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RADIATION APPROXIMATIONS FOR ESTIMATING THE COVER TEMPERATURE OF OUTDOOR STORAGE VESSELS

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This note is a 'by-product' of the development of some numerical questions for use in a postgraduate course on process safety. Some ideas have been engendered by it which are quite conceivably of interest in the development of safe storage practices for flammable substances, hence the choice of a journal such as this to record the ideas as a note.

According to a source cited by Thomas [1], for heat balance purposes, such as in weather forecasting, the sky can be treated as a black body at a temperature 5 to 20 K below that of the earth's surface at the place to which the heat balance relates. The author has recently [2] attempted to extend this idea to outdoor storage of flammable substances.

In the original formulation cited, radiation towards the sky is at night so the point on the earth's surface to which the heat balance relates receives no solar flux. By contrast the application herein is for daytime conditions. Anything on the earth's surface receives solar flux of about 1400 Wm^{-2} in daylight. However, this heat once received by the earth is redistributed in a number of ways. For example in the sort of situation under discussion having been absorbed by the earth's surface, this heat is in part transferred by convection to the air. If we treat a point on the earth's surface as being warmer than the sky, the heat which has been received from that direction in the first place has to be understood as now being transferable by modes of heat transfer other than radiation.

This approximation can be expressed more formally in the following way. Application of the approach under daylight conditions requires that the point – in the case of the calculation below a storage vessel – shall be a non-gray body. In thermal radiation a gray body, though less emissive at any one temperature than a black one, acts equivalently towards thermal radiation of all wavelengths. In this application, there is the requirement that the vessel, being metal and either polished or painted white, reflects most of the incident solar radiation which is therefore lost from the vessel. By contrast, it acts as a black body when itself radiating at low temperature. This is non-gray body behaviour, and it is not at all uncommon for practical materials to display such behaviour, especially when the incident and emitted radiation are widely separated in wavelength. Fig. 1 below shows the heat balance situation.

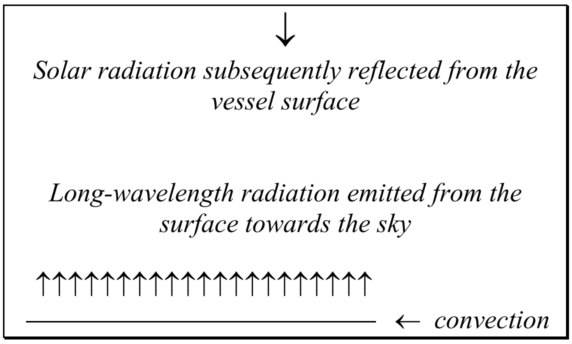

Fig. 1: Heat balance situation

Imagine a storage situation for liquefied natural gas (LNG), that is, the LNG is in a tank set in the ground with a metal cover over it. The air with which the outside layer of the cover is in contact is at temperature T_o K and the convection coefficient from air to cover is h $Wm^{-2}K^{-1}$. The space between the underneath side of the cover and the surface of the LNG is occupied by still air and can be taken to be insulating. Using the 'non-gray body' approximation outlined above, the following thermal influences therefore operate.

(a) heat transfer q_1 (W) <u>from</u> the outside surface of the cover to the sky by radiation.

(b) heat transfer q_2 (W) <u>to</u> the outside surface of the cover by convection from the air.

In considering (a) it has to be remembered that since there are two 'surfaces' – the cover and the sky – there are 2^2 = 4 view factors. This follows from basic radiation heat transfer principles, [e.g. 3]. It is however a fairly trivial exercise [2] to show that, because of the huge difference in area between the two surfaces in an application such as this, the equation for radiation is simply:

$$q_1 = A\sigma\varepsilon(T^4_{cover} - T^4_{sky})$$

where A is the cover area, ε the emissivity of the cover material and σ the Stefan-Boltzmann constant (5.7×10^{-8} $Wm^{-2}K^{-4}$); the subscripts on the temperatures are taken to be self-explanatory. If conditions approximate to being steady, the heat balance equation is then:

$$A\sigma\varepsilon(T^4_{cover} - T^4_{sky}) = hA\,(T_o - T_{cover})$$

$$\Downarrow$$

$$\sigma\varepsilon(T^4_{cover} - T^4_{sky}) = h(T_o - T_{cover})$$

Imagine that the LNG storage is in a place where the weather is cold and $T_o = 0^oC$ (273K). The ground temperature will be close to that of the air, so we take the sky to be at 253K. The cover will be taken to have a high emissivity at long wavelengths, approximating to 1.0, and mild convection will be represented by a coefficient h of 10 $Wm^{-2}K^{-1}$. Substituting into the heat-balance equation gives:

$$5.7 \times 10^{-9}\ T^4_{cover} + T_{cover} = 296.4$$

This has to be solved by trial and error, to give:

T_{cover} = <u>267 K (– 6 ^oC)</u>

so the cover settles to a temperature of 6 K below that of the air from which it is receiving heat by convection because of radiation to the sky. The numbers inserted into the heat balance equation are of course arbitrary but the calculation illustrates the not insignificant effect of radiation to the sky in outdoor storage situations.

Transforming the weather conditions to T_o = 318 K (45^{o}C) and T_{sky} = 298K (25^{o}C) whilst retaining the values of h and ε gives:

$$5.7 \times 10^{-9}\ T^4_{cover} + T_{cover} = 362.9$$

yielding the trial-and-error solution:

T_{cover} = <u>310 K (37^{o}C)</u>, about 8 K cooler than the air.

Examples could be multiplied indefinitely of situations where the principle of treating the sky as a black body could be incorporated into heat balance equations for storage out of doors of flammable substances and the above, with their simplifications, are mere examples. However, LNG is frequently carried long distances by ocean and this will involve entry to and departure from tropical regions. There is possible scope for further calculations of the type above in relation to this.

REFERENCES

1. L.C. Thomas, Heat transfer, Prentice-Hall, Englewood Cliffs, N.J. (1992).
2. J.C. Jones, Hydrocarbon process safety: A text for students and professionals, Whittles Publishing, Caithness – in press.
3. J.C. Jones, The principles of thermal sciences and their application to engineering, Whittles Publishing, Caithness and CRC Press, Boca Raton (2000).

Note added in proof

The reader will find a good discussion of radiation to and from the sky in:

Y.A. Cengel and R.H. Turner, Thermal-fluid sciences, McGraw-Hill, p. 835 (2001).