condition) does not necessarily mean that the cargo is safe for shipment. A can test cannot show that a cargo is definitely safe for loading. Expert advice should always be requested where the master is uncertain or has any concerns.

Advice to Owners and Masters on Loading

Although it is the shipper's duty under SOLAS to test and certify that a cargo is safe to load, experience has shown that in some cases this does not always occur. Therefore, the actions of owners and masters before arrival and, most importantly, at the load port are crucial in ensuring that a vessel is protected from loading a cargo that may liquefy.

Masters and ship operators should always bear in mind the possibility that the information contained within the shipper's declaration, for whatever reason, may not accurately reflect the true condition of the cargo.

Documentation and information

Members must ensure that cargo interests have provided the necessary cargo documentation, that the information is up to date (moisture content should be taken within seven days of loading) and takes into account any recent events (e.g. rainfall) that may change the safety characteristics of the cargo. The master should be made fully aware of the characteristics of the cargo to be loaded.

The provision of the information to the vessel should ideally take place well in advance of loading to enable the master to prepare for the planned loading, including the appointment of surveyors and or cargo specialists to protect member's interests if thought necessary. Members should endeavour to make the master aware of any known problems with a particular cargo or of any recent precipitation at the load port or point of origin of the cargo.

There are no circumstances in which it is considered prudent to load a Group A cargo without first having received the appropriate cargo documentation relating to the cargo to be shipped on that vessel, including a properly completed shipper's declaration and signed TML and moisture content certificate issued by a suitably competent laboratory confirming that the cargo is safe to load.

Decision to load

The master's decision to commence loading is critical in avoiding problems associated with cargoes that liquefy. High loading rates mean that vessels can have many thousands of tonnes of cargo loaded in just a few hours.

To safeguard a vessel and its crew and to avoid the delays, disputes and other problems associated with discharging a cargo that is unsuitable for transportation the master must satisfy himself, as far as can be reasonably determined, as to the suitability of the cargo for loading.

If at all practicable the master should arrange to view the cargo stockpiles to be loaded onboard as the condition of the stockpiled material may indicate potential problems, such as exposure to recent rain fall, free moisture and fluid conditions.

Where doubt exists as to the characteristics of the cargo to be loaded the Master should delay the start of the loading operation and contact owners. In such circumstances it is advisable to appoint an independent surveyor or cargo specialist for advice. Always remember that removing unsuitable cargo from the vessel can be highly problematic.

In the case of Group A cargoes and which have resulted in problems for vessels, such as iron ore fines from India, nickel ore from the Philippines or Indonesia during the south-west monsoon season, it will be to owners' advantage to appoint independent surveyors to sample and inspect the cargo to be loaded prior to a vessel's arrival and to assist the master throughout the load.

Awareness during loading

As the first cargo comes aboard the vessel the master and his officers should endeavour to collect samples on representative portions of the cargo, taking into consideration any variability composition (i.e different colour, wet, sticky and/or finer portions) and test them using the can test as described in Section 8 of the IMSBC Code. Ideally, further such testing should take place at regular and frequent intervals during loading. The location of the sample collection may be critical. A wet cargo exposed to sunshine for a few days may be dry on the surface but still have high moisture content at the base or at intermediate layers. It is therefore important that a cross section of the cargo composition is sampled to ensure that any variability is captured.

Bulk Cargo Liquefaction and Dynamic Separation (cont.)

The characteristics of the cargo within the hold should also be monitored for signs of a high-risk cargo, including:

- Visible moisture and/or fluid conditions from a properly executed can test.
- Excess moisture in the cargo.
- Fine, sticky and/or saturated material.
- Cargo stow slumping or flattening in the hold.
- Cargo spatter on the hold bulkheads. This should be treated with caution as cargo dropped from height may spatter anyway, however, if the grab is lowered into the hold the spatter can be masked.

When a master is in any doubt as to the suitability of the cargo for safe transportation, loading should be suspended, the owners informed, contact with the Club established and an independent surveyor or cargo specialist called in to assist the master with the further detailed assessment of the cargo.

Weather conditions during the load may also require the suspension of the loading operation. Loading cargoes liable to liquefy during rainfall is an unnecessary risk.

Cargo suspected of being unsuitable for shipment and already on-board should be inspected by specialists, representatively sampled and then tested by an independent laboratory. If the cargo is found to have moisture content equal to or in excess of its TML, then the safest option is to discharge the cargo. This sounds simple but unfortunately experience has shown that once a vessel has loaded unsuitable cargo the discharging operations at the load port can be highly problematic. Commercial reluctance on the part of the shippers and ports to accept/unload unsafe cargo can lead to severe delays and extensive costs. In some cases, these situations can drag on for months. There may also be damage to valuable commercial relationships should such a dispute arise.

It is always best for the vessel's safety and in the owner's interest that cargo unsuitable for safe shipment is identified prior to loading commencing.

Where the vessel is engaged in carrying a cargo that is not listed in the IMSBC Code then Section 1.3 of the Code should be followed.

