Reduction of sodium strengths in wastewater streams from food and beverage industries

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1. INTRODUCTION

The need to recycle water in industry is becoming increasingly important. There is also a growing need to reduce sewer loadings to achieve a higher quality of trade waste discharges and treated water. Total Dissolved Solids (TDS) levels in treated water have been identified as a key factor limiting water recycling due to their significant impact on soil productivity (DSE 2004). Generally, almost half of the TDS in treated water is produced by industry and commerce sectors. Therefore, water authorities are currently working with industrial and commercial customers and Environment Protection Authority (EPA) to develop cleaner production programs and to reduce TDS discharges. For example, in Australia, the food and beverage industries, which represent 22% of the total Victorian manufacturing turnover (ABS 2005), are significant contributors to trade waste and TDS discharges. A large proportion of sodium (approximately 50%) found in trade waste from some of the food and beverage industries originate from cleaning-in-place (CIP) practices (Palmowski 2005, Weeks, 2007). The reason for this is that conventional cleaning agents used in CIP systems are usually based on sodium hydroxide and require strong acids for neutralization. This results in high dissolved solids levels, especially sodium levels, being discharged from industries in trade waste. Therefore, it is important to identify CIP chemicals that have the potential to replace traditional CIP chemicals used in the food and beverages industries, to reduce TDS in trade waste.

Reduction of TDS in wastewater can be achieved by adopting prominent approaches such as end-of-pipe desalination technologies, segregation of salty streams at source and salt reduction and substitution at source. Among these approaches, salt reduction and
substitution at source, appear to be the best approaches as they avoid costly desalination technologies and the difficult handling of the segregated by-products. Therefore, the best way to reduce TDS loads, in particular, sodium discharged to the sewer is to look for alternate industrial cleaning practices, to recover and reuse cleaning chemicals for subsequent cleaning cycles.

1.1 CIP cleaning

In the food and beverage industries, cleaning is an essential procedure in the operation of an industry to achieve and maintain the high hygienic levels, remove soil from the processing equipment and maintain product quality. Over the last few decades, the use of CIP systems has brought more reliability in equipment cleaning. In CIP systems, complete plant items or pipeline circuits are cleaned without dismantling or opening the equipment. Little or no manual involvement on the part of the operator is required. CIPs are characterized by automatic cleaning programs based on a successive cleaning with water, cleaning chemicals and or disinfection agents that are discharged into sewer system along with large amounts of water necessary to rinse out residual chemicals [Canut and Pascual, 2008]. The use of CIP shows numerous advantages, compared to manual cleaning, which include improved cleaning efficiency, shortened cleaning cycles, improved occupational health and safety (OH&S) and reduced environmental impact (DEH, 2003). The introduction of CIP systems in a small and medium enterprise can also show economic and environmental benefits. For example, one of the brewery industries applied, extended and automated the reticulation of cleaning solution throughout their brewery and beverage plants. As a result, 60% reduction in cleaning agents was achieved in the brewery while the reduction reached up to 80% in the cider section of the beverage plant (DEH, 2003).

A typical CIP cycle is presented in the sequence below (Romney 1990; Australian Standards 2001). It is important to note that this cycle will differ from one site to another and from one process to another at the same site.

1. Products flush to remove product residuals. This is often carried out using water but is not a necessity.
2. Pre-rinse to remove any loosely-adherent residuals (and micro-organisms attached to these residuals). This is usually performed with water (or slightly alkaline solution) and reduces the amount of soil.
3. Main cleaning step to lift the soil from the equipment surface. The soiling compounds will be suspended or dissolved in the cleaning solution. This step, which is responsible for removing most of the soil and micro-organisms attached to surfaces, can be sub-divided into sub-steps to allow for various cleaning chemicals to be used. For example:
   a. Caustic cleaning, followed by
b. Intermediate rinse

c. Acid cleaning step (when required)

4. Final rinse to remove residuals of cleaning solutions
5. Disinfection/sanitising step to reduce the number of micro-organisms from previously cleaned surfaces
6. Post-rinse might be necessary to remove residuals of sanitisers

Each food and beverage industry type has different CIP requirements. Furthermore, each area of a food and beverage industry can have different CIP requirements. For example, the CIP requirements differ between open systems (e.g. vessels) and closed systems (e.g. pipes). The CIP performance in the former is easier to assess visually.

