McGill University

Optimization of Clean-In-Place Sanitation Systems for McCain Supply Chain

Client: McCain Foods

Capstone
Engineering Design – Final Project

Final Report
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Abstract

Clean-in-place (CIP) systems are the leading mechanisms for meeting cleaning and sanitation standards in food industries. Such systems have simplified the cleaning process of tanks, conveyers and other elements by mitigating the need to disassemble equipment before cleaning. However, CIP systems are limited by their high energy demand, water usage and plant space requirements. A McCain process plant for potato (french fry) production is analyzed and recommendations for optimization are provided following a thorough review of literature. To optimize cleaning processes in food industries, a multi-use system with a tankless water heater and an eductor controlled by high-response sensors to replace conventional CIP is proposed.

Keywords: CIP, clean-in-place, optimization, water, energy, space, food industries

1. Introduction

One of the major challenges in any engineering design is the optimization of the overall process or product in question. The analysis stage of the engineering design process employs the use of mathematical models and simulations to optimize the final solution and determine the most economical and efficient pathway to reach certain standards. (Kelley, 2010) Clean-in-place (CIP) processes are predominately used in food and pharmaceutical industries and until the 1950's, replaced closed system cleaning techniques which required time-consuming disassembly. Clean-in-place systems are automated processes used to clean the interior walls of pipes, ducts and tanks in food industries. CIP systems are necessary to reduce pipework fouling, cross-contamination and minimize the presence of microorganisms that pose threat to human health. (Davies et al., 2015) CIP systems are thus favored for their ease of use; they operate automatically and remove the need for manual labor that prior systems required. (Ashurst et al.) Energy consumption during the CIP cleaning process is mainly attributed to heating the cleaning media and maintaining them at a certain temperature. Some reports indicate that these energy-intensive cleaning processes in the food, beverage and pharmaceutical industry require up to 13.5-14% of the total process energy consumption. (Piepiórka-Stepuk et al., 2017) It would therefore be favorable to redesign such systems to reduce the energy and water demand, while maintaining the benefits of the process such as asepsis and ease-of-use. The demands placed on the process control sensors in CIP systems are especially high and are an interesting area of study for process optimization. (Zeta, 2019) Moreover, these processes involve the use of large volumes of water and harsh alkaline and acidic chemicals that must be flushed out completely before production can begin. (Crane Engineering, 2019). To optimize the overall CIP systems process, four key parameters should be analyzed: time, temperature, titer and turbulence. These parameters dynamically effect the efficiency of the overall system and are thoroughly analyzed in this report. Although these parameters have been acknowledged in the past by food process industries, very few manufacturers have put the tools in place that render the CIP process efficient. (Jude, B. & Lemaire, E. 2019) Recent innovations and sensory equipment allow large plants to calculate the optimal mix of water, chemicals and temperatures required to achieve safety standards while saving in overall cost, reducing the downtime required for cleaning and optimizing plant production. The optimization scheme of a CIP process presented in this report is adapted for McCain Foods plant applications.

2. Identification of a Need Based on Existing CIP System at McCain Foods

2.1 Food Product Identification for CIP Design

McCain Foods produces over one million pounds of potato products per hour in processing plants around the world. In fact, a quarter of global frozen fry production is manufactured by the company. (McCain Foods, 2019) McCain spends a lot of effort on building relationships with potato farmers. The company transports and receives potatoes from over 3000 suppliers every year (Hunt, 2006). This showcases the importance of conveying and processing potatoes in McCain manufacturing process. McCain supplies potatoes to multiple industries including retail and quick service restauration (European Commission, 2019). The unit processes are adapted to produce products with different attributes required by the end consumers. Potatoes are cut into strips for fries and nubbins (short pieces) for hash brown production.

2.2 Machine Identification for CIP Design

Tubular chain conveyors are the most appropriate type of equipment to move cut potatoes from one machine to another or towards a storage unit. (Luxme, 2018) This system is commonly used in food industries as it allows the maintenance of food quality and ensures that there is no cross-contamination due to the enclosed design. Moreover, the design of tubular chain conveyors is subject to USDA, CE, and/or FDA regulation standards.

Tubular chain conveyors are used to transport bulk material from one part of a production process to another. The design of such conveyors allows for the transport of materials such as cut potatoes in different planes (horizontal, vertical and diagonal). Additionally, they can be designed to have multiple elbows for directional changes (Modern Process Equipment Corporation, 2019). This feature allows for the conveying of product efficiently through different obstacles in a production plant. The tubular structure also ensures a dust-tight and air-tight environment. Tubular chain conveyors can be washed with an automatic CIP processes due to their enclosed and tubular structure. This is a major advantage for conveyor technology as it allows for washing of the machine in less than one hour. (Navam, 2016) Cleaning of conveyors is one of the main issues in food production that often requires multiple hours of manual labor and prevents continuous production. (Douglas Machines, 2019)

2.3 Structure of a Tubular Chain Conveyor

To design a CIP process for tubular conveyors, it is essential to understand the parts and functionalities of the system. The main parts of the tubular conveyor are the drive assembly, tension assembly, convey disc-chain assembly, brush station, turn station and link chain. (Navam, 2016) The basic principle is that the movement of the link chain with circular conveying discs contained in a pipe conveys substances contained in the spaces between the discs (Modern Process Equipment Corporation, 2019).

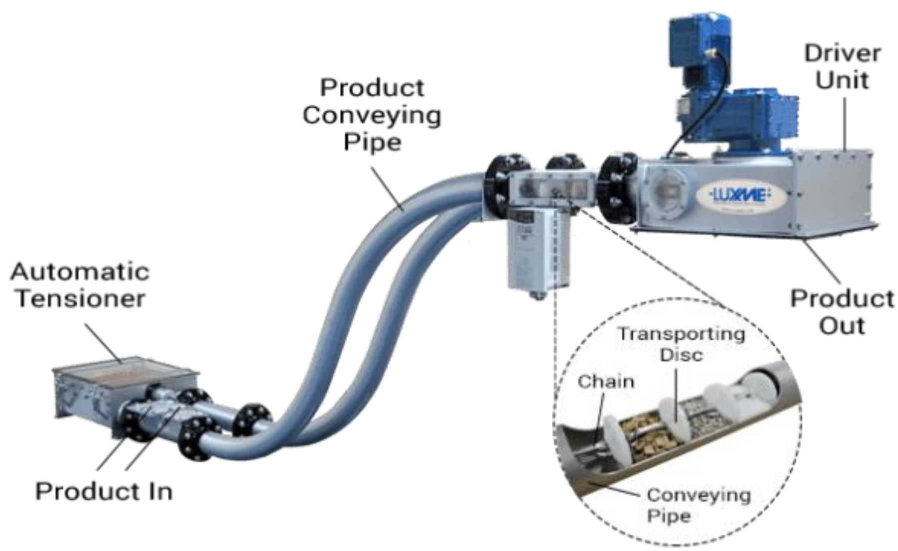


Figure 1- Typical tubular drag link-chain conveyor (From Navam, 2016)

Figure 1.0 - *Typical tubular drag link-chain conveyor* (From Navam, 2016)

A typical tubular conveyer system is shown in Figure 1.0 and constitutes the following: (Navam, 2016)

- **Drive station**—Consists of a chain drive system where sprockets are driven by a gear motor
- **Tension assembly**—Consists of a sprocket that automatically tensions the length of the link-chain during operation. It compensates for any fluctuations in the tension due to variations of friction generated by the conveyed product such as potato
- **Conveying Disc-Chain Assembly**—Consists of a link chain that acts as a universal joint between discs that transmits mechanical power from the motor. In the food industry such as McCain Foods, the discs are molded as an integral part of the chain. This allows to reduce the number of gaps that are hard to reach in washing processes
- **Brush Station**—Integral part of the drive station. Rotating brushes remove pieces of the conveyed products that might adhere to the discs
- **Turn Station**— "L" shaped part that acts as a join between two tubes. This allows to change the direction of the movement of the disc-chain assembly

3. Problem Definition

3.1 Problem Statement

When designing a CIP system, it is important to understand that such mechanisms rarely apply a "one-size-fits-all" approach. (CSI, 2019) The consulting process is an imperative one, as certain criteria need be discussed to maximize production efficiency. For example, the CIP systems used in dairy or pharmaceutical industries require much more complex cleaning agents and heating processes than industries dealing with fresh produce. If a system is over-implemented, plant efficiency is likely at risk. Timmerman (2018) reports that processes becomes exponentially longer if the system is not properly assessed. As a result, most CIP systems are over-cleaned by up to 50%. Although over-cleaning is carried out with the best of intentions, it is not often necessary and leads to increased production costs and downtime. Moreover, the traditional CIP process used at McCain requires keeping a large amount of liquid at a high temperature even if it is used once daily. (Emerson, 2019) The goal of the project is to redesign the CIP system for a tubular chain conveyor used for potato transportation at McCain foods. This should allow to reduce the energy and water demand, while maintaining the benefits of the process such as asepsis and ease-of-use. Moreover, the plant area required to build the solution should be smaller than the space occupied by CIP machinery used at McCain presently. Ideally, the impact on the environment of the waste liquid resulting from the process should be minimized.

3.1.1 Identification of Success Criteria for the Project

The following success criteria for the project were identified based on the problem statement.

- Reduce energy demand of CIP process
- Reduce water demand of CIP process
- Maintain ease-of-use of CIP machinery
- Minimize the plant area allocated to CIP machinery
- Meet Food Safety Production Requirements for the produce selected
- Reduce environmental impact of the waste produced by CIP process

3.1.2 Mission Statement

The following mission statement was established as a guideline for the design process:

"Innovative cleaning equipment for safe and efficient food production"

Each word was selected carefully to demonstrate project goals.

- *Innovation*: Optimizing original methods to solve a known problem
- *Cleaning equipment*: The CIP process is achieved by proper use of cleaning equipment
- *Safe*: Creating a system that is safe for the environment by neutralizing toxic waste and maintain safety of plant workers
- *Efficient:* Usage of minimal amount of water, energy, space and time

4. Review of Literature and Previous Optimization Strategies

4.1 Recommendations for rationalizing cleaning-in-place in the dairy industry: Case study of an ultra-high temperature heat exchanger

Ultra-high temperature (UHT) heat exchangers were designed to minimize potential damage to milk components during sterilization while successfully inactivating microorganisms leading to spoilage. (Manners et al., 2003) Current CIP systems in dairy industries undergo a nonproductive period ranging from 4 to 6 hours per day, where the recovery of plant performance is necessary to ensure hygienic quality and food safety. (Alvarez et al., 2010) The cleaning operations undergone during this lag period are extensive and influence a drastic decrease in plant production. Said operations also lead to a maximum of 95% of waste volume, translating to a range of 0.5 to 5L of water used per liter of processed milk produced. (Marty, 2001) Alvarez et al. present a new strategy towards CIP process optimization, specifically for use in dairy plants utilizing UHT heat exchanger treatments. The proposed strategy involves a critical analysis of the existing equipment with the proposal of revising the overall procedure in dairy plants. The study examines how the effects of minimizing each process duration and the installment of various sensors throughout the system influences the overall cleanliness of the system and the volume of effluent used. Experimental methods are presented to validate the suggested improvement and determine trends in residual milk components in the system.

The UHT heat exchanger (Invensys APV, Evreux, France) in question was composed of 316 stainless steel tubes (each 6.0 m long, composed of 7 channels 14.0 mm in diameter). A 5-zone sterilizer (preheating, heating, recovery 1, recovery 2, and cooling) was part of the process chain. In heat exchanger design, the fouling factor represents a theoretical resistance to the flow of heat caused by a build-up of substances on the tube surface. (HRS, 2018) The limiting zone was determined as the heating zone (inlet = 80°C; outlet = 128°C) due to a sharp increase in fouling caused a sudden temperature change to dairy product. The heating zone was thus chosen for analysis and optimization. The overall process design is illustrated in Figure 1.0 and represents a typical CIP system.

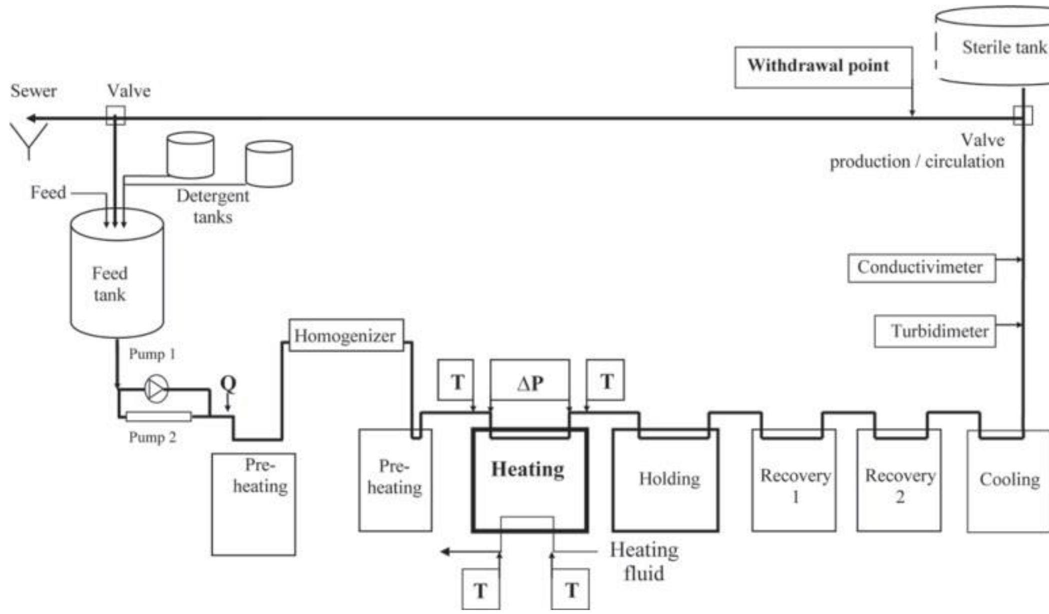


Figure 2-Schematic representing the industrial UHT heat exchanger (From Alvarez et al. 2010)

(where ΔP = differential pressure sensor; Q = flow-rate sensor; T = temperature sensor).

Table 1.0 in the Appendix of this report summarizes the sensors that were installed throughout the process chain. The installed equipment delivered real time data using a PL7 Pro software registering every 20 seconds during production and every 5 seconds during launching and cleaning steps. The most time-consuming cleaning sequence was analyzed and followed the steps below, representing the typical cleaning sequence of the plant:

1. Flushing phase; water is used to push out milk residues
2. First water-rinse; removal of components left slightly attached to equipment while reducing the load of forthcoming cleaning agents
3. First alkaline rinse with NAOH-1
4. Intermediate rinse to washout residual detergents
5. First acid rinse with HNO_3-1
6. Intermediate rinse to wash out residuals
7. Second alkaline rinse with NAOH-2
8. Second acid rinse with HNO_3-2
9. Final rinse to washout residuals

The cleaning phases that involve detergents (3,4,7 and 8) begins by direct addition of concentrated solutions in a feed tank through a valve, allowing for oscillations of detergent concentration with time. The study was repeated by reducing the duration of each sequence phase and used sensors to monitor the quality of water at the outlet. Before optimization, the duration of cleanup for all step was 143 min with an effluent volume of 8300L. Once the revised cleaning system was in place, the duration of all steps was 66 minutes with an effluent volume of 4400L. The report showed that drastic reduction in water usage was attributed to the use of appropriate tools (sensors, and tracers) that constantly monitored the system. On-line measurements of turbidity and conductivity were reported, and it was determined that the quality of water exiting the system was comparable to the non-optimized process.

4.2 Minimizing the environmental footprint of industrial-scaled cleaning processes by optimization of a novel clean-in-place system protocol

Fouling is a detrimental concern in CIP processes that may contribute to large cost and time inefficiencies. Palabiyik et al. (2015) investigated the removal kinetics of adhesive materials on CIP systems and designed a novel cleaning in place protocol for these kinds of materials at an industrial scale. The proposed solution sought to reduce the environmental impact of the cleaning process and assess the effects of temperature and water velocity on cleaning efficacy. The two-step CIP protocol as suggested by the study compared with conventional one-step CIP protocols found reductions in energy consumption by 40% without decreasing cleaning efficiency. Toothpaste was used as the model deposit and a pilot plant system at industrial scale was used to simulate a CIP set-up. (Cole et al. 2010) The pilot system was monitored to determine the cleaning procedure of the toothpaste within the pipe work. Although cleaning fluids are sometimes recirculated in such systems for efficiency purposes, the study did not recycle its water because one aim was to quantify the amount of water consumed per cycle. A schematic of the system is shown in Figure 3.0.

