How to Optimize Clean-in-Place (CIP) Processes in Food and Beverage Operations

by Benjamin Jude and Eric Lemaire

Executive summary

Existing clean-in-place (CIP) processes are time intensive and waste large amounts of energy, water, and chemicals. New innovations in CIP technology allow plant operators to cut costs in an earth-friendly manner while still conforming to regulatory safety standards. This paper explains how new CIP technologies can improve production efficiency by at least 20% while enhancing the ability to track consumption activity throughout the various steps of the cleaning cycle.

Schneider Electric

Introduction

A typical Clean-in-Place (CIP) process requires large amounts of water, chemicals and energy. It is estimated that on average, a food and beverage plant will spend 20% of each day on cleaning equipment, which represents significant downtime for a plant. Energy usage varies depending on the process. For example, a milk plant is likely to use 13% of its energy on CIP, whereas a powered milk, cheese and whey process is likely to use 9% of its energy on CIP[1]. In a fruit jam manufacturing facility in Manchester, England, cleaning hoses in the fruit room were identified as one of the highest end uses of water in the facility (17% of total site water consumption)[2].

Many manufacturers are unsure of how their CIP systems are performing. Therefore additional steps are often introduced as a safeguard to ensure adherence to sanitation standards. This practice results in higher consumption of water, chemicals, and energy than is necessary in order to avoid the contamination issues.

A number of companies have addressed CIP improvements with small modifications such as altering the chemical concentration, or by adjusting the time taken for each stage of the CIP process. However, very few food and beverage manufacturers have put tools in place that render the CIP process efficient. In fact, in an informal poll conducted by Schneider Electric on food and beverage clients in France, only 12% thought that their CIP systems were efficient yet only 18% of those surveyed had commenced a study around CIP optimization. Yet industry leaders are clearly indicating that progress needs to be made in the areas of waste reduction and water and energy efficiency (see **Figure 1**)[3].
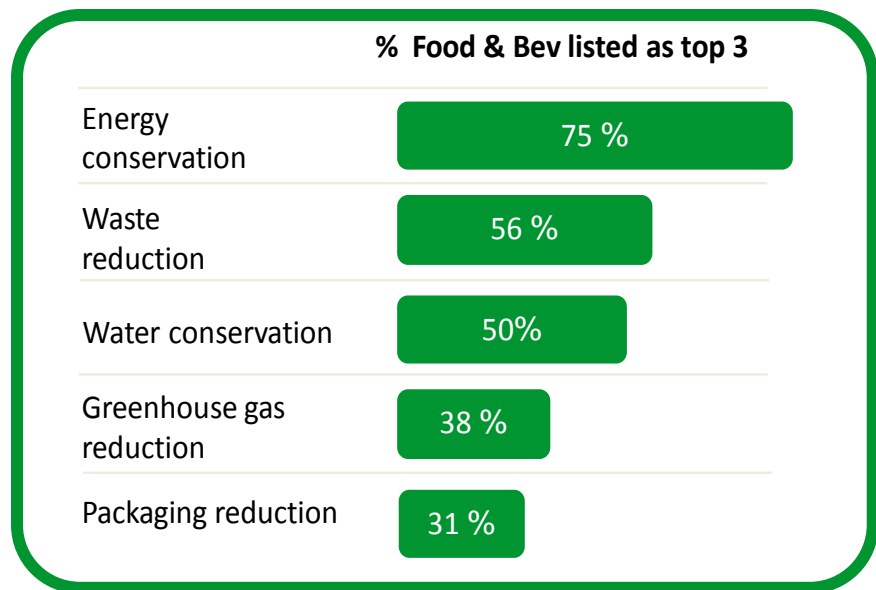
Figure 1

Top sustainability priorities of food & beverage and consumer products industries

% Food & Bev listed as top 3

Energy conservation	75 %
Waste reduction	56 %
Water conservation	50%
Greenhouse gas reduction	38 %
Packaging reduction	31 %

Recent innovations in technology now enable plant operators to calculate the optimal mix of water, chemicals, temperature and flow required to achieve safety standards while saving at least 20% in energy cost and by reducing the downtime for cleaning by at least 20%. In addition, all the steps in the process can be easily traced and automatically documented which simplifies any auditing requirements that need to be performed by regulatory inspectors.

