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SHORTCOMINGS OF COMMERCIAL STEAM DISINFECTION APPARATUS.

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(1) PRESENT PROCESSES.

Steam disinfection by Field Units is normally carried out with "current steam" apparatus at, or slightly above, atmospheric pressure, using one of the Disinfectors Portable Field or an improvised substitute. Disinfection in hospitals, and sterilization, is usually done in commercial pattern apparatus working at 15 or 20 pounds pressure per square inch. Commercial current-steam disinfectors are also employed.

In all cases the apparatus is relied upon to give contact with the disinfecting steam throughout the "charge" of articles treated for the full period required for disinfection. As regards the Service apparatus, full care is taken, before adoption of the type, that such confidence is justified. Tests and theory agree, however, that all commercially designed plant has inherent failings which render its operation unreliable.

"High-pressure" disinfectors all work on the same principles. The charge is put into a "container" made of wire-mesh on a steel framework. For treatment the container, which is fitted with wheels, is run into a cylindrical or oval "chamber" which has a door at each end. The doors being
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closed on the loaded container a vacuum is created inside the chamber. When a sufficiently high vacuum exists the air outlet is closed and the steam inlet turned on. Steam is admitted until the pressure reaches that specified for the apparatus and is held at that pressure for the disinfecting period of ten to twenty minutes. The steam is then allowed to escape and hot air is passed through the chamber to dry the charge. After the specified period of drying the hot air is shut off, the exit door opened, and the container is run out for unloading.

Commercial current steam disinfectors have the same general construction as the high-pressure type but no vacuum is created prior to steam-admission. An exhaust vent in the bottom of the chamber is opened when steam admission begins and air is thus flushed out of the chamber. Steam is then passed through continuously, for say half an hour, after which drying follows as before.

(2) Failure of Various Commercial Designs.

(a) Disinfector No. 1 (High Pressure).—15 lb. per sq. inch, portable, capacity between 50 and 60 cubic feet. Load scheduled in Appendix 15 of Army Manual of Hygiene 1934—50 to 60 blankets.

In January, 1941, a number of high-pressure disinfectors, adapted for field use, was offered for sale to War Department. One was ordered as a sample and went to the Army School of Hygiene for test and report. The tests were arranged and supervised by the staff of the School, as medical experts, and attended by one of the authors as engineer-inspection specialist. The tests were carried out with Army blankets in which temperature-indicator tubes were buried. Since the operating pressure was 15 lb. per sq. inch, the indicator tubes should have been such as would indicate the attainment of the temperature of steam at this pressure—namely 121°C. Such tubes were not available, however, and the 100°C. tubes made for testing the Service disinfectors had to be used instead. There is a negligible time-element in these tubes, which change colour almost immediately on subjection to a temperature of 100°C. The colour-change may begin, however, at a slightly lower temperature—say 94°C.—and must be complete to be satisfactory. Tubes remaining unchanged prove the maximum temperature reached in their locality to be well below 100°C.

The test load was 60 blankets, that is roughly one per cubic foot of chamber-volume, and was a normal full-load for the size of chamber and container. Out of ten indicator tubes used, five failed to change colour. A repeat test on the following day gave a similar result.

Following this failure, strenuous efforts were made to "turn" the tubes by doubling the time of subjection to pressure-steam, by raising the pressure to 20 lb. per sq. inch (126°C.), and by varying the method of loading the blankets. All the tests failed. The disinfector had been shown to be unreliable, even defining disinfection as the attainment of only 100°C. in an apparatus subjecting the charge to steam at a temperature of 26°C. higher.
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These results engaged the serious attention of those witnessing them. The manufacturers concentrated on making the plant effective by experiments on a similar model at their works while the authors looked for, and found, the basic causes of failure and the means of correcting them. It was, of course, realized generally that the immediate cause was the presence of unwanted air.

