



Carefully to Carry

Moisture migration and surface ventilation

This article explains how and why moisture migration takes place and discusses to what extent surface ventilation can reduce or eliminate the damage to which moisture migration gives rise. The answer depends on the commodity; with grain in bulk, surface ventilation can do little or nothing; with rice or cocoa in bags, surface ventilation can do much more, but it cannot guarantee a sound outcome in all circumstances.

Movement of moisture

Moisture migration is the name given to the movement of moisture within a cargo. Thus a situation may arise where the total amount of water held in a cargo in a given space may be the same at the end of a voyage as it was in the beginning, but as a result of moisture migration, the moisture contents of various parts of this cargo have changed considerably (gains or losses being found). It is more usual, however, for part of the moisture that migrates to be lost to the external atmosphere as a result of ventilation, or to be drained off into the bilges.

Physical considerations:

• Vapour pressure (VP) and relative humidity (RH)

Vapour pressure

The atmosphere comprises a mixture of nitrogen and oxygen in the proportion of 78% nitrogen to 20% oxygen; approximately 2% represents other gases and this includes water in the form of vapour. Pressure exerted by the atmosphere will partly be dependent upon the pressure exerted by the water in vapour form, and this proportion of the total atmospheric pressure is known as the 'water vapour pressure' of the air at that time.

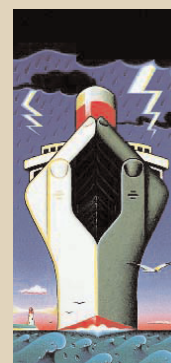
Saturation vapour pressure

Vapour pressure is measured in the same way as other gaseous pressures, i.e. in mm of mercury*. It will be recalled that the normal atmospheric pressure at sea level is 760mm Hg.

As the quantity of water in the atmosphere increases, so the vapour pressure will increase proportionately. At a given temperature, the air can only hold a specific amount of water vapour, and the pressure exerted in the atmosphere when this limiting point is reached is referred to as the 'saturation vapour pressure' of the air at the particular temperature.

Super saturation

Any attempt to increase the water vapour in the air at this point will produce 'super saturation' and then water will be deposited from the air in liquid form, either as droplets to form fog or cloud, or on suitable surfaces in the form of water drops, e.g. as sweat in a ship's hold.



"The carrier shall properly and carefully load, handle, stow, carry, keep, care for and discharge the goods carried."

Hague Rules, Articles iii, Rule 2

Carefully to Carry Advisory Committee

This report was produced by the Carefully to Carry Committee – the UK P&I Club's advisory committee on cargo matters. The aim of the Carefully to Carry Committee is to reduce claims through contemporaneous advice to the Club's Members through the most efficient means available.

The committee was established in 1961 and has produced many articles on cargoes that cause claims and other cargo related issues such as hold washing, cargo securing, and ventilation.

The quality of advice given has established Carefully to Carry as a key source of guidance for shipowners and ships' officers. In addition, the articles have frequently been the source of expertise in negotiations over the settlement of claims and have also been relied on in court hearings.

In 2002 all articles were revised and published in book form as well as on disk. All articles are also available to Members on the Club website. Visit the Carefully to Carry section in the Loss Prevention area of the Club website www.ukpandi.com for more information, or contact the Loss Prevention Department.

Relative humidity

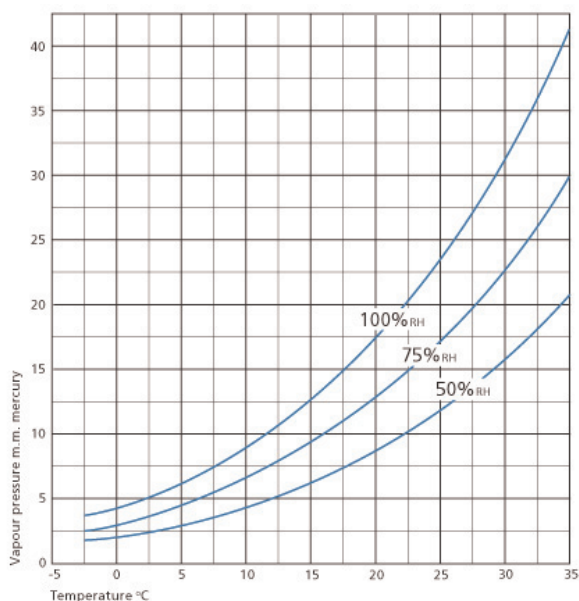
Under most circumstances, the vapour pressure of water in the atmosphere is less than the saturation vapour pressure. The percentage value of the actual vapour pressure in relation to the saturation vapour pressure is defined as the 'relative humidity' of the atmosphere. Thus, if the air only holds half its potential maximum amount of water in the form of vapour, then the relative humidity will be 50%, and at saturation vapour pressure the relative humidity will be 100%. Warm air is capable of holding more water vapour than cool air, so the actual weight of water that is required for saturation increases with increasing temperature. Thus for a given volume of air containing a constant weight of water vapour, the relative humidity will vary as the saturation vapour pressure changes with the temperature. If the temperature rises, the saturation vapour pressure will increase, so that the relative humidity will fall.

Temperature rises – relative humidity falls

This phenomenon may be illustrated with an example. Let it be assumed that a given quantity of air at 20°C has a vapour pressure of 9mm Hg. The saturation vapour pressure of air at 20°C is 17.5mm Hg. Therefore the relative humidity is $9/17.5=51.5\%$. If the air is heated to 30°C, the quantity of water in the air remaining the same, then the vapour pressure of the air will still be 9mm Hg (actually, there will be a slight rise in vapour pressure, but this may be ignored for the purposes of the example). However the saturation vapour pressure of air at 30°C is 31.8mm Hg. Therefore the relative humidity is $9/31.8$ or 28.3%, i.e. by increasing the temperature 10°C, a fall in relative humidity of 23.2% has occurred. The reverse effect occurs if air containing a given quantity of water is cooled.

