THE FACTORS INFLUENCING STERILISATION BY LOW PRESSURE STEAM

PART I. DESIGN AND INSTRUMENTATION

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A vessel has been designed for the study of the factors influencing sterilisation by steam at low pressure. Instruments have also been constructed for the conversion of pressure and the volume of condensate into electrical signals suitable for application to a recording potentiometer. Commercially available steam traps have been tested, compared, and found unsuitable and a modified steam trap has been produced, which is considered to be more efficient for this purpose than those normally used.

MOIST heat derived from steam under pressure is still considered to be the most satisfactory means of attaining sterility, and an exposure of at least 20 minutes to saturated steam at 121° C. (250° F.) is required[1].

According to Bowie[2], about 90 per cent of the sterilisers in British hospitals and pharmacies are obsolete and include representatives of all developments and stages in design since 1870, and he gives details of the conditions obtaining in such sterilisers. In 1956, Howie and Timbury[3] produced results obtained from a series of sterilisers showing the inadequacy of certain types and methods of sterilisation; these workers also pointed out that the sterilised content of an autoclave could be recontaminated during the drying process. Other factors which influence the conditions in a steam steriliser are the presence of air, which may hinder the penetration into fabrics by steam, and radiation effects from the chamber walls, and these may bring about localised unsaturation of the chamber atmosphere and possible non-sterility of the contents. It is usual to remove initial air from the chamber and its contents by one of two methods: (*a*) downward displacement, or (*b*) application of a vacuum derived from an ejector or a reciprocating pump, the former producing a vacuum of some 15 to 20 in. of mercury and the latter 28 to 29 in. For experimental work it is also possible to employ a high vacuum pump, so that the residual air pressure is only about a few millimetres of mercury. Evacuation[4] and downward displacement[2,5], have their protagonists, but the efficiency of sterilisation is dependent in addition upon factors such as the packing of the dressings and loading of the steriliser.

Metal drums, particularly if they are overpacked, are difficult to sterilise, as reported, for example, by Howie and Timbury[3], and penetration of steam is thought to be better into fabric wrapped packs.

The purpose of this investigation was to find the optimum conditions for sterilisation, and to study the construction of a suitable steriliser in which to bring this about. In the experiments we describe, steam is raised in a separate boiler and used as the sole source of heat.

Equipment and Installation

An experimental steriliser, 16 in. diameter by 36 in. long internal dimensions, with a steam jacket lagged externally, was constructed and provision made in the chamber wall for alternative steam inlets and condensate outlets at various points. The position and form of the condensate outlet and steam trap could also be varied and entries for thermocouple wires were provided.

To simulate conditions obtaining where sterilisers are commonly in use, provision was made for reducing the main steam pressure (80 lb. per sq. in.)

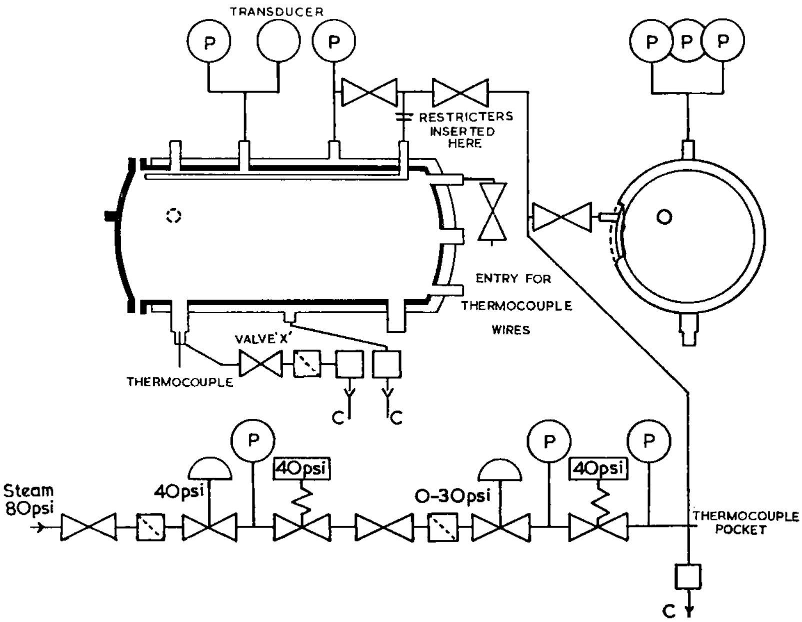


FIG. 1. General arrangement of steam supply and condensate flows connected with the steriliser. Graphical symbols B.S. 1553.

to working pressure. This system and the other connections are indicated in Figure 1. The condensate from the chamber and jacket were taken separately to waste. Only the jacket of the steriliser and the steam pipe to the first reducing valve were lagged, as is common practice in installations of this type.

