

Overview of Electrical Technologies for Controlling Dreissenids, with Emphasis on Pulse-Power Systems

BACKGROUND AND PURPOSE: Pulse-power technology, in one or more of its forms, has the potential to proactively control aquatic nuisance species, such as the zebra mussel (*Dreissena polymorpha*) or quagga mussel (*D. bugensis*) within water intakes and piping systems. At present, many facilities are protected using chemicals, either reactively or proactively. Effective chemicals, applied as prescribed, are relatively easy to use, are inexpensive, and can prevent major fouling and operational problems. They can, however, also cause environmental impacts in receiving waters and create human health risks. As an alternative to chemical treatment, pulse-power-driven systems (e.g., generation of pulse-power electric fields) may control mussels in a cost-effective and environmentally prudent manner.

The purpose of this technical note is to provide background information on the potential for control of the macro-fouling zebra and quagga mussels through the generation of energy fields. An overview of the potential for pulsed energy fields (pulse-power techniques) to control mussels is provided, with the emphasis on pulsed electric fields.

RECENT HISTORY OF ELECTRIC FIELDS IN ZEBRA MUSSEL CONTROL: Results of electric field studies conducted in the former USSR (Mackie et al. 1989) and in the United States (Tuttle 1990) have indicated that continuous high-voltage fields applied in fresh water can kill planktonic zebra mussels and could serve as a control. However, Tuttle (1990) stated that applying continuous high-voltage fields would be cost-prohibitive, if not totally impractical, when employed in the high-volume, high-velocity water flows typical in many service water systems.

Later research suggested relatively low-voltage electric fields (similar to cathodic protection systems) could control the settlement of zebra mussels on accessible structures with potentially acceptable costs (Fears and Mackie 1995; Lange et al. 1993; Pawson, Claudi, and Lewis 1995; Smythe et al. 1991; Smythe et al. 1994; Smythe et al. 1995). Short-term exposure to a low-voltage electric field could theoretically stun planktonic mussels, thus preventing settling activity for a time after exiting the field. The stun period is probably short (Smythe et al. 1995), possibly only seconds long. Planktonic mussel mortality rates resulting from exposure to a low-voltage field are probably insignificant. Thus, a low-energy field applied in flowing water may control mussel settlement in the near field, but will not protect pipes much beyond the electrodes. High-voltage, pulse-power-generated electric fields may cause longer stun periods in planktonic mussels and/or result in significant mortalities, while still remaining cost-effective. In a relatively low-voltage, pulse-power control study, a 78- to 88-percent reduction in mussel settlement was observed (Smythe et al. 1995), suggesting the level of control that a high-power system might achieve.

DESCRIPTION OF PULSE-POWER TECHNOLOGIES: The generalized term “energy field” can be defined as an area with a relatively high energy density; and when the type of energy creating a field is known (e.g., electricity, sound, magnetism), a more specific term is used (e.g., electric

field, acoustic field, magnetic field). Many researchers have suggested that high-energy fields, including pulsed fields, could be used to repel, stun, or kill mussels, clams, or other organisms.

Pulse-power technology, although not new, has only a limited history as a potential control for mussels, and possibly other organisms (Bushnell et al. 1993). Pulse-power systems typically derive their input energy from a continuous source of electricity (i.e., a common alternating- or direct-current (AC or DC) circuit). However, pulse-power systems, as the name implies, ultimately deliver short, discrete bursts of relatively high energy (e.g., pulsed light from a strobe) rather than in a continuous flow (e.g., the stream of electrical energy to, and light from, a flashlight bulb). The stream of relatively low energy AC or DC that is input between pulses builds an electrical charge in capacitor banks in pulsing systems. When advanced technology switches close, the capacitors rapidly discharge.

The relatively high-voltage discharge can be routed to electrodes, from which the energy is output to the environment as a pulsed electric field. Alternatively, the electrical pulse from the capacitors can be directed to the terminals of a transducer (e.g., a piezoelectric crystal, hydrophone, or photoelectric cell), which converts the electrical energy to another form before delivery to the environment.

The advantage of pulse-power systems is that they can deliver high-energy pulses (currently in the megawatt range), while remaining cost-effective compared with systems delivering a continuous or near-continuous energy output at the same or lower peak amplitude. The goal of research is to find the most cost-effective combination of pulse characteristics that will produce the desired effect in target organisms and to demonstrate that system components can perform over the long term.