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[1] Eco Efficiency for the Dairy Processing Industry – the UNEP Working Group for Cleaner Production in the food industry. Environmental Management Centre, the University of Queensland.

[2] Energy Efficiency Improvement and Cost Saving Opportunities for the Dairy Processing Industry, Ernest Orlando Lawrence Berkeley National Laboratory

[3] Making an Impact: Environmental Sustainability Initiatives in Canada's Food Beverage and Consumer Products Industry, KPMG

This whitepaper will review key elements of how to improve CIP energy and water consumption performance through audits, operational efficiency, process design, and advanced automation.

Risks of inefficient and ineffective CIP systems

Food safety and litigation

With many hundreds of metres of pipe work, and a multitude of valves, pumps and instrumentation that make up a typical CIP system (see **Figure 2**), the risk of equipment failure is high and can happen at any stage of the process with a potential impact on food safety. It is quite difficult to verify that all aspects of the cleaning process have been taken into account. Consider the instance of an operator who runs a cleaning process and does not even realize that a particular component (such as a pump) did not work because no alarm was generated.

The result of improper cleaning is costly to a plant in violation of food and beverage industry safety regulations. All-too-frequent incidences of food safety disasters around the globe are often caused by simple mistakes or faulty processes in a food or beverage factory which lead to sickness, injury, and even death for those who consume contaminated products. In addition to the human tragedy, these contamination incidents lead to the expense of product recalls, loss of confidence in a company's brand, and ultimately loss of revenue.

Food safety authorities conduct plant audits to ensure that the critical control points identified as HACCP (hazard analysis and critical control points) are monitored and reviewed for regulatory compliance and continuous improvement. In the event of a contamination incident, full traceability (enabled by software) and "proof of clean" will reduce the legislative and legal impact. The company involved will be in a better position to identify the contamination impact and to minimize the effort required to implement a withdrawal or recall procedure.
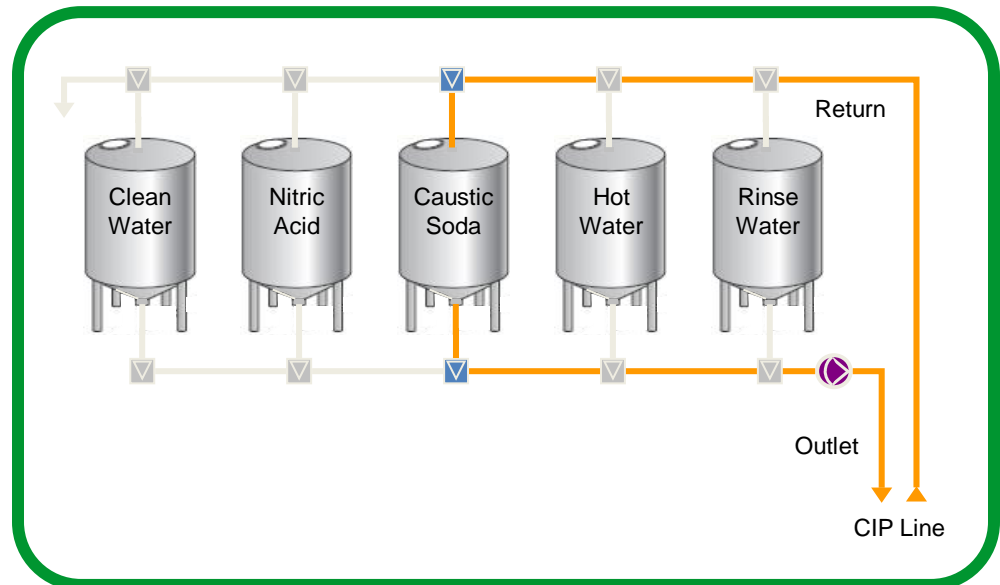
Figure 2
Example of a simple single line CIP system.