At their works the makers tried various expedients—improving the ejector, repeating the air-evacuation, reducing the load—but these were unsuccessful or impracticable. The results threw suspicion on the effect of a baffle-plate intended to prevent hot drying air from impinging on the charge. This was reduced in area by nine-tenths and, simultaneously, the effect of flushing the air out by steam, instead of using the ejector, was tried. The combination gave satisfactory results with a reduced load of 46 blankets. The necessary parts for conversion of the disinfector still lying at Aldershot were sent forward and fitted but a re-test after conversion was unsuccessful, one tube out of six remaining unchanged in the first trial, and two out of eight in the second. A visit was paid by the authors, who took with them various new parts to convert the plant to correct principles, which they had meanwhile deduced. On arrival, however, they found that the Army School of Hygiene had not been advised of the internal alterations necessary and, assuming this to be the reason, abandoned their project. As will be seen later, their proposals involved the use of a well-equipped workshop and moreover would have delayed acceptance of the disinfector which was now urgently required for use. The staff of the Army School of Hygiene then decided to remove the baffle-plate entirely, after which the disinfector gave good enough results to be put to use with a restriction placed upon the load.

It must be remembered, however, that the indicator tubes were still of the 100° C. type though the pressure had been raised to 20 lb.

(b) Decision to Test Other Designs.—During this time a decision was taken to conduct a series of tests of different commercial designs purchased by the War Department, with Army School of Hygiene and Inspection Department, Engineer and Signals Stores co-operating therein. As far as possible new plant was tested, operated by the makers at their works with steam from a steam main, thus obtaining the most favourable working conditions for the plant. Army blankets, as being the most commonly treated articles, were to be used and the load was to be a reasonably full one—that is, a quantity within the capacity of the container to hold without heaping, such as the operator would normally load up. The loads were generally below those scheduled in Appendix 15 of Army Manual of Hygiene 1934.

(c) Disinfector No. 2 (High Pressure).—15 lb. per sq. inch, stationary. Capacity between 60 and 70 cubic feet. Load scheduled by Appendix 15 of Manual, 60 blankets.

This was of different design from No. 1. It had just been installed in the Aldershot area and was tested by the Army School of Hygiene. The
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tests failed. With a load of 50 loose blankets, 2 tubes failed to change out of 12. Loading the same number of blankets in 5 rolls each of 10 blankets, 5 tubes remained unchanged out of 15.

(d) Disinfector No. 3 (High Pressure).—15 lb. per sq. inch, stationary, capacity between 30 and 40 cubic feet. Scheduled load 30 blankets.

This was generally similar to Disinfector No. 1 but a stationary model. In three tests, with a load of 30 blankets in rolls of 10 blankets each, the tubes found unchanged numbered 9, 11 and 8 out of 11, 15 and 15 respectively. The disinfector was then altered in the same way as No. 1, after which it treated 30 loose blankets successfully.

(e) Disinfector No. 4 (High Pressure).—20 lb. per square inch, stationary; capacity between 115 and 125 cubic feet. Scheduled load 120 blankets.

The above results apparently created some discussion in the disinfector world for the authors were then asked by the makers of yet another design to test their standard apparatus at their works. The request was at first declined, as there were no War Office orders open at this firm, but was granted on being repeated and pressed a few days later. In the first test 47 tubes were used in a charge of 98 folded blankets and no fewer than 30 tubes remained unchanged. A repeat test with 60 loose blankets gave 9 tubes unchanged out of 26. A third test was made also with 60 loose blankets but with the evacuation process carried out twice over and the period of holding at disinfection pressure lengthened by 50 per cent. In this test, which took 127 minutes, all the 23 tubes used were changed, but the blankets were all rendered unserviceable and had to be "written off."

(f) Disinfector No. 5 (Current Steam).—Pressure virtually atmospheric. Stationary, capacity between 55 and 65 cubic feet. Scheduled load, 50 blankets.

Two months later a current-steam disinfector ordered for a Reception Station came up for acceptance tests at the makers' works. With an easily permeable load of one flock mattress success was obtained but, with a load of 40 loose blankets, 6 tubes out of 18 failed to change colour. The makers thought they could correct matters and were given an opportunity to do so. They split the load into two by a horizontal grid half-way up but with 40 loose blankets 5 tubes out of 18 remained unaffected. The cold spots were concentrated around and above the exhaust vent. The only way to make this disinfector acceptable now appeared to be reconstruction to the authors' ideas, of which an explanation follows.

(3) Reasons for Failures (see diagrams).

