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Paper Session III-A - NASA Technology Provided Alternative Water Purification Method for Domestic Use

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ABSTRACT

A need for a simple and effective method of providing biologically safe potable water on the Shuttle Program resulted in the development of the Microbial Check Valve (MCV®[1]). Subsequently, the need for extended duration potable water microbiological treatment on the proposed International Space Station required the development of the Regenerable Microbial Check Valve (RMCV). This paper will describe the technology relating to this development and discuss the commercial potential of the devices.

The MCV® is a flow through canister containing iodinated ion exchange resin. It provides a means to disinfect the Space Shuttle fuel cell produced water prior to its stowage and use as drinking water. The MCV® produces a significant contact kill of a broad variety of microorganisms and additionally provides a controlled release of biocidal concentrations of elemental iodine into the flowing water stream. Similar devices are used as bacterial filters to prevent back contamination of the water supply when cooling water is supplied to the Extravehicular Mobility Units (EMU) used by astronauts during spacewalks. The patented RMCV provides for in situ replenishment of the iodine in the resin bed. This will make the RMCV useful for protracted use in the International Space Station when extended space occupancy is planned.

The basic MCV® technology is currently being applied in terrestrial water purification systems ranging in size from portable travel filters and countertop units for home use to 15 gpm units for schools, hospitals, and other community facilities in third world nations. The RMCV with its improved cost effectiveness is being developed for significantly larger applications up to small city size.

The development of the MCV® and RMCV technology are examples of how a space flight need has led to the development of technology that has commercial terrestrial applications. The technology developed in this instance provides for a simple, effective and reliable means of providing microbially safe drinking water in a variety of applications.

1.0 INTRODUCTION

The Microbial Check Valve (MCV®) is a passive device used to significantly reduce microbial populations in water. It acts as a contact biocide and also maintains

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[1]MCV® is a registered trademark of Umpqua Research Company.

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long-term microbial control by providing a persistent iodine residual in the water that passes through it. The device, acting as a contact biocide, has been shown to decrease the concentration of a variety of microorganisms normally associated with potable water (Reference 1) by several orders of magnitude. Even lower microbial concentrations (in the range of <1 CFU/100 ml) cen be achieved by lower flow rates, but more importantly by subsequent I_2 contact time. Therefore, different models of the device have been designed to each impart a different concentration of residual iodine at a predetermined design level in the range 0.5 to 8 ppm.

The active portion of the MCV® is a bed of iodinated polymer resin beads. Water passed through the bed attains an equilibrium iodine concentration essentially independent of flow rate over a wide range. The specific baseline equilibrium concentration of iodine can be preset by adjusting the characteristics of the base polymer, the manufacturing procedure, the total throughput, and the operating temperature.

2.0 HISTORY

An early description of a halogenated ion exchange resin for the disinfection of water is found in a patent assigned to the Dow Chemical Company in 1969 (Reference 2). This patent describes the use of a resin impregnated with any halogen (including iodine) at a level that imparts 5-1000 ppm of the active halogen to the water, and subsequently removing the halogen with a second untreated bed of resin.

In 1970, Kansas State University (KSU) (Reference 3) reported a resin that contained a stoichiometric amount of triiodide ion that deactivated a number of bacteria and did not impart a measurable iodine residual to the water. The first of several petents covering this resin was published in 1974.

In 1976 Umpqua Research Company (UMPQUA) was awarded a contract by NASA/JSC to develop a device to prevent the back contamination and/or cross contamination of water lines in the Space Shuttle. This is the origin of the term Microbial Check Valve. UMPQUA considered a variety of approaches, including hollow fiber membranes and the zero residual triiodinated resin developed at KSU. The iodinated resin concept was selected for further development, and samples of the resin were provided by KSU. These resins imparted an I_2 residual of less than 0.25 mg/l to deionized water, which was considered to be an inadequate level to effect microbial control in the effluent and distribution system. Samples were also evaluated from a company licensed to manufacture the KSU resin. These commercial samples were found to impart widely variable amounts of iodine to the weter. Modifications of the resin preparation procedures by UMPQUA soon produced a resin that imparted a predictable iodine residual to the water, approximately 2 ppm, that was not markedly affected by flow rate. This resin was shown to be effective at devitalizing a wide variety of microorganisms during the development program.

Microbial challenges were made with individual suspensions of seven different representative microorganisms and a mixed suspension that contained all seven of the organisms. The organisms used represented types that had previously been found in the water and wastewater systems of manned space flights and manned chamber tests, or were considered to represent "worst case" possibilities. They included: Grampositive rods, Gram-negative rods, obligate anaerobes, spore formers, Fungi and enterovirus. The actual microbial suspensions used in the challenges are summarized in Table 1 (from Reference 1).

