Relative Humidity in Incubators

ELIZABETH BARDELL, JILL FREEMAN, and E. N. HEY
*From the Medical Research Council Group on Respiration and Energy Metabolism in the Newborn,
The London Hospital Medical College, London E.1*

In a previous paper Hey and Maurice (1968) have reported the effect of changes of relative humidity on the heat production and heat loss in normal naked babies in a specially constructed metabolic chamber under controlled environmental conditions. In order to evaluate the clinical relevance of these observations we have studied the control of relative humidity that could be achieved in three commercial incubators. A means of assessing the operative environmental temperature in such incubators has already been published (Hey and Mount, 1967).

The amount of water that can be contained as vapour in air depends on the temperature of the air (Fig. 1 heavy line, 100% relative humidity). By definition the absolute humidity is the amount of water present as vapour in a given weight or volume of air, and the relative humidity (RH) is the amount of water vapour actually present, expressed as a percentage of the maximum amount that could be present at that temperature. The air in hospital wards is usually about 50% RH (Fig. 1 point A); if this air is warmed from about 20 to 30° C. without the addition of extra water vapour, its absolute humidity will remain constant but its relative humidity will fall to 25% (Fig. 1 point B). For this reason warm-air incubators contain humidifying devices.

Air can contain more water than indicated by the heavy 100% RH line in Fig. 1 at any given temperature only as liquid droplets, and these droplets of mist will only remain in suspension for a limited time, depending on their size. Avery, Galina, and Nachman (1967) have recently reviewed the use of mist therapy in paediatrics. This specialized aspect of humidity control was not covered in the present study.

Material and Methods

Tests were undertaken in a temperature-controlled room on three empty incubators of different design, an Oxygenaire Series III natural convection incubator, a New Oxygenaire Nursing forced-convection incubator, and a Standard C-86 Isolette forced-convection incubator. Temperatures were measured with 36 s.w.g. thermocouples and recorded on a 12-channel Cambridge D.E. Recorder at one-minute intervals. Incubator air was sampled from 5 cm. above the centre of the mattress and its water content monitored continuously with a wet and dry thermocouple assembly of the type described by McLean (1963), through which air was drawn at 100 cm./sec. The whole assembly was mounted inside the incubator. Regular cross checks were performed using a small aspiration psychrometer (Haenni, Jegenstorf, Switzerland) inside and outside the incubators. The discrepancy between the two readings was never more than 2%. The operative environmental temperature within the incubator was measured using the methods described by Hey and Mount (1967).

The rate at which fresh ward air was being drawn into the incubators (I) was assessed by measuring the equilibrium fractional concentration of oxygen achieved
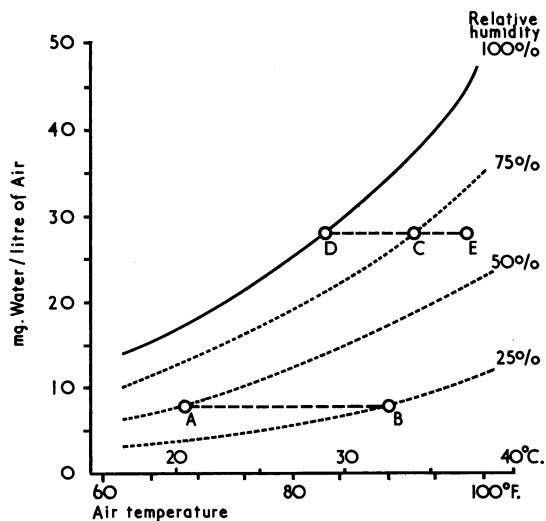

