Chapter 32

SHIPBOARD OPERATIONS

This Chapter takes the reader through a complete cycle of tanker loading and discharging operations, from a gas-free condition until a change of cargo is planned.

When a gas carrier first comes alongside a berth to carry out cargo handling operations, it is essential that the preliminary procedures be properly completed. In particular, the questions given in the Safety Check-List should always be addressed. In line with Check-List questions, cargo handling plans should be developed and agreed jointly. Furthermore, written procedures should be established for controlling ship/shore cargo flow rates and for procedures covering general emergencies. It is in accordance with these plans that safe operations, as outlined in this Chapter, can be ensured.

32.1 Sequence of Operations

Assuming a gas carrier comes directly from a shipbuilder or drydock, the general sequence of cargo handling operations is as follows.

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TANK INSPECTION
  ↓
DRYING
  ↓
INERTING
  ↓
GASSING-UP
  ↓
COOL-DOWN
  ↓
LOADING
  ↓
LOADED VOYAGE
  ↓
DISCHARGE
  ↓
BALLAST VOYAGE
  ↓
CHANGING CARGO
  ↓
PREPARATION FOR TANK INSPECTION OR DRYDOCKING
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32.2 Tank Inspection, Drying and Inerting

32.2.1 Tank Inspection

Before any cargo operations are carried out, it is essential that cargo tanks are thoroughly inspected for cleanliness; that all loose objects are removed; and that all fittings are properly secured. In addition, any free water must be removed. Once this inspection has been completed, the cargo tank should be securely closed and air drying operations may start.

32.2.2 Drying

Drying the cargo handling system in any refrigerated tanker is a necessary precursor to loading. This means that water vapour and free water must all be removed from the system. If this is not done, the residual moisture can cause problems with icing and hydrate formation within the cargo system. (The reasons are clear when it is appreciated that the quantity of water condensed when cooling down a 1000 m³ tank containing air at atmospheric pressure, 30°C and 100% humidity to 0°C would be 25 litres.)

Whatever method is adopted for drying, care must be taken to achieve the correct dew point temperature - see Table 27.3(b). Malfunction of valves and pumps due to ice or hydrate formation can often result from an inadequately dried system. While the addition of antifreeze may be possible to allow freezing point depression at deep-well pump suction, such a procedure must not substitute for thorough drying. (Antifreeze is only used on cargoes down to -48°C; propanol is used as a de-icer down to -108°C but below this temperature no de-icer is effective.) Tank atmosphere drying can be accomplished in several ways. These are described below.

Drying using inert gas from the shore

Drying may be carried out as part of the inerting procedure when taking inert gas from the shore (see Section 31.7) and this is now commonly done. This method has the advantage of providing the dual functions of lowering the moisture content in tank atmospheres to the required dew point and, at the same time, lowering the oxygen content. A disadvantage of this and the following method is that more inert gas is used than if it is simply a question of reducing the oxygen content to a particular value.

For pressurised tanks the procedure should include a leak test with some overpressure.

Drying using inert gas from tanker’s plant

Drying can also be accomplished at the same time as the inerting operation when using the tanker’s inert gas generator but satisfactory water vapour removal is dependent on the specification of the inert gas system. Here, the generator must be of suitable capacity and the inert gas of suitable quality - but the necessary specifications are not always a design feature of this equipment. The tanker’s inert gas generator is sometimes provided with both a refrigerated dryer and an adsorption drier which, taken together, can reduce dew points at atmospheric pressure to -45°C or below.

A shipboard nitrogen generator is much more efficient.
On board air-drying systems

An alternative to drying with inert gas is by means of an air-drier fitted on board. The principle of operation is shown in Figure 32.1. In this method, air is drawn from the cargo tank by a compressor or provided by the on board inert gas blower (without combustion) and passed through a refrigerated drier. The drier is normally cooled by R22 refrigerant. Here the air is cooled and the water vapour is condensed out and drained off. The air leaving the drier is, therefore, saturated at a lower dew point. Further reduction of the dew point can be achieved by a silica gel after-drier fitted downstream. Thereafter, the air may be warmed back to ambient conditions by means of an air heater and returned to the cargo tank. This process is continued for all ship tanks (and pipelines) until the dew point of the in-tank atmosphere is appropriate to carriage conditions.

![Figure 32.1 - Air Drying – operational cycle](image)

32.2.3 Inerting - Before Loading

Inerting cargo tanks, cargo machinery and pipelines is undertaken primarily to ensure a non-flammable condition during subsequent gassing-up with cargo. For this purpose, oxygen concentration must be reduced from 20.9 per cent to a maximum of five per cent by volume although lower values are often preferred - see Table 27.3(b).

However, another reason for inerting is that for some of the more reactive chemical gases, such as vinyl chloride or butadiene, levels of oxygen as low as 0.1 per cent may be required to avoid a chemical reaction with the incoming vapour. Such low oxygen levels can usually only be achieved by nitrogen inerting provided from the shore (see Sections 27.7 and 31.7.2).
There are two procedures which can be used for inerting cargo tanks: displacement or dilution. These procedures are discussed below.

**Inerting by displacement**

Inerting by displacement, also known as piston purge, relies on stratification of the cargo tank atmosphere based on the difference in vapour densities between the gas entering the tank and the gas already in the tank. The heavier gas (see Table 27.5) is introduced beneath the lighter gas at a low velocity to minimise turbulence. If good stratification can be achieved, with little mixing at the interface, then just one tank volume of the incoming inert gas is sufficient to change the atmosphere. In practice mixing occurs and it is necessary to use more than one tank-volume of inert gas. This amount may vary by up to four times the tank volume, depending on the relative densities of the gases together with tank and pipeline configurations. There is little density difference between air and inert gas (see Table 27.4); inert gas from a combustion generator is slightly heavier than air while nitrogen is slightly lighter. These small density differences make inerting by displacement difficult to achieve and usually the process becomes part displacement and part dilution (discussed below).
Inerting by displacement is an economical procedure as it uses the least amount of inert gas and takes the shortest time. However, it is only practical when mixing with the initial tank vapour can be limited. If the tank shape and the position of pipe entries are suitable for the displacement method, then results will be improved by inerting more than one tank at a time. This should be done with the tanks aligned in parallel. The sharing of the inert gas generator output between tanks reduces gas inlet speeds, so limiting vapour mixing at the interface. At the same time the total inert gas flow increases due to the lower overall flow resistance. Tanks being inerted in this way should be monitored to ensure equal sharing of the inert gas flow.

**Inerting by dilution**

When inerting a tank by the dilution method, the incoming inert gas mixes, through turbulence, with the gas already in the tank. The dilution method can be carried out in several different ways and these are described below:

**Dilution by repeated pressurisation**

In the case of Type ‘C’ tanks, inerting by dilution can be achieved through a process of repeated pressurisation. Each repetition brings the tank nearer and nearer to the oxygen concentration of the inert gas. Thus, for example, to bring the tank contents to a level of five per cent oxygen within a reasonable number of repetitions, inert gas quality of better than five per cent oxygen is required.

It has been found that quicker results will be achieved by more numerous repetitions, each at low pressurisation, than by fewer repetitions at higher pressurisation.

**Continuous dilution**

Inerting by dilution can be carried out as a continuous process. Indeed, this is the only diluting process available for Type ‘A’ tanks which have very small over-pressure or vacuum capabilities. For a true dilution process, (as opposed to one aiming at displacement) it is relatively unimportant where the inert gas inlet or the tank efflux are located, provided that good mixing is achieved. Accordingly, it is usually found satisfactory to introduce the inert gas at high speed through the vapour connections and to discharge the gas mixture via the bottom loading lines.