CIP system is controlled by several parameters such as type of detergent, temperature, flow rate and time [Wilson et al, 2002, Bird and Espig 1994, Bird and Bartlett 1995]. Bird and Bartlett (1995) made a rigorous optimization study to determine the relationship between different parameters such as temperature and concentration of detergents for a dairy industry. Several detergents have been used in CIP system; the most common among them is sodium hydroxide. Therefore, it is important to identify cleaning chemicals that have the potential to replace traditional chemicals used in the food and beverage industry. There is a wide variety of cleaning agents currently available that could provide an alternative to sodium hydroxide which is discussed in the following section.

1.2 Alternative non-sodium and reduced sodium cleaning chemicals

Sodium hydroxide or caustic soda (NaOH) is the most widely used alkaline detergent in the food and beverage industry, due to its low price and high cleaning efficiency for fat and protein soils. The most commonly used acidic detergents are nitric acid and phosphoric acid. These conventional cleaning chemicals contribute significantly to the TDS and sodium levels discharged by food and beverage industries. As a result of high TDS and sodium concentrations, some restrictions exist on treated water recycling to avoid any damage on soils and vegetation. Therefore, there is a clear need to identify alternative chemicals to reduce the use of traditional chemicals throughout the food and beverage industry.

The range of alternative cleaning chemicals includes:

• Potassium hydroxide (KOH) based products
• Low sodium alkaline cleaners
• Built NaOH or built KOH. These chemicals contain additives which enhance the performance of the cleaning and reduce the chemical usage.
• NaOH/KOH blends
• Biotechnology based cleaners, mainly consisting of enzyme-based cleaners
• Alternatives to alkaline cleaning agents, including plant-based cleaners
- Alternative acid cleaners
- Alternative sanitisers, including non-chemical based sanitisers

All the above options offer a possible reduction in TDS and/or sodium in trade waste, which are discussed in more detail below.

1.2.1 Potassium hydroxide (KOH) based products

The use of potassium hydroxide based cleaning agents is one of the methods to reduce the sodium levels found in trade waste. However, the main limitation to use potassium hydroxide has been its price. Similar to sodium hydroxide, potassium hydroxide is prepared by electrolysis of a brine solution. In the case of KOH, the brine solution consists of potassium chloride, which is not as ubiquitous as sodium chloride and needs to be extracted from mined resources. As a result, KOH is more expensive than NaOH. Additionally, different market drivers exist for sodium and potassium hydroxide, leading to different price fluctuations.

1.2.2 Low sodium alkaline cleaners

Chemical manufacturers have developed products with lower sodium concentrations. One type of low sodium alkaline cleaners includes chlorinated alkaline detergents, which are mostly used in overseas. Typical sodium concentration in ready-to-use cleaning solutions ranges from 0.02 to 2.9 g Na/kg in cleaning solution.

1.2.3 Built NaOH or built KOH

The additives (or builders) are often added to cleaning solutions to improve their properties and cleaning efficiency. Cleaning solutions that contain additives are called “built” cleaning solutions. The use of built cleaning solutions can reduce cleaning times, rinse water consumption and/or cleaning chemical concentrations. This can therefore lead to improved trade waste discharges. Typical additives include dispersing and suspending agents, emulsifiers and surfactants, sequestrants, wetting agents and rinsing agents. For example, sequestrants are widely used to remove hardness from water. According to Prasad (2004), hard water could result in scale build-up, which affects the capacity of detergents and sanitisers to contact the surface and could lead to excessive scaling in boilers and cooling towers. Therefore, hard water may need some treatment such as ion exchange or the use of detergents and sanitisers containing specially formulated additives (Prasad 2004).

1.2.4 NaOH/KOH blends

To increase the commercial competitiveness of potassium hydroxide while partially maintaining its environmental benefits over pure sodium hydroxide, blends of potassium...
and sodium are available on the market from various suppliers.

### 1.2.5 Biotechnology based cleaners, mainly consisting of enzyme-based cleaners

Biotechnology based cleaning agents include bacteria-based agents and enzyme-based agents, the latter being far more widely used in industries. ETBPP (1998) reported that a poultry processing company had extreme difficulty in cleaning an area that was soiled with faeces, blood, urine, grease, fat and feathers, even with sodium hydroxide. They applied a biotechnology based cleaning agent and found that all traces of organic matter were removed efficiently. There was a reduction in cleaning time as well as energy consumption because hot water was not required.

The main advantages and disadvantages of biotechnology based cleaning agents include (ETBPP 1998):

**Advantages**
- Usually less harmful to the environment
- Very specific cleaning action
- Can be used at lower temperatures than conventional chemical cleaners
- May be cheaper
- Reduce effluent disposal costs as they produce an effluent with a lower chemical oxygen demand (COD)
- Non-corrosive

**Disadvantages**
- May take longer to act than traditional chemical cleaners

Enzyme-based cleaners in the food industry are becoming increasingly popular. There has been a resurgence of interest in enzymes because they offer a number of advantages over traditional caustic or acid cleaning regimes (D’Souza and Mawson 2005). One of the main factors responsible for the growing popularity of enzyme-based cleaners is new developments in enzymology (Kumar et al. 1998). Enzymes used for detergent production comprised 28% of the global market for industrial enzymes in 1994 (Kumar et al. 1998).