Relationship at different temperatures

The graph shows the relationship between the vapour pressure and relative humidity at different temperatures, e.g. 100% relative humidity at 10°C represents a water vapour pressure of 9.2mm Hg; at 20°C of 17.5mm Hg, and at 30°C of 32mm Hg – i.e. an increase of 20°C has resulted in a more than three-fold increase in the water-holding capacity of the atmosphere.



Condensation

If air is cooled to the point where saturation (100% relative humidity) is reached, then moisture will begin to be deposited in the form of droplets or mist i.e. condensation will occur.

Ship's sweat

If the air in a ship's hold is warm and it comes in contact with the deckhead which has become cooled by the outside atmosphere, so that the temperature of the air close to the surface of the deckhead may be reduced below that at which saturation vapour pressure for that particular water content is reached, i.e. 100% relative humidity, then condensation will normally form on the deckhead in the form of sweat.

• Equilibrium relative humidity (water activity)

Equilibrium point

All biological materials normally contain a certain amount of water. The amount of moisture present at any given time is the moisture content. If the material is put in contact with dry air, then it will tend to lose a small proportion of its water to the air in the form of water vapour. This process will continue until an 'equilibrium' of the air in contact with the material of that particular moisture content and at that particular temperature. Equilibrium relative humidity is sometimes referred to as 'water activity'. The latter is measured as a ratio rather than as a percentage thus equilibrium relative humidity of 50% is equivalent to a water activity of 0.5.

Usually, with a biological cargo, the condition of the atmosphere within the cargo (that is, of the air trapped between the various particles of the cargo) is controlled largely by the condition of the cargo. In cargoes such as bulk grain, where air movement within the bulk is very restricted, the moisture content of the atmosphere within the cargo (which is also termed the 'interstitial' or 'inter particular' air) is, under normal conditions, completely controlled by the temperature and moisture content of the cargo.

Experimental work with maize has made it possible to construct graphs that equate equilibrium relative humidity with moisture content at various temperatures. Such graphs are known as 'desorption isotherms', since all the experiments were constructed so that to achieve equilibrium relative humidity, moisture was given up by the maize to the surrounding air. If the air around the maize is wetter than the equilibrium relative humidity, then the maize will absorb moisture from the air. Such a process is known as 'adsorption' and a similar series of curves or isotherms can be constructed which are called 'adsorption isotherms'. The relationship between adsorption and desorption isotherms is a complex one and it is not proposed to discuss it at length in this article. However, it may be stated that under conditions of desorption, the equilibrium relative humidity at any given moisture content is slightly lower than under conditions of adsorption. Normally in the grain trade, from harvesting through to the discharge of cargo, there is a tendency for the grain to lose moisture to the surrounding atmosphere, and thus behaviour patterns should be deduced by a study of desorption isotherms. If a situation occurs where the grain is absorbing moisture from the atmosphere, strictly speaking, the behaviour pattern should be deduced by a study of adsorption isotherms.

■ Moisture migration

The mechanism of moisture migration It is necessary to understand the definition referred to above in order to appreciate the process of moisture migration. We will illustrate the mechanism by which moisture migration operates by considering a cargo of bulk maize. With this commodity migration is slow.

Change of temperature – change of ERH – change of vapour pressure

We have already stated that the interstitial air that occupies some 40% of the cargo space in the case of maize in bulk will contain water vapour, and the vapour pressure in this air will rapidly reach equilibrium with the moisture content of the maize. In maize with a moisture content of 14% and a temperature of 25°C, the relative humidity of the interstitial air will rapidly reach 68% and the water vapour pressure in the air at that time will be 16.3mm Hg. A change in the temperature of the maize will result in a change of the equilibrium relative humidity and in the vapour pressure. The table below shows equilibrium temperatures for maize at 14% moisture content. The temperatures at which saturation vapour pressure occurs (i.e. 100% relative humidity) are included in the table. These temperatures are known as the 'dew points'.

Table 1. Temp / ERH / VP / DP – Relationship of maize at 14% moisture content

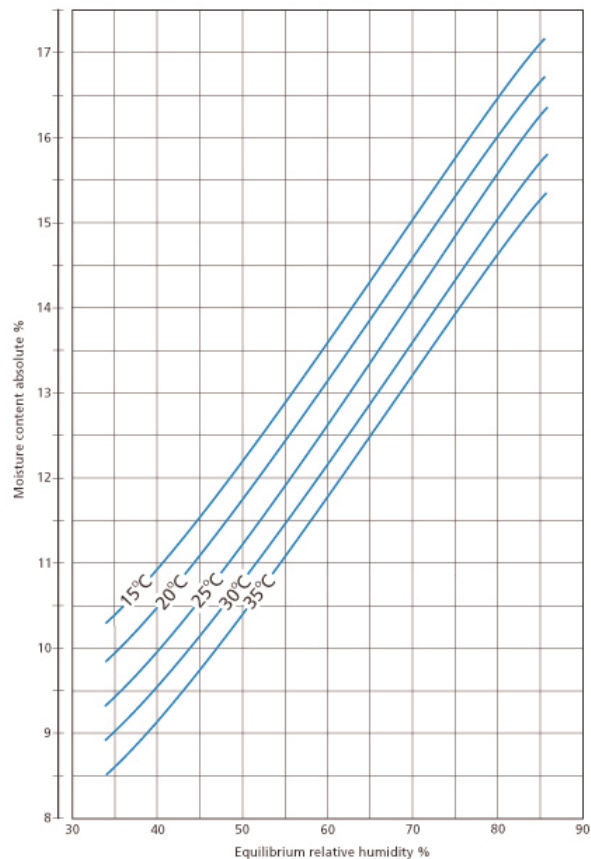
Temp °C	Equilibrium RH %	Vapour Pressure mm Hg	Dew Point °C
15	60.0	7.1	7.4
20	64.4	11.2	13.0
25	68.0	16.3	18.7
30	71.5	22.9	24.3
35	75.0	31.5	30.0