FIG. 1.—*Relation between absolute humidity, relative humidity, and air temperature (barometric pressure 760 mm.Hg).*
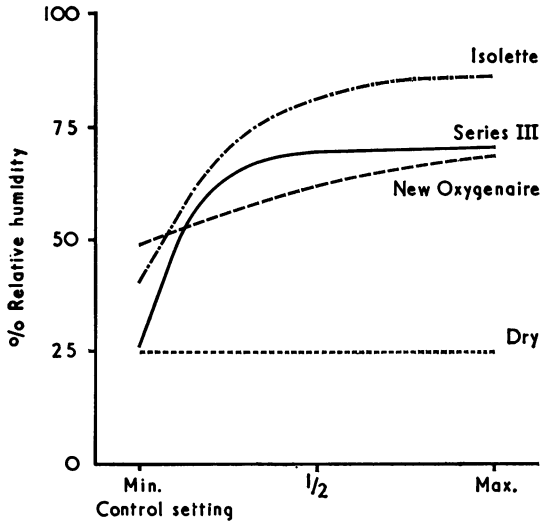
FIG. 2.—*Relation between control setting and RH achieved inside three commercial incubators when room RH is 50%.*

inside (x) when a known amount of pure oxygen (y) was also added each minute. The rate was then calculated from the relation:

$$I = y(1-x)/(x-0\cdot021).$$

Rates of between 1 and 5 cubic metres per hour were encountered.

Assessment of Three Standard Incubators

Control. Each of the incubators was placed in turn in a room at a temperature of 20° C. with RH held at 50±3% (mean±SD), and the incubator adjusted so that the temperature of air 5 cm. above

the centre of the mattress was 32° C. The humidity in the incubator was measured when the humidity reservoir was empty and at four different settings of the humidity shutter or control knob when the reservoir was full of water. It was found that the range of control available in the New Oxygenaire incubator was small, and the level of humidity achieved in the other two incubators was not linearly related to the control setting (Fig. 2). Because the humidity reservoir is not completely closed off by the control mechanism in the New Oxygenaire and Isolette incubators, really low humidity could only be achieved by draining the humidity reservoir of all water (Fig. 2). When the control setting was altered, an increase in humidity was quickly achieved in all three incubators, but a decrease took very much longer (e.g. Fig. 3). When the incubator doors were opened (even briefly) changes occurred in incubator humidity in the direction of that existing in the room (Fig. 3). (Similar brisk changes in the percentage of oxygen present could be detected when a door was opened while a high oxygen level was being maintained within the incubator.) Some minor fluctuations in humidity occurred in the Series III Incubator in time with the cycling of the thermostat (Fig. 3); no such fluctuations could be detected in the other two incubators.

Effect of temperature. The maximum and minimum humidity achieved was measured at different room and incubator air temperatures with room humidity held at 50±3%. It was found that the magnitude of the difference between room and incubator air temperature affected the minimum
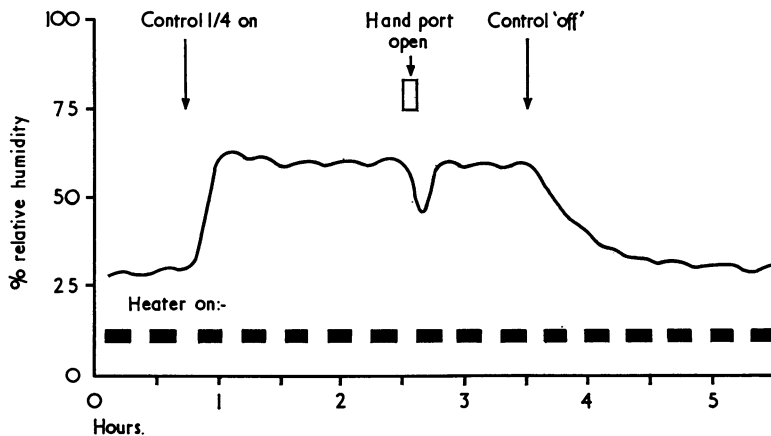

