HVS-Electrochemical activation (ECA)

Chemical-Free Water Treatment Module to control scale, algae, bio-fouling and corrosion in cooling tower water distribution system
**Executive Summary:**

Cooling tower is a heat removal devices used to eliminate waste heat of air released to atmosphere. This process allows airborne contaminants, organic matters and particles to become deposited into the cooling water. This, combined with the contaminants in the feed water, creates an environment for microorganism growth, solid deposits and scaling. Improperly treated cooling tower water could be an amplifier of biological hazardous agent. The warm and moist environment of a cooling tower favors the growth of Legionella bacteria which causes the outbreak of the deadly Legionnaires’ disease. Thus, cooling tower water quality must be controlled and monitored in a regular basis to prevent spreading of diseases to users.

HVS Engineering Pte Ltd has successfully completed the testbed in Singapore and has successfully optimized the state-of-art novel HVS-ECA System which can produce environmental-friendly disinfectants in the form of active oxidants to replace the traditional standard biocide chemicals to kill water-borne bacteria and mitigate calcium and magnesium scale without the use of harsh chemicals.
Commercialization Opportunities and Target Market

Potential application of the successful completion of HVS-ECA System test bed for chemical-free & sustainable cooling tower water treatment are as follows:

- HVAC Water Treatment System
- Oil Rigs & Platforms process water
- Oil Refineries Process water
- Mining Industries Process water
- Offshore Process water treatment
- Power Plant cooling water treatment
- Petrochemical cooling water treatment
- Boiler Feed Water Treatment System
- Industries Using Fire Water Systems
- Cooler Water Treatment System
Potential Areas of application for HVS-ECA System

As a point of reference, the following systems could all be potential sources of legionella bacteria wherein the HVS-ECA System can be applicable:

- Cooling Tower
- Evaporative Condenser
- Humidifiers
- Hot and Cold Water Systems
- Hot Tubs and Heated Swimming Pools
- Natural Thermal Springs and their distribution systems
- Respiratory and other medical therapy equipment
- Drinking Fountains/Decorative Fountains/Sprinklers
- Water Cooled Machine Tools
- Car Washes
- Any untreated body of water that may exceed 70°F that could be splashed, sprayed or aerosolized.
- Any system that contains water that may exceed 70°F and could emit a spray or aerosol during their operation or maintenance.
Commercial Interest Generated for HVS-ECA System

Pre-commercialization marketing of HVS-ECA System has generated commercial interest for early adoption. HVS will closely follow-up with these leads and start doing the commercial agreements upon finalizing the full HVS-ECA design.

- Sumitomo Corporation Japan
- Asia Pacific Brewery Singapore,
- Coco Cola Manufacturing, Singapore
- Makino Asia, Singapore
- Halliburton Singapore
- Abbot Manufacturing
- GSK Singapore
- SSMC Singapore
- Bharath Mall, India
- Infosys, India
- Lulu Mall, India
- Sheraton hotel, India
- Park Plaza, India
- Dyna Aircon PVT. LTD, India
- Sri Infra Consultants Pvt Ltd, India
- Mint water, India
Full Set-Up of HVS-ECA System at JTC Clean Tech One

Figure 1 - Non-chemical Cooling Tower Water Treatment System: HVS-Electrochemical Activation (ECA) testbed installation at JTC Cleantech 1.

HVS Engineering Pte Ltd has completed the testbed of HVS-Electrochemical Activation chemical-free cooling tower water treatment process (HVS-ECA System) successfully in Singapore at JTC Cleantech 1 cooling tower. (Please see Figure 1)

HVS Electrochemical Activation (ECA) has proven to control bacteria, biofouling, scale, algae and corrosion in cooling tower water distribution system. Cooling tower water distribution system provides ideal conditions for scale formation, bacteria growth and mould growth due to the combination of heat, moist areas, and re-circulating water. Mitigating the water related problems in cooling tower is a primary concern by building operators resulting in considerable environmental and economical issues due to usage of large amounts of chemical compounds and large amounts of water.
Testbed Approach Protocol of HVS-ECA System at JTC Clean Tech One

The testbed project was executed in two phases. Phase I consisted of understanding the cooling tower operations at Cleantech 1 to establish suitable sizing of the HVS-ECA System. Detailed cooling tower system and process analysis were carried out and the HVS-ECA modules were optimized accordingly and pre-installation testing of the ECA modules were systematically carried out at the fabricator site and actual cooling tower site in India. HVS-ECA System treats the water by continuously generating disinfecting ions utilizing on-site electro-chlorination technology to remove bacteria and waterborne organics. Phase 2, consisted of on-site detailed laboratory testing of the HVS-ECA modules at JTC Cleantech 1 with systematic monitoring of the chemical and biological properties of the cooling tower water. Finally, the actual HVS-ECA testbed to treat 650m³ of cooling tower water was performed.

Test Bed Methodology for Phase 1 & Phase 2

Flowchart 1: Methodology of the test bedding of non-chemical HVS-ECA cooling tower water treatment system.
Aim of HVS-ECA System Test Bed Project

HVS has identified that electrochemical water activation would be the preferred non-chemical technology method of water treatment in the near future to solve the problems faced by cooling towers. HVS aspires to be the pioneer in this field and be ready when the market is ready to adopt ECA as the method of chemical-free water treatment for cooling tower applications. The aims of the testbed as follows:

- **Test for Singapore condition:**- To treat a Singapore based cooling tower water without the use of harsh chemicals. Replace the traditional standard biocide chemicals to kill water-borne bacteria. Reduce scaling and corrosion in cooling tower water body.

- **Test for adaptability:**- To test HVS-ECA to control bacteria, biofouling, scale, algae and corrosion in a cooling tower water distribution system at Singapore.

- **Test for development:**- Understand the real life operational challenges and process for the HVS-ECA onsite-generated oxidants to mitigate corrosion, bio-fouling, scaling, micro-organism growth and the spread of waterborne bacteria in a Singapore based cooling water system. Studies and results of testing to learn from findings and evaluate further implementation.

- **Industry standard operations:** To understand industry standards in cooling tower water treatment process applicable in Singapore and to develop the non-chemical HVS-ECA treatment process to produce environmental-friendly disinfectants in the form of active oxidants to meet these standards in terms of disinfection, corrosion and scaling of cooling tower systems. To verify if HVS-ECA System can prevent scale from forming if chemical and physical conditions such that scale would normally form. This shall be a on-site lab-based experiment using the Singapore cooling tower water. To determine if HVS-ECA System will remove already-formed scale from a system in a Singapore cooling tower system.
Aim of HVS-ECA System Test Bed Project (Con't)

- **Adaptability:** To achieve installation of the non-chemical electrochemical Activation (HVS-ECA) System in Singapore at the JTC CleantechOne building and monitor the efficacy in the bacteria disinfestations, corrosion reduction, scale removal and inhibition, reduce bio-fouling and reduce algae proliferation.

- **To establish a local condition baseline** of operating parameters and threshold of scale formation and bio-contamination of cooling tower in Singapore.

- **To establish the optimal operation characteristics** of HVS-ECA System to achieve adaptability to suit local conditions of a typical cooling tower in Singapore.

- **To integrate HVS Automatic Tube Cleaning System** with HVS-ECA System.

- **User friendly protocol development:** Develop a user-friendly operation and maintenance protocol operations in Singapore for the non-chemical HVS-ECA system by being fully automated, with a self-cleaning and self-calibrating design configuration.

- **To develop a matrix table for the optimal disinfectant dosage** requirement of HVS-ECA System for the various sizes of cooling tower to achieve effective sanitization.

- **Economic viability:** Reach savings up to 60% on operational cost by means of savings on chemicals purchase, decrease the water usage, lower energy and labor costs. To document the water conservation, pollution prevention, cost effectiveness in the operations, maintenance and applicability of the HVS-ECA System as chemical-free cooling tower water treatment scheme, with numbers drawn from the actual Singapore testbed site.

- **Smart system:** To conceptualize a smart system based on the test bed conditions, the operation parameters and key input & output data of HVS-ECA System management by a proprietary HVS Data Acquisition System (DAS) and manipulation of the DAS to be done by GSM technology and through the internet protocol. To develop an integrated Data Acquisition System to manage HVS-ECA System. (Future Research Works)
Achievements of HVS-ECA System Test bed

In this testbed, HVS has developed a novel HVS Electrochemical Activation System (HVS-ECA System) to treat cooling tower water non-chemically. In order to overcome the limitations of conventional cooling water treatment procedures (i.e. the need for addition of chemicals or by water softening), HVS has undertaken to testbed the HVS ECA product to separate scale/hardness by electrolytic means. The HVS-ECA System treats the water by continuously removing dissolved scale and hardness and generates disinfectants onsite.

HVS Engineering has successfully tested and verified that the HVS-ECA System which can produce environmental-friendly disinfectants in the form of active oxidants to replace the traditional standard biocide chemicals to kill water-borne bacteria and can mitigate the calcium and magnesium scale without the use of harsh chemicals. The onsite-generated oxidants mitigate corrosion, bio-fouling, scaling, micro-organism growth and the spread of waterborne bacteria.

Figure 2 - Block schematic of the HVS ECA testbed module.

Figure 2 shows the Block schematic of the developed HVS ECA System, which can produce on-site oxidants, remove scale-forming ions from cooling tower water.
In this test bed, the achievements are listed below.

- **Pollution Prevention** – To control bacteria, mold, and scale - cooling towers typically rely on biocidal, water conditioning, dispersant, and scale-inhibiting chemicals, including chlorine, various brominated compounds, phosphates, molybdenates, acids (including sulfuric acid), and zinc compounds. The HVS-ECA System being the non-chemical water treatment, minimizes associated issues of chemical storage, handling, and disposal, and aims to permit on-site reuse of cooling-tower “blow-down” water as “grey water”.

- **Water Conservation** – Cooling towers dissipate heat through evaporation. As “make-up water” replaces evaporated water, it increases concentrations of minerals in the water and exacerbate the formation of scale crystallizing on heat transfer surfaces. This is partially controlled by “blowdown,” a process of periodically replacing some of the solids-laden and ionic-laden recirculating water with additional make-up water. **HVS-ECA System increases the period between required blow-down cycles, thus reducing water consumption.**

- **Cost-effectiveness** – HVS-ECA technology proves as effective as chemical treatment for controlling bacteria, mold and scale, it has potential to reduce total life cycle cost based solely on the reduction in chemical usage, water savings and operational costs.

- **Operations and Maintenance** – Conventional chemical water treatment is typically performed by a contractor or sub-contractor. While application of HVS-ECA technology reduces or eliminates chemical costs, it also reduces other contractor costs.

- **Applicability** – HVS-ECA technology is applicable to all condenser water systems (e.g., cooling towers). Due to water conservation and pollution prevention, the technology is poised to have widespread application in HVAC water treatment.
Background of HVS-ECA Testbed

Heating ventilation air-conditioning (HVAC) process

Figure 3 shows typical configuration of heating ventilation air-conditioning (HVAC) system. Cooling towers are integral part of such HVAC systems. Most buildings equipped with central air conditioning system in Singapore have a water-cooled cooling tower. The most cost effective cooling technology for commercial air conditioning and industrial processes are provided by evaporative cooling towers. But drought conditions and an increase in water usage have contributed to the decreased availability and increased cost of good quality water and low hardness water – the preferred water quality for cooling tower makeup use. Also, stricter environmental restrictions on effluent discharge have resulted in increased fees for disposal of cooling tower blowdown to the sewers. In addition to these concerns, the existing requirements for control of scale, corrosion, deposition, and biological fouling has increased the difficulty and costs associated with operating a cooling tower water system. In spite of these concerns, treatment and control of cooling tower water is commonly neglected, which is then responsible for substantial problems due to downtime, equipment damage, loss of process control, high water use, environmental violations, safety hazards, and increased energy usage. The HVS-ECA System is a non-chemical water treatment system which can address these issues and be environmentally friendly.