Thus, air at 25°C and 68% equilibrium relative humidity will have a vapour pressure of 16.3mm Hg, but if this air is reduced to a temperature of 18.7°C, then moisture will be deposited because the saturation vapour pressure will then be reached. If we assume that the ship carrying this maize of 14% moisture content and of temperature 25°C passes into a region of colder water, then the outside of the cargo will assume the temperature of the cold sides of the vessel, and if we assume this to be 15°C, it can be seen from the table that such maize will have an equilibrium relative humidity of 60% and a vapour pressure of 7.1mm Hg. The cooling process of the colder sea will not noticeably affect the maize in the centre of the bulk, since maize is a poor conductor of heat. Its thermal conductivity at normal moisture contents is less than five times as great as that of loose cork insulation and only one fifth the average value for concrete. Thus the maize in the centre of the stow will still have a temperature of 25°C and the interstitial air in this region will still have a vapour pressure of 16.3mm Hg.

ARGENTINE MAIZE

The isotherm graph below shows equilibrium relative humidity plotted against moisture content.

A vapour pressure difference is therefore created, between the interstitial air in the maize in the centre and the interstitial air in the maize on the periphery of the stow.



Consequently, there will be a flow of moisture vapour from the high pressure region to the low pressure region in order to equalise the pressure difference, and water will thus move from the centre towards the periphery.

This movement of water from the inner portion of the cargo will have the immediate effect of causing a reduction in the vapour pressure of the air there, but equilibrium conditions will be restored as result of more water moving from the grain into the interstitial air, so that the original vapour pressure of 16.3mm Hg will be maintained. Consequently, there will be continuous flow of water vapour from the warmer part of the stow to the colder part.

Cargo sweat at periphery

In the example which we have given, the overall effect of this transfer of moisture vapour will be to cause deposition of physical water in the periphery of the stow in contact with the cold hull. This follows from the table, which shows that a vapour pressure of 16.3mm Hg at 25°C will have a dew point of 18.7°C. As this dew point is higher than the temperature of the cargo at the periphery, water will be deposited on the cargo. This illustrates the mechanism whereby 'cargo sweat' is produced* .

The above example is an over-simplification of what happens in practice, since there is a tendency to set up a temperature gradient in the maize, along the route from the inside of the stow to the outside, and there will be a gradual drop in the temperature of the air which moves and the grain in contact with it. Hence water vapour will be absorbed en route, lowering the dew point of the air moving towards the periphery of the stow. Thus it is not possible to make an exact prediction of what conditions are necessary for cargo sweat to occur.

Heating up

If there is a temperature differential between the outside of the stow and the inside, then moisture migration will result from the mechanism previously described. Such moisture migration will also occur when one part of the bulk becomes heated-up for any reason, e.g. insect infestation, microbiological activity or proximity to a hot bulkhead. In all these circumstances moisture will migrate from the warmer region to colder parts of the stow.

Warmer to cooler

We have illustrated, taking maize as an example, the reasons why moisture migration occurs. As with maize, the problem of moisture migration is most evident with exports of biological materials from warmer climates to cooler climates. Moisture migration can occur from many causes but, however the temperature differential comes about, the result will always be (where the moisture content is uniform) a movement of moisture from the warmer to the cooler parts of the cargo.

Moisture migration is observed in cargoes where 'insect infestation' occurs. Here, centres of heating arise from the respiratory heat from the insects and moisture migrates from these spots to form a wetter shell in the cooler cargo immediately surrounding the heated zone. As heating becomes progressive, the heating zone of course expands as the wetter shell moves outwards.

A second example is where 'ship's heat' causes a localised rise in the temperature of the cargo in contact with the source of the heat – e.g. an uninsulated engine room bulkhead. Here moisture migrates from the warm cargo and forms a layer of increased moisture content in the cooler cargo adjacent to it.

Unfortunately, the straightforward pattern of moisture movement resulting from a vapour pressure differential is not the only phenomenon that results from temperature differential in a cargo. Where temperature differentials are present, convection currents are set up owing to the fact that warm air is less dense than cold air. Thus, if heating occurs within a cargo, there will be a tendency for moisture to migrate in all directions from the heating zone. But there will also be a tendency for hot air to rise from the heating zone, to be replaced by cooler air coming in from the sides and underneath. The warm air will carry moisture with it, so that the pattern of moisture movement will be distorted in a vertical direction. In fact, where a hot spot occurs in a cargo, moisture movement is greater in a vertical direction than either laterally or downwards, because convection currents reinforce the upward movement of moisture. Thus for grain loaded warm and subjected to peripheral cooling, the major amount of moisture movement will be in a vertical direction, i.e. more water will pass towards the top of the cargo than towards the sides. If it is not possible to remove the water migrating to the top region of the cargo by ventilation, a subject that is discussed later in this report, more damage may be anticipated in the top layers than at the sides.

• The rate of moisture migration

Having established the causes and the pattern of moisture migration, we now consider the quantitative aspects of the phenomenon.

