1933-05

Apparatus for the Maintenance of Constant Temperature and Humidity

Eagleson, C. W.

The Ohio Journal of Science. v33 n3 (May, 1933), 194-203
http://hdl.handle.net/1811/2631

APPARATUS FOR THE MAINTENANCE OF CONSTANT TEMPERATURE AND HUMIDITY.

C. W. EAGLESON,
Ohio State University.

The exacting demands for accuracy in modern biological research make necessary precise control of temperature and humidity. This paper is intended to set forth certain considerations which enter into the construction and operation of thermostats and humidostats.

AIR THERMOSTATS.

The physical properties of air must be borne in mind in order to be successful in maintaining it as a thermally static system. Salient characteristics of air are its low specific heat, or thermal capacity, and low thermal conductivity. A volume of air contains only one three-thousandth as many calories of heat as a similar volume of water. Hence in a given volume, a small loss or gain of heat produces a relatively great change in its temperature. Conversely, an object surrounded by air of different temperature will be affected very slowly because the air contains such a relatively small amount of energy to impart to the object. So it is that air is such an excellent insulator. For these reasons an air bath needs no elaborate insulation, and it is desirable to use heaters of small size. Moreover, a quick-responding thermoregulator is necessary.

Cabinets in which temperatures are to be held constant do not need to be elaborate or expensive. The success of accurate control depends more upon the perfection of the controlling instruments than upon excess insulation. A double-walled cabinet made of some insulating fiber board such as "Masonite" or "Cellotex," nailed to a light but rigid framework of wood, will give ample insulation for all but extreme temperatures. Dead air spaces of about two centimeters should be provided between layers of insulation. The case should be of air-tight construction.

Long low cabinets are the most practical. Such design gives better air circulation and more floor space. Since entomological experiments are usually carried on in rather small containers, a greater efficiency is enjoyed where there is more floor area and less waste space at the top of the cabinet. A cabinet of good dimensions is 65 to 70 centimeters high, 80 centimeters deep, and as long as desired—perhaps 1.7 to 2 meters. Doors should be wide enough to accommodate good sized trays; moreover, one can work more effectively through an opening which provides ample elbow room. It is a good plan to hinge the door at the bottom to provide a work shelf when it is open. Doors without glass are lighter and more easily made. Observation windows may be built above the doors, thus giving the operator clear vision through the window while working with his hands through the door. Interior illumination is very helpful. A cabinet is more convenient if its floor is on a level with the worker's elbows. The floor should be of some material that is easily washed.

A rapid circulation of air in the cabinet is essential for uniform temperature. A small house fan may be set inside the chamber, or a larger slow-speed motor may be mounted on the outside and belted to a shaft running through the cabinet wall. But such a shaft is difficult to construct, and must be provided with good metal bearings to be free from vibration. A false inner back in the cabinet will form a duct to provide for the return of air to the heating units and fan. One adjustable opening, 15 centimeters in diameter, in the wall behind the fan, is sufficient for a fresh air supply. If an inside fan is used, an adequate cooling system should be provided to offset the heat generated by the motor. It is a good plan to construct a flue, opening through the bottom and top of the cabinet and enclosing the motor of the fan. Convection currents will carry out this troublesome extra heat.

All cabinets should be built to allow maintenance of a constant humidity. From the experience of Richardson, it seems unnecessary to line the cabinet with sheet metal or glass. The walls may be successfully waterproofed with two coats of priming shellac or lead paint, a coat of under-varnish, and two coats of the best waterproof spar; or three coats of "Duco" may be used.