Figure 3: Heating ventilation air-conditioning (HVAC) system operation.
Evaporative Cooling Tower:

A cooling tower is a device which rejects unwanted heat into the atmosphere. These towers dissipate heat through evaporation, using large thermal transfer areas wetted by recirculation water. This is achieved partly by an exchange of enthalpy of vaporization resulting from the evaporation of some of the circulating water, and partly by enthalpy change due to cooling. Figure 4A., represents a typical block diagram of a cooling tower water line system. Cooling tower is usually placed at the building roof tops and the chillers are placed at the basement plenum. These cooling towers are the most cost-effective option for removing heat generated in manufacturing, power generation, and large, refrigerant-based air-conditioning systems. Moreover, operation of cooling tower is a water guzzler monster which consumes about 50-60% of a typical building with central air conditioning facility.

Figure 4B. shows a typical water consumption pattern in a commercial building with installed cooling tower. In a typical building, improving the water distribution efficiency of the cooling tower water flow will automatically increase heat removal capability resulting in power and water consumption improvement.

Figure 4: Cooling tower A) Configuration of Cooling Tower, Chillers, AHUs and Pumps in HVAC Application. B) Typical Cooling Tower Water Consumption Pattern
A typical cooling tower water usage can be accounted as illustrated in Figure 5; this is called Cooling Tower Water Balance Equation. The cold cooling water is recirculated by the recirculating water pump and heat is transferred to the water in heat exchangers (condensers). The hot water enters the cooling tower at the top. The water is sprayed through nozzles in order to disperse it into small droplets. In open recirculating cooling water systems, the water passes through the heat transfer equipment and is continuously reused. This cooling water circulates to operating units where it picks up heat as it cools the process stream and the resulting warm water is returned to the cooling tower. The main function performed by a cooling tower is to cool the warmed water. During this process, there is exchange of heat with the incoming air flow that is sucked into the cooling tower. Figure 6 below illustrates the general operation principle of the cooling tower.

Evaporation of water in the cooling tower results in concentration of the dissolved salts found in almost all water sources, which increases the potential for scale, corrosion, and biological fouling. Evaporation water usage by the cooling tower is a necessary loss in order to remove heat. It is highly less possible to prevent this loss, unless the evaporated water is collected back and used as return water to the cooling tower. Blowdown (BD), or intentional removal of water from the cooling tower, is required to prevent over concentration of salts and insoluble airborne debris which results in potential environmental problems, increased water use, and wastewater disposal costs.
The number of times that the makeup (MU) is increased in concentration is commonly referred to as cycles of concentration (COC), which is calculated by dividing the dissolved solids level (commonly measured as conductivity) in the cooling water by that of the conductivity of makeup water. While generally not important unless a cooling tower is to be operated at zero blowdown, windage (W) is a small loss of cooling water into the air stream passing through a cooling tower. Windage loss is a direct function of the design of the cooling tower and water recirculation rate through the unit. Typically, windage loss will be between 0.01% and 0.05% of the cooling water recirculation rate. Drift loss and windage/splash-out loss can be minimized with better cooling tower design. Leak and overflows can be avoided with scheduled maintenance to prevent unnecessary water losses. In many other countries scale formation due to poor makeup water quality prevents any cycling, while other areas are severely limited as to the maximum obtainable. Chemical treatment of the cooling water is thus required in many areas to permit cycling operation, to reduce water usage of an evaporative cooling tower without formation of scale.

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<tr>
<th>New cycles of concentration C3</th>
<th>Percentage of make-up water saved</th>
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Table 1: Potential Water Savings with cooling tower operating at higher COC

Please see the potential water savings with improved COC as illustrated in Table 1. Bleed loss can be reduced by enabling the cooling tower to operate at higher cycle of concentration (COC). HVS-ECA System is aimed at increasing the COC by being a non-chemical water treatment system. In Figure 6, the typical relationship between the water use and the COC in cooling tower is provided. From Figure 6, it is clear that a COC of 7 is ideal and can result in good savings. Further increase in COC does not really result in a marked reduction in the makeup water usage. Hence, HVS-ECA System targeted to achieve a COC of 10~12 without the formation of scale.
However, in Singapore since the makeup water quality is very good. (The details of Singapore water quality will be provided in the later parts of this report). The major concern during operating a cooling tower in Singapore is not scale build up or blow down. Achieving a non-chemical bacteria disinfection system is primary requirement for the tropical nature of Singapore weather.

![Figure 6: Typical relationship between the water use and the COC in cooling tower. Based on these literature reports HVS-ECA targets to achieve a COC of 10.](image)

Cooling towers come with multiple operational challenges. The combination of heat, moist areas, and re-circulating water, creates ideal conditions for scale formation, bacteria and mold growth as shown in Figure 7. Extensive scale formation and algae growth within the infill of cooling tower will drastically affect the flow distribution efficiency and reduce heat transfer capability. Some of the inherent operational challenges with water-cooled cooling tower operation faced by maintenance engineers are corrosion, scale, bacteria infestation, bio-fouling and algae proliferation. The currently industrial norm is to use of harsh chemicals, expensive and environmentally unfriendly approach to mitigate problems associated scale formation and algae growth.
proliferation within the infills of cooling tower. Together they create major operational issues, including health hazards to maintenance workers, increased electricity usage, increased water consumption, reduced cooling efficiency and shortened life expectancy of equipment. Till now, the common method of water treatment of cooling towers to control the above mentioned problems entailed the use of harsh toxic chemicals. To this direction, HVS-ECA System is a non-chemical less corrosive process which can eliminate bacteria, mold, bio-fouling and mitigate the scale formation in cooling towers.

HVS Engineering Pte Ltd team has visited many cooling tower sites to understand the operating conditions, the water treatment protocol studies and regimes monitoring methodology were observed and studied. The typical operational procedures in the cooling towers of this region were observed. We have visited many cooling towers in the region to study and understand the typical operating conditions. Figure 10A shows the Photograph of site visit to Singapore poly-technique building cooling tower, Singapore. In Figure 10B, Site visit to Prestige Shanthinikethan, India, Bangalore Figure 10C photo of cooling towers Manila, Philippines, Figure 10D shows the project site at JTC CleanTech One. Other sites visited are IMM building, Singapore, Makino Singapore, Changi Airport Singapore, Suntech City Singapore, Fusionopolis & Biopolis building cooling tower Singapore, Infosys campus Bangalore, Biocon campus, Bangalore etc. During the study, we have understood the typical operating methods, problems, solutions, drawbacks and advantages. In Figure 10E and 10F, typical nature of large cooling tower fan hub and Cooling tower basin water and water level float valves are shown.
Figure 10: Typical photos of Cooling Tower for Air Conditioning. A) Site visit to Singapore poly-technique building cooling tower, Singapore. B) Site visit to Prestige shanthinikethan, India, Bangalore. C) Site visit to Cooling tower at manila Philippines D) Site visit to Cooling tower at JTC CleanTech One. E) Cooling tower fan hub F) Cooling tower basin water and water level float valves.
Scale formation in cooling tower water system:

Scale forms when total dissolved solids (TDS) – generally minerals such as calcium carbonate, calcium phosphate and magnesium silicate and other insoluble chemical compounds and elements in the water crystallize and precipitate on surfaces. The scale sticks to the surfaces of pipes, valves, sensors, heat exchanger tubes and gradually builds up and form tenacious scales. As the thickness of scale increases over time, it will interfere with valve closure, flow pattern, affect pipe flow pattern, deteriorate heat transfer and increase water pressure. Examples of tenacious scale formed inside a typical heat exchanger tubes as detected by boroscope inspection as shown in Figure 11A & Figure 11B. Among the dissolved solids, calcium and magnesium minerals which are the main contributors to the water hardness play a major role in the scale formation. This further reduces the cooling tower system’s efficiency by clogging water paths and reducing heat-transfer areas. Scale, in addition to causing physical blockage of piping, equipment, and the cooling tower, also increases the energy use of the chillers used in comfort cooling.

Figure 11: A) Hardened scale of 2mm thick as detected inside a grooved heat exchanger. B) Thick scale inside a grooved tube affecting heat transfer efficiency and flow pattern
Figure 12: Scale and fouling of the cooling tower in-fills A) Extensive scales being removed from infill by Off-line cleaning of cooling tower. B) Scale debris from a cleaning of cooling tower infill

Further, the scale formation in between the infill of cooling tower will greatly affect the flow pattern of the water which will in turn reduce the heat removing capacity. Please see Figure 12 illustrating the scale formation in infill. Great care in the maintenance of cooling tower system is required to operate efficiently by protecting and extending the life of cooling tower system to ensure good heat transfer. Figure 12A & 12B illustrate the extensive scales being removed from the cooling tower infill.

With the installation of the HVS-ECA System, it is expected that a certain amount of, calcium and magnesium minerals are constantly precipitated out and removed physically from the water system. HVS-ECA System also destroys the organic matrix holding together the in-organic scale. This helps in mitigation of scale and aid to operate the cooling tower system at higher COC without any scaling problems. In this test bed, it was our aim to determine the applicability of such mechanisms under Singapore conditions.
Corrosion in cooling tower water system

Described as the “universal solvent,” water corrodes all materials of construction at different rates. Steel, being the lowest cost construction material for cooling systems, is very common and is readily corroded by most cooling waters. Other materials, such as copper, brass, and galvanized steel, are also corroded, though at generally lower rates. To obtain a useful life from a cooling system, corrosion inhibitors are generally used to control the corrosion rates to an acceptable level.

Bio-fouling and microorganisms in cooling tower water system:

The cooling water environment (warm with high dissolved solids and debris loading) is an excellent medium for growth of microorganisms that may cause many severe problems. Not only is there an increased risk of Legionnaires’ Disease, but biofilms also affect flow pattern, reduce water passages and piping, help to accelerate corrosion, and reduce heat exchanger efficiency. The effect of biofilms on the power cost of chiller operation is often not appreciated. Looking at the thermal conductivity of biofilm, typically 0.2 btu/[hr(ft²)(F/in)], it is substantially more insulating (4 times less conductive) than the common calcium carbonate scale. Therefore, while a system may be scale free, any biofilm present will still cause excessive energy use.

Legionella pneumonia & bacteria

The bacterium is found naturally in fresh water. It can contaminate hot water tanks, hot tubs, and cooling towers of large air conditioners. The concern with respect to cooling tower exhaust is the airbourne mist. Mist drift from cooling towers has been implicated as a source of infections of Legionella pneumophila. Since a cooling tower uses sprays of water to cool the working liquid, the exhaust air from a cooling tower contains fine droplets of water. As such fine water droplets may contain bacteria, algae and viruses, the mist will also contain these biological species, which may include Legionella. Figure 13 shows typical Transmission Electron Microscopy image of Legionella bacteria.
Water systems have been identified as a source of Legionella pneumophila. Legionella pneumophila serogroup 1 is the most common cause of legionellosis, a sporadic and endemic disease that may be acquired from different environmental sources. Legionnaires’ disease is a form of a typical pneumonia caused by any type of Legionella bacteria. Signs and symptoms include cough, shortness of breath, high fever, muscle pains, and headaches. Nausea, vomiting, and diarrhea may also occur. This often begins two to ten days after being exposed. Legionella Pneumophila is usually spread by breathing in mist that contains the bacteria. There is no vaccine. Prevention depends on good maintenance of water systems. Treatment of Legionnaires’ disease is with antibiotics. Legionella pneumophila SG1 (Sero Group 1) and SG 2-14 (Sero Group 2 to 14). The two names are variations of the legionella Pneumophila bacteria. It will also present different antigens for antibodies to bind to. SG 1 is far more virulent than the other SGs, with SG 1 accounting for 80-90% of legionella cases, however SG 2-14 are more commonly encountered in the environment. Worldwide, L. pneumophila sg 1 is the most common agent of Legionnaires’ disease (80 to 90% of the reported cases). In contrast, L. pneumophila sg 2–14 account for only 15 to 20% of community-acquired cases, although they account for over 50% of the environmental isolates. The discrepancy between environmental isolates and clinical cases of disease suggested that there are differences in virulence.
The Traditional Chemical Treatment of Cooling Tower Water.