### 1.2.6 Alternatives to alkaline cleaning agents, including plant-based cleaners

Alternative cleaning agents, such as plant-based cleaners, are used in some circumstances as replacements for traditional alkaline cleaners. The categories of products include:

- plant-based products, which can be of various origin:
  - tall oil fatty acids, which are derived from pine pulp production
  - citrus based products, containing concentrated d-limonene
chemical origin, including ethylene and glycol derivatives
• products of unknown composition or origin

The SGS U.S. Testing Company performed a 28-day biodegradability test on Citra-Solv® Cleaner and Degreaser to determine the biodegradability of this cleaning agent in a closed aqueous system. Citra-Solv® is a concentrated d-limonene based product derived from the extract of orange peels. The results of the study showed that Citra-Solv® degraded 75.6% as determined by Total Organic Carbon (TOC) reduction and 209% by CO₂ evolution within 28 days (Naval Facilities Engineering Service Center 1999).

1.2.7 Alternative acid cleaners

Acids are used principally to dissolve precipitates of inorganic salts or oxide films. Conventional acid cleaners contain nitric and/or phosphoric acids, which can lead to nutrient problems in effluent discharges. Alternative acid cleaners are mainly based on citric acid. It also rinses easily and does not corrode surfaces (D’Souza and Mawson 2005).

One of the dairy industries replaced the nitric and phosphoric acid normally used in their CIP process with Stabilon (DEH, 2005a,b). Prior to the changeover, 200 litres of nitric and phosphoric acid were used every day for CIP processes in the cheese manufacturing plant. DEH (2005b) reported that the use of Stabilon decreased the CIP wash time by 1.5 hours per day. Consequently, this enabled the plant to increase production time by 9 hours per week. The net savings to the industry was $312 per day. Although phosphorus and nitric acid levels were reduced by using Stabilon, the total wastewater volume actually increased. This was because more production took place each day. When the volume of wastewater was related to the amount of cheese produced, it was found that utilising Stabilon resulted in roughly the same volume of effluent discharged per tonne of cheese produced as that of nitric and phosphoric acid (DEH, 2005a, DEH, 2005b).

1.2.8 Alternative sanitisers

Many detergents have been found to have a disinfecting ability. Typical sanitisers are based on chlorine, sodium hypochlorite, hydrogen peroxide and quaternary ammonium compounds. A wide range of chemical sanitisers are used within the food industry.

In one of the studies, Dufour et al (2004) developed a laboratory scale system to quantify the effectiveness of chlorine and alternative sanitizers in reducing the number of viable bacteria attached to stainless steel surfaces. The experimental system, which consisted of a continuous flow reactor and recirculating test loop, was used to model the development of dairy biofilms on stainless steel surfaces under conditions of growth and cleaning regimes typically encountered in dairy processing plants. Stainless steel tubes were placed in the recirculating loop and exposed to a standard CIP regime. The tubes were then exposed to
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chlorine (200 ppm) and combinations of nisin (a natural antimicrobial agent, 500 ppm), lauricidin (a natural microbial product, 100 ppm), and the lactoperoxidase system (LPS) (enzyme-based, 200 ppm) for different lengths of time (10 min or 2, 4, 8, 18 or 24 h) (Dufour et al. 2004). It was found that increasing the concentration of the chemicals did not always lead to a greater reduction in the number of attached cells. Log reductions varied between 0 and 2.1. Dufour et al. (2004) also investigated the effectiveness of chlorine, nisin + LPS, and lauricidin + LPS against biofilms following the standard CIP regime. They reported that none of the sanitizers significantly reduced the number of attached cells after a 10-minute treatment. However, after 2 h of exposure, all three treatments significantly reduced bacterial counts on the stainless steel tubes. Exposure times greater than 2 h did not bring in any further significant microbial reductions.

The use of ozone in CIP processes has been tested in the form of ozonated water. Lagrange et al. (2004) carried out a study to determine the antimicrobial efficiency of ozonated water applied in a CIP system on the surfaces of food processing plants. Under optimal conditions, ozonated water showed excellent microbicidal and fungicidal characteristics within seconds. However, these characteristics were extinguished in the presence of protein soil. It was concluded that a suitable use of ozonated water for sanitation was only possible after efficient cleaning (Lagrange et al. 2004).