As mentioned, pulse power can be applied to a transducer. In an acoustic transducer, the electrical energy is converted into high-energy sound/pressure waves (with the potential secondary production of short-lived, short-range cavitation bubbles). The frequency and intensity of a pressure wave from a single transducer or series of properly phased transducers could affect mussel health or disturb their habitats, thus controlling mussel settlement.

Similarly, the pulse from the capacitors could be routed to a pair of closely spaced, small-diameter electrodes (e.g., 2 to 3 mm) that are placed under water. This design creates a momentary electric field of high energy density, which causes formation of a plasma (ionized area) and an electrical spark (or arc) that jumps between the electrodes. In forming a spark, the plasma-arc type of pulse-power system converts most of the electrical energy discharged from the capacitors into other forms of energy (e.g., heat, ultraviolet and other frequencies of light, sound/pressure-waves, and possibly cavitation bubbles). The mortality rates for planktonic dreissenid mussels in preliminary field evaluation of a small plasma-arc device were greater than 90 percent in some tests conducted at Buffalo District's Black Rock Lock off the Niagara River (Smythe, Lange, and Tuttle 1997). Significant effects on adult mussel settlement and health were reported in trials of a low-pulse-rate commercial plasma-spark device that was deployed in PVC test pipes at a Great Lakes site (Mackie 1999). If spark systems prove successful in long, large-diameter pipes, the major mussel control vector, or energy component providing mussel control, will probably be the pressure wave (i.e., based directly on its amplitude, velocity, and/or frequency).

Unlike the plasma-arc systems described above, the objective of a pulse-power electric field system is to maintain a field between the electrode plates that will provide effective mussel control. Designs that maintain the energy density at a level to preclude arcing are used to accomplish this control objective. The spacing and area of the electrode plates are relatively larger than in the plasma-arc systems, which reduces the energy density. The pulse amplitude can be matched to the conductivity of the water and the plate configuration to prevent an arc. The velocity of water and diameter of the pipe to be protected dictate the area and possibly the spacing of electrodes. Thus, the electrical energy per pulse typically will vary directly with the size of the pipe. For practical purposes, an electric field is contained between the electrodes, although in theory, a low-intensity component of the field extends to infinity.

A generation of high-energy pulse-power devices and switch technologies that were used exclusively in military applications have recently been assessed for their efficacy as means of zebra mussel control. The new devices can provide high-energy megawatt-range pulses using a relatively short pulse duration (e.g., 2 to 5 microseconds). Tidal water studies using new pulse-power switch technology on marine/estuarine macrofoulers indicated that intense, pulsed electric fields can kill bacteria and planktonic organisms in pipes at a significantly reduced electrical energy cost relative to continuously generated fields (Schoenbach et al. 1995, 1996, 1997; Schoenbach, Alden, and Fox 1996, 1997).

Results of Mississippi River studies, which evaluated the effects of high-energy pulse-power electric field systems relative to dreissenid mussel settlement, indicated that even compromised systems produced control efficacies of 92 percent (Smythe et al. 1998) and 43 percent (Smythe, Lange, and Schoenbach 1999). Effects on planktonic mussels were demonstrated using a system outputting less than half the designed energy, which still produced dreissenid veliger and post-veliger mortalities (maximum 36- and 42-percent, respectively) (Smythe, Lange, and Schoenbach 1999).

COSTS: The average energy costs to produce pulse-power electric fields in fresh water are low, even when the power per pulse is in the megawatt range and the pulse rate is 10 to 100 Hz. A rough estimate of operating cost indicated that pulsed electric fields could protect a 10,000-gpm freshwater service water system at 99-percent efficiency for about \$20/day, assuming a power release at about this level and rate provides the protection needed (Smythe et al. 1998).

The cost to operate pulse-power devices and, to some extent, the effect on a species, depends mainly on the magnitude of three factors: (a) pulse rate, (b) pulse amplitude, and (c) pulse duration. A fourth factor, pulse shape, also may be important. Although a pulse is delivered as the sum of all factors, the factors can be set and varied individually. The cost and control efficiency of a pulse-power system will depend on the combination of settings. System cost optimization will be achieved by varying the settings to the lowest level that provides the desired control effect (i.e., threshold settings).

