Fire Research Note No. 633

HIGH MEAN TEMPERATURES IN SHIPS' HOLDS

by

P. C. BOWES

FIRE RESEARCH STATION

F. R. Note No. 633
October, 1966.

HIGH MEAN TEMPERATURES IN SHIPS' HOLDS

by

P. C. Bowes

SUMMARY

For the purpose of assessing the spontaneous ignition hazard of a limited class of goods carried on board ship, estimates have been made of the highest time-mean temperatures likely to be encountered in the upper regions of ships' holds in some of the hottest sea areas.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

HIGH MEAN TEMPERATURES IN SHIPS' HOLDS

by

P. C. Bowes

INTRODUCTION

Rules for the carriage of liquefied gases on board ship[1] are based on a temperature of 65°C (149°F) as the maximum likely to be encountered on board ship in tropical zones, and on 45°C (113°F) for temperate zones. Here a hazard arises from exposure to these high temperatures for short periods - say an hour or so when the daytime temperature is near its peak value.

For most commodities subject to self-ignition arising from slow self-heating, however, the situation is different. Such commodities (e.g. activated carbon, fishmeal, oilseed cake etc.) have thermal diffusivities of order 10^{-3} cm^2 s^{-1}, and the minimum size of stow for self-ignition tends to be large. Attenuation coefficients, for the penetration by conduction, of 24-hour periodic changes of ambient temperature are about 0.2 cm^{-1}; whence an amplitude of 10°C in the ambient temperature will be reduced to 1°C at a depth of about 12 cm. Mielke[2] has reported, in fact, that the diurnal variations of temperature above the cargo in a ship's hold are not noticeable at a distance of 2 metres below the surface of the cargo. Under these conditions, the risk of self-ignition in a stow of given size, will depend on the maximum value of the mean ambient temperature likely to be encountered on board ship for intervals of at least a few days rather than on daytime peak values.

An attempt is made in this note to derive a reasonable estimate for this maximum mean temperature. This is done by first of all estimating the maximum mean excess temperature in a ship's hold, from published observations, and then adding this to the mean air temperature for regions in which high temperatures commonly occur.

PUBLISHED TEMPERATURE MEASUREMENTS - ESTIMATION OF EXCESS TEMPERATURE

Continuous records of temperatures in ships' holds, suitable for the present purpose, have been published by Baumbach[3] and Höller[4] of the Deutscher Wetterdienst (Seewetteramt). The first (for August 1955) in M.S. "STECKELHORN", covers the West African route from Biscay to Liberia

and the second (Feb - May 1958), in T.S. "DUSSELDORF", the route from Hamburg to Valparaiso via Panama.

In general, the records show a pronounced fluctuation in the temperature of the air in the hold above the waterline associated with the daily cycle of direct sunshine or sky radiation. Near the weather deck and side plates, these fluctuations can regularly cover a range of 10-20°C (ca. 20° - 40°F) in tropical waters, but the minima are usually within 1° or 2°C of the temperature of the outside air. Below the waterline, the hold temperature is related primarily to the sea temperature.

The detailed behaviour of the temperature at different points in the holds, which is most relevant to the present enquiry, may be summarised as follows:-

1. During the outward voyage of T.S. "DUSSELDORF", the highest temperatures, and widest fluctuations, were recorded above the upper surface of the cargo in the "spardeck" (upper tweendeck) of No. 3 hold. The point of measurement was ½ m (20 in) below the steel weather deck exposed to the sun and adjacent to an intake ventilator.

   During an eleven day period covering the passage of the Caribbean Sea, the Panama Canal and the North West coast of South America to Guayaquil (roughly latitude 15°N to 3°S) the outside air temperature was within the limits 28 ± 2°C (82 ± 4°F) for most of the time and the mean temperature for the period at the above point in the hold was 33°C (91°F); i.e. 5°C (9°F) above the mean for the outside air. On two days in this period (in port at Guayaquil), when the daytime maximum in the hold reached 44° and 45.5°C (111° and 114°F), the 24-hour mean temperature was 35° - 36°C (95° - 97°F); this was 7° - 8°C (13° - 14°F) above the corresponding mean for the outside air.

   In the Caribbean, Panama Canal and at Guayaquil deck temperatures of around 60°C (140°F) were measured.

2. For the passage of the Caribbean, temperature records were obtained also for the air in the exit ventilator of the "spardeck" (which would be expected to give an indication of the spatial mean temperature of the air in the compartment), for a point above the cargo in the "tweendeck" (i.e. lower tweendeck) and another among items of cargo in the lower hold.*

---

*It appears that one or more of these points was in No. 4 hold, but it is not clear which.

The range of the diurnal fluctuation in the temperature of the air from the "spardeck" did not exceed 6°C, and the mean value of the temperature for the period of 5 days was about 4°C (7°F) above the mean for the outside air; peak temperatures did not exceed 35°C (95°F).

Apart from one day, when a maximum of 36°C (97°F) occurred, the diurnal fluctuation of the temperature in the lower tweendeck was only 3° - 4°C (5° - 7°F), and the mean was about 2°C above the mean for the outside air.

