

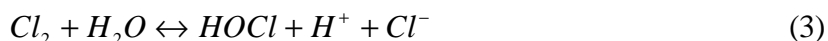
Salt Chlorination

Millions of people worldwide enjoy swimming pool activities every year. Traditionally, chlorine-containing chemicals have been used as the sanitizing agent. Some chlorine containing chemicals used include chlorine gas, sodium hypochlorite, calcium hypochlorite, lithium hypochlorite, and chlorinated isocyanurates. These chemicals enter the pool as a concentrated solution, or in the form of hypochlorite salt tablets, to form the killing agent, hypochlorous acid.

Currently, a new way to produce hypochlorous acid has been developed. The theory is based on an electrolysis reaction using an electrolytic cell. The cell utilizes common table salt, $NaCl$, in solution. Passing a current through the solution liberates chlorine ions, Cl^- , at the anode, and hydroxide ions, OH^- , at the cathode. These reactions are illustrated below ¹:



Chlorine produced from the electrolytic cell reacts with water in the same way as conventional chlorine containing chemicals. The products are chlorine ions, hydrogen ions, and hypochlorous acid.



Chlorine usage, storage, and transport present major safety concerns. Chlorine compounds are highly corrosive and toxic. The use of a salt chlorination system reduces the rate of corrosion of pool equipment and bleaching of swimsuits. There is less irritation to skin due to softer water. The small amount of salt required reduces storage area. Insurance premiums are

less for public facilities due to no on-site chlorine, and there are no EPA inspection fees for salt storage or use.²

Several theories exist explaining the killing mechanism of hypochlorous acid. In each of the theories, the newly formed compound is assumed to cause microbial death. One theory proposes a switching of chlorine with hydrogen in a *NH* group of a protein peptide bond. The switching causes a more complex protein to be formed, which accounts for microbial destruction.³

An alternative theory suggests a change in the valence number of the nitrogen in the peptide bond. The change causes the peptide to react with a water molecule, which ionizes to a base.³ The base then reacts with the hypochlorous acid.

Another theory considers the abolishment of enzyme action in the cell. This is accomplished through the oxidization of enzymes containing sulfhydryl groups. This theory proposes hypochlorous acid as the oxidizing agent.³

The goal of this investigation was to optimize the temperature, number of plates in the electrolytic cell, and the plate spacing for residential and commercial pools. The residential pool had a 50,000 gallon capacity, and the commercial pool had a 200,000 gallon capacity. The depth for both pools was 12 feet. Calculations were based on the inlet suction being one foot above the pool bottom, and an outlet 2 feet below the surface. Outlet pressure was taken to be 200 kPa. The residential pool system consisted of 2" piping while the commercial pool used 4" piping. Both pool sizes use 50 feet of pipe, 10 elbows, and 2 T-sections. The commercial pool required a filter size of 0.35 m³ and 0.16 m³ for the residential pool.

Constraints on the cell considered maximum velocity, cell width, and plate spacing. A maximum velocity of 3.5 m/s was assumed. At higher velocities, erosion becomes a problem.

The cell width could not be larger than the pipe diameter. Larger diameters introduce problems with plate destruction. The end plates begin to loosen from the constant flow of water pushing on them. Plate spacing could be no less than 0.5 cm. Small spacing introduces construction and stability problems. An additional constraint was that the cell depth could not be any less than 1/10 the width. This constraint was placed for stability and to give adequate reaction space.

In order to design a system using an electrolytic cell to create a pool sanitizing system, the overall process that circulates pool water was examined. A diagram of water circulation can be seen in Figure 1. This figure shows that water leaves through the bottom of the pool, and is sent to Unit 100. In Unit 100 hypochlorous acid is produced. The stream is then sent from Unit 100 back to the swimming pool.