It will be realized that any air remaining in the charge during the period of treatment will be a grave deterrent to proper sterilization or disinfection, firstly because air is an efficient heat-insulator and secondly because bacterial organisms have a much greater resistance to hot air than to steam. With all high-pressure steam disinfectors or sterilizers, air-extraction is carried out with a steam ejector in which steam at high velocity is directed through
A nozzle past an orifice opening from the chamber containing the charge. The steam flow draws air from the chamber, creating a partial vacuum. The extent of the vacuum so formed depends on the efficiency of design and use of the ejector and may vary from about 16 inches of mercury up to 24 or 25 as a maximum. A complete vacuum, i.e. the extraction of all air, is represented by the barometric pressure—say 30 inches—and is unattainable.

I.—Current Steam Disinfector. Present design.

Operation.—Cocks A and B both opened, steam is passed through continuously for disinfection, but finds easy passage to exhaust round sides and ends of container. No compulsory passage through charge in container.

II.—High Pressure Disinfector. Present design.

Operation.—(i) A, shut; B, opened. Some air extracted via B by ejector, leaving up to one-third remaining within chamber and charge. (ii) B, shut; A, opened. Steam admitted to fill chamber and build up pressure. Air and steam in unknown state of mixture fill chamber and charge. Steam penetrates charge from all sides without expelling air therefrom.

It is thus impossible to extract the whole of the air from chamber and charge. With a vacuum of 20 inches (an average figure in practice) and assuming constant temperature, about one-third of the original air-content remains. With a chamber of say 120 cubic foot capacity, the quantity of air retained is seen to be huge.
When the vacuum is sealed and the steam admitted all this air is trapped. Exactly how it behaves is problematical. That which surrounds the charge will intermix readily with the incoming steam condensing some as it heats up; that which occupies the interstices of the charge may be forced inwards as the steam pressure, to which the charge is exposed on all sides, rises. The extent of admixture with steam of the contained air will be greatest at the surface of the charge and least towards the heart. Since air is heavier than steam, the areas where air is richest will be somewhat below the actual centre-line, and it is here that "cold spots" will be found.

The richer the air the cooler the mixture. With the customary rate of steam admission, therefore, the situation at the moment when the pressure has reached that specified (say 15 lb. per square inch) will be that there exists in the chamber a temperature gradually diminishing from a maximum somewhere near that of saturated steam (121 °C.) to a minimum which may be little above that of the ambient atmosphere. It is misleading to say that the "disinfecting period has begun." The disinfecting temperature within the charge is a long way from being reached. More steam has to penetrate the outer layers of the charge until it is condensed in giving up its latent heat to warm up the air and the material. Still more must follow it, reaching a little further, and so on until the heart is reached and then sufficiently heated. How long it will take before the air-steam mixture in the heart reaches even 100 °C. cannot be stated and there is no visual or other sign to indicate completion.

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III.—Both Types as Converted.

D is automatic valve or coupling.

Operation.—(i) A, B', B² all open, incoming steam rapidly displaces "free" air from chamber via B', during which time partial penetration of charge occurs from top only, as shown by arrows. (ii) B² is closed as soon as free issue of steam from it shows displacement of "free" air to be complete. Incoming steam can now only escape via B², i.e. downwards through charge, completing penetration and air expulsion as shown by arrows. Penetration complete as soon as steam issues full bore from B². (iii) Current steam type. Steam passage from A to B² continued for as long as is considered necessary for steam at 100 °C. to kill bacteria. High pressure type. Valve B² shut and steam admission continued until required pressure is built up. Pressure then held as long as desired.
In the current-steam commercial designs a somewhat similar result is obtained in a different way. The chamber is not sealed so no air is trapped. The "free" air is rapidly displaced from the chamber altogether by the incoming steam. So far, so good. Now the steam has to remove, or heat up, the air contained in the charge. Finding an easy path through the chamber from inlet to exhaust around the sides and ends of the container it naturally takes it, avoiding the charge itself, and we are back to the same gradual penetration and intermixing as before. Moreover there is now no "spare heat." The steam is at virtually 100° C. itself whereas its temperature is 121° or 126° C. in the high-pressure types. An air-steam mixture at a temperature 20° below that of the pure steam will still suffice in the high-pressure apparatus—or so we hope. With current-steam it is virtually useless, regarded as disinfection and not mere disinfestation.

