



Coal cargoes: Avoiding explosion and self-heating

Despite its contribution to greenhouse gas emissions, global coal consumption climbed to an all-time high in 2022 and is on track for a record-breaking 2023 and 2024. In this article, we focus on the safety measures needed to reduce the risk of fire and explosion when dealing with coal cargoes.

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According to [the International Energy Agency](#) (IEA) both China and India set new coal production records in March 2023, with China surpassing 400 million tonnes for the second time ever and India surpassing 100 million tonnes for the first time. Indonesia, the world's greatest exporter of thermal coal, exported almost 50 million tonnes in March 2023, a volume never shipped by any country before.

Coal is a fossil fuel with varying properties, depending on its source and handling before it is loaded aboard ship. Some coals can self-heat, and some emit methane – characteristics that can create fire and explosion risks to the crew, vessel and cargo. Gard has had several cases involving problematic coal cargoes, particularly those originating in Indonesia. While our Members involved in this trade are mindful of the risks of self-heating and the potential to emit methane, our particular focus in this article is how to deal with a cargo that is *both* self-heating and emitting methane, and how to monitor for both conditions.

The IMSBC Code and shipper's declarations

Coal cargoes are covered in the IMSBC Code schedule and appendix for coal. The Code requires that the shipper provides the Master with the characteristics of the coal in writing for all types of coals. This should as a minimum contain the coal's moisture content, sulphur content, size and whether the cargo may be liable to emit methane or self-heat. In our experience, it is common for coal cargo declarations to be inaccurate. For example, coal loaded in Indonesia / Borneo / Kalimantan often tends to self-heat, without being declared as such. Some charterparties or associated documents have required masters of vessels to treat such coal as liable to self-heat, regardless of the shipper's declaration. The IMSBC Code indicates that precautions for self-heating apply if the coal has been declared as liable to self-heat. However, it is usually best to treat coal as if it is liable to self-heat and emit methane in the first instance, and use initial, frequent gas measurements to check the actual situation and act accordingly. Given that the cargo declaration may be inaccurate, Gard's advice has been to treat all coal as self-heating until it is shown that it is not.

Methane emission and self-heating

Some coal may emit methane (CH₄), which can produce flammable mixtures with air / oxygen (O₂) in hold ullages, presenting an explosion risk. CH₄ emission is usually dealt with by ventilating to keep the level of CH₄ well below the minimum that will support flaming combustion or explosion. The minimum CH₄ or other flammable gas that will support an explosion is the 'lower explosive limit' (LEL), and 100 %LEL is the minimum that can produce an explosion in air.

Many types of coal tend to self-heat, which can lead to toxic atmospheres, ignition ('spontaneous combustion'), and production of flammable gases. Self-heating is due to reaction between the coal and O₂ in air which produces heat, carbon monoxide (CO), carbon dioxide (CO₂), breakdown products of coal including flammable gases, and reduced O₂ levels in [enclosed spaces](#) such as holds. Self-heating is usually dealt with by excluding air / O₂, by trimming stows flat and closing hatches and vents. These steps restrict O₂ entering the holds and the stows and, once the O₂ in the hold is used up, the self-heating reactions are reduced or stopped.

In some cases, although uncommon, coal can both self-heat and produce CH₄. This is more difficult to deal with because the two effects need opposite actions. Self-heating is controlled by depriving the coal of oxygen in a sealed hold while explosion risk due to methane emission is controlled by ventilation. The IMSBC Code does not give explicit instructions for this situation, but it is often (correctly) taken to indicate that ventilation should take priority, due to the acute nature of explosion risks. In this situation expert advice is usually appropriate, and more detailed comments are below.

Because self-heating can produce flammable gases, and gas detectors are usually calibrated for CH₄ and display results as CH₄, self-heating is sometimes misinterpreted as CH₄ emission. This can lead to holds being ventilated, which worsens the self-heating. Due to the potential for misinterpretation of flammable gases from self-heating, hereafter this article refers to CH₄ / flammable gas together.