Production downtime

Lowering operational expenditure and reducing waste to lower the cost of production without impacting product quality are universal goals of food and beverage enterprises. However, when a CIP process is in operation, production uptime is stopped. This impacts profitability. As a result two tendencies manifest themselves which are both negative to the business:

1. When a problem occurs, there is a natural reaction to avoid seeking the root cause of the problem. Such an intervention could involve even more time-consuming maintenance work.

2. With the risk of contamination at the forefront of most operators' minds, the tendency of the CIP operator is to overcompensate with increased cleaning time.

Fortunately, new CIP technologies alleviate the above problems because of significant improvements in efficiency:

- More advanced CIP automation enables dramatic reductions in trouble-shooting time in the event of a problem, cutting what once took hours to perform into minutes of diagnostics.
- An optimized CIP process can reduce cleaning times by up to 20%. If CIP currently takes around 5 hours of each day, a 20% reduction in cleaning time will deliver approximately an extra hour of production time to each day.

High consumption of energy and water

"A 20% reduction in cleaning time will deliver approximately an extra hour of production time to each day."

Efficiency improvement does not only focus on reducing cycle time, and energy, water, and chemical consumption. The primary purpose of the CIP system is to remove fouling from the equipment. When production equipment is not completely clean, expensive raw materials have to be thrown out. Effective cleaning results in fewer instances of contamination and therefore improved production efficiency.

The cleaning function, however, is energy intensive. Almost half of a milk processing facility's energy is used to clean the processing lines and equipment[4]. Calculating the precise temperature needed to clean equipment is critical to reducing the energy consumption. For every $1^{o}C$ reduction in CIP temperature there will be a $1/60^{th}$ reduction in the energy needed to heat the fluid[5].

The amount of water or chemicals used can also be reduced by introducing recovery tanks so that the liquid can be reused instead of sent down the drain.

Loss of innovation and flexibility

Food and beverage manufacturers must innovate in order to remain competitive. Recipes need to be improved and new product lines developed. Therefore, CIP systems need to be flexible in order to adapt to different types of fouling on the equipment as product lines evolve. Operators need to be able to alter cleaning recipes to suit particular types of fouling, whether product (sugar, fat, protein, or minerals) or microbial (vegetative micro-organisms, or spore forming micro-organisms) and ensure that the CIP system is operating in an efficient manner. Chocolate, for example, will require a different cleaning recipe for butter than it will for flour.

Modern CIP systems, equipped with automation software enable a simple drill down into any aspect of the process. This traceability of the system offers a number of benefits:

1. Operators can check each CIP operation to verify whether it has worked correctly

2. Diagnostics are simple to perform and deliver detailed information on each element of the cleaning cycle

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[4] Next generation clean in place report from 2009 Innovation Center for U.S Dairy

[5] This is based on the caustic soda temperature being $80^{o}C$ and acid temperatures at $65^{o}C$ with an ambient temperature of $20^{o}C$. *Carbon Trust : Industrial Energy Accelerator – Guide to the Dairy Sector*

3. Faults and issues can quickly be highlighted and rectified
4. Plant managers can generate detailed operational reports
5. Food security reporting to regulators is easy to assemble and more comprehensive

Incremental process improvements

Equipment manufacturers ensure that CIP systems are installed and in good working order but these systems need to be fine tuned based upon the environment of the particular plant.

Some food and beverage manufacturers have tried to improve the efficiency of their CIP systems. The process involves a manual, trial-and-error approach which does not consider a holistic view of the system. These efficiency improvement techniques involve the following:

- **Modifying chemicals** – New chemicals can be experimented with or the concentration of existing chemicals can be altered to see if cleanliness is achieved more easily. The risk is that new versions may prove to be more costly.
- **Altering cleaning times** – Increasing or decreasing the time taken for rinse or for chemical solution cycles may result in some efficiency gains although the balance of downtime to production output and impact on safety tolerance levels will need to be reconsidered.
- **Adjusting water temperature** – Increasing the temperature of water to decrease the cleaning time or conversely decreasing the temperature to lower energy costs are also possible options.
- **Reconfiguring settings** - A study of CIP lines usage can be a useful way to improve production efficiency. For example if line 1 is at 100% capacity and line 2 is rarely used, a simple re-balancing would be to move some equipment cleaning to line 2.
- **Maximizing chemical effectiveness** – The introduction of enzyme-based detergents to speed up chemical reactions or membranes to filter chemicals and enable them to be re-used for longer helps save resources.
- **Implementing eco-friendly solutions** - Bio-decontaminants eliminate the need for the use of harsh chemicals and can help reduce the amount of energy, time and water for the cleaning process.
- **Using ozonated water** – Disinfection with ozonated water is effective on a range of micro-organisms and can save on water, chemicals, and energy. The typical five tank process is reduced to just three and it is extremely safe for the environment because its byproduct is oxygen. However it may be more costly to implement into an existing CIP system as it requires the addition of an ozone station and other equipment on site.
- **Developing conservation mindset** – The replacement of faulty valves and fittings, switching off water sprays and hoses when not in use, and disconnecting or removing redundant pipework help to improve efficiency. Installing meters on equipment will help to monitor water consumption. An example of this is installing flowmeters on inlet and outlet pipes to verify the volume of liquid sent and received. This can be analysed to indentify any unusual losses through the leak chamber of the valve.

"A holistic approach which automates performance through software makes the biggest impact on cost savings and safety improvement."

Each of these above strategies is often performed in isolation and the outcomes documented. The downside of this trial-and-error approach is that it is time consuming and much waste generated in trying to determine the proper mix of water, chemicals, and energy.

This tweaking of the CIP system can deliver some benefits, however a holistic approach incorporating automation software makes the biggest impact on cost savings and safety improvement. The complexity of finding the optimal combination for cleaning the equipment while meeting required standards is simplified thereby saving time, reducing errors, and lowering water use and energy consumption.

Optimization strategy

While every food and beverage processing plant's requirements are different and details will vary, experience has shown the most successful approach for CIP is based on three pillars:

- Effective & efficient design
- Energy efficiency
- Automation optimization

An initial audit of each of these elements helps to identify any existing gaps and can establish an execution roadmap for leveraging efficiency and safety gains.

Efficient and effective design

Efficiencies can be gained by introducing smaller, decentralized CIP systems to the plant. This approach reduces the amount of energy required to transport heated chemicals through long pipes to far corners of the production installation. The shorter distances for delivery of detergents, saves water, energy, and time.[6] **Figure 3** illustrates an example of a decentralized architecture that utilizes two cleaning lines.
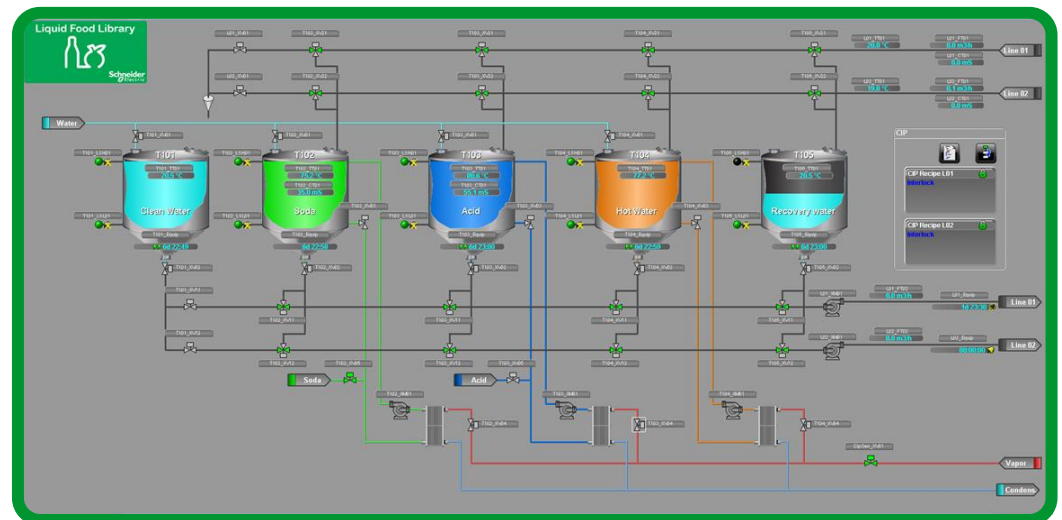
Figure 3
Example of CIP process diagram with two cleaning lines,