Difference in vapour pressure

The rate at which moisture moves from a warm to a cold region is dependent to a large extent on the difference in vapour pressure between the warmer and colder parts of the cargo. From Table 1 it will be seen that the vapour pressure of interstitial air of a cargo of maize at 14% moisture content does not increase directly with temperature. Thus an increase in temperature from 15°C to 25°C will give a vapour pressure increase of 9.2mm Hg, whereas a rise in temperature from 25°C to 35°C will give a vapour pressure increase of 15.2mm Hg. It therefore follows, that moisture migration will be greater, all other things being equal, when moisture is moving from cargo at 35°C to cargo at 25°C than when moisture is moving from cargo at 25°C to cargo at 15°C, although the temperature difference in both cases is the same. Thus, when considering rate of moisture movement within a cargo, not only is difference in temperature important, but also the 'actual temperatures'. A further factor is of course the differential in temperature in relation to distance – thus moisture will move more rapidly from cargo at 25°C to cargo at 15°C if the distance through which it must travel is only 1m rather than 10m, because it will be obvious that the vapour pressure gradient is much greater in the former case. In this respect the 'thermal conductivity' of the cargo in question is of considerable importance; the lower the conductivity, the slower heat will move through a cargo, and hence the less the potential for moisture movement.

Initial moisture content

The initial moisture content is also important. If we consider a cargo of maize at 14% moisture content loaded at 35°C with its periphery cooled down to 25°C, the equilibrium vapour pressures will be 31.5mm Hg and 16.3mm Hg respectively, giving a differential of 15.2mm Hg. Under the same temperature conditions, but with maize at moisture content of 11%, the equilibrium vapour pressures will be 22.4mm Hg and 11.6mm Hg, giving a differential of 10.8mm Hg. Thus the differential at lower moisture contents – therefore moisture movement – is less. In addition, (and this is of considerable practical importance), a much greater quantity of water can be absorbed by the cooler grain before the moisture content is raised to a level at which spoilage will commence.

Compactness

Because of the importance of convection currents in moving moisture, the more readily air can move through a cargo, the more rapidly moisture can be carried through that cargo in the moving air, so that all other things be in equal, there will be more rapid moisture movement through a cargo that is less compact (e.g. pellets) than through a cargo which is for example powdered, where the movement of air will be very limited.

The cargo itself

Finally, when considering the rate at which moisture may move through a cargo, it is necessary to consider the nature of the cargo itself. Thus cargo such as grain, which consists of seeds grown in dry climate, has comparatively low moisture content and the seed itself has a protective outer skin, which is relatively impermeable to moisture. In fact, one of the main purposes of this skin is to prevent the seed from drying out, either during growth or subsequent to growth and prior to germination. Thus moisture is

released rather slowly from seed products such as wheat and maize when compared with other products, particularly those grown under wet conditions in the tropics, where there is no natural necessity to conserve moisture. Similarly, whole grain will lose moisture much more slowly than grain that has been milled or pulverised in some way, where the natural protective coating is disrupted.

Quantitative data for the release of moisture from various products is scanty, and direct comparisons are particularly difficult. We have therefore not been able to give examples to illustrate the above.

When studying moisture movement there are two factors of interest. The first is the actual quantity of water moving from one place to another. The second is the rate at which the 'zone of enhanced moisture' moves forward. We have done some work on the latter factor with maize.

It was found that in 28 days, a zone of enhanced moisture had moved approximately 1 m in a vertical direction (i.e. with convection currents reinforcing the moisture movement) from the hot spot. The temperature differential in this experiment was from 40°C to 21°C over a distance of approximately 1.25m. The actual quantities of water involved could not be accurately determined. There is no doubt whatsoever, that with other types of cargo both the rate of movement and the quantities of water moved would have been many times greater than was found with maize.

Therefore, when considering the significance of potential moisture migration in a cargo, it is necessary to consider the vapour pressure differential in relation to the distance between the hotter and colder zone, the temperature of the hotter material and the temperature of the colder material to which moisture is migrating, the initial moisture content, the nature of the cargo and the ease with which air may move through it.

Practical application

To take simple practical illustrations of this, it is not unusual to shift bulk grain round the world in tankers (where of course there is no possibility of ventilation) and to store bulk grain in unventilated silos for long periods of time where considerable differences in temperature can occur between summer and winter. This is only possible because under normal conditions, the rate of moisture migration in bulk grain is low. When cargoes of cocoa or rice are considered, the rate of moisture migration is many times greater. It would of course be courting disaster to attempt to carry cocoa from West Africa to Northern Europe in tankers. Thus the quantitative aspects of moisture migration are of primary importance when considering the best method of carrying a particular cargo on a particular voyage.

No general rules

In the following section, we discuss ventilation in general terms in order to illustrate how the use of ventilation can assist in minimising the deleterious effects of moisture migration. Because of the many factors involved however, it would be unwise to attempt to formulate general rules for the carriage of cargo to minimise the effects of moisture migration.

Grain in bulk

General

Vessels which carry grain in bulk vary in their capability for ventilating the cargo. Considerable quantities of grain are carried in tankers with no ventilation whatsoever. Sometimes grain is carried in vessels fitted with a sophisticated *Cargocaire* system of surface ventilation, which also has facilities for pre-conditioning the ventilating air. Other vessels have fan-assisted surface ventilation and quite a large proportion have the normal type of surface ventilation through cowls, unassisted by any mechanical effort, the flow of air being dependent upon the movement of the ship. Some bulk carriers which successfully carry many thousands of tonnes of grain etc. have no means whatsoever of ventilating the surface of the cargo.

It should be pointed out, that vast quantities of grain are transported around the world, and in the great majority of instances, the cargoes outturn in a sound condition. This is true also of tankers, which indicates that surface ventilation is not a necessary pre-requisite to successful carriage.

On numerous occasions, claimants have been advised by their experts that spoilage of grain in transit has resulted from unsatisfactory ventilation. Alternatively, it has sometimes been suggested that lack of ventilation has exacerbated damage caused by other factors.

We consider that a bulk cargo of grain, if stowed in accordance with SOLAS Regulations - see later - cannot be significantly affected by surface ventilation or from a lack of it. Oxley* states:

"...popular opinion greatly exaggerates the virtues of ventilation...gaseous diffusion and heat movement in grain are both exceedingly slow and in the absence of mechanical means of forcing air through the bulk, changes in the atmosphere at the surface have a negligible effect on the intergranular atmosphere and on the water content or temperature of the grain."

