A Material Processing Cell Utilizing Black-water Hydrostatic Pressure: A Student Project

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Abstract:

Autoclaves and hydroclaves are devices that contain and control moderate to large hydrostatic gas or fluid pressure. These devices are used with hot fluids (gas for autoclaves, water for hydroclaves) to heat and squeeze polymers, metals and/or ceramics during diffusion or pressure gradient controlled solid and liquid-phase materials processing. Autoclave and hydroclave technology are limited by traditional steel construction to a range of pressure-volume performance that may hinder visionary designers of objects and structures composed of advanced materials. This paper will examine some practical limitations of autoclave and hydroclave technology with trend data from an ad hoc survey. A new concept for autoclave design will be introduced, one that employs blue or black-water hydrostatic pressure. A student team's experiences in the construction and field test of a working prototype will be documented.

Autoclaves are typically large steel cylinders that contain and control moderate to large hydrostatic gas or fluid pressure. This pressure is used to promote material flow and/or diffusion during some controlled manufacturing process. The most common use for autoclaves (outside the medical field where they are used in equipment sterilization) is in the processing of polymeric matrix, fiber reinforced composites. Applications for these materials abound in aircraft systems and are found increasingly in marine infrastructure and surface ship due their high specific structural performance and resistance to corrosion. An autoclave under construction at San Diego State University's Facility for Applied Manufacturing Enterprise [1,2] is shown in concept drawing form in Figure 1. The steel shell for the autoclave was donated by a commercial gas company and has a length of 15', a working diameter of 28" and a thickness of 3". Working diameter, shell thickness, pressure ratings and estimated purchase cost for an informally surveyed list of commercially available autoclaves are shown in Figure 2. The underlying limitation evident in the figure is that the autoclave shell's design stress in tension is not permitted to exceed 10,000-12,000 PSI. Given that the stored energy in a 3' diameter, 6' long vessel operating at 500 PSI is on the order of 1 MJ (Sorry for the unit change), conservative design is the only prudent course[3]. A material change to exotic alloys or composite materials might increase the not-to-exceed stress by a factor of five, but factors of safety related to the increased energy storage became the limiting concern. Indeed, hydroclaves are employed at pressures above 500 PSI. These devices use water as the internal pressurizing medium to reduce the energy stored in material compressibility.