A Bristol's Dynamaster Recording Potentiometer with integral cold junction compensation, modified so that it could also be used at will as an indicator on any of its six channels, was used for all temperature readings, and also by adaptation for recording pressures and volume of condensate produced by the chamber steam trap. The thermocouples were of iron: constantan wire sheathed in woven glass fibre and coated with Araldite resin as a further protection. They were inserted in the chamber through modified Kontite fittings, with rubber gaskets to ensure steam and water tightness.

The commercial instruments measuring changes in pressure within the chamber proved insensitive and irregular in operation and it was necessary to construct one to meet our own needs (Fig. 2). A transducer was connected in a Wheatstone's bridge circuit[6] and this device gave a suitable signal for application to the potentiometer, the effect of the automatic cold junction compensation being offset by introducing into the circuit an iron: constantan thermocouple immersed in melting ice. No other compensation for change in ambient temperature was found necessary, except to surround the bridge network by a box to prevent draughts impinging on the resistors.

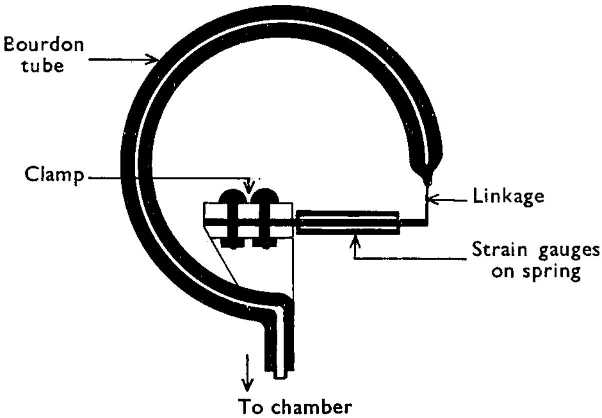


FIG. 2. Transducer. Strain gauges were of etched foil (Ferry) and were cemented on the spring with araldite strain gauge cement.

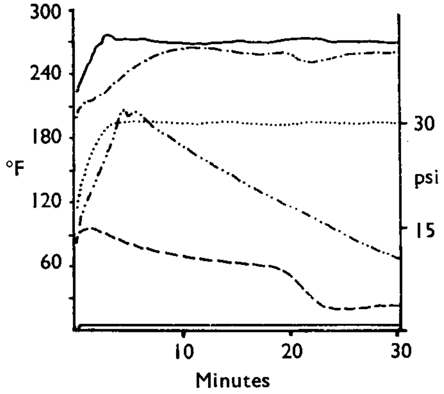
To measure the amount of steam used, and the time of its use, a tilting bucket mechanism was devised. Each time the bucket emptied an electrical impulse recorder made a mark on the chart which also recorded temperatures and pressure.

CHECKING OF INSTRUMENTS

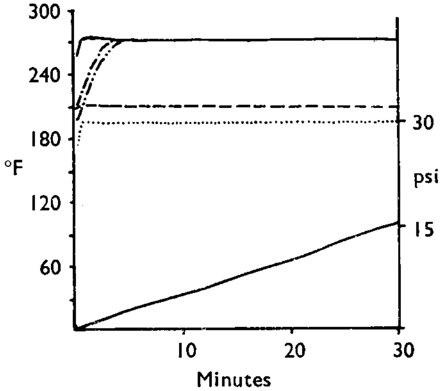
Thermocouples and recorder. The thermocouples were calibrated against melting ice 0° C. (32° F.) and boiling distilled water 100° C. (212° F.) with due correction for atmospheric pressure and using N.P.L. standardised mercury-in-glass thermometers for day-to-day checks. Adjustments for calibration errors in the recorder were according to the makers' instructions.

The effect of the water equivalent on the response of the thermocouples was checked by first allowing them to equilibrate with ambient temperature (about 65° F.) and timing the period required for a 75° C. (135° F.) change in temperature. The time was five seconds and this was considered an adequately rapid response.