The type of heating unit depends upon the temperature to be maintained. When only a small amount of heat is necessary it is common practice to use electric light bulbs. They are not efficient heaters because they consume more current per calory of heat delivered than any other type of heater, and consequently overburden the thermoregulator or relay contact points. The points are then much more apt to stick and fail to turn off the heat. The old-fashioned electric room heaters, known as "Luminous Radiator Units," are very satisfactory heaters. They have a large heating surface and very low lag in heat delivery. These factors are vitally important in air conditioning. If such bulbs cannot be obtained, good heaters can be made of bare resistance wire wound on porcelain rods or asbestos. The flat resistance wire used in flat-irons is good. As a matter of fact, an electric heater, with more resistance wire added to reduce the wattage, makes an admirable heater for a high temperature air bath.

To be independent of surrounding temperatures a thermostat must have a cooling system such as cold water flowing through a metal tube. The flow of water may be adjusted so that the heater is off and on for equal periods. A more nearly constant temperature is obtained when the intervals of heating and cooling are short.

In certain situations gas heat might prove superior to electric. A very simple and not inefficient mercury thermoregulator to control the flow of gas to a burner can be purchased or made of glass tubing as illustrated.

WATER BATHS.

Maintenance of constant temperatures in liquid systems is in some ways much easier than in gaseous ones. The calorie content of water per volume is so very much greater than that of air that the heat interchange by conduction between water and the surrounding air is small. Hence careful insulation of the waterbath is not at all necessary. In case of a metal water container, insulation such as one layer of fiber board or an inch-thick layer of newspaper is sufficient. Such a tank will allow maintenance of temperature to within 0.01° C. On the other hand, considerable heat is lost as a result of evaporation from an exposed water surface. The evaporation rate varies with the weather and any draft that may blow. A tight cover over the bath will eliminate this cause of temperature fluctuations. Or if more practical, the water surface may be protected with an inch-layer of pure white oil which will both insulate and stop evaporation.

A good waterbath may be constructed from any one of the many types of non-rusting water containers. Glass aquaria are often desirable if the experiment must be inspected closely. Usually they need no additional insulation. One of the most serviceable types of container is the wooden barrel or hogshead. Barrels are cheap and readily obtained, and they lend themselves to all manner of carpentry for installation of instruments, water pipes, etc. No additional insulation is needed.

Rapid agitation of the water is of cardinal importance for accurate temperature regulation. A small propeller working in a vertical brass tube, so that a down current of water is created within the tube, is an efficient stirrer for a small bath. A heater of the knife-blade type can be placed in the tube and thus insure a rapid distribution of the heated water. Such a stirrer may be connected directly to a small motor, but it is usually more convenient to belt it to a motor located elsewhere. For a larger body of water a good agitator may be made from a piece of heavy sheet brass cut and bent like a boat propeller. This may be fastened to a horizontal shaft passing through the side of the tank and belted to a motor. A surface agitator of the centrifugal type can be fashioned from a vacuum sweeper. The discharge opening should be cut away so that the water will surge out on the same plane in which the fan turns, and the fan blades trimmed down somewhat. It is necessary to connect a large rheostat in series with such a motor to reduce the speed.

Most immersion water heaters on the market are serviceable. The "Luminous Radiator Units" are excellent water heaters. There should be no appreciable lag in heat delivery, but the heating surface presented to the water is not so important if good circulation occurs. A cooling system is a necessity for close temperature regulation.

It is sometimes convenient to pipe water of uniform temperature from the water bath to the instruments or animal chambers than to immerse them in the main body of water. A small brass centrifugal pump taken from a truck engine circulates water through such an outside circuit in the author's laboratory.

THERMOREGULATORS.

Ordinary thermoregulators depend on expansion as the acting force. Hence the coefficient of expansion and thermal conductivity of a substance determine its usefulness as a thermoregulator medium. Gasses show the greatest volumetric reaction to temperature changes and are most sensitive in effect. However, the great changes in volume of gas produced by fluctuations of barometric pressure obviate the possibility of causing a gas filled thermoregulator to maintain a given temperature. Gas filled wafers are sometimes used in incubators, but they do not give dependable control.