NASA selected the concept of a Microbial Check Valve, containing the resin that produced a predictable iodine residual, as the baseline biocide dispenser for the potable water system of the Space Shuttle. A smaller unit was also chosen to serve as an interface between the Extravehicular Mobility Units (EMU) charging system and the potable and waste water tanks.

TABLE 1.

CHALLENGE ORGANISMS	TEMP. °F	CONCENTRATION OF CHALLENGE ORGANISMS COMPLETELY REMOVED Number/ML
Escherichia coli	35 70	10^6 10^6
Streptococcus faecalis	35 70	10^6 10^6
Staphylococcus aureus	35 70	10^6 10^6
Bacillus subtilis	35 70	10^6 10^6
Pseudomonas aeruginosa	35 70	10^6 10^6
Clostridium perfringens	35 70	10^4 10^4
Aspergillus niger	35 70	10^5 10^5
7 Organism Mixture	35 70	10^6 10^6
Poliovirus, Type 3	35 70	10^4 10^4
Reovirus, Type 1	35 70	10^4 10^4
Adenovirus, Type 2	70	10^4

3.0 SPACE SHUTTLE MICROBIAL CHECK VALVE

Electrical energy on board the Shuttle Orbiter is provided by fuel cells which combine gaseous hydrogen and oxygen to produce electricity and chemically pure water as a byproduct. This is the only source of water for crew and other demands. Water from the fuel cell is collected in several tanks. Before being stored in the primary tank it passes through the flight Microbial Check Valve shown in Figure 1. All water consumed by the crew is taken from the treated tank, while the excess is stored in untreated tanks. Prior to launch the entire water system is preconditioned with a nominally 30 ppm iodine solution, and preflight samples historically show virtually no microbial contamination. Post flight samples from the treated tank also reliably show less than 1 CFU per 100 ml, however samples from the untreated tanks consistently show levels of contamination on the order of 10^3 to 10^5 CFU/100 ml.

4.0 EMU RECHARGE FILTER

The EMU commonly referred to as back packs rely on the evaporation of water to provide cooling for the space suit. The evaporator requires water free of particles including microorganisms. A small cartridge containing a 5 micron particle filter and MCV® resin is used to guarantee particle free water when charging the back pack. After each use, the water remaining in the EMU is drained to the Shuttle waste water tank through an identical filter. In this instance the filter is intended to function as a microbial check valve: preventing the possibility of back contamination from the waste water tank.

5.0 TERRESTRIAL APPLICATIONS

Over one-and-a-half billion people worldwide lack daily access to safe drinking water. Microbial related diseases such as dysentery, cholera, typhoid and others combine to form the world's number one health issue. Decades of neglect, chemical contamination and sewage pollution, have seriously diminished the supply of this most precious resource. Despite increases in the percentage of people supplied with safe water and adequate sanitation, growing numbers of people still remain without access to these basic services due to population increase. The interrelationship between health and development and between national and international health issues is clear. For example, it was estimated that the outbreak of cholera in Peru could have cost that impoverished economy up to U.S. $1 billion in 1991 as a result of reduced economic activity, losses in the fishing, agriculture and tourism sectors, unemployment, reduction of exports, and general health infrastructure costs (Reference 4).

Direct correlation between life expectancy and infant mortality with clean water supplies has repeatedly been demonstrated. Eighty percent of disease in developing countries is from water-borne sources. Over three million deaths of children under age five and over one million adults result from diarrheal diseases each year. Over one-third of hospital admissions in some developing countries are for the treatment of diarrheal disease placing a heavy burden on limited health budgets.

Two distinct types of devices utilizing MCV® resin are currently being developed by a number of companies: purifiers intended for short term uses, and long term or permanent installations. The major difference in devices intended for these two applications is the requirement for the removal of all traces of iodine and iodides if the use is intended to be long term. This requirement is not a problem in some parts of the world where iodine deficiency in the diet is a major concern, and active measures are being taken to provide iodine as a dietary supplement. As many as 400 to 800 million people around the world are at risk of health complications resulting from the lack of iodine (Reference 5). Larger commercial systems can be adjusted to provide a controlled blend of pre-iodine removal and post-iodine removal water streams to provide the World Health Organization recommended minimum daily intake of 100 micrograms of iodine per capita per day.

