Observational Study of the I2 Air Purge Flush Method for Biofouling Control on UV Lamp Sleeves

Michael Radicone

I2 Air Fluid Innovation, Inc., Oceanside, NY, USA, DSMI, Barrie, Ontario, Canada

ABSTRACT

This paper reports on an observational study to determine the efficacy of an in situ Air Purge Flush protocol, using a proprietary cleaner, in conjunction with iodinated bubble stream for eliminating existing foulants from UV lamp sleeves, while reducing future fouling rate without the need for UV purifier disassembly. This protocol has been used for many years to eliminate bio-fouling within dental equipment waterlines and for the elimination and prevention of bio-fouling in geothermal heat exchangers.

The study was initiated by The Atlantic Ultraviolet Co., Hauppauge, NY, The Queens Botanical Gardens (QBG), Queens, NY and the New York City Department of Design and Construction (NYC DDC) which supervised and observed protocol implementation. This study was performed in response to rapid fouling caused by iron reducing bacteria (IRB) within the UV purifiers.

The Queens Botanical Garden develops, teaches and utilizes eco-friendly protocols at its facility. Therefore, UV purification was a logical choice for coolant water disinfection. Not originally part of the 150 gpm geothermal system, the purifiers were put online to reduce well fouling. Diffusion well fouling increases well back pressure and reduces water flow. The purifiers were installed to inactivate IRB before introduction into the heat pumps and injection wells. At installation, UV sleeve intensity was 100%, but the system began fouling shortly afterwards, despite mechanical wiping. UV light intensity meter display readings degraded to single digits within weeks. Visual inspection of the sleeves indicated IRB fouling. Mechanical wiping became difficult due to buildup on the sleeve and mechanism.

The QBG does not have an onsite HVAC mechanical staff that could maintain the UV purifiers in the event of fouling and was motivated to find a sleeve cleaning method that would remove existing fouling. The requirements were:

- *Effectively remove existing sleeve foulant*
- *No UV purifier disassembly, sleeve removal or daily wiper use*
- *No mechanical impact to UV purifier or geothermal system*
- *A reduction in the future fouling rate*
- *No environmental impact or use of caustic chemicals*
- *Minimal down time and labor needs*

After a presentation to members of the NYC DDC and QBG, a two month study by I_2 Air Fluid Innovation, Inc (I_2 AFI) was accepted. The purpose of the study was to determine whether I_2 AFI's method for heat exchanger/geothermal well maintenance protocol would be applicable for UV purifiers.

Keywords: Ultraviolet Disinfection, Iron, Bio-Fouling, UV Sleeves, Geothermal, Heat Exchanger, Botanical Gardens, Iron Reducing Bacteria

INTRODUCTION AND BACKGROUND

A geothermal heat pump is an eco-friendly cooling/heating system that pumps heat to or from the ground. It uses the earth as a source of heating or cooling. It is designed to take advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems. Geothermal systems are cost effective, generally returning the cost of the setup in reduced energy needs over 3-10 years. Open loop systems rely on a supply well as a water source, and diffusion or injection wells as a return site. As a means to utilize the temperature variant for facility use, a heat exchanger is used. Supply well water chemistry and bacteriological makeup are a concern, since fouling on the plates within the exchanger reduces heat transfer. This increases the need for auxiliary heating or cooling resulting in higher energy needs. Additionally, as bio-fouling occurs within the exchanger, pieces break off and cause downstream occlusion of screens within the diffusion or injection well. This has the effect of adding increased back pressure which slows water flow through the exchanger and thus reduces heat transfer. This condition adds additional load on supply well pumps increasing energy demand and reducing pump life.

Although ultraviolet disinfection is a proven, eco-friendly method for reducing microbial content within the coolant water, fouling of the quartz sleeves may limit its effectiveness. Bacteriological films (biofilms), in conjunction with mineral deposits, present a difficult maintenance challenge. Biofilms are a polysaccharide matrix that stick to

surfaces and protect microbial colonies from potentially disruptive or destructive water conditions (i.e., biocides, turbulence, etc.). Biofilms draw in minerals that harden their composition making them difficult to remove with mechanical or automated wiping. Their growth extension into the water flow reduces the surface water velocity and allows for additional bacterial attachment. Iron reducing bacteria (IRB) derive their energy and multiply by oxidizing dissolved ferrous iron into insoluble ferric oxide. IRB form a biofilm that appears as a brown gelatinous slime that coats quartz sleeves and breaks off for downstream occlusion.