Figure 2 shows a process flow diagram for Unit 100. The unit pulls unsanitized water from the pool, which is designated as Stream 1. Stream 1 is pumped to a higher pressure by P-101. Next, the high-pressure feed is then sent to the sand filter (F-101), where solids such as dirt, particulates, leaves, and other debris are removed as Stream 4. Stream 5, the purified water, is sent through E-101, an optional natural gas heater. The heated stream is then sent through an electrolytic cell, where a small fraction of the NaCl is transformed into 3 ppm HOCl. Next, if the salt level is below the required 3,000 ppm, salt is added by the salt hopper, SH-101. ⁴

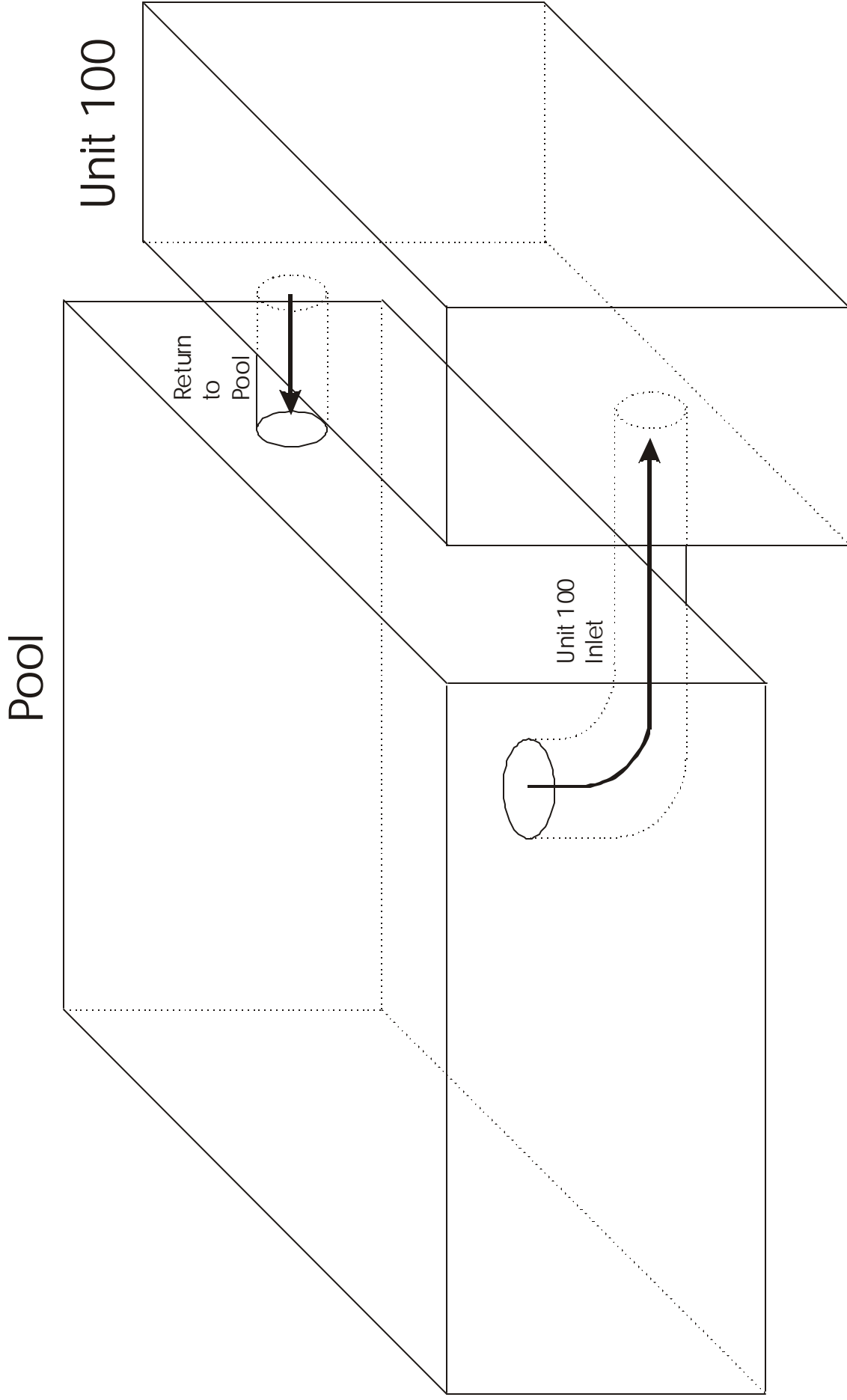


Figure 1: Pool Water Circulation

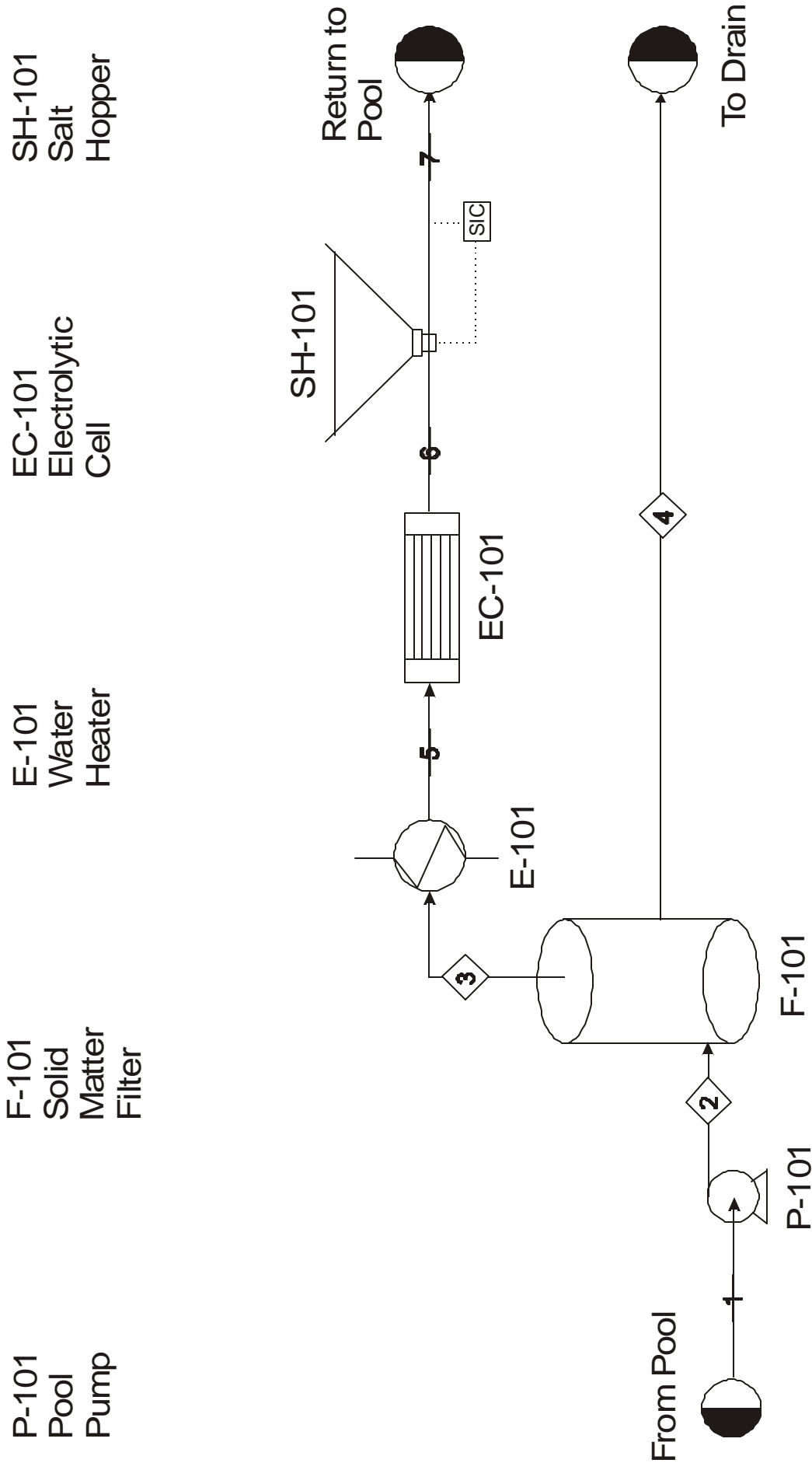
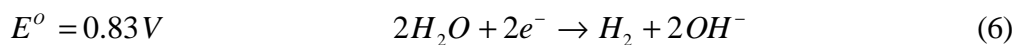
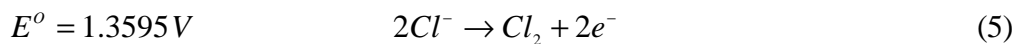