Where a number of tanks are to be inerted, it may be possible to achieve a reduction in the total volume of inert gas used, and the overall time taken, by inerting tanks one after the other in series. This procedure also inert pipelines and equipment at the same time. (On some tankers, cargo and vapour pipeline arrangements may prevent more than two tanks being linked in series.) The extra flow resistance of a series arrangement will decrease the inert gas flow rate below that achievable when inerting tanks individually.

As can be seen from the foregoing discussion, the optimum arrangement for inerting by dilution will differ from tanker to tanker and may be a matter of experience.
**Inert gas - general considerations**

It can be seen from the preceding paragraphs that inert gas can be used in different ways to achieve inerted cargo tanks. No one method can be identified as the best since the choice will vary with tanker design and gas density differences. Generally, each individual tanker should establish its favoured procedure from experience. As already indicated, the displacement method of inerting is the best but its efficiency depends upon good stratification between the inert gas and the air or vapours to be expelled. Unless the inert gas entry arrangements and the gas density differences are appropriate to stratification, it may be better to opt for a dilution method. This requires fast and turbulent entry of the inert gas, upon which the efficiency of dilution depends.

Whichever method is used, it is important to monitor the oxygen concentration in each tank from time to time, from suitable locations, using the vapour sampling connections provided. In this way, the progress of inerting can be assessed and, eventually, assurance can be given that the whole cargo system is adequately inerted.

While the above discussion on inerting has centered on using an inert gas generator, the same principles apply to the use of nitrogen. The use of nitrogen may be required when preparing tanks for the carriage of chemical gases such as vinyl chloride, ethylene or butadiene. Because of the high cost of nitrogen, the chosen inerting method should be consistent with minimum nitrogen consumption.

**Inerting prior to loading ammonia**

Modern practice demands that ships' tanks be inerted with nitrogen prior to loading ammonia. This is so, even though ammonia vapour is not readily ignited.

Inert gas from a combustion-type generator must never be used when preparing tanks for ammonia. This is because ammonia reacts with the carbon dioxide in inert gas to produce carbamates. Accordingly, it is necessary for nitrogen to be taken from the shore as shipboard nitrogen generators are of small capacity.

The need for inerting a ship's tanks prior to loading ammonia is further underscored by a particular hazard associated with spray loading. Liquid ammonia should never be sprayed into a tank containing air as there is a risk of creating a static charge which could cause ignition. (Mixtures of ammonia in air also introduce an additional risk as they can accelerate stress corrosion cracking - see Section 27.5.)
32.3 Gassing-up

Gassing-up is absolutely necessary if a cooling plant is to be used since cooling plants cannot handle inert gases.

Gassing-up operations are undertaken using cargo supplied from the shore. At certain terminals, facilities exist to allow the operation to be carried out alongside but these terminals are in a minority. This is because the venting of hydrocarbon vapours alongside a jetty may present a hazard and is, therefore, prohibited by most terminals and port authorities.

Thus, well before a tanker arrives in port with tanks inerted, the following points must be considered by the Master:

- Is venting allowed alongside? If so, what is permissible?
- Is a vapour return facility to a flare available?
- Is liquid or is vapour provided from the terminal for gassing-up?
- Will only one tank be gassed-up and cooled down initially from the shore?
- How much liquid must be taken on board to gas-up and cool-down the remaining tanks?
- Where can the full gassing-up operation be carried out?

Before commencing gassing-up operations alongside, the terminal will normally sample tank atmospheres to check that the oxygen is less than five per cent for LPG cargoes (some terminals require as low as 0.5 per cent) or the much lower concentrations required for chemical gases such as vinyl chloride - see Table 27.3(b).
Where no venting to atmosphere is permitted, a vapour return facility must be provided and used throughout the gassing-up operation. In this case, either the tanker’s cargo compressors or a jetty vapour blower can be used to handle the efflux. Some terminals, while prohibiting the venting of cargo vapours, permit the efflux to atmosphere of inert gas. Thus, if a displacement method of gassing-up is used - see Section 32.2.3 - the need for vapour return to shore may be postponed until cargo vapours are detected at the vent riser. This point may be considerably postponed if tanks are gassed-up one after the other in series.

Figure 32.3(b) - Gassing-up cargo tanks using vapour from shore

Where a terminal supplies a liquid for gassing-up, it should be loaded at a carefully controlled rate. It is then passed through the tanker’s vaporiser. Alternatively, the liquid may be allowed to vaporise in the ship’s tanks. If vapour is supplied, this can be introduced into the tank at the top or bottom depending on the vapour density (see Table 27.5). Figures 32.3(a) and 32.3(b) show typical gassing-up operations using liquid from shore and vapour from shore, respectively.

When a tanker arrives alongside with tanks containing a cargo vapour which requires to be replaced with the vapour of a different grade, then the terminal will normally provide a vapour return line. The vapours taken to the shore will be flared until the desired vapour quality is achieved in the tanks. At this point cool-down can begin.
Recent developments have been made in LPG vapour recovery systems. Such systems are using the energy obtained from vapourising liquid nitrogen to reliquefy the cargo vapour returned from the tanker, either during gassing-up operations or during inerting operations, (see Section 32.9.3) thus avoiding any venting of hydrocarbon gases. The skid mounted unit would receive liquid nitrogen from a truck, vapourise it for delivery to the tanker and at the same time reliquefy the return cargo vapour for storage and further usage.

32.4 Cool-Down

Cool-down - refrigerated tanker

Cooling down is necessary to avoid excessive tank pressures (due to flash evaporation) during bulk loading. Cool-down consists of spraying cargo liquid into a tank at a slow rate. The lower the cargo carriage temperature, the more important the cool down procedure becomes.

Before loading a refrigerated cargo, the cargo tanks must be cooled down slowly in order to minimise thermal stresses. The rate at which a cargo tank can be cooled, without creating high thermal stress, depends on the design of the containment system and is typically 10°C per hour. Reference should always be made to the tanker's operating manual to determine the allowable cool-down rate.

The normal cool-down procedure takes the following form. Cargo liquid from shore (or from deck storage) is gradually introduced into the tanks either through spray lines, if fitted for this purpose, or via the cargo loading lines. The vapours produced by rapid evaporation may be taken ashore or handled in the tanker's reliquefaction plant. Additional liquid is then introduced at a rate depending upon tank pressures and temperatures. If the vapour boil-off is being handled in the tanker’s reliquefaction plant, difficulties may be experienced with incondensibles, such as nitrogen, remaining from the inert gas. A close watch should be kept on compressor discharge temperatures and the incondensible gases should be vented from the top of the condenser as required (see Section 32.6).
As the cargo containment system cools down, the thermal contraction of the tank combined with the drop in temperature around it tend to cause a pressure drop in the hold and interbarrier spaces. Normally, pressure control systems supplying air or inert gas will maintain these spaces at suitable pressures but a watch should be kept on appropriate instruments as the cool-down proceeds.

Cool-down should continue until boil-off eases and liquid begins to form in the bottom of the cargo tanks. This can be seen from temperature sensors. At this stage, for fully refrigerated ammonia for example, the pool of liquid formed will be at approximately -34°C while the top of the tank may still be at -14°C. This gives a temperature difference of 20°C. The actual temperature difference depends on the size of the cargo tank and the spray nozzles positions.

