EFFICIENCY OF STEAM STERILIZERS

BY

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Experiments recently published in the *British Medical Journal* (Hayes, 1937) indicate that surgical sterilizers may be dangerously inefficient. Stress has been rightly laid on the mode of packing and the nature of the material sterilized. It seems worth while inquiring, however, whether the usual method of pressure-gauge control and the system of timing the period of sterilization now used are satisfactory in these instruments. Nearly all the published tables giving the properties of saturated steam have been constructed on empirical formulae based on the researches of Regnault on pure steam. Table I (Low, 1931) gives the figures for pure saturated steam at pressures and temperatures within a range applicable to the subject under discussion.

TABLE I

P (lb.)	PG (lb.)	T (F.)	T (C.)
20	5.3	227.9°	108.8°
24	9.3	237.8°	114°
25	10.3	240°	115.5°
26	11.3	242.2°	116°
27	12.3	244.3°	118°
28	13.3	246.3°	119°
30	15.3	250.3°	121.5°

P=Absolute pressure; PG=Gauge pressure; T=Temperature.
Absolute pressure=gauge pressure+atmospheric pressure (14.7 lb. per sq. in.).

It is certain, however, that in the majority of sterilizers in use to-day we are not dealing with pure saturated steam but with a mixture of steam and air, and the inferential temperatures in these tables, therefore, cannot without modification be applied directly in practice.

If the degree of preliminary vacuum in a chamber is known it is a simple matter to ascertain the true pressure of the steam in any given mixture of steam and air. The usual pattern of ejector used in sterilizers cannot be expected, in a single operation, to produce a vacuum of more than 10 inches of mercury (Underwood). Suppose the preliminary vacuum to be 10 inches; the residual air will then be at a pressure of 10 lb. per square inch (approx.). If steam is now let in up to a gauge pressure of 15 lb. the absolute pressure of the mixture will be 30 lb., of which the steam accounts for 20 lb. (Dalton's law). Steam at an absolute pressure of 20 lb. can only attain a temperature of 227.9° F. (see Table I), but it is not uncommon for a maker to assume that a gauge reading of 15 lb. obtained in this way is sufficient evidence of safe working.

Table II shows the possible temperatures of steam at different pressures for given mixtures of steam and air. It can be seen from this table that a temperature above

TABLE II.—Temperatures at Different Pressures of Mixtures of Air and Steam

Gauge Pressure in lb.	Pure Steam	Steam and Air at 22.5 inches Vacuum	Steam and Air at 15 inches	Steam and Air at Atmospheric Pressure—that is, no Vacuum
10	240°	230°	220°	193°
15	250°	242°	224°	212°
20	259°	258°	245°	228°

240° F. with a gauge reading of 15 lb. is only possible in a chamber with a preliminary partial vacuum of 22 inches of mercury, a figure which is more than double the capacity of the average steam-ejector mechanism for a single working.

The standards for effective sterilization given in surgical and bacteriological textbooks are not comprehensive enough. The usual expression met with is "pure steam at a temperature of 240° F. for twenty minutes," and while this is strictly accurate as a statement of fact it is of little use in practice to makers and operators, since pure steam is not used in the vast majority of sterilizers on the market to-day. A practical and comprehensive standard should read as follows:

"A temperature of 240° F. or 115° C. obtained by pure steam under a pressure of 10 lb. per square inch, or, if any mixture of steam and air is used, at such additional pressure as will fully compensate for the partial pressure of the air."