FIG. 3.—*Record of RH within an Oxygenaire Series III incubator (incubator air 32° C., room 20° C., and RH 50%).*
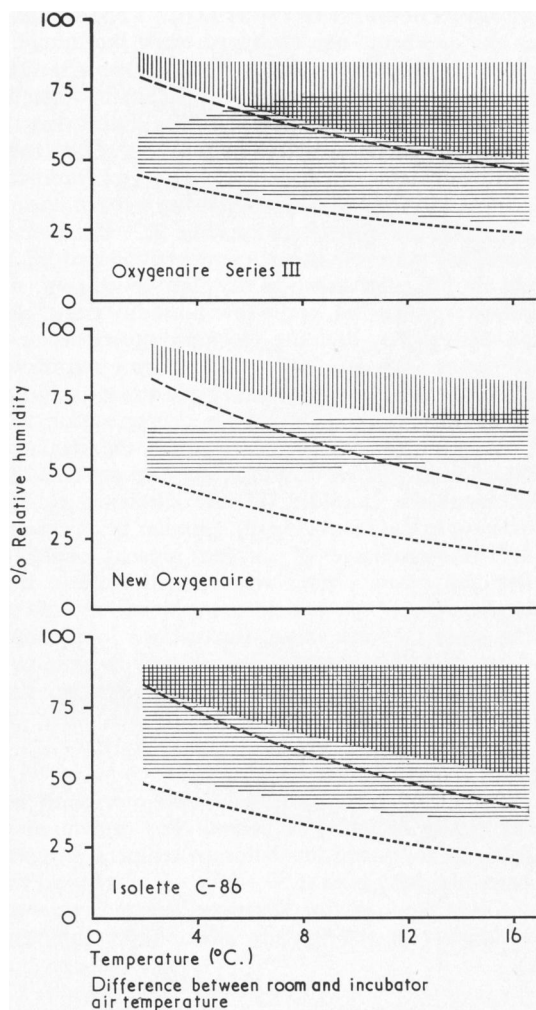
FIG. 4.—*Shaded areas indicate the range over which relative humidity can be controlled inside three different commercial incubators when room RH is 50% (≡) or 90% (||||). The lines represent the minimum humidity obtainable when all water is removed from the humidity tanks and room RH is 50% (·····) or 90% (−−−−−). The amount by which incubator temperature exceeds room temperature is plotted on the horizontal axis.*

humidity achieved in all three incubators, and also the maximum humidity achieved in the Series III Incubator (Fig. 4).

Room humidity. These tests were then repeated with the room humidity at 90±4%. It was found that the rise in room humidity influenced the minimum humidity achieved in all three incubators in a predictable manner and also the maxi-

mum humidity obtainable in the two Oxygenaire Incubators (Fig. 4).

Added oxygen. The addition of 2 to 4 litres dry oxygen per minute from a cylinder had no significant effect on the general level of incubator humidity. Higher oxygen concentrations can most conveniently and economically be achieved by leading oxygen into a small Perspex hood placed over the infant's head, but the infant will of course be breathing exceedingly dry gas unless this oxygen is first warmed and then humidified (Warley and Gairdner, 1962).

Humidity levels with an infant present. Tests were repeated when a premature infant was being nursed within the incubator, to see if the humidity was increased under these conditions. The differences observed were small, and suggested that the presence of a baby never increased the humidity by more than 4%. This agrees reasonably with theoretical predictions based on estimates of the rate at which fresh air is drawn into the incubators. A really wet napkin significantly increased the child's total evaporative heat loss, but not the humidity within the incubator.

Mean radiant temperature. Changes in relative humidity produced only very small and rather variable changes in the mean radiant temperature. Condensation of water on to the sides of the incubators led to a slight rise of surface temperature which was probably due to the release of latent heat from the water. However, variations in air temperature also occurred: in the Isolette incubator, in particular, air temperature at the inlet fell several degrees when the air was routed over the humidifying water tray; though mean air temperature within the incubator was little affected, radiant surface temperatures near the inlet fell in consequence.