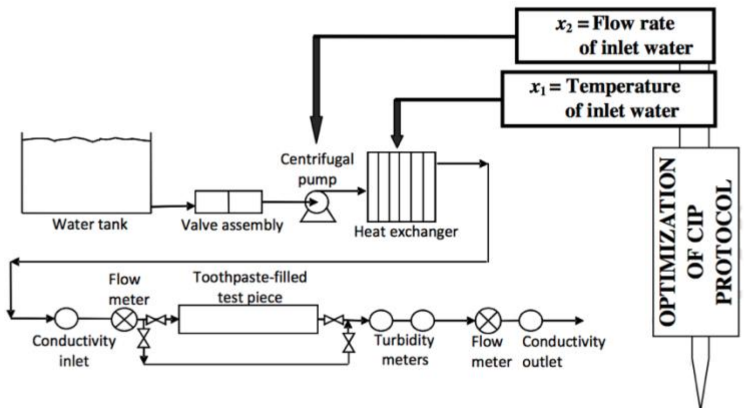


Figure 3-Schematic representation of the pilot plant. (From Palabiyik et al., 2015)

System monitoring was aided by use of conductivity probes, flow meters and turbidity meters. A selection of 3 ppm on the turbidity meter marked the end-point for proper cleaning. (Palabiyik et al., 2015) The research found typical cleaning behavior and cleaning regions as shown in Figure 4.0. The response of the turbidity meter was set when the temperature reached 70°C and the flow rate reached 1.75 m/s. Cleaning began at very high rate with the turbidity meter saturated up to 125 seconds (stage 1 duration). The response then decreased exponentially until the end of cleaning, which was defined as region 2 and lasted 90 seconds.

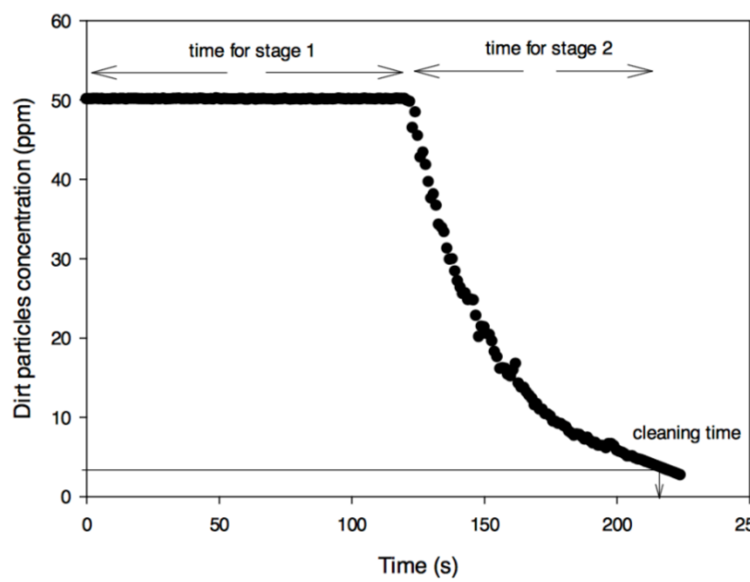


Figure 4-Graph demonstrating turbidity meter response (from Palabiyik et al., 2015)

Water and energy consumption was calculated using the following equations:

$$[\, V = Qt\,/\,3600] \quad (1)$$

$$[\, E = \frac{V\rho g h}{\varepsilon} + V\rho c_p \Delta T] \quad (2)$$

where V (m^3) was volume of the water used during cleaning, Q (m^3/h) was the volumetric flow rate and t (s) was time for each region. E was the energy consumed (MJ), ρ was the density (kg/m^3) of water, g (9.81 m/s^2) the acceleration due to gravity, h (m) was the friction head loss component of the system, ε was pump efficiency, cp (4185.5 J/kgK) was heat capacity of water and ΔT (K) was temperature difference (temperature of cleaning water - datum temperature). Datum temperature was the average ambient temperature (17 °C), and 20°C was selected for the minimum temperature experiments. Models were constructed and described the effect of the independent variables (cleaning water temperature and flow rate) on the cleaning time, energy and water consumption for both regions 1 and 2. Region 1 was termed the "film removal" section, which represented the first cleaning time and first energy consumption. Region 2 was the "patch removal stage" which represented the second cleaning time and second energy consumption. Results determined that each model gave a better description of cleaning kinetics when those regions were considered separately instead of added together for a total cleaning time and energy consumption. This indicated the need to consider both processes separately when designing an optimal CIP protocol. For the most desirable optimization of each response variable (time, energy and water consumption) at each removal stage, Palabiyik et al. report the following findings, where the following conditions should apply:

- A temperature of 20°C and flow rate of 16 m^3/h (2.5 m/s) in region 1

  At this circumstance, the solution had the lowest value of the first cleaning time (42.6 s), first energy consumption (22.6 MJ) and first water consumption (727.4 L) values to get the optimum CIP protocol.
- 70°C and 16 m^3/h (2.5 m/s) in region 2, which induced the lowest value of second cleaning time (39.1 s), second energy consumption (25.2 MJ) and second water consumption (108.9 L) values according to response surface models.
- For the conventional CIP system (without applying different conditions throughout the cleaning process), 70°C and 16 m^3/h (2.5 m/s) should be used for the total cleaning. At this instance, the solution had the lowest value of total cleaning time (64.5 s), total energy consumption (89.2 MJ) and total water consumption (178.2 L) values.

An optimum CIP protocol was built based on the above findings and was compared to conventional industrial protocols that use water at much higher temperatures. The research found that the optimum CIP protocol reduced the amount of waste water and cleaning time by 50% and 53%, respectively. It also found a 39 MJ less energy (40%) consumption. The results deduced that the optimum CIP protocol had a big advantage over conventional CIP protocols and substantially decreased the carbon footprint and fuel costs in plants where adhesive products are manufactured. It was also found that temperature reductions in CIP processes are advantageous for minimizing the energy consumption while conserving system cleanliness.

5. Establishment of Design Criteria and Constraints

5.1 Safety Standards

Food production is subject to multiple guidelines and standards as food safety is crucial for public safety. However, most of the governmental and industry requirements for CIP are related to the establishment of processes and frameworks to validate the efficiency of the equipment. This can be related to the fact that CIP processes consist of unique equipment and process that are adapted for a use case. Moreover, McCain produces products in over 160 countries. (McCain, 2019) Thus, they must comply to multiple country-specific standards. The following paper will outline Canadian and international standards. The Canadian Food Inspection Agency has published guidelines on Safe Food for Canadian Regulations. These guidelines describe in-depth standards for both processed and fresh foods of all kinds, with specific subdivisions pertaining to each category. In Subdivision B: Whole fresh fruits or vegetables, article 113 states that “potatoes that are imported must meet the requirements for the grade Canada No. 1 that are set out in the Compendium”. Potatoes coming from the United States are considered to meet the requirements set in the Canadian Food Inspection Agency’s report entitled: Grade Standard Requirements for Fresh Fruits or Vegetables Imported from the United States. The CFIA has published criteria pertaining to the handling standards of imported potatoes. (CFIA, 2019) These criteria are based primarily on the diameter, weight and variety of the food. There are regulatory guidelines for cleaning and sanitation that must be applied to each component of the system. Cleanliness is an important part of the Canada No. 1 grade, which requires potatoes to be “reasonably clean”. According to the CFIA:

Reasonably clean has been defined to suggest:

- The potatoes are reasonably free from dirt; and

- Where the potatoes are in a container, there is not more than a slight amount of loose dirt or foreign material in the container.

It is thus important for the CIP cleaning system to adequately remove all the residual dirt left on the tubular chain conveyors. Additionally, the conveyors are exposed to several pests such as fungi, bacteria, insects, nematodes, and weed seeds. Many of these pests can be spread from tube to tube or field to field on equipment or in storage and cause problems in future crops if not eliminated or at least minimized.

The CFIA also requires that food production be compliant to FDA HACCP guidelines. (Government of Canada, 2017) HACCP, or the Hazard Analysis Critical Control Point system is a framework that allows to identify possible risks in food production and adopting methods to mitigate them. HACCP requires to implement processes and conduct a series of activities for 7 principles (FDA, 2017).

5.2 Hazard Analysis and Mitigation using HACCP Framework

In order to analyze and identify potential hazards in the CIP process and mitigate certain risks by considering them in the design process, the HACCP framework was utilized.

- Principle 1: *Conduct a hazard analysis*

The main hazards in potato production are contamination of foodborne bacteria. During harvesting, potatoes could be exposed to *E.coli* 0157:H7 and Salmonella due to exposure to manure. Human presence during production also increases the chances of contamination. A detailed list of hazards in potato production is outlined in figure 5.0.

- Principle 2: *Determine the critical control points* (CCPs).

Critical Control Points (CCPs) typically include flow rate, temperature and chemical solution strength. (McCarthy, 2015) These are the points that must be accounted for to adequately meet safety standards. Control points can be monitored manually or automatically through the use of sensors. An identification of risks in the design process would allow to identify the critical control points.

- Principle 3: *Establish critical limits*

According to the CFIA, a critical limit is the limit at which a hazard is acceptable without compromising food safety. CIPC Compliant (2013) published a detailed HACCP report for potatoes from harvest to sprout control, as can be seen in Figure 5.0. Critical limits identify the acceptance or rejection of certain parameter in the CIP Process. If the critical limit of a parameter is achieved, the parameter must be rejected, and a corrective action must be taken by plant manager to ensure sanitary production. An analysis of critical limits from potato harvest to end consumption is delivered in Figure 5.0 of the Appendix.

- Principle 4: *Establish monitoring procedures*.

Detailed monitoring activities are essential to ensure operations are safe. The addition of sensors in CIP design could facilitate monitoring procedures.

The following 3 steps will not be considered in the scope of the design project but should be analyzed if the CIP process would be implemented in a McCain Foods plant.

- *Principle 5*: *Establish corrective actions.*

If critical limits are not met, corrective actions determine the appropriate response.

- Principle 6: *Establish verification procedures.*

To reduce the need or occurrence of corrective actions, verification procedures should be constructed.

- Principle 7: *Establish record-keeping and documentation procedures*

Proper documentation, record-keeping and data of all hazard analyses should be kept for later reference.

6. Problem Analysis

6.1 Parameters Under Consideration

Efficiency improvements do not only focus on minimizing time, energy, water, and chemical usage. CIP systems aim primarily to remove fouling from equipment caused by a buildup of residual food components. When process equipment is not entirely clean, raw materials must be discarded and the cleaning process needs to be repeated before subsequent production can take place. Effective cleaning results in fewer instances of contamination and therefore improves the efficiency of the overall process. (Jude, B. & Lemaire, E., 2019) The parameters of the CIP process must be adapted to the specific case of the tubular chain conveyor in use. At McCain Foods, this use is attributed to cut potato transportation. It is important to note that CIP standards vary depending on the residual product that must be removed. (CSI, 2019). In order to establish the proper parameters, the specific machine that the CIP process will be applied to must also be considered. Proper cleaning of piping, tubing, and in-line fittings is a primary focus for any clean-in-place system. Regardless of the time, temperature and chemical concentration of your cleaning fluid, the flow velocity must be high enough to create turbulent flow or “action.” This mechanical action is primarily responsible for dislodging residual product from the interior surface of the process lines and fittings. The correct supply flow rate creates enough turbulence throughout the complete circuit. The larger the line size, the more flow required to achieve required velocity This section examines the parameters under consideration during the optimization process.

6.1.1 Temperature

Calculating the precise temperature needed to clean food process equipment is critical to reducing CIP energy consumption. According to Benjamin & Lemaire (2019), every 1°C reduction in CIP temperature induces a reduction of temperature required to heat fluids by $1/60^{th}$. OpX (2018) published a guide on clean-in-place guidelines for consumer packaged goods manufacturers, in which they report that warmer temperatures are generally more effective for cleaning. It is important to note that temperatures that are too high or too low can effect the chemical performance of the cleaning agent used. OpX suggests:

- Rinses typically utilize ambient water.
- The system should be designed to minimize drastic temperature changes between the wash and rinse fluids which could cause equipment damage.
- For proper measurement of CIP fluid temperatures, the CIP system should have two temperature indicators (one on the supply line and one on the return line)
- The return line indicates the minimum temperature experienced by the entire system and should therefore be used for recording and verification.
- The supply line temperature transmitter is used to control the CIP fluid supply temperature.
- Delay in response of the return line temperature can be alarmed to indicate loss of fluid or other failure mode.

6.1.2 Water

The quality of water used for aqueous cleaning is critical for performance and depends on both chemical properties (pH, hardness, etc.) and biological properties (bioburden, endotoxins). (Jeffery & Sutton, 2019) Water hardness is a measure of how much calcium and magnesium there is in the water and is an important consideration in CIP systems. Tetra Pak's (2018) publication of guidelines for CIP systems reports that high levels of chloride and chlorine in water causes the corrosion of stainless steel. Most CIP guidelines therefore require that the quality of water used in cleaning should meet drinking water standards.

6.1.3 Chemical Usage

Many variables are considered when selecting the right chemicals for each CIP application. The right chemical cleaning agents in the right concentrations make a significant difference in the efficiency of the overall process. When used properly, CIP cleaning agents: (CSI, 2019)

- Reduce surface tension of water, making it easier for the cleaning solution to penetrate soil
- Break down bonding forces between soil and surface
- Soften fats so they can be rinsed away
- Dissolve soils for easier cleaning
- Emulsify water-soluble soil in the cleaning solution for easier transport

CSI Designs (2019) summarizes the common CIP chemicals and gives a general guideline for their use:

	Summary	*Advantages*	*Disadvantages*
Caustic	Also known as caustic soda, sodium hydroxide or NaOH. This is an alkali with a very high pH that is typically used in a concentration range of 0.5-2.0%. Concentrations as high as 4% may be used for highly soiled surfaces.	Typically used as the main detergent in most CIP wash cycles Softens fats, making them easier to remove. Non-foaming formulation can help reduce pump cavitation and increase efficiency.	Not effective for removing scaling.
Acid	Nitric acid is the most commonly used wash for scale removal and pH stabilization after a caustic wash Used at a typical concentration of 0.5%, it can be used effectively at lower temperatures than caustic solutions, requiring less heating. Phosphoric acid is sometimes used but is somewhat less common.	Brightens up discolored stainless steel by removing calcified mineral stains	Must be used with caution because they can attack some elastomers in the system like gaskets or valve seats causing premature degradation or failure.
Sanitizer or Disinfectant	The job of a sanitizer, also referred to as a disinfectant, is to reduce microorganisms to a level where they don't pose a risk to food safety	Relatively inexpensive to use	Can be very harmful to stainless steel, causing staining, corrosion and pitting.

	For many years, various hypochlorite solutions (potassium, sodium or calcium), also known as “hypo,” have been used as sanitizers in many CIP cycles.		Can cause some significant environmental problems when dissolved in wastewater streams by killing vital microorganisms in streams and waterways.
Sterilizer	Sterilizing a system means complete elimination of all living microorganisms. Sterilization can be done using chemicals but it is usually done with high pressure steam (approx. 250° F for 30 minutes). Food, dairy and beverage processing plants seldom require sterilization in their CIP process	Strong disinfectant even at low temperatures Rinses away well leaving little or no chlorine residue to corrode stainless steel Effective against all microorganisms Proven to be more eco-friendly in the wastewater stream	Strong, pungent odor Should only be used in well-ventilated areas

Table 2.0 – *Summary of Chemical Agents Involved in CIP Process* (From CSI Designs, 2019)

6.1.4 Time

In general, time required to clean is directly proportional to degree of difficulty to remove the soil load from the surfaces. Light, water soluble products take less time to clean than fatty products and denatured or burned on proteins. Time is usually the least available, yet most impactful variable of CIP. It is the only variable that does not have an upper limit, although there is a point of diminishing return. Time spent within acceptable ranges for chemical concentration, temperature, and flow is a critical parameter of each step in the cleaning sequence. As such, step time does not start until all required fluid parameters have been achieved. Time to achieve temperature, stabilize concentration, should be accounted for the total time of a cleaning sequence. The actual time required to clean any circuit or piece of equipment can only be truly determined once the system is in place and in use.

6.1.5 Fouling

Fouling is a costly and unavoidable problem in most food and beverage industries. Fouling occurs when heat treatments are used on the product to achieve a desirable taste, texture or safety standard. For example, in dairy industries heat treatments used for protein denaturation causes subsequent deposits of protein molecules or calcium buildup on the inner surface of the media. (Jeurnink, 2019) In the case of most fresh produce plants, this is usually due to residual soil matter or microbial adhesion. Microbial adhesion on pipe surfaces and subsequent growth of organisms is an important concern and is often the result of poor response to fouling. (Goode et al. 2013). A thorough discussion of fouling mechanisms is offered in Figure 6.0 of the Appendix.