In addition to the effect of residual air on temperature it is important to examine the time factor. A pressure-gauge reading is the result of a comparatively rapid response of the instrument to any changes in pressure. This condition, however, cannot obtain with regard to temperature. Time is necessary to build up a given temperature, and a thermometer rise will always show an appreciable lag after a given pressure-gauge reading. It is thus clear that if the standard accepted is twenty minutes at 240° F., then it will be some appreciable time after the gauge reaches the desired pressure before the whole mass of dressings attains the required temperature. That this period is not negligible has been experimentally proved, and the curves in Fig. 1 show that it may be so prolonged that the standard of 240° F. for twenty minutes is never fulfilled in what may be regarded as normal working conditions for many sterilizers on the market to-day. This temperature lag period, since it depends on many factors, cannot be arbitrarily fixed before the operation. It will vary with different instruments. In the same instrument, moreover, it will vary with different loads, depending on their nature and quantity, and also in summer and in winter. Further, if the same instrument is worked more than once in succession, the second working in a warm apparatus will need a shorter time-lag allowance than the first working. A strong case exists, therefore, for thermometric rather than gauge control of the time factor in sterilizers.

FIG. 1 (from Underwood).—Temperature obtained, at 15 lb. gauge pressure, in a sterilizer with varying degrees of preliminary vacuum, showing lag in rise of temperature and the degrading effect of residual air on the temperatures anticipated from gauge readings.

Numerous devices are on the market for insertion among the dressings which, by fusion or a change of colour, indicate that the desired temperature has been reached inside the drums. These devices are not always reliable (Hayes, 1937; Underwood, 1934), and they have the grave defect, even when functioning accurately, of not showing the precise moment when the required temperature has been attained. They are of no value, therefore, in controlling the variable time-lag factor. The lag in building up the temperature may be so excessive from various causes that the fusion or colour change may actually occur just a moment before the period of sterilization is brought to an end and the sterilizer opened (Fig. 1).

It now remains to discuss the means by which sterilizers can be efficiently worked and the maximum degree of safety ensured. There are two ways in which the problem may be dealt with: (1) the gravity discharge system; (2) the direct internal thermometer control system.

The Gravity Discharge System

This is the name given by Underwood to his system of sterilizer operation. It is applicable to any existing form of sterilizer provided the steam inlet and outlet are suitably placed. The following is a brief description of the method: Air is twice as heavy as steam, and steam when run into a chamber containing air tends to float on a bed of air. Gravity therefore tends to locate the air in the lowest parts of the chamber (see Fig. 2). If

FIG. 2 (from Underwood).—Curves showing differences in temperature readings in different parts of a sterilizer. The coolest part of the chamber is at floor level. No air has been evacuated. The three lowest curves are by temperature readings, the top curve by inferential gauge reading.

now, while steam is being run in, the exhaust pipe from the chamber is kept open a discharge of air and steam and condensed water vapour will escape. With the escape of air and steam there is of course a drop in the jacket pressure, which at the start should have been at its maximum—that is, 10 lb. The chamber pressure, owing to the fact that the exhaust is open, will only rise slightly—about 3 or 4 lb. It should not rise more than this. If this process is continued long enough (five minutes recommended) the operator will notice a change in the nature of the escape. It will at about the end of the period consist of a fine feathery discharge presumably of pure steam, as all the air inside the chamber will have been removed by the so-called gravity displacement. The exhaust outlet is at this stage almost but not quite shut

off. It is left open just enough to allow a continuous escape of this fine feathery steam vapour *throughout the entire operation of sterilization*. As there is only a slight escape of steam the chamber pressure, if the heating arrangement is strong enough, should continue to rise until a pressure of 10 lb. is obtained. The operation of sterilization is timed to begin at this point and continued for twenty minutes, the required pressure being maintained by the safety-valve and the intensity of the heaters or burners. With this method Underwood has found that with 10 lb. pressure a temperature of 240° F. can invariably be obtained inside the chamber, as tested by potentiometer readings. The temperature inside the chamber can also be deduced indirectly. When all the air is out and the fine feathery vapour is continuously escaping from the outlet, it is evident that a thermometer placed in the path of this vapour will give a reading which cannot be higher than the temperature of the steam in the chamber. Underwood claims that a thermometer placed in this discharge vapour will record a temperature between 240° and 250° F. for 15 lb. pressure, and by actual experiment I have been able to show a temperature of 239° F., working at 10 lb. pressure.