Difficulties that may occur during cool-down can result from inadequate gassing-up (too much inert gas remaining) or from inadequate drying. In this latter case, ice or hydrates may form and ice-up valves and pump shafts. In such cases, antifreeze can be added, provided the cargo is not put off specification, or the addition will not damage the electrical insulation of a submerged cargo pump. Throughout the cool-down, deepwell pump shafts should be turned frequently by hand to prevent the pumps from freezing up.
Once the cargo tanks have been cooled down, cargo pipelines and equipment should be cooled down. Figure 32.4 shows the pipeline arrangement for tank cool-down using liquid supplied from the shore.

**Cool-down - semi-pressurised tankers**
Most semi-pressurised ships have cargo tanks constructed of steels suitable for the minimum temperature of fully refrigerated cargoes. However, care must be taken to avoid subjecting the steel to lower temperatures. It is necessary to maintain a pressure within the cargo tank at least equal to the saturated vapour pressure corresponding to the minimum allowable steel temperature. This can be done by passing the liquid through the cargo vaporiser and introducing vapour into the tank with the cargo compressor. Alternatively, vapour can be provided from the shore.

### 32.5 Loading

#### 32.5.1 Loading - Preliminary Procedures

Before loading operations begin, the pre-operational ship/shore procedures must be thoroughly discussed and carried out. Appropriate information exchange is required and the relevant parts of the *Safety Check List* should be completed. Particular attention should be paid to:

- The setting of cargo tank relief valves and high alarm pressures.
- Remotely operated valves.
- Reliquefaction equipment.
- Gas detection systems.
- Alarms and controls, and
- The maximum loading rate.

This should all be carried out taking into account restrictions in ship/shore systems.

The terminal should provide the necessary information on the cargo, including inhibitor certificates where inhibited cargoes are loaded (see Section 27.8). Any other special precautions for specific cargoes should be made known to tanker personnel. This may include the lower compressor discharge temperatures required for some chemical gas cargoes (see Section 32.6). Where fitted, variable setting pressure relief valves, high tank pressure alarms and gas detection sample valves should be correctly set.

The ballast system for gas carriers is totally independent of the cargo system. Deballasting can, therefore, take place simultaneously with loading, subject to local regulations. Tanker stability and stress are of primary importance during loading. Procedures for these matters are in accordance with normal tanker practice.
The tanker’s safety

Trim, stability and stress

The cargo plan should allow for distribution within the tanker in order to achieve acceptable structural stress and the required trim to meet safe stability conditions when underway. For these purposes, the weight of the cargo in each tank will need to be known. For tanker stability purposes, the weight in question is the true weight-in-air.

The weight-in-air of liquefied gases, calculated for cargo custody purposes, is not exact in that the cargo vapour in these calculations is assumed to be liquid of the same mass as the vapour. Thus, the air buoyancy of the cargo vapour spaces has been neglected. However, for practical purposes concerning a tanker’s stability calculation, this may be ignored.

Often gas carriers, as part of the statutory requirements, are provided with stability data, including worked examples showing cargo loaded in a variety of ways. In conjunction with consumables such as fresh water, spare parts and bunkers on board, these conditions provide cargo storage guidelines to tanker’s personal in order to maintain the tanker in a safe and stable condition. Additionally, as part of the requirements to obtain a Certificate of Fitness in compliance with the Gas Codes, the stability conditions must be such that, in specified damaged conditions, the tanker will meet certain survival requirements. It is, therefore, essential that all relevant guidance concerning the filling of cargo tanks be observed.

Figure 32.5 - Loading with vapour return
32.5.2 Control of Vapours During Loading

The control of cargo vapours during loading can be carried out by using:

- A vapour return line to the shore coupled to a gas compressor.
- The tanker’s reliquefaction plant for liquid return to the ship’s tanks, or
- Both of the above.

When loading with a vapour return line in use, the loading rate is independent of the capacity of the ship’s reliquefaction plant and is governed by:

- The flow rate acceptable to the tanker and terminal, and
- The capacity of the cargo vapour compressor.

For fully refrigerated or semi-pressurised LPG tankers, a vapour return line is normally connected to the tanker’s vapour manifold but this is most often put in place for safety relief purposes. Normal loading practice on such tankers is to load through the liquid header, to draw off excess vapour via the vapour header, to operate the reliquefaction plant and to return the liquid to the ship’s tank via the condensate return line.

![Figure 32.6 - Loading without vapour return](image)
This operation controls cargo boil-off and ensures that tank pressure limits are not exceeded. The pipeline arrangement is shown in Figure 32.6. The introduction of a reliquefaction plant in the system can mean that loading rates are restricted by the capacity of the machinery. It is in this sense that the vapour return line acts as a safety device; should tank pressures become excessive, the tanker’s vapour manifold valve can be opened to relieve the situation. (For pressurised LPG carriers, the system should be similar to that described in this paragraph, and a vapour return should be fitted for safety relief purposes. However, a reliquefaction system is not fitted to such tankers and loading is normally achieved by shore pumps creating sufficient pressure to allow cargo tank vapour to continuously condense into the bulk liquid.)

Where refrigerated storage is found in a terminal, the terminal’s reliquefaction capacity is usually greater than that provided on board tanker. As a result, where an LPG vapour return is used loading rates can be higher than those described in the previous paragraph. However, while advantageous, such systems for LPG are relatively rare.

A problem experienced when using vapour returns in the LPG trades is that terminals can be concerned about the vapour quality to be returned to the shore. This is especially so at the early stages of loading. Terminal personnel can be concerned about residual nitrogen which acts as an incondensible during reliquefaction. They may also be concerned about contamination with vapours from previous cargoes. It is also difficult to account for the vapour returned to shore, especially if it is flared. This can lead to an overstatement of the Bill of Lading quantity, unless credit is given for the returned vapour. For these reasons it is unusual to find LPG terminals accepting return gas other than for safety reasons and then only to a flare.

32.5.3 Loading - Early Stages

Loading refrigerated tankers

When liquefied gas is being loaded, it is necessary to consider the location, pressure, temperature and volume of the shore tanks as well as the terminal’s pumping procedures. Fully refrigerated tankers usually load from fully refrigerated storage where tanks typically operate at a pressure of approximately 60 millibars. This pressure will allow the cargo at the bottom of a full shore tank to sustain a temperature perhaps one degree Centigrade warmer than its atmospheric boiling point.

When this cargo is pumped to the jetty, the pumping energy required for transfer is dissipated in the liquid as heat, to which must be added the heat flow into the liquid through the pipelines. The cargo may, therefore, arrive on the tanker at an even warmer temperature. When loading without a vapour return line being used, the vapour which is displaced by the incoming liquid must be reliquefied on board. The power required for this, and to compensate for the pumping energy and the heat flux through the insulation, may leave little capacity for cooling the cargo during loading.
Therefore, as can be seen from the foregoing paragraphs, the early stages of loading can be critical, particularly where significant distances exist between the storage tank and jetty. The ship’s tank pressures must be regularly checked and on no account should relief valves be allowed to lift. Loading rates should be reduced, and if necessary stopped, when difficulties are experienced in maintaining acceptable tank pressures. In some ports in hot countries, where the terminal has long pipelines, this feature can be difficult to overcome. Under these circumstances, cargo stoppage would allow the pipeline contents once again to rise in temperature. Accordingly, in such ports, cargo flow should be maintained as long as it is safe to do so until cold product can be received on board at which time tank pressures will fall.