In the United States the EPA has declared that any disinfectant material or device is a pesticide, and is subject to regulation under the FIFRA (Referance 6). They have further taken the position that devices that leave a measurable iodine residual in the water will only be approved for short term, recreational or emergency use. Further the device must be tested to show a six log reduction in bacteria, and four log reductions in virus and three log reductions of cysts (currently *Cryptosporidium*) over the claimed life of the device under several worst case conditions (Reference 7).

To date the principal need for water purification devices is outside of North America. Thus the majority of manufacturers developing devices, using MCV® resin are limiting their products to export opportunities.

Short Term Devices

Purifiers intended for short term use include funnels containing MCV® resin and small cartridges containing MCV® resin followed by an empty chamber to allow for contact time in the iodinated water and finally enough activated charcoal to remove the iodine taste. In the case of the funnel devices, water containing elemental iodine is consumed directly. These devices have been shown to be effective against a wide range of bacteria and viruses if the contact time is sufficient, however they are only marginally effective against *Giardia* and not effective against *Cryptosporidium* cysts. One developer of a small portable device includes a 2 micron filter which is effective against cysts and is actively pursuing EPA certification for sale in this country.

In general, the short term devices are only intended for emergency, recreational, and travel uses, and are effective against pathogenic bacteria and viruses which are of major concern, but only marginally effective against cysts which normally cause intestinal discomfort but are rarely fatal.

Long Term Use Devices

Purifiers intended for long term use vary in size from single cartridge countertop devices such as that shown in Figure 2, to large systems capable of serving schools, hospitals, or even small villages as shown in Figure 3. Most domestic or point of use devices are used only to purify water intended for cooking and drinking. They usually consist of one or two cartridge countertop units or two or three cartridge under sink units with a separate faucet. These systems are sold in foreign countries where the municipal water supply is suspect, or where a source of untreated water is available. They all incorporate filters capable of removing cysts, MCV® resin, a contact chamber and iodine removing materials. To date the most efficient iodine removal technology involves activated carbon followed by anion exchange resins, or silver impregnated charcoal. Both systems are capable of removing elemental iodine and iodides below detectable levels.

The larger systems capable of producing up to 15 gallons per minute contain the same basic capabilities as the point of use systems, however they also require pretreatment equipment. The pretreatment varies according to the individual source of the water which may vary from properly designed and developed deep wells to muddy lakes or streams. These systems are used to provide a central source of safe water to a community replacing the town cistern or watering hole. The systems are regularly serviced by trained personnel thus providing safe potable weter in an underdeveloped area economically and reliably.

In all of the above applications, the MCV® resin has a limited life and must be periodically replaced. The development described below makes the use of MCV® resin on a long term basis even more economical.

Regenerable MCV®

The Microbial Check Valve contains iodinated ion-exchange resin that binds iodine in the I_n^- form where n is an odd number greater than 1. As water passes through the MCV®, iodine is released as an I_2 residual. As the throughput increases, the concentration of iodine in the effluent slowly decreases. Regeneration of the resin may be accomplished by replacing the I_2 when the throughput or effluent iodine concentration reaches a predetermined point. This concept involves placing a bed of iodine crystals upstream of the MCV® to use as a source of replacement iodine. The solubility of pure iodine in room temperature water is approximately 300 mg/l. By periodically passing the influent stream through the bed of crystalline I_2, the MCV® can be regenerated without removing it from the system or involving crew interaction. A proposed flight system is shown in Figure 4.

Laboratory tests have shown that the MCV® resin is capable of being regenerated hundreds of times using three different types of water expected to be encountered on a Space Station.

The extension of this technology to large terrestrial systems indicates that drinking water may be disinfected at a cost of less than two cents per gallon.

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FIGURE 1, SPACE SHUTTLE MICROBIAL CHECK VALVE

Rated at 0.5 liters/min

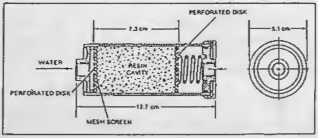


FIGURE 2,
Countertop Unit

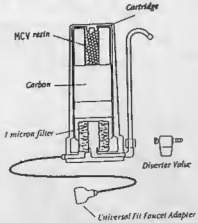


FIGURE 3, LARGE SCALE SYSTEM

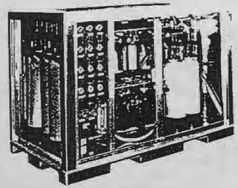
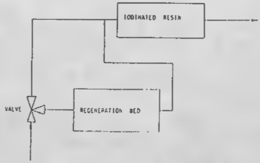


FIGURE 4, REGENERABLE MICROBIAL CHECK VALVE



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