It is important to note that it is not possible to prove this effectively by merely holding the thermometer in the steam current as it escapes from the outlet. Steam released from a chamber under pressure expands almost adiabatically. It thus becomes unsaturated and heats a thermometer very slowly (Watson, 1926). To repeat the experiment correctly the thermometer bulb should be in the path of the steam in the outlet tube, preferably on the proximal side of the exhaust valve.

Some sterilizers have the outlet located at the top. Steam is usually allowed to escape for five minutes and the exhaust completely closed before sterilization is started. Owing to the relative densities of steam and air a complete evacuation of residual air cannot be effected in these sterilizers. The essential requirements are an exhaust at the lowest level in the sterilizer, an inlet at a high level in the chamber, and a continuous escape of a fine stream of vapour during the whole process of sterilization.

In actual practice the sterilizers made to Underwood's design have a thermostatic control at the outlet. It expands when heated and contracts when cool. The size is so adjusted to the outlet that at a given temperature it expands just enough to allow the slight continuous escape of steam essential to the correct working of this method. In the path of the discharge a thermometer is inserted, and in some models it may be connected with a recording device. Automatic control with complete elimination of the personal factor is a comparatively simple engineering problem, and is effected by operating a timing device from the discharge thermometer.

Direct Internal Thermometer Control System

There are many obvious ways of working this. The Cambridge Instrument Company, Ltd., produce a mercurial type of thermometer enclosed in a bulb of special heat- and pressure-resisting steel, which is connected by means of a metal capillary tube to a dial or other recorder outside the chamber. The range of temperature is from 50° to 300° F., and such thermometers find many applications in trade and industry. The capillary tube, however, is not a flexible arrangement, so that the location of the thermometer is of necessity limited: it would normally be fixed to the floor or wall of the chamber. This disadvantage can be overcome by the use of a potentiometer such as a Leeds and Northrup potentiometer with flexible thermocouples, which can be inserted through or under the door of the sterilizer. Potentiometers are, however, delicate and costly instruments, and not adapted to routine use. A simpler and less costly device is that described by Rosenau (1903) and Hayes (1937), although with this instrument only a definite predetermined maximum reading of temperature can be recorded.

Large and costly machines with patented fully automatic devices controlled from the pressure gauge alone may be seen in most hospitals and disinfection stations to-day. Unhappily it is not yet clearly appreciated that they are defective in two essential features and may be dangerous. These defective features are, first, the use of the pressure gauge as an inferential device for reading or recording temperature, and, secondly, the timing of the sterilizing process, which is regulated by clock to commence from the moment the desired pressure is attained on the gauge. I have convinced a well-known firm of manufacturers of these real defects, and they have now produced an automatic control dependent on a mercurial thermostat located inside the chamber. It must be remembered, however, that it is possible for a thermometer in one part to show the required temperature while another part of the chamber, depending on its position and the nature of its contents, gives a lower reading (vide Fig. 2). To meet this difficulty and also to protect the thermostat from wear and tear it has been located in a suitable dummy drum placed low down and attached permanently to the door of the sterilizer. This dummy drum is the model drum, and is packed with a sample of the most difficult type of material used, and the operator is instructed to see that no other drum in the load is packed more tightly. Any temperature attained in this drum by reason of its contents, the method of packing, and its low level with reference to the outlet must be lower than or equal to that attained in any other drum in the load.

It has been suggested that a thermostat located near the wall of the chamber is subject to radiation effects from the jacket, and may show a higher reading than the deeper contents of the chamber. This objection is unimportant, as the jackets of sterilizers do not extend over the doors, and, if anything, that part of the chamber near the door is the coolest part so far as the walls are concerned, since it is subject to most loss by radiation to the metal door. Smaller and cheaper sterilizers without automatic control which have little room for a dummy drum can be worked on the same principle, with a thermostat located in a small flat metal cage on the floor, the electrical connexions being carried through insulated openings in the jacket.