In order to reduce moisture movement and its effects within a grain cargo, it is necessary to reduce the moisture content throughout. This will not only cut down the rate of moisture movement but will also mean that greater variations in moisture can occur within the cargo without commercial loss caused by the development of microbiological activity. Alternatively, the temperature differential may be reduced by cooling the bulk of the grain; this again would cut down the amount of moisture movement. A reduction in moisture content and a reduction in temperature could both be achieved by passing significant quantities of air through the cargo. Through ventilation, although possible in some silos ashore, is not possible onboard ship. In practice, onboard ship, only surface ventilation is available to attempt to control the deleterious peripheral effects resulting from moisture migration in bulk grain.

Cargo sweat

In the case of tankers, all are agreed that nothing can be done about ship's sweat should it occur, but it is suggested in the case of vessels fitted with natural or mechanical ventilation, that the moist air may be continuously removed from the headspace above the cargo and the quantity of condensation occurring on the deckhead accordingly reduced or eliminated.

It must, however, be remembered in these circumstances that the air used for ventilation is at the same temperature as, or below, the temperature of the deckhead and hatch-covers. If the ventilating air is cool, then the immediate effect will be to take up moisture vapour by diffusion from the interstitial air in the surface layers of the cargo, because the vapour pressure of the interstitial air will be higher than the vapour pressure of the ventilating air. At the same time, the surface of the cargo will be cooled, both directly by contact with the cooler ventilating air and as a result of evaporation of moisture. The temperature of the surface layer of the cargo may therefore be reduced below the dewpoint of the warm moist air rising from within the bulk. Water will then condense in the cooler surface layers of the cargo thus producing a wet cake just below the surface. Microbiological spoilage will eventually occur in this wet cake. Even if no condensation occurs in the surface layer, the moisture content of these layers may rise as a result of absorption of moisture, to a level where microbiological activity can commence – although this damage does not arise strictly from 'cargo sweat'.

Thus, if the external ambient conditions are such that ship's sweat would occur in the absence of ventilation, then cargo sweat will frequently occur just below the surface if ventilation is employed. This means in fact that, under these circumstances damage will result whether ventilation is used or not.

Surface ventilation is also claimed to be useful in removing heat from cargo that is heating, thus minimising the increase in temperature which might cause further deterioration of the cargo. It is, however, generally agreed that heat transfer through bulk grain is a very slow process. Work carried out using a vertical heat transfer system with a temperature differential of 20°C indicated that about 32 days continuous heating was required before there was a rise in temperature of 3°C in maize one metre from the heat source. This practical data is in line with calculations published by Leninger* and the views of Oxley (ibid). Indeed, it is because of this very fact that microbiological spoilage does produce serious heating up. Hence surface ventilation cannot significantly affect a heating process which is occurring more than about a metre below the surface. What can occur when the surface of a heating cargo is continuously cooled by ventilation, is that the vapour pressure differential between the interior of the cargo and the periphery is maintained and consequently the phenomenon of moisture migration is encouraged.

Stowage regulations

The irrelevance of surface ventilation to the carriage of grain is apparent from the stowage regulations in force in all major grain exporting countries, which insist that the vessel be stowed so that shifting of the cargo is impossible. Under these regulations, a ship's grain carrying compartments are classified as either partly filled or full. Grain in partly filled compartments must be levelled and topped off with bagged grain or other suitable cargo, tightly stowed and extending to a height of 1-2m above the bulk. The bagged grain or other suitable cargo must itself be supported by a platform made either of close boarded wood, or strong separation cloths laid over the whole surface of the bulk cargo.

These regulations provide that in compartments totally filled with grain, the grain shall be trimmed so as to fill all the spaces between the beams, in the wings and ends.

Further, to ensure that the compartment is maintained fully filled during the voyage, the compartment must be equipped with a feeder, from which grain can flow into the compartment if the cargo settles during the voyage. Alternatively the grain in the area of the hatch may be trimmed hard up to the deckhead beyond the hatchway to form a saucer. This saucer and the hatchway above is then filled with bagged grain or other suitable cargo extending to a height of at least two metres in the centre of the saucer. The bagged grain or other suitable cargo must itself be stowed tightly against the deckhead, and the longitudinal bulkheads, the hatch beams and hatch coamings.

The express purpose of the regulations, is to reduce to a minimum – and if possible to eliminate – the head space between the surface of the cargo and the overlying deck. With cargo stowed correctly in this way there is no possibility of effective surface ventilation.

Other cargoes where moisture migration is substantially more rapid

We took grain stowed in bulk as a first example because this probably represents a cargo in which moisture migration is the slowest compared with other cargoes which may be carried both in bulk and in bags.

The rate of moisture migration and the amount of moisture moving in other cargoes may be higher because, on the one hand, of differences in voyage and loading temperature, and, on the other, of the physical nature of the cargo stowed.

A typical cargo in which rapid moisture movement can occur is bagged rice. This cargo is usually loaded at a high temperature and at a moisture content just below the critical level which is about 14%. If the cargo is stowed in a block, stow temperature changes in the external atmosphere and sea water may set up serious temperature gradients between the centre and peripheral regions of the stow, with the result that massive moisture movement occurs leading to the formation of both cargo sweat and ship's sweat. This in turn results in part of the cargo becoming excessively wetted. Microbiological deterioration occurs in the wetted cargo.

In order to prevent or minimise this problem, bagged rice is normally stowed so that linked vertical and horizontal ventilation shafts are incorporated in the stow to facilitate moisture movement from the bulk to the external atmospheres.

Even with this form of stowage, when a rapid fall in external temperature occurs, as might be experienced with a vessel sailing to Northern Europe in the winter, serious sweat formation can result. This is well known to surveyors working in Northern European ports.