Dealing with simultaneous self-heating and CH₄ / flammable gas emission is covered in the list of points below.

Safely handling coal cargo

Loading

- Coal that is liable to self-heat should not be loaded on board vessels if its temperature exceeds 55°C. This is because self-heating reaction rates increase very fast (exponentially) as temperatures rise. As shippers' declarations may not be reliable, proper temperature measurement before loading is very often appropriate, for example in Indonesia, even if the coal is not declared as liable to self-heat.
- Temperature measurement of the coal to be loaded needs to be done at multiple points, to pick up hot spots. The temperature should preferably be measured below the surface, because if there is any self-heating the bulk will be hotter than the surface. If that cannot be done, then freshly exposed coal should be measured before it has been able to cool. Infrared thermometers ('IR temperature guns') can help by providing surface temperatures remotely and quickly, but as with all equipment they must be used within their capabilities and according to the manufacturer's instructions. For example, most ships' IR thermometers indicate average temperature over a large spot size if the target is far away. Large spot sizes mean that other, cooler things such as bulkheads may be included and reduce the indicated temperature. Dust or water vapour in the air can also reduce IR temperature readings. As IR thermometers measure the surface, allow for the bulk being hotter.
- Once coal is on board, temperatures are more difficult to measure. Temperature sounding pipes within the holds are often used, but their readings are of limited value because bulk coal transmits heat poorly.
- The emphasis should preferably be on temperature measurement before loading, to get the best possible measurements and to avoid having to discharge hot coal that has been loaded mistakenly.
- The IMSBC Code indicates that coal stows should be trimmed 'reasonably level' to the hold boundaries. This is to minimise the exposed surface area, and to avoid cracks, hence minimising air entry and self-heating. Along with an accurate stowage plan, it is good practice to take photos of the coal stows at the completion of loading to show the final trim, and to record the ullage size.
- Once coal is loaded, avoid ignition sources such as smoking, hot work and chipping paint, in case flammable / explosive atmospheres are produced. Holds and adjacent spaces must not be entered without proper precautions to ensure that the atmosphere is safe, because coal often removes O₂ from air and produces toxic gases such as carbon monoxide (CO), a deadly, colourless, odourless, poisonous gas.
- If there are delays of more than a few hours with no loading, consider closing holds and measuring gases in the meantime, as below. This is to minimise self-heating, by limiting air / O₂ access to the coal.

Carriage

- Once holds are full, the IMSBC Code provides that, unless indicated otherwise, ventilate for the first 24 hours after departure from the load port, and measure gases once during this period, after closing vents for a suggested period of not less than 4 hours. With self-heating coal that might not be declared as such, venting may worsen self-heating. It is often best to measure gases early within the first 24-hour period, after closing vents for the suggested period for measurement, and to repeat gas measurements frequently thereafter until conditions are seen to be stable. This is to check early for excessive CH₄/ flammable gas (which indicates explosion risks), and CO (which indicates self-heating reactions, although not necessarily problematic self-heating). The initial gas results will indicate the correct approach, such as venting to deal with CH₄/ flammable gas, or keeping vents closed to address self-heating. For example, if no CH₄/ flammable gas is indicated early on, there is no reason to ventilate further, so vents should be closed, and gases monitored. Gas measurement equipment and procedures are critical for carriage of coal, and they are covered in a separate section below.
- It may well be appropriate to reduce the gas measurement frequency later, once the situation has stabilised, but at the minimum gas should be measured daily throughout the voyage.
- If CH₄/ flammable gas concentrations remain below 20 %LEL, then holds should remain closed and unventilated. This is to exclude air / O₂ and hence minimise the potential for self-heating.
- If CH₄/ flammable gas is increasing and above 20 %LEL, ventilation needs to be considered as a priority, to avoid explosion risks which are more acute than self-heating. However, the %LEL action level for ventilating also depends on the ventilation history, the O₂ and CO levels and other factors, for example those mentioned below. It is advisable to get expert advice if the CH₄/ flammable level is increasing and close to or above 20 %LEL.
- Ventilation can hide self-heating problems, by introducing a lot of air and diluting the hold gases. This can suppress CO measurement results, whereas CO is the best indicator of self-heating. Therefore, gas measurements need to be assessed carefully and ventilation needs to be controlled correctly, to avoid both explosion risks and self-heating.
- If gas measurements indicate that CO is rising above 50 parts per million (ppm) in unventilated holds, that indicates that the coal has propensity to self-heat. Expert advice is advisable if the CO level is above 50 ppm, as indicated in the IMSBC Code. In such cases gas measurements should be taken at least every 12 hours until the situation is stable. With self-heating coal, in the few days after loading, the CO level can commonly rise to hundreds of ppm, even above the CO measurement limit of the gas detector, which is commonly 500 ppm or 1,000 ppm. If there are high CO levels it is important to keep all vents and hatches closed and sealed, to exclude air / O₂, which suppresses self-heating reactions. Check for any leaks or open vents and close them as well as possible. If the holds are kept closed and sealed, typically these high CO concentrations fall steeply over the following days, once the air / O₂ in the hold is used up. Sealing holds applies unless ventilation is indicated by high CH₄/ flammable gas levels, to address explosion risks, as mentioned above.