Thresholds will vary based on the desired effect (i.e., typically to stun or kill), and may either be species-specific or affect whole phyla. Environmental or physiological condition or organism structure may alter an effect (Food and Agriculture Organization of the United Nations (FAO) 1967), and the relative size of an organism may be a major factor in the effect of an electric field within or among species (at least for fish). Once a threshold is reached, the effect of the field increases directly

with the length of a fish (FAO 1967). Preliminary field results indicate that a pulsed electric field had an effect on larval dreissenid mussels, although some other organisms of a similar size appeared unaffected, suggesting there could be a differential effect among phyla.¹

POTENTIAL STRUCTURAL, ENVIRONMENTAL, OR HEALTH ISSUES RELATED TO THE USE OF ELECTRIC FIELD OR OTHER PULSE-POWER SYSTEMS: In general, the potential for negative effects from pulse-power systems used to control mussels are minor. There has been concern, however, that the intensity and/or frequency of sound or pressure waves developed with spark or transducer-type, pulse power systems might cause structural damage to pipes and concrete, or that the propagation of waves would affect fish behavior near an intake. The authors of this technical note are unaware of any research evaluating this concern; however, a full-scale system could be engineered to avoid such health and safety problems.

A low-voltage, pulse-power electric field control system deployed on intake trashracks may have a minor effect on fish resident in the immediate vicinity of the racks and electrodes, as the racks are often placed on the plant-receiving water interface. Alternatively, the electrodes can be deployed relatively deep inside a facility's intake or pipes of a service water system (i.e., away from the receiving water). For practical purposes, the electric field in the pipes would affect organisms only while they were between the electrodes; thus, the chance of an accidental human electrocution at the electrodes is minimal. Safety codes and standards would have to be followed for the installation of any commercial pulse-power electrical equipment, so the chance of an accident should be the same as for any other piece of high-voltage equipment in an industrial facility (i.e., quite low).

CONCLUSIONS AND RECOMMENDATIONS: Small-scale research studies reviewed in conjunction with the preparation of this technical note indicate that pulse-power technology can affect the settlement and planktonic life stages of dreissenids. Further controlled studies should be conducted on the same and larger scale using existing or refined pulse-power equipment. If these studies demonstrate a high control efficacy, then the technology could provide macrofouling control at industrial, drinking water, and power plants. In addition, the technology might be used to control nonindigenous species and aquatic nuisance species in ship ballast water.

POINTS OF CONTACT: This technical note was written by Messrs. A. Garry Smythe, Beak Consultants, Lancaster, NY, and E. A. (Tony) Dardeau, Jr., U.S. Army Engineer Research and Development Center (ERDC). For additional information, contact Mr. Dardeau, (601) 634-2278, e-mail: dardeae@wes.army.mil. Dr. Ed Theriot, ERDC, (601) 634-2678, is Manager of the Zebra Mussel Research Program.

This technical note should be cited as follows:

Smythe, A. G., and Dardeau, E. A., Jr. (1999). "Overview of electrical technologies for controlling dreissenids, with emphasis on pulse-power systems," *Zebra Mussel Technical Notes collection* (ZMR-3-22), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/elpubs/zebtnote.html

¹ A. Garry Smythe and Cameron L. Lange, Beak Consultants, Lancaster, NY.