Utilising chemicals to controlling water chemistry is and has always been a delicate balancing act. The chemical treatment may be part of the problem and not part of the solution. Scale, bio-fouling, bacteria infection, corrosion problem are inherent in cooling tower operations. Treating cooling-tower water to prevent biological fouling, scale, and corrosion is a complex, and highly monitored process. Figure 26 shows the cause and effect of different chemical treatment process in cooling tower.

Highly toxic chemicals referred to as “biocides” are added to cooling towers to control the growth of unwanted microorganisms in the cooling water. Most are accomplished with biocidal, conditioning, dispersant, and scale-inhibiting chemicals, including chlorine, various brominated compounds, phosphates, molyddenates, acids (including sulfuric acid), and zinc compounds. While chemicals do get the job done somewhat, there are considerations beyond the tower. The traditional chemical treatments have inherent technical challenges. Figure 14 illustrates the inter-relationships and inter-dependencies between cause and effect of the standard chemical treatment approach and its subsequent negative effects on the cooling tower system.
Conventional cooling towers require that acidic chemicals or/and alkaline chemicals to be periodically added to manipulate and re-balance the pH range to prevent scale formation and high corrositivity in the water distribution system. In addition, periodic dosing of biocides is needed to retard biological growth and other chemicals to control pH level, scale, corrosion and algae.

The HVS-ECA chemical-free water treatment scheme proposed herein, can help to mitigate all the above mentioned issues of a cooling tower water system.

**The HVS-ECA System being developed should be able to carry out the following actions:**

- To control scales formation at all wetted portions in water distribution pipelines and infill of cooling tower
- To eliminate biofouling in the cooling tower water distribution pipelines including valves, sensors, cooling tower infill, water basin and sump
- To minimize bacterial counts in cooling tower water basin
- To mitigate corrosion to all wetted portions of the water distribution system of the cooling tower.
• No external chemicals are to be used. HVS-ECA System should be an onsite chemical free cleaning system. HVS-ECA System should remove calcium and magnesium scale without the use of harsh chemicals and should produce environmental-friendly disinfectants in the form of active oxidants to replace the traditional standard biocide chemicals to kill water-borne bacteria.

• HVS-ECA System should reduce and eliminates chemical usage in the treatment of cooling-tower.

• Single step HVS-ECA process produces onsite the active agents to removing scale, and providing disinfection

• Ca\(^+\), Mg\(^+\), Si\(^+\) and Fe\(^+\) ions are to be removed from the cooling tower water by the HVS-ECA technique. The scale contributing concentration is maintained over time. No bleed off is required.

• Since the scale forming ions are always removed continuously, the system does not lead to dangerous scale building and regular blowdown is not required or substantially reduced. The frequency of water quality monitoring can be reduced to a minimum.

• A saving of 60% on operational cost by means of savings on chemicals purchase, decrease the water usage, lower energy and labour costs is anticipated.

• Leave no synthetic chemical residue

**Working principle of HVS-ECA Electrochemical Activation System**

In HVS-ECA System, direct current flows between the anode and cathode which disassociates the salts available in the water into ions. In the electrochemical reaction chamber, cations are attracted to the negative electrode while anions are attracted to the positive electrode. The cations include calcium, combines with carbonate among others – which are the scale builders in the water– responsible for scale formation to any wetted surface in the water distribution system. During the electrolysis process, the reactor chamber having high electric & magnetic field will convert the crystalline structure of calcium-based molecules from calcite to aragonite. This calcium carbonate
in the form of aragonite which is softer and not as tenacious as calcite is being flushed out periodically through drainage valve. HVS-ECA System includes electro-chlorination component which generates free chlorine with the residual chloride itself – taking care of bio-fouling, mould, fungi and algae.

When the cooling tower water is electrolyzed and activated – at the anode side, a mixture of hypochlorite (HOCl) is produced. HOCl is a powerful disinfecting compound that can be used effectively for water purification. These on-site generated activated species such as negative ions and chlorites are environmentally friendly since they can degrade to their native state without leaving behind any free radical residue. This key feature makes the technology green and environmentally friendly.

The general principle of ECA technology is already increasingly being used in washing, meat processing, ice-making, dairies bakeries, hospital, healthcare, hospitality sectors, hotels, restaurants as an effective sanitizer and cleanser. However, ECA technology for cooling tower water treatment application for controlling scale, corrosion, biofouling and as water disinfectants is not widely adopted in the industry. The use of electrolyzed water to achieve higher cycles of concentration than that allowed by conventional cooling tower chemical treatment programs is not a common practice and not an industry standard. We are of the view that this is a virgin niche market that has not been addressed and we aspire to test bed the proposed HVS-ECA System in order to capitalize on this untapped opportunity.

**Bacteria, Micro-organism and Biofilm Removal Mechanism**

A biofilm is a layer of micro-organisms contained in a matrix of slimy layer also known as extracellular polymeric substance (EPS), which forms on surfaces in contact with water. The temperature and free nutrients readily available in cooling towers make them ideal for biofilm growth. These layers of bio-matrix (EPS) encapsulates the pathogens within such EPS forming a protective shield for the pathogens against the concentrations of biocides (conventional chemical treatment) that would otherwise kill or inhibit these organisms, if such pathogens are freely suspended in water or there is no such bio-matrix EPS protective layer. Figure 16 shows the schematic illustration on the formation of biofilm and EPS.
The Legionella pneumophila (LP) Bacteria breeds in cooling tower water systems, leading to risk of infection to humans. The LP bacteria is very resilient, reproduces at temperatures of 20°C to 45°C and can survive in water with temperatures of up to 70°C.

Biofilm is 4 times more insulating than carbonate scale. Hence 1mm of biofilm has the same insulating effect as a 5mm carbonate scale layer. Highly insulating biofilm layers over heat transfer surfaces are not desirable. The electro-chlorination system produces NaOCl in low concentration which can result in automatic control and eradication of microorganisms, including Legionella Pneumophila bacteria. When bacteria is eradicated, then there will be no biofilm and hence heat transfer surfaces shall be free from biofilm and EPS.

In conventional chemical treatment regime, harsh chemicals are deployed to disinfect such water. The advantage of the HVS ECA module is onsite on-demand production of disinfectant without the use of conventional chemicals. Therefore, there is no transportation risk or special storage or precautionary requirement of toxic chemicals. This physical chemical dosing of hypochlorite can disinfect the same way as HOCl and is effective against bacteria, viruses and fungi, it only operate at a narrow window of pH range. Whereas in the HVS-ECA System onsite-produced HOCl is remain as effective disinfectant in a wider pH range— making this a more flexible choice.
Scale Removal Mechanism

Theory for HVS-ECA for scale mitigation system design of Ca+ and Mg+

Natural scheme of carbonate dissolution: The calcium carbonate which forms scale in cooling systems is dissolved in fresh water naturally. Rain water mixes with carbon dioxide forming carbonic acid as it falls to earth and later enters the aquifer. The water plus carbon dioxide react to form carbonic acid. This is the same acid that is produced when a carbonated beverage is shaken.

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \]

As the carbonic acid rain water reacts with bedrock, calcium reacts with the carbonic acid and is dissolved in the ground water where it remains until pumped from wells into commercial cooling systems. The water contains calcium ions in solution where they remain waiting to precipitate when energy is applied. Calcium ions need to form a bond with bicarbonate ions in order to precipitate naturally.

\[ \text{Ca}^{++} + 2(\text{HCO}_3^-) \rightarrow 2\text{CaCO}_3 + \text{H}_2 \]

To effectively resist the precipitation process, the carbonic acid must be converted to bicarbonate and then to carbonate. An indication that this conversion has been achieved is when the pH of the solution rises from about 6 to about 8.2. This is called the saturation state where there is a shortage of ions to react with the calcium ions to form precipitate. pH above 8.2 indicates a scarcity of available ions to react with the calcium ions.

\[ \text{H}_2\text{CO}_3 \rightarrow (\text{HCO}_3^-) \rightarrow (\text{CO}_3^-) \]

Carbonic Acid \(\rightarrow\) Bicarbonate \(\rightarrow\) Carbonate

\[ \text{pH} = 4.2-6.0 \quad \text{pH}=6.0-7.5 \quad \text{pH}=7.5-8.3 \]

Basic Water Quality Analysis & Comparison

First principle basic experiments on electrolysis were carried out as part of the laboratory studies and development work. The basic experiments gave us good knowledge and hands on experience to design and select suitable materials for the electrodes, power supply and casing systems. The basic experiments helped to study
different quality of water available in the regions. We have studied water quality for NEW water, PUB water, cooling tower water, river water, lake water in Singapore. All the water readily available in Singapore is soft water, without much Ca+ or Mg+ ions in them. Most of the water are surface water such as rain water after treatment or re-use treated water. NEWater is very clear and sparkling. The river sources and reservoir water has more color as they contain more minerals and organic substance. We have also studied oversees water quality from cooling towers in Philippines and India.

<table>
<thead>
<tr>
<th>Description</th>
<th>PUB’s Water Quality</th>
<th>NEWater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity (NTU)</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Colour (Hazen units)</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>&lt;250</td>
<td>&lt;250</td>
</tr>
<tr>
<td>pH Value</td>
<td>8.1</td>
<td>7-8.5</td>
</tr>
<tr>
<td>Total Dissolved Solids (mg/L)</td>
<td>154</td>
<td>&lt;150</td>
</tr>
<tr>
<td>Total Hardness (CaCO3) (mg/L)</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
</tbody>
</table>

Table 2: Singapore: Water quality analysis of NEW water and PUB water. Source: PUB website

<table>
<thead>
<tr>
<th>Description</th>
<th>Mani Wing (Shang) Recycle</th>
<th>East Wing (Shang) Recycle</th>
<th>SM. SAN. Pablo</th>
<th>Asian Hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.89</td>
<td>8.46</td>
<td>8.46</td>
<td>8.74</td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>3700</td>
<td>822</td>
<td>2510</td>
<td>1058</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>1858</td>
<td>412</td>
<td>1255</td>
<td>529</td>
</tr>
</tbody>
</table>

Table 3: Preliminary water quality analysis from a cooling tower in Philippines.

<table>
<thead>
<tr>
<th>Description</th>
<th>Prestige shanthnikethan Bangalore</th>
<th>Chennai, Tiaano factory sump water</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.7</td>
<td>7.5-8.5</td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>3554</td>
<td>822</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>1858</td>
<td>412</td>
</tr>
</tbody>
</table>

Table 4 Preliminary water quality analysis from a cooling tower in Bangalore India and underground sump water from Chennai, India.
In Table 2, 3 & 4 are listed preliminary water quality analysis of water from Singapore, Philippines and India. From these water analysis results, we conclude that hard water is not readily available in Singapore. To develop and optimize the HVS-ECA System, considerable and easy availability of hard water is necessary.