Figure 2: Unit 101. Electrolytic Cell Arrangement

The cell, hopper, sensor, and AC/DC converter are pieces of equipment that are only needed in the salt chlorination system. The rest of the equipment is standard for any pool system. For the standard chlorine system start-up, chlorine is needed rather than salt. These costs were found by shopping at various web sites and pool dealers, then taking a discount by assuming bulk purchasing.

The diagram of the workings of the electrolytic cell can be seen in Figure 3. Water flows parallel to a set of plates which are charged. In the water between the plates, the desired reactions occur. These plates act as both cathodes and anodes, on opposite sides. The plates on either end of the cell induce this effect. The material used to manufacture the electrolytic cell is DSA, which primarily consists of titanium embedded with rare earth metals.

The electrochemical cell works by passing a current through a solution of water containing common table salt, $NaCl$. Chlorine ions are generated at the anode and hydroxide ions are generated at the cathode. The following electrochemical reactions are represented below with corresponding standard equilibrium potentials: ⁵



To calculate the plate area, the following equations were used. First, the total current between plates can be calculated using this equation: ⁶

$$I_{Gap} = \frac{F}{t} \sum \frac{n_{rcted}}{n_{gap}} \sum \frac{n_{elec}}{n_{gap}} \qquad (7)$$

where:

$$F = 96,487 \frac{coulomb}{mol} \text{ is Faraday's constant}$$

$$t = 60 \text{ seconds is constant}$$

n_{rcted} = flow rate through cell [mol/min]

n_{elec} = flow rate of electrons generated in cell [mol/min]

n_{gap} = number of gaps in the cell

The total current through the cell can be found by multiplying the current between one plate by the number of gaps.

The voltage needed by the system is linked to current, area, conductivity, and plate spacing in the equation below ⁶:

$$V_{Ohm} = \frac{I_{Gap}}{A} \left(\frac{S}{\mathbf{k}} \right) \quad (8)$$

where:

S : plate spacing [cm]

\mathbf{k} : conductivity [(ohm·cm)⁻¹]

A : area required by the cell [cm²]

I_{Gap} : total current between plates [amp]

For one set of plates, the difference between these standard potentials is the voltage required to drive the reactions, V_{Req} . The voltage needed by the cell, but not used to run the reaction, V_{Ohm} , is calculated as follows ⁶:

$$V_{Ohm} = V_{Tot} - V_{Req} \quad (9)$$

The cell potential is represented by V_{Tot} . The V_{Tot} was estimated using a plot of cell potential versus current density.⁷

After optimizing this process, several innovations were considered. After evaluating the economic benefits and consumer convenience of several possibilities, the following innovations were found to have merit: a salt hopper that automatically adds salt and a device to clean the salt sensor.

The salt hopper system was created to control salt addition to the system electronically. A diagram of this system can be seen in Figure 3. The control unit uses a feedback loop to monitor the salt concentration in the pool. As the salt concentration falls below 3000 ppm, an automated dispensing wheel turns and adds the needed amount of salt. An alternative would be to inject a highly concentrated saline solution into the stream.