There are three identified mechanical methods that may initiate and promote fouling;

- Heat induced precipitation of metals on the sleeve surface
- Foulant settling on the upper sleeve surfaces due to fluid motion and gravitational influence within the UV purifier chamber
- Low velocity zones near sleeve surfaces and around fixtures that may impede water flow allowing for attachment

The I2 method is a patented protocol, patent number 7,329,385, for the reduction of microbes through the intermittent infusion of iodinated air bubbles into a fluid. Used in the health industry and geothermal heat exchangers, the I_2 method eliminates the needs for high levels of biocides through a novel air/iodine vapor/microbe interaction. Additionally, the bubble stream acts as an air sparging device which helps to prevent bacterial and mineral attachment. Used initially to remove existing foulants and then monthly, the I_2 Air Purge Flush (APF) protocol removes bio-film and minerals from internal surfaces through pressurization, purging, agitation and flush, using an EPA approved proprietary oxygen based cleaner with detergents prior to APF bubble stream introduction. It cleans interior components including sleeves, wipers and chamber and does not expose staff and environment to caustic chemicals.

OBJECTIVE

1. To determine the effectiveness of a protocol that uses an in situ method for the disruption and removal of formed bio-film/mineral coatings on the UV lamp sleeves.

2. To determine the reduction in fouling rate through the intermittent introduction of iodinated air bubbles into the UV purifier chamber by the:

- Elimination of low velocity zones
- Removal of recently attached foulants
- Prevention of Brownian motion and gravitational effects
- Prevention of attachment of biological and inorganic foulants
- Mitigation of higher temperature zones near the sleeve surface
- Inactivation of bacteria within the purifier

MATERIALS AND METHODS

The UV purifier specifications are as follows; Atlantic Ultraviolet SANITRON® Model S10,000C Maximum Flow Rate: 166 gallons per minute (gpm) Material of Construction: Stainless Steel Type 316 Power Consumption: 560 watts

The Disinfection Chamber: consists of four (4) SANITRON® Model S2400C closed chambers coupled together (two sets of two) by means of 2" PVC unions, elbows and close nipples. Each chamber measures 5.50 inches in diameter. In the center of each chamber is a single port which is used to attach an ultraviolet sensor probe assembly for use with a Guardian Ultraviolet Monitor.

Ultraviolet Lamps: each chamber houses one low pressure, rapid start, mercury arc germicidal lamp that produces approximately 90% ultraviolet energy at 253.7 nanometers. The lamp has an arc length of 38 inches which produces 42 ultraviolet watts at 110 volts.

Dual Action Wiper Mechanism: a mechanical device built into the removable head of the chamber, facilitates periodic cleaning of the quartz sleeve with a series of circular Teflon® wipers are drawn across the surface of the quartz sleeve to remove any fouling or deposits.

Guardian Ultraviolet Monitors: port site monitored intensity meter.

The study was performed under normal operating conditions and during normal working hours. The APF protocol requires a water source for mixing the cleaner, compressed air source and a drain. The iodinated bubble infusion uses a compressed air source and I2 Air Infuser. All infusion and drainage is done through the APF assembly attached to the purifier drain. Water was introduced to the purifiers through two gate valves monitored by flow meters which indicated 124 gpm flow at 62 psi.

The study included the following:

- Initial testing of influent water to determine mineral and bacteriological composition
- Selected UV purifiers were subjected to the APF protocol with readings compared before and after to determine effectiveness in removing existing films
- After cleaning, the purifier was allowed to foul to determine the rate of foul layer formation without I_2 infusion
- After cleaning, fouling rate comparison was done in purifiers that have either I_2 infusion or not

The APF protocol consists of UV purifier isolation, pressurization, purging, cleaner introduction, cleaner agitation and flush. The time allotted is 15 min preparation, 40 min agitation, and 5 min flush.

The I_2 bubble infusion is produced by injecting iodinated air from the I_2 Air Infuser Cartridge through diffuser tips into the UV purifier chamber. During the study period, the air infusion cycle took place for 15 minutes each hour, using a timer control to develop data for performance comparison.

