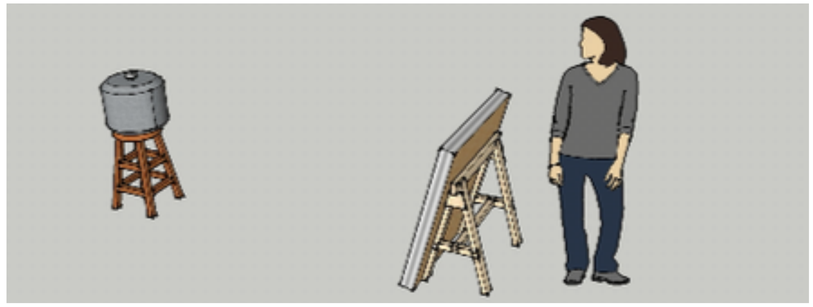
Introduction

- **Autoclave:** a pressure vessel used for sterilizing medical equipment, generally with pressurized steam.
- Without a reliable electrical grid, this technology is unable to function in the same way as in an industrialized country.
- Our team partnered with a non-profit, *Grupo Fenix*, that implements engineering solutions to problems in the developing world.
- Two major design considerations: (1) how to achieve/hold pressure and (2) how to heat the system.
- Our solution: Combine a simple/inexpensive pressure cooker with a rudimentary solar reflector/concentrator.
- Our prototypes concentrate between one and two square meters of solar energy onto a pressure vessel large enough to hold medium-sized medical tools.

Duke UNIVERSITY | BASS CONNECTIONS

Sterilizing Medical Equipment With The Sun

A NON-ELECTRIC AUTOCLAVE FOR RURAL MEDICAL CLINICS



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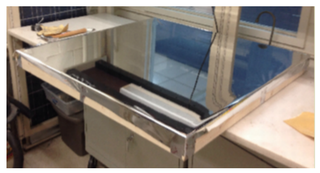
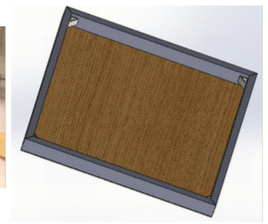
Objectives & Goals

- Create an effective Solar Autoclave for use in rural Nicaragua to fill the need identified by Non-profit *Grupo Fenix*.
- “An inexpensive, non-electric autoclave that would guarantee sterile medical instruments in these remote locations”
  – Grupo Fenix
- Design a product that will consistently sterilize instruments to a certified standard of 121°C and 15 psi for 30 minutes.
- Must be cost effective and feasible for use by local communities.
- Achieve a final product by May 2015 (we are nearing this target).
- Several volunteers have attempted to achieve this benchmark, none have succeeded.
- During testing we have achieved 90°C, but **testing is incomplete as of this time.**

Prototype #1





- 1 m^2 wooden 2x4 frame
- Medium density fiberboard (MDF) backing
- Stretched highly reflective mylar sheet (same material as “space blankets”)
- Sealed with silicone caulk
- Installed check valve allows air to be removed from the system, creating a vacuum
- Vacuum creates naturally near-parabolic shape in mylar sheet, which concentrates/focuses sunlight

Reflector did not perform well. Too heavy to be useful, and would not hold vacuum seal.

Prototypes #2 & #3

Prototype #2

- 22-qt pressure cooker
- Insulated with two layers of R-10 foam insulation
- 1 m^2 plastic drainage tray with stretched reflective mylar sheet
- Vacuum sealed to create parabolic shape

#1 unable to achieve temperature and pressure benchmarks as of early April 2015.

Prototype #3

- Reduced pressure cooker size to 8-qt model for proof of concept
- Added a second 1 m^2 reflector (identical to other)
- Testing is still in progress (early April)

x 2

Heat Transfer Analysis: Theoretical

Heat Needed to Reach 121°C

$Q_{heat\ water} = cm\Delta T = (4.19\frac{J}{g°C})(2521.97g)(121 - 25\ °C) = 1,014,437\ J$

$Q_{heat\ Al} = cm\Delta T = (.900\frac{J}{g°C})(5897\ g)(96\ °C) = 509,500.8\ J$

$Q_{latent} = m_{vaporized}L$

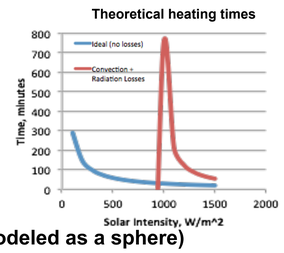
$pV = nRT = 2.022atm(20.82\ L) = n(.08206\frac{L\cdot atm}{mol\cdot K})(394.15K)$

$n = 1.3\ mol\ H_2O$

$m = 18\frac{g}{mol}(1.3mol) = 23.4g\ H_2O$

$Q_{latent} = (.0234kg)(2.26x10^6\frac{J}{kg}) = 52,884\ J$

$Q_{total} = 1,014,437J + 509,500.8J + 52,884J = 1,576,821.8\ J$



Convection Losses (cooker modeled as a sphere)

$Re = \frac{u_\infty D}{\nu} = \frac{(3.6\ m/s)(.45m)}{2.056x10^{-5}\ m^2/s} = 78,794 \rightarrow$ Laminar Flow

$\overline{Nu} = 2 + (.4Re^{1/2} + .06Re^{2/3})P^{2/5}\left(\frac{\mu}{\mu_s}\right)^{1/4} = 225.4$

$\overline{h} = \frac{\overline{Nu}_{s,b}}{D} = \frac{(225.4)(.0295\frac{W}{m°K})}{.45m} = 14.8\ \frac{W}{m^2K}$

