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Integrating cleaning studies with industrial practice: Case study of an effective cleaning program for a frozen meat patties SME factory

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ABSTRACT

Cleaning of process equipment is a necessity in the food industry. There is no standard cleaning program formulated for all food industries. Thus, in order to achieve economic objectives and to comply with food hygiene regulations, specific cleaning problems need to be solved to achieve an optimal solution. In this work, a cleaning program was proposed for a local frozen meat patties Small and Medium Enterprise (SME) factory, X. Several cleaning tools such as a portable cleaning unit and industrial cleaning brushes with different functionality were used to ensure the effectiveness of the cleaning program. The portable cleaning unit was used to evaluate the impact of water jet with different nozzle distances (10 cm and 20 cm), cleaning times (30 s and 120 s), and temperatures (35 °C and 65 °C) in reducing different food-borne pathogens (*Escherichia coli*, *Listeria monocytogenes,* and *Salmonella enteritidis*). Two places of food processing equipment with two different stainless steel surfaces were tested. First, a former of meat patties (mesh wire surface), and second, a mixer (smooth surface). The results were then compared with factory X's current cleaning program and have shown that this new cleaning program can achieve physical clean level and helped to reduce microorganism to non-detectable level (less than 2.0 CFU/cm^2). For the evening cleaning, the suggested cleaning program is using the portable cleaning unit at 65 °C, 120 s, 10 cm nozzle distance, and 5.2 bar. For the morning cleaning before production, the same parameters are suggested except for the temperature which is slightly higher at 75 °C.

1. Introduction

Generally, large food manufacturers have their own research and development teams who are responsible to find new techniques, knowledge, and innovation in designing optimal cleaning program (Goode et al., 2013; Khalid et al., 2016). However, from a Small and Medium Enterprise (SMEs) perspective, cleaning can be complex and costly (Khalid et al., 2016; Köhler et al., 2015; Noor Hasnan et al., 2014). Cleaning costs include the costs of cleaning chemicals, energy consumption to heat up and pump the cleaning solution, production loss because of cleaning, wastewater treatment, and plant downtime cost during cleaning (Bird and Espig, 1994; Khalid et al., 2016). In the brewery industry, for instance, the costs for water used as a cleaning fluid can vary between 0.19 €/m^3 and 2.30 €/m^3 (Köhler et al., 2015). Khalid et al. (2016) had shown that costs for cleaning chemicals can consume up to 58% of the total cleaning costs when 2.0 wt% NaOH are used for removal of pink guava puree (PGP) fouling deposit. Moreover, it is hard for SMEs to maintain good food hygiene practices due to lack of knowledge and shortage of skilled human capital resources (due to high turnover of staff and lack of training) (Noor Hasnan et al., 2014). Studies performed by Ismail et al. (2016) and Abdul-Mutalib et al. (2012) revealed that food manufacturers in Malaysia are well aware of the importance of cleaning in food factories and the impact of food hygiene to health and living. However, some of them are taking the issue lightly and this leads to

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increasing cases of food poisoning. A specially designed cleaning program is needed for every SME to fulfill hygienic and economical aspects (Wilson, 2005). Even if the workers keep changing, companies can still maintain a hygienic factory environment when a standard operation procedure for cleaning program has been established (Wilson, 2005).

Effective cleaning, application of appropriate cleaning tools, and cleaning costs are the main factors to be considered in designing a validated cleaning program (Wilson, 2005). Effective cleaning can be achieved when the food processing equipment reaches the cleanliness target. Physical, chemical, and microbiological cleanliness are the most common cleanliness standards associated in the development of a cleaning program (Khalid et al., 2015, 2016, 2014; Tamime, 2008). A physical, chemical, or microbiological contaminant can jeopardize the safety, appearance, and quality of food products (Ismail et al., 2016; Tamime, 2008). Physically clean can be defined as the absence of obvious liquid and solid residues and any noticeable "off" odor. Sensory evaluation which includes visual, touch, and smell inspection were used to validate the cleaning program. Equipment can be considered chemically clean when there is no chemical residues remaining after cleaning. If the conductivity of the final rinse water is equal with normal water source, it may be considered chemically clean (Khalid et al., 2016). Microbiological acceptance criteria for cleaning procedures are established based on products types. For instance, *Listeria monocytogenes, Escherichia coli,* and *Salmonella enteritidis* are the most common foodborne pathogens present in the meat processing industry. Thus, the effectiveness of the cleaning program can be validated by the level of microbes (non-detectable level) after cleaning is performed.