The Two Systems Contrasted

I now come to the relative advantages of these two systems. Both appear to fulfil the conditions which I have stressed in the foregoing paragraphs. The choice will perhaps depend on cost and applicability to local conditions, or other features which have little bearing on their efficiency. There are certain arguments, however, which should be given close attention before a final decision is arrived at. It is claimed that in the gravity discharge system the control temperature at the discharge must be lower than any temperature which is attained in the chamber. It is not certain, however, that the steam cannot on occasion make a rapid transit through an artificial channel among the dressings from inlet to outlet, leaving pockets of air in dead ends among the dressings. The outlet temperature would then approximate to or even equal the inlet temperature, and yet appreciable areas of the chamber may be left at dangerously cool levels. The case, therefore, for a reasonably high degree of preliminary vacuum which would assist diffusion of steam into the recesses of dressings remains a strong one. This applies with special force when sterilizing containers with fluid media or saline, etc., which must of necessity stand with their openings upwards and thus offer the most adverse conditions for any gravity effects on their contained air. Each container in effect acts as a miniature chamber, with its inlet in the worst possible position—namely, at the top.

Another factor, depending on the behaviour of gases when mixed, should be taken into account when considering the value of a preliminary vacuum. If we have a chamber from which all air has been removed, and by

means of a steam pipe suddenly place it in communication with a boiler containing boiling water, the water will at once produce enough vapour to saturate the space, and the pressure will rapidly rise to a given value depending on the intensity of heat applied to the boiler (Watson, 1926). If, however, we have a chamber which has not been subjected to any preliminary vacuum and we place it in connexion with a steam boiler, the process of building up the pressure and temperature will be much slower. Thus when the gravity method is used the total time during which surgical materials are exposed to heat is necessarily longer than if a vacuum process is used. Although the earlier stages of heating in both methods will be represented by curves in which no point is higher than the final 240° F., nevertheless with a preliminary vacuum the rise of the curve to 240° F. will be steep and rapid, but with the gravity displacement it must be slower and less steep, and the difference between the two curves will be accentuated the heavier the load and the more intricate the interspaces in the dressings. The balance of economy in fuel, in time, and particularly in perishable rubber materials by reason of the additional baking period, is therefore in favour of a preliminary vacuum, since the variable time-lag factor will be less with this method.

Another possible objection to the gravity discharge type of sterilizer is the use of the expansion thermostat at the outlet. Even the best of these are subject to fatigue changes, and unless an adequate service department is available to effect an alteration in this device when necessary it may become a source of trouble and therefore not be so reliable as an internal mercurial thermostat with automatic control. It is also possible, with a thermostatic control in the outlet, to have prolonged working without the desired temperature being attained owing to clogging of the restricted opening in the discharge valve, resulting in fuel waste and working troubles. These objections lose their force in technically advanced countries, but may attain considerable importance under conditions of working in India and other places abroad, with less expert staffs. They do not apply in the case of simple sterilizers without any form of thermostatic control. With such sterilizers the gravity discharge system of working should be the universal method for ensuring the maximum possible air evacuation.

Summary

1. Arguments are offered against the use of the pressure gauge for inferential readings of temperatures in sterilizers.
2. Residual air and lag in temperature rise are two fundamental causes of inefficiency in working.
3. No instrument designed to work at 10 lb. pressure can be effective unless a preliminary vacuum of not less than 30 inches has been secured in the chamber, and if 15 lb. is used the minimum vacuum necessary is at least 21 inches to secure a lethal temperature of 240° F.
4. Two systems for ensuring maximum efficiency in sterilizers are described and their relative merits discussed.

I have to acknowledge with thanks permission from W. B. Underwood to reproduce Figs. 1 and 2 from his textbook.

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The Middlesex County Council has resolved to rebuild the North Middlesex Hospital at a cost of £1,219,000. The original scheme for a building costing £1,680,208 did not meet with the approval of the Ministry of Health. To provide the hospital accommodation needed the Council will erect a new building at Theobalds Park and add 100 beds to the proposed new hospital at Finchley.