Accessories. An Oxygenaire humidity 'atomiser' was fitted to the back wall of the Series III Incubator and tested. With a through flow of 2½ l./min. from a cylinder this accessory was capable of producing 100% RH in the incubator independent of the main humidity control setting. However, this input of cold air into a natural convection incubator produced a 3° C. fall in air temperature above the mattress. The Isolette was also tested with its 'Vapojette' accessory. The effect on incubator air temperature was negligible (except when the heater was full on) because of the compensating effect of the thermostat, but with the

main humidity control open, the 'Vapojette' accessory only increased humidity a further 7%.

Water level. Variation in the amount of water present in the humidity tank in the two Oxygenaire incubators (within the limits set by the marked maximum and minimum water levels) caused no changes in humidity. No such working limits for the water level were marked on the Isolette*. In this incubator water had to be visible more than an inch deep in the transparent filling receptacle before appreciable quantities entered the humidity tray, and when the water level was low it was impossible to raise incubator humidity above 55%. It is our experience that all three incubators are often used with less than the minimum effective amount of water present in the humidity tank, and that this is not appreciated because no reliable means is provided of measuring humidity.

Measurement of incubator humidity. The Series III Oxygenaire Incubator was the only incubator fitted with a hygrometer; in the other incubators no means of measuring internal humidity was provided, even as an optional extra. The series III direct reading paper hygrometer was tested on receipt and found to be accurate to within 3% except for an hour or two after becoming saturated at 100% RH, but those in constant ward use soon became inaccurate for lack of servicing or adjustment (though the majority of the nursing staff had not appreciated this). The hygrometer was screwed through one of the Perspex walls. In this position the dial was easy to read, but, because it was fixed to a relatively cold outer wall, the instrument was in a cold layer of boundary air where the relative humidity was higher than in the main body of the incubator. Thus, with an air temperature of 34° C. and an RH of 75% in the body of the incubator (Fig. 1 point C) in a room at 20° C. the relative humidity recorded close to the outer walls approached 100% (Fig. 1 point D) because the temperature here was below 29° C.

Visibility. Because the incubator wall temperature is influenced as much by the temperature of the room as by the temperature of the air within, it follows that misting and condensation will occur on these relatively cool surfaces long before the relative humidity in the main body of the incubator reaches 100%, unless the difference between room and incubator air temperature is small. Thus, visibility through the walls of the Series III incubator is frequently obscured by condensation during

routine use, even though it can be shown that the air inside is not more than three-quarters saturated. After some time water starts to run down the side walls and even the mattress becomes wet. The problem is even more acute in those incubators capable of producing higher internal humidity.

Assessment of an Experimental Double-walled Incubator

In the belief that the greater insulation offered by *sealed* 'double glazing' might ease the problem of condensation and consequent loss of visibility, an experimental double-walled canopy was made for the Isolette incubator. A thin sheet of Perspex was placed a few mm. inside the main Perspex canopy: all the walls and dome were so covered except for the four hand ports, and the edges of the inner wall were sealed to the main canopy all round leaving a cavity of trapped air between the two Perspex sheets. The outer surfaces of the modified canopy were easily cleaned; it was thought that the inner surfaces would not require attention if the sealing was sufficiently thorough.

The thermal environment provided within this experimental canopy was then compared with that achieved in the Standard Isolette C-86 incubator and the incidence of condensation studied.

Air speed was measured directly and found to be low (4–10 cm./sec.) immediately above the mattress. The relation between average surface temperature and room and incubator air temperature is indicated in Fig. 5a, and the effect of room temperature on the mean radiant temperature within the two incubators is summarized in Fig. 5b. The thermal environment provided by the Standard Isolette incubator is seen to be very similar to that provided by the two Oxygenaire Incubators studied previously (Hey and Mount, 1967); the discrepancy between air temperature and mean radiant temperature is approximately halved by the use of a sealed double canopy. When humidity within the incubator was high, condensation occurred on to the cold parts of the canopy in both models, but the greater insulation provided by a sealed cavity wall reduced the incidence of this problem.