(4) Method of Correction.

It will be as well to compare the machines so far discussed with any of the Service Disinfectors—for example the Disinfector Portable Field No. 3—particularly since the correction of the failings follows the design and operation of this apparatus. The Disinfector Portable Field does achieve the full disinfecting temperature by contact with steam in every part of the charge—in one of very many tests, carried out without a single failure, over 150 indicator tubes were used in a full charge of 32 blankets, i.e. 256 thicknesses. It does this with a load of three blankets per cubic foot of chamber compared with one, or under one, ineffectively treated in commercial models and in less than half the time.

These results are due to the rapidity, reliability and completeness of air-displacement, which is achieved as follows: The charge is held in an impermeable sheet-steel open-topped container which it closely fits. Steam is admitted to the top of the charge only and the exhaust opening is arranged so that steam can only escape to atmosphere by passing right through the charge itself in a downward direction. The difference of density between steam and air, and the pressure built up above the charge, combine to urge the air gently through the charge and out of the exhaust at the bottom. No air is trapped and there is an almost negligible amount of intermixing. The uninterrupted emission of pure steam from the exhaust is a visual indication that the expulsion of air is as nearly complete and perfect as can be and a few minutes of steam passage is enough to ensure that the charge is wholly filled with pure steam at atmospheric pressure. Any higher temperature could now be reached merely by closing the exhaust and continuing steam admission until the pressure equivalent of the desired temperature was attained. For now we are dealing with pure steam, not with air-steam mixtures of varying and unknown composition, while, since the container is steam jacketed, there is no heat-loss through the walls.

All that is necessary in commercial designs, therefore, is to apply these principles of construction. The container, instead of being made of wire-
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mesh, will have sheet-metal sides and bottom with an open top. From an opening in the container bottom an exhaust-pipe will be led through the chamber-wall to atmosphere. The container will be so loaded that no gaps or easy paths are left down which steam will flow in preference to passing through the mass of the charge. There are other details to attend to—for example the fitting of a cock to the container exhaust-pipe outside the apparatus, to be closed for building up pressure, and the provision of a coupling to the container-exhaust inside the chamber, capable of being broken or made from either end of the chamber, to enable the container to be run in or out. But these offer no constructional difficulty. The main principle is merely "downward displacement" which has been the feature of all Service disinfectors for many years.

(5) Tests of Reconstructed Disinfectors.

(a) Disinfector No. 5.—With the approval of the Directorate of Scientific Research full details of conversion of Disinfector No. 5 were given to the manufacturers of this current-steam plant by the authors and the work was at once put in hand. After some delay owing to difficulty in obtaining certain materials the altered disinfecter was ready for test by July 21. The disinfecter-container had been provided with an automatically operating exhaust coupling and the whole plant was a workable outfit ready for immediate installation. The shape of the container had not been altered and was normal for a cylindrical chamber.

Instant success was achieved with a remarkable shortening of the total time taken for each cycle. Forty loose blankets were effectively disinfected in eleven minutes and forty folded blankets in thirteen minutes. After adjustment of the automatic valves the time to disinfect 40 folded blankets was reduced to eight-and-a-half minutes from closing the entrance door of the chamber to opening up for unloading. Remembering that the indicator tubes required the full saturated steam temperature of 100° C. to liquefy them, it will be realized how rapidly and thoroughly every vestige of air had been expelled and replaced by steam. The improved disinfecter was at once accepted, and its despatch to site for installation was ordered.