After the initial testing and with further operational insights, the HVS-ECA System was further modified to include two chamber and two pumps. The two chambers are in series and the pump is used on a standby mode basis to achieve continuous operations. The residence time of water in contact with the electrode is found to be very important in providing good ionization. Figure 18 shows the block schematic of the second generation developed HVS ECA system.
In conclusion, the integrated HVS-ECA System is designed and fabricated to achieve the following:

- HVS-ECA System Model 2 is an integrated single component system.
- Electrochemical activation technique is used to generate the descaling and disinfecting agents.
- When hardwater water is used, the scale causing ions crystallize at the cathode electrode. Localized formation of scale is easy to handle and can be easily separated from the cooling tower water.
- Corrosion is avoided by not using any harsh external chemicals.
- Legionella Bacteria, Slime, Biofilm, Algae is reduced by HOCl and NaOCl.
- HOCl and NaOCl also prevent scale formation.
- Simple cyclonic filtration is used to separate large debris.
Figure 19 shows the first installation of the integrated HVS ECA system at Prestige Shanthinikethan, India Bangalore. 4 units of the HVS ECA system was installed at the cooling tower site. This installation has been in operation for the past 18 months. The operation of the system is closely monitored by both the HVS and Tiaano team on-site in Bangalore. The non-chemical water treatment system was installed in India, since the water quality at the location is hard water. The units are installed beside the cooling tower, with one ECA system to one cooling tower configuration.
To remove automatically the scale from the electrodes, reverse polarity technique is used to automatically remove the scale collected from the electrodes. Electrolysis attracts calcium to the electrodes; excessive calcium build up will reduce the performance and life span of the HVS-ECA electrodes. We have a reverse cycle built into our system programming, also known as self-cleaning because they are designed to remove automatically the scale build up on the electrodes. As the electricity used in is DC (Direct Current), scale will build up on the cell blades at one polarity. The power supply will reverse the flow of electricity after a programmed amount of time to dissolve the scale off the blades. The reverse polarity time is programmable to best match scale removal needs.

The duration and timing of the reverse polarity are very important factors to be considered and tuned to match excellent removal of the formed scale. However, even with reverse polarity, periodic regular cleaning of the electrode still need to be carried out. Some residue scale can still remain at the electrodes even with applying reverse polarity.
Figure 20 shows the typical photograph of the electrode after acid/water flush cleaning process. After the periodic manual cleansing with acid/water flushing, there is no scale sticking to the electrodes.
Figure 21 shows the typical collection of the scale at the bottom of the cyclone in the collection chamber. Such large amount of scale is collected due to hard water being used at the Bangalore Prestige Shanthiniekthan site. Photos are for chamber 1 and 2 of the HVS-ECA System connected to cooling tower number 7. The numbering of the cooling tower connected is painted on the reaction chamber body for ease of identification.

Figure 21: Typical collection of the scale at the bottom of the cyclone in the collection chamber.
The key to proper scale precipitation by HVS-ECA electrolytic operation is governed by water flow, residence time, current density and cathodic surface area of the electrolytic reaction cell. Cathodic collection of calcium carbonate effectively establishes calcium transport out of a cooling system apart from that provided by bleed off. So long as sufficient cathodic area, driving force and residence time are available to limit microcrystal growth for a given set of cooling system operating conditions, there may be much less or no reliance on bleed-off to control residence time. Operating experience verifies this observation, indicating average water cycles of concentration to be more than double without bulk phase precipitation or heat exchange deposition. Under some conditions, zero discharge is also possible and could be achieved.

**HVS-ECA project execution**

For easy understanding, In Figure 22, the different activities in Phase 2 of the testbed project are shown in a flowchart format.
Figure 23: Arrival, unpacking, hookup and commissioning of the HVS-ECA System at the JTC Cleantech One, Singapore.
Figure 24: Hookup and commissioning of the HVS - ECA at the JTC CleanTech One, Singapore.
Figure 25: Photo of the internal PLC control system of HVS-ECA system. Reverse polarity circuit is incorporated.

Water leak test was performed after the installation. All the electronic and electrical components as shown in Figure 25 were hooked up and tested successfully. The reverse polarity feature of the HVS-ECA system was ready for operations in March 2016 at JTC Cleantech One Singapore (Figure 26). The system was powered on for functionality test and HVS is ready for full scale test bedding at Singapore. Careful grounding of the system is done. Figure 26C and 26D show scale collection chamber before and after the initial operations of the HVS-ECA System.
Figure 26: HVS-ECA installation in Singapore is completed and is ready for testbed.
Figure 27: HVS-ECA System after 20 days of operation. The electrode quality was monitored and scale formation in the electrode is observed and removed off by physical scrubbing and chemical cleaning.

The testing and commission of the HVS-ECA System was performed for 20 days on a continuous mode. After 20 days of operation, in order to investigate the quality of the electrodes such as the nature of the electrode coating and the scale formation over the electrodes - we opened the chamber and undertook a visual inspection of the electrode. Formation of scale at the cathode electrode of the HVS-ECA System under Singapore water quality conditions is clearly observed. The electrode was then scrapped and water jet cleaned, acid cleaned and placed back to the HVS-ECA chamber. Before carrying out the full scale cooling tower water treatment, we performed the laboratory scale cooling tower treatment to optimize the operational parameters and identify the sweet spot for doing the HVS-ECA treatment.
Laboratory testing of HVS-ECA System at JTC CleanTech One cooling tower site.

The aim of laboratory tests is to determine the best operational conditions for the HVS-ECA treatment technology for handling the cooling tower at JTC CleanTech One Singapore.

Establishing correlation between the BactiQuant(BQ) counts obtained using the Mycometer and the laboratory microbial analysis.

Figure 28 shows the correlation BactiQuant (BQ) Vs Heterotrophic plate count. This information was provided by Mycometer manufacturer. The HPC limit of operation for the cooling tower is <100,000, hence the BactiQuant reading should be less than 50,000. To be on a safer side, it would be good to have a BQ value of less 15,000

Figure 28: BactiQuant Vs Heterotrophic plate count
(Correlations in the Lab, reference information provided by Mycometer)
Mycometer has been used to monitor the hygiene in a large cooling systems. Based on the information provided by Mycometer as a reference. According to this information a normally effective operating cooling system will have a BQ value in range less than 15,000.

Figure 29: Non-cooling tower water samples: Typical BQ value for different water samples tested in Singapore
The bar chart in Figure 29 shows the BQ value of the typical water tested in Singapore. We have tested the BQ value for PUB tap water at different locations, stored and bottled water, industry feed water, RO water, cooling tower makeup water, New water Singapore. We have also tested cooling tower water from Makino, SIA hanger 2, UOB Plaza 2, Abbott, Biopolis, Halliburton, Hillside pool, Paragon for BQ value base lining with Mycometer. (Please refer to Figure 30).
Figure 31: Setting up of the analysis procedure to carry out the Bactiquant measurements using the Mycometer.
The standard procedure to determine the BQ value adapted is as below:

- All the Mycometer measurements were carried out after using a blank.
- A 0.22 micrometer filter was used to perform the localization of the bacteria and be captured for the enzyme reaction.
- 40ml of the water sample was measured using a syringe and loaded to the filter.
- Uniform reaction time of 10 minutes was employed all through the study.
- Finally the Mycometer was used to determine the florescence and a normalization formula was used in a Excel calculation sheet to determine the BQ value.

![Figure 32: Variation of ORP for free Chlorine as a function of pH (Reference data from internet)](image)

In general, though, one can see that ORP increases logarithmically with increasing HCOI concentration. OCI has a much lower ORP value than HCOI which is consistent with its much lower activity as a sanitizer.

The inter-dependencies of ORP, pH and free chlorine are shown in Figure 32. Solid lines show the variation of ORP readings in the pH range of 7 to 8 for total free chlorine levels of 0.3, 0.5, 1.0 and 3.0 ppm respectively. As the pH increases between 7 and 8,
the ORP sensor shows a marked decrease in value for all chlorine levels. It shows that the decrease of the ORP reading with increasing pH closely parallels the decrease in concentration of HOCl. It explains why the ORP sensor can be used very effectively to monitor HOCl in the water. In this laboratory study and the test bed we have optimized the HVS-ECA process such that a optimum condition of the ORP, free chlorine are obtained to achieve a good Mycometer reading under the limitations of operating conditions.

**Phase 2: Laboratory testing onsite to identify the optimum level of catalyzing media required to carry out the operation of the HVS-ECA System**

The laboratory model of HVS-ECA System consists of co-cylindrical meshed electrodes coated with catalytic layers housed inside a solid transparent acrylic body chamber as shown in Figure 33. The tangential water inlet at the top of the chamber helps to generate the water cyclone effect to segregate the scale formed at the electrode and to collect them at the bottom scale collection chamber. The exit port at the bottom can be used to discharge off the scale whenever required. The filtered water after treatment moves back to the 100L holding chamber. The HVS-ECA chamber itself is used as the holding chamber. Figure 33 shows the HVS-ECA laboratory test reactor components being used for the laboratory studies.
Figure 33: HVS-ECA laboratory test reactor. Hooked up at the cooling tower site at JTC CleanTech One Singapore
To avail to actual cooling tower water, the laboratory studies were performed by hooking up this prototype unit to the cooling tower. For these laboratory tests, 100 Liters cooling tower water, taken at the cooling tower return pipe was used.

Figure 34: Catalyst and pH buffer addition for laboratory tests; Catalyst in pouch and pH buffer in syringe ready to be introduced to the testing chamber.

Figure 34 shows typical process for the careful weighing of the catalyst and pH buffer for the addition to the cooling tower water for carrying out the laboratory tests. Catalyst in pouch and pH buffer in syringe ready to be introduced to the testing chamber.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>After laboratory HVS – ECA treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>BQ value</td>
<td>275,627</td>
<td>83,929</td>
</tr>
<tr>
<td>ATP meter</td>
<td>203</td>
<td>178</td>
</tr>
<tr>
<td>Total Legionella count (cfu/ml) (Setsco lab test)</td>
<td>360</td>
<td>140</td>
</tr>
<tr>
<td>Heterotrophic plate count (cfu/ml)</td>
<td>390</td>
<td>680</td>
</tr>
<tr>
<td>Total Coliform count (MPN100 ml)</td>
<td>&lt;1.8</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>Total Escheria Coli count (MPN100 ml)</td>
<td>&lt;1.8</td>
<td>&lt;1.8</td>
</tr>
</tbody>
</table>

Table 5: HVS-ECA laboratory treatment of cooling tower water. No catalyst and no pH reduction agent are added.

Table 5 shows the first laboratory experiment using the HVS-ECA System. The total Legionella count also is above the limit of 10cfu/ml. The Legionella count however decreased from 360 to 140 cfu/ml, indicating that the HVS-ECA treatment does produce disinfectants but the concentration is much lower than what is needed for effective disinfection. However, surprisingly the Heterotrophic plate count has increased from 390 to 680 cfu/ml which further confirms that the HVS-ECA System when operated under these circumstances with low chloride levels (the chloride content of makeup water in JTC CleanTech One is about 6 ppm, however the chloride content in Bangalore water is very high at 125 ppm. Such 20 times difference in the chloride content of the water available at Singapore and Bangalore could result in a marked difference in the optimal operations of the HVS-ECA System in Singapore and elsewhere with typically low chloride content of feed water.
On 3 September 2016, the HVS-ECA Water Treatment process was switched on. After 20 hrs of HVS-ECA by Scheme 1 treatment (HCl 1250ml, NaCl 250 grams), a marked decrease in BQ is observed. The BQ value after the treatment is equal to the BQ value for PUB drinking water. This clearly shows complete disinfection is achieved. The HVS-ECA water treatment progression is shown in the black colored line. The reference PUB water BQ value is shown in dark green colored line.

Theoretically, pH regulation is important; however, from the experiments, we found that the salinity of the water is more detrimental in defining the efficacy of the HVS-ECA water treatment process.
As such, we have carried out comparative study of the rate of disinfection with and without pH regulation. These results are explained later.

Systematic tests to understand the rate (Kinetics) of disinfection during the HVS-ECA water treatment process are performed. We have systematically monitored BQ value, ATP value, pH, salinity, ORP, TDS, Free chlorine, Total Chlorine and corrosion rate as a function of the reaction time. The aim of this study is to identify the HVS-ECA scheme which is least corrosive and best suited for Singapore cooling tower operating conditions.

Figure 36 shows the kinetics of microbial disinfection monitored by the BQ value during the HVS-ECA scheme 7 (NaCl 40gms, HCl 350ml) treatment. The BQ value decreased suddenly from 71214 to less than 15000 within 60 minute of HVS-ECA operation. The horizontal line drawn in the kinetics graph shows the intersection point to visually see the quick action of the HVS-ECA process under Scheme 7.

