THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**Induction Mixer**	
APPLICATION:	**Disinfection of Wet-Weather Flows**	
TECHNOLOGY NAME:	**Water Champ® F Series Chemical Induction System**	
COMPANY:	**USFilter/Stranco Products**	
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Wet-Weather Flow (WWF) Technologies Program, a part of the Water Quality Protection Center, one of six Centers under ETV. The WWF Program recently evaluated the performance of a chemical induction system that can be used in the disinfection of wet weather flows such as combined sewer overflows and sanitary sewer overflows. This verification statement provides a summary of the test results for the Water Champ® F Series Chemical Induction System manufactured by USFilter/Stranco

Products. Alden Research Laboratory, Inc, performed the verification testing as the designated ETV Field Testing Organization, using the facilities of USGS's Conte Anadromous Fish Research Center, Turners Falls, Massachusetts.

TECHNOLOGY DESCRIPTION

Induction mixers are mechanical mixers that can inject and disperse both gaseous and liquid chemicals into potable water, process water or wastewater. Induction mixers can draw chemicals from the point of chemical storage to the point of injection, and disperse the chemical into the water. The dual functionality of the induction mixer essentially eliminates the need for a separate injection system and diffuser system as commonly found in typical mixing installations.

The major components of an induction mixer are:

- A submersible motor with a propeller shaft,
- A uniquely shaped propeller, and
- A vacuum body surrounding the propeller shaft.

The submersible motor spins the propeller shaft and uniquely shaped propeller in excess of 3000 rpm. The rotation of the propeller causes a reduction in pressure in the vacuum body surrounding the propeller shaft. This reduced pressure is used to draw chemical from the storage location into the induction port. The chemical is then propelled outward by the rotating propeller and mixed vigorously with the water.

Induction mixers have many applications, most of which include the transferring of a chemical (either gaseous or liquid) into a potable water, process water or wastewater. Induction mixers are most commonly used for chemical disinfection of potable water or secondary treated wastewater. Induction mixers are effective disinfection mixers because they provide a rapid and thorough dispersion of disinfectant that greatly improves the reaction between the chemical disinfectant and the water. This translates into chemical disinfectant and energy savings.

Recently, induction mixers have been used for the disinfection of wet-weather flows. However, because wet-weather flows are typically characterized by fluctuating flow rates, the performance of these mixers may vary as compared to their use for potable water or wastewater disinfection applications where flows are relatively constant. The performance of an induction mixer can be assessed by the following three parameters:

1. The size of the plume in which the chemical is transferred,
2. The uniformity of the chemical concentration within the plume, and
3. The rate at which the chemical reaches the extents of the plume.

These performance criteria are reported in this verification study in the following manner:

1. Isopleth diagrams showing the size of the plume into which the chemical can be transferred,
2. The uniformity of the chemical concentration within the plume as defined by the mix factor, and

3. The rate at which the chemical reaches the extents of the plume as identified graphically by the isopleth diagrams.

For this induction mixer verification study, different size induction mixers were operated and these parameters measured at a hydraulic laboratory where clean water was used as a surrogate to wet-weather flow and a tracer dye was used as a surrogate to the chemical disinfectant. Using this controlled laboratory approach provided greater accuracy in measuring the size and uniformity of the chemical plume created by the induction mixer. The objective of the study was to verify the achievement of effective mixing within the designated parameters of the testing program.

VERIFICATION TESTING DESCRIPTION

Test Facility

Testing was performed at the S.O. Conte Anadromous Fish Research Center (CAFRC), Turners Falls, Massachusetts. The CAFRC is a hydraulic laboratory, consisting of three indoor flumes (10 ft wide, 10 ft deep, and 104 ft in length) with a total capacity of 150 ft^3/s. For this verification study one of the three flumes was modified in size so that the induction mixers could be tested at specified channel dimensions and flow velocities. Water was directed to the test flume in the building via an inlet structure on the bank of the large canal on which the CAFRC is located.

Each induction mixer was tested in a rectangular flume, incorporating a channel section 7 ft wide with a water depth of 7 ft. To provide for a relatively uniform velocity distribution at the mixer, the length of the flume upstream of the mixer was 20 ft, and the test channel entrance was rounded to avoid flow separation. Upstream of the test channel entrance, the flow was guided by a straight flume 10 ft wide and 32 ft long, with an upstream flow distributor. Downstream of the mixer, the test flume was 28 ft long before expanding to the wider 10 ft flume width. Provisions were made to accommodate installation of the mixer at the designated location in the test flume, in accordance with instructions and mounting hardware from the manufacturer.