Liquids display a lower coefficient of expansion, but the rate of thermal conductivity is about twenty times as great for liquids as gasses. Fluids offer the most practical solution to the problem of precise temperature control. Metals have a much lower coefficient of expansion than liquids, but they have a high rate of thermal conductivity. In spite of their low sensitivity metals are most frequently used as the agent in thermoregulating devices because a metallic regulator can be built to handle 110-volt current without a relay.

Metallic Thermoregulators.—Of the metallic thermoregulators, the DeKhotinsky type seems to be the most satisfactory. It is made of a metal helix whose torque opens and closes contact points with changes in temperature. They are especially dependable when provided with twin contact points, and under favorable conditions will regulate the temperature to within 0.5° C. Bimetallic or metal-nonmetal regulators will usually keep the temperature to within 1° or 2° C. of that desired, but they are inferior and not overly dependable.

Most metallic thermoregulators are designed to make and break a 110-volt circuit directly without the aid of a relay. The burden thus placed on the breaker points is severe. Only metals having the highest melting points will resist the intense heat of the tiny electric arcs which are produced each time the circuit is broken. If the contact points are broad, the arcs will be diffused over the surface and will be less apt to melt out minute pockets or fuse the points together. Rough contact surfaces cannot meet exactly flush and so they foster arcing and sticking. Contact points are highly polished when manufactured because the reliability of the instrument depends on the mirror surface of the points. Therefore the points should be given good care, and never scraped with a file or knife. If the surfaces become dirty, impregnate soft paper with Jewelers rouge (Ferric Oxide powder) and draw it several times between the points. If they have become pitted so that rouge is insufficient, use the finest emery dust on soft paper or

No. 0000 emery cloth. Finish with a prolonged polishing with rouge, and adjust so that the points make contact over their entire surface. Emergency contact points may be made out of small discs of coin silver highly polished.

It is important to guard against overloading the thermoregulator. As small heating units as possible should be used, and if their combined power consumption is more than 200 watts it is better to split the circuit. When most of the load burns continuously and only a small fraction is in series with the regulator it will adjust the temperature much more accurately.

Liquid Thermoregulators.—For the maintenance of temperatures within a range of less than 0.5° C., it becomes necessary to use liquid as the regulator medium.

The sensitivity of a thermoregulator fluid is determined by the relationship of the specific heat, density, and coefficient of expansion of the thermoregulator fluid, to the specific heat and density of the substance whose temperature is regulated. In other words, the calorie content per volume of the bath medium should be greater than that of the thermoregulator liquid. Such a relationship exists between water and mercury or organic fluids. It seems both in theory and practice that a well designed mercury thermoregulator is not excelled for water baths.

The case of air conditioning is quite different. The calorific ratio is reversed so that air contains much less heat per volume than the regulator liquid. The temperature of the air can change considerably before sufficient energy is transferred to alter the temperature and volume of the liquid. This time factor is apparently responsible for the difficulties encountered in maintaining temperatures in an air bath within less than half a degree. In order to offset this condition it is of unquestioned value to employ an organic fluid in order to benefit by the higher coefficient of expansion (about ten times that of mercury).

Electric Thermoregulators.—Rarely and for the most exact temperature regulation, thermoregulators have been built to make use of the changing resistance of a band of metal, or changing potential of a thermocouple. Such slight electrical variations are recorded by a sensitive galvanometer. A small light beam is reflected from the galvanometer mirror to a light-sensitive cell some distance away. When the temperature rises, the mirror deflects the light beam onto the cell, activating it to pass a small electric current. This current is amplified in a vacuum tube relay so that it will operate a magnetic relay which breaks the heating circuit. Although complicated, this method has been reported successful in holding temperatures in a very small bath to plus or minus one one-thousandth degree.

Mercury Thermoregulators.—Mercury filled thermoregulators are so frequently used that almost every laboratory has its own design of instrument. Most of them are good, but the one described here is superior in simplicity and ease of construction. It can be quickly made by a person unfamiliar with glass blowing.