A number of non-chemical sanitisers have been reported in the literature including thermal sanitising, steam and hot water (ADHS 2005). Two alternatives to using sanitation chemicals are ionisation and ultraviolet light (UNEP 2004). Ionisation involves the use of an electrode cell to release silver and copper ions into a stream of water. The positively charged silver and copper ions are attracted to the negatively charged surface of the micro-organisms, distorting the cell structure and preventing the absorption of nutrients (UNEP, 2004). Ultraviolet (UV) disinfection systems destroy micro-organisms through interaction with microbial DNA (UNEP, 2004).

A cheese processing plant in South Africa required a non-chemical brine disinfection system that would not alter the quality of the cheese and would also be simple and easy to maintain (UNEP, 2004). The company installed an UV disinfection system. The operating costs for the UV system were reported to be far lower than the operating costs of pasteurisation. A food processing plant in the UK has installed a medium-pressure UV disinfection system to treat water originating from a private borehole (UNEP, 2004). The water is treated using an iron and manganese filter before being passed through a membrane filter. The final stage of the treatment process is to pass the water through the UV system. Approximately 95% of the UV-treated water is used for washing and treating equipment while the remaining 5% is used in product make-up. The products from the plant are not affected in any way by using this source of water.
In many food processing plants, it has become a common practice to combine detergency and sanitisation to form one stage in the cleaning process instead of two separate stages. The main benefit of this approach is that it saves considerable time. However, it is important to realise that there can be a loss of disinfection action so it is important to consider the final effect of combing detergency with sanitising (Loghney and Brougham 2005).

2. DESK-TOP REVIEW OF THE IMPACT OF IMPLEMENTATION OF ALTERNATIVE CHEMICALS

This section presents a desk-top assessment on the possible implementation of alternative chemicals. Based on information from the chemical suppliers, literature references, internet sites or industries, this assessment has been done in terms of sodium discharge reduction.

To assess the potential reduction in sodium discharge that could be achieved through the changeover to alternative cleaning chemicals, the sodium concentration in the cleaning solution itself (after dilution of the bulk chemicals) has been used. This was calculated using the sodium concentration of the bulk chemical as well as the chemical in-use concentration (as recommended by the chemical suppliers). The reference for comparison is pure sodium hydroxide, with a recommended in-use concentration of 0.5–4%, depending on the process and equipment to be cleaned. Sodium hydroxide was chosen as a reference because of its large use across many food and beverage industries.

The cleaning chemicals have been grouped according to their categories as identified in the sections above. The lower recommended concentration of each chemical was compared with the 0.5% NaOH solution while the higher recommended concentration was compared with 4% NaOH solution. The results are presented in Table 1.

This table shows that the use of alkaline cleaners with medium and low sodium concentrations can lead to significant reductions in sodium discharge from the alkaline step of a CIP cycle. Large reductions can also be obtained from NaOH/KOH blends, which can be attributed to the use of KOH instead of NaOH and also to the use of alternative chemicals in the blends. Furthermore, the use of potassium based cleaners, enzyme products or other alternative cleaning agents can reduce the sodium concentration to almost zero. In order to investigate the efficiency of these alternative cleaning chemicals, a pilot study was carried out and is discussed in the following sections.

3. EXPERIMENTAL STUDY

A test rig was designed and fabricated to simulate fouling and cleaning process that occur at the beverage industries. The cleaning process, especially, CIP, an automated cleaning system, was mainly focused in this study.
Table 1: Sodium concentration in various cleaning solutions

<table>
<thead>
<tr>
<th>CIP Cleaning Chemicals</th>
<th>Sodium concentration in cleaning solution [gNa/kg cleaning solution]</th>
<th>Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure NaOH (at 0.5 to 4% NaOH)</td>
<td>2.88 – 23</td>
<td>Reference*</td>
</tr>
<tr>
<td>Alkaline cleaners with medium sodium levels</td>
<td>0.63 – 2.9</td>
<td>78 – 87%</td>
</tr>
<tr>
<td>Alkaline cleaners with low sodium levels</td>
<td>0.02 – 0.8</td>
<td>99.3 – 96.5%</td>
</tr>
<tr>
<td>KOH based products</td>
<td>0 or negligible</td>
<td>Almost 100%</td>
</tr>
<tr>
<td>NaOH/KOH blends</td>
<td>Intermediate between pure NaOH and pure KOH</td>
<td></td>
</tr>
<tr>
<td>Enzymes and other biotechnology based cleaners</td>
<td>0 or negligible</td>
<td>Almost 100%</td>
</tr>
<tr>
<td>Alternatives to alkaline cleaning agents, including plant-based cleaners</td>
<td>0 or negligible</td>
<td>Almost 100%</td>
</tr>
</tbody>
</table>