Methods and Procedures

USFilter/Stranco Products provided a 5 HP, 10 HP and 20 HP induction mixer for verification testing. Each induction mixers was installed in the test flume, and tested separately under nominal flow velocities of 0.5 ft/s, 1.25 ft/s, and 3.0 ft/s. For each test, the flow velocity was held steady at a water depth of 7 ft and the mixer was operated with a tracer dye as a surrogate for the chemical disinfectant. A sampling rig was positioned at locations 5 ft, 10 ft, and 15 ft downstream of the mixer to collect samples over the entire cross section of the flume. The size and nature of the "chemical" plume was characterized by measuring the dye concentration over the entire cross section of the flume. Figure VS-1 describes the test conditions under which samples were collected during the verification testing.

5 HP mixer operated at **0.5** ft/s and samples taken at **5, 10 and 15** ft downstream of mixer.	**5** HP mixer operated at **1.25** ft/s and samples taken at **5, 10 and 15** ft downstream of mixer.	**5** HP mixer operated at **3.0** ft/s and samples taken at **5, 10 and 15** ft downstream of mixer.
10 HP mixer operated at **0.5** ft/s and samples taken at **5, 10 and 15** ft downstream of mixer.	**10** HP mixer operated at **1.25** ft/s and samples taken at **5, 10 and 15** ft downstream of mixer.	**10** HP mixer operated at **3.0** ft/s and samples taken **at 5, 10 and 15** ft downstream of mixer.
20 HP mixer operated at **0.5** ft/s and samples taken at **5, 10 and 15** ft downstream of mixer.	**20** HP mixer operated at **1.25** ft/s and samples taken at **5, 10 and 15** ft downstream of mixer.	**20** HP mixer operated at **3.0** ft/s and samples taken at **5, 10 and 15** ft downstream of mixer.

Figure VS-1 – Operating Conditions for Induction Mixer Verification

Rhodamine WT tracer was used as the injection tracer. A stock injection solution of the tracer was prepared by serial dilution of 20% commercial solution with distilled water. The injected tracer rate and concentration were selected such that a mixed concentration at the sampling rig location of approximately 10 ppb to 20 ppb was achieved.

The sampling rig had 25 withdrawal ports located equally spaced across the 7 ft x 7 ft cross-section. Only one downstream position was sampled at a time, and provisions were made for locating and moving the sampling rig so that only one sampling rig would be in the flume channel at one time. Samples from the 25 suction tubes were drawn at approximately equal flow rates for about 10 to 12 minutes. This continuous sampling time was adequate to produce a time average or typical concentration reading. Each of the 25 samples was then analyzed for concentration of tracer using a laboratory-calibrated fluorometer.

The tracer dye concentration at each of the 25 sampling ports throughout the cross section of the flume allowed for the development of isopleth diagrams that were used to demonstrate the extent and uniformity of the chemical plume. Figure VS-2 shows an example of a concentration isopleth diagram.