- In cases of both self-heating and emission of CH₄ or other flammable gases, the IMSBC Code does not give explicit instructions. It is often (correctly) taken to indicate that ventilation should take priority, but ventilation should be limited to the minimum necessary to limit CH₄ or other flammable gases to a reasonable level. In such cases, expert advice is usually appropriate. For practical reasons, experts often assist remotely, particularly if adequate gas measurement equipment is already available on board. The usual approach is to ventilate just enough to keep the CH₄/flammable gas sufficiently below 100% LEL to provide a safety margin against explosions, while still minimising air / O₂ entry. For example, vent for a short time only, say 2 hours, and then re-close vents and check the %LEL again. The IMSBC Code indicates waiting for not less than 4 hours after closing vents, before measuring gases, but shorter intervals may be appropriate. The aim is to do the minimum venting (if any at all) to keep CH₄/flammable gas to an acceptable level while minimising air/ O₂ entering the holds.
- In such cases it may be appropriate to allow the CH₄/flammable gas level to become higher than the IMSBC Code's usual 20 %LEL action level for CH₄ emitting coal, while still maintaining an adequate safety margin against explosions. Any appropriate higher action level above 20 %LEL would depend on other factors such as the O₂ concentration, and would be determined with expert advice, frequent gas measurement and venting as needed. Again, as an example, if the O₂ level is low (below about 10% oxygen), this alone may provide a reasonable safety margin because the low oxygen prevents flaming combustion and explosion, even if flammable gases are at a high %LEL. At low O₂ levels, however, many flammable gas detectors are not reliable, as discussed in the section on gas measurement below. Also, if the CH₄/flammable gas level becomes high, it is important to consider what will happen when holds are eventually opened or ventilated, and whether air entry would cause the mixture of hold gases and air to be flammable / explosive.

Discharge

- For coal with any self-heating tendency, once the vessel arrives at the port of discharge it is recommended to keep all cargo holds and vents closed and to measure gases until the discharge operation is ready to start. This applies to all holds individually meaning those holds that are not actively being discharged should remain closed. Pre-discharge surveys should not cause holds to be opened, allowing air / O₂ entry to the holds, unless discharge is to commence very shortly, or gas measurements have shown that there is no self-heating tendency.
- If coal is showing signs of problematic self-heating, then it should be discharged all in one go, without delays. It is preferable to have a discharge plan to facilitate this, if it is possible within ship loading and stability limits.
- If there are any significant delays during discharge in any holds, consider re-closing those holds and measuring gases. The reason for this is to minimise exposure of the coal to air / O₂, thus minimising self-heating reactions. However, if ullages are large due to prior discharge, depending on the timing, closing holds may not help much, due to the large quantity of air / O₂ in the ullage.
- In case of severe self-heating or fire in coal, The IMSBC Code mentions avoiding using water when at sea. Our experience is that spraying water can help to suppress heating and fire, usually at anchor or alongside. Care must be taken to keep within loading and stability limits, for example by pumping out water to an appropriate tank. Fresh water is preferred because seawater is often detrimental to the end use of the coal.
- Severe self-heating or fire during discharge should not occur if the coal has been loaded and carried properly. However, if there is severe self-heating or fire then hot coal, smoke, high CO or low O₂ may prevent stevedores from entering holds to operate payloaders for the latter stages of discharge. As for loading and carriage, holds and adjacent spaces must not be entered for discharge without proper precautions to ensure that the atmosphere is safe. Spraying water on the coal, preferably fresh water, is sometimes used to reduce the effects of self-heating or fire enough to complete the discharge.