Economic penalties of fouling in heat exchangers are discussed by Müller-Steinhagen (2000):

- **Capital expenditure**—excess heat transfer surface area compensating for the occurrence of fouling
  - Increased heat transfer from heat exchangers due to fouling is estimated as an average of 30% additional capital cost.
  - Higher transport and installation costs for bigger and heavier equipment.
  - Cleaning systems—installation and maintenance costs.
- **Fuel cost**—Possibility of extra energy required to keep the fouled heat exchanger operating for the required performance.
- **Maintenance cost**—Of the heat exchanger, cleaning system, and any ancillary equipment in the process loop (chemical tank level probes, flow meters, interface probes).
- **Cost due to production loss**—Cost of continuous production as compared to the actual production cost.

Accurate measurements of fouling effects are therefore critical for plant efficiency. These measurements are achieved by following the change in heat transfer over a fouling period by including a fouling resistance, R_f, in the equation relating the initial (clean) heat transfer coefficient, (U_0), to that at any time t, (U):

$$[\frac{1}{U} = \frac{1}{U_o} + R_f] \tag{3}$$

6.1.6 Rinse Water Recovery and Drainage

6.1.6.1 Single-Use Systems

Simple applications of CIP systems involve single-use systems in which water can be used once and then discarded to drain. This process is very expensive as cleaning chemicals, water and effluent costs are quite high. In addition, the operation is not considered sustainable. Such systems are justified when it is essential to prevent microbiological cross-contamination of different areas of the process plant. (SPX, 2019) Recovery of cleaning solutions in a recovery tank and restoration of the original concentration of the cleaning fluid is recommended but is an additional (high) cost.

Single-use systems require extensive monitoring for the build-up of residual soils and cleaning chemicals.

6.1.6.2 Multi-Use Systems

Multiple-use systems are generally preferred for their consideration of waste water reduction. The option of water recycling gives producers the ability to clean multiple processes by cycling waste water from one procedure, filtering out chemicals and residuals and reusing the water for another procedure. However, such operations have high capital costs, require more space and induce higher risks of contamination if filtering is not carried out properly. (SPX, 2019)

6.2 Analysis of the CIP Process Used at McCain

As the goal of the project is to optimize the CIP Process used by McCain, it is essential to build a good understanding of all the required components. An analysis of the considerations outlined in the previous sections will allow to determine the main areas of improvement. An interview with an engineer that worked on the implementation of CIP processes at McCain Foods allowed us to plot a schematic of the CIP process in AutoCAD showcased in Figure 7.0 of the Appendix of this report. The name of the engineer was omitted in this report for confidentiality purposes. Moreover, the steps involved in the CIP process were also documented in Figure 10. The main features of the design are outlined in this paper. The current CIP process is a single-use system that utilizes 4 tanks and a 6 steps process. Caustic solution and sanitizer at concentration indicated by the manufacturer (2-3%) are pre-mixed in the tanks. The CIP process is used once daily. The presence of an air line allows to control solenoid valves. The same air line is also utilized to create turbulent flow in the tubular chain conveyor to decrease fouling. The liquid coming from the tanks is pumped into three points in the tubular chain conveyor; the drive station, the tension station and the product inlet. This allows to fill up the tubular chain conveyor more efficiently. Thus, the tubular chain conveyor is also drained from those three points. If the liquid level at the tension station or the drive station is too high, the overflow water is sent to the drain in pipes designed for this purpose. Temperature sensors were added to the design to monitor critical control points. Accordingly, a temperature sensor is submerged in each tank and at the drive station.

Tubular chain conveyor parameters were also provided by an engineer. The following chain length conveying speed and internal volume will be used as base assumptions in the design of the optimized CIP process and analysis of current CIP process used at McCain Foods.

Chain Length	100	ft
Conveying Speed	42	ft/min
Total Conveyor Internal Volume	45	cu.ft
Total Water Flow Rate Consumption	100.1	US Gallons/min

Table 3.0 – *Summary of Values and Parameters Supplied for Conveyer System*

The conveyor internal volume converted into liters (1264 L) and in US Gallons (334 US Gallons) As turbulence is required to effectively wash machinery, the minimum turbulence should be calculated. However, a high turbulence level could also damage the conveyor. The consulted engineer shared the experimentally found ideal turbulence speed for tubular chain conveyors. The following equation allows to approximate it:

$$Turbulence\ speed = Conveying\ speed * 1.5 = 42*1.5 = 63ft/min$$

The cycle time can be defined as the time required for a substance to travel 1 turn at conveying speed in the tubular chain conveyor.

$$Cycle\ time = (Average\ Chain\ length/\ Average\ Conveying\ Speed) = 100/42= 2.38\ min$$

The conveyor filling time is an important parameter for the CIP design as CIP time should be minimized.

$$Conveyor\ filling\ time = Total\ Conveyor\ Internal\ Volume\ /\ Total\ Water\ Flow\ Rate\ Consumption = 334/100.1= 3.33\ min$$

To estimate the amount of energy required to heat up the liquids stored in CIP tanks; the volume of water must be calculated. The equipment is rinsed with hot water during the pre-wash step and rinsing step. The time required for both steps can be estimated using the conveyor filling time.

An additional 10 percent of water will be added to each step to account for possible volume measurement errors and possible leaks that can occur in the lifetime of the equipment.

Total Rinse Water Consumption + 10%=Total Rinse time Total Water Flow Rate Consumption*1.10=(3.33+3.33)*100.1*1.1=734 US gallons= 2778.49 L*

The same approach was used to estimate the total detergent consumption and the total sanitizer consumption. Both require 367 US Gallons or 1389.25 L of solution to be stored in tanks to wash a 100 ft conveyor once.

The total volume of liquid that is heated in the current McCain Foods CIP process is 5,560 L

7. Consideration of Alternative Designs

7.1 Identification of Variations of the Optimized CIP Process

Alvarez et al. (2010) present the usage of ultra-high temperature heat exchangers to optimize a CIP process in the dairy industry as describes in section *4.1* of this report. The design outlined in the paper would allow to eliminate the non-productive period time of CIP processes. However, safety standards for CIP processes in the dairy industry are considerably different then standards developed for vegetables like potatoes (BCCDC,2019). Moreover, UHT heat exchangers heat up liquids to temperatures between 70 °C and 140 °C and have high energy consumption rates (Tetra Pak, 2019). Palabiyik et al. (2015) found that the ideal CIP process requires water at 20 °C and 70 °C. Therefore, a UHT heat exchanger would not be suitable for a CIP process applied in a non-dairy industry as it overshoots the output temperature range. However, an industrial tankless water heater would allow to reach the required temperature output while maintaining all the benefits outlined by Palabiyik et al. Additionally, it would considerably reduce the cost and energy demand required by the CIP Process. Eemax (2019) a supplier of industrial tankless water heaters advertises a reduction of energy waste of 50% associated to the usage of their heating equipment. Preliminary calculations using RUUD (2019) calculator are showcased in Figure 11. The calculated energy cost reduction for the McCain Foods CIP Process is 39%. Another method to reduce the energy requirement would be to rinse with water at 20 °C during the pre-wash step as outline by Palabiyik et al. (2015). The second rinse step would still require hot water. The efficiency of the CIP process could be further increased by selecting the best chemical for potato equipment cleaning. This analysis will be conducted in later stages of the project when equipment constraints will be identified. Finally, a reduction of water consumption could be achieved by designing a multi-use system.

7.2 Optimized CIP Process

Based on the optimization parameters described above, two schematics were designed on AutoCAD to display the improved CIP designs. Both design alternatives utilize tankless water heaters. An eductor with two inlets would allow to mix caustic concentrate and sanitizer concentrate as the water is flowing through the pipe. The assumption that the water heater has an integrated flow sensor and temperature sensor was made. This would allow to monitor critical limits at this control point. The drain layout, the air line and the CIP equipment connection points to the tubular chain conveyor were not modified from the original design. Figure 8.0 represents the optimized CIP process with no water reuse. Figure 9.0 represents the same process with a water recovery system. Water reuse is achieved by an automatic diverter switch that would redirect water directed into the drain into a storage tank. Moreover, the water is filtrated before being stored in order to eliminate any hazard. A combination of three diverter valves is used in the design to reduce the number of pumps required. The same pump that is used to move the water from the tubular chain conveyor outlets is also used to feed it back into the tankless heater.

7.3 Comparison of Designs

The development of a Pugh Matrix qualitatively ranks the multi-dimensional components of the design and weighs the importance of each criteria on the total design. Below is the Pugh Matrix associated with the optimized design. The baseline is the CIP process used at McCain currently. The weight given to each criterion was based on project goals and the mission statement of our team. Both solutions allow to reduce plant space using tankless water heaters. However, the initial investment related to this element is higher than tank heaters. Water consumption is only reduced if water is reused and this would also allow to decrease the CIP process time due to a higher volume of water. The Pugh Matrix allowed us to determine that the best solution to achieve our goals was the CIP process with water reuse.

			Alternatives			
	Weight	***Baseline***	***Optimized CIP Process with Water Reuse***		***Optimized CIP Process with No Water Reuse***	
Criteria			*Rating*	*Weighted*	*Rating*	*Weighted*
Plant Space Requirements	*3*	*0*	*1*	*3*	*1*	*3*
Water Consumption	*5*	*0*	*1*	*5*	*0*	*0*
Energy Consumption	*5*	*0*	*1*	*5*	*1*	*5*
Initial Investment	*5*	*0*	*-1*	*-5*	*-1*	*-5*
Operating Cost	*5*	*0*	*1*	*5*	*1*	*5*
Contamination Risk	*2*	*0*	*-1*	*-2*	*1*	*2*
CIP Process Time	*5*	*0*	*0*	*0*	*-1*	*-5*
Total		*0*		*11*		*5*

Table 4.0 – *Pugh Chart for Overall Design Process*

8. Identification of Risk

The table below summarizes the risks associated with the design and the various safety, economic, environmental and social parameters under consideration.

	Safety	Economic	Environment	Social
Associated risks	➢ Chemical usage and worker safety ➢ Health of consumers is dependent on success of cleaning operation	➢ Costly installment ➢ Loss of production time when new system is being implemented	➢ Waste water management (Including effects of chemical agents and volume of water used and voided)	➢ Possibility of diminishing user-friendliness or ease-of-use due to new proposed mechanism
Plans for mitigating such risks	Adequate attention to chemicals used, determination of the cleaning agent with highest cleaning capabilities with lowest associated risk Close attention to Food Safety Standards	Analyze the inputs and outputs to determine if the goal is profitable and in which ways profits can be made Implement a pilot scale system first	Determine if recycling of water is optimal for McCain and if so, deliver a recovery system that will reduce the water consumption Use chemical agents at lower than	Discuss the benefits of optimization and pitch the design in a way that highlights it's obvious strengths, in this way plant managers are not reluctant to

	Constant monitoring of system via sensors (temperature, turbidity, etc.)	Communicate with engineers as much as possible Implement the system when production time is at its lowest	suggested concentrations and determine the effects on cleanliness	changes in operations

Table 5.0 – *Summary of Risk Assessment*

9. Scope of Design

9.1 Educator Mechanics

The current CIP design at McCain involves the use of three large storage tanks that are maintained at high temperatures, even when not in use. The proposed design incorporates the use of an eductor, also known as a jet pump or Venturi pump, to replace the leading tank design. Eductors operate by utilizing the kinetic energy of one liquid to cause the flow of another (Northeast Controls, 2019). The specific geometry of the design produces a high velocity jet of fluid flow, consequently producing a vacuum that sucks in another fluid through a side or suction port. The emulsified liquids form a solution that is propelled forward through the pump at high pressure (Schutte and Koertings, 2020).

9.2 Eductor Advantages and Alternatives

The obvious advantage of the eductor pump is its ability to fully replace the leading multi-tank system currently used by most food industries. Tanks are maintained at heated temperatures throughout the day in preparation for cleaning. In this design, a calculated volume of water passes through the water heater before reaching the eductor. Once pulled in through the suction port, cleaning agents are sucked into the body of the eductor and homogenized at high pressure. As the solution flows at high velocity out of the eductor, it cleans and sanitizes the system. An alternative system to the proposed design is the ProMinent Sigma3, a pump that can be used in a variety of applications such as the time-controlled additional of chemicals in water circuits or volume-contolled addition of chemicals in water treatments (ProMinent, 2020). According to specialists, McCain would require three Sigma3 pumps, one for each chemical in solution, at an estimated retail cost of $7000 each. Given the complexity of these pump systems, there would be a higher risk of failure for this system in comparison to the proposed design. The eductor design proposed in this report is a small, simple yet effective intermediate that is added to the process chain, delivering the necessary power output at a fraction of the cost, space and time as leading systems.

10. Cost Benefit Economic Analysis

A cost benefit economic analysis was performed to determine if the project is justifiable and feasible, i.e. its benefits outweigh costs its costs.

1. Goal and Objectives

The goal and objective is to replace an energy-intensive, outdated cleaning and sanitation system with a simple system that can be incorporated directly into the water line.

2. Alternatives

Presently, a similar alternative is the ProMinent Sigma3. Three of these systems are required and would cost McCain a retail price of $21,000. Since these systems are more complex, they require more training with more expensive parts that need to be replaced more frequently.

3. Stakeholders Involved

The main stakeholders involved are

A. McCain – the biggest stakeholder with the most to gain or lose

B. The engineers and design company

C. Employees

4. Costs and Benefits

Cost Benefit Analysis: Eductor Pump				
Costs				
Category	**Item**	**Quantity**	**Price**	**Total**
Hardware	Digital High Accuracy Pressure Gauge w/ Transmitter – 0-10V DC Output, 0-40 psi	1	$396.67	$396.67
	316 SS Threaded Pipe Fitting, Low pressure, Straight Connector	1	$47.92	$47.92
	Brass Body Solenoid On/Off Valve, 24V AC, 2 NPT Female, 53 Cv	1	$556.26	$556.26
	Clamping Precision Flexible Shaft Coupling, 303 SS	1	$197.90	$197.90

	Speed-Control Motor, 120V AC, NEMA 34, 1/3 hp, 1750 rpm	1	$1061.34	$1061.34
	Eductor Main Input	1	$170.53	$170.53
	Eductor Outlet	1	$170.53	$170.53
	Piston	1	$213.82	$213.82
	Piston Housing	1	$61.66	$61.66
	Piston Screw	1	$11.70	$11.70
	Piston Guide	2	$27.07	$54.14
	O-Ring, AS 568 – DASH # 234, 568S	1	$34.08	$34.08
	Stand	4	$23.75	$95.00
	Magnetic Induced flow meter	1	$125.45	$125.45
System Training	System overview	1	$1000.00	$1000.00
				TOTAL COSTS: $4197.47
Benefits				
Yearly	Energy savings (49%)			$16, 937.09
	Downtime reduced, i.e. higher production			$23, 478.10
				TOTAL BENEFITS: $40, 415.20

Prices retrieved from McMaster-Carr, 2020

The estimated cost of one eductor unit, including installment and system training is an estimated $4197.47. Most eductor parts were obtained from McMaster-Carr (2020). The cost of parts that were not available for purchase on McMaster-Carr were estimated based on similar pieces that were. It was determined earlier that the proposed system would maximize savings up to 49%. The product of volume of water for a yearly run of CIP and the cost of water were used to determine the energy savings. The benefit of increased production due to reduced downtime was estimated based on the current manufacturing rate and the rate of cleaning given the eductor pump over the CIP tank system.

11. Literature Review

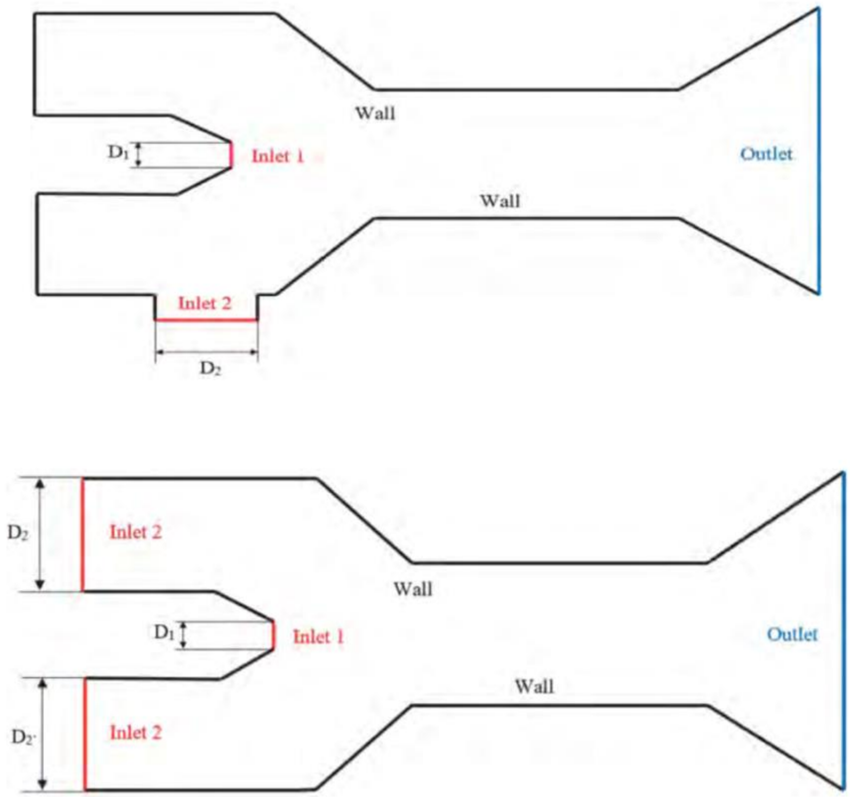
Once sufficient background knowledge of alternative solutions was obtained, the second focus of the literature review was to determine how effective and feasible our proposal was. The following segment provides the most valuable components of the research that was considered for the design of the eductor. Although many papers were reviewed, the following studies were considered imperative to our design.

