On the Non-Constant Gamma

C. J. STIGTER

Department of Physics, University of Dar es Salaam, Tanzania

23 June 1976

ABSTRACT

It is shown that a recently suggested use of a pressure dependence of the psychrometric "constant" is no improvement on existing practice. A plea is made for a thorough experimental and theoretical investigation into the pressure dependence of γ, given the facts that we do still rely completely on empirical values at normal pressure and that our lack of understanding of processes involved is still high.

1. A known pressure dependence

The interest in the energy budget and equilibrium methods of estimating evapotranspiration is not so recent as suggested by Storr and den Hartog (1975). It has been known for some time that in calculations of evaporation and transpiration for highland areas we have to use a pressure-dependent psychrometer "constant" γ. And, of course, the *Smithsonian Meteorological Tables* also indicate the pressure reduction of γ (List, 1971, p. 366). Using the Penman formula for potential evaporation and transpiration calculations has become routine procedure in East Africa (Brown and Cochemé, 1969, 1973) and as early as 1965 this correction and a more empirical one were taken into consideration in Penman tables by McCulloch (1965). Corrected tables can also be found in Doorenbos and Pruitt (1975).

Table 1 shows the values of $s/(s+\gamma)$ (with s the slope of the saturation vapor pressure-temperature curve) taken from McCulloch's tables compared to those arrived at by Storr and den Hartog (1975). The differences of 1–2% between them arise mainly from different approximations chosen for the specific heat calculation involved, implying among other things a constant relative humidity of 50% chosen by Storr and den Hartog. Their method cannot be claimed to be more accurate, and for Penman calculations the use of tables must be preferred above laborious mathematical expressions unless computer programs are used [e.g., Chidley and Pike (1970), who did not include this correction].

Of more interest is the other approach of Storr and den Hartog (1975) shown in the multiple regression analysis closely representing the more complicated mathematical expression. A representation of the pressure dependence with their "gamma-gram" can be of value in rapid evaporation calculations using nomograms (e.g., Koopmans, 1969) or other graphical representations (e.g., Messem, 1975) with the condition that in the gamma-gram the error (K) is given in °C and that, as argued below, we use it only for the time being.

2. An unknown pressure dependence

A more fundamental point to be brought up in this discussion on the psychrometer non-constant is the

TABLE 1. Values of $s/(s+\gamma)$ obtained by Storr and den Hartog (1975) and McCulloch (1965)

Height (m)	T (°C)	$s/(s+\gamma)$ Storr and den Hartog	$s/(s+\gamma)$ McCulloch
0	15.0	0.620	0.615
500	11.75	0.591	0.585
1000	8.5	0.561	0.553
1500	5.25	0.528	0.519
2000	2.0	0.494	0.485

Unauthenticated | Downloaded 11/27/21 03:47 PM UTC

fact of the accidental agreement between the *purely empirical* values normally used for γ (such as 0.66 mb K^{-1}) and the approximation for γ used by Storr and den Hartog (1975). The "text-book formula" which they used is

$$\gamma = C_p P/(\epsilon L),$$

where C_p is the specific heat of air at constant pressure (J kg^{-1} K^{-1}), P the atmospheric pressure (mb), ϵ the ratio of molar mass of water vapor to that of dry air and L the latent heat of vaporization of water (J kg^{-1}).

This formula is only valid for an adiabatic system (e.g., Monteith, 1973) to which the measuring systems with which the *empirical* γ values have been determined (well-ventilated dry and wet bulb thermometry) do not conform.

As made most clear in the work of Wylie (1969), the best theoretical evaluation of what really happens at the well-ventilated wet bulb yields a γ of 5.8 mb K^{-1} (at 1000 mb and between 0° and 20°C). This is nearly 9% lower than the empirical value of 6.3 mb K^{-1}, obtained after application of a longwave radiation correction, arising from practical performance, to the empirical values used in practice (Wylie, 1969; Tanner, 1972). The fact that the adiabatic case closely represents at normal air pressure and temperature the uncorrected empirical γ values must be seen as purely accidental.