A rise in ship’s tank pressure in the early stages of loading can also be controlled to some extent by loading limited quantities of liquid into the cargo tank via the top sprays, if fitted. This will help to condense some of the cargo vapours.

**Loading pressurised tankers**

Pressurised tankers normally arrive at a loading terminal having cargo tanks at atmospheric pressure. Firstly, the tanker requests vapours from the shore to purge any remaining nitrogen or contaminants from the tanks. This also allows the equalisation of tanker and shore pressures. Thereafter, the method used is to start loading in one tank at a high flow rate via the bottom line to avoid local low temperatures.

In this case, as the liquid is allowed through, local flash-cooling can occur and it is important to ensure that at no time, tank or pipeline temperatures are allowed to fall below design limitations.

**Loading pressurised tankers from refrigerated storage**

The cargo tanks on fully pressurised tankers are made from carbon steel which is only suitable for a minimum temperature of between 0°C and –10°C. In contrast, LPG when stored in the fully refrigerated condition is maintained at the temperatures given in Table 27.5. Consequently, some refrigerated cargoes require considerable heating prior to loading on such tankers. Given that fully pressurised tankers may not have cargo heaters fitted on board, all heat input must be provided by pumping through heaters fitted on shore.

Of course, on a pressurised tanker, having loaded a cargo at close to 0°C, the cargo may warm up further during the voyage in accordance with ambient conditions. The Gas Codes only allow cargo to be loaded to such a level that the tank filling limit will never be more than 98 per cent at the highest temperature reached during the voyage. This means that, during pre-loading discussions, tank topping-off levels must be established to allow sufficient room for liquid expansion into the vapour space while on voyage.
Loading semi-pressurised tankers from refrigerated storage

The cargo tanks on semi-pressurised tankers are usually constructed of low temperature sheets able to accommodate fully refrigerated propane at temperatures of between -40°C and -50°C - or even for ethylene carriers at -104°C. Refrigerated cargoes can therefore be loaded directly to such tankers without heating. In addition, these tankers can usually maintain fully refrigerated temperatures on voyage and this is often done to gain more space so that a greater weight of cargo can be carried. The tank pressure must however always be maintained slightly above atmospheric. Temperatures of sub-cooled products under vacuum conditions can reach levels much lower than what is acceptable for the tank material. However, when discharge to pressurised storage is planned, this is conditional on the tanker having suitable equipment to warm the cargo. On semi-pressurised tankers, the cargo is occasionally allowed to warm up during the loaded voyage and in this case, a similar procedure to that described for fully pressurised tankers applies.

Terminal pipeline system and operation

Where a terminal can expect to load fully pressurised tankers not fitted with their own heaters, in-line equipment fitted to terminal pipeline systems is needed. This usually comprises the following:

- Shore tank.
- Cargo pump.
- Booster pump.
- Cargo heater.
- Suitably sized loading arm.

When considering a refrigerated terminal loading a fully pressurised tanker, given that loading temperatures on these tankers are limited to about 0°C, loadings can normally be managed by pumping through the refrigerated pipelines rated at 19 bar.

Operation of the system takes the following form: Firstly, until back pressure starts to build up from the tanker, loading is carried out by pumping only through the cargo heater then, as the back pressure increases, the booster pump is also brought into operation.

At the start of loading, the pressure in a ship's tank should be at least 3 bar. This pressure will limit flashing-off and sub-cooling as the first liquid enters the tank. At this time, in-tank cargo temperatures should be carefully watched. Practical observation is also of value, with the sighting of ice formation on pipelines acting as a warning that temperatures on board the tanker are falling below safe levels. In such cases, loading must be stopped until temperatures increase and the problem is resolved.

Small tanker problems at large berths

A primary concern for the loading of small tankers is that refrigerated storage is most often designed for large ship/shore operations. At the jetty, this means that mooring plans must be properly adapted to accommodate the very different mooring patterns from small tankers and that loading arms or hoses are of a size suited to the operation.
Large loading arms can introduce difficulties on small tankers. If the berth is in an exposed area, a small tanker (being more sensitive, than a larger tanker, to the sea state) may roll and pitch at the berth. The loading arm has to keep pace with these fast movements and this is quite a different question from any slow changes (say tidal) which may be accommodated under normal design considerations. Here, the inertia of the loading arm has to be taken into account. At present, such dynamic forces are not considered in loading arm design and manufacturers leave this for terminal managers to address in operational procedures. In such cases, a possible solution is the use of cargo hose.

32.5.4 Bulk Loading

Depending on the efficiency of the earlier gassing-up operation, significant quantities of incondensible gases may be present in tank atmospheres and, without vapour return to shore, these incondensibles will have to be vented via the tanker's purge-gas condenser (where fitted) or, alternatively, from the top of the cargo condenser. Figure 31.17 shows a purge-gas condenser arrangement. Care must be taken when venting incondensibles to minimise venting of cargo vapours to the atmosphere. As the incondensibles are vented, the condenser pressure will drop and the vent valve should be throttled and eventually closed.

A close watch should be kept on the ship's cargo tank pressures, temperatures, liquid levels and interbarrier space pressures, throughout the loading operation. Monitoring of liquid levels may present difficulties when the reliquefaction plant is in operation. This is because the liquid in the tank is boiling heavily at these times and, as a result, vapour bubbles within the liquid increase its volume, thus giving false readings when using float-type ullage gauges. Accurate level monitoring can be achieved by suppressing boiling and this can be done by temporarily closing the vapour suction from the tank.

Towards the end of loading, transfer rates should be reduced as previously agreed with shore personnel in order to accurately top-off tanks. On completion of loading, tanker's pipelines should be drained back to the cargo tanks. Remaining liquid residue can be cleared by blowing ashore with vapour, using the tanker's compressor. Alternatively, this residue may be cleared by nitrogen injected into the loading arm to blow the liquid into the ship's tanks. Once liquid has been cleared and pipelines have been depressurised, manifold valves should be closed and the hose or loading arm disconnected from the manifold flange.

In many ports it is a requirement, before disconnection takes place, for the hard arm, hose and pipelines at the manifold to be purged free from flammable vapour.

The relief valves of some tankers have dual settings to allow higher tank pressures during the loading operation. If relief valve settings are altered by changing the pilot spring, then the procedure must be properly documented and logged and the current MARVS must be prominently displayed. Relief valves must be reset before the tanker departs. When relief valve pressure settings are changed, high pressure alarms have to be readjusted accordingly.
32.5.5 Cargo Tank Filling Limits

The goal of filling limits is:

- Economical and safe use of tank capacity.
- To avoid overfilling of tanks, in this respect more than 98 % is seen as overfilling.
- To avoid tank failure in the exceptional case of fire conditions.

The use of different settings of safety valves should be avoided as far as practical or only with additional safety procedures.

Tanks should be provided with double safety valves with a manual valve under each safety valve. Both safety valves should be in the open position under normal conditions. There should be means to avoid the possibility to close both valves at the same time.

Chapter 15 (amended 1994) of the IGC code gives guidance for “best practice” on how to determine the maximum filling limits. This includes the required technical lay-out and procedures.

**Short description of the IGC Code regulation:**

The large thermal coefficient of expansion of liquefied gas necessitates requirements for maximum allowable filling limits for cargo tanks in order to avoid over filling of the cargo tanks.