One of the challenges in cleaning for meat processing factory is the removal of invisible fat-based fouling deposit which remains on the equipment surfaces. The fat-based fouling deposit acts as a protective layer which prevents microbes and other food compositions (e.g. protein, carbohydrates) to be removed. Thus, prior to chemical rinse step, hot water rinse is essential to melt the fat layer and to reduce the adhesiveness between the fat layer and surfaces. Hot rinsing will melt the fat layer and eventually help in removing most of the fat layer from the equipment. Application of mechanical action (water jet) during cleaning can also enhance the fouling deposit removal. Manual cleaning and cleaning-out-place (COP) are common cleaning practice since SMEs apply batch processing in their production. Tamime (2008) stated 8 basic cleaning steps: 1) removal of gross debris, 2) pre-rinse, 3) detergent wash (usually alkaline wash), 4) intermediate rinse, 5) second detergent wash (usually acidic wash: optional), 6) intermediate rinse, 7) disinfection, and 8) final rinse (optional). Each of these cleaning steps is essential to ensure cleanliness of the food processing equipment. Rinsing (including pre-rinse, intermediate rinse, and post-rinse) is responsible to ensure the physical and chemical cleanliness. Alkaline wash is used to assist removal of fat-based, carbohydrate-based and protein-based fouling deposit, while acidic wash is used to remove mineral-based fouling deposit. Different cleaning parameters such as temperature, fluid velocity, chemical types, and chemical concentration are chosen during the detergent (alkaline and acid) wash. Disinfection is a process to reduce the number of microbes to an acceptable level using a suitable disinfectant such as sodium hypochlorite or peracetic acid solution. However, it is also possible to use hot water at the disinfection stage rather than a chemical agent (Etienne, 2006; Heinz and Hautzinger, 2007; Hui, 2012; Stanga, 2010; Tamime, 2008). Even though it might be costly (due to generation of thermal energy), the benefit is that this will lead to a more sustainable program in which less wastewater treatment is needed. These basic 8 steps need to be integrated in designing a cleaning program, and suitable cleaning parameters must be chosen.

The use of automated cleaning process tends to yield more reproducible results compared to manual systems. Cleaning programs using manual cleaning are more suitable in terms of cost and applicability. There is still a lack of study on manual cleaning in SME food factories. Jet cleaning is one of the alternatives to reduce the time to clean different types of food-contact surfaces. Jet cleaning system are divided into 3 types which are (1) spray ball, (2) solid stream nozzle, and (3) rotating spray arms (Wang et al., 2015). Different operating parameters of the water jet can influence the removal of the fouling deposit (Köhler et al., 2015; Wang et al., 2015). A study conducted by Köhler et al. (2015) shows that the width of cleaned area increased when a wider nozzle diameter was used. This indicates that using a wider nozzle can clean larger dirty area. However, the cleaned area width decreased when the speed of the moving water jet was increased (Köhler et al., 2015). Higher speed causes less contact time between the water jet and surface. From industrial point of view, it is difficult to handle a portable water jet with different functions (changeable nozzle), especially for SMEs. In Malaysia, most of SME workers are foreign workers whose stay in Malaysia is restricted by working permit (temporary working pass) which allow them to stay for 12 months only (Immigration Department of Malaysia, Ministry of Home Affairs, 2019). Thus, SMEs lack skilled workers (Noor Hasnan et al., 2014). This causes high turnover rate in the company. For SMEs companies, the portable water jet is quite expensive and they are afraid that the negligence of unskilled worker might cause the breakdown of the water jet. Thus, they decide to avoid changeable nozzles. Moreover, they feel, that frequent and repeatable training on portable water jet for foreign workers would be quite laborious and a waste of time.