![Figure 36: Kinetics of microbial disinfection monitored by the BQ value during the HVS-ECA Scheme 7 (NaCl 40gms, HCl 350ml) treatment.](image-url)
Table 6: Kinetics and laboratory analysis of HVS-ECA process, Kinetics of microbial disinfection by HVS-ECA scheme 7 HVS-ECA. External laboratory results for the laboratory testbed water samples before and after HVS-ECA treatment

Table 6A, shows the tabulated values of BQ, ATP, pH, Salinity, ORP, TDS, free chlorine and total chlorine during the HVS-ECA scheme 7 treatment. pH decreased from 9.26 to 8.01 and later slowly raised to 8.39. The salinity remained constant at 0.9 psu. The general salinity of cooling tower water is 0.4 psu. ORP increased from 61 to 640mV. TDS from 560 to 1164. Free chlorine from 0.03 to 3.7ppm. Having seen very quick decrease in the microbial contamination as hinted by the drastic reduction in the BQ value, these water samples before and after the HVS-ECA treatment was sent to the external accredited laboratory (Setsco) for confirming the on-site tests. The sample sent out had undergone 6 hours of HVS-ECA water treatment process. The laboratory analysis is provided in the Table 6B. The Total Legionella count (cfu/ml) decreased from 1000 to < 1 cfu/ml. This clearly confirms the efficacy of the HVS-ECA water treatment process. In conclusion: Higher BQ as obtained in the quick test using the Mycometer provides good indication of the presence of Legionella and heterotrophic bacteria. After
HVS-ECA water treatment, the BQ reduces substantially and it is correlated by the results from the Setsco laboratory tests.

Further, to understand the initial kinetics of disinfection, the on-site water sampling was performed for every 30 minutes. Figure 37 shows the kinetics of microbial disinfection monitored by the BQ value during the HVS-ECA Scheme 8 (with NaCl 40gms, HCl 350ml) treatment. The horizontal intersection of BQ 15000 is at 60 minutes of HVS-ECA kinetics. The horizontal line in blue showing the BQ for the PUB water intersects the kinetics graph at approximately 165 minutes.

![Figure 37: Kinetics of microbial disinfection monitored by the BQ value during the HVS-ECA scheme 8 (NaCl 40gms, HCl 400ml) treatment. Monitoring is done every 30 minutes](image)
Figure 38 shows comparative microbial disinfection rate by the HVS-ECA water treatment process with 40g chloride added to 100L cooling tower water with the addition of HCl (Scheme 8) and without the addition of HCl (Scheme 9). This study is performed to understand the pH dependency (or independency) of the HVS-ECA process. The rate of disinfection represented by the slope is practically equal for the Scheme 9 as compared to Scheme 8. However, it should be noted that time required to reach the lower saturation level is comparable for both the schemes considering the initial higher value of the BQ count for the sample with HCl. In cooling tower disinfection, the disinfection process could be such that it takes a little longer to achieve and maintains the bacteria count low is good enough. Considering this scenario, the final conclusion is, not to use any HCl in the disinfection scheme. Only chloride is considered more important, that is salinity is the dominant aspect of the cooling tower water which determines the efficacy of the HVS-ECA water treatment process. This suggests that in cooling tower water, the free chlorine is still available to disinfect the microbial load. This pH independent HVS-ECA process is most striking, because in cooling tower it is very common to have marked changes in the pH due to many operating scenarios. This is again a striking advantage of the onsite generated non-chemical HVS-ECA process. Such pH independent process is most ideal for the Singapore weather conditions.
Table 7A shows the tabulated values of BQ, ATP, pH, Salinity, ORP, TDS, free chlorine and total chlorine during the HVS-ECA Scheme 9 treatment. pH increased from 9.13 to 9.26. The salinity remained constant at 0.8 psu. ORP decreased from 298 to 37mV. Complete disinfection is achieved with the BQ value equal to the PUB water is achieved in 75 minutes. TDS from 599 to 1060. Free chlorine increased from 0.0 to 0.6ppm. This clearly shows that salinity is an important factor in determining the efficacy of HVS-ECA water treatment. Another significant advantage of HVS-ECA water treatment is that its operational efficacy and effectiveness is independent of pH condition of cooling tower water.

To further confirm the disinfection results and to correlate with Mycometer BQ value, we have performed an independent microbial water analysis at Setsco- an accredited laboratory. Table 7B, shows the tabulated values of the Setsco laboratory results. The
Total Legionella Count (cfu/ml) (Setsco lab test) decreased from 720 cfu/ml (before HVS-ECA Treatment) to being ‘Not Detected’ (after HVS-ECA Treatment). The Heterotrophic Plate Count (cfu/ml) decreased from 110 cfu/ml to 9 cfu/ml which is way below the threshold of 100,000 cfu/ml. This is evidence of good disinfection treatment by HVS-ECA System.

### Table 7: Scheme 9 Kinetics analysis of HVS-ECA process without the addition of any pH reducing agents

<table>
<thead>
<tr>
<th>Time (Min)</th>
<th>BQ value</th>
<th>ATP value</th>
<th>pH</th>
<th>Salinity (PSU)</th>
<th>ORP (mV)</th>
<th>TDS (ppm)</th>
<th>Free chlorine (ppm)</th>
<th>Total Chlorine (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle 10</td>
<td>Scheme 9 (NaCl 40gms,HCl 0ml)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>122368</td>
<td>246</td>
<td>9.13</td>
<td>0.5</td>
<td>292</td>
<td>598</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>50</td>
<td>6260</td>
<td>120</td>
<td>9.17</td>
<td>0.9</td>
<td>-15</td>
<td>1078</td>
<td>0.14</td>
<td>0.21</td>
</tr>
<tr>
<td>75</td>
<td>117</td>
<td>120</td>
<td>9.21</td>
<td>0.8</td>
<td>-19</td>
<td>1068</td>
<td>0.15</td>
<td>0.26</td>
</tr>
<tr>
<td>120</td>
<td>73</td>
<td>64</td>
<td>9.24</td>
<td>0.8</td>
<td>-3.8</td>
<td>1054</td>
<td>0.35</td>
<td>0.54</td>
</tr>
<tr>
<td>180</td>
<td>73</td>
<td>11</td>
<td>9.26</td>
<td>0.8</td>
<td>37</td>
<td>1060</td>
<td>0.60</td>
<td>0.70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scheme 9 - 100L:40g salt:0ml HCl</th>
<th>Baseline</th>
<th>After HVS -ECA Water Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>BQ value</td>
<td>122368</td>
<td>&lt;73 (Below the detection limit)</td>
</tr>
<tr>
<td>ATP meter</td>
<td>246</td>
<td>64</td>
</tr>
<tr>
<td>Total Legionella count (cfu/ml) (Setsco lab test)</td>
<td>720</td>
<td>Not detected (After 3 hours of HVS-ECA treatment)</td>
</tr>
<tr>
<td>Heterotrophic plate count (cfu/ml)</td>
<td>110</td>
<td>9</td>
</tr>
<tr>
<td>Total Coliform count (MPN100 ml)</td>
<td>&lt;1.8</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>Total Escheria Coli count (MPN100 ml)</td>
<td>&lt;1.8</td>
<td>&lt;1.8</td>
</tr>
</tbody>
</table>
Testbed HVS-ECA System Conclusion:

- The HVS-ECA Water Treatment System is a pH independent cooling tower non-chemical water treatment system. The pH independence could be attributed to on-site generation of the disinfectants and their freshness in treating the cooling tower water.

- To achieve water microbial disinfection and treatment, it is not a necessity to have very high positive ORP. By careful tuning of the process, it is observed that even with a low ORP, it is possible to eliminate the Legionella and other microbial bacteria. The Total Legionella Count (cfu/ml) was decreased to less than the limit of 10cfu/ml. The heterotrophic plate count was maintained much less than 100,000 cfu/ml.

- Salinity is a very important factor which determine the efficacy of the HVS-ECA process. However, one important consideration is to control the corrosivity of the cooling tower water during the HVS-ECA water treatment process. It is hence, advisable to perform the treatment by an optimal low salinity and low TDS.

To further optimize the HVS-ECA water treatment system, we undertook yet another set of systematic analysis of the disinfection using different concentration of the chloride i.e. by controlling the salinity. Figure 39 shows the variation in BQ versus time with increasing salinity of the cooling tower water. With low concentration of chloride, the disinfection is a slow process. Increased chloride concentration helps to achieve effective and quicker disinfection as is clearly seen in the graph depicted in Figure 39 below. There is practically no action of HVS-ECA water treatment when the cooling tower salinity is 0.4psu. (Experiment Scheme 11). This is reflected in the high BQ value (Experimentally obtained BQ value is 83929) which is much greater than the threshold of (＜15,000) even after 4 hours of HVS-ECA treatment. The kinetics of disinfection is shown in Figure 39, black line profile.
Referring to Table 8A, the salinity of the cooling tower water remains constant at 0.4psu, ORP decreases from 106 to -114mV. TDS as expected remains constant at 580. Free chlorine has a marginal increase from 0.01 to 0.02 - all these data recorded during the HVS-ECA process. The HVS-ECA process generates disinfecting agents even without the addition of NaCl (no increase in salinity). However, the generated disinfecting agents are not in high concentration to be able to quickly realize the required microbial decontamination and destruction of the organic matrix. In Bangalore, since the natural water (the cooling tower makeup water) is chloride-rich and hence, it is just sufficient to generate the active ions to disinfect and remove the scaling.

In Table 8B, the Setsco laboratory tests also confirm the presence of legionella in the cooling tower water treated by HVS-ECA Scheme 11. Eventhough the Total Legionella
Count has decreased from 360 to 140 cfu/ml – it still exceeded the threshold of 10 cfu/ml. This however, confirms the ability of HVS-ECA System to eliminate partially the Legionella bacteria. The heterotrophic plate count increased from 390 to 680 cfu/ml. The observation is surprising. It is thus inferred that at low salinity, the HVS-ECA produced disinfectant are less reactive with the microbial bacteria species, whose concentration is reflected by the heterotrophic plate count. After about 550 minutes of HVS-ECA operation, the BQ value of <15,000 is obtained - this is shown the horizontal purple line graph intersecting the kinetics graph. Hence, HVS-ECA System is able to operate even in the absence of the sodium chloride or pH regulator. However, for practical applications, this kinetics of disinfection is very slow and it is not advisable to use this scheme of operation for Singapore water conditions.