Discussion

Where no accurate means of measuring RH in the incubator is available the findings summarized in Fig. 2 and 4 can be used to predict approximate humidity, but where accuracy is required the actual RH should of course be measured. For this purpose a direct-reading hygrometer conforming to British Standard 3292(1960) would suffice, as long as care is taken not to place it in a cold layer of

---

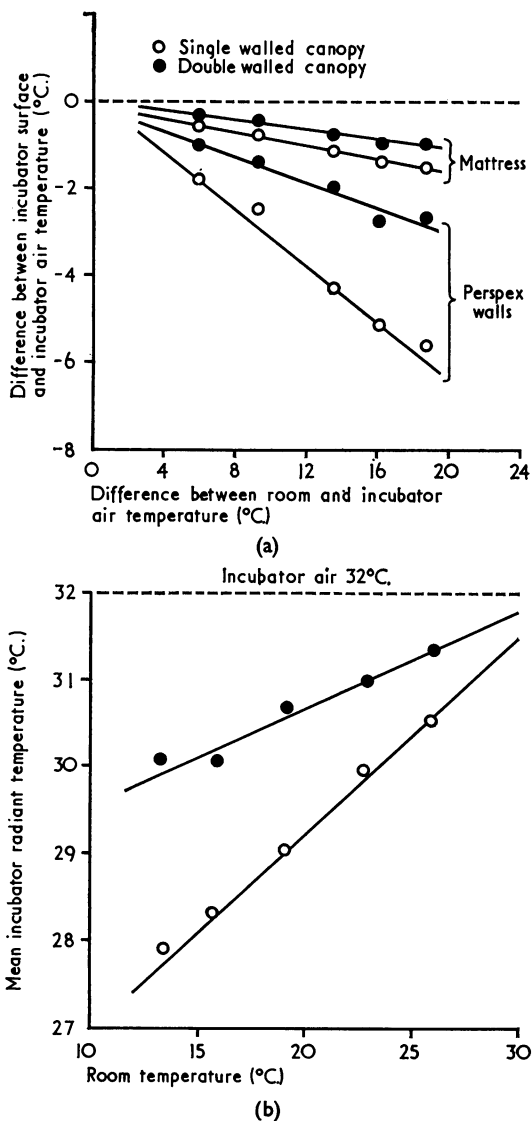* We understand that the firm intend to provide these in future.

FIG. 5.—(a) *Effect of room temperature on surface temperatures inside a Standard Isolette incubator, and inside a prototype with a double-walled canopy.* (b) *Effect of room temperature on mean radiant temperature in these two incubators when air temperature inside is maintained at 32° C.*

boundary air. Any such hygrometer would require regular servicing and periodic recalibration, particularly if the hygrometer is left permanently *in situ*, because dirt and chemicals affect the sensing element.

It has been shown that, unless an accessory nebulizer is used, the relative humidity in the three incubators tested can only be controlled and varied between about 30 and 85% RH, though there are significant differences in the performance of the three models studied. From the previous paper (Hey and Maurice, 1968), it can be seen that variation of humidity within this range has comparatively little effect on an infant's heat loss or energy metabolism, particularly if the surroundings are warm and the infant's heat production minimal. The effect on the infant's water balance is probably also marginal, though O'Brien, Hansen, and Smith (1954) have shown that large changes of humidity affect water balance and haemoconcentration in infants starved for the first 3 days of life. The effect of humidity on bacterial contamination in incubators is poorly documented, though the danger of the humidity reservoir and other damp surfaces becoming colonized with pseudomonas is now widely recognized.