The salt chlorination system has an inherent problem with the buildup of salt on the sensor. Instead of taking the piping apart to clean the sensor every 3 days, a more convenient system was developed and can be seen in Figure 4. This shows a plunger connected to a plastic scrubbing pad. Every few days, someone comes in, pushes down the cleaning mechanism, and twists. This system should keep the salt sensor clean and operational.

The sensor and control package used in this system consists of a salt sensor, an oxidation reduction potential sensor (ORP), a pH sensor, and a programmable control panel. The amount of hypochlorous acid is controlled by a feedback loop consisting of the ORP sensor, the controller, and the cell. The pH is measured and displayed on the device. The salt sensor works with the salt hopper and controller to manage the salinity of the pool.

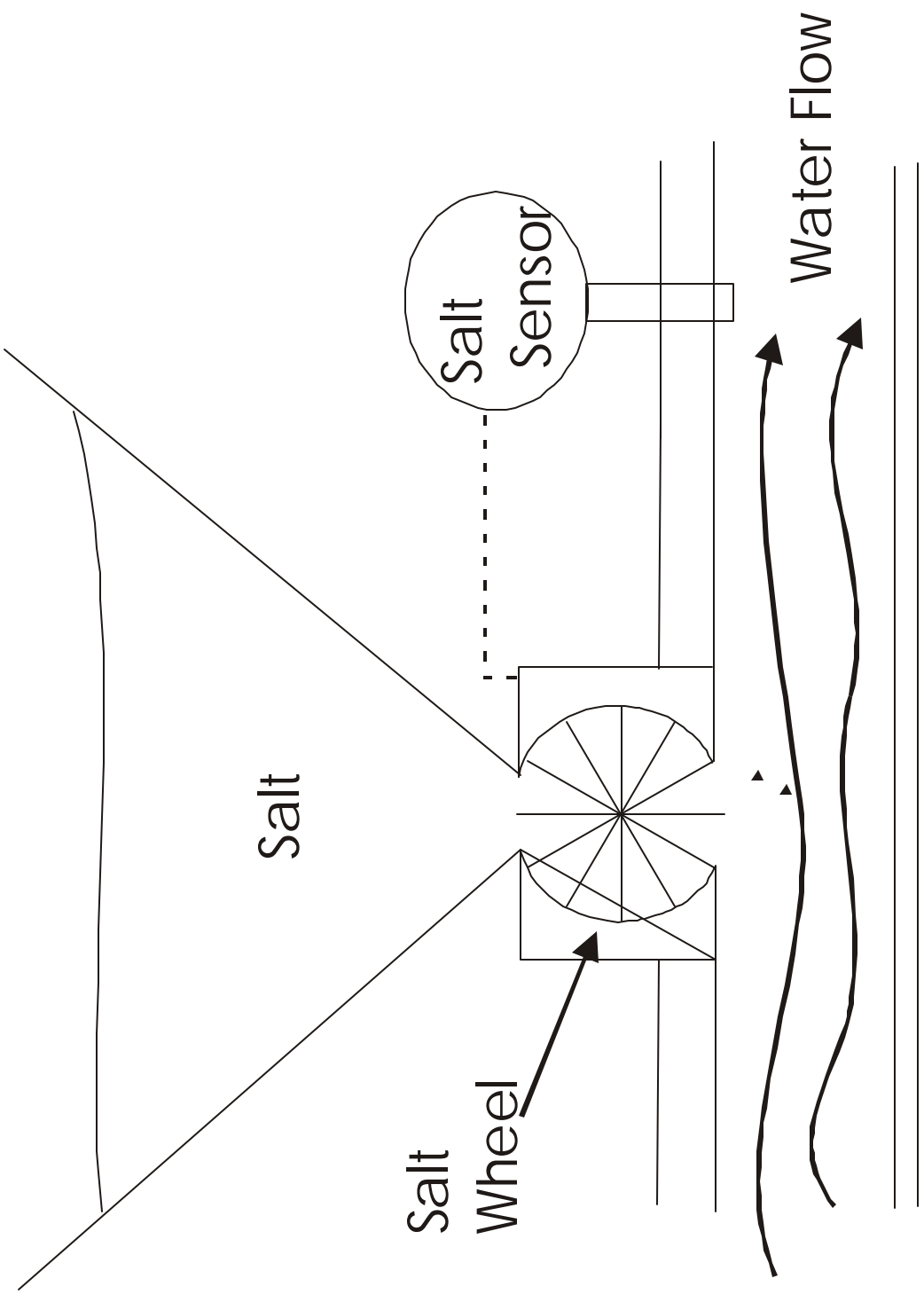


Figure 3: Salt Addition From Hopper

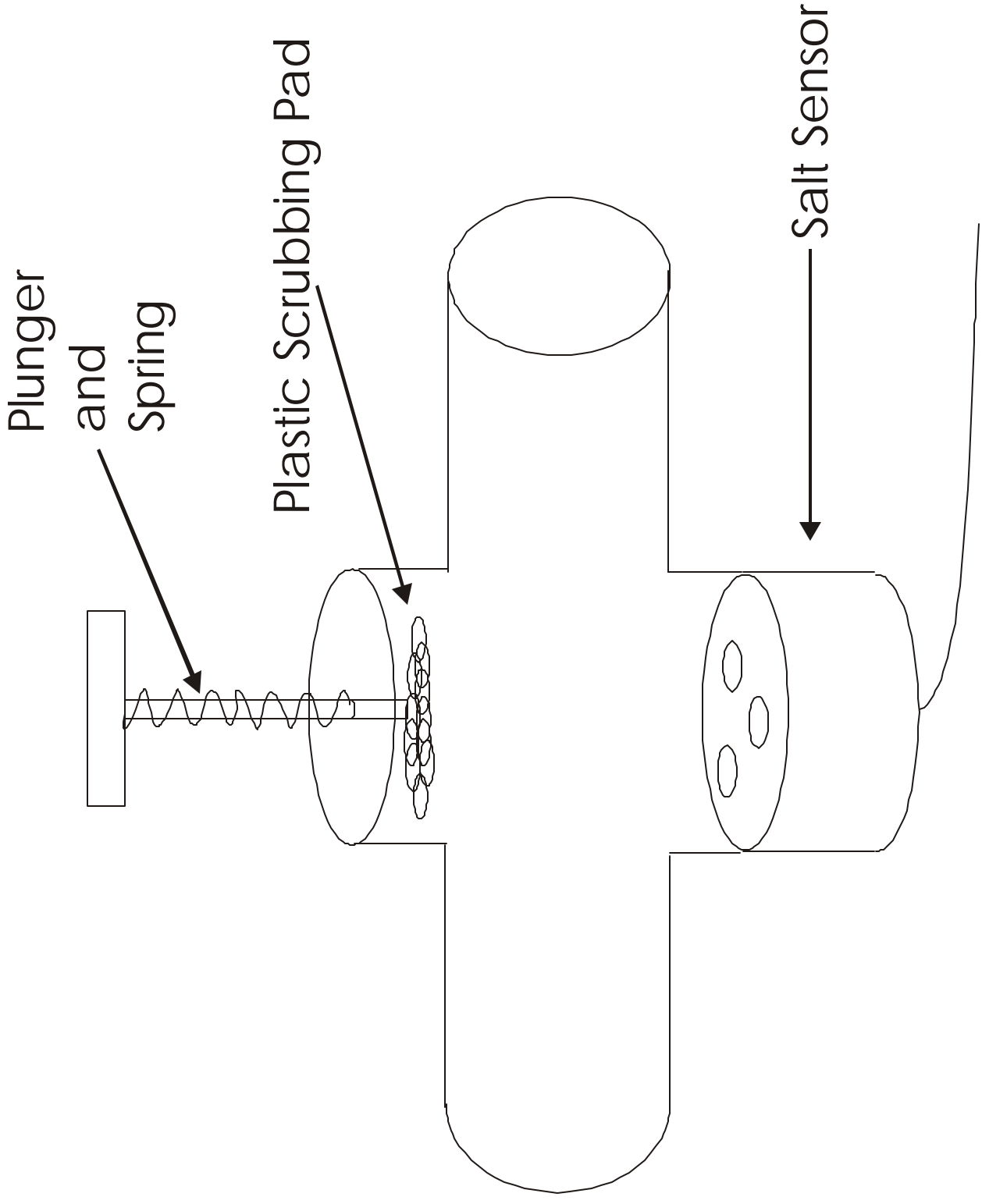


Figure 4: Salt Sensor Cleaner

cell. In addition, for the operating costs, only the pump electricity costs, the chlorine costs, and any heating costs were considered.