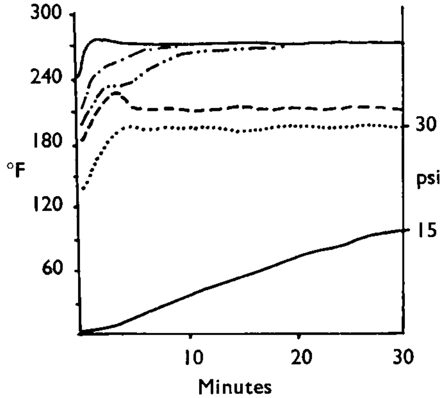
To estimate the effect of conduction of heat along the thermocouple wires one was heated some 12 in. from the junction and it was some minutes before any significant increase in temperature was indicated.



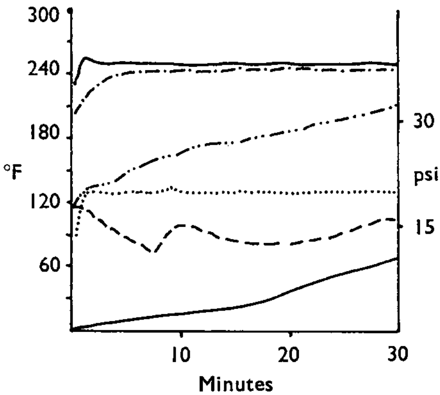
A. Experiments Nos. 1 and 11.



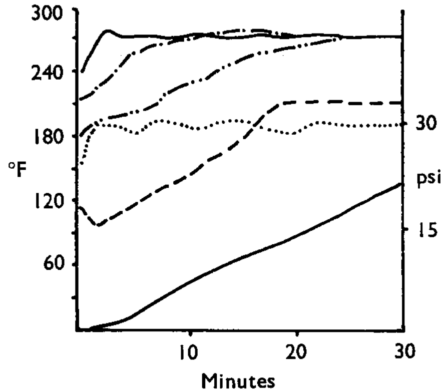
B. Experiments Nos. 2, 12, 14, 16.



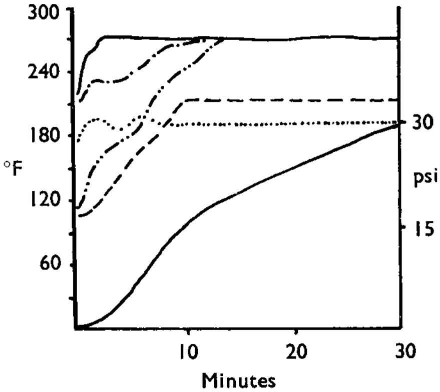
C. Experiment Nos. 3–8.



D. Experiment Nos. 9, 10.



E. Experiment No. 13.



F. Experiment No. 15.

FIG. 3. Operating conditions shown by temperatures, pressure and steam usage. For explanation see text. Key on facing page.

The effect of radiation from the inner surfaces of the chamber was examined by fitting the junctions with thin aluminium shields which allowed free circulation of vapour but prevented the absorption of radiation. It was found that their behaviour was identical with unscreened junctions similarly positioned in the chamber.

Pressure transducer and gauges. These were checked against a mercury manometer in an upward and downward direction.

Tilting bucket. The volume per delivery of each bucket was measured over a period and found to be sufficiently consistent for comparative purposes.

EXPERIMENTAL

Arrangement of inlet and outlet. The first experiments were made by introducing the steam through a sparger lying horizontally along the top of the chamber and collecting the condensate in a single large outlet hole at the bottom front of the chamber connected to a steam trap.

Using downward displacement of air, a thermostatically controlled steam trap, which operated in the near-to-steam range, and an empty chamber, tests were made at varying steam pressures. At the same time the disposition of the thermocouples within the chamber was examined for variations in temperature when the chamber was in equilibrium.

No significant difference between the temperatures of the thermocouples wherever disposed was observed once equilibrium had been achieved, but when they were positioned at different levels, including in the outlet drain, they reached the operating temperature successively from top to bottom, the one in the drain being the last to achieve the maximum temperature. This phenomenon was most noticeable when the chamber was heated up from cold with no steam-heat applied to the jacket.