Cargo deterioration whilst at sea

Despite the provisions of SOLAS, the IMSBC Code and BLU Code, it is still the case that cargo unsuitable for safe transportation is loaded and carried. In recent years there have been a number of incidents involving the loss of vessels and of life that have been attributed to cargo deteriorating whilst the vessel at sea. There have also been numerous instances of vessels losing stability, but not capsizing, which are known to have been caused by liquefaction, dynamic separation and/or cargo shift.

The ISM Code requires that potentially hazardous situations are risk assessed and have procedures in place to deal with the situation should it occur. Clearly such cargo deterioration places the vessel in a hazardous situation and procedures to deal with potential occurrences should be developed if not already in place.

Whilst every such situation will have its own unique set of circumstances, as a minimum owners/vessel should:

- Ensure that detailed stability calculations are carried out before departure from the load port for every cargo loaded. The calculations will then serve as baseline data in the event of an incident.
- The master must immediately notify owners. Owners should seek the advice of a specialist in these circumstances. The likely effect of ballasting the vessel to correct a vessel's list needs to be calculated and carefully considered before any such operation takes place. Incorrect ballasting may exacerbate the situation causing a further reduction in stability. Even where ballasting has taken place and is successful in returning a vessel upright, the cargo onboard is still in a dangerous state and may further jeopardise the safety of vessel and crew.
- The vessel may need to implement safe passage planning and seek the nearest port of refuge.
- Often the surface moisture can be managed with the use of an operable submersible pump, so all vessels should ensure they have one available and working.

Bulk Cargo Liquefaction and Dynamic Separation (cont.)

Protect Your Interest

The loading and carriage of Group A cargoes takes place every day, all over the world and the vast majority of voyages pass off without incident. However, the potential consequences of loading a cargo that is unsuitable for carriage due to its inherent characteristics and moisture content are of such seriousness that vigilance when dealing with these cargoes can never be relaxed.

Familiarity with the IMSBC Code and awareness that its Annexes are not exhaustive is important. Always bear in mind that some cargoes

(a) do not appear in the IMSBC Code,

(b) their physical properties detailed in Appendix 1 are for guidance purposes only,

(c) their hazard classification may be incorrect *and*

(d) some of these cargoes may be high risk.

The best way to protect both the crew and the owner's interests is by ensuring that the provisions and advice of the IMSBC Code are followed at all times and by being vigilant before, during and after loading.

Disclaimer

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APPENDIX: EXEMPLAR SHIPPER'S CARGO DECLARATION

Australian Government
Australian Maritime Safety Authority

SHIPPER'S DECLARATION

Note: This form is not applicable if the cargo to be loaded requires a declaration under the requirements of SOLAS 1974, Chapter VII/R4, MARPOL 73/78 Annex III/R4, and the IMDG Code Chapter 5.4 (Documentation).
This form meets the requirements of SOLAS 1974, Chapter VI, Reg 2 (for general cargo, cargo in cargo units, cargo carried in solid bulk) and the IMSBC Code, section 4.2.

General Information

Shipper	Transport document number
Consignee	Carrier
Name/means of transport	Instructions or other matters
Port/place of departure	
Port/place of destination	

Cargo Information

General description of the cargo (For solid bulk cargo – type of material/particle size)	
Gross mass (kg/tonnes) General cargo: Bulk cargo: **Verified gross mass (kg/tonnes)** Cargo unit(s):	Relevant special properties of the cargo (eg highly soluble in water. For solid bulk cargo, see Section 4 of the IMSBC Code)

Solid Bulk Cargo Information

BCSN	
Specification of bulk cargo (if applicable) Stowage factor: Angle of repose: Trimming procedures: If potential hazard - chemical properties*: **eg: Class, UN number or MHB*	Group of the cargo ☐ Group A and B* ☐ Group A* ☐ Group B ☐ Group C ** For cargoes which may liquefy (Group A and Group A and B cargoes)*
Classification relating to MARPOL Annex V ☐ Harmful to the marine environment ☐ Not harmful to the marine environment HME information is for the Master to consider in relation to how cargo residues generated by this cargo may be handled and disposed of after discharge of the cargo.	Transportable moisture limit Moisture content at shipment
Additional certificate(s) (if required) ☐ Certificate of moisture content* ☐ Certificate of transportable moisture limit* ☐ Weathering certificate ☐ Exemption certificate ☐ Approval Certificate for the procedures for sampling, testing and controlling the moisture content for a solid bulk cargo that may liquefy (*see 4.3.3 of the IMSBC Code)* ☐ Other (specify): **May be combined into a single certificate*	

Declaration

I hereby declare that the consignment is fully and accurately described and that the given test results and other specifications are correct to the best of my knowledge and belief and can be considered as representative for the cargo to be loaded.		
Name/status, company/organisation of signatory	Place and date	Signature on behalf of shipper

Shippers' may deliver this declaration by fax or other electronic means. In any electronic transmission, where the signature of the declarant cannot be transmitted, full name of the declarant in capital letters must be provided on the form.

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