A large tube, with bulbous end or not, is slightly flared at the top by heating and spreading with a metal triangle or carbon rod. This tube should hold about one kilogram of mercury. A second piece of glass tubing which will fit snugly into the first is cut about 10 cm. long, and enlarged at one end to form a cup. This may be accomplished by heating and working a hot carbon rod into the bore to swell the tube. A piece of 2 mm. capillary tubing, 5 cm. long is flared very slightly at both ends so that it will just slip into the neck of the second tube. The capillary is coated on both ends with soft DeKhotinsky's cement or "lac-wax,"* preparatory to sealing in the second tube. A copper wire to make fixed contact with the mercury is laid along the side of the capillary and inserted along with it into the neck of the second tube. A gentle warming will melt the wax and seal both capillary and wire in place. This assembly is then inserted in the neck of the mercury reservoir and sealed in place with wax or plaster of Paris. A metal bracket is fastened about the top of the regulator to support the contact wire which extends into the capillary tube. Either a screw or sliding clamp makes a fine adjustment of this wire possible. Platinum wire should be used for the tip of the electrode, since it does not amalgamate with mercury. It may be joined to a copper wire by first welding to constantan wire in a blast lamp and then soldering the latter to copper. Platinum is exceedingly difficult to solder. A temporary joint may be made by cleaning both wires and winding two or three

*"Lac wax" is a convenient sealing compound made of flake orange shellac and pine tar in proportions according to the hardness desired. It is not resistant to strong chemicals, but is more easily handled and much cheaper than DeKhotinsky's cement.

turns of the copper wire about the platinum, then mashing them together and covering the union with sealing wax.

Organic Liquid Thermoregulators.—Toluol is often recommended as a thermoregulator liquid. The author has found carbon tetrachloride much superior except for temperatures above 70° C. Carbon tetrachloride has a slightly higher coefficient of expansion, greater density, is non-inflammable and is cheaper and more easily obtained. Methyl Alcohol is another good regulator fluid for biological work.

A section of unused automobile radiator-core, which holds about two liters, is used as the reservoir for the regulator fluid. Such a container exposes the liquid to a maximum surface per unit volume, insuring a rapid response to the temperature fluctuations of the air. The section of radiator is converted into a tight container by soldering suitable covers over the two ends where openings are exposed. Two copper tubes are soldered into opposite ends of the top. One is short and serves to permit the escape of air during filling; when the container is full and all air excluded this tube is pinched shut and soldered The other tube leads to the glass manometer in which a small droplet of mercury makes and breaks contact with a platinum wire. In order to prevent carbon tetrachloride from dissolving the stop-cock grease and leaking out, or evaporating from the open reservoir, it is necessary to provide for a trap liquid to seal it in the reservoir. A small brass trap chamber, where carbon tetrachloride and water meet, is soldered to the second tube leading from the reservoir. This trap prevents water being drawn into the radiator or carbon tetrachloride coming in contact with the stop-cock. A "T" tube is attached to the trap, one arm of which connects with a stop-cock and filling reservoir, and the other to the glass manometer. The manometer is made of 2 mm. capillary tubing. In the rear arm a small bulb is blown to serve as a trap to prevent mercury from being drawn into the metal part of the instrument. (Mercury will amalgamate with and dissolve soldered joints.) A copper wire is inserted through the rear arm of the glass "U" tube to make contact with the mercury. The manometer tube is cemented to the copper tube with wax, through which joint the contact wire protrudes. To fill the instrument carbon tetrachloride is poured through the filling reservoir until the instrument is entirely full and overflowing at the overflow tube. Then sufficient water is poured in to half fill the trap chamber

At this juncture the overflow tube is pinched together and soldered. Next a droplet of mercury, large enough to fill the "U" manometer up to its trap is introduced through the open end. Finally a rubber tube is slipped over the free arm of the manometer and water run past the mercury in its trap until all air has been expelled from the connecting tubes and filling reservoir. The mercury drops back into place as soon as water ceases to flow past. The excess water can then be removed and a platinum electrode inserted into the free arm.