Filling limits differ and depend on: product, transport conditions and regions. For particular regions there may be prescribed filling conditions which must be adhered to.

The latest developments for determining filling limits are laid down in the amended Chapter 15 of the IGC code.

For the purpose of this Chapter the following definitions apply:

1. Reference Temperature means the highest temperature which may be reached upon termination of loading, during transport, or during unloading, under the ambient design temperature conditions.

2. Filling limit (FL) expressed in % means the maximum allowable liquid volume in a cargo tank relative to the tank volume when the liquid cargo has reached the reference temperature.

3. Loading limit (LL) expressed in % means the maximum allowable liquid volume relative to the tank volume to which a tank may be loaded in order to avoid the liquid volume exceeding the allowable filling limit in service.

The administration may allow a higher filling limit than the limit of FL = 98% specified at the reference temperature, taking into account the shape of the tank, arrangements of pressure relief valves, accuracy of level and temperature gauging and the difference between the loading temperature and the reference temperature, provided the conditions specified in the IGC Code, Chapter 8.2.17 are maintained.
The maximum loading limit (LL) to which a cargo tank may be loaded is determined by the following formula:

\[
LL = \frac{\rho_R}{\rho_L} \text{FL}
\]

where:

- \( \text{FL} \) = filling limit as specified
- \( \rho_R \) = relative density of the cargo at the reference temperature.
- \( \rho_L \) = relative density of the cargo at the loading temperature and pressure.

**Information to be provided to the Master**

The maximum allowable tank loading (LL) for each tank should be indicated for each product which may be carried, for each loading temperature which may be applied and for the applicable maximum reference temperature, on a list to be provided by the administration. The pressure at which the pressure relief valves have been set should also be stated on the list. A copy of the list should be permanently kept on board by the Master.

The use of the above formula requires a special layout of the venting system which is laid down in Chapter 8 of the Gas Code.

There are good safety reasons for minimising cargo shut-out. The concept is very simple. The fuller the tank, the longer the tank structure will be able to withstand fire conditions. The tank contents, when exposed to a fire, will boil at a constant temperature until the bulk of the liquid has been vented through the relief valve system. After this, the upper regions of the tank become exceedingly hot and eventually fail. However, the greater the mass of liquid inside the tank, the longer the tank can withstand unacceptable external temperatures.

**General**

Local requirements may have different approaches to the prescription of maximum filling limits but, in any event, the temperature influences on liquefied gases should not be ignored.
Example

Case 1 (amended Gas Code regulation)
A fully pressurised ship loading propane at 5°C.

$$\frac{\rho R}{\rho L} \quad LL = FL \quad \frac{\rho R}{\rho L}$$

Reference temperature as calculated under amended Gas Code 20°C
Density of liquid propane at 20°C = 500 kg/m³
Loading temperature 5°C
Density of liquid propane at 5°C = 522 kg/m³

$$\frac{500}{522} = 93.9\%$$

Thus, the tank can be loaded to 93.9% of tank volume.

Case 2 (amended Gas Code regulation)
A fully-pressurised tanker loading propane at -10°C.

Reference temperature as calculated under amended Gas Code +15°C
Density of liquid propane at 15°C = 508 kg/m³
Loading temperature = -10°C
Density of liquid propane at -10°C = 542 kg/m³

$$\frac{508}{542} = 91.9\%$$

Thus, the tank can be loaded to 91.9% of tank volume.

32.6 The Loaded Voyage

Cargo temperature control

For all refrigerated and semi-pressurised gas carriers, it is necessary to maintain strict control of cargo temperature and pressure throughout the loaded voyage. This is achieved by reliquefying cargo boil-off and returning it to the tanks (see also Sections 32.5 and 31.5). During these operations, incondensibles must be vented as necessary to minimise compressor discharge pressures and temperatures.

Frequently, there are occasions when it is required to reduce the temperature of an LPG cargo on voyage. This is necessary so that the tanker can arrive at the discharge port with cargo temperatures below that of the shore tanks, thus minimising the amount of flash gas. Depending on the cargo and reliquefaction plant capacity, it can often take several days to cool the cargo by one or two degrees centigrade, but this may be sufficient. The need for this will often depend on the contractual terms in the charter party.
In this respect, poor weather conditions can sometimes present problems. Although most reliquefaction plants have a suction knock-out drum to remove liquid, there is a risk, in gale conditions, that entrained liquid can be carried over into the compressor. For this reason, it is preferable not to run compressors when the tanker is rolling heavily, if there is risk of damage.

In calm weather conditions, if the condensate returns are passed through the top sprays, because of the small vapour space and poor circulation in the tank, it is possible that a cold layer can form on the liquid surface. This enables the compressors to reduce the vapour pressure after only a few hours running, when in fact the bulk of the liquid has not been cooled at all. To achieve proper cooling of the bulk liquid, the reliquefaction plant should be run on each tank separately and the condensate should be returned through a bottom connection to ensure proper circulation of the tank contents. After the cargo has been cooled, reliquefaction capacity can be reduced to a level sufficient to balance the heat flow through the tank insulation. Figure 32.7 shows the arrangement for cooling down cargoes on a loaded voyage.

If the reliquefaction plant is being run on more than one tank simultaneously, it is important to ensure that the condensate returns are carefully controlled in order to avoid the overfilling of any one tank.

![Figure 32.7 - Cargo refrigeration at sea](image)
Prevention of polymerisation

Where butadiene cargoes are being carried, the compressor discharge temperature must not exceed 60°C and the appropriate high discharge temperature switch must be selected. Similarly, in the case of vinyl chloride, compressor discharge temperatures should be limited to 90°C to prevent polymerisation (see also Section 27.8).

Condition inspections

Throughout the loaded voyage, regular checks should be made to ensure there are no defects in cargo equipment and no leaks in nitrogen or air supply lines. Such inspections must comply with all relevant safety procedures for entry into enclosed spaces and due regard must be given to hazardous atmospheres in adjacent spaces.

32.6.1 Operation of the Reliquefaction Plant

As already mentioned in Section 31.5, the reliquefaction plant is used during cargo loading to handle the vapours formed by evaporation and displacement. At this time, it is likely that the maximum compressor capacity will be required.

On the loaded voyage, and depending on cargo temperature, ambient temperature, and the design of tank insulation, the plant may be operated continuously or intermittently. If it is necessary to reduce the temperature of the cargo before reaching the discharge port, for example, to comply with the receiving terminal requirements or charter party stipulations, the plant will again be operating continuously.

Before starting the reliquefaction plant, it is necessary to ensure that oil levels in the compressors are correct and that the glycol/water cooling system is ready for operation (see Section 31.6.1). This will require a check to make sure the header tank is full and that the cooling fluid is circulating.

The lubricating oil in compressors must be compatible with the cargo being handled and must be changed if necessary. (When changing from butane/propane mixtures to other grades, it will be necessary to change the oil.) Before starting a cargo compressor, the condenser cooling system must be operating with harbour water circulating or the R22 system running. Compressors should always be started and stopped in accordance with the manufacturer’s instructions. Compressor discharge valves should be opened and suction valves opened slowly to minimise damage from liquid carry-over (see Section 31.6.3). The cooling water outlet temperature should be adjusted in accordance with the manufacturer’s instructions. The following details should be checked regularly:

- Suction, inter-stage (see Section 31.5) and discharge pressures.
- Lubricating oil pressures.
- Gas temperatures on the suction and delivery side of compressor (high discharge temperature switches protect the compressor). Here, inspection of the appropriate Mollier diagram will assist in gaining maximum benefit from the compressor by ensuring that it operates along the appropriate line of constant entropy (see Section 27.21).
- Current drawn by electric motor.
- Oil leakage from shaft seal, and
- Cooling water temperature.
Stopping the cargo compressor should always be carried out in accordance with the manufacturer's instructions. Generally, the first action is to stop the compressor. This is followed by closure of the suction and discharge valves. The glycol/water system (see Section 31.6.1) is left running to provide crankcase heating or, alternatively, the lubricating oil heater should be left switched on.