In the middle of the cargo in the lower hold, the temperature fluctuations associated with the daily insolation were absent, and the measured temperature, which was rising steadily, tended to be 1° or 2°C below the mean for the outside air.

3. Records for the voyage of M.S. "STECKELHORN" show a mean temperature for the hold above the waterline of 3° - 6°C higher than the daily mean for the outside air for a period when daily maxima in the hold, near to the side of the ship, were 35° - 36°C. During this period, cloud cover varied from 25 per cent to 75 per cent and rainfall occurred during the last half.

Summing up, it appears that the mean temperature over periods of several days in ships' holds, above the waterline, can frequently exceed the mean shade temperature of the outside air by up to about 5°C in the tropics; an excess of 7° - 8°C has been observed on two days.

These excess temperatures are found under the weather deck and near the sides of the ship; at the lower levels of the hold above the waterline the mean air temperature tends to be close to that for the outside air.

In addition to the deck temperatures of 60°C observed in the Caribbean and elsewhere[4], a value of 70°C is quoted for a voyage of M.S. "CAP ORTEGAL". Mielke[2], as an example for a hot tropical day, quotes a deck temperature of 65°C; on this occasion, the air temperature above the cargo in the ship's hold was 16°C higher than that for the outside air. These deck temperatures are within the range of high temperatures observed on bare ground in locations such as the Sahara and Central Asia[5]. Even so, it is probable that the small number of observations made on board ship so far have not covered the most extreme conditions likely to be met; such as, for example, might conceivably occur in the hold of a ship in ports in the Red Sea or Persian Gulf - when a combination of reduced ventilation in the hold and hot winds off the land might lead to even higher deck temperatures and to a more widespread distribution of high temperatures in the hold.

It is suggested therefore, that for the time being, the highest observed excess of 7 - 8°C might be rounded up to 10°C, as a reasonable estimate for the maximum amount by which the mean air temperature in a ship's hold (averaged over intervals of a few days) is likely to exceed the corresponding mean outside shade temperature.

Since night minimum temperatures in a ship's hold have been observed to be close to the corresponding minima for the outside air, an excess mean temperature of 10°C implies a daytime peak temperature in a ship's hold of about 20°C above the corresponding peak for the outside air. This is within the range of excess temperatures observed for some comparable situations on land. Thus, some unpublished data[8] shows that in the hottest shelters on land, the peak temperatures (obtained from the daily cycle of temperatures in the shelters - averaged over several days - in a cold spell in winter in one location and hot spells in summer in other locations), exceeded the corresponding shade temperatures by amounts between 17 and 24°C. Further[9], under extreme conditions, the temperature under the roof of a standing steel box car at Yuma, Arizona, exceeded the ambient air temperature (112°F, 45.5°C) by 22°C (39°F). It is understood that, in the former examples[8], the shelters were unventilated (although not airtight); the degree of ventilation of the box car is not stated but there is some indication that the doors were closed. It may be concluded that the estimate of 10°C for the maximum excess mean temperature likely to occur in a ship's hold includes an adequate allowance for occasional poor ventilation.

As far as can be seen from an inspection of the temperature records (for T.S. "DUSSELDORF" especially), the above estimate of the maximum excess for the time-mean temperature in the hold above the waterline is free from any marked bias due to the lag in the response of the cargo to long term changes in the temperature of the outside air. The effect of this lag is most apparent during the passage from tropical zones to temperate zones and vice versa; for the former direction in particular, this lag can increase the difference between temperatures measured in the hold and in the outside air but, since the actual values of the air temperature are then lower than in the tropics, the effect is unimportant for the present purpose.

HIGH MEAN AIR TEMPERATURES OVER THE SEA

Charts showing the distribution of air temperatures over the sea for each month of the year have been published by the Meteorological Office[6, 7]. They are based on screen temperatures observed on board ship (windward side), at 00, 06, 12 and 18 hours G.M.T. for a period of many years. The charts show isotherms at intervals of 5°F for the upper and lower 5 percentiles (designated maximum and minimum), means and ranges for each month; these are derived from the highest and lowest temperatures recorded for each month during the period. The highest values occur in the Persian Gulf and the Red Sea in August, and these are tabulated below:-

	Max.		Min.		Mean		Range	
	°F	°C	°F	°C	°F	°C	°F	°C
Persian Gulf	95	35	85	29	90	32	8	5
Red Sea	90+	32+	85+	29+	90	32	8-12	5-7

The figures in the table (and below) refer to the highest isotherm over the sea in the given region and it is to be understood that temperatures of up to 5°F (3°C) higher may be encountered towards nearby land masses. As an indication of the upper limit to the air temperature over the sea, it is understood that peak values of 105°F (41°C) are very occasionally reported in the Red Sea; it is not known, however, to what extent these high values are influenced by the ship itself.