Three of the four purifiers were used for the study; upper front UF, upper back UB and lower front LF. Lower back LB was not used due to a malfunctioning meter.

All services were performed by I_2 Air Fluid Innovation and overseen by members of the NYC Department of Design and Construction who observed and confirmed all readings.

The study began on 11 May 2009 and water composition from purifier LF, as determined by IME test ampoules, Industrial Municipal Equipment, Inc., Eldersburg Maryland were as follows;

Iron: Product Code #: IM42667	5 ppm
Hardness IME Product Code #: IM42847	Moderate
Iron bacteria, Product Code #: IM97017	Positive 24 hours/high

The initial weight of the I_2 cartridge was 2118.2 g.

Dried air was passed through the I_2 cartridge and iodinated air was introduced to the LF purifier to observe the effect of air bubbling on the system. Air flow was .25 cfm @ 62 psi. Water pressure into the purifier was 60 psi.

Prior to the application of the APF protocol, the Guardian monitor readings (0 - 100 scale) were:

UB (4), UF (1), LF (3)

Note: The wipers were frozen.

Initially, the APF protocol was performed on only two of the three UV purifiers, UB and UF. The LF UV purifier was left untouched but would be addressed during future treatments. A dilute, half strength cleaning solution was used and allowed to dwell for half the time without agitation to test for component compatibility. No damage was visible.

Following the protocol, the study UV purifier monitors read:

UB (39), UF (37), LF (3)

Wipers were freed considerably allowing for full stroke motion.

No I_2 infusion was performed to allow fouling to take place.

27 May 2009 - a complete APF protocol was performed on all three purifiers using a full strength cleaning solution, agitation and standardized dwell time of 60 minutes.

Monitor readings afterwards read:

UB (98), UF (100), **LF (98)**

No I_2 infusion was performed to allow fouling to take place.

3 June 2009 - the APF protocol was performed on the LF UV purifier only.

Monitor readings afterwards were:

UB (46), UF (38), **LF (97)**

No I_2 infusion was performed to allow fouling to take place.

10 and 17 June 2009 - APF protocol repeated with Monitor resultant reading:

6/10/09	UB (34), UF (37), **LF (98)**
6/17/09	UB (32), UF (27), **LF (98)**

No I_2 infusion was performed to allow fouling to take place.

22 June 2009 - a reduced cleaning protocol was performed on purifier LF and iodinated infused air was introduced to the LF UV purifier only at a rate of .25 cfm and 62 psi.

Immediately after start of air infusion the monitors read:

UB (30), UF (22), **LF (93)**

Air was constantly infused into the LF UV purifier until the next visit.

3 July 2009 - no cleaning was performed and infused air was continued to the LF purifier only. Monitor read:

UB (11), UF (18), **LF (87)**

10 July 2009 - prior to cleaning, the monitors read:

UB (11), UF (14), **LF (79)**

Subsequently, UV purifiers UB, UF and LF UV purifiers were cleaned using the APF protocol. All monitors read 100 at the end of the procedure. The UV Purifiers UF and LF received infused air intermittently using a timer and solenoid, air was introduced continually for 24 hours and then stopped for 24 hours.

17 July 2009 - the final day of active study, no cleaning protocol was performed and all air infusion stopped.

Purifiers with iodinated air infusion read: **UF (96) and LF (94)**

Purifier UB without iodinated air read (57).

The weight of the I_2 cartridge was 2114.1 g, indicating a loss of 4.1 g of iodine after 4 weeks. Water composition:

Water from lower front (LF) UV

Iron	3 ppm
Hardness	Moderate
Iron bacteria, slime producing	IRB negative 72+ hours

3 August 2009 - monitors read (14), UF (42), LF (39) indicating rapid fouling without air infusion seventeen days after end of active studies:

Observations

Prior to the study, all meters indicated advanced fouling with single digit monitor readings. Visual observation of the sleeve and monitor lens confirmed fouling. The foulant appeared to be a hardened, reddish/brown film that could not be removed by mechanical means. Water composition testing indicated high levels of iron and the presence of slime forming IRB. The wiper mechanism was frozen on all tested purifiers.