11.1 Numerical Modelling of Flow in the Eductor Pump

Research focused on fluid dynamic models for determining the optimal efficiency and geometry the eductor. Dimofte et al. (2019) present a numerical model for the flow of water through an eductor with the use of computational fluid dynamics (CFD) software ANSYS. The software was used to solve complex three-dimensional Reynolds-averaged Navier–Stokes equations (Dimofte et al., 2019). Numerical modelling was performed on two eductor geometries, each with a computational domain of 750 cm^2 but with varying fluid nozzle dimensions. Air was used as both the driving fluid and the mixing fluid for both trials.

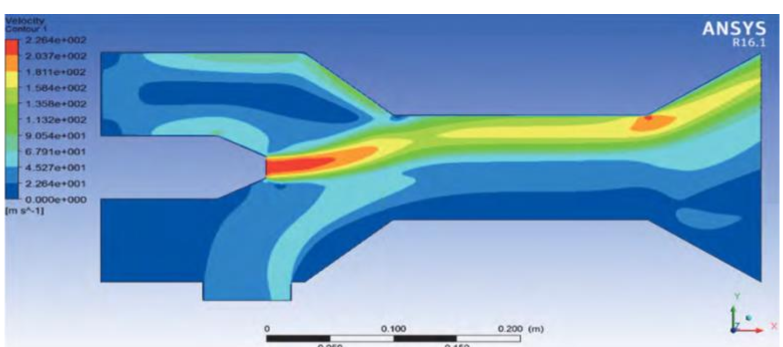
	Diffuser throat dimeter D1	Suction fluid nozzles D2, D2’	Flow geometry	Mass flow rate
1st test geometry	2 cm	7 cm	Suction fluid enters the driving fluid perpendicularly in mixing segment	5 kg/s
2nd test geometry	2 cm	9 cm	Suction fluid enters the mixing section parallel with the driving fluid	5 kg/s

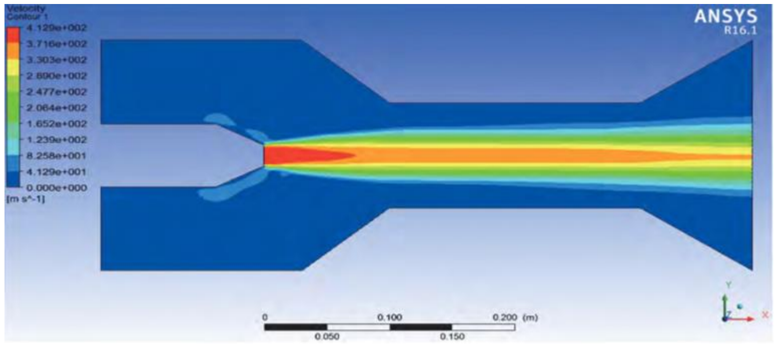
Table 6.0 – *Overview of eductor geometries (Dimofte et al., 2019)*



Geometries of eductor test 1 (top) and eductor test 2 (bottom) (Dimofte et al., 2019)

Using the same initial and boundary conditions, the ANSYS software provided numerical simulations for both geometries. In the case of the first geometry with suction fluid entering perpendicularly to the driving fluid, the simulation determined that the high-velocity nature of air entering the suction port, the mixing flow deviated upwards for this geometry. When the suction fluid enters parallel to the mixing fluid, the ANSYS software showed a high velocity forward flow through the eductor.





*ANSYS simulations depicting fluid flow of first test geometry (top) and second test geometry (bottom) (*Dimofte et al., 2019)

The results of the numerical modelling showed higher efficiency for eductors with parallel flowing fluids. This was considered for the design of our system; however multiple inlets were needed to account for various cleaning solutions. The review provided some insight on the use of fluid dynamic boundary conditions as mathematical models for the basis of design.

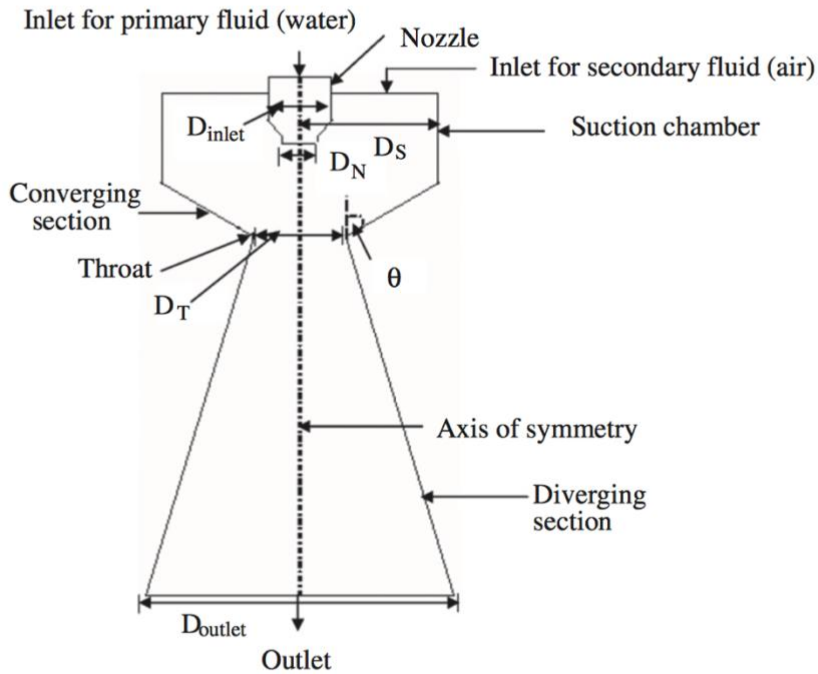
11.2 Design aspects of ejectors: Effects of suction chamber geometry

Yadav and Patwardhan (2008) also provide a research article on the effects of suction chamber geometry in ejector loop reactors. The work focused on optimization of the ejector and suction chamber with use of computational fluid dynamics (CFD). Several aspects were considered, including the effect of: (Yadav and Patwardhan, 2008)

1. Projection ratio (LTN/DT*)*, the ratio of the distance between the nozzle tip and throat *(LTN)* to the throat diameter (DT)
2. Diameter of the suction chamber (DS)
3. Angle of the converging section (Ø) on the entrainment rate of the secondary fluid
4. Projection ratio (PR), or distance between the nozzle tip and throat entry
5. Suction chamber area ratio (AS /AN)

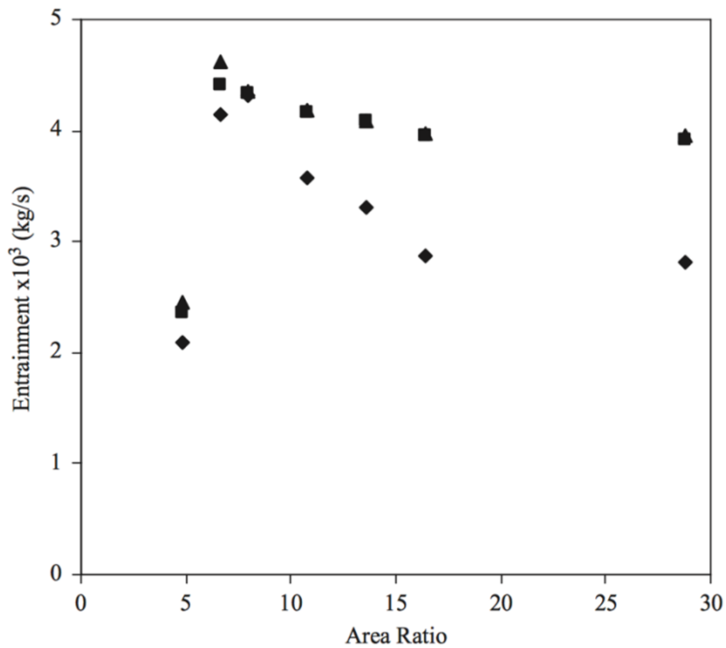
When considering the performance of the liquid jet ejector, Yadav and Patwardhan discuss the significance of nozzle geometry, the size and shape of the suction chamber and geometry of the diffuser. Background theory discusses that increasing the projection ratio causes an early breakup of fluid flow and thus a large amount of energy loss, however smaller PRs cause lower rates of momentum transfer between the two fluids. A CFD model was set up to determine the true effects of the PR on overall dynamics. The entrainment rate was defined as a function of the prevailing fluid dynamics, also determined by a set of geometrical parameters. The FLUENT 6.2 CFD modelling software was used to model two equations; the Euler-Lagrange equation and the Euler-

Euler equation. Several PR values were tested (2.5, 5 and 14.5) and further analysis determined that the entrainment rate was maximized at a PR of 5. Effects of the converging angle of in the suction chamber (Ø) were also analyzed. Lower entrainment rates were characteristic of lower angles, whereas higher entrainment rates were noticed as the value of the converging angle was increased. For this reason, the results suggest maintaining a convergence angle between 5º-15º.



Geometry of ejector (Yadav and Patwardhan, 2008)

The effect of the diameter of the suction chamber (DS) was determined by analyzing the area available for both air flow and water with use of the dimensionless parameter $(DS^2 - DN^2)/(DN^2)$.



Effect of area ratio ($DS^2 - DN^2)/(DN^2)$ on the rate of entrainment for different PRs (Yadav and Patwardhan, 2008)

The optimal efficiency of the ejector was found at a $(DS^2 - DN^2)/(DN^2)$ value of 6.6. It was concluded that the three primary geometrical parameters investigated in this study (PR, diameter of the suction chamber and angle of the converging section were imperative to the dynamic properties of the operating liquid.

12. Applications in Food Production

Venturi pumps and eductors are used in a variety of industries for an array of purposes. Food industries may benefit from replacing their leading CIP systems with the proposed eductor system if they wish to make their cleaning processes more effective. The eductor designed in this report was targeted to a McCain supply chain and was built to meet the health and safety regulations provided in Section 5. The design should be altered depending on the products being manufactured and the cleaning specifications the equipment must meet.

13. Overview of Eductor Design

13.1 Constraints of Eductor Design

The CIP process outlined in previous sections of this design paper involves the usage of caustic and sanitizer solutions. Both solutions must be prepared by mixing water with 2 or 3% of each chemical concentrate. In the traditional CIP process, those solutions are mixed in large heating tanks. However, our design replaces the usage of those tanks by a continuous water heater to improve the energy efficiency of the system. Therefore, an eductor with four inlets was designed in the scope of this project to mix the caustic and sanitizer solutions as water flows through the CIP system. The system could function with only two inlets. The additional two inlets included in the design allow McCain to have more flexibility as the eductor could be used in a more complex CIP process with additional chemicals. Additionally, the eductor must operate at 40 psi which is the city water pressure. Moreover, the tubular chain conveyor total fluid consumption based on the nozzle capacity is 100.1 GPM. Those parameters of the CIP process were considered in the eductor design and validated by simulation.

13.2 Simulation

A typical eductor functions on the principle that a moving fluid flowing through a nozzle creates a low-pressure region around it. This pressure gradient is utilized as a driving force for a second fluid that passes through the suction chamber (Yadav & Patwardhan, 2008). The two liquids are then mixed and ejected through the outlet as a homogenous solution. A study conducted by Yadav et al. showcased that the geometry of the eductor nozzle and the suction chamber are key parameters for the operation of the eductor. The same study also concluded that the geometry of the eductor must be adapted to the operating conditions and the type of fluids that must be pumped and mixed (Yadav & Patwardhan, 2008). Dimofte et al. (2019) also analyzed geometries of eductor and outlined the importance of simulations. Accordingly, the design of an eductor is a complex multivariable problem. A CFD simulation would allow to validate the geometry of the eductor design without making a large amount of assumptions that could compromise the efficiency of the system. Solidworks CFD was used to validate the original eductor design and make multiple iterations to the drawing. The eductor CAD drawings were exported from CatiaV5 in a STEP file and imported into Solidworks CFD. The goal of the simulation was to validate the geometry of the eductor. The design will be correct if the flow of water creates suction of caustic or sanitizer solution.

13.2.1 Simulation Assumptions and Initial Conditions

1. As properties of the caustic and the sanitizer solution required for a CFD analysis are unknown to our design team, we modelled both fluids as ethanol. This assumption could be changed in later stages of the project by gathering all the required properties and adding caustic and sanitizer solution to the Solidworks fluid library.
2. The effects of the eductor surface roughness are negligible on the fluid flow
3. Steady state conditions were assumed, meaning that all the defined boundary conditions are time independent.
4. The eductor is operated at room temperature 293.2 K
5. The environmental pressure is 1 atm (101.
6. The eductor has no velocity parameters as the device is operated statically

Initial Conditions

Thermodynamic parameters	Static Pressure: 101325.00 Pa Temperature: 293.20 K
Velocity parameters	Velocity vector Velocity in X direction: 0 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: 0 m/s

Material Settings

Fluids

Water
Ethanol

The selected CFD analysis type was internal, as we are focusing on the inside of the eductor rather than the outside surface of the design. Planar faces (lids) were added to the simulation to block all the holes and create a closed space that will be analyzed in the simulation. Thus, only one ethanol inlet was left open and a boundary condition was defined at that point. Three boundary conditions were defined for the simulation.

13.2.2 Simulation Boundary Condition Definition

Water Inlet

Static Pressure 1 represents the boundary condition for the inlet of the eductor. Water enters at room temperature and with a constant static pressure of 40 psi. The pressure is defined by the city water line minimal pressure (PlumbingSupply, 2020). As standard SI unites were used for the simulation, this pressure was converted to Pascals (275790.00 Pa).

Static Pressure 1

Type	Static Pressure
Faces	LID100-1/Imported1//Face
Coordinate system	Face Coordinate System
Reference axis	X
Thermodynamic parameters	Static pressure: 275790.00 Pa Temperature type: Temperature of initial components Temperature: 293.20 K
Concentrations	Substance fraction by volume Water 1.0000 Ethanol 0
Turbulence parameters	
Boundary layer parameters	Boundary layer type: Turbulent

Solution Outlet

Outlet Volume Flow 1 represents the boundary condition for the eductor outlet. The concentration of water and ethanol at this point is unknown as it depends on the suction created in the eductor. Therefore, an outlet volume flow boundary condition was used instead of a static pressure. The tubular chain conveyor total fluid consumption based on the nozzle capacity is 100.1 GPM. This number was converted to SI units for the simulation (0.0063 m^3/s).

Outlet Volume Flow 1

Type	Outlet Volume Flow
Faces	LID90-1/Imported1//Face
Coordinate system	Face Coordinate System
Reference axis	X
Flow parameters	Flow vectors direction: Normal to face Volume flow rate: 0.0063 m^3/s

<u>Caustic/ Sanitizer Concentrate Inlet modeled as Ethanol</u>

Static Pressure 2 represents the ethanol inlet point. The fluid is exposed to normal storage conditions. Therefore, an atmospheric pressure of 1 atmosphere or 101325.00 Pa was selected. Moreover, the caustic solution and sanitizer solution modelled as ethanol for the purpose of the simulation, must be maintained at room temperature.