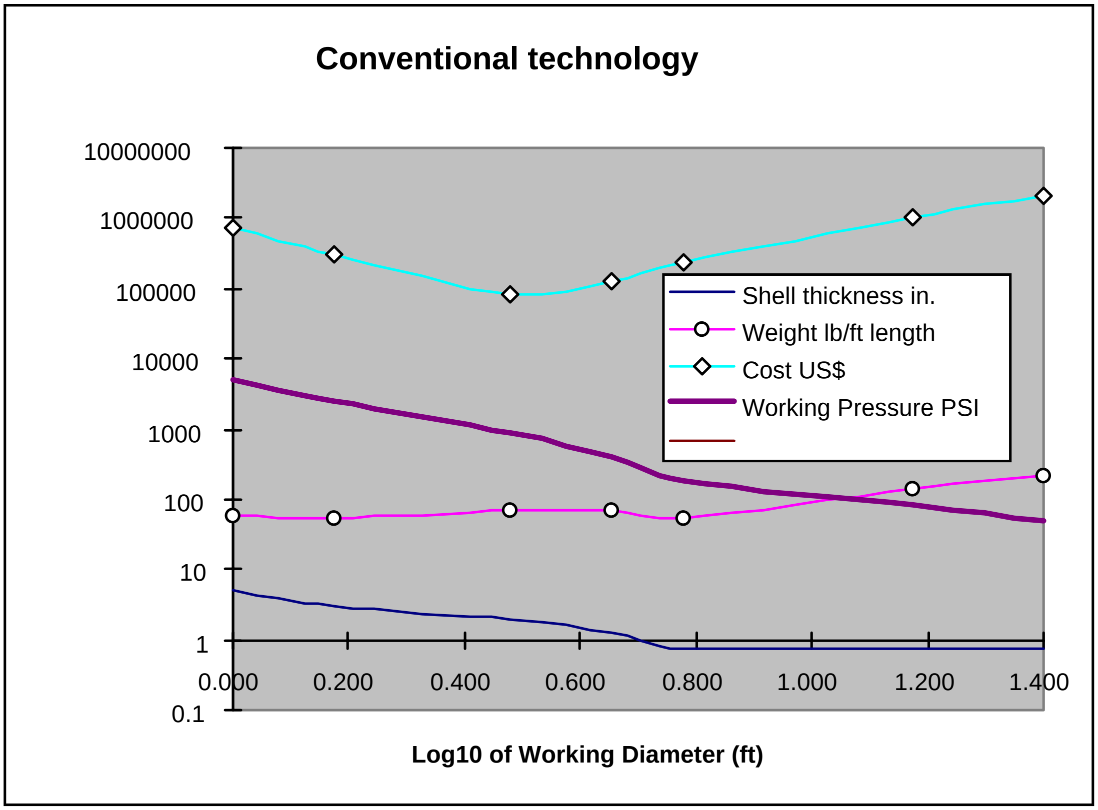

Figure 2. Figures of merit for conventional autoclaves

The author offers the following cost proxy formula as a basis for comparing the utility of various autoclave configurations in performing their function:

$$C.P. = \$\frac{W}{PD^2}$$

where \$ is the system purchase cost, W is the system weight, P is the working pressure, and D is the autoclave diameter or smallest process zone dimension. This proxy was formulated from a dimensionless grouping that rewards minimum system weight and maximum pressure and part area. As system weight has a strong direct correlation to installation and operation costs and as the square of the shell diameter is a good estimate of working area, this proxy should serve as an acceptable inverse for utility. The proxy permits comparison of a range of autoclave configurations in Figure 3. Here cost proxy is plotted vs. working pressure. Ignore for now the two outlying points in the figure.

The figure indicates that the most cost effective (by the authors rule) autoclave or hydroclave has a cost proxy of around $400 US. Figure 4 (again ignoring the outlying points), illustrates the same information, but reveals the working area of each configuration. Pressure and working area are certainly independent choices that will determine the actual equipment selected. Both figures indicate that as pressure or working area increase, the associated cost proxy, even as plotted on Logarithmic scale, increases rapidly. Clearly, cost limitations indicated here prevent processes that require much higher pressures or produce much larger components, or both in combination, from receiving serious design consideration.

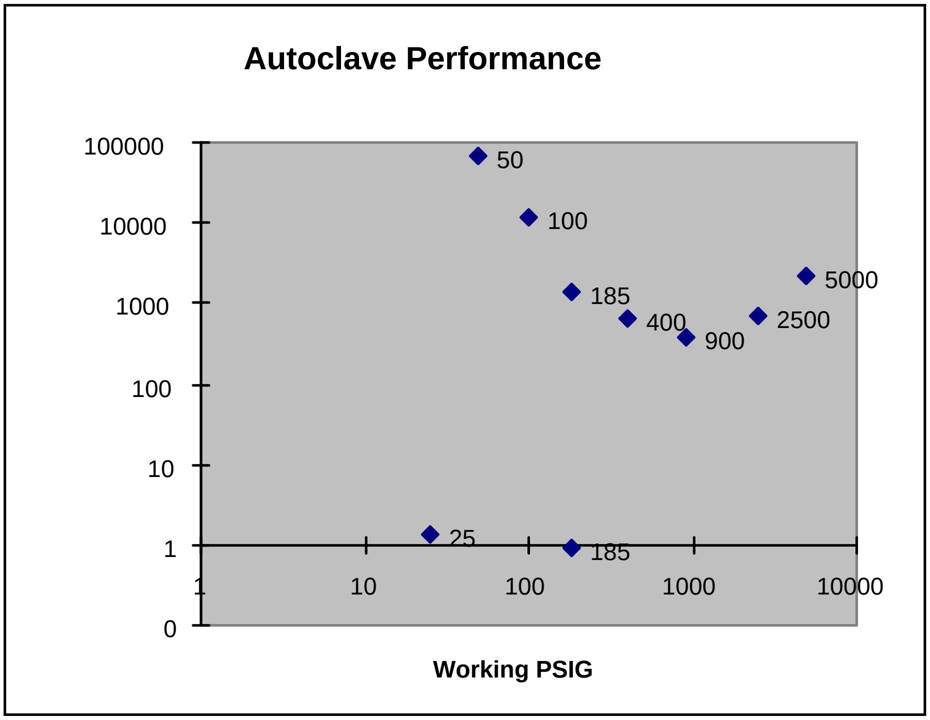

Figure 3. Pressure vs. Cost for a range of autoclaves

What applications might require currently unattainable process conditions? Consider warm sintering of phase-sensitive rare-earth alloy precursor powders into large magnets under high pressure. Consider stealth surface ships with one-piece superstructures for elimination of slot antenna effects at seams. Consider the next generation of acrylic-sphere style deep submersible or underwater habitat.