The adjustment of this thermoregulator to any desired temperature is quick and easy. When the stop-cock is open, the mercury in the "U" tube will stand at a certain level. The platinum electrode is set very close to the mercury meniscus. The air bath is then heated to the temperature desired and the stop-cock closed. The regulator will then hold the temperature at that point.

Mercury displays considerable adhesion to glass. Therefore, any movable column of mercury tends to stick to the glass with the result that the mercury meniscus is often greatly distorted or movement actually delayed. A lubricant consisting of a 5% solution of Phenylhydrazine Base in dibutyl phthalate will effectively prevent such difficulty.

MOVING CONTACT MECHANISM.

When more exact temperature regulation is desired than an ordinary mercury or carbon-tetrachloride regulator will afford, a device may be installed which will greatly increase the sensitivity of either of these types. Any sort of a mechanism will serve which will continuously lift and lower the platinum contact wire in the capillary tube a distance of one to three millimeters. A frequency of 40 to 60 times a minute is best.

In the case of any fixed contact regulator, there is always a lag in operation behind the temperature of the bath. The bath is overheated before the regulator turns off the heating current and overcooled before contact is made again. Furthermore, the longer the periods of heating and cooling are, the more irregular will be the curve of temperature. When a moving contact is used the alternations of heating and cooling are so rapid that lag in operation is circumvented. Also the temperature curve will be reduced to a nearly straight line. Usually there is no possibility of graduating the amount of heat supplied to a bath—either the heater delivers maximum heat or none.

If a moving electrode is used it produces the effect of a graded temperature change, for when the mercury rises slightly the needle is immersed for a longer fraction of each stroke and the heater therefore delivers a slightly smaller amount of heat per minute. Yet it does not let the bath cool rapidly as though it were entirely shut off. Such a delicate tempering of heating and cooling makes possible most exact temperature control.

Besides these, there are other advantages which make an interrupter-regulator more dependable. There is a positive mechanical rupturing of the mercury meniscus, so that the oxide film can never retard or prevent contact being made at the proper instant. Also, the constant agitation of the meniscus keeps it in a more regular form.

Any device which operates smoothly in lifting and lowering the contact wire is adaptable. The author uses a water motor made from a two-ounce salve box. A disc of thin brass is incised from the edge and the sectors turned 90° to make the paddle wheel. The bearings through which the brass axle protrudes are merely pieces of copper tubing soldered to the lid and bottom. The intake is soldered obliquely through the side of the box, with an outlet more than twice as large on the opposite side. A midget pulley with a cam to move the contact wire is belted to the axle of the water motor with a rubber band. A more elegant mechanism is an electric windshield wiper with slightly altered gears. A storage battery supplies current.

The Physiology of Farm Animals.

This book fills a long vacant niche in the literature pertaining to the physiology and nutrition of farm livestock. It was originally planned that this work should appear in two volumes, the first as an application of the general principles of physiology to farm animals, and the second, a volume dealing with animal nutrition. The first volume, by Marshall, was published in 1920 and is now out of print. The publishing of the second volume was abandoned following the death of Professor Wood, the senior author.

The Physiology of Farm Animals, by Marshall and Halnan, is the result of a thorough revision of the first volume, plus the addition of the material originally intended for the volume on nutrition. Therefore, this book includes a wealth of subject material of value to students of agriculture, especially those interested in farm animals and poultry.

The book is well written and amply illustrated. It should find ready acceptance as a textbook or reference for elementary courses in physiology as applied to farm animals.

EDWIN E. HEIZER.

Physiology of Farm Animals, by F. H. Marshall and E. T. Halnan. 366 pp., 118 ill. Cambridge, The University Press; New York, the MacMillan Company, 1932. $3.25.