<table>
<thead>
<tr>
<th>Time (Min)</th>
<th>BQ value</th>
<th>ATP value</th>
<th>pH</th>
<th>Salinity (PSU)</th>
<th>ORP (mV)</th>
<th>TDS (ppm)</th>
<th>Free chlorine (ppm)</th>
<th>Total Chlorine (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>275627</td>
<td>203</td>
<td>9.33</td>
<td>0.4</td>
<td>106</td>
<td>549</td>
<td>0.01</td>
<td>0</td>
</tr>
<tr>
<td>80</td>
<td>193778</td>
<td>119</td>
<td>9.32</td>
<td>0.4</td>
<td>11.9</td>
<td>579</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>260</td>
<td>83929</td>
<td>178</td>
<td>9.34</td>
<td>0.4</td>
<td>-114</td>
<td>587</td>
<td>0.02</td>
<td>0.08</td>
</tr>
</tbody>
</table>

**Scheme 11 (NaCl 0gms,Hcl 0ml)**

<table>
<thead>
<tr>
<th>Time (Min)</th>
<th>BQ value</th>
<th>ATP value</th>
<th>pH</th>
<th>Salinity (PSU)</th>
<th>ORP (mV)</th>
<th>TDS (ppm)</th>
<th>Free chlorine (ppm)</th>
<th>Total Chlorine (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>275627</td>
<td>203</td>
<td>9.33</td>
<td>0.4</td>
<td>106</td>
<td>549</td>
<td>0.01</td>
<td>0</td>
</tr>
<tr>
<td>80</td>
<td>193778</td>
<td>119</td>
<td>9.32</td>
<td>0.4</td>
<td>11.9</td>
<td>579</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>260</td>
<td>83929</td>
<td>178</td>
<td>9.34</td>
<td>0.4</td>
<td>-114</td>
<td>587</td>
<td>0.02</td>
<td>0.08</td>
</tr>
</tbody>
</table>

**Scheme 11 100L: 0g salt:0ml HCl**

<table>
<thead>
<tr>
<th>BQ value</th>
<th>ATP meter</th>
<th>Total Legionella count (cfu/ml) (Setsco lab test)</th>
<th>Heterotrophic plate count (cfu/ml)</th>
<th>Total Coliform count (MPN100 ml)</th>
<th>Total Escheria Coli count (MPN100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>275627</td>
<td>360</td>
<td>390</td>
<td>&lt;1.8</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>After laboratory HVS - ECA treatment</td>
<td>83929</td>
<td>140</td>
<td>680</td>
<td>&lt;1.8</td>
<td>&lt;1.8</td>
</tr>
</tbody>
</table>

**Table 8: Scheme 11 Kinetics analysis of HVS-ECA process without the addition of any Sodium chloride and the pH reducing agents**

In Figure 39, the kinetics for the cooling tower water with salinity of 0.5psu (Scheme 10) is shown in red colored line graph. Initially, the kinetics shows a quick decrease in the BQ value, similar to the cooling tower water with 0.6 psu, however, at 200 minutes (~ 3 hours) the BQ value of <15,000 is obtained. This is shown whereby the horizontal purple line graph intersecting with the red colored line of the kinetics graph. However,
after this point the disinfection kinetics gets saturated. This Scheme 10 is not suitable for practical application for treating the Singapore cooling tower water - since firstly it requires 3 hours to reach the BQ limit for microbial free water. Secondly, the stagnating disinfection activity is not desired.

Table 9A shows the Scheme 10 Kinetics Analysis of HVS-ECA process at a salinity of 0.5psu. Under Scheme 10, HVS-ECA treatment process, the salinity of the cooling tower water remains constant at 0.5psu, ORP decreases from 158 to -25mV. TDS increases from 605 to 677. Free chlorine have a marginal increase from 0.00 to 0.03. Hence the HVS-ECA treatment of cooling tower water at 0.5psu is not suitable to be utilized. In Table 9B, surprisingly even though the BQ value for the raw water is high, the Setsco lab test shows no detection of the legionella. However, the heterotrophic plate count is 59, and decreases to 15cfu/ml after HVS-ECA treatment. This shows that even the laboratory testing could be sometimes a mislead. The Mycometer readings are more reliable and consistent in this sense.

### Table 9A: Scheme 10 Kinetics Analysis of HVS-ECA process at a salinity of 0.5psu

<table>
<thead>
<tr>
<th>Time (Min)</th>
<th>BQ value</th>
<th>ATP value</th>
<th>pH</th>
<th>Salinity (PSU)</th>
<th>ORP (mV)</th>
<th>TDS (ppm)</th>
<th>Free chlorine (ppm)</th>
<th>Total Chlorine (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>121267</td>
<td>140</td>
<td>9.34</td>
<td>0.5</td>
<td>158</td>
<td>605</td>
<td>0</td>
<td>0.02</td>
</tr>
<tr>
<td>50</td>
<td>69259</td>
<td>90</td>
<td>9.33</td>
<td>0.5</td>
<td>-15</td>
<td>683</td>
<td>0.02</td>
<td>0.07</td>
</tr>
<tr>
<td>120</td>
<td>28909</td>
<td>-</td>
<td>9.39</td>
<td>0.5</td>
<td>-30</td>
<td>683</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>270</td>
<td>3090</td>
<td>99</td>
<td>9.4</td>
<td>0.5</td>
<td>-25</td>
<td>677</td>
<td>0.03</td>
<td>0.07</td>
</tr>
</tbody>
</table>

### Table 9B: Cycle 11 (Scheme 10 - 100L:10g salt :0ml HCl)

<table>
<thead>
<tr>
<th>BQ value</th>
<th>ATP meter</th>
<th>Total Legionella count (cfu/ml) (Setsco lab test)</th>
<th>Heterotrophic plate count (cfu/ml)</th>
<th>Total Coliform count (MPN100 ml)</th>
<th>Total Escheria Coli count (MPN100 ml)</th>
<th>Baseline</th>
<th>After laboratory HVS - ECA treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>121267</td>
<td>140</td>
<td>Not detected</td>
<td>59</td>
<td>&lt;1.8</td>
<td>&lt;1.8</td>
<td>3090</td>
<td>Not detected, Note: After 4 hours of HVS-ECA treatment</td>
</tr>
</tbody>
</table>

**Table 9: Scheme 10 Kinetics analysis of HVS-ECA process at a salinity of 0.5psu**
The blue line graph in Figure 39 corresponds Scheme 12 with a salinity of 0.6psu. The initial activity is similar to that of Scheme 10. The BQ limiting value of <15000 is reached in approximately 200 minutes. However, unlike the Scheme 10, in Scheme 12, 13 and 14 Kinetics analysis, there is no saturation.

Table 10 shows the BQ value of Scheme 12, 13 and 14 Kinetics Analysis of HVS-ECA process at a salinity of 0.6, 0.8 (40g salt - high) and 0.8 (30g salt - low) psu respectively. The Scheme 13 is by adding 40g NaCl (0.8psu high) and Scheme 14 is by adding 30g NaCl (0.8psu low). The salinity meter does not reflect this change due to the meter resolution being only 1 digit. Hence, we have represented them as high and low respectively.

The kinetics of disinfection results for these Scheme 12, 13 & 14 are summarised in Figure 39 in blue, pink and orange line graphs respectively. Scheme 13 with highest salinity of 0.8psu shows the most rapid disinfection, which is expected. The BQ value of <15000 is achieved in just 20 minutes of HVS-ECA operation. This Scheme 13 shall be taken as the optimal operating conditions for HVS-ECA Water Treatment System.

Figure 40 shows the plot of disinfection duration required to reach the acceptable disinfection (BQ value <15,000) upon the HVS-ECA treatment with cooling tower water of increasing salinity. This graph clearly indicates that HVS-ECA water treatment process with salinity above 0.8 is essential to achieve good and quick disinfection. This is represented by the vertical line in purple color.
Table 10: Kinetics analysis of HVS-ECA process at a salinity of 0.6 psu, 0.8 psu (high) and 0.8 psu (low) respectively.

Figure 40: Time required for acceptable disinfection (BQ value <15,000) after HVS-ECA process with cooling tower water of different salinity.
Since, it is now already established that a BQ value less than 15000 implies that there is no legionella (<10 cfu/ml) or the heterotrophic plate count (<100000 cfu/ml).

Figure 41 shows the Comparative Plot of Bactiquant (BQ), Legionella Count (LD), Heterotrophic Plate Count (HP) and ATP RLU count (ATP).

- The higher the BQ value, the higher the LD and HP. This is quite expected. The BQ is an indication of the total bacteria content in the water. It is advisable to use only one method as a reference rather than relying on many methods. Hence, for the test bed, we have extensively used only the Mycometer monitoring protocol.
- There is no linearity between the measured BQ, LD and HP. Such a non-linearity is expected since there is a time lag in the measurements. This makes it difficult to estimate the exact value of BQ which corresponds to a LD value of 10 cfu/ml. However, a lower value of BQ in the range <30000 corresponds to 0 cfu/ml (not detected) of total LD.

Figure 41: Comparative plot of Bactiquant (BQ), Legionella count (LD), heterotrophic plate count (HP) and ATP RLU count (ATP). It is advisable to use only one method as a reference rather than relying on many methods.
Excellent and quick disinfection is observed when salinity is in range of 0.8psu. The HVS-ECA process creates large volumes of a gentle but extremely potent anti-microbial solution capable of rapid reduction of bacteria, viruses, spores, cysts, scale and biofilm. The HVS-ECA process is cost-effective to produce, greener than traditional chemical technologies. The disinfecting oxidizing agents in the HVS-ECA process are due to a mixture of free radicals, giving it an anti-microbial effect.

![Image of HVS-ECA equipment and corrosion measurements](image)

**Figure 42:** Corrosion measurements
- Total Dissolved Solid (TDS) versus Salinity
- Corrosion Rate versus Salinity
Figure 43: HVS-ECA laboratory test reactor with scale formation on the electrode. Collection of the scale at the cyclone chamber.
The core technology of HVS-ECA System for scale removal is predicated on a unique electrochemical process for the production of an oxidant solution containing HOCl (hypochlorous acid) whose activity is pH independent and can effectively mitigate biofilm formation by killing off bacteria.

Biofilm typically facilitate the scale deposition by acting as nucleation site. Biofilm is normally sticky and gel-like and will trapped precipitated scales and other suspended solids floating in the bulk water. Once some solid particle of scales are entrapped on the biofilm, rapid and accelerated scale deposition will occur. The unique activity of HVS-ECA chemistry serves to prevent nucleation on any wetted surfaces through the prevention.

**Phase 2:- Live testing of HVS-ECA at JTC CleanTech One cooling tower site**

Integrated HVS-ECA System along with HVS Automatic Tube Cleaning System was tested at JTC CleanTech One. Detailed onsite study to evaluate the integrated system performance was carried out for the Cooling Tower 1. Other cooling towers were not operated during this testbed period. This arrangement was necessary as this project is sized to meet the requirements of only one cooling tower during continuous operation. The operational optimization analysis is achieved by incorporating all the necessary monitoring system such as water quality, water disinfection efficacy, observation of biofilm formation, water temperature, energy and water consumption for the cooling tower in the building. Comparison between the parameters of the JTC CleanTech One cooling tower before and after the installation of the HVS-ECA system are detailed in this section.

The HVS-ECA System reaction chamber was connected to the cooling tower water system via a HVS Automatic Tube Cleaning System circulation pump and the cooling tower water was circulated to the HVS-ECA System reaction chamber and back to the cooling tower water distribution system. The chemical-free HVS-ECA module was connected to the cooling water system externally so no intervention and stoppages in the cooling system is needed. This significantly reduced installation costs and time.
The HVS-ECA reaction chamber has two electrodes acting as cathode and anode. The scale collected at the cathode can be periodically washed out using pressuring and pressurized water. (Presence of remaining scale was removed using 2% HCl water is required to flush out and remove the scale)

Figure 44 shows the typical installation of the HVS-ECA system along with the HVS Automatic Tube Cleaning System. The new upgraded HVS Automatic Tube Cleaning System with the HVS-ECA module was placed in a nearby position.

Figure 44: Installation of HVS Auto Tube Cleaning System combined with the HVS-ECA system for complete treatment of building HVAC requirements.
Throughout the test period, flowing condenser water samples was monitored for instantaneous corrosion using Nalco Corrosion Monitor (NCM100). Figure 46 shows the graph of corrosion (mpy) versus the monitoring period. The corrosion remained constant all through the testbed duration and the value is within the corrosion threshold of the PUB water.
The TDS is monitored to maintain a predefined COC in the circulating water before auto blow down is activated. However, the corrosion monitor is a better gauge to determine the blow down requirement. The online corrosion monitor was very much reliable and showed values equaling to the PUB water. The automatic blow down was scheduled to happen when the TDS reaches the limit of 1500 ppm. Referring to Figure 47, this limit was never reached during the testing period.
During the pre-HVS-ECA monitoring period from 16 Nov 2015 to 8 Dec 2015, the TDS of Cooling Tower 1 has increased from 225ppm to 350ppm - a 60% increase of TDS over a period of 23 days. We will expect the TDS to gradually increase over time.

After the installation of HVS-ECA system, during the post-HVS-ECA monitoring period from 3 Oct 2016 to 2 Nov 2016, the TDS of Cooling Tower 1 has increased from 950ppm to 1200ppm - a mere 28% increase of TDS over a period of 30 days (Please refer to Figure 47).