Static Pressure 2

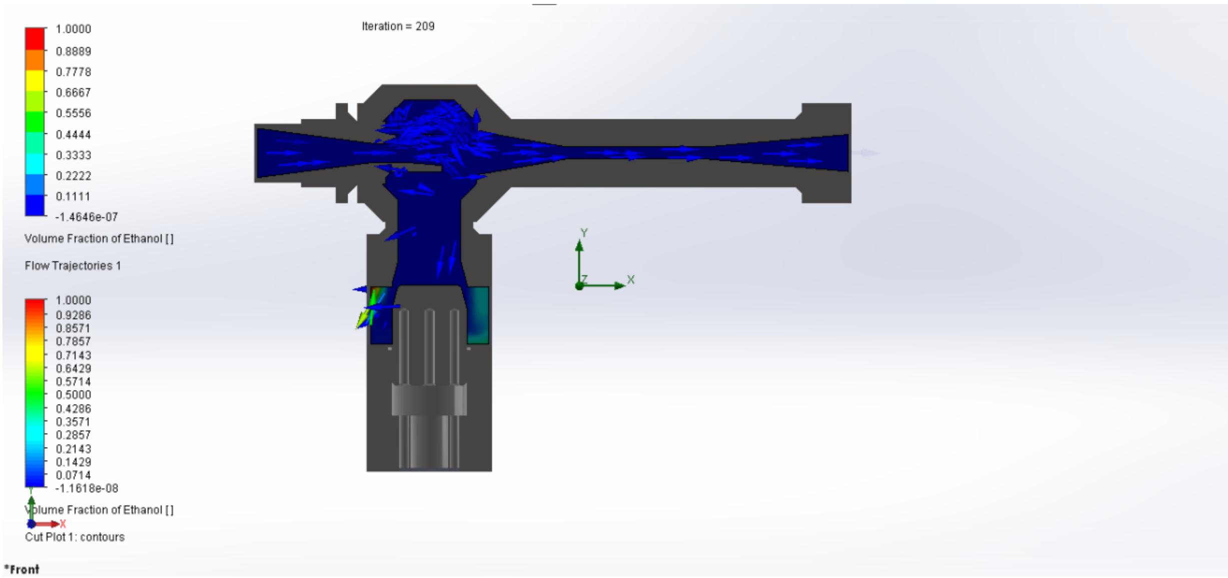
Type	Static Pressure
Faces	LID98-1/Imported1//Face
Coordinate system	Face Coordinate System
Reference axis	X
Thermodynamic parameters	Static pressure: 101325.00 Pa Temperature type: Temperature of initial components Temperature: 293.20 K
Concentrations	Substance fraction by volume Water 0 Ethanol 1.0000

13.2.3 Simulation Results

The parameters of the simulation, including the initial conditions and boundary conditions remained constant for all the simulation trials. Thus, the CAD design of the eductor was modified based on the results and a new simulation was ran to validate that the modifications to the design leaded to significant operational improvements. The results of three simulation trials are presented in this paper to outline key functionalities of the design and major improvements.

13.2.4 Simulation Results-First Trial

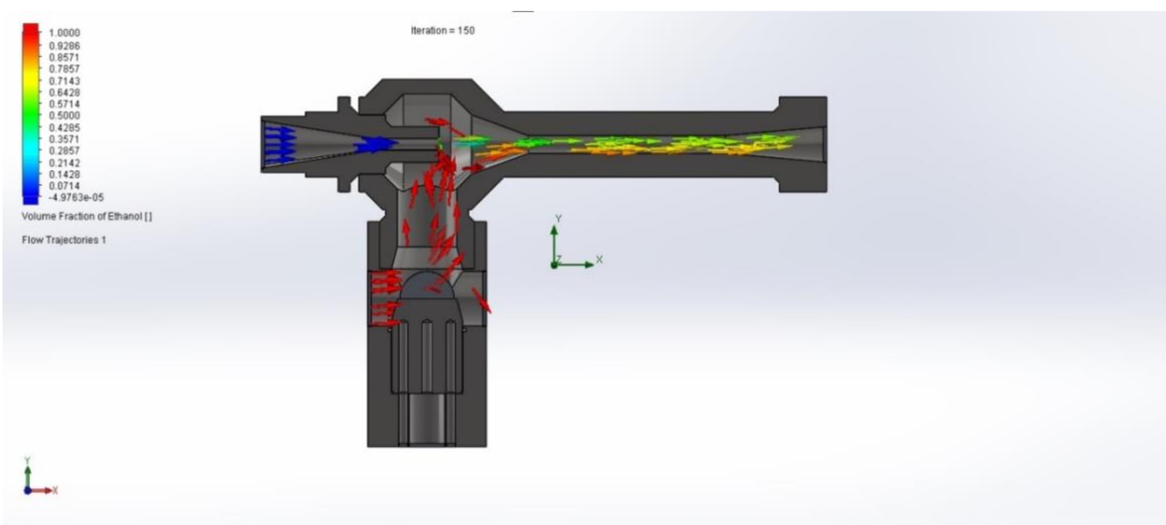
The results of the first simulation indicated that the eductor is not functional. This was evident as the flow trajectories of ethanol and water pointed towards the ethanol inlet. Consequently, the ethanol that represents caustic or sanitizer concentrate in our design would leak out of the eductor. Additionally, the ethanol would not mix with the water and pure water would come out of the eductor outlet. Those issues were caused by the lack of pressure gradient due to a faulty geometry. In order to correct the design, we referred to the findings of Yadav and Patwardhan (2008) and found that the nozzle was too wide. Accordingly, we made the nozzle narrower and ran the simulation again.



13.2.5 Simulation Results-Improved Design

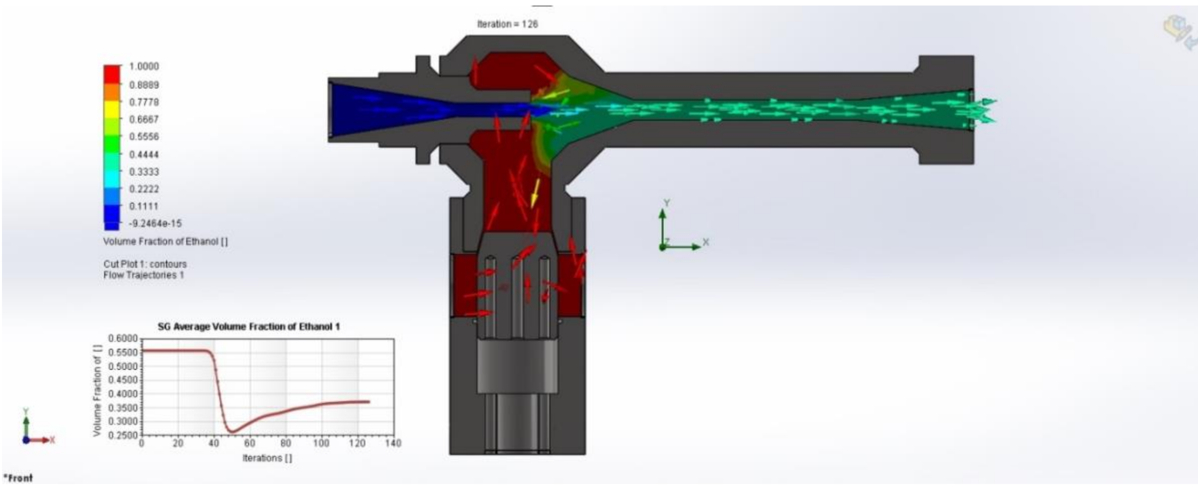
Lowered Piston

The simulation results of the improved eductor design, where the nozzle is narrower showed more promising results. In fact, the flow trajectories of ethanol indicated that a vacuum is created in the eductor. Moreover, this simulation trial allowed to confirm the functioning of the piston mechanism. When the piston is lowered, the concentration of ethanol should be higher. The results of the following simulation presented in this paper shows the effects of raising the piston.



Raised Piston

The results of the simulation of the improved eductor design where the piston is raised showed a lower ethanol concentration like expected. This confirms that the piston mechanism is efficient to adjust the concentration of caustic and sanitizer concentrate in the solution. The solution at the outlet of the eductor is also homogeneous, meaning that the eductor mixes the concentrate at lower concentrations like required.

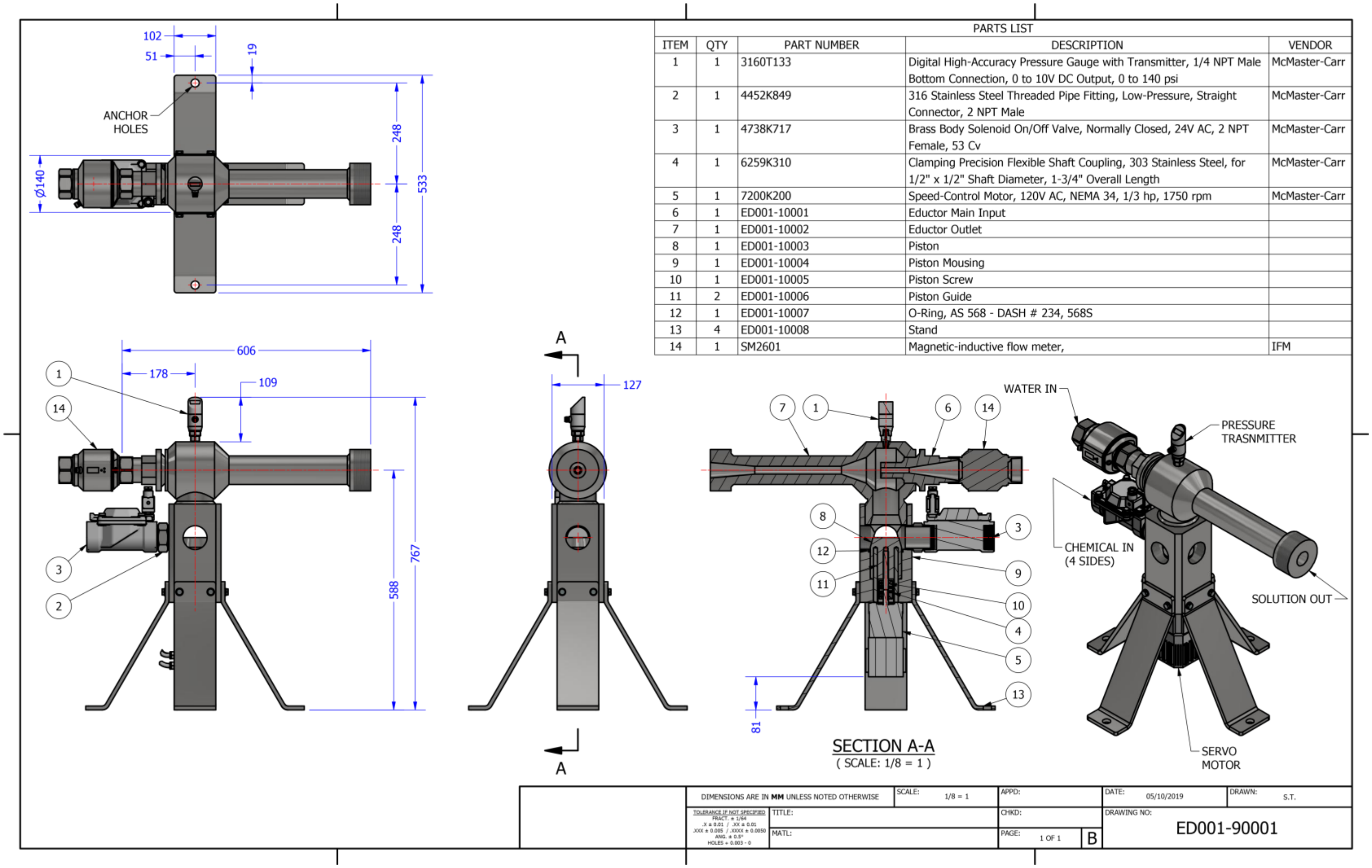


13.3 Bill of Materials

The following table displays the different parts that make up the eductor assembly. The parts designed by our team in Catia V5 are highlighted in green. The description of the purpose of the parts can be found in the "Description" column.

Item	Quantity	Description	Vendor
Digital High Accuracy Pressure Gauge w/ Transmitter – 0-10V DC Output, 0-40 psi	1	The digital Pressure Gauge will allow to monitor pressure inside the eductor. This monitoring device is essential to keep the concentration of the caustic or sanitizer solution constant as suction depends on the pressure in the eductor.	McMaster
316 SS Threaded Pipe Fitting, Low pressure, Straight Connector	1	The pipe fitting allows to connect the solenoid valve to the body of the eductor	McMaster
Brass Body Solenoid On/Off Valve, 24V AC, 2 NPT Female, 53 Cv	1	The solenoid valve allows to open or close the inlet of caustic, sanitizer or any other concentrate required for the CIP process	McMaster
Clamping Precision Flexible Shaft Coupling, 303 SS	1	The shaft coupling allows to connect the shaft of the speed motor to the piston screw	McMaster
Speed-Control Motor, 120V AC, NEMA 34, 1/3 hp, 1750 rpm	1	The motor rotation allows the translation of the screw. Thus, the position of the piston can be adjusted	McMaster
Eductor Main Input	1	Water inlet in the eductor. Part of the eductor geometry.	TBD (custom part)
Eductor outlet	1	Cleaning solution outlet. Part of the eductor geometry	TBD (custom part)
Piston	1	Piston translation allows to adjust the area of the cleaning concentrate inlet	TBD (custom part)
Piston Housing	1	Contains the piston and allows to attach cleaning concentrates containers to the eductor.	TBD (custom part)
Piston Screw	1	Rotation of the screw allows the translation of the piston	TBD (custom part)
Piston Guide	2	Guides the translation of the piston	TBD (custom part)
O-Ring, AS 568 – DASH # 234, 568S	1	Prevents leakage of fluid	McMaster
Stand	4	Acts as a support to the eductor body and allows to fixate the apparatus to the ground	TBD (custom part)
Magnetic Induced flow meter	1	Allows to monitor inlet water flow	IFM

13.3.1 Eductor Assembly

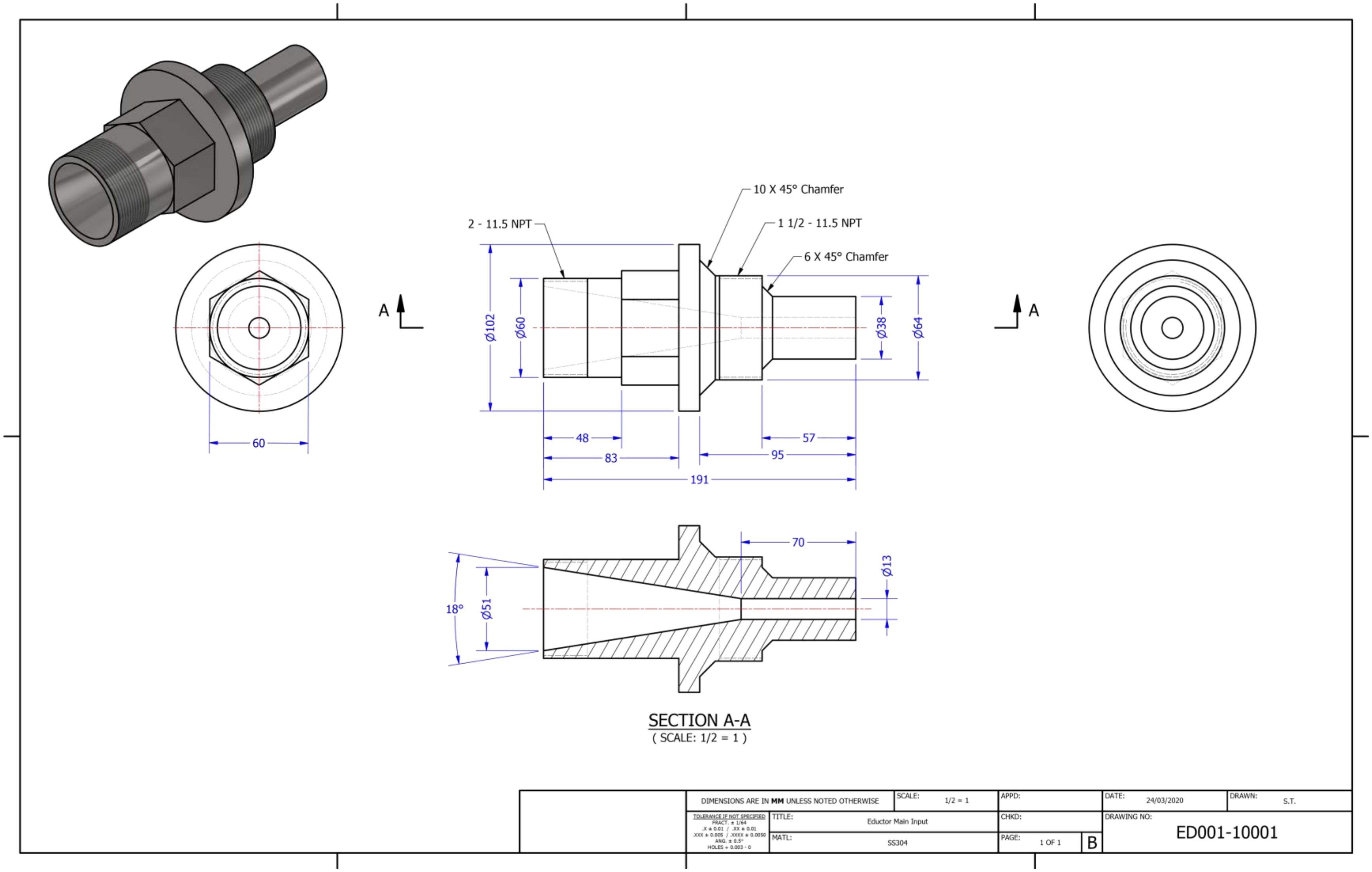


PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION	VENDOR
1	1	3160T133	Digital High-Accuracy Pressure Gauge with Transmitter, 1/4 NPT Male Bottom Connection, 0 to 10V DC Output, 0 to 140 psi	McMaster-Carr
2	1	4452K849	316 Stainless Steel Threaded Pipe Fitting, Low-Pressure, Straight Connector, 2 NPT Male	McMaster-Carr
3	1	4738K717	Brass Body Solenoid On/Off Valve, Normally Closed, 24V AC, 2 NPT Female, 53 Cv	McMaster-Carr
4	1	6259K310	Clamping Precision Flexible Shaft Coupling, 303 Stainless Steel, for 1/2" x 1/2" Shaft Diameter, 1-3/4" Overall Length	McMaster-Carr
5	1	7200K200	Speed-Control Motor, 120V AC, NEMA 34, 1/3 hp, 1750 rpm	McMaster-Carr
6	1	ED001-10001	Eductor Main Input	
7	1	ED001-10002	Eductor Outlet	
8	1	ED001-10003	Piston	
9	1	ED001-10004	Piston Mousing	
10	1	ED001-10005	Piston Screw	
11	2	ED001-10006	Piston Guide	
12	1	ED001-10007	O-Ring, AS 568 - DASH # 234, 568S	
13	4	ED001-10008	Stand	
14	1	SM2601	Magnetic-inductive flow meter,	IFM