REFERENCES

- Bushnell, A. H., Dunn, J. E., Clark, R. W., and Pearlman, J. S. (1993). "High pulsed voltage systems for extending the shelf life of pumpable food products," U.S. Patent 5,235,905, U.S. Patent Office, Washington, DC.
- Fears, C., and Mackie, G. L. (1995). "Efficacy for low level electric current (A-C) for controlling quagga mussels in the Welland Canal," *Proceedings, 5th International Zebra Mussel and Other Aquatic Nuisance Organisms Conference*, 113-6.
- Food and Agriculture Organization of the United Nations. (1967). "Fishing with electricity, its application to biology and management," R. Vibert, ed., White-Friars Press, London.
- Lange, C. L., Smythe, A. G., Doyle, J. F., and Sawyko, P. M. (1993). "Application of low-voltage electric fields to deter attachment of zebra mussels to structures (Phase II)," abstract and paper presented at *Third International Zebra Mussel Conference* (not in proceedings).
- Mackie, G. L. (1999). "Use of plasma pulse technology for controlling zebra mussel settlement," *Proceedings, 9th International Zebra Mussel and Aquatic Nuisance Species Conference*, in press.
- Mackie, G. L., Cibbons, W. L., Muncaster, B. W., and Gray, I. M. (1989). "The zebra mussel, *Dreissena polymorpha*: a synthesis of European experiences and a preview for North America," report prepared for Water Resources Branch, Great Lakes Section, ISBN 0-7729-5647-2 (available from the Queen's Printer for Ontario, Toronto).
- Pawson, P. R., Claudi, R., and Lewis, D. (1995). "Electrolyte protection for control of zebra mussel biofouling on steel and concrete structures: Pilot studies," abstract and paper presented at the *5th International Zebra Mussel and Other Aquatic Organisms Conference* (not in proceedings).
- Schoenbach, K. H., Abou-Ghazala, A. Y., Alden, R. W., and Fox, T. J. (1997). "Biofouling prevention with pulsed electric fields," *Proceedings, 7th International Zebra Mussel and Aquatic Nuisance Species Conference*, 163-7.
- Schoenbach, K. H., Alden, R. W., and Fox, T. J. (1996). "Biofouling with pulsed electric fields," *Conference Records, 22nd International Power Modulator Symposium, Boca Raton, FL, June 1996*, 75-8.
- Schoenbach, K. H., Alden, R. W., and Fox, T. J. (1997). "Effect of pulsed electric fields on aquatic nuisance species," *Zebra Mussels and Aquatic Nuisance Species*, F. M. D'Itri, ed., Ann Arbor Press, Chelsea, MI, 399-406.
- Schoenbach, K. H., Peterkin, F. E., Alden, R. W., and Beebe, S. (1996). "The effect of pulsed electric fields on biological cells: Experiments and applications," invited paper, *Special Issue on Pulsed Power and Technology; IEEE Transactions in the Plasma Science*, 284-292.
- Schoenbach, K. H., Peterkin, F. E., Beebe, S., Bryars, D., Alden, R. W., Adolphson, P., and Turner, T. (1995). "Effect of pulsed electric fields on micro-organisms: Experiments and applications," *Proceedings, 10th International Pulsed Power Conference, Albuquerque, NM, June 1995*, 25-33.
- Smythe, A. G., Doyle, J. F., Reed, T. J., and Sawyko, P. M. (1994). "Application of cost effective electric fields to deter attachment of zebra mussels to structures," *Proceedings, Fourth International Zebra Mussel Conference*, 335-50.
- Smythe, A. G., Lange, C. L., and Schoenbach, K. H. (1999). "Application of pulse-power electric fields as a control for settlement and planktonic-stage zebra mussels (*Dreissena spp.*): Phase II," *Proceedings, 9th International Zebra Mussel and Aquatic Nuisance Species Conference*, in press.
- Smythe, A. G., Lange, C. L., and Tuttle, L. R. (1997). "Evaluation of an in-line pulse-power plasma generator as a method to control zebra mussels," *Zebra Mussels and Aquatic Nuisance Species*, F. M. D'Itri, ed., Ann Arbor Press, Chelsea, MI, 439-65.
- Smythe, A. G., Lange, C. L., Doyle, J. F., and Sawyko, P. M. (1991). "Application of low-voltage electric fields to deter attachment of zebra mussels to structures," abstract and paper presented at *Second International Zebra Mussel Research Conference* (not in proceedings).
- Smythe, A. G., Lange, C. L., Doyle, J. F., Masc, J. E., and Sawyko, P. M. (1995) "Pulse-power generated electric fields as a means to control zebra mussels," *Proceedings, 5th International Zebra Mussel and Other Aquatic Nuisance Organisms Conference*, 431-6.

- Smythe, A. G., Lange, C. L., Schoenbach, K. H., and Abou-Ghazala, A. Y. (1998). "Pulse-power electric fields as a method to prevent settlement of and/or reduce mortality in zebra mussels (*Dreissena spp.*), *Proceedings, 8th International Zebra Mussel and Aquatic Nuisance Species Conference*, 243-51.
- Tuttle, L. R. (1990). "Electric barriers for veligers," *Dreissena polymorpha Information Review*," Vol. 1, No. 2 (December).