Gas and other measurements for coal

- Gas measurements are the required method (and the only reliable one) for monitoring coal during the voyage. Temperature measurements are of limited use after loading because they only indicate temperatures next to sounding pipes or bulkheads. Holds should not be opened to measure temperatures or gases.
- As well as gas measurements, check and report on any hot external surfaces, condensation from hatch coaming drains, smoke, or smells of burning, which can indicate self-heating or fire.
- A good daily record should be kept throughout the voyage, of the cargo hold ullage gas measurements, ventilation condition (open / closed), bilge level and pH.
- Ships' gas detectors are usually 4-gas types which measure O₂(in %), flammable gases (in %LEL), CO (in ppm), and hydrogen sulphide (in ppm). Usually, the flammable gas detectors respond to nearly all flammable gases, but they are calibrated with CH₄, and the results are reported as 'CH₄', in %LEL. It is important to remember that 'CH₄' readings do not necessarily indicate just methane, but potentially other flammable gases, which might be produced by self-heating.
- Gas detectors need to be calibrated at appropriate intervals, with records maintained. Preferably calibration gases should be on board to check the detector performance at regular intervals (a 'bump test').
- Gas detectors need to have a pump to draw in gas from the hold ullage through a tube, preferably through purpose-made sample points fitted in the hatch covers or coamings. The tube needs to seal properly to the gas meter and go well into the hold, at least 1 metre, to avoid the detector drawing in outside air from the sample point or nearby hatch joints. The IMSBC Code mentions metal tubes, but they may give unrepresentative readings if they are too short or draw in outside air for other reasons.
- Crew must know how to use gas detectors and take reliable gas measurements, covering all the points mentioned above.
- Because gas measurements are critical to indicate the correct measures for safe carriage of coal, it is best to have two or more gas detector devices. Also, gas sensors may fail after a lot of exposure to hold gases, hence a back-up is advisable. Initially, the gas concentrations should be measured with two different gas detectors at the same hold positions close together in time, to act as a check. This should be repeated every few days, or sooner if there are anomalies.
- Many flammable gas / CH₄ detectors do not work reliably at low O₂ concentrations, such as below 10% O₂. This must be borne in mind when considering gas measurement results. In such cases a simple splitter device [or dilution tube, e.g.: [Industrial Scientific 17041740 Dilution Tube](#)] can be used to feed about half fresh air and half ullage gas to the detector, so that O₂ in the gas reaching the detector is above 10%. Duplicate measurements without the splitter are needed, and a correct calculation is needed to obtain the true results.

Concluding remarks

Given that cargo declarations may be unreliable and faced with the prospect of catastrophic losses to people and property, it is important that care be taken at each stage, from loading to discharge, to independently monitor loading temperatures and, critically, gas levels on board. If the ship's crew or the Members are in any doubt, they should contact the Association for advice and assistance, either directly or through the local correspondent.

It should be noted that coal has other characteristics not addressed here. For example, some coal can also liquefy or produce acidic liquids which may corrode the vessel's structure. This is covered in the IMSBC Code. Finally, as indicated, coal is a cargo that depletes oxygen in closed spaces and may produce carbon monoxide. All those entering the holds and adjacent spaces, including crew and stevedores, must take appropriate measures to avoid asphyxiation.

See also Burgoynes: [Coal Cargoes - Some Recent Developments 9 March 2016](#)