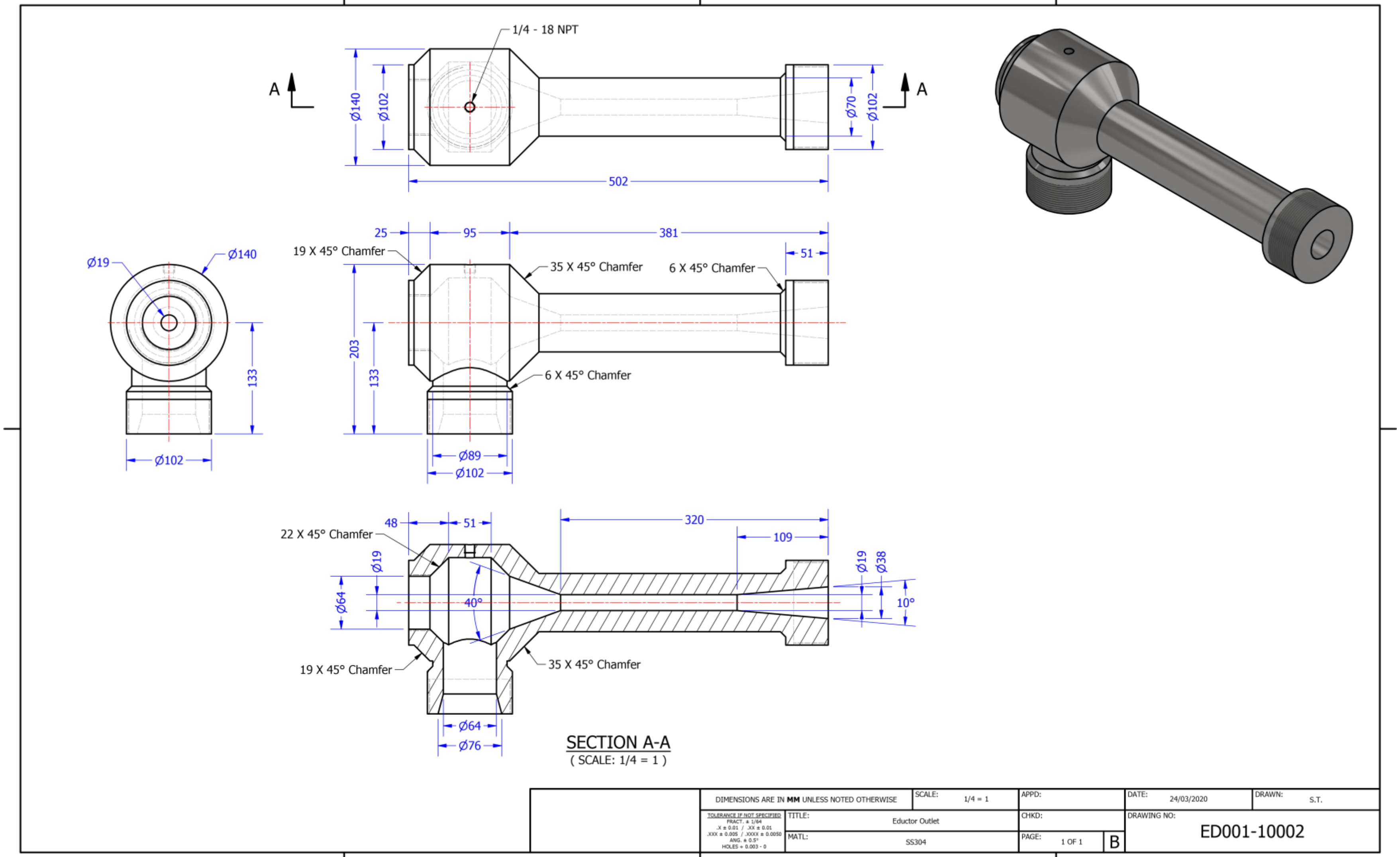
Eductor Assembly

13.3.2 Eductor Main Input



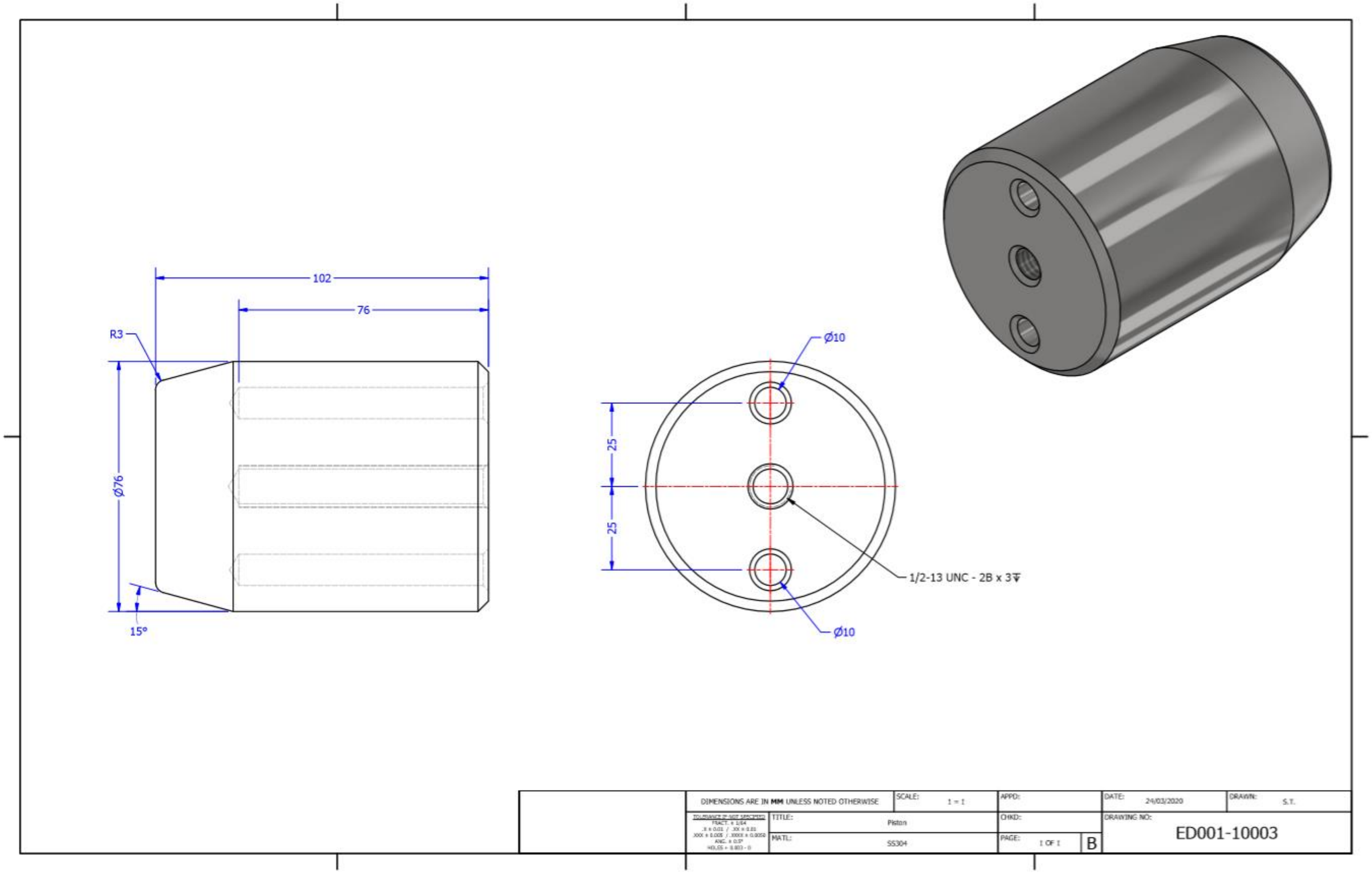
Eductor Main Input

13.3.3 Eductor Outlet



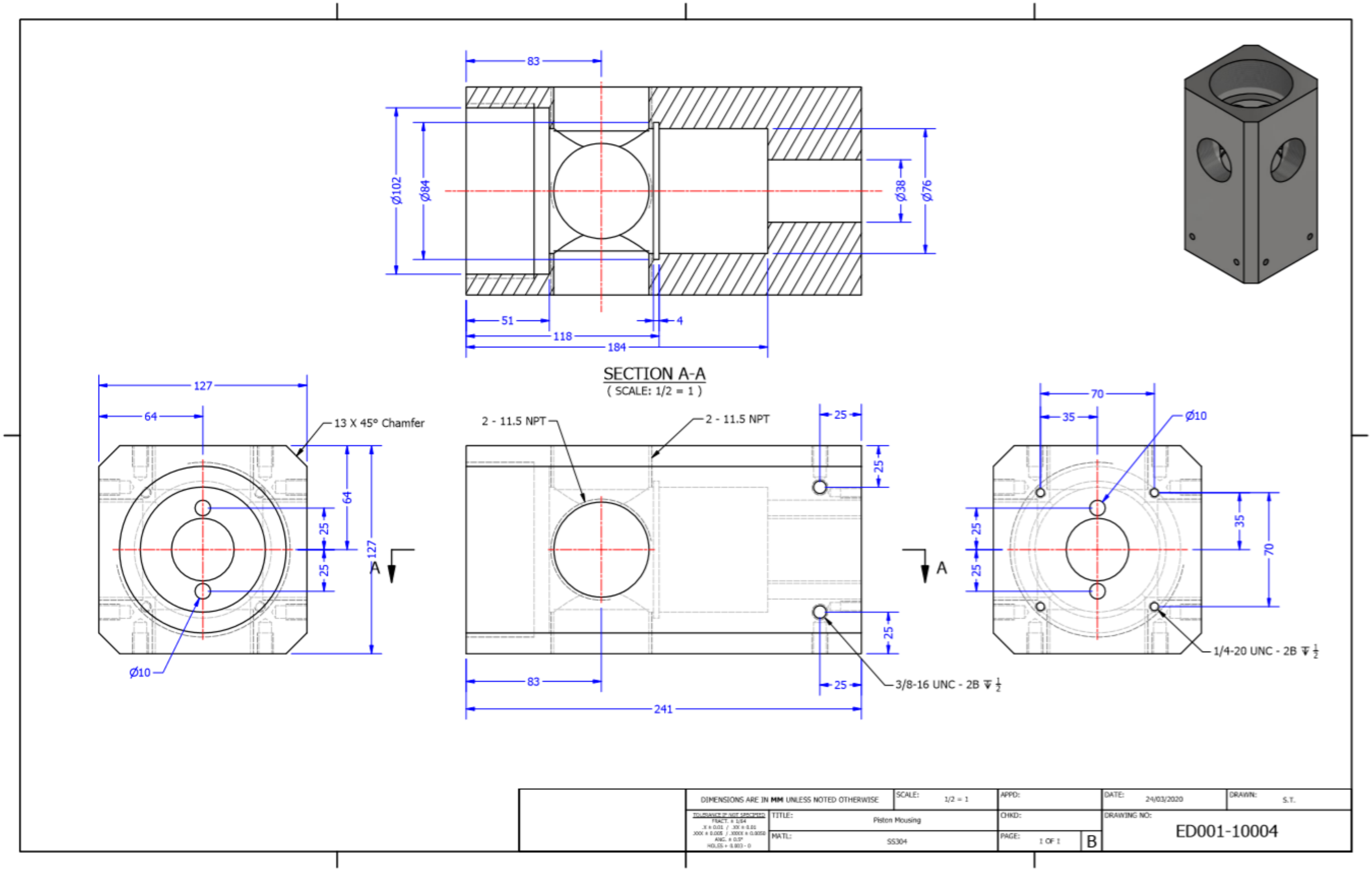
Eductor Outlet

13.3.4 Piston



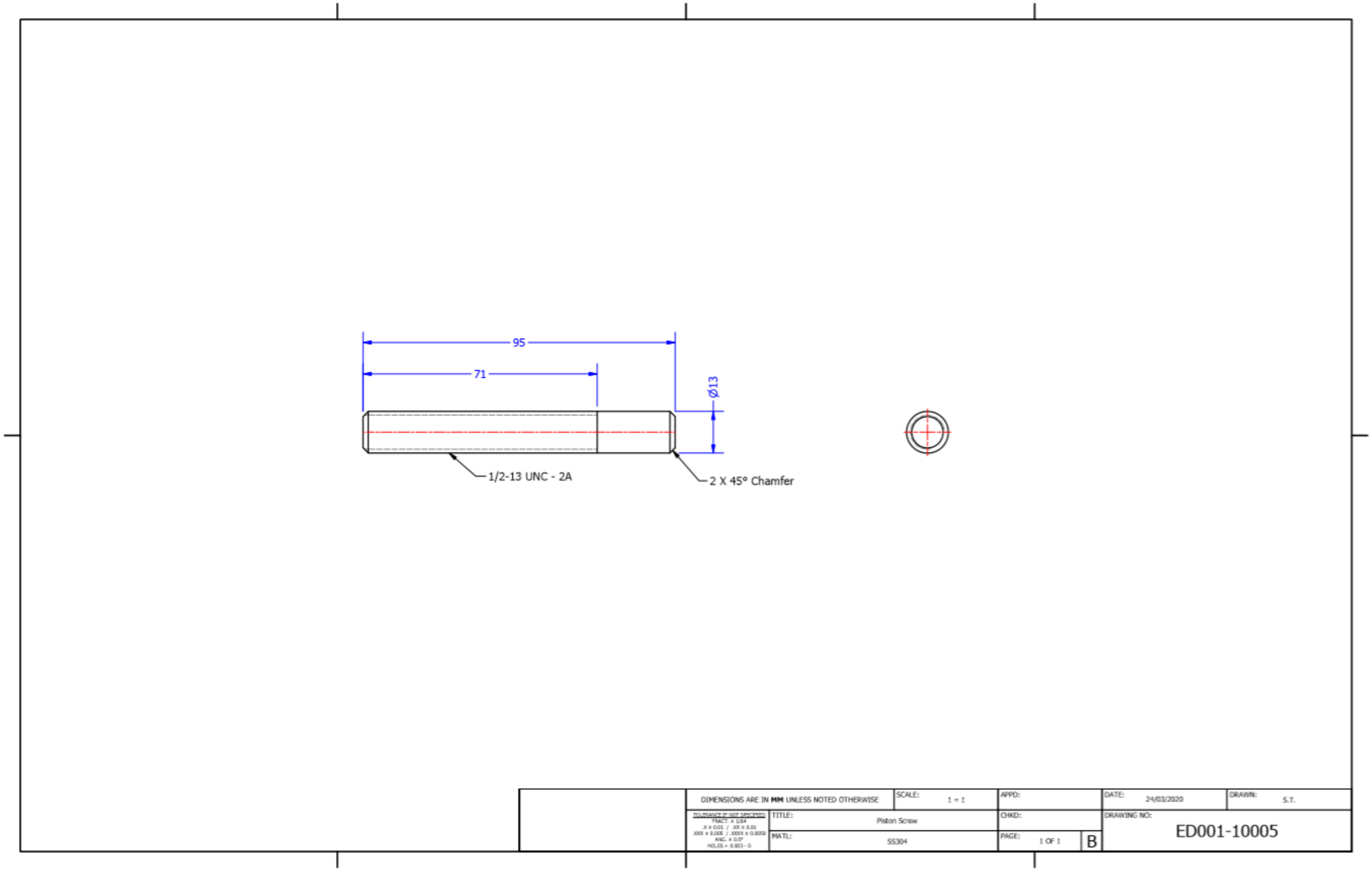
Piston

13.3.5 Piston Housing



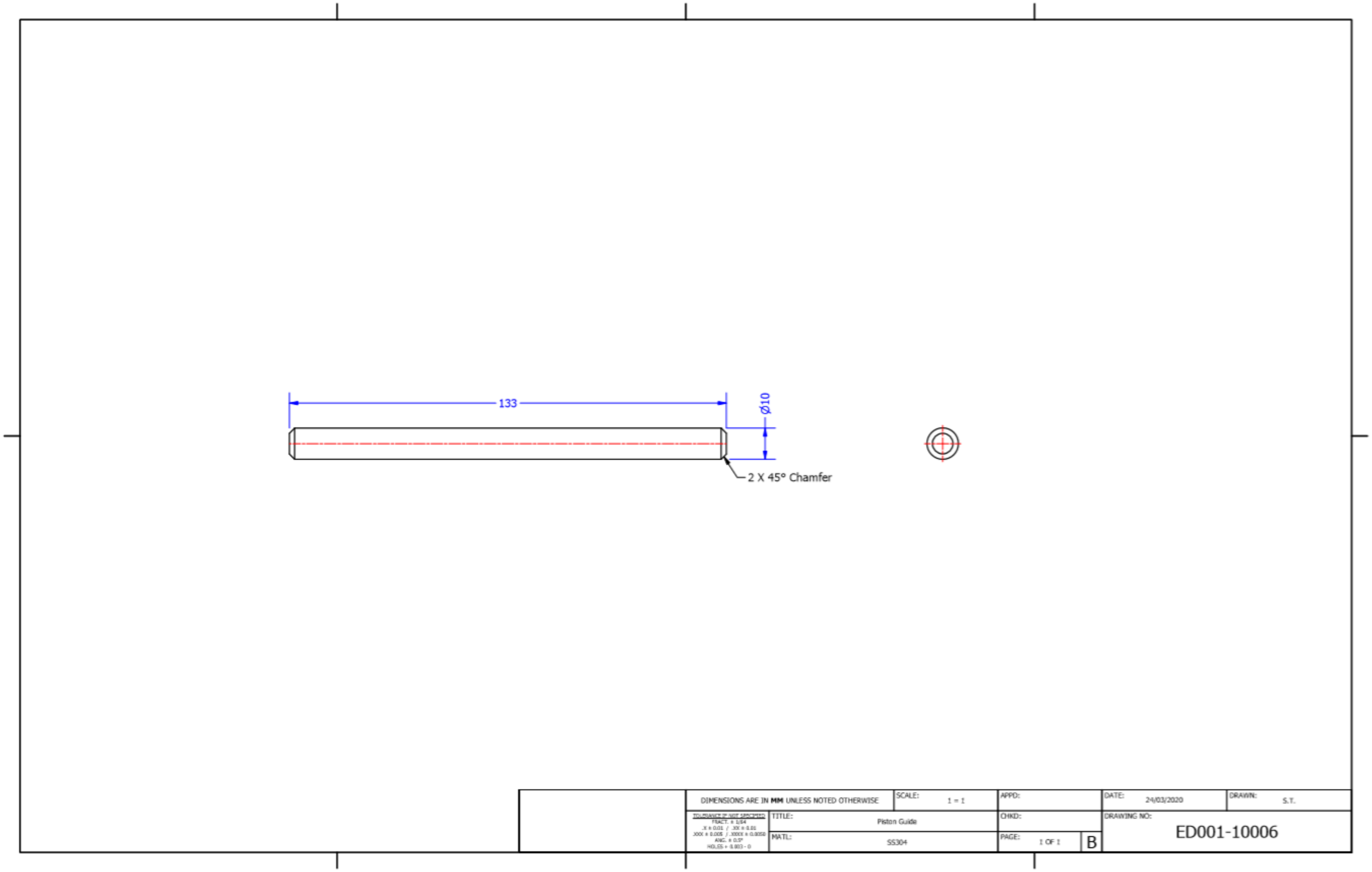
Piston Housing

13.3.6 Piston Screw



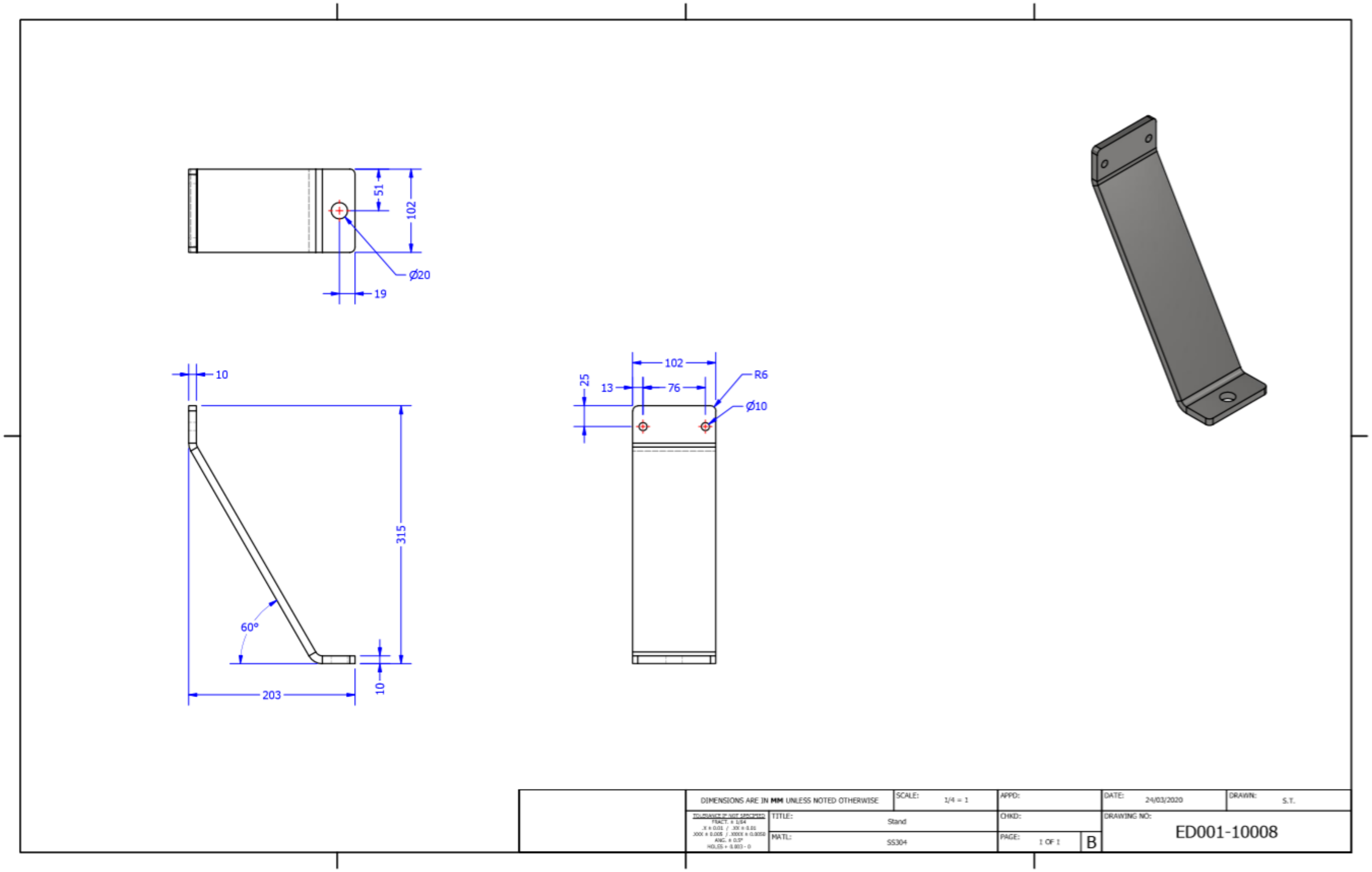
Piston Screw

13.3.7 Piston Guide



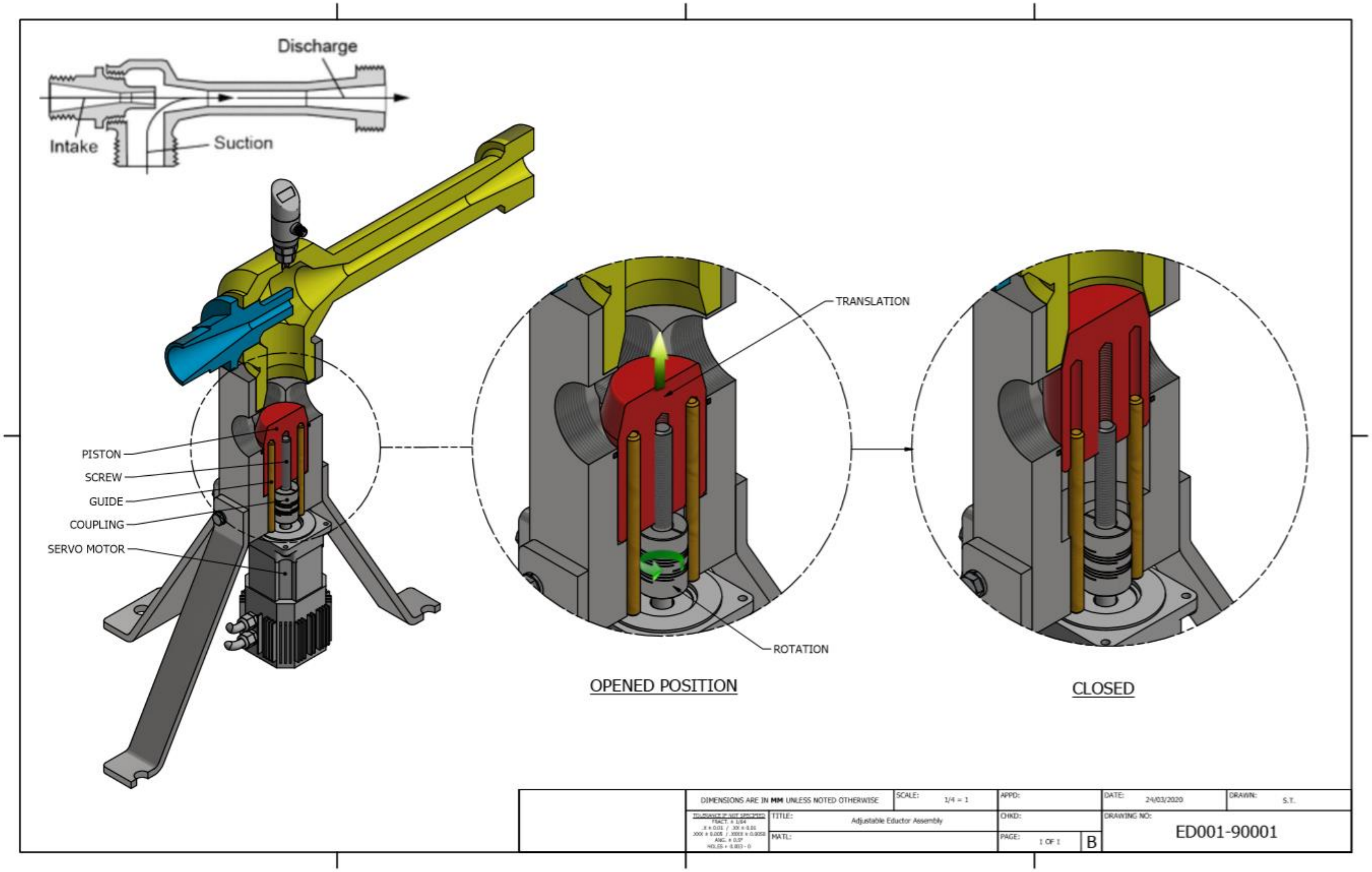
Piston Guide

13.3.8 Stand



Stand

13.4 Piston Mechanism



Piston Mechanics

Conclusion

The Clean-In-Place sanitation process is in fact a complex procedure involving thorough examination and consideration. This report justifies the proposal of a new CIP system that mitigates the need for large storage tanks by design of an intermediate component in the process chain. This report develops a review of literature for plausible approaches that can be used to optimize current CIP systems. It describes the various parameters, standards, guidelines and other considerations that must be met when designing a new cleaning system. The report describes the design process of an eductor that is to be implemented at McCain, the world's largest producer of fried potatoes and potato products. To meet current cleaning standards and be considered as an alternative solution, the eductor was designed with various inlet ports for both cleaning and sanitizing solutions. A thorough review of literature on eductor design was performed and considered. The design, fluid flow and functionality of the eductor was modelled and simulated with SolidWorks CFD and CATIA V5 software was used for CAD design. Furthermore, it was determined that the net cost of implementing the eductor into the process chain would be a fraction of the yearly benefits obtained by the new system, with energy savings up to 49% and a major increase in manufacturing productivity.

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Appendix

Measurement Device	Measured quantity	
Electromagnetic flow meter	Q = 2.0 m^3/h	(±0.5%; Magflo 6000, Danfoss,Trappes, France)
Differential pressure sensor		(±0.2% of the global scale of 10 × 10^5 Pa, 2010 TD, 0–18 bar, ABB, Minden, Germany)
Temperature sensors		(±0.4°C)
Conductivity meter with integrated 100-Ω platinum temperature sensor and a turbidimeter		(LMIT 08, 0–200 mS/cm, Henkel Ecolab, Nanterre, France) (Optec M, TTS Technologies, Saint Sébastien sur Loire, France)

Table 1.0: *Summary of Measurement Devices*

Process step	Hazard	Risk level	Preventative measures	Critical limit	Monitoring procedure	Corrective action
Harvesting	Physical	Low	Well-maintained machinery	No potential crop contaminants	Machinery maintenance records Pre-harvest field inspection	Regular machinery checks by operator
Off-field grading	Physical	High	Specific daily instructions to grading staff. No smoking. Inspection of all equipment and boxes.	No potential crop contaminants	Daily machinery checks	Reject contaminated crop