Multi-use CIP systems can also generate significant water and chemical savings. For example, a dairy processor in Australia had previously utilized a single use CIP system. In their old system, all the water and chemicals were used once and then discharged to waste. The system was replaced with a multi-use CIP system that recycles the final rinse water for the pre-rinse cycle. All chemicals used in the system are also returned and circulated through holding vats, where temperature and conductivity are monitored and automatically adjusted to meet specifications. The new CIP system saved the company Aus\$40,000 per year with a payback period of only one year.[7]

Improvements such as repairing leaks, removing dead legs (stagnant water in pipes that could grow bacteria), installing self-priming pumps to avoid cavitation issues (bubbles or "voids", caused by changes in pressure that can lead to early pump wear), and replacing static spray balls with rotating ones for tank cleaning can lead to significant water savings and improved productivity.

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[6] Source: Bulletin of the International Dairy Federation 401/2005

[7] Source: Eco efficiency for the dairy processing industry.

Energy efficiencies

Up to 30% in energy savings can be gained by making improvements to inefficient, outdated equipment components that waste electricity and by modifying wasteful business processes. Examples include introducing variable speed drives rather than fixed speed drives so that operators can specify the flow rate within the recipe parameters. On the process side, adjustments can be made by better balancing rinsing time to rinsing volume.
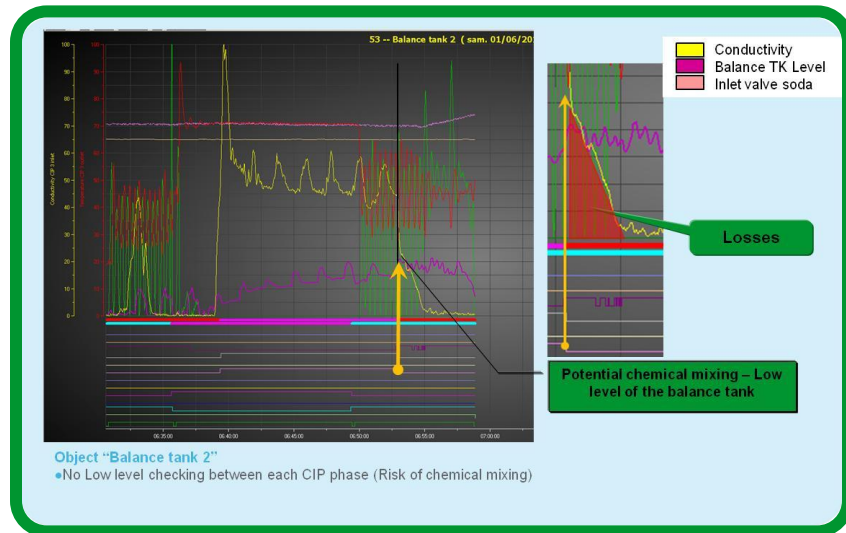
Figure 4
An example of how chemical mixing can be monitored and managed

Energy efficiencies can also be gained from a better managed heating and chemical sorting process (i.e., the transition phases between water > chemical and chemical > water). Software monitoring will prevent fresh water from infiltrating the chemical tank which then avoids having to reheat the chemical tank (**see Figure 4**).

For example, the fresh water should be maintained at a 10-15°C / 50-59°F temperature and the caustic soda tank temperature should be maintained at around 80°C / 176°F. If the programmable logic controllers (PLCs) that manage the CIP are not set up correctly, fresh water can enter the caustic soda tank. This lowers the caustic soda tank temperature. In order to return the caustic soda tank to proper operational temperature, some steam (and therefore energy) will be need to be used.

