USE OF THE SOLAR PANEL COOKER FOR MEDICAL PRESSURE STEAM STERILIZATION

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ABSTRACT

The expense, unreliability or unavailability of fuel and electricity in many areas hampers the ability of medical facilities to autoclave implements and supplies. This paper describes the adaptation of a large, simple, low-cost panel cooker to greatly reduce the reliance on conventional heat sources. The hybrid apparatus integrates propane for backup in case the available sunlight is insufficient. In good sunlight, sterilization runs can be completed on solar power alone. The efficient design also reduces fuel use even when no sunlight is available. The concept and operating guidelines for practical clinical use draw on the principal author's experience as a surgical nurse. Described are the principles of operation, design, construction and experimental results for a prototype unit – including verification of sterilization. The apparatus is also highly effective for general cooking, pressure-cooking and pressure food preservation ("canning"). The wind and rainproof design allows efficient and reliable operation under all weather conditions.

Keywords: autoclave, medical, sterilization, pressure, hybrid, propane backup

1. INTRODUCTION

Medical autoclaving typically employs electrical energy or propane to fire a pressure vessel to produce steam of sufficient temperature to destroy infectious agents. This article presents the results of testing our prototype unit incorporating a large panel cooker similar in design to the Solar Cookers International "CooKit." The unit incorporates an instantly available propane backup Burner to assure no sterilization run has to be aborted because of time constraints, excessive load, weak sunlight or changing weather conditions. The backup Burner is integrated into the apparatus in such a way that a Sterilizer vessel under pressure never has to be moved to another source of heat to finish sterilization. This low-tech apparatus can be constructed at relatively low cost using materials readily available in the USA. The entire apparatus can remain outdoors as a fixture. It may be disassembled for storage or transportation. The components are light enough to be carried short distances and assembled by a single person. They are small enough to be carried in most standard U.S.A. passenger cars.

1.1. Purpose of Investigation

(1) Demonstrate that medical pressure steam sterilization (autoclaving) can be practically achieved using solar energy alone. (2) Demonstrate that the use of propane as a backup fuel for the apparatus can be integrated in a safe and convenient fashion. (3) Measure the reduction in fuel consumption afforded by the use of a Hood, even when no sunlight is available. (4) Prove that sterilization temperature was reliably achieved for surgical packs using established medical procedures and test methods. (5) Indicate procedures for integrating use of the apparatus in real-world clinical settings. (6) Demonstrate that pressure-cooking and pressure-"canning" are readily achievable. (7) Provide design and construction suggestions.

2. BACKGROUND

The hybrid solar process described herein employs "classical" autoclaving procedures in common practice before the present day advent of purchased packages of disposable supplies. In addition to saving on energy expenses, the availability of an autoclaving process enables further cost reduction by allowing the reuse of non-disposable medical supplies and equipment.

We tested this system by sterilizing simulated operating room packs and other medical equipment. The clinical process involves careful on-site cleaning, sharpening and repairing equipment, plus washing and drying reusable cloth items. All materials (dressings, surgical implements and the like) needed for a particular procedure are then wrapped in three layers (or more) of cotton cloth, such as sheets in good condition. The packs are held under steam pressure for 35 minutes in the Sterilizer. The live steam thoroughly penetrates the cloth wrapping, sufficiently heating the contents to destroy infectious agents. The sterilized packs are set aside to dry. The layers of cloth maintain the sterile integrity in storage until the time of use.

3. THIS PROJECT

3.1. Equipment

Our system comprises four main components: the Sterilizer, the Solar Reflective Panels, the insulating Hood and the propane Burner.