*Pure NaOH has been used as reference for comparison with all other chemicals

3.1 Food and Beverage Industries

As part of this study, a survey of 15 food and beverage industries was undertaken in the Melbourne Metropolitan region, Australia to understand typical cleaning practices of food and beverage industries and to gather information on manual cleaning methods, CIP systems, cleaning frequencies and types of chemicals used. Based on the review of the survey and the interest of the industries, three industries were selected for investigation to represent the spectrum of the chosen industries. A product from one of the industries was used for this study.

3.1.1 Industry 1

Industry 1 manufactures mainly wet and a small amount of dry (powder) industrial and retail food ingredients such as sauces, marinades, fondants syrups. The process has a single CIP system used for kettles and marinades only. The remaining equipment is cleaned 'batch wise'; that is, chemical is manually prepared and flushed through tanks and equipment. A 10,000 litre tank stores used caustic detergent (sodium based). The caustic is re-used for approximately 10 cycles and then it is automatically refreshed.

Several visits were made to this industry, to understand the process during production of the beverages and cleaning of the fouling. As the production is relatively medium and open to visual inspection, the visits to this industry were more educative and useful in the consideration for the design of test rig for this study. Sodium hydroxide of 1.5% concentration is used as the main detergent in cleaning. It is recycled 10 times before it is drained to sewer. This industry uses the processing equipment for a duration that ranges...
from 3 hours to 5 days depending on the product produced. If the same product is produced, cleaning will not take place until different beverage is produced. Among the beverages, barbeque sauce was found to produce highest fouling in the industry trials. Therefore, it was selected for this study to create a similar fouling as that of the industry. Pre-pasteurized samples of barbeque sauce were collected from Industry 1. They were stored at 0°C in a cold storage room. The solid content of the barbeque sauce is found to be 17.7%.

3.2 Fabrication of Test Rig

A test rig was designed and fabricated based on the flow characteristics and design of the processing equipment such as heat exchangers and mixing/balance tank of the chosen food and beverage industry (Industry 1). Heat exchanger plays a crucial in the design. It is found that most of the beverage industries use shell and tube heat exchanger. As Reynolds number and residence time are critical, they are used in deciding the diameter of the tubes of the heat exchanger. As the heat exchanger is a major component where most of the fouling occurs, a test rig that comprises of two tubular heat exchangers, one for heating and another for cooling, a feed tank of 25 Kg capacity and a steam generator, was considered. A generic design of the tubular heat exchanger was carried out by taking into account the processing parameters such as flow rate, diameter of the tube, number of tubes, length of the pass and number of passes [Coulson and Richardson, 2005]. It is to be noted that a single tube heat exchanger with a length and a diameter that can generate 1300L/hour, an equivalent flow rate of 13,000 L/hour that is being used in the industry, was taken into account in the design.

Figure 1 provides the detailed diagram of the test rig layout. A steam boiler is used to achieve steam temperature of more than 140°C for fast ramping of temperature to 95°C.

3.3 Materials and Experiment

The details of the detergents and the conditions of their use are provided in Table 2. It is to be noted that all these commercial detergents contain additives such as sequestrants and wetting agents to enhance the cleaning efficiency. The additives in the detergents contribute to COD as can be seen in Table 2.

It is to be noted that enzyme needs the processing temperature below 60°C to avoid any inaction and achieve maximum efficiency. All alkaline detergents are used around 70°C. Organic acid based detergents are used in the range from 55°C to 60°C and herbal detergent can be used at temperatures that range from 20°C to 95°C. Three different combinations of NaOH and KOH, namely, 1:3, 1:1 and 3:1 of NaOH and KOH ratio were also used in the evaluation. As Avoid was used by this industry for cleaning CIP system, it was used in our trials for comparison.
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Figure 1: Photograph of Test Rig