### 32.7 Discharging

When a tanker arrives at the discharge terminal, cargo tank pressures and temperatures should be in accordance with terminal requirements. This will help maximum discharge rates to be achieved.

Before the discharge operation begins, the pre-operational ship/shore procedures should be carried out along similar lines to the loading operation previously outlined.

The method of discharging the tanker will depend on the type of tanker, cargo specification and terminal storage. Three basic methods may be used:

- Discharge by pressurising the vapour space.
- Discharge with or without booster pumps.
- Discharge via booster pump and cargo heater.

These methods are discussed in 32.7.1, 32.7.2 and 32.7.3 below.

#### 32.7.1 Discharge by Pressurising the Vapour Space

Discharge by pressure using either a shore vapour supply or a vaporiser and compressor on board is only possible where Type 'C' tanks are fitted. It is an inefficient and slow method of discharge and is restricted to small tankers of this type. Using this system, the pressure above the liquid is increased and the liquid is transferred to the terminal. An alternative method is to pressurise the cargo into a small deck tank from which it is pumped to the shore.

#### 32.7.2 Discharge by Pumps

**Starting cargo pumps**

A centrifugal pump should always be started against a closed, or partially open, valve in order to minimise the starting load. Thereafter, the discharge valve should be gradually opened until the pump load is within safe design parameters and liquid is being transferred ashore.

As the discharge proceeds, the liquid level in the cargo tanks should be monitored. Discharge and ballasting operations should be carefully controlled, bearing in mind tanker stability and hull stress.
Removal of liquid from the cargo tank may cause changes in interbarrier space pressures and these should be monitored throughout the discharge.

Discharging by centrifugal cargo pumps, either alone or in series with booster pumps, is the method adopted by most tankers and an understanding of the centrifugal pump characteristic (as outlined in Section 31.2) is essential for efficient cargo discharge. Figure 32.8 shows a cargo pump Q/H curve (flow against head) superimposed on a system resistance curve (or system characteristic). The graph shows the head or back pressure in mlc (metres liquid column) in the terminal pipeline system against flow rate measured in cubic metres per hour. Increasing the flow rate increases the back pressure. This varies approximately as the square of the flow rate, giving the shape of system characteristic curve as shown. The point where the two curves intersect is the flow rate and head at which the pump will operate.

Some of the above points are further demonstrated by inspection of Figure 32.9. This diagram shows a gas carrier alongside a jetty discharging to shore storage set at some elevation. The elevation of the tank introduces the concept of static head - this being the back pressure exerted at the pump even when pumps are not running. It can be seen that the static head changes as the tanker moves up and down with the tide and as the level in the shore tank alters. The diagram also indicates that the friction head loss is largely dependant on the length of the pipeline system.
Consider now the situation where pumps are run in parallel, as would be the normal case for a gas carrier discharge. Figure 32.10 shows the pump characteristics using one pump and when using two, three or four similar pumps in parallel. (This family of curves is derived from the principles discussed in Section 31.2).

Superimposed on the pump characteristics are a number of system characteristics labelled ‘A’, ‘B’ and ‘C’. System characteristic ‘A’ indicates a small diameter shore pipeline, ‘B’ a larger diameter pipeline and ‘C’ a very large diameter pipeline with shore tanks situated nearby. The latter provides the least resistance to cargo flow.

The actual system characteristic applicable at any terminal should be known to shore personnel and they should have such curves available. In preparing such graphs, personnel should note, as mentioned above, that the system characteristic can vary with the size of the chosen pipeline and with variation in the pipe-lengths from the jetty when alternative shore tanks are used. If a range of pipelines and tanks are available at any one terminal, then, it may be appropriate for terminal personnel to have a number of system characteristics, already pre-calculated and available, for use during pre-transfer discussions.
In any case, during the pre-transfer discussions (see Section 22.4), such matters should be covered and the optimum transfer rate should be agreed.

To clarify some of these issues, two of the system characteristics, as shown in Figure 32.10, are covered in detail below.

If a tanker, having the pumping characteristics as shown in Figure 32.10 (numbered 1, 2, 3, and 4), is discharging to a terminal presenting only minor restrictions to flow, then the shore system characteristic may be equivalent to ‘C’. The operating point of the ship/shore system moves from points C1 through to C4 as the number of cargo pumps in operation is increased from one to four. Under such conditions, the total flow achieved (when using four pumps) is only marginally less than the total theoretical flow (assuming no resistance). With such a shore pipeline system, it is therefore probable that all four pumps (and maybe more) can be run to good effect.

In the case of system characteristic ‘A’, where flow restrictions are high, it can be seen how little extra flow is achieved by running more than two pumps. By running three pumps the operating point moves from A2 to A3, achieving some extra throughput. By running four pumps the operating point moves from A3 to A4, achieving an increased flow of virtually zero. In such cases, much of the energy created in the additional pumps is imparted to the cargo. This is converted to heat in the liquid and results in an increase in cargo temperature. This increases flash-gas boil-off as the liquid discharges into shore storage and this excess must be handled by the shore compressors. If the shore compressors are unable to handle the additional flash-gas, the terminal will require a reduction in flow rate to avoid lifting the shore relief valves. Therefore, the net effect, in restricted circumstances, of running an unnecessary number of pumps can be to decrease rather than to increase the overall discharge rate.

Figure 32.10 - Combined tanker and shore cargo pumping characteristics - parallel pumps
Observing pressure gauges at the manifold will give a good indication if it is worthwhile running, say, four pumps or six pumps. The discharge rate should not be reduced by throttling valves at the tanker's cargo manifold if the shore cannot accept the discharge rate. Throttling in this manner further heats up the cargo. However, those gas carriers with only limited recirculation control may have to use manifold valves to throttle pumps.

Figure 32.11 - Discharge without vapour return

Figure 32.12 - Discharge with vapour return
It also may be desirable to throttle a cargo pump discharge when it is used in conjunction with a booster pump. This may be done in order to reduce the pressure in the booster module. Any additional control of flow, however, should be carried out by throttling the booster pump discharge, by opening the main pump recirculation or by a combination of the two. It should be noted that control of flow solely by throttling the main pump discharge may cause loss of booster pump suction.

As liquid is being pumped from the tanker, tank pressures tend to fall. Boil-off due to heat flow through the tank insulation takes place continuously and this generates vapour within the tank. The boil-off is usually insufficient to maintain cargo tank pressures at acceptable levels but this ultimately depends upon discharge rate, cargo temperature and ambient temperature. Where vapours produced internally are insufficient to balance the liquid removal rate, it is necessary to add vapour to the tank if discharge is to continue at a constant rate. This vapour may be provided, either by using the tanker’s cargo vaporiser (see Section 31.4), or from the terminal (via a vapour return line). When using the cargo vaporiser, the liquid is normally taken from the discharge line and diverted through the vaporiser. Figure 32.11 shows a discharge operation without the vapour return facility; Figure 32.12 depicts a similar operation but with a vapour return in use.