Superheat of the steam was checked during each experiment from the thermocouple and pressure gauge inserted into the supply pipe and reference to steam tables. At no time did the steam temperature differ by more than 1° F. from the temperature obtained by referring the indicated pressure to the tables. A satisfactory determination of the quality of the steam by the bucket calorimeter was found to be impracticable.

Variations in steam inlet. When the rate of entry of steam at 30 lb. per sq. in. into the chamber was varied by throttling with restricters in the form of annuloid discs, changes were seen. The time to attain equilibrium was the same for $\frac{1}{2}$ in. and $\frac{3}{8}$ inch bore; for $\frac{1}{4}$ in. the time was prolonged and with $\frac{1}{8}$ in. much prolonged. The same thing was seen at 20 and 10 lb. per sq. in.

Effect of steam trap. During this work it was noted that the temperatures within the chamber and the steriliser drain lagged behind steam

Key to Figure 3.

———————	Temperature at the top of the chamber.
— • — • —	Temperature at the bottom of the chamber.
• • • • • • • • •	Chamber pressure.
— — — —	Temperature in the steam trap delivery pipe.
— • • — • •	Temperature in drain.
———————	Lower trace: steam usage.

temperature, and it was observed that once the trap had shut for the first time it ceased to pass air, thus causing a build-up in the air concentration within the chamber.

Since no published work on the subject of steam traps used on steam sterilisers could be traced, experiments were devised to examine this phenomenon and to investigate the behaviour of representative types of commonly used traps. Observations were made from thermocouples in the following positions: 2 in. below the top of the chamber, 2 in. above the bottom of the chamber, in the drain leading from the chamber to the steam trap, and in the steam trap condensate outlet immediately below the trap.

Experimental conditions. Throughout these experiments reproducibility could be established only if the following conditions were observed. The autoclave chamber remained empty. The jacket remained heated during the intervals when the chamber was opened. The chamber, initially at operating conditions, was emptied of steam and the door opened to the atmosphere for a period of ten minutes. The interval was kept as short as possible between closing the door and admitting steam to the chamber as it was found that initial superheating of the admitted steam was affected by the length of this interval.

Each steam trap was installed in the manufacturer's recommended position, except in Experiment No. 11 where this alteration was deliberate and suggested as a possible way of ensuring the venting of air, as the bellows would then be constantly immersed in condensate.

The experiments with the various steam traps have produced the following information, which should be read in conjunction with the numbered diagrams of examples of the records obtained (Fig. 3).

Experiment No.	*Conditions of Test*	*Results*
1.	All outlets from the chamber closed (Fig. 3A).	Uniform conditions in the chamber were not reached, and the temperatures, particularly that in the drain, dropped slowly due to the accumulation of air and of condensate. Layering was very pronounced. Little steam was used within the chamber.
2.	A slightly opened valve in place of the trap so that steam was being blown off at a moderate rate during the whole of the cycle (Fig. 3B).	Uniform conditions were reached rapidly and smoothly, and the temperature of the drain soon attained steam temperature.
3.	Steam trap with liquid-filled bellows operating in the near-to-steam range (Fig. 3C). (See also Fig. 23, cf. ref. 7.)	A steady attainment of steam temperature throughout the chamber and drain. The peak, as recorded in the steam trap delivery,

		showed a time lag in the operation of the valve, probably due to the thermal capacity of the liquid-filled bellows. Slight initial superheating took place in the top of the chamber.
4.	Liquid-filled bellows operated; low pressure type (Fig. 3C). (See also Fig. 23 of ref. 7.)	Another steady, but slightly more rapid attainment of steam temperature. Some slight accumulation and subsequent release of air inside the drain was indicated by variations in the temperature in the drain.
5.	Liquid-filled bellows operated (Fig. 3C). (See also Fig. 3 of ref. 7.)	Again steady concurrence of chamber temperatures, but the trap appeared to allow greater accumulation of air in the chamber drain before release. The temperature in the drain was not completely stable.
6.	One float-operated valve and one liquid-filled bellows operated valve incorporated in the same body but operating independently (Fig. 3C). (See also Fig. 19 of ref. No. 7.)	The initial rise in the temperature at the bottom of the chamber and in the drain was not so great as in Experiment Nos. 3, 4 and 5. The eventual coincidence of the three temperatures was reached sooner, and no subsequent variations in the drain temperature occurred.
7.	A single valve controlled by a combined float and bi-metallic strip mechanism (Fig. 3C.)	The temperature characteristics of the chamber thermocouples were closely similar to Experiment No. 6, but fluctuations in the drain temperature indicated less effective elimination of air.
8.	A pressure - compensated balanced valve operated by a bi-metallic strip mechanism, with provision for adjusting the operating temperature. (See Fig. 21 of ref. 7.)	Steady attainment of steam temperature. The valve in the trap was found to stick frequently, making the operating temperature adjustment difficult to set and operation inconsistent. (This appeared to be a characteristic of the valve design.) Again the record of this experiment was closely similar to that of Experiment No. 6 and that used in Figure 3 is illustrative of the type of trace obtained.