Table 2: Alternate non-sodium detergents

<table>
<thead>
<tr>
<th>Detergents</th>
<th>Type</th>
<th>COD (mg/L)</th>
<th>Concentration (%)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoid</td>
<td>NaOH</td>
<td>748</td>
<td>2 v/v</td>
<td>70</td>
</tr>
<tr>
<td>Conquest K</td>
<td>KOH</td>
<td>440</td>
<td>2 v/v</td>
<td>70</td>
</tr>
<tr>
<td>Easi Advantage plus</td>
<td>NaOH/KOH</td>
<td>212</td>
<td>4 v/v</td>
<td>70</td>
</tr>
<tr>
<td>Quatrazyme</td>
<td>Enzyme</td>
<td>7100.5</td>
<td>1 v/v</td>
<td>55-60</td>
</tr>
<tr>
<td>Purline 382A</td>
<td>Sulphamic Acid/Oxalic Acid</td>
<td>583</td>
<td>1.5 v/v</td>
<td>50-60</td>
</tr>
<tr>
<td>Triple 7</td>
<td>Herbal</td>
<td>9330</td>
<td>2 v/v</td>
<td>20-95</td>
</tr>
<tr>
<td>Citronox</td>
<td>Citric Acid</td>
<td>9031</td>
<td>2 v/v</td>
<td>55-60</td>
</tr>
<tr>
<td>NaOH/KOH (1:1)</td>
<td>NaOH/KOH</td>
<td>0</td>
<td>1.5 w/v</td>
<td>70</td>
</tr>
<tr>
<td>NaOH/KOH (1:3)</td>
<td>NaOH/KOH</td>
<td>0</td>
<td>1.5 w/v</td>
<td>70</td>
</tr>
<tr>
<td>NaOH/KOH (3:1)</td>
<td>NaOH/KOH</td>
<td>0</td>
<td>1.5 w/v</td>
<td>70</td>
</tr>
<tr>
<td>Concept C20</td>
<td>KOH</td>
<td>0</td>
<td>2 v/v</td>
<td>70</td>
</tr>
</tbody>
</table>
Pre-pasteurized barbeque sauce of 25 kg obtained from Industry 1 was used for each trial. Ramping time of 12 minutes was used to reach 95°C. Barbeque sauce was circulated at 95°C for 2 minutes at a flow rate of 500 L/hour for all the experiments. After draining the processed barbeque sauce, the test rig was cleaned by circulating water at 1300 L/hour for 7 minutes, which is called pre-rinse. Detergent of the recommended concentration was circulated at 1300 L/hour for 30 minutes and it is called detergent wash. After circulation of the detergent wash was completed, it was drained and the test rig was cleaned by circulating water at 1300 L/hour for 7 minutes and it is called post-rinse. Steam temperature and cooling rate were manually controlled to achieve the expected temperature. In order to find out the degree of cleaning for all the chosen detergents, final cleaning with detergent wash was carried using Avoid after completion of three stages of cleaning, namely, pre-rinse, detergent wash and post-rinse at the end of each trial. This is called post-cleaning. In order to understand the fouling at the mixing tank and heat exchanger, the samples from pre-rinse, detergent wash and post-rinse were collected periodically. The samples are analysed for COD, electrical conductivity and turbidity to determine the nature and level of fouling. Analysis of the pre-rinse samples is carried out to understand the nature and level of fouling at the processing equipment surface. Almost all the tenacious fouling that sticks to the surface is normally removed by reducing the surface energy during detergent wash. In addition, partial reaction of alkaline chemical(s) and separation of the fouling from the surface would also take place. Analysis of the post-rinse samples provides us the qualitative picture of the cleanliness of the processing equipment. Performance of the detergents can be gauged using the COD, electrical conductivity, turbidity and concentration values of the samples. Swap tests are carried out after cleaning with each detergent. The surface can be considered hygienically 100% safe for further production when no micro-organism is found with swap test.

4. RESULTS AND DISCUSSION

Barbeque sauce form Industry 1 has been used throughout to create fouling and evaluate cleaning efficiencies of alternate non-sodium detergents. 25 kg of barbeque sauce was used for each trial in the evaluation of alternate detergents. Pre-rinse time of seven minutes, detergent wash time of thirty minutes and post-rinse of seven minutes has been used as per the procedure followed by the Industry 1. Steam temperature and cooling rate were manually controlled to achieve the expected temperature. Details of processing conditions for barbeque sauce are shown in Table 3. Cleaning conditions used to clean the fouling are shown in Table 4. Notations “T” in the table indicate the serial number of the each trial. As barbeque sauce changes its nature after 15 minutes, the whole processing was completed within this time for all the trials from T10 onwards to create the realistic fouling. The quality of cleaning by the chosen detergents was assessed by cleaning the cleaned CIP system again with a reference detergent (Avoid) at the standard cleaning condition that was used
by the industry 1. The COD level of the samples from this cleaning was measured.