32.7.3 Discharge via Booster Pump and Cargo Heater

Where cargo is being discharged from a refrigerated tanker into pressurised storage, it is necessary to warm the cargo (usually to at least 0°C). This means running the cargo booster pump and cargo heater in series with the cargo pump. To operate the booster pump and heater, it is necessary to first establish water flow through the heater. Thereafter, the booster pump and heater may be slowly cooled down (prior to full operation) by very slow throughput of liquid from the cargo pump discharge. Once cooled down, the discharge valve can be opened until the desired outlet temperature is reached. It is important to ensure that the cargo pumps maintain adequate flow to the booster pump at all times. Figure 32.13 shows the usual layout.
Heating cargo during discharge always entails a risk of freezing the circulating water in the heater. In addition to checking the cargo outlet temperature and the booster pump suction during operation, attention should also be paid to the water inlet and outlet temperatures and pressures. The water outlet temperature must not be allowed to fall below the manufacturer’s recommended limit. A low temperature switch should stop cargo flow through the heater in case of low water discharge temperature.

As will be noted, this method of cargo heating depends on a suitable water temperature. In cold water areas, the efficiency of the system can be seriously affected and slow discharge rates can result and if water temperatures are below 5°C the risk of freezing becomes much greater. To cover such possibilities, sometimes thermal oil heaters are fitted to tankers.

### 32.7.4 Draining Tanks and Pipelines

It has already been noted in Section 31.2 and illustrated in Figure 31.3 that in order to avoid cavitation of a centrifugal pump, the pressure of the liquid at the pump suction needs to exceed the saturated vapour pressure (SVP) by an amount termed the minimum Net Positive Suction Head (NPSH). The required minimum NPSH, expressed as an equivalent head of liquid above the pump suction, may vary from one metre (at maximum pump capacity) to 200 millimetres (at reduced flow). If the vapour space pressure can be increased above the SVP by the supply of extra vapour from the shipboard vaporiser, the onset of cavitation, as the liquid level approaches the bottom of the tank, can be delayed. Such augmentation of vapour space pressure is usual practice on fully pressurised and semi-pressurised tankers and may also be carefully applied to fully refrigerated cargoes, particularly where maximum cargo out-turn is required in preparation for gas freeing. Whether this extra vapour pressurisation is used or not, there will be a liquid level at which the pump becomes erratic. Gradual reduction of the flow rate at this point, by careful throttling of the discharge valve, reduces the NPSH requirement and permits continued discharge to a lower level. It should be remembered, however, that a pump discharge valve should not be used for flow control if the pump is operating with a booster pump since the booster pump might cavitate, resulting in damage (see Section 32.7.2).

On completion of discharge, liquid cargo must be drained from all deck lines and cargo hoses or hard arms. Such draining can be done from tanker to shore using a cargo compressor. Alternatively, it may be carried out from shore to tanker, normally by blowing the liquid into the ship’s tanks using nitrogen injected at the base or apex of the hard arm. Only after depressurising all deck lines and purging with nitrogen should the ship/shore connection be broken.
32.8 The Ballast Voyage

It is frequent practice in some refrigerated trades to retain a small quantity of cargo on board after discharge and the amount retained is known as the *heel*. This product is used to maintain the tanks at reduced temperature during the ballast voyage but this procedure only applies when the same grade of cargo is to be loaded at the next loading terminal.

In general, the quantity retained on board as a heel depends on:

- Commercial agreements.
- The type of gas carrier.
- The duration of the ballast voyage.
- The next loading terminal's requirements, and
- The next cargo grade.

With LPG cargoes, the small amount of liquid remaining after discharge should be sufficient to provide the necessary cooling effect during the ballast voyage. This is carried out by intermittent use of the reliquefaction plant, returning the condensate to the tanks to ensure arrival at the loading port with tanks and product suitably cooled.

If the tanker is proceeding to a loading terminal to load an incompatible product, none of the previous cargo should be retained on board. This avoids contamination of the following cargo and allows the maximum quantity of the new cargo to be loaded (see Section 32.9).

32.9 Changing Cargo (and Preparation for Drydock)

Of all the operations undertaken by a gas carrier, the preparation for a change of cargo is the most time consuming. If the next cargo is not compatible with the previous cargo, it is often necessary for the tanks to be gas-freed to allow a visual inspection - see Table 27.3(b). This is commonly the case when loading chemical gases such as vinyl chloride, ethylene or butadiene.

When a tanker receives voyage orders, a careful check must be made on the compatibility of the next cargo. (It is also necessary to check compatibilities and the tanker's natural ability to segregate, if more than one cargo grade is to be carried. On such occasions, special attention must be given to the tanker's reliquefaction system.) There may also be a need, when changing cargoes, to replace the lubricating oil in compressors for certain cargoes - this is discussed in Sections 32.6.1 and 31.6.1.

Tables 27.3(a) and 27.3(b) provide a guide to the compatibility of gases. The tables also cover cargo compatibility with respect to the construction materials commonly used in cargo handling systems.

In order to obtain a gas-free condition, the full process is as shown below. However, depending on the grade switch, it may not be necessary to include all these steps:

- First, make the tank liquid free.
- Then, warm the tank with hot cargo vapours (if necessary).
- Next, inert the tank, and
- Finally, ventilate with air.
These procedures are preliminary to tank entry for inspection or when gas freeing the tanker for drydock.

32.9.1 Removal of Remaining Liquid

Depending upon cargo tank design, residual liquid can be removed by pressurisation, normal stripping or, in the case of fully refrigerated tankers with Type ‘A’ tanks, by using the puddle heating coils fitted for this purpose. (An older method of warming Type ‘A’ tanks with hot vapours from the compressor - but without puddle heating - is now generally out of favour due to the extended time taken).

The first operation to be carried out is the removal of all cargo liquid remaining in the tanks or in any other part of the cargo system. Due to enhanced evaporation in a non-saturated atmosphere, residual liquid can become super-cooled to a temperature which could result in brittle fracture of the tank. Furthermore, any liquid retention will frustrate the future inerting operation.

When all cargo tank liquid has been removed, the tanks can be inerted either with inert gas from the tanker’s supply or from the shore, as required by the next cargo. Alternatively, gassing-up using vapour from the next cargo may be carried out - but this is increasingly unusual (see Sections 32.2.3 and 32.3 for more detail of the procedure).

Liquid stripping for Type ‘C’ tanks (Pressurised tanks)

For tankers having Type ‘C’ cargo tanks a cargo stripping line is often provided (see Figure 31.1).

By pressurising the cargo tanks on these tankers, (using the cargo compressor) residual liquid can be lifted from the tank sump into the stripping line and thence to deck level. It may then be stored temporarily in a chosen cargo tank for returning to the shore. This draining should continue until all liquid cargo is removed from the cargo tanks, as checked through the bottom sampling line. The compressor pressure necessary to remove residual liquid will depend on the specific gravity of the cargo and the depth of the tank (see Figure 32.14).

![Figure 32.14 - Removal of cargo liquid residue by pressurisation](image)
**Liquid freeing for other tank types**

For tankers with Type ‘A’ or ‘B’ tanks the removal of all cargo liquid residues is not possible by pressurisation. Instead, cargo liquid residues must be vaporised. This is normally achieved using puddle heating coils.