Another advantage of the salt chlorination system is the convenience of the system. Traditional chlorine systems require careful daily monitoring of the chlorine levels in the pool. This system is automated and requires only the 3-day sensor cleaning. Many chlorine alternatives are on the market and thriving on the value of convenience.

References

1. "Chlorine and Sodium Hydroxide." *Chemical of the Week*. World Wide Web. <http://scifun.chem.wisc.edu/chemweek/Cl2&NaOH/Cl2&NaOH.html>. 31 Jan. 2000.
2. Musser, Donna. Pool Supervisor. Richmond, VA. Personal Interview. 5 Jan. 2000.
3. *Scientific America*. Online. World Wide Web. <http://www.sciam.com/askexpert/environment22/environment22/>
4. *Clormatic II Plus Owner's Manual*. Huron Tech Corp, 7 Sept. 1999.
5. Latimer, Wendell M. *Oxidation Potentials*. New York, Prentice-Hall, Inc., 1952, p. 53.
6. Pickett, David J. *Electrochemical Reactor Design*. New York, Elsevier Scientific Pub. Co., 1977, Ch 1.
7. Bockris, John O'M. and Amulya K. N. Reddy. *Modern Electrochemistry 2*. New York, Plenum Press, 1970, p. 1370

Other References

Adams, Ralph N. *Electrochemistry at Solid Electrodes*. New York, Marcel Dekker, Inc., 1969.