$Q'_{conv} = h_c A\Delta T = (14.8\frac{W}{m^2K})(.62m^2)(394.15 - 299.82K) = 865.6W$

$\overline{h_{max\ wind}} = 23.2\ \frac{W}{m^2K}$

$Q'_{conv,max\ wind} = 1357\ W$

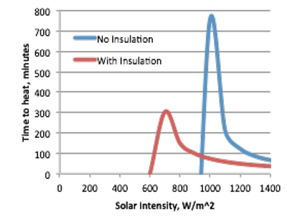
Critical Insulation Thickness

$Q'_{out,\ max\ wind} = \frac{\Delta T}{\frac{1}{A1\ h1} + \frac{r_{insulation}}{A1} + \frac{1}{A1}} = \frac{394.15 - 299.82}{\frac{1}{(12.2)(1)} + \frac{r_{insulation}}{(97.6)} + \frac{1}{(97.6)}} \leq 700\ W$

$t_{insulation} = 0.0018\ m$

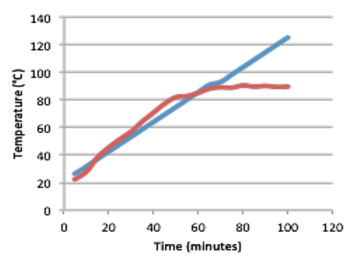
$Q'_{out,\ average\ day} = \frac{\Delta T}{\frac{1}{A1\ h1} + \frac{r_{insulation}}{A1} + \frac{1}{A1}} = \frac{394.15 - 299.82}{\frac{1}{(12.2)(1)} + \frac{.0018}{(97.6)} + \frac{1}{(97.6)}} = 543.5\ W$

Theoretical heating times based 8 mph winds for insulated and uninsulated vessel



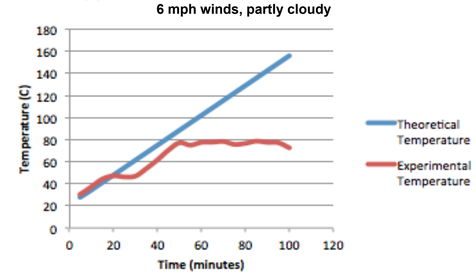
Experimental Data Analysis

22-qt pressure cooker with one reflector and insulation, 14 mph winds



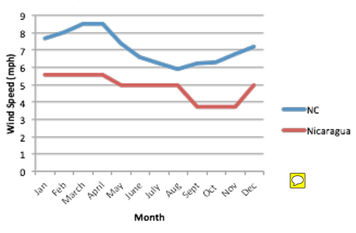
Note: Latent heat was accounted for over the whole curve rather than at one point, accounting for discrepancies in theoretical vs. experimental

8-qt pressure cooker with one reflector and insulation, 6 mph winds, partly cloudy



Weather Comparison

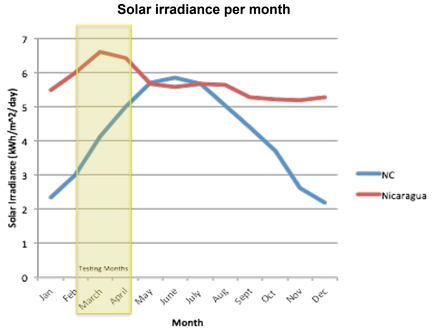
Average wind speed per month



Average annual wind speeds

Greensboro, NC	7.2 mph
Managua, Nicaragua	4.9 mph

Solar irradiance per month



Environmental Impact Assessment

Regulations:

- Governed by Ministry of Environment and Natural Resources (MARENA)
- Municipal governments must be consulted by MARENA
- Environmental Impact Statement must include alternatives to project
- Positive Impacts: energy savings
- Negligible soil and groundwater impacts

Eco properties: Polyethylene Terephthalate (PET)		
Global Production, main component	9.5 x 10^6	metric ton/yr
Embodied energy, primary production	81 – 89	MJ/kg
CO_2 footprint, primary production	3.7 – 4.1	kg/kg
Water usage	14.7 – 44.2	l/kg
Eco-indicator	276	millipoints/kg

Maintenance: Spare gasket - $10/2 years

Major Replacement: Pressure cooker - $35/6 years

Budget

Research & Development Budget		
Category	Expenditures	% of Total Budget
Mylar Roll	$37.81	7.5%
Pressure Cookers	$102.10	20.3%
Wood + Screws	$49.33	9.8%
Tape + Caulk	$62.90	12.5%
Spill Trays	$237.20	47.2%
Sterilization Indicator Kit	$13.08	2.6%
Total	**$502.42**	**100.0%**

Projected Unit Cost of Solar Autoclave		
Category	Cost	% of Total Cost
Mylar Roll	$3.78	7.1%
Pressure Cooker	$35.45	66.6%
Plastic Swimming Pool	$11.99	22.5%
Adhesive	$1.96	3.7%
Sterlization Indicator Kit	$0.05	0.1%
Total	**$53.23**	**100.0%**
Sales Price	Profit per Autoclave	Profit Margin
$75.00	$21.77	29.0%

Conclusions

Testing is still in progress.

The following ~~are the~~ tests ~~that~~ will be performed in the coming weeks:

- 22-qt pressure cooker with 2 solar reflectors
- 8-qt pressure cooker with 1 solar reflector
- 8-qt pressure cooker with 2 solar reflectors
- Increased insulation to lower wind losses
- Increase water level (to decrease volume for steam to fill)