It is to be noted that the rate of TDS built-up is reduced by approximate 2 times with post-HVS-ECA System (28% increase basing on absolute TDS value) as compared to pre-HVS-ECA System (60% increase basing on absolute TDS value) for Cooling Tower 1 continuous operation over a period of 30 days.

From our systematic study, the corrosion rate during the testbed period from 3 Oct 2016 to 2 Nov 2016 is maintained at a very low level of 0.14 mpy. Hence, it is concluded that salinity of 0.8psu is optimum to operate the HVS-ECA System without increasing risk of corrosion to the cooling tower system.
Figure 48 shows the In-line salinity (psu) being monitored during the testbed window period from 3 Oct 2016 to 2 Nov 2016.

![Salinity (psu) monitoring during the testbed monitoring window](image)

Figure 48: Salinity (psu) monitoring during the testbed monitoring window

Figure 49 shows the pH monitored during the testbed window period from 3 Oct 2016 to 2 Nov 2016. The pH is constant throughout the study period. The pH is always less than 9.5. The pH monitoring helps to effectively estimate the dosage of the free chlorine. This can be achieved by changing the current density or by increasing the number of HVS-ECA chambers as required. These issues, however, were not experimented during the present testbed exercise as these optimization protocol are beyond the mandate of the current testbed project.

The free chlorine generated on-site was measured to be in range of <0.06ppm of free chlorine and <0.06 ppm of total chlorine at all times during the entire test bed period from 3 Oct 2016 to 2 Nov 2016. The free chlorine generated at the outlet of the HVS-ECA system was >8.8ppm and the total chlorine was also always >8.8ppm. The rapid decrease and the recorded low free chlorine (<0.06ppm) of the cooling tower basin water reflects a strong indication of the large bacteria and organic matrix load being present in the bulk water system.
Free chlorine monitored data is the main indicator for the active loopback to the operating system to optimally generate HOCl – the active disinfecting agent. In our laboratory experiments, we have found that even with lower ORP, it is possible to achieve good disinfection. The loopback is performed by increasing the salinity as and when required for increasing the current density or the number of electrode chambers in series. A constant and optimized ORP reading of 150 ~ 200 mV is maintained in the water line (Please refer to Figure 50). The ORP and pH meters are always measured on-site to make the data highly objective and do not have wrong readings due to time lag. The recording and feedback were performed on a weekly basis since drastic changes were not observed and we just need a trending view.

Figure 49: pH monitoring during the testbed monitoring window
Mycometer BQ values is observed to be stabilised in the range of 20000 to 30000 towards the end of the testbed period from 3 Oct 2016 to 2 Nov 2016. (Please refer to Figure 51). Initially the BQ value was in the range 50000 to 60000 which then decreased upon continued side stream HVS-ECA treatment of the cooling tower basin. The initial increase could be due to the sudden release of the microbial load from the already formed biofilm. However, as time progresses, these microbial load would be disinfected by the HVS-ECA System over time and the BQ value is expected to decrease as HVS-ECA Water Treatment progresses.

The targeted BQ value to reach is <15,000 ~ 25,000 and it is expected to decrease to the desired range over the next few weeks with the continuous HVS-ECA operation.
On 4 Nov 2016, upon the completion of the full fledge testbedding cycle, HVS-ECA treated water samples with a measured BQ value of 30000 were sent to Setsco for bacteria and Legionella testing and verification.

Appended below is the full Setsco Report that correlate well with the Mycometer BQ value. It has been confirmed that Legionella is not detected which strongly supports the fact that HVS-ECA Water Treatment System is performing well as designed.
TEST REPORT
(This Report is issued subject to the terms & conditions set out below)

Your reference No.: –
Our reference No.: FB122534/A

DATE : 10/11/2016
TESTED FOR : HVS Engineering Pte Ltd
1 Bukit Batok Crescent
#09-45 WCEGA Plaza
Singapore 658064
Attn: Mr Alex

DATE SAMPLE RECEIVED : 04/11/2016
DATE COMMENCED : 04/11/2016
SAMPLE DESCRIPTION : Water sample was received from HVS Engineering Pte Ltd with the following references:

<table>
<thead>
<tr>
<th>SAMPLE ID NO.</th>
<th>SAMPLE DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>FB122534001</td>
<td>Clean Tech One: HVS-ECA System (Cycle 23 - Far End Cooling Tower 1)</td>
</tr>
</tbody>
</table>

RESULTS : On analysis, the following results were obtained:

<table>
<thead>
<tr>
<th>SAMPLE DESCRIPTION</th>
<th>METHOD</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Bacteria Count</td>
<td>(cfu/ml)</td>
<td>APHA 9215B</td>
</tr>
<tr>
<td>Total Coliform Count</td>
<td>(MPN/100ml)</td>
<td>APHA 9222B</td>
</tr>
<tr>
<td>Total Escherichia coli Count</td>
<td>(MPN/100ml)</td>
<td>APHA 9222G</td>
</tr>
</tbody>
</table>

Remarks:
2. Environmental Public Health (Cooling Towers and Water Fountains) Regulations 2001: Legionella Count not exceeding 100cfu/ml

Detection limit for Legionellae is 1 cfu/ml

Results highlighted in Bold exceeded the specified limit

LEI ZHI PEI
SENIOR MANAGER

BIOLOGICAL & CHEMICAL TECHNOLOGY DIVISION
TEST REPORT

(This Report is issued subject to the terms & conditions set out below)

Your reference No.: –
Our reference No.: FB122536/A

DATE : 10/11/2016
TESTED FOR : HVS Engineering Pte Ltd
1 Bukit Batok Crescent
#09-45 Weega Plaza
Singapore 658064
Attn: Mr Alex

DATE SAMPLE RECEIVED : 04/11/2016
DATE COMMENCED : 04/11/2016

SAMPLE DESCRIPTION : Water sample was received from HVS Engineering Pte Ltd with the following references:

<table>
<thead>
<tr>
<th>SAMPLE ID NO.</th>
<th>SAMPLE DESCRIPTION</th>
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<tbody>
<tr>
<td>FB122536001</td>
<td>Clean Tech One: HVS-ECA System (Cycle 23 - Near End Cooling Tower 1)</td>
</tr>
</tbody>
</table>

RESULTS : On analysis, the following results were obtained:

<table>
<thead>
<tr>
<th>SAMPLE DESCRIPTION</th>
<th>METHOD</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Bacteria Count (cfu/ml)</td>
<td>APHA 92158</td>
<td>9600</td>
</tr>
<tr>
<td>Total Coliform Count (MPN/100ml)</td>
<td>APHA 9222B</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>Total Escherichia coli Count (MPN/100ml)</td>
<td>APHA 9222G</td>
<td>&lt;1.8</td>
</tr>
</tbody>
</table>

Remarks:
2. Environmental Public Health (Cooling Towers and Water Fountains) Regulations 2001: Legionella Count not exceeding 50 cfu/ml
3. Detection limit for Legionella is 1 cfu/ml

Results highlighted in bold exceeded the specified limit.

LEI ZHI PEI
SENIOR MANAGER

BIOLOGICAL & CHEMICAL TECHNOLOGY DIVISION

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1. The Report is prepared for the use of the Client and is prepared based upon the data submitted, the services rendered by the Client and the conditions under which the services are performed by SETSCO. The Report is not intended to be exhaustive of the Client’s services performed or accuracy of the data or the condition of the Client’s services performed. The report does not constitute any endorsement by SETSCO of the Client.
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3. The Report may be used by the Client or by any other entity as may be required by the Client.
4. SETSCO shall not be liable to the Client for any services or representations, in respect of, but including negligence or breach of statutory duty or omissions or any other privity or duty or event or of any errors or omissions for any services provided by SETSCO.

HVS-Electrochemical activation (ECA)
**HVS Electrochemical activation (ECA)**

**TEST REPORT**

(This Report is issued subject to the terms & conditions set out below)

**Your reference No.:**

**Our reference No.: FB122534/B**

**DATE:** 19/11/2016

**TESTED FOR:** HVS Engineering Pte Ltd

1 Bukit Batok Crescent

#09-45 WCEGA Plaza

Singapore 658064

Attn: Mr Alex

**DATE SAMPLE RECEIVED:** 04/11/2016

**DATE COMMENCED:** 04/11/2016

**SAMPLE DESCRIPTION:** Water sample was received from HVS Engineering Pte Ltd with the following references:

<table>
<thead>
<tr>
<th>SAMPLE ID NO.</th>
<th>SAMPLE DESCRIPTION</th>
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<tbody>
<tr>
<td>FB122534001</td>
<td>Clean Tech One: HVS-ECA System (Cycle 23 - Far End Cooling Tower 1)</td>
</tr>
</tbody>
</table>

**RESULTS:** On analysis, the following results were obtained:

<table>
<thead>
<tr>
<th>SAMPLE DESCRIPTION</th>
<th>METHOD (cfu/ml)</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legionella Pneumophila SG 1</td>
<td>AS/NZS 3896:1998</td>
<td>Not Detected</td>
</tr>
<tr>
<td>Legionella Pneumophila SG 2-14</td>
<td>AS/NZS 3896:1998</td>
<td>Not Detected</td>
</tr>
<tr>
<td>Other Legionella spp.</td>
<td>AS/NZS 3896:1998</td>
<td>Not Detected</td>
</tr>
<tr>
<td>Total Legionella Count</td>
<td>AS/NZS 3896:1998</td>
<td>Not Detected</td>
</tr>
</tbody>
</table>

Remarks:

- Environmental Public Health (Cooling Towers and Water Fountains) Regulations 2001: Legionellae Count not exceeding 10 cfu/ml
- Detection limit for Legionellae is 1 cfu/ml

**LEI ZHI PEI**

**SENIOR MANAGER**

**BIOLOGICAL & CHEMICAL TECHNOLOGY DIVISION**

---

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2. SETSCO reserves the right to refuse to perform the Services if the services, fees, charges, and/or any other conditions are not in accordance with the specifications of the Services.

3. SETSCO shall not be responsible for any loss, injury, or damage caused by the services performed by SETSCO, the Services provided by SETSCO, or the Services themselves.

4. The Client shall indemnify SETSCO against all claims, losses, damages, and expenses arising from or in connection with the Services provided by SETSCO.

5. The Client shall indemnify SETSCO against all claims, losses, damages, and expenses arising from or in connection with the Services provided by SETSCO.