The monitor lens had a reddish/brown stain on the leading edge to water flow. When the lens was cleaned with oxalic acid and returned into the purifier, the meter readings rose slightly. Lens cleaning was always performed prior all monitor readings.

After cleaning the UV purifiers with the APF protocol, the monitor readings averaged 96. This was observed on multiple occasions and on various system UV purifier chambers. The APF protocol was easy to implement and required no disassembly of the purifier or sleeve removal. The average procedure time was 67 min which included 40 min dwell time. The APF cleaner removed the existing biological and mineral films through agitation and chemical cleaning. The sleeves appeared undamaged and transparent. The wiper mechanism became unfrozen and moved freely.

Without I_2 infusion, the readings would decline by an average 40 to 60% within one week. When I_2 containing air was injected into the purifier after cleaning, the sleeve fouling declined approximately 6% to 10% a week. An active profusion bubble

pattern was observed in flowing water from both distal and mesial ends of the quartz sleeve. The bubbles rose from the air inlet situated at the drain port, moved in a linear direction along and up the quartz sleeve to exit into the outlet port at the distal end of the UV purifier.

CONCLUSIONS

The APF protocol cleaned the interior components and appears to be a simple to implement. The time required for cleaning allowed for both sets of UV purifiers to be addressed in one session. The cleaner appears to be active at varying dilutions which would allow its use on larger or smaller systems. Reducing or eliminating the need for mechanical removal of the sleeve should preserve sleeve and gasket integrity and replacements due to cleaning breakage would be reduced or eliminated. Both wiper use and failure would be reduced through foulant removal.

The I_2 infusion reduced fouling rates through a change in water flow pattern within the chamber. This appeared to eliminate low velocity zones and prevent sedimentation. The active bubbles appeared to act as a sparger, lifting existing biofilms and preventing attachment by planktonic bacteria and insoluble minerals. The infusion maintained meter readings long enough to allow for a monthly one hour APF protocol application. Water tested for hardness from a purifier using an IME ampoule during active iodinated air bubbling showed a reduction in hardness indicating the possibility there may be some conversion of insoluble calcium carbonate to soluble calcium iodide. Future studies should be performed to indicate the degree of conversion if any.

The protocol used approximately four grams of iodine in one month's time. It appeared to have no physical effect on the UV purifiers, sleeves or interior components. Additionally, the bubbling had no effect on the system piping, gaskets or heat pumps. The bubbling appears to reduce the required APF protocol time by presenting reduced sleeve foulant surface content.

Table I: Test results from action and measured light intensity (0-100 scale) reading

	Monitor Readings			
Date	UB	UF	LF	Comments
5/17	4	1	3	Monitor readings at start of study
5/17	39	37	3	Monitor readings after 50% APF UB/UF cleaning
5/27	98	100	98	Monitor readings after 100% APF
6/3	34	37	98	Monitor readings after APF protocol performed on LF only
6/17	32	27	98	Monitor readings after APF protocol performed on LF only Infused air started to LF afterwards
6/22	30	22	93	Continued infused air to LF. Reduced APF protocol performed
7/3	11	18	87	Continued infused air to LF. No APF protocol performed
7/10	11	14	79	Continued infused air to LF. No APF protocol performed
7/10	100	100	100	APF performed on all purifiers Infused air to UF and LF
7/17	57	96	94	No APF protocol. Infused air stopped Monitor readings at end of study
8/3	14	42	39	Indication of purifiers fouling

Intermittent air infusion appears to have a similar effect as constant addition in delaying fouling.

The total protocol time per month was approximately 60 minutes with actual labor time 20 minutes. The air infusion required no staff involvement. Although performed by I_2 Air Fluid Innovation, the protocol could have been performed by the botanical garden staff. It was estimated that cartridge and cleaner costs would be approximately $540.00 per month for this system. Larger multi lamp systems would not require much more in labor time or material costs. This appears to be less expensive than the costs involved with UV purifier disassembly, sleeve removal and manual cleaning considering the time expenditure. Additionally, it would reduce the possibility and associated costs of sleeve damage and replacement.

The I_2 Air Purge Flush protocol appears to have met all QBG requirements.

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Contact

For additional information contact info@i2airfluidinnovation.com or larrysmiller@rogers.com (Canada)