When puddle heating coils are used, the heat source in the coils is hot gas discharged from the cargo compressor. Vapour is drawn from the cargo tank atmosphere and passed through the compressor where the heat of compression causes increased vapour temperatures. By by-passing the condenser, hot vapour can be led directly to the heating coil system and heat is transferred to the liquid cargo residue. In this way remaining liquid is evaporated and an effect of the heat transfer is to turn the hot vapour in the coils into liquid which is then normally piped to the shore.

An alternative to the use of puddle heating coils is to supply hot cargo vapours (from the compressor) directly to tank bottoms. However, as already covered earlier in this Section, this results in much slower evaporation of remaining liquids than the method described above as the hot gas only flows over the surface of the liquid pool rather than causing boiling within it.

To finalise either type of operation, cargo tank vapours should be vented off to a shore installation or condensed and pumped to the shore.

When all tanks have been satisfactorily liquid-freed, pipework and other in-line equipment must be blown free from liquid and drained through the appropriate drain valves.

**32.9.2 Warming-up**

When cargo tanks have to be fully ventilated with fresh air, it is often necessary, depending on tank temperatures and design considerations, to warm-up the tanks prior to inerting. This is achieved by controlled circulation of warm cargo vapours through the tanks and is done before inerting takes place.

As for the cool-down (see Section 32.4), the rate of warm-up should be carefully controlled in accordance with the shipbuilder’s guidance.

Warming up is vital where cargo tanks are at very low temperatures. On such tankers, compressors and heaters are operated to circulate warm gas. First, this evaporates any residual liquid and, thereafter, the whole tank structure is warmed to ambient conditions.

If warming up to ambient temperature is not carried out, freezing of carbon dioxide from within the inert gas can result. (Moreover, greater volumes of inert gas will be required at low temperatures.)
32.9.3 Inerting - After Discharge

Removal of cargo vapours with inert gas is carried out to reduce gas concentrations to a level where aeration can take place without the tank atmosphere passing through the flammable envelope (see Figure 27.21). The level to which the hydrocarbon vapour must be reduced varies according to the product. In general, when inerting in this way, it is necessary to reduce the hydrocarbon content in the inert atmosphere to about 2 per cent before air blowing can begin.

![Figure 32.15 - Inerting of cargo tanks](image-url)

In the past, some grade-changing operations involved the replacement of existing tank vapours with the vapours of the next cargo to be loaded. However, this is now seldom carried out. As shown in Table 27.3(b), this method can only ever be appropriate when switching to compatible grades and when air is not to be introduced into the tank.

Once the cargo system has been satisfactorily freed of liquid and warmed up, inerting operations may start. This involves the replacement of the vapour atmosphere with inert gas or nitrogen. The need of inerting will depend on:

- A desire to gain tank entry for inspection.
- Last cargo.
- Next cargo.
- Charter party terms.
- Requirements of the loading terminal.
- Requirements of the receiving terminal, and
- Permissible cargo admixture.
Where tanks must be opened for internal inspection, inerting is always necessary. This is to reduce the content of flammable gases within tank atmospheres to the safe level required before blowing through with fresh air. This safe level will correspond to a point below the critical dilution line (see Figure 27.21) as found on a graph for the product in question. The procedure for inerting after cargo discharge is similar to that described in Section 32.2.3.

### 32.9.4 Aerating

After the foregoing procedures have been addressed, the cargo tanks can be ventilated with air. The air is supplied using compressors or air blowers and air dryers in the inert gas plant. This should continue until the oxygen content of the whole tank is at 20.9 per cent and hydrocarbon levels are at the zero percentage of the Lower Explosive Limit. In order to ensure uniformity in the tank atmosphere, various levels and positions in the tank should be monitored prior to tank entry. Figure 32.16 shows a pipeline set up for aerating tanks.

It is important to note that ventilation with air should only take place once the ship’s tanks are warmed to ambient conditions. If the tank is still cold when air is allowed inside, any moisture in the air will condense on tank surfaces. This can cause serious problems when preparing the tank for new cargoes. If condensation is allowed to form, its removal can be a protracted and costly operation.

![Figure 32.16 - Aeration of cargo tanks](image-url)
32.9.5 Ammonia - Special Procedures

Certain cargoes present particular difficulties when trying to remove all traces of the product. Ammonia is one such case. When a tanker is switching from ammonia to LPG, virtually all traces of vapours must be removed from the system. Prior to loading the next cargo, an allowable concentration of ammonia vapour in a tank atmosphere is usually quoted at less than 20 parts per million by volume. This results in a time consuming operation which is covered in more detail below.

The first operation when switching from ammonia is to remove all liquid ammonia from the system. This is important as ammonia, when evaporating to air, is particularly likely to reach super-cooled conditions. Therefore, unless all liquid is removed, dangerously low liquid temperatures can result and tank fractures could ensue. Confirmation that all liquid has been removed can be established, during warming-up, by carefully observing tank temperature read-outs.

Once cargo tank temperatures have been warmed to substantially above the dew point of the air, the ammonia vapours are usually dispersed by blowing warm fresh air through the system. (For ammonia the inert gas plant must not be used due to the formation of ammonia carbamates when ammonia is in contact with carbon dioxide.) The continued use of warm dry air should avoid water vapour condensation, thus limiting the seepage of ammonia into porous tank surfaces. The ventilation of tanks and the cargo system at the highest practical temperature is advantageous as this encourages release of ammonia from rusty surfaces. (Ammonia is released ten times faster at 45°C than at 0°C).

Washing with fresh water to remove ammonia is sometimes carried out. This can be most effective as ammonia is highly water soluble. However, the following points should be noted:

- The benefit of water washing is limited to certain types of tank. (This technique is not always practical for large fully refrigerated tankers with prismatic tanks.)
- When switching from ammonia to LPG, water can hold ammonia in solution and this can be a contaminant for future cargoes. Accordingly, water washing is only recommended for cargo tanks which are completely clean, rust-free and have minimum internal structure, so allowing full and effective drainage.
- All traces of water must be removed at the end of washing to stop the formation of ice or hydrates.
- The high solubility of ammonia in water (300:1) can lead to dangerous vacuum conditions being created within a tank. It is, therefore, essential to ensure adequate air or nitrogen entry into the cargo tank during the water washing process.

After water washing, it is essential that all water residues are removed using either fixed or portable pumps. Subsequently, tanks and pipelines must be thoroughly dried before further preparations for cargo loading are made. In order to maintain maximum dryness, it is important to continue ventilation of the tanks using air with a dew point lower than the tank atmosphere for the reasons discussed above.
32.10 Ship-To-Ship Transfer

In recent years, the transfer of Liquefied Gas cargoes from one tanker to another has become a common practice in many areas where there is insufficient terminal infrastructure. Detailed recommendations for the safe conduct of such operations are given in the (local) Ship-to-Ship Transfer Guide (Liquefied Gases). Before any such operations are arranged, it is recommended that this publication be consulted and its procedures be adopted. Many port authorities require special permission for ship-to-ship transfer.

32.11 Conclusion

This completes the cycle of gas carrier operations. It is important for every tanker to have its own detailed operational procedures clearly listed. What can be done on one tanker may not be possible or even desirable on another. However, the basic principles of cargo handling for liquefied gas remain the same for all gas carriers. A safe operation is invariably also an efficient operation and, if in doubt about the safety of any operation, tanker’s personnel and terminal staff are recommended to seek further advice.