After installation, the authors attended its first putting to service, taking indicator tubes. A load of 60 blankets (20 per cent higher than the scheduled figure) was laid down as the standard maximum. The piping layout, having been designed for the original model, was unfavourable but its correction had to be deferred and, in any case, its effect was only to lengthen the operating cycle. The first operation was allowed to be carried out by the R.A.M.C. Corporal in charge, without fully instructing him, so as to prove to him the necessity for the simple precautions to be taken. Before the disinfecter was unloaded, he was told that the tubes, which had been evenly distributed throughout the charge of 60 blankets, would reveal failure. In fact 5 tubes out of 19 failed to respond, the unchanged tubes being found in the precise places which had been forecast. Next, the correct
handling of the plant was demonstrated with satisfactory results. Check tests were carried out on four occasions in the following weeks—once to verify that the operator was still working correctly, once to observe the effect of the altered piping layout and twice to carry out overload tests. On October 1, 1941, a load of 6 rolls of 10 blankets each, with 7 extra blankets added, was tried using three tubes in the middle of each roll. This is an unfavourable way of preparing blankets and had proved incapable of giving 100° C. disinfection in any high-pressure apparatus so tested, even when in Disinfector No. 1 a pressure of 20 lb. per sq. inch had been maintained for forty-five minutes. The second overload test was made on November 14, when no fewer than 90 folded blankets were crowded into the heaped container with forty tubes evenly distributed throughout the charge. Both of these severe tests were passed by what the authors hold to be the first commercial steam disinfector ever installed which can be relied upon to do its job.

(b) Disinfector No. 6 (High Pressure).—15 lb. per sq. inch, 120 cubic foot chamber, 11 cubic foot container. Special model.

Meanwhile the manufacturers of Disinfector No. 4 had independently constructed a high-pressure disinfector working on the same downward displacement principles. They demonstrated this plant to us on July 18. It was of an experimental type, consisting of a normal 120 cubic-foot cylindrical chamber in which had been fixed a container which was an exact duplicate of that of the Disinfector Portable Field No. 3. This container is rectangular, of capacity only 11½ cubic feet, and looked odd in such surroundings. It was fitted with an exhaust of screwed steel pipe with no coupling so that, although there was no chance of steam leaks, there was equally no possibility of withdrawing the container from the chamber. The container was loaded (with difficulty owing to the heat inside the steam-jacketed chamber) with 32 blankets folded as prescribed for the Disinfector Portable Field No. 3. Buried in the charge were indicator tubes of a different type, of which a description must be given. These are glass tubes containing a red liquid. On being heated, this liquid changes colour gradually through amber and olive to bright green and the temperature to which it is subjected is indicated by the time taken to effect the complete change—or, alternatively, the extent of the colour change in a given period of time. The tubes are designed to change from red to green in a temperature of 115° C. (equal to 10 lb. steam pressure) held for twenty-five minutes but will do so at higher temperatures for shorter periods or lower temperatures for longer periods. The heat effect is cumulative—that is to say, a tube partly changed by subjection to 115° C. for ten minutes will, after cooling, complete its colour-change on being reheated to the same temperature for the other fifteen minutes. Similarly a tube heated at 100° C. for five minutes will afterwards require less than twenty-five minutes at 115° C. to complete its change, while a tube not completely “turned” after twenty-five minutes’ subjection to an unknown test temperature may finish its conversion to
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green if afterwards subjected to a lower temperature for a few extra minutes. All these factors, though rather involved, have a bearing on tests conducted with this type of control.

The test of the "mock-up" high-pressure apparatus was entirely successful. Since the load consisted of 32 blankets only this may at first sight be unimpressive, but that is only due to the choice of a container of unsuitable size and shape for the chamber. Even so, the load amounted to a solid wad of 256 thicknesses of blankets and, when it is remembered that the test was now $115^\circ$ C. held for twenty-five minutes, not $100^\circ$ C. for a few seconds, the immense improvement in air-expulsion and steam-penetration is manifest.

(c) Disinfector No. 7.—120 cubic foot capacity, 15 lb. per sq. inch, scheduled load 120 blankets.

In October, 1941, these manufacturers produced their first commercial model—a 120 cubic foot disinfector, to a War Department order, which was operated by them at their works. The container was found still to follow the Disinfector Portable Field No. 3 design, being a long rectangular sheet metal box divided by removable vertical slides into four compartments each similar to the Disinfector Portable Field No. 3 container. The slides would be taken out to accommodate mattresses. Sixteen $115^\circ$ C. tubes were used in a charge of 98 folded blankets. No more blankets were available.

The design and operation revealed an incomplete understanding of the principles involved and the authors were not altogether surprised when one of the tubes failed to complete its colour-change. The test conditions were not unfavourable to the apparatus. The control tubes were sensitive to a temperature of $6^\circ$ C. below that of the steam while the effect on them of their subjection to steam at varying pressures from atmospheric to 15 lb. during the periods of air-expulsion, building-up pressure, and releasing pressure must be taken into account, as well as the twenty-five minutes of actual disinfection. It is clear that the "unturned" tube shows that this particular disinfector still falls short. It can, however, be easily converted to a completely reliable apparatus by the authors and probably will be.