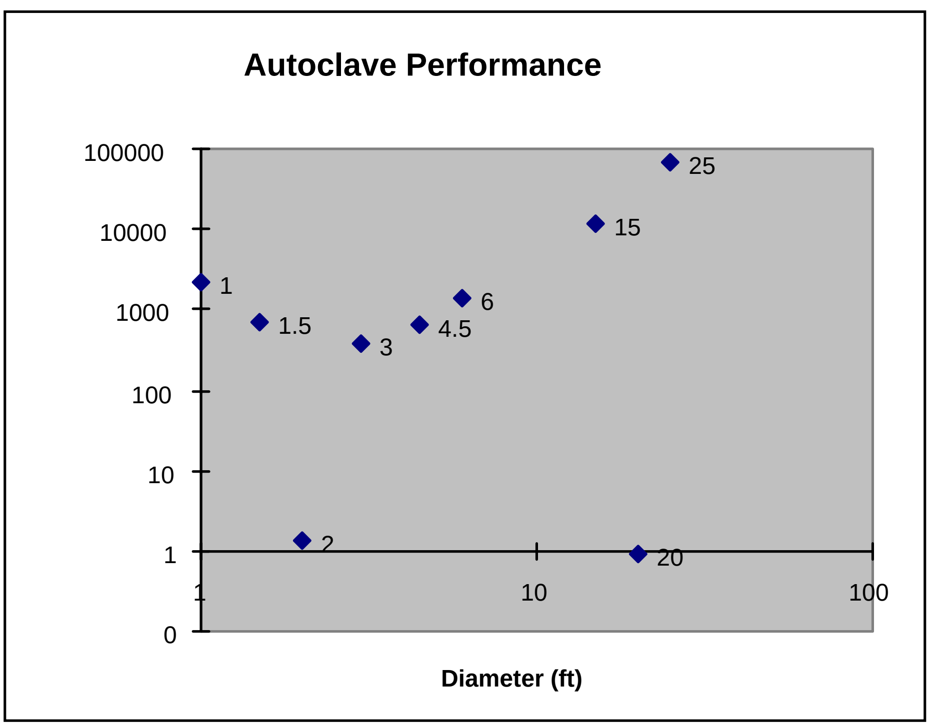

Figure 4. Diameter vs. Cost for a range of autoclaves

Four San Diego State University students designed and constructed a prototype autoclave-like processing cell under the direction and sponsorship of Ailanthus, Inc. of El Cajon, CA. This autoclave design uses hydrostatic pressure from a surrounding aqueous medium to provide confinement for an internal gaseous pressurizing medium used to promote flow and/or diffusion driven processing. A schematic of the cell is shown in Figure 5. The cell was designed to be lowered by cable from a surface ship to a depth at which confinement pressure reached desired process pressure. Incremental pressurization of the larger internal cavity balances the external pressure and permits the use of a thin-walled confinement vessel. Evacuation of the smaller internal chamber creates a uniaxial pressure gradient useful in materials processing.

Pro/ENGINEER has been used to document the design and construction of the device. Initial prototype design was driven by materials and components selected by students for availability and low acquisition cost. Since sea trials were planned to validate the design, corrosion was also a consideration. Figure 6 illustrates elements of the design. Buoyancy of the device attributable to the inner cavity volume, necessitated the use of cement weights to achieve neutrality. Round exercise weights were used to permit rolling of the device. A swimming pool trial verified the effectiveness of the team's buoyancy control efforts. Floodability of the non-water tight volume of the enclosure, as well as access to compressed gas and vacuum controls was afforded by large access holes and smaller vent holes. Incremental pressurization was controlled by an automatic valve capable of tracking the external pressure to within 1/2 PSI. the upper cavity membrane and attachment was designed from this consideration.