Turton, Bailie, Whiting, and Shaeiwitz. *Analysis, Synthesis, and Design of Chemical Processes*. New Jersey, Prentice Hall PTR, 1998.

Bockris, John O'M. and Amulya K. N. Reddy. *Modern Electrochemistry 1*. New York, Plenum Press, 1970. Ch 1&4.

Bohackova, V. and J. Dvorak and J. Koryta. *Electrochemistry*. London, Methuen & Co. Ltd., 1970. Sec II.

Dorsey, N. Ernest. *Properties of Ordinary Water Substance*. New York: Reinhold Publishing Corporation, 1940. p. 381.

Dotson, Ronald. "Chemical Process Design and Operation." *Encyclopedia of Chemical Processing & Design*. Vol. 17, 1983, pp. 323-326.

Dotson, Ronald. "Electrochemical Engineering: Theory." *Encyclopedia of Chemical Processing & Design*. Vol. 17, 1983, pp. 291-306.

Hamer, Walter J. *The Structure of Electrolytic Solutions*. New York, John Wiley & Sons, Inc., 1959. Ch 1.

Kaufmann, Dale W. *Sodium Chloride*. New York, Reinhold Publishing Corporation, 1960, Ch 10.

Malkin, Irving. "Electrodes: Industrial." *Encyclopedia of Chemical Processing & Design*. Vol. 17, 1983, pp. 337-343.

Robinson, R.A. and R.H. Stokes. *Electrolyte Solutions*. London, Butterworth & Co. Ltd., 1959, Chs 5, 6, 7.