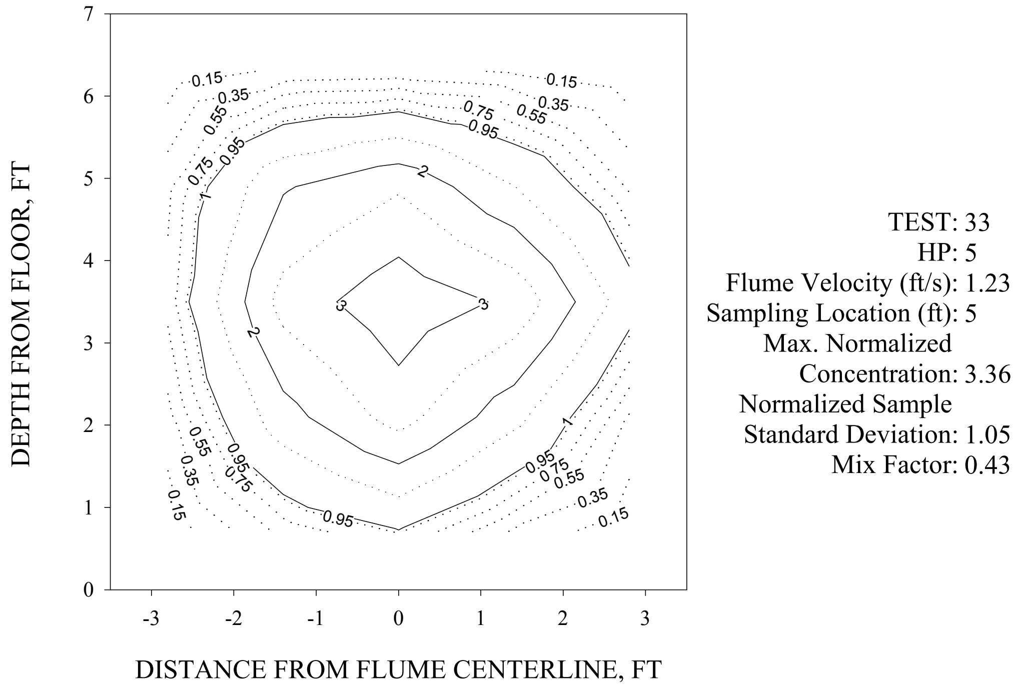

Figure VS-2 – Example of Normalized Concentration Distribution Isopleth Diagram

The isopleth diagrams were prepared for each test condition using normalized concentration values. The measured tracer concentration at each cross-section was normalized by dividing the measured concentration by the uniform concentration (C_u) (where C_u is the tracer concentration), if the tracer was equally dispersed throughout the cross-section of the flume. Thus, a normalized concentration of 1.0 means that the theoretical targeted concentration has been achieved. The performance of the induction mixers was interpreted from these isopleth diagrams.

VERIFICATION OF PERFORMANCE

The mixers produced a roughly circular plume with higher concentrations in the center. Smaller plume areas and higher peak concentrations were observed under the higher flow velocity conditions. In other words, as the energy imparted by the mixer became smaller in relation to the kinetic energy of the flow in the flume (related to flow velocity), the level of mixing observed also lessened. At the lowest flume velocity (0.5 ft/s), the tracer concentrations were more evenly distributed across the flume cross-section and approached a uniform mix, as the plume was able to spread rapidly.

The normalized concentration values and the corresponding isopleth diagrams were used to generate the numerical performance indicators for each of the induction mixers. These indicators are described below and the results are presented in Table VS-1.

A mix factor, F, was calculated for each test using the isopleth diagram. The mix factor indicates the percentage of the total cross-sectional flume channel area that experienced a theoretical complete mix (i.e. equal dye concentration throughout the entire cross-sectional area). By definition, a mix factor of 1 (or 100%) indicates that complete theoretical mixing has occurred. The mix factor provides insight into the area affected by a concentration of chemical greater than the theoretical uniform concentration. In general, the channel area affected by the mixer increased as horsepower increased and decreased as flow velocity increased. For example, as presented in Table VS-1, at 10 ft downstream of the mixer and a flume velocity of 0.5 ft/s the 5 HP mixer affected 68% of the channel area whereas the 20 HP mixer affected 84%. Additionally, when considering the 5 HP mixer at the 10-ft downstream sampling location, the area affected at a flume velocity of 0.5 ft/s was 68% as compared to only 35% at 3.0 ft/s.

The maximum (peak) normalized concentration is the highest concentration of tracer dye observed within the plume, which generally occurred in the center of the channel, closest to the point of injection. The maximum normalized concentration is an indicator of the uniformity of the plume concentrations produced by the mixer. This factor is important because it is possible to have two sets of plume data with similar mix factors but with substantially different maximum concentrations. For example, the 5 HP mixer at the 3.0 ft/s flume velocity at the 10-ft and 15-ft downstream sampling location had approximately equal mix factors of 0.35. With no further information, this could lead to an erroneous conclusion that the plume does not spread as it moves downstream away from the mixer. The maximum normalized concentrations from the two sets of data, however, reveal that the plume is in fact continuing to disperse as it moves downstream, with the maximum value decreasing from 7.14 times to 5.11 times the theoretical average as it moves from 10 ft downstream to 15 ft downstream.

The standard deviation of the normalized dye concentrations at each sampling location characterizes the uniformity of plume concentrations produced by the mixer. The standard deviation is the mathematical expression of the variation of chemical concentration around the average concentration. More uniform mixing is represented by smaller standard deviations. A standard deviation of 0.0 would represent complete uniformity of mixing. Similar to the mix factor trend, uniformity of the chemical concentration within the plume increased as mixer HP increased and decreased as the flow velocity increased.

Table VS-1 below provides a summary of the mix factor, maximum normalized concentration, and standard deviation for the three induction mixers at each of the three flume velocity conditions.

Table VS-1 Summary of Numerical Performance Indicators

	5 ft downstream of Mixer			10 ft downstream of Mixer			15 ft downstream of Mixer		
	5 HP	10 HP	20 HP	5 HP	10 HP	20 HP	5 HP	10 HP	20 HP
Flume Velocity 0.5 ft/s									
Mix Factor, F	0.65	0.77	0.74	0.68	0.80	0.84	0.68	0.76	0.92
Maximum Normalized Concentration	1.64	1.21	1.14	1.32	1.10	1.04	1.16	1.07	1.00
Standard Deviation	0.33	0.09	0.07	0.17	0.05	0.03	0.10	0.04	0.05
Flume Velocity 1.25 ft/s									
Mix Factor, F	0.43	0.62	0.79	0.49	0.69	0.86	0.46	0.69	0.92
Maximum Normalized Concentration	3.33	1.78	1.39	2.55	1.42	1.19	2.07	1.24	1.10
Standard Deviation	1.04	0.42	0.17	0.74	0.24	0.09	0.54	0.16	0.05
Flume Velocity 3.0 ft/s									
Mix Factor, F	0.28	0.37	0.44	0.35	0.38	0.46	0.36	0.39	0.46
Maximum Normalized Concentration	10.75	5.88	3.30	7.14	4.19	2.50	5.11	3.40	2.09
Standard Deviation	2.31	1.64	1.00	1.80	1.26	0.70	1.48	1.04	0.54