6. The Client shall indemnify SETSCO against all claims, losses, damages, and expenses arising from or in connection with the Services provided by SETSCO.
TEST REPORT

(This Report is issued subject to the terms & conditions set out below)

SETSCO Services Pte Ltd
18 Telok Blangah Crescent
Singapore 068925
Tel: (65) 6555 7777
Fax: (65) 6555 7716
www.setsco.com

Your reference No.: ~
Our reference No.: FB122536/8

DATE:
15/11/2016

TESTED FOR:
HVS Engineering Pte Ltd
1 Bukit Batok Crescent
#09-45 WCEGA Plaza
Singapore 658064
Attn: Mr Alex

DATE SAMPLE RECEIVED:
04/11/2016

DATE COMMENCED:
04/11/2016

SAMPLE DESCRIPTION:
Water sample was received from HVS Engineering Pte Ltd with the following references:

<table>
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<th>SAMPLE ID NO.</th>
<th>SAMPLE DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>FB122536001</td>
<td>Clean Tech One: HVS-ECA System (Cycle 23 - Near End Cooling Tower 1)</td>
</tr>
</tbody>
</table>

RESULTS:

On analysis, the following results were obtained:

<table>
<thead>
<tr>
<th>SAMPLE DESCRIPTION</th>
<th>METHOD</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legionella Pneumophila SG 1 (cfu/ml)</td>
<td>AS/NZS 3896:1998</td>
<td>Not Detected</td>
</tr>
<tr>
<td>Legionella Pneumophila SG 2-14 (cfu/ml)</td>
<td>AS/NZS 3896:1998</td>
<td>Not Detected</td>
</tr>
<tr>
<td>Other Legionella spp. (cfu/ml)</td>
<td>AS/NZS 3896:1998</td>
<td>Not Detected</td>
</tr>
<tr>
<td>Total Legionella Count (cfu/ml)</td>
<td>AS/NZS 3896:1998</td>
<td>Not Detected</td>
</tr>
</tbody>
</table>

Remarks:
* Environmental Public Health (Cooling Towers and Water Fountains) Regulations 2001; Legionella Count not exceeding 100cfu/ml
Detection limit for Legionella is 1 cfu/ml

LEI ZHI PEI
SENIOR MANAGER

BIOLOGICAL & CHEMICAL TECHNOLOGY DIVISION

Terms & Conditions:

(1) The Report is prepared for the sole use of the Client and is prepared based upon the data submitted by the Client. The data is submitted by the Client and is not verified by the Client.
(2) The results are representative of the samples tested and are based on the samples submitted by the Client. The results are not guaranteed to be representative of the entire system or facility.
(3) The Client is responsible for ensuring that the samples submitted are representative of the entire system or facility.
(4) The Client is responsible for ensuring that the samples submitted are representative of the entire system or facility.
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Below is the summarised results:

<table>
<thead>
<tr>
<th>Report Date</th>
<th>Sample ID</th>
<th>Bacteria/Legionella Type Tested</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/11/2016</td>
<td>Cooling tower 1 water (Far End) (FB122534001- 4 Nov)</td>
<td>Total Bacteria count (cfu/ml)</td>
<td>620</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Coliform count (MNP/100 ml)</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Escheria Coli count (MNP/100 ml)</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>10/11/2016</td>
<td>Cooling tower 1 water (Near End) (FB122534001- 4 Nov)</td>
<td>Total Bacteria count (cfu/ml)</td>
<td>9600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Coliform count (MNP/100 ml)</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Escheria Coli count (MNP/100 ml)</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>16/11/2016</td>
<td>Cooling tower 1 water (Far End) (FB122536001- 4 Nov)</td>
<td>Legionella Pneumophila SG1 (cfu/ml)</td>
<td>Not Detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Legionella Pneumophila SG2-14 (cfu/ml)</td>
<td>Not Detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other Legionella spp (cfu/ml)</td>
<td>Not Detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Legionella Count (cfu/ml)</td>
<td>Not Detected</td>
</tr>
<tr>
<td>16/11/2016</td>
<td>Cooling tower 1 water (Near End) (FB122536001- 4 Nov)</td>
<td>Legionella Pneumophila SG1 (cfu/ml)</td>
<td>Not Detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Legionella Pneumophila SG2-14 (cfu/ml)</td>
<td>Not Detected</td>
</tr>
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<td>Not Detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Legionella Count (cfu/ml)</td>
<td>Not Detected</td>
</tr>
</tbody>
</table>

Table 20: Post HVS-ECA System (Microbial Report by Setsco)
Figure 52 shows the XRD analysis for scale after the HVS-ECA treatment. The scale sample (after HVS-ECA treatment) crystallises into a mixture of aragonite and calcite polymorph of the CaCO3 crystallization. All the peaks corresponding both the aragonite and calcite phase are clearly identified. This is as expected basing on our earlier hunch.

Figure 52: XRD analysis for scale after HVS-ECA treatment
Figure 53 shows the XRD analysis for scale before the HVS-ECA treatment. Scale sample (before HVS-ECA treatment) crystallises predominantly into the calcite polymorph of the CaCO3 crystallization. All the peaks corresponding the calcite phase are clearly identified. This evidence confirms our earlier assertion.

![XRD analysis for scale before the HVS-ECA treatment](image)

**Figure 53: XRD analysis for scale before the HVS-ECA treatment**

The findings of the XRD analysis further supports the fact that HVS-ECA treatment is able to soften scale for ease in removal as well as scale mitigation by getting rid of biofilm. The HVS-ECA process is hence able to alter the structural characteristics of the scale deposits. We can see preferencial development aragonite crystals facilitating scale mitigation mechanisms due to the HVS-ECA process.
The scanning electron microscopy (SEM) images also clearly confirm the XRD results. The signature needle-like structure of the aragonite CaCO3 crystals are prominently visible in the scale produced during the HVS-ECA process. Figure 150 shows the SEM images of the scale after HVS-ECA treatment.

Figure 54: SEM analysis for scale after HVS-ECA treatment
However, in Figure 55, the SEM images of the scale taken from sample before HVS-ECA treatment shows clearly the calcite phase of the CaCO3. Moreover the fibrous organic matrix which is the nucleating sites for the scale formation can also be observed. From this objective evidence, HVS-ECA treatment can very well remove such organic nucleating matrix and help in the scale mitigation.
Figure 56 and Figure 57 shows the Thermo Gravimetric Analysis of the scale samples after and before HVS-ECA treatment respectively. The scale sample tested before HVS-ECA treatment shows the organic endothermic peak at low temperature. Such a peak is clearly not visible in the samples after the HVS-ECA process. This scientific evidence clearly confirms the removal of organic matrix by HVS-ECA process – resulting in an efficient scale mitigation protocol.
Small amounts of chlorine and hydrogen gas are produce during the treatment process. These gases are dissolved in the circulating cooling water and they will be aerated and dispersed safely at hot water basin and at the infills of the cooling tower. Most of the chlorine gas will be consumed by oxidation with bacteria and the rest is immediately absorbed in the water.

In the HVS-ECA System, it is strongly advised not to run the electrolysis process without water circulating through the reaction tank to prevent chloride and hydrogen gas build up. Typically, a residue of chlorine of < 0.05 ppm will be present in the tower discharge water - which is well below the regulatory limit.

Along with accelerated scale deposition, collection and disposal at the reactor, there are additional benefits derived from continuous side stream electrolysis. The loosely packed crystals of scale that are formed with rapid forced precipitation of calcium carbonate facilitate capture, co-precipitation and adsorption of organic contamination. Organic contamination is troublesome due to its microbial nutrient potential. Since there is direct correlation between organic loading (‘food’ for bacteria) and biomass development, any captured or removal of organics is beneficial in limiting biofilm and biomass formation.

HVS-ECA Technology is a chemical-free online water treatment system developed primarily for cooling tower applications. HVS is fine-tuning the mineral scale removal mechanism with the electro-chemical activated water on a sub-stoichiometric. This means that a relatively low concentration of electrolyzed water is capable of mitigating large amounts of scale deposit.

Considering the above existing drawbacks and limitations of the current chemical treatment and mechanical online water treatment technology, HVS has embarked on developing and adapting HVS-ECA System for cooling tower water treatment thereby reducing the discharge of chemicals into our waterways. The HVS-ECA System can generate onsite on-demand a slew of harmless active oxidants to descale, sanitize and remove the biofilm.
Innovative Features of HVS-ECA System

HVS-ECA System chemical-free water treatment has the following innovative features and advantage over the conventional chemical treatment regime:

- **The HVS-ECA System onsite on-demand generated hypochlorites can react with the scale and biofilm in sub-stoichiometric proportions.** The drawback of current conventional online chemical treatment process is that the chemicals react stoichiometrically - that is, more chemical will need to be added in direct proportion to remove more of the water hardness, total dissolved solids (TDS), total suspended solids (TSS), etc.

- **HVS-ECA System is a chemical-free water treatment approach which do not use any toxic chemicals.** As such, HVS-ECA System presents a very low degree of corrosion potential. The major drawback to the current on-line chemical cleaning regime is the increased corrosion potential of the chemical cleaning solutions. Draining, rising and neutralization of cleaning solutions are necessary to prevent unacceptable corrosion.

- **The HVS-ECA System electrolyser powered by a pulsed DC power source is 60% more efficient** than the conventional electrolysers which operate with a DC power only.

- Easy operation
- Low maintenance.
- HVS-ECA System is fully modular
- Minimum handling.
- Small footprint
- No usage of chemicals to treat cooling tower water.
- No handling and movement of hazardous chemicals are required.
- Low energy Consumption
- Leaves no synthetic chemical residue
- Green technology
- Environmentally friendly
**Benefit of HVS-ECA Technology**

Efficient operation of cooling tower would result in a good heat exchange process in air-conditioning system for energy efficiency and water saving. With the incorporation of the new electrochemical cooling tower water treatment module HVS-ECA System coupled with the HVS Automatic Tube Cleaning System, an energy savings of between 5% and 15% as well as a potential water savings of between 20% and 40% can be achieved (surpassing today’s Green Mark Platinum Buildings requirement).

**Scale and Corrosion Control:**
- All scaling salts precipitation occurs in the reaction chamber.
- Mitigate scale in the heat exchanger and the cooling tower systems.
- Mitigate corrosion potential due to controllable pH and low aggression of water.

**Longer system lifespan:**
- Cooling tower system and chiller works better, longer with low maintenance.

**Full control and supervision:**
- Performance is monitored with complete control of all the cooling tower water quality parameters.
- Operation and maintenance of the HVS-ECA System is user-friendly and fully automated (future models), due to its self-cleaning and self-calibrating design configuration. The operation parameters and key input & output data of HVS-ECA System is managed by a proprietary HVS Data Acquisition System (DAS) and manipulation of the DAS can be done by GSM technology and through the internet protocol (future models). Upon installation of the new HVS-ECA System, a saving of 60% on operational cost by means of savings on chemicals purchase, decrease the water usage, lower energy and labour costs is anticipated.
Summary & Conclusion

Using a unique electrochemical process, HVS-ECA System has successfully designed and developed an efficient and cost-effective solution to deal with the problems associated with cooling water systems without using harmful chemicals.

HVS has successfully completed the testbed in Singapore and is ready to introduce to market the state-of-art novel HVS-ECA System which can produce environmental-friendly disinfectants in the form of active oxidants to replace the traditional standard biocide chemicals to kill water-borne bacteria and mitigate calcium and magnesium scale without the use of harsh chemicals.

HVS-ECA System has also successfully been integrated to the HVS Auto Tube Cleaning System to provide one-pot HVAC water solution.

Potential application of HVS-ECA System are as follows:

- HVAC Water Treatment System
- Oil Rigs & Platforms process water
- Oil Refineries Process water
- Mining Industries Process water
- Offshore Process water treatment
- Power Plant cooling water treatment
- Petrochemical cooling water treatment
- Boiler Feed Water Treatment System
- Industries Using Fire Water Systems
- Cooler Water Treatment System
The successful outcome of the HVS-ECA Systems could be deployed to any potential sources of legionella/bacteria as follows:

- Cooling Tower
- Evaporative Condenser
- Humidifiers
- Hot and Cold Water Systems
- Hot Tubs and Heated Swimming Pools
- Natural Thermal Springs and their distribution systems
- Respiratory and other medical therapy equipment
- Drinking Fountains/Decorative Fountains/Sprinklers
- Water Cooled Machine Tools
- Car Washes
- Any untreated body of water that may exceed 70°F that could be splashed, sprayed or aerosolized.
- Any system that contains water that may exceed 70°F and could emit a spray or aerosol during their operation or maintenance.

Commercial Interest Generated for HVS-ECA System

Pre-commercialization marketing of HVS-ECA System has generated commercial interest for early adoption. HVS will closely follow-up with these leads and start doing the commercial agreements upon finalizing the full HVS-ECA design.

- Sumitomo Corporation Japan
- Asia Pacific Brewery Singapore,
- Coco Cola Manufacturing, Singapore
- Makino Asia, Singapore
- Halliburton Singapore
- Abbot Manufacturing
- GSK Singapore
- SSMC Singapore
- Bharath Mall, India
- Infosys, India
- Lulu Mall, India
- Sheraton hotel, India
- Park Plaza, India
- Dyna Aircon PVT. LTD, India
- Sri Infra Consultants Pvt Ltd, India
- Mint water, India