3.1.1. The Sterilizer

This vessel is basically a food pressure-preservation "canner" modified with specialized components provided by the manufacturer, and marketed as a Pressure Steam Sterilizer (autoclave). See Fig. 3. A sterilization run begins with the Control Valve open. As water beneath the Inner Container boils, steam rises above the air in the Inner Container. As the steam gathers in the chamber, it forces the more dense air pocket downward and out the Air Exhaust Tube, leaving pure live steam to fill the entire volume of the vessel after a few minutes. At this point, the operator closes the Control Valve to pressurize the Sterilizer, causing the steam temperature to increase , heating the packs to the required 121 ^{0}C.

The spring-loaded Relief Valve on the Cover is a safety device. It is set to release steam if the pressure rises to 26 PSI plus or minus 1 PSI (pounds per square inch), which is 173 to 187 kPa (kiloPascals). In normal operation, it is expected that the operator would maintain the pressure below the threshold of this device. The Sterilizer also incorporates a silicone Overpressure Plug in the Cover. This secondary safety device will "blow" between 30 to 50 PSI (200 to 350 kPa) if the Relief Valve fails to open. Note: Sterilizers with metal Overpressure Plugs do not work in solar cookers. The plugs will melt prematurely from the heat of direct sunlight.

3.1.2. The Reflective Panels

The reflective panels are plywood covered with kitchen aluminum foil. The pair of Rear Reflectors adapt to low or high sun angles by dint of inverting them. The edges of the Rear Reflectors are cut square along one side to stand perpendicularly to direct low sun angle light onto the vessel. See Fig.1.When this pair of Rear Reflectors is turned over so that the opposite edges rest on the Base Reflector, the slant of these edges causes the panels to lean back to bounce high angled solar rays onto the vessel. The angle of the Front Reflector is adjustable relative to the Base Reflector. For low angle sunlight, it is set horizontal. For higher angle sunlight, the Front Reflector is raised until the radiation strikes the Sterilizer. Fig.4 shows a method for holding the Front Reflector securely at the correct angle, even under strong wind conditions.

The solar collector adapts to low angle sunlight, as encountered in winter, at high latitudes, or early or late in the day. It also adapts to high angle sunlight, as encountered in summer, at more equatorial latitudes, and toward the middle of the day. The entire apparatus consisting of Base Reflector, Rear Reflector pair, Front Reflector, Sterilizer, Hood, Burner and propane tank is periodically rotated east to west throughout the day to face the sun and maximize solar energy collection.

3.1.3. The Hood

The Hood is a transparent or translucent cylinder to hold in Sterilizer heat. It is closed on the top, and large enough in diameter to clear the handles at the sides of the Sterilizer. It encloses the Sterilizer supported on the Burner stand, with 2-1/2 cm clearance above the Control Valve lever when it is in the up position. The Hood is used in all heating modes – from full solar to 100% backup fuel. The dual-port arrangement atop the Hood eliminates the need to turn it during a sterilization run to gain access to the lever or to view the Steam Gauge. The Hood blocks wind, retains a layer of hot air next to the Sterilizer, and impedes loss of infrared heat radiation from the body of the Sterilizer. Its use is mandatory when collecting solar energy. It is also highly desirable when firing outdoors with propane to protect against the wind blowing the flame away from the Sterilizer, or extinguishing the Burner altogether. The Hood also

significantly increases fuel efficiency even when propane alone was used indoors.

During solar-only operation Shutters cover the Ports nearly all the time. They are opened momentarily as needed to view the Steam Gauge or to access the Control Valve. The Shutters are made of translucent or clear material to allow passage of sunlight.

When propane backup is used, adequate air must be provided for the flame. The Port for viewing the Steam Gauge must remain open when propane is in use in order to vent combustion gasses. The other Port remains closed nearly all of the time to prevent excessive air circulation and is opened only momentarily for access to the Control Valve.

The Hood may be fabricated from transparent or translucent flexible sheet material, thin plastic film over a cage, or from of glass. Our prototype has used a durable, translucent, flexible, UV resistant, heat resistant, fiberglass, greenhouse-glazing sheet material (see 3.4.).

3.1.4. The Burner

The Burner is integrated with a sturdy stand which supports the weight of the loaded Sterilizer.