(6) DISCUSSION OF TESTS.

Lack of space prevents the publication of full details of all the tests. These have been tabulated with remarks and a copy can be obtained by any interested reader on application to either of the authors at Shepherd's Green, Chislehurst, Kent (Telephone: Chislehurst 1953). The extracts already given will, it is hoped, suffice for this discussion. The tests show the inability of apparatus of present design to disinfect with certainty a normal load of blankets in the specified times. They indicate also that doubtful results may be obtained even with much-reduced charges.

(a) Inadequate Testing.—This situation has arisen, in our opinion, through the use of too few "tell-tales" in the customary disinfector tests. Except in the Service, tests are customarily made with bacterial tubes, using only a few at a time. Such tests may easily fail to find the "cold
spots” in a bulky charge. In the Service this has always been realized and Service-designed apparatus has always been subjected to tests even more rigorous than those now discussed. In most Service tests of disinfectors, however, the temperature-indicating tube is used for convenience instead of cultures.

(b) Characteristics of Temperature-Indicating Tubes.—The temperature-indicating tube has great advantages over the use of cultures. It is cheap, small, easy to handle, visibly responsive, and can be used in abundance to give a true picture of what actually happens. But its use outside Service circles seems to be almost non-existent. None of the manufacturers concerned in these tests had ever used them—most, if not all, had never seen one. Perhaps, on that account, some reassurance regarding its accuracy is desirable. Most of the 100° C. tubes used in these tests were made either by the Army School of Hygiene or by the Royal Army Medical College and the others were specially developed for us by the makers of the 115° C. tubes. A percentage was checked in boiling water or atmospheric steam while those which failed to react in the disinfecter tests were usually either put into boiling water or put back in the disinfecter on top of the load in the next test. In no case did the tubes fail to respond.

Since, however, the Army School of Hygiene and Royal Army Medical College 100° C. tubes start to colour a few degrees below 100° C. they are a better indication of failure to disinfect (when they remain unaffected) than as positive proof of disinfection. For the latter purpose, complete liquefaction is necessary, and owing to re-cooling this requires speed as well as judgment by the observer.

The 115° C. tubes could not be so simply checked owing to the heat-accumulation effect. Of these, therefore, a proportion was tested in thermostatically-controlled muffles in the Inspection Department Engineer and Signals Stores, a further proportion being similarly tested in the laboratories of a well-known instrument firm. Time-temperature curves were plotted which agreed well with each other while the results at 115° C. were close to the twenty-five minutes specified by the makers. The reliability of both types of tube was therefore adequately demonstrated.

(c) Lessons of the Tests.

(i) Irregularity of Results.—Failure to “turn” indicator tubes was found to occur in apparently different places and to a different extent when trying to repeat a test in any particular plant. This may be partly due to the tubes not being in exactly the same position but is more likely to be caused by slight variations in the packing of the blankets such as will occur in use.

There is apt, however, to be a weak feature in any one design causing a persistent “cold spot”—for example the baffle plate in Disinfector No. 1 and the exhaust-hole in Disinfector No. 5 before its conversion. So that not only is an adequate margin of safety to cover variations in packing neces-
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Sary in the operation of the plant but special study is desirable of the weaknesses of any particular installation.

(ii) **Maximum Load.**—The loads given in Appendix 15 of the Army Manual of Hygiene and Sanitation, 1934, are far too great. It is almost certainly fatal to disinfection to load up the container level with blankets to the top.

(iii) **Method of Packing.**—Blankets should be loaded loose. Rolls of ten should be forbidden.

(iv) **Permeability.**—It is the compactness and depth of a charge, i.e. its nature and the distance to its heart, which affect results most. The bigger the container the bulkier is a full load and the worse are the results. Refer para. (2) (e) above. The load of 98 blankets was well below that given in Appendix 15 of the Manual.

(v) **How to Test.**—In an investigation a multiplicity of tell-tales should be used, at first, say 30, fewer as the story unfolds. Finally, as a check on measures taken, about 30 again, evenly distributed in the mass.