None of the incubators tested provided a RH of 95%, as required by the current British Standard for incubators 3061(1965), without auxiliary equipment. However, the British Standard requirement in this respect is not very precise and is probably in need of revision. It remains, of course, most important to be able to maintain a high inspired air humidity when nursing an infant who has been tracheostomized or intubated. Here the *inspired* air should ideally be fully saturated at body temperature whatever the humidity of the rest of the air in the incubator may be. Air fully saturated at 29° C. (Fig. 1 point D) will be only 65% saturated at body temperature (Fig. 1 point E).

The loss of visibility due to the condensation that occurs when internal humidity exceeds 75% RH is of considerable consequence, since ease of observation is one of the principal reasons why incubators are used in preference to heated cots or devices such as a Charlotte's box. The use of a sealed air gap in the wall of the Perspex canopy reduced the incidence of this problem and also decreased the discrepancy between air temperature and mean radiant temperature within the incubator under normal ward conditions. Measurements of heat flow through, and temperature gradient across, the canopy walls confirm that this improvement is due to the thermal insulation being greater than that afforded by a similar thickness of solid Perspex. The number of air : surface interfaces has been increased from 2 to 4, and this would be expected to about double the thermal insulation provided by the canopy, and approximately halve the net difference between internal air and radiant temperatures. Fig. 5 shows that these predictions are fulfilled. The exact extent of insulation provided will be determined by the width of the gap between

the two Perspex walls which was not constant in the prototype canopy tested. The optimum gap is probably nearly 1 cm., but minor deviations are unlikely to make a detectable difference.

The use of a wall standing further away from the main canopy, with free circulation of warm incubator air over both its surfaces, as suggested by Hey and Mount (1966), is more effective in reducing the discrepancy between air temperature and mean radiant temperature, but does nothing to combat condensation. Thus, a choice between these two methods of modifying the design of warm air incubators to control radiant heat loss should depend in part on a clinical decision as to the importance of nursing infants in more than 75% humidity.

Summary

The range of relative humidity (RH) that can be achieved in three standard commercial incubators has been investigated under a variety of conditions. The range of control was sometimes limited, and often not linearly related to the control setting. In none of the incubators tested was it possible to achieve a maximum RH of 95% (as currently required by the British Standard specification), even under optimum conditions, without the use of accessory equipment. A means of measuring humidity was only provided with one incubator, and, since this hygrometer was fixed to the canopy in the boundary layer of relatively cold air, the instrument gave a falsely high reading. Marked condensation on to the cold Perspex walls obscured visibility when incubator air was more than three-quarters saturated under normal ward conditions; the provision of a double-walled canopy with a sealed cavity reduced the incidence of this problem as well as halving the discrepancy between air temperature and mean radiant temperature within the incubator.

REFERENCES

Avery, M. E., Galina, M., and Nachman, R. (1967). Mist therapy. *Pediatrics*, **39**, 160.
British Standard 3292 (1960). Specification for direct reading hygrometers. British Standards Institution, London.
—— 3061 (1965). Specification for electrically heated incubators for babies. British Standards Institution, London.
Hey, E. N., and Maurice, N. P. (1968). Effect of humidity on production and loss of heat in the newborn baby. *Arch. Dis. Childh.*, **43**, 166.
——, and Mount, L. E. (1966). Temperature control in incubators. *Lancet*, **2**, 202.
——, and —— (1967). Heat losses from babies in incubators. *Arch. Dis. Childh.*, **42**, 75.
McLean, J. A. (1963). Measurement of cutaneous moisture vaporization from cattle by ventilated capsules. *J. Physiol. (Lond.)*, **167**, 417.
O'Brien, D., Hansen, J. D. L., and Smith, C. A. (1954). Effect of supersaturated atmospheres on insensible water loss in the newborn infant. *Pediatrics*, **13**, 126.
Warley, M. A., and Gairdner, D. (1962). Respiratory distress syndrome of the newborn—principles of treatment. *Arch. Dis. Childh.*, **37**, 455.