	Microbial	Low	Staff training. Staff hygiene policy	Staff must be clear of stomach disorders for 48 hours	Staff comply with hygiene policy	Fit, healthy, trained staff
	Allergen	Low	No eating in grading area	n/a	Staff comply with hygiene policy	Provide correct staff facilities
Rodent control	Chemical	High	Trained personnel used, bait boxes mapped and secured	No unprotected baits in storage area	Operator records Frequent visual checks	n/a
Store cleaning	Chemical	Low	Use specific store cleaning chemicals	n/a	Visual check and record	n/a
	Physical	Medium	Storage area free from foreign bodies	No potential crop contaminants	Visual check and record	
Store maintenance	Physical	Medium	Purpose designed building	No potential crop contaminants	Inspection of building, including lights	Building fabric to be kept sound and secure
Box filling	Physical	High	Use only sound, clean boxes	No potential crop contaminants	Visual inspection of box prior to filling	Do not use contaminated boxes
Store loading	Physical	High	Regularly maintained machines	n/a	Frequent checks for wear and tear Check belts are free from contaminants before switching on	n/a
Sprout control	Chemical	High	Correct chemical recommendation and application from trained operators and calibrated machinery	MRL	Residue Analysis	Do not market crops with residue levels exceeding MRL

Figure 5.0 – *Potato HACCP protocol* (From CIPC Compliant, 2019)

Fouling mechanism	Underlying process
Crystallization	Formation of crystals on the surface formed from solutions of dissolved substances when the solubility limit is changed. Cooled surfaces are subject to fouling from normally soluble salts, fats, and waxes. Inversely soluble salts, such as calcium phosphate deposits on heated surfaces. Where the fluid or components of the fluid solidify onto the surface, this is called *solidification fouling* (Sharma and others 1982).
Particulate deposition	Small suspended particles such as clay, silt, or iron oxide deposit onto heat transfer surfaces. Where settling by gravity is the determining factor, this is then called *sedimentation fouling*.
Biological growth (biofouling)	The deposition and growth of organic films consisting of microorganisms and their products, called biofilm.
Chemical reaction at fluid/surface interface	Reaction of some part of the flow to generate insoluble material. The deposit formed on the surface (particularly heat transfer surfaces) has a different composition to the process fluid (for example, in petroleum refining, polymer production, and dairy plants).
Corrosion	The material of the heat transfer surface is involved in reactions with components of the fluid to form corrosion products on the surface, a specific type of chemical reaction fouling.
Freezing	Deposit formed from a frozen layer of the process fluid, for example, ice from water or solid fats from a food fluid.