Automation optimization

Controls, sensors and alarms are all elements of automation that enable dashboards to be implemented and key performance indicators (KPIs) to be set. Typical KPIs may include cubic meters (m$^{3)}$) of water per number of CIPs, water re-use %, megajoule (MJ) of energy consumed per tonne of product, or kilogram (kg) of wastewater generated per kiloliter (KL) of product.[8]

Automation improves the quality of information available and allows tighter control of the various parts of the cleaning process (such as creating parameters around the opening and closing of valves and pump operation). It is important that the automation architecture is open; this enables the CIP processing equipment to communicate with other process equipment such as tanks or pasteurizers. Integrated "status check" ability streamlines the efficiency of the operation.

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[8] Excerpt from Typical key performance indicators for a dairy processor: *Eco Efficiency in the Dairy Processing Industry.*

Key automation parameters

An efficient cleaning recipe is based on four key parameters (sometimes referred to as "The 4 T rule"). The process automation system monitors and verifies these four fundamental parameters. By using software to calculate the optimal combination of each parameter, a dramatic reduction in costs can be achieved. The four "Ts" are defined as follows:

- **Time** - duration of the cleaning cycles
- **Temperature** - the temperature of the cleaning products
- **Titer** – the concentration of the cleaning products
- **Turbulence** – the speed and impact of liquids projected by cleaning products that need to be generated to perform the cleaning task (1.5 meters / second minimum speed)

A good analogy for understanding how the 4 T rule works, is to compare the process to a human washing his greasy hands. Grease on skin needs a particular amount of soap or detergent to remove the grease (titer). In addition, the water needs to be hot enough to react with the grease and detergent (temperature). The hands need to be rubbed together (turbulence) for long enough (time) to be completely clean. If any one of these elements is not quite right, e.g., not enough soap, the water is cold, or the hands are not washed for long enough, then the hands won't get clean.

In addition to cleaning recipes, system optimization also hinges on the design and interconnectivity of the pipe work, valves, pumps, instrumentation and PLCs. This infrastructure enables the software to communicate within the system. An expert with knowledge of process and instrumentation drawings (PID), automation software, and food and beverage industry cleaning applications can simplify the planning, design, and operational deployment process.

A PLC/ SCADA application with dedicated library for CIP enables an operator to have full visibility over the automation system, and to deploy the correct recipes (implementing the 4T principles) at the right time **(see Figure 5).**
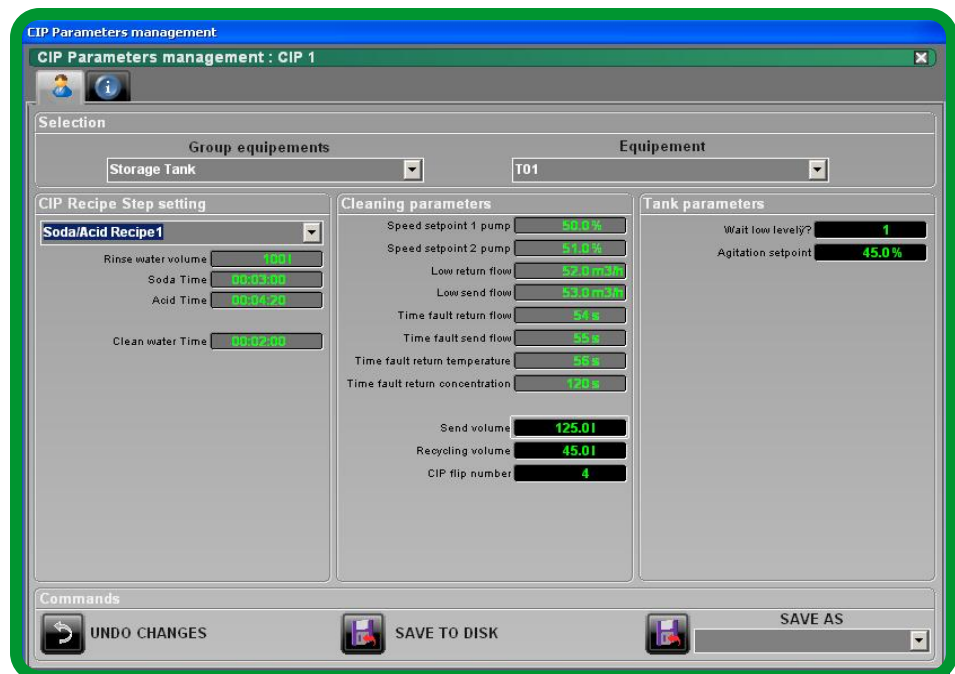
Figure 5