(vi) **Further Tests.**—There is a case for more thorough and scientific investigation which should be extended to steam sterilizers also.

(d) **Improvement of Existing Plant.**

(i) **Reconstruction.**—We advise against Medical Officers attempting (unless experimentally) the reconstruction of their apparatus to the principles expounded in paragraph (4). Each design of plant needs special treatment with a fuller understanding of the process than is there explained. The construction is the subject of patent applications though the State will no doubt have "free user" rights.

(ii) **Improvement without Reconstruction.**—There is some possibility of improvement by variation of the technique. Displacing the "free" air by steam, instead of creating a vacuum, may or may not bring any definite gain. But the effect of using both methods—that is, first flushing out the free air by steam and then "drawing a vacuum" in the steam-filled chamber is worth trial. So also is the use of a wire-mesh "core," either cylindrical or of the same cross-section as the container, around which to pack the charge. We suggest loading say one-quarter of the blankets first, then laying the core on them, then loading the remaining blankets around the sides and over the top of the core. The objects are to increase the area of surface open to steam penetration and to reduce the thickness of the charge. The core must extend from end to end of container, of course, and its ends be left unobstructed. An automatic limitation of load will be obtained.
Splitting the charge horizontally by a mattress-like wire grid may also be worth further trial.

In general, however, the weaknesses of the particular plant should be studied first.

(e) Immediate Action Advisable.

We believe that meanwhile it is necessary to impose drastic limitations on the number of blankets loaded. Disinfector No. 1 was restricted to 30 blankets, i.e. one per 2 cubic feet of chamber-volume, and we believe this to be the limit of safety for 60-foot disinfectors. Twenty is our idea of the limit for disinfectors of 30 to 40 cubic foot capacity and 40 for those of 120 cubic feet. The proportion of blankets to volume should diminish with the increase in volume to avoid increasing the depth of the charge appreciably.

With the above charges, a minimum of twenty minutes at full pressure should be given and we prefer thirty. We assume that a minimum of 20 inches vacuum is obtained. Forty minutes "contact" in a current-steam disinfectors should be given.

The output of the plant, which is already costly, clumsy, uneconomical and slow, will be made even worse. About 200 blankets a day will be the output of a 60-foot disinfectors. This is one hour's output of the Disinfector Portable Field No. 3, or eighty minutes with the Disinfector Portable Field No. 1. It is only four hours' output even of the little Disinfector Portable Field No. 2 which a couple of men can carry about.

(7) Drying Blankets.

During these tests some interesting points arose in connexion with the drying operation. Designs were seen in which the drying air is taken from inside the "dirty" room where the loading is done—with Disinfector No. 2 the air intake was actually only about 18 inches from the floor where lay dust and fluff from "dirty" blankets.

The drying air is heated to an unknown temperature, probably well below that which is necessary to sterilize it. A thermometer in the air-outlet from the heater might give surprising readings.

Finally, to establish a conviction that hot-air drying was ineffective, we weighed a loaded container before treatment, after disinfection but before drying, after drying, and after vigorous shaking. The results were as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of blankets</td>
<td>46</td>
</tr>
<tr>
<td>Weight of blankets and container</td>
<td>298 lb.</td>
</tr>
<tr>
<td>&quot; before disinfection</td>
<td></td>
</tr>
<tr>
<td>Weight of blankets and container</td>
<td>309 lb.</td>
</tr>
<tr>
<td>&quot; after 30 minutes' drying</td>
<td>306½ lb.</td>
</tr>
<tr>
<td>Weight of container</td>
<td>301 lb.</td>
</tr>
<tr>
<td>&quot; after shaking out</td>
<td>24 lb.</td>
</tr>
<tr>
<td>Final gain in weight</td>
<td>3 lb.</td>
</tr>
</tbody>
</table>

In steaming the gain was roughly 4 ounces per blanket. Half an hour's drying removed an average of less than 1 ounce. Of the balance, two ounces were removed by shaking, leaving a final gain of one ounce per blanket. The fact is that hot-air drying affects the outside of the charge only, the heart remaining as full of steam as ever. Prompt and vigorous shaking is necessary in any case. It is quite sufficient by itself.