Warning! Propane stoves are notorious for producing odorless, colorless, deadly carbon monoxide gas. Use in a well-ventilated area.

3.2. Testing

Test runs successfully demonstrated hybrid solar/propane pressure preservation of food ("canning"), solar (only) autoclaving and autoclaving using propane (only). These tests are summarized below. Consult the references for detailed test data.

3.2.1. Verification of Air Elimination and Sterilization

Proper sterilization and food "canning" require that all air be exhausted from the vessel and replaced by steam. Failure to do this will cause the temperature within the vessel to be lower than indicated by the pressure reading, with the result that the packs will be incompletely sterilized or the food inadequately preserved. The Operating Instructions provided by the manufacturer of the Sterilizer describe how to determine when the air has been adequately exhausted by observing a strong jet of steam escaping from the open Control Valve for seven minutes. However, this is not a practical method for either solar operation or for backup Burner operation, when using the hybrid system, since a visible (cloudy) steam jet does not form under the Hood. Instead, an alternative criterion must be used. Testing with standard medical temperature measuring equipment embedded in the centers of packs (Diack wax ampules [6], Therma-logs [7] and Sterilization Indicator Tape [8]) has established that either the occurrence of ample condensed steam on the inside walls of the Hood, or in a jar held over the Control Valve, both reliably indicate the exhaustion of air from the Sterilizer. Such sterilization could occur only if live steam had sufficiently replaced the air in the Sterilizer.

3.2.2. Hybrid Pressure Preservation Test [4]

October 12, clear sky, Reflectors in low sun-angle position. Safe "canning" of beans at our elevation of 1770 meters requires 18 PSI [1] (124 kPa) for 250 ^{0}F (121 ^{0}C). We operated at 20 PSI (138 kPa) for 253 ^{0}F (123 ^{0}C) in order to allow time to cope with changes needed in the event of falling pressure. Seventeen one-liter jars of pre-soaked pinto beans (250 ml dry volume), with 600 ml water each, were placed in the 39.5-liter Model 1941X Sterilizer. The heavy load required a propane assist to get up to pressure, but once that was achieved, solar alone was more than sufficient to maintain pressure for the duration of the cooking time. All of the jar lids sealed. The beans were soft and tasty. None spoiled after several months of storage.

9:20	Started on solar alone. Periodically re-aim to face sun.
12:20	Hot, but no steam, turned on Burner, 15,000 btu/hour rating. (1000 cal/sec) (4400 watts). Hood is in place.
13:00	Solid plume of steam observed. Control Valve closed.
13:28	20 PSI, Propane turned off, 68 minute burn, 4300 k-cal produced by Burner. 340 g propane consumed.
14:45	Held steady @ 20 PSI on solar alone for 1 hr. 17 min.

3.2.3. Test of Solar-Only Sterilization [4]

October 26, full sun with calm winds, Reflectors in low sun-angle position. The goal was at least 19 PSI (131 kPa) yielding 252 ^{0}F (122 ^{0}C) for 35 minutes. One liter of water was used to produce steam. The total mass included the water (1 kilo), the load of surgical/suture packs, half filling the Inner Container (2.6 kg), the aluminum Sterilizer (18.6 kg), and the weight of the iron propane stove, (3.6 kg). Once pressure was reached, rotation of the apparatus toward or away from the sun to control heat input easily maintained 20 PSI. A Diack wax ampule [6], Therma-log [7] and Sterilization Indicator Tape [8] were placed in each pack. All showed that sterilization temperature had been achieved.

11:00 Load started
13:20 Copious steam condensing in Hood. Exhaust/ Control Valve closed.
14:00 19 PSI pressure. Front Reflector removed to check pressure rise.
14:07 22 PSI. Array rotated to reduce sun collection.
14:10 23 PSI. Rotated further away from sun.
14:18 20 PSI. Rotated more toward sun.
14:35 19.5 PSI. Run completed.