Example of CIP parameters management

Historical data generated by such a system can help to further optimize the operational parameters. The CIP optimization software can be configured with different cleaning recipes which can be implemented at the push of a button, making plant operation more flexible. Different recipe settings and cleaning parameters can be aligned with specific pieces of equipment.

The automation software also enables simplified root cause analysis of any issues. The information stored in the library can also be utilized to generate "proof of clean" reports as requested by food sanitation authorities.

System performance efficiency can also be tracked and compared to an established benchmark. If any anomalies are observed the software can drill down into specific elements or sub-processes of the system and troubleshoot any issues.

For example, an incident was observed recently in an Australian dairy factory. A valve opened to indicate that the cleaning cycle was in progress. To the operators, the system appeared to be functioning properly. The CIP optimization software discovered later that a pump was not working (therefore, no cleaning fluid had passed through the pipes). The repercussions of not being aware of this problem could have been very serious. However, the problem was averted as the faulty pump was picked up by the automation system report. The incident was examined in the library to identify the root cause of the problem. Without such a reporting process it is possible that system operators may have realized that a problem existed and re-run the CIP process just to make sure it was clean. However in this particular instance a re-run would not have helped.

Within such a system, it is possible to define which sequence has the best profile according to the 4T rule (this is called a "golden CIP ratio") and then compare this optimal ratio to the actual performance each time a cleaning program is run. If the chemical tanks are displaying an incorrect temperature or an incorrect percentage of chemical (titer), or if the duration (time) is not the same, or if the flow (turbulence) is not the same, the tool will decrease or increase the golden CIP ratio according to the difference. The golden CIP is benchmarked at 100. If the number shows 50 it means that there was a significant problem during the caustic soda or acid phase or both. Within the software windows it is possible to check the detail as to which parameter was not performing according to the weight that has been pre-defined for each key "T" parameter (see **Figure 6**).

Figure 6
Colour-coded chart indicates any issues to the operator
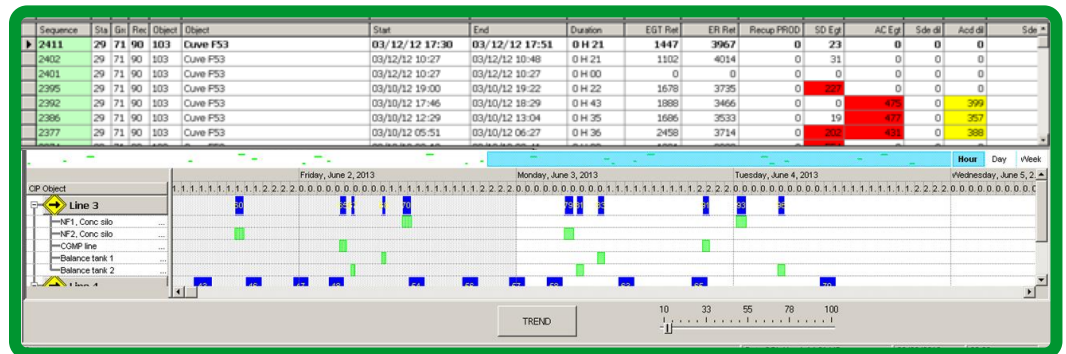
It is also possible to track and manage all chemical waste that goes down the drain. If the conductivity meter indicates that it is in a chemical phase and the drain valve is still open, the software tool has a counter showing the volume going down the drain. To manage this volume it is possible to configure a threshold by colour-coding the counter (such as red or yellow) when it reaches this threshold.

A final check can be made following the last rinse. The software will indicate a "remaining conductivity" measurement. If this number is high then it means that the final rinse was not well done and that some chemicals are still present in the pipe work.