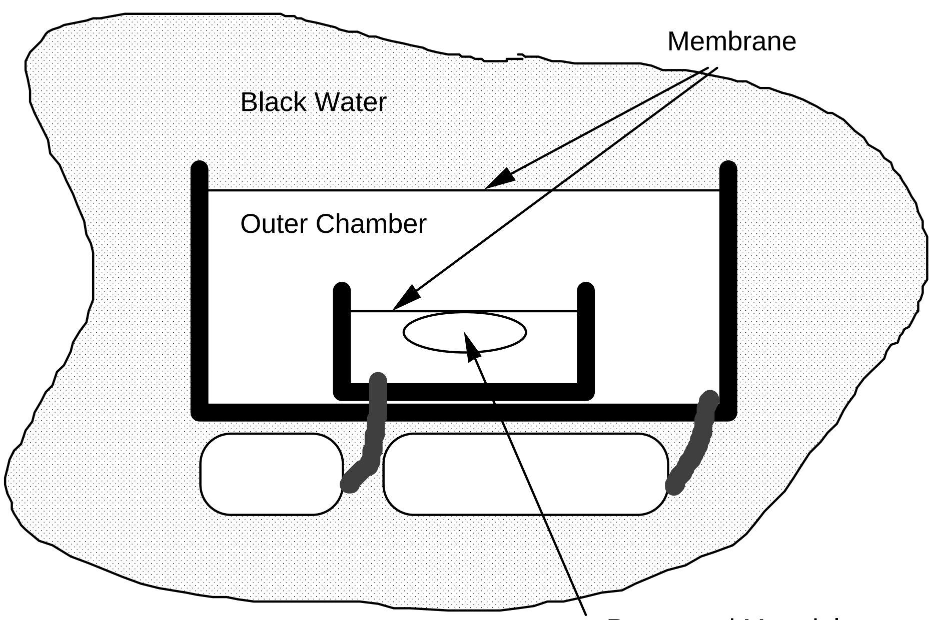

Figure 5. Device Schematic

A sea trial in San Diego's Mission Bay was performed under the supervision of SDSU's diving safety coordinator. Initially, the dive plan called for the use of a university-owned surface vessel. Considerations related to safe loading and unloading of the device in open water and diving with a relatively inexperienced student diver lead the diving coordinator to hold the trial as a shore dive in the shallow water near the marina boat ramp. Two divers accompanied the device to a depth of approximately 50' and turned a manual valve to evacuate the inner cavity. Ascent was uneventful and venting was accomplished successfully. A piece of clay placed in the inner cavity was examined after the trial and found to be deformed by the action of differential pressure.

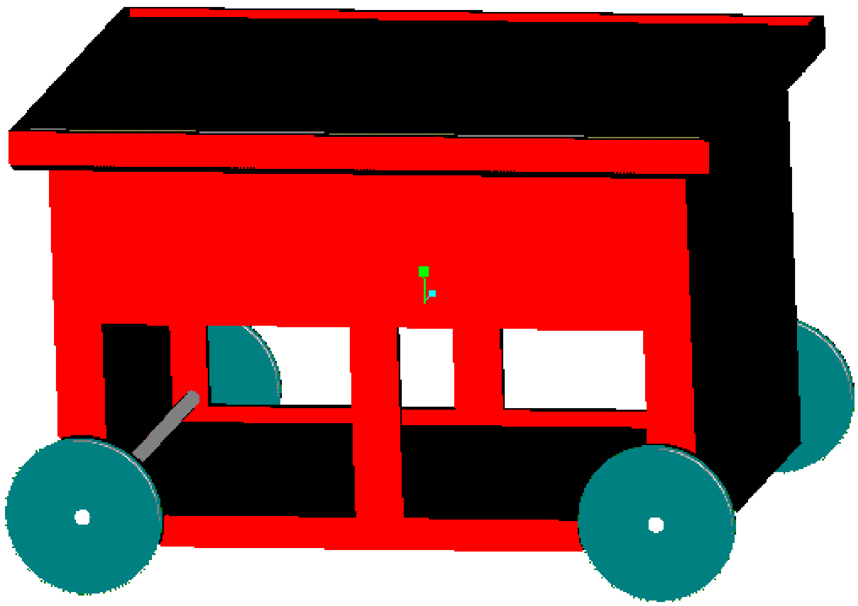

Figure 6. Pro/E model rendering

The outlying points in Figures 3 and 4 represent performance of the first SDSU prototype processing cell and projected performance of a second prototype currently under development. This cost proxy information hints at a tremendous leap in performance for the new approach.

Planned future work includes redesign of the cell for reduced hydrodynamic drag, reduced buoyancy, reduced overall weight, improved water tightness, research into low volume high pressure differential pumps, addition of heating elements, sensors and automatic controls, power and telemetry cabling, and tethering improvements.

References

[1] Autoclave project web page, San Diego State University, www-rohan.sdsu.edu/dept/medept/fame/clave/MAIN.HTM

[2] FAME program web page, San Diego State University, www-rohan.sdsu.edu/dept/medept/cim.html

[3] Shigley, Joseph E., Mischke, Charles R. *Mechanical Engineering Design*, 5th ed. New York: McGraw-Hill, 1989.

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