9 & 10.	Float-operated valve; working pressure 20 lb. per sq. in. (Types I and II) (Fig. 3D). (See also Fig. 20 of ref 7.)	Uniform temperature inside the chamber was never attained throughout the duration of the experiments; the drain temperature remained very low, and the flow of condensate recorded was much less than with any other trap, so indicating a slow rate of heating.
11.	The same trap as in Experiment No. 1 but installed in an inverted position (Fig. 3A).	No improvement was obtained by inverting the trap.

The differences in the chamber and drain temperatures appear to be explained by the layering of air and steam within the chamber to varying degrees, that is, the separation into layers of increasing air content downwards. It was also obvious that the air was not being satisfactorily eliminated by any of the traps tested.

The trap which appeared to perform most satisfactorily (Experiment No. 6), was now modified by including a small continuous by-pass. This allowed a test to be made which approximated to the Conditions of Test in Experiment No. 2 without large volumes of steam being wasted. The liquid-filled bellows unit, which normally operated to close the thermostatic valve, was removed. The remaining orifice was used as a by-pass, in two ways, full bore and also restricted by pieces of wire. Records 12 and 13 were obtained with orifices 2·0 and 0·65 sq. mm., respectively in area, with the jacket heated, and 14 and 15 with the same orifices, with the jacket unheated. The cold jacket made the differences more obvious.

Experiment No.	*Conditions of Test*	*Results*
12.	Trap as in Experiment No. 6, modified so as to provide a small permanent by-pass. See experimental detail. 2 sq. mm. by-pass.	Very close agreement in behaviour with Experiment No. 2. Air and condensate were rapidly eliminated, although there was a slight degree of super-heating initially at the top of the chamber; steam temperature was fairly rapidly attained and maintained in all parts, including the drain. The bucket section of the trap appeared to be working normally.
13.	As Experiment No. 12, but with 0·65 sq. mm. by-pass. (Fig. 3C.)	Less rapid elimination of air and layering was clearly indicated.

14.	As Experiment No. 12, but with 2·0 sq. mm. by-pass. (Fig. 3F.)	Similar to Experiment No. 12.
15.	As Experiment No. 12, but with 0·65 sq. mm. by-pass.	Layering suggested, with less rapid elimination of air; the complete elimination was sharply indicated by a sudden rapid rise in the delivery pipe and drain temperatures.

In an attempt to improve matters further, the same trap was again modified. The bellows were replaced and a small permanent by-pass, 0·5 sq. mm. in area, drilled in the casting in addition to the float-operated valve. Under these conditions the thermostatic bellows, float-operated valves and by-pass were all operative.

The jacket of the steriliser was heated.

Experiment No.	*Conditions of Test*	*Results*
16.	Completely modified steam trap. See experimental detail. (Fig. 3B.)	Closely similar to Experiment No. 2.

The behaviour of the modified trap produced the conditions required for the satisfactory operation of the steriliser under conditions of air elimination by downward displacement.

Discussion

It seems that commercially available steam traps are not capable of passing the volume of air met within a steam steriliser in its normal cycle of use. This defect from the point of view of our needs is a feature of their design, since thermostatic traps will still respond to hot air or steam and air mixtures and yet remain closed, although there is air on the input side. Bucket traps are equally unsuitable since they have only a small hole to vent the air in any case. A way of overcoming this shortcoming has been found and an improvement in the steam trap demonstrated.

The steriliser and instrumentation have been carefully checked and shown to be sound apparatus for further experimentation.

We wish to thank F. C. J. Caliendi of the De Havilland Aircraft Co. Ltd., Hatfield, Herts, for information concerning the strain gauges.

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