Operational Savings

An example from a Schneider Electric customer illustrates operational savings gained from an optimized CIP system (see **Figure 7**)[9]. In this instance the costs of water, caustic soda, and acid were calculated for three months before CIP redesign and for three months afterwards. While the water usage increased slightly as a result of the optimization, this was more than balanced out by the dramatic reduction in chemical needs.
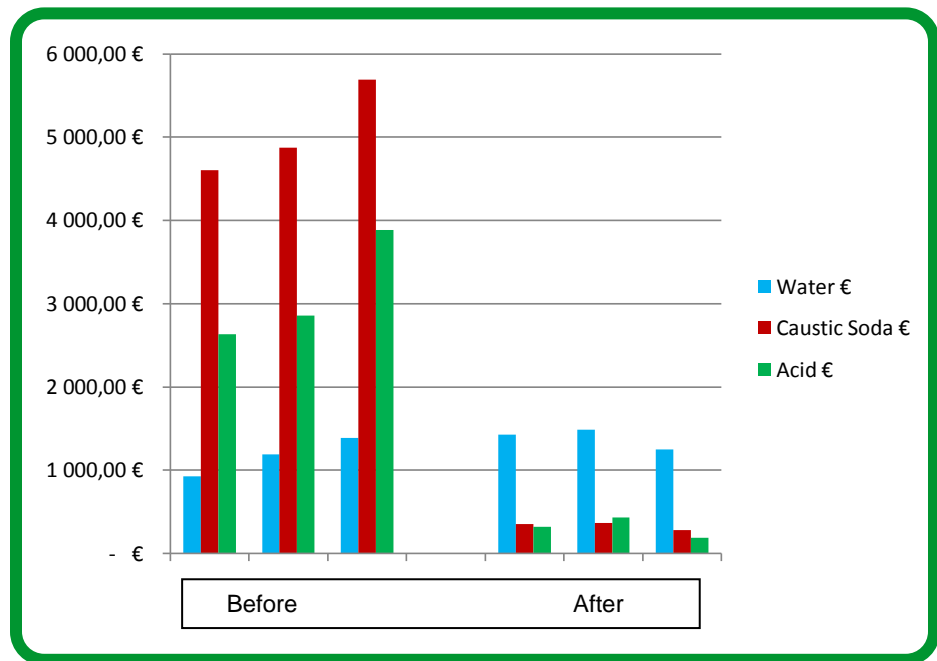
Figure 7

Monthly costs before and after CIP optimization

An annual savings of approximately €90,000 was realized without taking into account the increase in production uptime or reduction in energy consumption.

Cleaning the Cleaning System

Periodically the cleaning system itself needs to be cleaned. It is important to include this aspect in the CIP design as it requires dedicated pipe and spray balls to be fitted in the CIP tanks. CIP automation software should feature an auto cleaning recipe that can be activated by the operator at regular intervals. This auto cleaning will remove build-up of cleaning products and residue in the pipe work and tanks, therefore enabling the CIP system to operate at maximum efficiency.

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[9] Data for this graph was taken directly from a report provided by a Schneider Electric customer in France

Conclusion

Food and beverage manufacturers who seek to drive operational efficiency and cut costs should begin by performing an audit of their CIP system to identify areas for improvement. The audit will help determine whether incremental improvements such as balancing out the line capacity or adding a recovery tank to re-use water need to be made.

A high level of efficiency can be achieved by addressing CIP design, energy efficiency improvements, and advanced process automation. Such an initiative will result in a positive impact on waste, energy costs, and environmental resource issues. Improved food safety and increased production will benefit both peace of mind and profit margins.

✎ About the authors

Benjamin Jude is a Global Solution Architect / Food & Beverage Vertical Expert at Schneider Electric. For over 20 years he has specialized in automation and process engineering, and has provided turnkey solutions for firms within the food and beverage and pharmaceutical industries. He has particular expertise in process design and electrical control engineering, batch management, Manufacturing Execution systems (MES) and compliance with FDA requirements.

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