For separate days in a month, or a series of days, high daytime maximum temperatures may be expected to be associated with high night minimum temperatures. Hence the mean temperature for a few consecutive days in a given month may be expected on most occasions to fall between the mean and the upper 5 percentile for the month derived as above (where the highest daytime maximum is associated with the lowest minimum for a given month). For the present purpose, it is suggested that these upper 5 percentiles might be regarded as reasonable estimates for the maximum mean air temperatures likely to be encountered for periods of a few days. Further, 3°C (5°F) may be added to allow for proximity to land or periods in port.

On the above basis the estimate for the likely maximum mean air temperature, for a period of a few days, is 38°C (100°F) for the Persian Gulf and about 35°C (95°F) for the Red Sea. In view of the rarity of peak temperatures such as 41°C (105°F) it is probable that these estimates will usually err on the side of safety; the longer the period to which the estimates are applied the greater will the factor of safety be.

The corresponding estimate for the air temperature over the sea off the West Coast of Africa is 29°C (85°F) and 32°C (90°F) for the Caribbean Sea and Panama.

CONCLUSIONS AND COMMENTS

1. For purposes of assessing the risk of self-heating to ignition in commodities such as activated carbon, fishmeal, oilseed meals etc. carried on board ship in the tropics it is necessary to know the maximum mean temperature* likely to be encountered in the hold of the ship for periods of at least a few days.

2. Mean temperatures in the upper levels of a ship's hold above the water-line tend to be higher than the mean temperature of the outside air, due to a net absorption of solar radiation. It is estimated that the highest excess in the mean temperature for a period of a few days in a ship's hold near deck and side plates exposed to the sun, is likely to be 10°C (18°F) above the corresponding mean for the outside air (shade temperature).

3. Adding this excess to estimates of maximum mean air temperature for periods of a few days over the sea, the following estimates are obtained for the maximum mean temperature for such periods likely to be encountered in ships' holds:

Persian Gulf	48°C (118°F)
Red Sea	45°C (113°F)
West Coast of Africa	39°C (103°F)
Caribbean Sea and Panama	42°C (108°F)

*"Mean temperature" here means the temperature averaged over a period of time at a given location in the hold. It refers only to temperatures determined by climatic factors and the initial temperature of the cargo, and no account is taken of proximity to engine-room bulkheads or refrigerated spaces.

4. The above estimates apply to the hottest parts of a ship's hold, i.e. within a distance of the order of 1 metre of steel deck and side plates exposed to the sun, and include an allowance for proximity to land and periods in port. Exceptionally, in a landlocked port such as Basra, they may be exceeded but, usually, they are likely to err on the side of safety.

5. The estimates are intended as a basis for assessing the probable behaviour of relatively small parcels of cargo (say of the order of 10 tons), susceptible to self-heating and which is stowed, for example, immediately below the weather deck or in a forecastle space. For materials which are relatively unreactive, such that the critical size for ignition occupies a large proportion of an upper hold space of a ship, these figures will be too high; for this case the average shade temperature over a period of the order of weeks will be more appropriate. For materials such as unstable chemical compounds, which are so reactive that the critical size is of the order of a single 10-gallon drum and less, the estimates will tend to be low. More precise assessment of the hazard in this region of small sizes must await a solution of the problem of self-heating and ignition in the presence of a periodically varying ambiemt temperature. For these reasons the temperature estimates must be applied with some care.

ACKNOWLEDGMENTS

The author is indebted to Commander C.E.N.Frankcom of the Meteorological Office and to members of his Panel on Climatic Hazards in the Transport and Storage of Goods (British Standards Institution, P/192/1) for criticism of the first draft of this note and to Mr. N. Bradbury, Mr. R. Frost and Mr. G. W. Rattray, of the Meteorological Office for discussion.

REFERENCES

(1) "The carriage of dangerous goods and explosives in ships". Report of Minister's Standing Advisory Committee. Ministry of Transport H. M. Stationery Office, 1961.

(2) MIELKE, H. "On the climatic requirements of stored goods in sea transport". Verpackungs Rundschau, 1962 13 (12) 93-99.

(3) BAUMBACH, S. "Analysis of temperature, moisture and ventilation measurements in cargo spaces". Deutscher Wetterdienst, Seewetteramt, 1956 No. 9, 22-30.

(4) HOLLER, E. Results of the third research voyage on cargo-space meteorology in T.S. "DUSSELDORF" of the Hamburg-America Line to the West coast of South America 1958. Deutscher Wetterdienst, Seewetteramt. 1960, No. 27, 5-36.

(5) Anon. "Note on the temperature of an object exposed to the rays of the sun". Meteorological Office. 1948, unpublished pamphlet.

(6) "Monthly Meteorological chart of the Indian Ocean". Meteorological Office, Marine Branch, H.M. Stationery Office, 1949.

(7) "Monthly Meteorological Chart of the Atlantic", Meteorological Office, Marine Branch, H.M. Stationery Office, 1948.

(8) BRADBURY, N., Meteorological Office, Personal Communication.

(9) PORTER, W. L. Occurrence of high temperatures in standing boxcars. Quartermaster Research and Development Command, Technical Report EP-27, 1956.