**Table 3:** Fouling details for barbeque sauce processing

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Ramp time (min)</th>
<th>Residence time (min)</th>
<th>Flow rate (L/hr)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T10</td>
<td>10-12</td>
<td>5</td>
<td>500</td>
<td>95</td>
</tr>
<tr>
<td>T11</td>
<td>10-12</td>
<td>2</td>
<td>500</td>
<td>95</td>
</tr>
<tr>
<td>T12</td>
<td>10-12</td>
<td>2</td>
<td>500</td>
<td>95</td>
</tr>
<tr>
<td>T13</td>
<td>10-12</td>
<td>2</td>
<td>500</td>
<td>95</td>
</tr>
<tr>
<td>T14</td>
<td>10-12</td>
<td>2</td>
<td>500</td>
<td>95</td>
</tr>
<tr>
<td>T15</td>
<td>10-12</td>
<td>2</td>
<td>500</td>
<td>95</td>
</tr>
<tr>
<td>T16</td>
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<td>T17</td>
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<td>T18</td>
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<td>500</td>
<td>95</td>
</tr>
<tr>
<td>T19</td>
<td>10-12</td>
<td>2</td>
<td>500</td>
<td>95</td>
</tr>
<tr>
<td>T20</td>
<td>10-12</td>
<td>2</td>
<td>500</td>
<td>95</td>
</tr>
</tbody>
</table>

**Table 4:** Cleaning details for barbeque sauce processing

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Detergent Name</th>
<th>Detergent Type</th>
<th>Flow rate (L/hr)</th>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>Concentration (%v/v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T10</td>
<td>Avoid</td>
<td>NaOH</td>
<td>1300</td>
<td>70</td>
<td>30</td>
<td>2%</td>
</tr>
<tr>
<td>T11</td>
<td>Conquest K</td>
<td>KOH</td>
<td>1300</td>
<td>70</td>
<td>30</td>
<td>2%</td>
</tr>
<tr>
<td>T12</td>
<td>Easi Advantage Plus</td>
<td>NaOH/KOH</td>
<td>1300</td>
<td>70</td>
<td>30</td>
<td>4%</td>
</tr>
<tr>
<td>T13</td>
<td>Quatrazyme</td>
<td>Enzyme</td>
<td>1300</td>
<td>60</td>
<td>30</td>
<td>1%</td>
</tr>
<tr>
<td>T14</td>
<td>Purline 382A</td>
<td>Sulphamic/Oxalic acid</td>
<td>1300</td>
<td>60</td>
<td>45</td>
<td>1.50%</td>
</tr>
<tr>
<td>T15</td>
<td>Concept 200 S</td>
<td>Herbal</td>
<td>1300</td>
<td>60</td>
<td>30</td>
<td>2%</td>
</tr>
<tr>
<td>T16</td>
<td>Concept 200 C</td>
<td>Citric Acid</td>
<td>1300</td>
<td>60</td>
<td>30</td>
<td>2%</td>
</tr>
<tr>
<td>T17</td>
<td>NaOH/KOH 1:1</td>
<td>NaOH/KOH</td>
<td>1300</td>
<td>70</td>
<td>30</td>
<td>1.50%w/v</td>
</tr>
<tr>
<td>T18</td>
<td>NaOH/KOH 1:3</td>
<td>NaOH/KOH</td>
<td>1300</td>
<td>70</td>
<td>30</td>
<td>1.50%w/v</td>
</tr>
<tr>
<td>T19</td>
<td>NaOH/KOH 3:1</td>
<td>NaOH/KOH</td>
<td>1300</td>
<td>70</td>
<td>30</td>
<td>1.50%w/v</td>
</tr>
<tr>
<td>T20</td>
<td>Concept C20</td>
<td>KOH</td>
<td>1300</td>
<td>70</td>
<td>30</td>
<td>2.00%</td>
</tr>
</tbody>
</table>
The turbidity profiles for the all trials during pre-rinse, are shown in Figure 2. It can be seen that the turbidity level during pre-rinse is so low after 3 minutes for all the detergents. It indicates that most of the particles that stick to the wall of the test rig are removed after 3 minutes. The turbidity levels of detergent wash for the duration of 30 minutes are shown in Figure 3. The turbidity levels for all the detergents except NaOH/KOH 1:3 (T18) is less than 50 NTU. However the turbidity profile for post rinse is again so low after 3 minutes for all the detergents (Figure 4). The turbidity level for the post-rinse is brought to almost zero after 5 minutes, which can be seen in Figure 4. It indicates that even the particles that stick to walls are removed with all the selected detergents.
Reduction of sodium strengths in wastewater streams from food and beverage industries

Figure 4: Turbidity profiles during post rinse

Electrical conductivity (EC) profiles for pre-rinse, detergent wash and post rinse for all the detergents are shown in Figures 5, 6 and 7 respectively. It can be seen that all the detergents have lower EC than Avoid (T10) during the pre-rinse. On the other hand, Purline 382A (T14), Quartzyme (T13) and Citronex (T16) show higher EC values compared to other detergents during detergent wash. In the post-rinse, the EC values for all the detergents reached similar values after 1 minute but higher than the EC values of detergent wash.