3.2.4. Test of Propane-Only Sterilization

This test was conducted to determine fuel usage with and without the Hood in place, and to measure the reduction afforded by use of the Hood. Ambient relative humidity 32%. Load was one surgical pack and plus 2 liters water in standard autoclaving configuration. The amount of water boiled off during the run was measured by weighing before and after. The goal was to maintain 17 to 19 PSI (117 to 131 kPa) for 35 minutes.
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	No Hood	With Hood
Run time	102 min	96 min
Propane use	275.7 g	195.2 g
	3276 k-cal	2444 k-cal
Water loss	579 g	631 g
Exhaust time	38min	48 min
(time to reach Control Valve closure)		
Pressurization time	30 min	13 min
(time after closure to reach full pressure)		

Obviously, the Hood yields more efficient use of fuel, as less propane was required to boil off more water – 0.31 *versus* 0.48 g-propane per g-water. The data suggest that even better fuel savings could have been achieved by starting with the Hood removed, and then emplacing it only after the Valve was closed. This technique also conforms to the long accepted practice of viewing steam clouds to verify air exhaustion. Potentially, the best fuel savings might be obtained with the Hood on for the whole run using the "jar" method, which seems to be more sensitive in the judgment of steam. See 3.2.1.

3.3. Sterilization Procedure

A non-professional staff member can handle much, if not all, of the solar sterilization process. The idea is to have an operator constantly attending the Sterilizer and to minimize the hands-on involvement of a supervisor. As with any sterilization process, temperature indicators (Therma-logs, temperature indicating tape or preferably Diack wax ampules) should always be placed inside packs to assure that indeed sterilization has occurred.

An early start is recommended, since the initial heating of the Sterilizer each day requires several hours. Subsequent sterilization runs are much faster since the mass of the water and vessel is already hot. To speed the process further, loads may be separately preheated in a solar cooker or any other available source of heat while awaiting placement in the Sterilizer.

A more detailed procedure can be found the Kerr-Cole Sustainable Living Center web site [2].

3.3.1. Operating Instructions

(1) Load the Sterilizer with surgical packs as described in the Sterilizer Manual [5.] Open the Control Valve and place the Hood over the Sterilizer and Burner. Close both Ports if using solar heat only. Leave one Port open if using backup fuel.

(2) Focus the apparatus. The east-west azimuth angle, Rear Reflector slant, and Front Reflector elevation need adjustment once an hour to insure maximum solar collection efficiency. Judge correct panel positions by observing maximum reflection onto the vessel. Alternatively one may use the more rigorous methods described on our web page [2].

(3) Exhaust the air. When copious steam is observed, per 3.2.1, close the Control Valve to allow pressure to build in the vessel.

(4) Backup with propane if needed if the required pressure cannot be reached or maintained using solar alone. At night the droplets and rivulets can be seen by shining a light on the Hood.

(5) Control the sterilization pressure to hold it above the minimum for 35 minutes. The required Steam Gauge pressure to hold 250 deg ^{0}F (121 ^{0}C) for sterilization depends on altitude.

Altitude		Steam Gauge Reading	
feet	meters	PSI	kPa
0000 to 2000	0000 to 0600	16 to 18	110 to 124
2000 to 4000	0600 to 1200	17 to 19	117 to 131
4000 to 6000	1200 to 1800	18 to 20	124 to 138
6000 to 8000	1800 to 2400	19 to 21	131 to 145
8000 to 10,000	2400 to 3000	20 to 22	138 to 152
10,000 to 12,000	3000 to 3600	21 to 23	145 to 159

To minimize the loss of water, avoid allowing the Excess Pressure Relief Valve to vent steam. If operating under pure solar heating, and the pressure rises too high, reduce heat by shading the Hood, rotating the apparatus away from the sun, folding up or removing the Front Reflector or removing the Hood. If operating with supplemental propane, achieve fine regulation of pressure by varying the solar input and use Burner adjustment for coarse

control. If operating with propane only, removing the Hood could help check a rise in pressure.