Without going into details of the possible explanations (Wylie, 1968) and practical consequences thereof (Stigter, 1976; Stigter and Welgraven, 1976), it must be stated that the problem of this discrepancy between theory and practice has not yet been solved. This being so, ultimate care should be taken in accepting the pressure dependence of γ in the simple adiabatic case as the one valid for psychrometric measurements. One obvious point which has not been taken into consideration is the pressure dependence of the transport coefficients.

The present author is not aware of systematic measurements having been reported on the pressure dependence of γ under real conditions of ventilated dry and wet bulb thermometry. After having relied for almost a century on empirical γ values at normal air pressure and given the complicated physical approach necessary to make our lack of understanding clear (Wylie, 1968, 1969), we should use both of these two approaches (measurements and physical theory) to make the pressure dependence of γ more accurately known.

One may correctly argue that the γ used in energy budget and equilibrium methods of estimating evaporation and transpiration should not be the empirical γ which is determined by ventilated dry and wet bulb thermometry. But in that case the story given above, *mutatis mutandis*, applies to the natural evaporating system concerned (water, leaf, soil). These systems are also not adiabatic and we do not know more about them in relation to the non-constant gamma than about the evaporating wet bulb (Yu and Brutsaert, 1967; Gale, 1973). Again, more systematic measurements in combination with physical theory are necessary regarding the pressure dependence of γ in other evaporating systems. This will surely be of benefit to evaporation and transpiration estimations in regions such as the East African Highlands that are important areas in third world agricultural production.

REFERENCES

Brown, L. H., and J. Cochemé, 1969: FAO/UNESCO/WMO interagency project on agroclimatology. Technical report on a study of the agroclimatology of the Highlands of Eastern Africa. FAO, Rome.

——, and ——, 1973: A study of the agroclimatology of the Highlands of Eastern Africa. WMO Tech. Note No. 125 (WMO No. 339).

Chidley, T. R. E., and J. G. Pike, 1970: A generalized computer program for the solution of the Penman equation for evapotranspiration. *J. Hydrol.*, **10**, 75–89.

Doorenbos, J., and W. O. Pruit, 1975: Guidelines for predicting crop water requirements. Irrigation and Drainage Paper No. 24, FAO, Rome.

Gale, J., 1973: Experimental evidence for the effect of barometric pressure on photosynthesis and transpiration. Plant Response to Climatic Factors, R. O. Slatyer, Ed., *Ecology and Conservation Series*, Vol. 5, UNESCO, Paris.

Koopmans, R. W. R., 1969: De bepaling van de verdamping met behulp van nomogrammen. *Cult. Tech. Tydschr.*, **9**, No. 2, 1–10.

List, R. J., 1971: *Smithsonian Meteorological Tables*, 6th rev. ed. Smithsonian Institute, Washington, D. C.

McCulloch, J. S. G., 1965: Tables for the rapid computation of the Penman estimate of evaporation. *E. Afr. Agric. Forest. J.*, **30**, 286–295.

Messem, A. B., 1975: A rapid method for the determination of potential transpiration derived from the Penman combination model. *Agric. Meteor.*, **14**, 369–384.

Monteith, J. L., 1973: *Principles of Environmental Physics*. Edward Arnold, London.

Stigter, C. J., 1976: Water vapour pressure within a maize crop. *Arch. Meteor. Geophys. Bioklim.*, **B24** (in press).

——, and A. D. Welgraven, 1976: An improved radiation protected differential thermocouple psychrometer for crop environment. *Arch. Meteor. Geophys. Bioklim.*, **B24**, (in press).

Storr, D., and G. den Hartog, 1975: Gamma—The psychrometer non-constant. *J. Appl. Meteor.*, **14**, 1397–1398.

Tanner, C. B., 1972: Psychrometers in micrometeorology. *Psychrometry in Water Relations Research*, R. W. Brown and B. P. van Haveren, Eds., Utah State University Press.

Wylie, R. G., 1968: An outline of some recent experiments on the psychrometer. CSIRO Div. Phys. Rep. PIR-63, 10 pp.

——, 1969: The psychrometer problem—a precise analysis. CSIRO Div. Phys. Rep. PIR-65, 22 pp.

Yu, S. L., and W. Brutsaert, 1967: Evaporation from very shallow pans. *J. Appl. Meteor.*, **6**, 265–271.

Unauthenticated | Downloaded 11/27/21 03:47 PM UTC