A similar phenomenon also occurs with bagged cocoa shipped from West Africa to Northern Europe. Here, the cargo is artificially dried so that ventilation in the early stages of a voyage, i.e. before about the latitude of Dakar, can result in the cargo picking up moisture from the atmosphere and is not normally recommended.

After this, ventilation may be used to minimise sweat formation; but it must be borne in mind that cooling the

surface of the cargo encourages moisture migration by increasing the temperature gradient between the bulk and the surface of the cargo, and may also result in the formation of cargo sweat. Thus, shock cooling of the surfaces of the cargo should be avoided and ventilation during the hours of darkness or during cold weather is probably best avoided.

It can be shown by calculation that, in any event, when cold conditions are encountered, the rate of emission of moisture from a normal cargo of cocoa can be substantially higher than the rate at which such moisture can be removed by a normal ventilating process, even assuming the ventilating atmosphere becomes saturated as it passes over the cargo. Thus, sweat damage under some circumstances is inevitable.

It will be seen from the foregoing sections that moisture migration within, and from, a water-holding cargo must occur as the vessel moves through different climatological regions. The purpose of ventilation is to minimise damage to the cargo resulting from this moisture migration. However, it will also be seen that such ventilation cannot always be completely effective and under some circumstances can be at least partially self-defeating. It follows that with certain cargoes, especially those where moisture movement is rapid, such as bagged rice and cocoa beans – which have been taken as examples in this article - no normal ventilating system can prevent cargo damage occurring as result of the conditions encountered during certain types of voyage.

The rate of moisture migration and the amount of moisture moving in water-holding cargoes will vary between the two extremes of bulk grain on the one hand and rice or cocoa beans on the other; but because of the wide variety of voyages undertaken and types of product carried, it is impossible to give precise recommendations (except under special circumstance) as to when ventilation should be practised. Many surveyors at present, work on the ad hoc basis that ventilation should be practised whenever weather conditions permit and, if under these circumstances sweat is formed, they consider the ship's personnel have taken all reasonable steps to ensure a sound outturn. This is subject to the qualification that what is crudely termed 'moisture migration in reverse' does not occur; in other words, that the ventilation air introduced into the hold does not give up its moisture to the cargo. Moisture will be absorbed into cargo whenever the dewpoint of the interstitial air is lower than the dewpoint of the ventilating air.

Unfortunately, however, it is virtually impossible onboard ship to measure the dewpoint of the interstitial air, and thus the decision of when or when not to ventilate cargoes of this type must still be based on a compromise between the scientific theory of the text book and the practical experience of those engaged in the trade.

Ventilation experiments

Introduction

When maize arrives damaged by heating, the cargo interests frequently allege that the damage is caused by unsatisfactory ventilation. Thus it may be suggested that inadequate ventilation has permitted sweat to form on the ship's structure, with the result that the cargo has been wetted on the surface. Alternatively it may be claimed that, because the ventilation is inadequate, the heat produced in a cargo was not removed, with the result that the damage becomes progressive. Damage as a result of ship's sweat is readily recognisable, and takes the form of a layer of mouldy grain on the surface of the cargo.

In many instances, particularly where the amount of damage is appreciable, a defence against a claim for such damage is to demonstrate that if in fact ventilation had been practised, the air would have been sufficiently cold to have cooled the top layer of grain with the result that moisture in vapour form would have migrated from within the bulk to the cooler surface. But, on encountering the cooler cargo in the surface layer, the vapour would have given up its moisture in the form of condensation on the cargo. Thus instead of 'ship's sweat', there would have been 'cargo sweat' – the total damage however, about the same*

This is, simply stated, the theory of 'moisture migration', which was judicially considered in *John v The Turnbull Scott Shipping Co. Ltd. (The Flowergate)* [1967] 1 Lloyd's Rep.1 – see in particular, the evidence of Dr Milton, quoted on pages 32 and 33 of the judgement.

Serious claims for damage however, normally arise from heating up within the bulk of the cargo and the question of efficacy of ventilation in removing heat and minimising progressive heating up in such instances has never been thoroughly examined on a scientific basis.

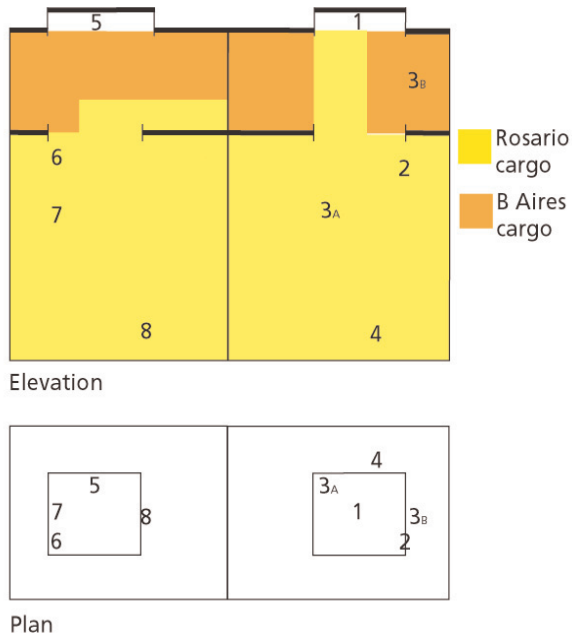
Ideally, of course, it would be desirable to find pockets of heating damage of equal size and intensity within an identical cargo in two cargo spaces on the same vessel, and to ventilate one and not the other and from this demonstrate whether ventilation had any effect. Such an experiment is completely impractical, and could probably never be satisfactorily achieved.

However, if ventilating the surface of a cargo is to have any effect on heating up within the bulk, it must be assumed that the ventilating air will have a cooling effect on cargo within the bulk of the maize. If this is the case, it must equally be true that ventilating air would affect the temperature of maize within a bulk whether heating up occurred or not.