(6) End the run when the pressure has been held for 35 minutes. Remove the Hood and shut off the Burner, then lift the Control Valve to vent steam pressure. Remove the packs to the drying area. Before the next run is begun, check the water level in the Sterilizer to insure the depth is between _ inch and one inch (20 to 25 mm). If closing down for the day, empty the Sterilizer and dry it. To hasten startup the next day, turn the apparatus eastward to face the sunrise, Sterilizer atop the stove, Hood in place and Reflectors set for morning sun angle.

3.4. Notes on Construction Materials

Sun-Lite HP fiberglass glazing material
Solar Components Corporation
www.solarcomponents.com/sun.htm
Sold in cut sheets, various sizes, 0.040 or 0.060 inch thickness.

or

Glasteel ™ Flat Roll Fiberglass Reinforced Plastic Panel
425 Industrial Drive, Moscow, TN 38057
Sold in 50 foot by 4 foot rolls
Phone (901) 877-3010, www.glasteel.com

Use 100% silicone sealant to construct Hood. Pop rivets will facilitate holding the Hood cylinder together during construction.

4. CONCLUSION

The goals per 1.1 have been achieved for our design at 35 degrees north latitude. Our Sterilizer vessel could at any time be returned to conventional standard (non-solar hybrid) use, if desired. The bakelite handles, Steam Gauge, Control Valve, Excess Steam Pressure Relief Valve and Overpressure Plug remained in good condition and functional throughout our tests when used in the solar/hybrid apparatus, with no sign of degradation due to the heat under the Hood. Other test runs not included in this paper demonstrate that the backup Burner can be used simultaneously with solar energy to maintain adequate pressure under fluctuating cloud cover. The apparatus is left exposed to strong winds when not in use without damage. The panels deflect wind to make propane operation practical in the wind. Switching from total solar to solar/propane to propane-only can be done efficiently and safely, without reconfiguration of the apparatus or having to move the Sterilizer under pressure. The design appears to be adaptable to other cultures and locations.

4.1 Future Development

The intent of this paper is to present our results to stimulate work by others. We welcome collaboration. Field-testing for practicality in clinical settings is now needed. Some other projects might be: (1) Approval by regulatory agencies and health organizations. (2) Scientific testing in academic settings yielding published papers to verify reliability of this method of sterilization. (3) Engineering studies to optimize equipment (Port size, Burner capacity for best fuel efficiency, panel design / sizes / angles for various latitudes). (4) Eliminate cords and weights holding the Reflectors. (5) Hybridizing with kerosene or solid fuels like wood or dung.

5. REFERENCES

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2. Barbara Kerr and Jim Scott, *A System for Medical Sterilization (Autoclaving) Using Solar-Generated Steam Pressure,* Autoclave page, www.solarcooking.org/bkerr.

3. Barbara Kerr, *A Simple Solar (Sunflower) Autoclave Design*, Solar Cooking Archives. http://solarcooking.org/autoclave.htm.

4. Barbara Kerr, *The Kerr-Cole Large Solar Panel/Propane Hybrid Stoves*, Solar Cooking Archives. http://search.msn.com/results.aspx?FORM=FREESS&cp=1252&q=autoclave&q1=site%3Asolarcooking.org

5. All American *Non-Electric Pressure Steam Sterilizers Model 1915X, 1925X, 1941X Operating Instructions* - Wisconsin Aluminum Foundry Co., Inc., P O Box 246, 838 S 16th St., Manitowoc, Wisconsin, U.S.A., 54220. Phone (414) 682-8286

6. *Diack Control, 250 deg F, 121 deg C* (wax ampules) Diack Inc., 7755 Narrow Gauge Road, Beulah MI, 49617, (616) 882-7251