Figure 6.0 – *Summary of Fouling Mechanisms* (From Müller-Steinhagen, 2000)

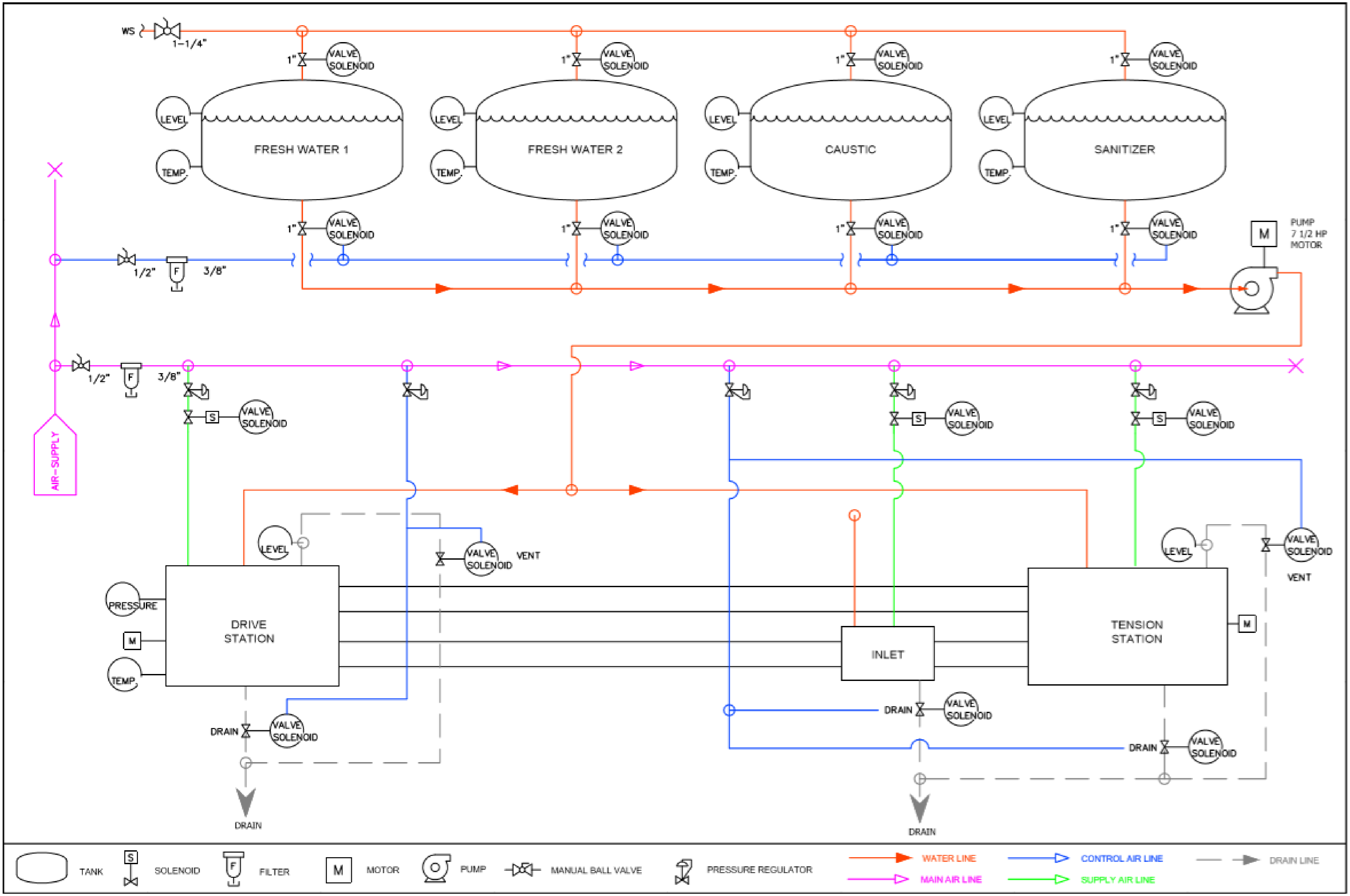

Figure 7.0 – *Non-Optimized Process Overview of McCain's Tubular Conveyer System*

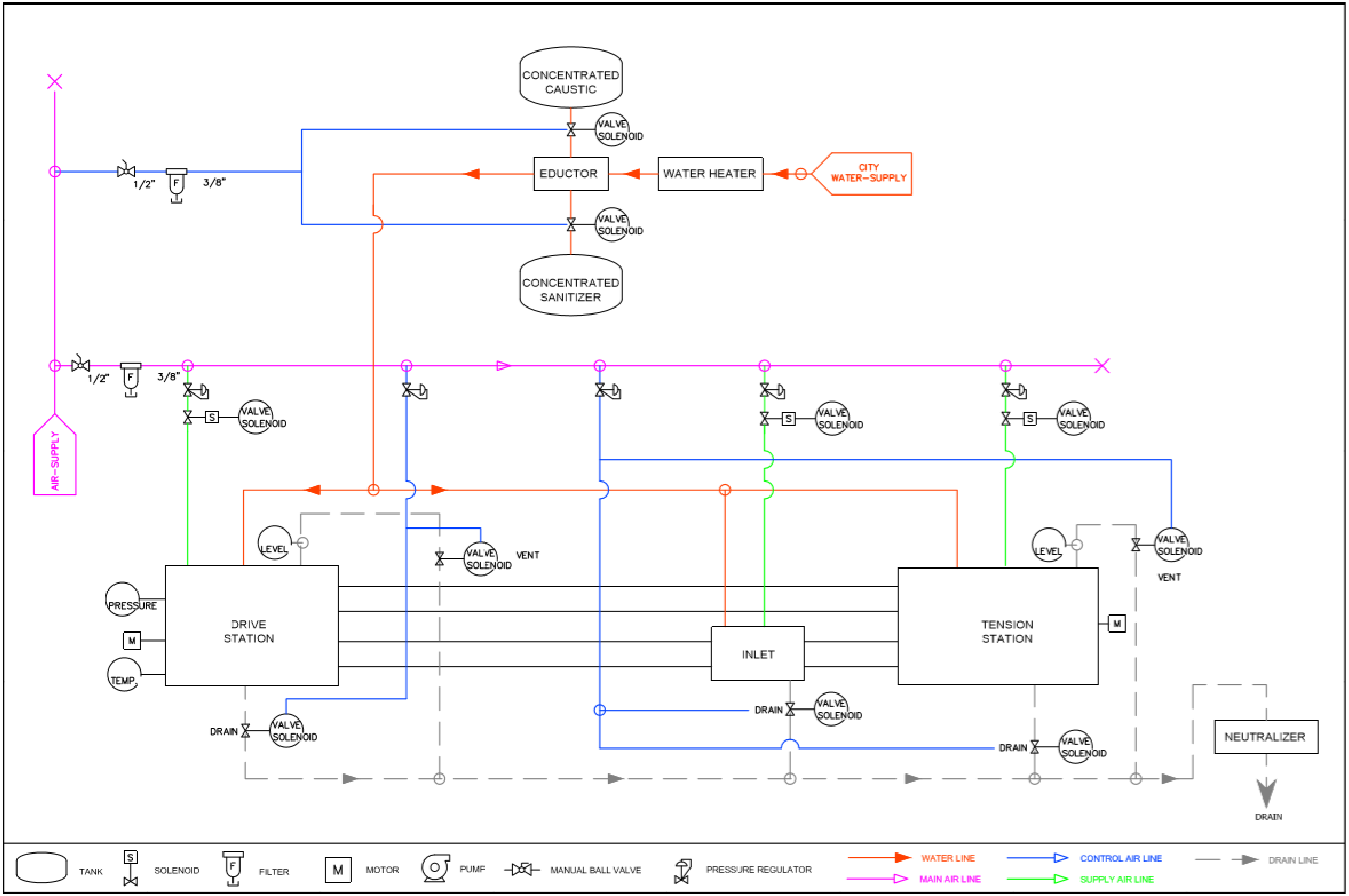

Figure 8.0 – *Optimized Process Overview of McCain's Tubular Conveyer System with no Water Recovery*

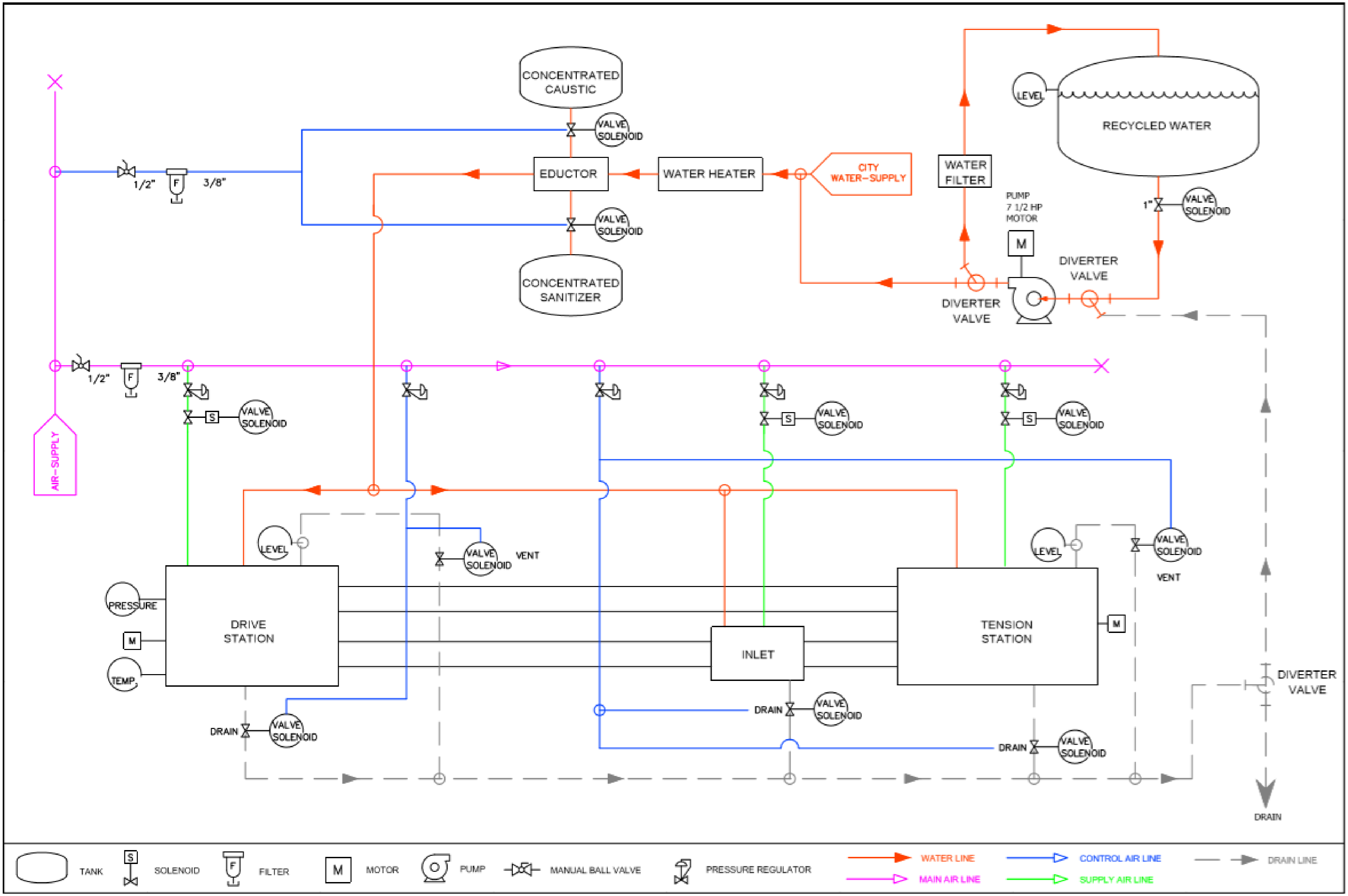

Figure 9.0 - *Optimized Process Overview of McCain's Tubular Conveyer System with Water Recovery*

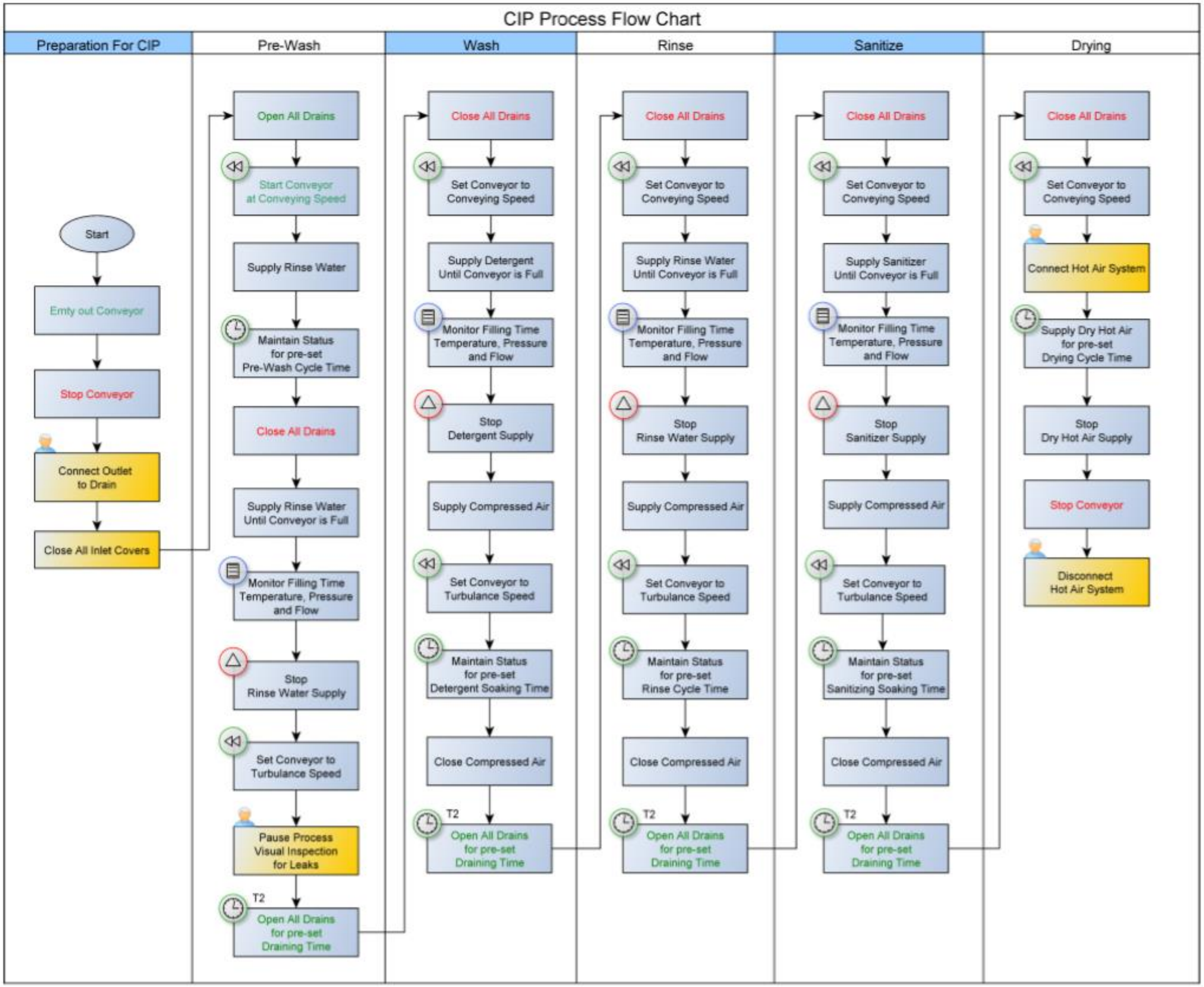

Figure 10 – *Steps Involved and Overview of CIP Process at McCain*

Fill in the blanks in the grey shaded areas. This comparison does not reflect stand-by heat loss; or recovery.

This comparison is not a true reflection of energy use over time; only the costs to heat one tank of water from a cold start; and see how the 3 fuels compare. This spreadsheet uses the actual calculations from the GAMA Directory.
Visit GAMA on the web at http://www.gamanet.org

Natural Gas ** To determine yearly cost multiply daily cost time 365

Volume of Hot Water Heated	H2O Weight	Temperature rise in degrees F	BTUs required to heat water	EF rating of the water heater	BTUs purchased to heat water	Cost per therm	Actual daily cost to heat the water **
5560	8.33	78	3,612,554	0.62	5,826,701	$1.2000	$69.920

Electric

Volume of Hot Water Heated	H2O Weight	Temperature rise in degrees F	BTUs required to heat water	EF rating of the water heater	BTUs purchased to heat water	Cost per KW/hour	Actual daily cost to heat the water **
5560	8.33	78	3,612,554	0.94	3,843,143	$0.0841	$94.699

BTUs are used to convert electric for comparion purposes. The math calculation is accurate for electricity.

Propane Gas

Volume of Hot Water Heated	H2O Weight	Temperature rise in degrees F	BTUs required to heat water	EF rating of the water heater	BTUs purchased to heat water	Cost per gallon propane	Actual daily cost to heat the water **
5560	8.33	78	3,612,554	0.62	5,826,701	$1.2100	$77.013

Tankless

Volume of Hot Water Heated	H2O Weight	Temperature rise in degrees F	BTUs required to heat water	EF rating of the water heater	BTUs purchased to heat water	Cost per gallon propane	Actual daily cost to heat the water **
5560	8.33	78	3,612,554	0.82	4,405,554	$1.2000	$57.748

Tankless Energy Calculator provided by Rheem Manufacturing

Figure 11 – *Cost Comparison of Water Heating Equipment*