Figure 5: Electrical conductivity profiles during pre rinse
The COD levels of detergent wash for different trials are shown in Figure 8. The COD values become steady after 10 minutes for all the detergents except that of Quaterzyme wash. The action of enzymes in Quaterzyme wash on the fouling was found to be slow in the beginning and active until 30 minutes. It was found that COD values of the samples from the post-rinse are under 10 mg/L after 3 minutes for all the detergents. It was also found that COD for the post-rinse is negligible after 4 minutes for most of the trials tested. It indicates that cleaning is almost complete after this time, which is similar to the cleaning at the industry.
4.1 Evaluation of Alternate Detergents

The performance of the detergents can be evaluated in terms of their cleaning efficiency. In these trials, the cleaning efficiency of the detergents is determined by looking at the remnants of the fouling in the post-cleaning wash for each detergent. As discussed in the previous section, post-cleaning was carried out with Avoid detergent at 70°C for 30 minutes. COD was tested for all samples of the post-cleaning solutions. The COD values for all alternate detergents are shown in Figure 9. Avoid detergent has organic compound in the form of sequestrants and wetting agent, which form 50% of the active concentration. The influence of COD from Avoid was eliminated by subtracting the COD component of Avoid from the post-cleaning solution of each detergent. It can be inferred that Easi Advantage Plus (T12), Triple 7 (T15) and Citronox (T16) have better performance among the commercial alternate detergents. NaOH/KOH of 1:3 proportions is found to be better than other combinations. It also indicates that the cleaning efficiency is improved with increase in KOH concentration. The cleaning performance of Conquest K (T11), Quaterzyme (T13) and NaOH/KOH 3:1 (T19) was found to be inadequate. It implies that the cleaning parameters such as washing time and concentration need to be varied to achieve optimum results.

4.2 Cost benefit analysis

In order to carry out the cost benefit analysis, the total detergent used by the Industry 1 for a week was calculated and extended it to the whole year. Table 5 provides the details of Avoid detergent that is currently being used for CIP cleaning at the industry 1.

The change in cost was calculated by subtracting the price of Avoid from the price of the particular detergent. It is also shown in Figure 10.
Table 5: Expenditure incurred on detergent by Industry 1

<table>
<thead>
<tr>
<th>Details</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detergent currently Used</td>
<td>Avoid</td>
</tr>
<tr>
<td>Detergent used / week (L)</td>
<td>80</td>
</tr>
<tr>
<td>Detergent used / annum (L)</td>
<td>4160</td>
</tr>
<tr>
<td>Cost of current detergent per litre ($)</td>
<td>2.5</td>
</tr>
<tr>
<td>Total cost ($)</td>
<td>10400</td>
</tr>
</tbody>
</table>

Figure 9: Relative performance of alternate detergents

Figure 10: Change in price of alternate detergents with reference to Avoid
It is to be noted that the cost of KOH based Conquest K, is comparable to that of NaOH based Avoid detergent. The costs of herbal based Triple 7 and enzyme based Quaterzyme detergents are two times more than that of Avoid detergent. Citric acid based Citronox detergent is around 6 times costlier than that of Avoid detergent. However, the performance of this detergent is found to be better than that of Avoid detergent. It is recommended that sensitivity analysis needs to be carried out to determine the detergents that can balance the cost and the performance of the detergents.

5. CONCLUSION

This investigation made a detailed pilot scale based study about alternative cleaning chemicals and practices with the aim to reduce the environmental impact of cleaning in food and beverage industries. A pilot-scale rig was developed to investigate fouling and cleaning of food and beverage processing equipment using non-sodium based detergents. The cleaning performance of these detergents was evaluated. The following conclusions were made based on this study.

1) Experiments with different non-sodium based detergents produced results that can be used as guidelines in choosing the non-sodium based detergents.
2) Detergents based on herbal extract and citric acid was found to show better performance among the commercial alternate detergents, but they are not cost effective.
3) Exhaustive study is recommended to determine the detergents that can balance the cost and the performance of the detergents.

However, while these preliminary results are encouraging, it is necessary to test the efficiency of these alternative cleaning chemicals in industry environments and for specific processes and equipment. Further studies are required to measure cleaning performance of selected cleaning chemicals in other food and beverage industries.

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