7. *3M Comply Thermalog Steam Chemical Integrator* (temperature indication strips). 3M Center, Building 275-5W-06, St. Paul, MN 55133. (651) 733-4365

8. *Sterilization Indicator Tape* Propper Mfg. Co. Inc., 36-04 Skillman Ave., Long Island City, NY 11101 1-800-832-4300, www.proppermfg.com

TRANSLUCENT FIBERGLASS HOOD RETAINS HEAT

3 CORDS TO WEIGHTS SECURE ARRAY AGAINST WIND, 2 ON SIDES AND 1 IN REAR

Fig.1 Hybrid Autoclave in SolarOperation. Low sun elevation configuration, Rear Reflectors vertical, Front Reflector horizontal. Unit pivoted toward sun.

COVER, FROM LEFT:
STEAM GAUGE, RELIEF VALVE,
CONTROL VALVE

INNER CONTAINER

PRESSURE VESSEL

RACK UNDER INNER CONTAINER
(NOT VISIBLE)

Fig.3 Sterilizer Components. The Air Exhaust Tube extends from beneath Control Valve to bottom of Inner Container.

BLACKENED STERILIZER SUPPORTED BY BURNER

PROPANE TANK RIDES ON BASE REFLECTOR

NOTE FLEXIBLE METAL GAS HOSE

A BLACKENED SHEET METAL BACKDROP BEHIND BURNER MAKES FLAME VISIBLE

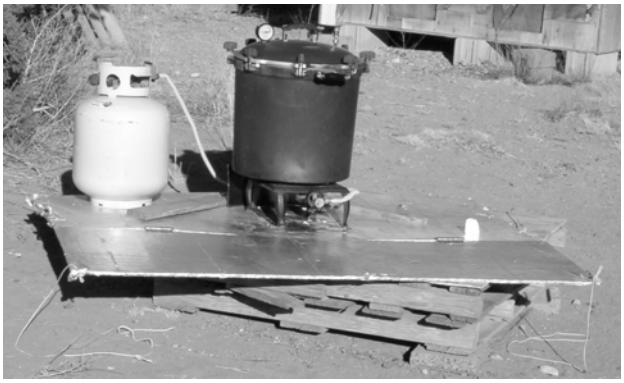

Fig. 2 Hood and Rear Reflector Removed. Base Reflector pivots on platform. Sterilizer at solar focus, over Pivot Pin

CORD TO WEIGHT SECURES FRONT REFLECTOR
FRONT REFLECTOR: 152 X 46 CM

BASE REFLECTOR: 152 X 76 CM
PIVOT (D) AT FOCUS 38 CM FORWARD OF BACK

REAR REFLECTOR: (A) 65 X (B) 122 X (C) 102 CM. ANGLES AB AND BC ARE RIGHT ANGLES

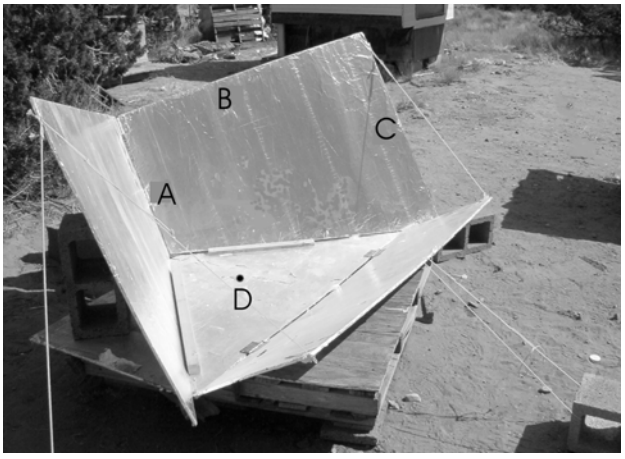

Fig. 4 High Angle Configuration. Rear Reflectors slant back. Front Reflector elevated. Dimensions for 1941X Sterilizer