It was therefore decided to examine the changes in temperature within the bulk of maize cargoes during shipment from South America to Europe. In all, four ships were fitted with equipment capable of recording every hour, the temperatures registered by up to eight thermometers (thermistors) buried at various places in the cargo of maize in the ship's holds. Unfortunately, on two ships the experiment proved abortive. On the remaining two ships, it was possible to complete the experiment as planned.

Ship 1

This was a Liberty ship which loaded maize at Rosario and Buenos Aires in June and early July 1965. The thermometers were placed in the cargo stowed in holds 2 and 3. In each hold three probes were buried in the cargo; a fourth being placed on the surface of the cargo underneath the weather-deck hatch boards. The approximate position of the probes is shown in the diagram. Probe 3A in no. 2 lower hold ceased to function on the 18 June and was replaced at Buenos Aires with probe 3B in no. 2 tween deck on 2 July.

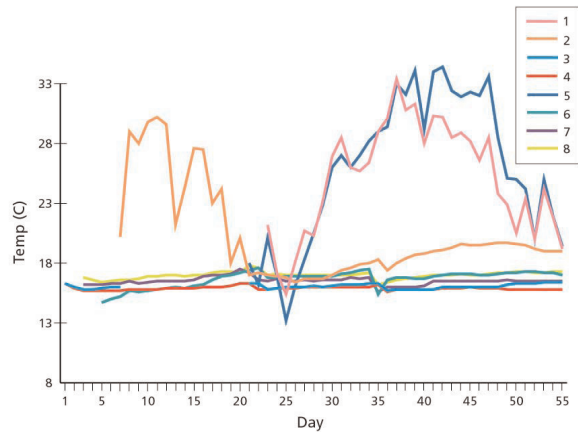


Ship 1. Plan and elevation showing position of probes in holds

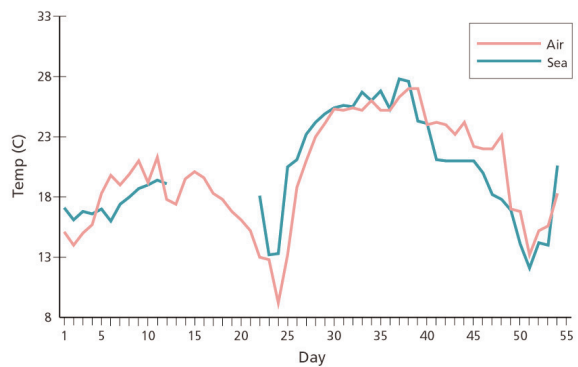
Each time a probe was placed in the cargo, a sample was taken from that vicinity, sealed, and subsequently tested for absolute moisture content. The results ranged between 12.8% and 14.5%. The temperatures of the samples, ranging from 15°C to 20°C showed that the cargo was in general hotter than the ambient air on the day it was loaded. Microbiological spoilage was not anticipated on these figures.

In order to keep the air space between the surface of the cargo and the deckhead to a minimum, the cargo was trimmed between the deck beams and into the hatch coamings. Prior to sailing, ventilator cowls were unshipped and the ducts plugged. During the crossing, which lasted 31 days, the cargo received no ventilation whatsoever.

The graphs show, firstly, the maximum temperature recorded daily by the equipment for each probe and, secondly, the temperature of the ambient air and the temperature of the river/sea water at noon each day as recorded by the ships (no readings of the river/sea water were taken between 23 June and 2 July as the ship's thermometer was broken).



Ship 1. Cargo hold probe temperature readings



Ship 1. Air and sea temperature readings

Apart from probes 1 and 5 which, being situated on the surface of the cargo close to the weather-deck, tended to follow the ambient temperatures, five of the six remaining probes did not show a temperature variation exceeding 2.7°C during the 69 days the cargo was onboard. The other, probe 2, fluctuated according to the ambient air until cargo was loaded into the no. 2 tween deck at Buenos Aires. This seems to indicate that prior to that time, probe 2 was lying on, or very close to, the top of the Rosario cargo.

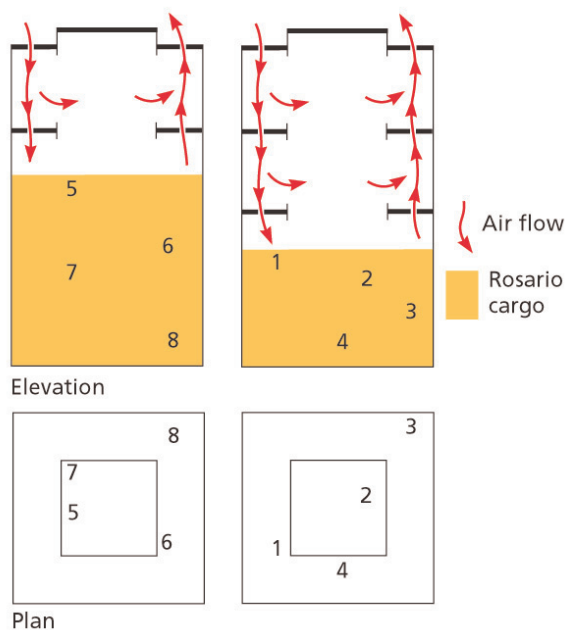
The maize outturned sound. Samples taken on discharge in the vicinity of each probe showed no evidence of deterioration.