Mean velocity gradient (G) is a measure of mixing intensity and has become an industry standard for representing the fluid dynamics of mixing. The G number gives an indication of turbulence as it relates to head loss, which in turn relates to mixing, and is a therefore a parameter of disinfection efficiency. The mean velocity gradient for a typical well-designed diffuser grid system is on the order of 200-500/sec. Research indicates that a G number between 700 and 1,000/sec may be appropriate for disinfection (White, 1992). For the purposes of the verification testing, the mean velocity gradient is used to gauge whether a particular sized induction mixer at a particular velocity is capable of providing mixing adequate for disinfection.

In order to calculate the mean velocity gradient, a minimum affected volume of process water must be calculated. The method used to define the affected volume in the open channel during verification testing was to define the downstream boundary of the channel length beyond which the mix factor ceased to improve by more than five percent. This criterion was made on the assumption that the energy imparted by the mixer had a less significant role in mixing than the energy imparted by the kinetic energy of the flowing process water.

By determining the smallest size of mixer that results in sufficient mixing, an appropriate ratio of horsepower to flow (MGD) can be established. The following criteria were used to assess if sufficient mixing was provided for disinfection of wet-weather flow process water for the purposes of verification testing:

- The standard deviation for the mixing zone was less than 0.5, and consequently the maximum normalized concentration of the tracer was not significantly more than twice the normalized mixer concentration, which suggested the energy imparted by the mixer dispersed disinfectant effectively across the cross-sectional area;

- The mix factor ceased to improve by more than five percent, which suggested the energy imparted by the mixer dispersed disinfectant more aggressively than the kinetic energy of the flow of process water, which defines an affected volume of disinfected water from which to calculate the mean velocity gradient; and,

- The mean velocity gradient (G) is close to, if not greater than, 700/sec within the minimum established volume of water, which can assist in determining an appropriately sized motor for a particular application.

The following is a summary of the verification tests in which a sufficient mixing criteria was achieved, and the correlating power to process water volume ratio:

- The 5 HP mixer provided sufficient mixing at a flume velocity of 0.5 ft/s within the 7 ft x 7 ft open channel five feet downstream of the mixer. The 5 HP unit failed to provide sufficient mixing at flume velocities greater than 0.5 ft/s. This equates to a horsepower to MGD ratio of 0.31.

- The 10 HP mixer provided sufficient mixing at flume velocities of 0.5 ft/s and 1.25 ft/s within the 7 ft x 7 ft open channel five feet downstream of the mixer. This equates to a minimum horsepower to MGD ratio of 0.26.

- The 10 HP mixer provided sufficient mixing at a flume velocity of 3.0 ft/s within a plume-delineated mixing zone 5.5 ft in diameter, 15 feet downstream of the mixer, but did not achieve uniform mixing within the entire 7 ft x 7 ft open channel. This equates to a minimum horsepower to MGD ratio of 0.22.

- The 20 HP mixer provided sufficient mixing at flume velocities of 0.5 ft/s within the 7 ft x 7 ft open channel 10 feet downstream from the mixer, and the 1.2 ft/s flume within the 7 ft x 7 ft open channel five feet downstream from the mixer. The 20 HP marginally failed to provide adequate mixing at 3.0 ft/s within five feet downstream of the mixer. This equates to a minimum horsepower to MGD ratio of 0.28.

In summary, the data indicated a mixer sizing criteria of between 0.22 and 0.31 HP/MGD resulted in mixing sufficient for disinfection for mixing applications in the 7 ft x 7 ft open channel with flow velocities between 0.5 and 3.0 ft/s. The data also indicated a break point in the data at a flow velocity of 1.25 ft/s, where at higher velocities the influence of higher horsepower on the size of the mixing zone volume has diminishing returns. It is clear that flow velocity significantly influences the ability of the mixers to effectively disperse tracer. Therefore, expected range of flow velocities must be considered when selecting an appropriately sized mixer during the design of open channel mixing facilities.

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Availability of Supporting Documents
Copies of the *ETV Protocol for Equipment Verification Testing Induction Mixers Used for High Rate Disnfection of Wet Weather Flows* dated July, 2001, the Verification Statement, and the Verification Report (NSF Report #02/01/EPAWW399) are available from the following sources:

(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

1. Water Quality Protection Center ETV Program Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. NSF web site: http://www.nsf.org/etv (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)