Ship 2

This was a cargo vessel, built in 1961 in Yugoslavia, and equipped with the *Cargocaire* system of ventilation. This was one of the most sophisticated systems of surface ventilation available. It was designed to permit continuous ventilation of cargoes in all holds, regardless of the dew point of the ambient (external) air. Each cargo space was fitted with inlet and outlet ducts just below the level of the deckhead. Thus, in hold 2 for example, there were three sets of ducts, in the lower hold, in the lower tween deck and in the upper tween deck. The ducts ran into a common main duct in each hold, the main outlet duct being fitted with a suction fan and a dew point sensing element. The dew point sensing element was connected to a recorder situated on the bridge. This instrument recorded the dew point of the atmosphere passing through the main duct. In normal operation, external air was continually drawn in through inlet ventilators and exhausted through outlet ventilators. The dew point of the ambient air was also continuously recorded by the instrument situated on the bridge. Should the dew point of the incoming air have exceeded that of the atmosphere issuing from any hold, condensation could have occurred on the surfaces within that hold. Hence, when such a situation prevailed, pre-dried air was forced into the hold, the outlet duct closed and the injected air re-circulated.

Cargocaire had the following advantages over normal ventilation:

- It could be practised continuously.
- The use of inlet ducts permitted a more even air flow through the top of the cargo space.
- The dew point of the average atmosphere within a hold and also of the ambient air were measured continuously and more reliably than by normal methods.



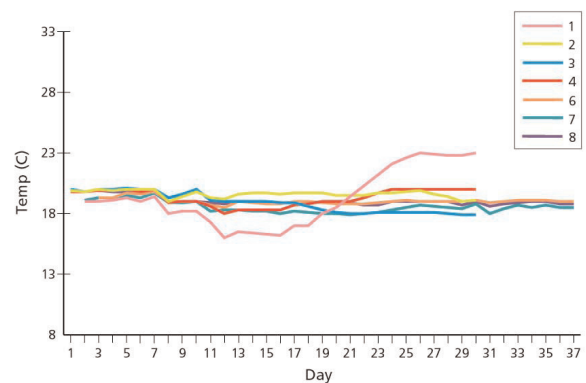
Ship 2. Plan and elevation showing position of probes in holds.

Maize was loaded at Rosario in late June/early July 1965 and the probes were placed in holds 2 and 5. In each hold, three probes were buried in the lower hold cargo and the fourth was placed on the surface of the cargo in way of the tween deck hatch, the approximate positioning being shown in the diagram. General cargo was loaded in the tween decks of each hold.

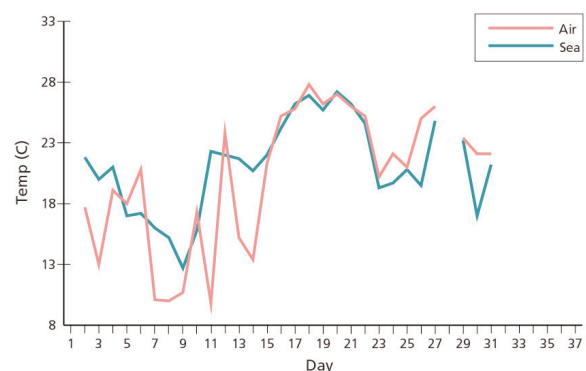
Each time a probe was positioned, a sample of the cargo in the vicinity was taken, sealed and subsequently tested for absolute moisture content. The results again ranged between 12.8% and 14.5%. The temperatures of the samples, ranging from 19°C to 22°C, exceeded in every case the temperature of the ambient air on the day the cargo was loaded. On these figures, microbiological spoilage was not anticipated, unless the voyage was prolonged.

During the crossing – from 6 July to 25 July - the *Cargocaire* ventilation system was in continuous normal operation except for a brief period at Santos on the 9 and 10 July, when pre-dried air was circulated in the holds. The temperature of the river/sea water, and the temperature of the ambient air were both recorded each day, and are plotted on the graphs opposite, but as the equipment had apparently been used only intermittently during discharging, this date has been omitted for the period subsequent to the 29 July.

The graphs also show the maximum temperature recorded daily for each probe. Probe 5 was unfortunately stolen by the loading stevedores before any readings were obtained from it. Probes 1,2,3 and 4 were broken by the stevedores during discharging at Marseilles, and no readings were obtained after 28 July, until temporary repairs were effected on the 2 August and 4 August.



Ship 2. Cargo hold probe temperature readings



Ship 2. Air and sea temperature readings

Apart from probe 1, no probe registered a variation over a period of 38 days in excess of 2.4°C.

The maize, some of which had been onboard for 42 days (discharge being finished only on the 9 August), outturned in perfect condition. Samples taken from the vicinity of each probe on discharge showing no signs of deterioration.

Conclusion

The experimental shipments indicate that maize of low moisture content, loaded cool, will carry well over a relatively long voyage whether or not the surface of the bulk is ventilated. They show further that it is only the surface of the cargo that responds to ventilation, the bulk of the stow remaining unaffected.

This perhaps, is not surprising when one remembers how resistant maize is to the transfer of heat; its coefficient of thermal conductivity is less than that of asbestos, and as an insulator, it is about one-third as good as cork.

In general it can be said that the experiments confirm the view previously expressed by Dr Milton, namely that ventilation is irrelevant to the carriage of maize in bulk.

Footnotes

1. Vapour pressure can also be measured in terms of other units – either in atmospheres or kilopascals. 1 atmosphere (1 atm) = 760mm mercury (mm Hg) = 101.325 kilopascals (kPa).
2. Actually, there will be a very slight rise in vapour pressure, but this may be ignored for the purposes of the example.
3. Recent studies have shown that cargo sweat, i.e. the depositing of liquid water on the surface of maize grains is extremely unlikely, either as a result of the transfer of moisture from warm ventilating air to a cold surface layer of grain, or from warm moisture-laden air rising from a bulk of warm grain towards a cold surface layer. However, moisture transfer would still occur in either situation causing the moisture content of the cold grain to rise. The effect is therefore the same.
4. Scientific Principles of Grain Storage, Liverpool, 1948, p23
5. Ayerst & Leniger: Report on Heat Damage to Argentinian Maize during shipment to Europe, December 1967
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