The objectives of this study are to apply the portable cleaning unit with a fixed water jet function in the cleaning program, to identify food processing equipment for a case study, and to evaluate the efficiency of various cleaning programs in reducing microbes for meat patties factories. The parameters of cleaning are nozzle distances (10 cm and 20 cm), cleaning times (30 s and 120 s), and temperatures (35 °C, 65 °C and 75 °C). The costs of the proposed cleaning program are also calculated.

2. Materials and method

2.1. Identifying of process and equipment for case study

A frozen meat patties factory (factory X) in Sungai Chua, Selangor, Malaysia was selected for the case study. The factory is a Small and Medium Enterprise (SME) facility with an average capacity production of 1000 kg–1500 kg patties per day and the factory operates for 8 h daily. Fig. 1 shows the manufacturing process of frozen meat patties at factory X. Every process is a batch processing which use different types of food processing equipment. The function of each piece of equipment is also shown in Fig. 1. Each piece of equipment and the production area are cleaned at the end of factory operation.

The current cleaning practice was expected to be inefficient as cleaning was performed with tap water at room temperature, using domestic tap water pressure, and without well-designed cleaning program. High risk equipment were identified based on observation of different criteria such as 1) type of food-contact surfaces (smooth surfaces or rough surfaces), 2) geometry or size of the equipment, 3) cleaning time, and 4) cleaning difficulty.

2.2. Cleaning techniques

The current cleaning practice at factory X was observed for 1

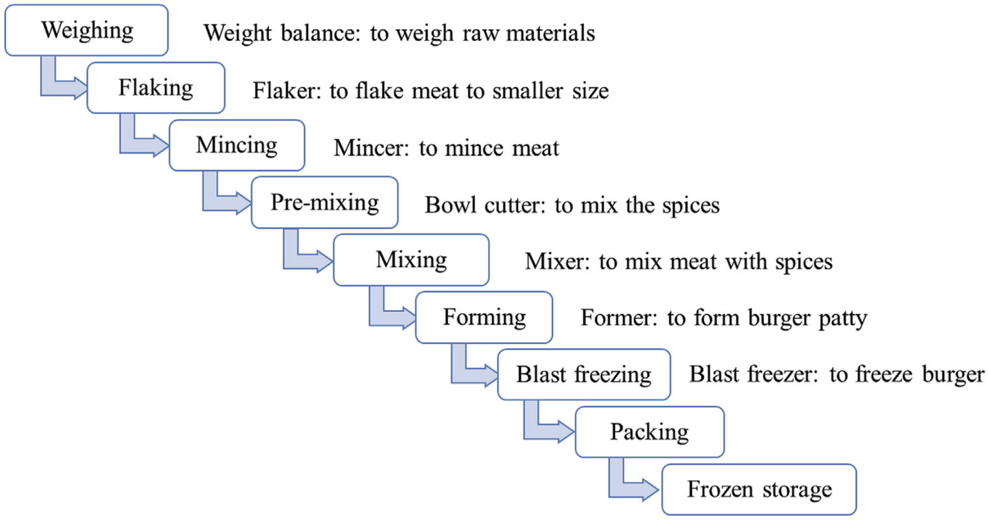


Fig. 1. Process flow for production of frozen meat patties in factory X.

week and this practice was recorded and analyzed. A portable cleaning unit and several cleaning apparatus were applied during the experiment of the new cleaning program. A portable cleaning unit was used for a hot water rinsing step. The portable cleaning unit has two main parts; (1) a storage tank, and (2) a spray nozzle. This portable cleaning unit was designed and constructed in the Process and Food Engineering laboratory of the Faculty of Engineering, Universiti Putra Malaysia, Malaysia (Fig. 2). This cleaning unit has a stainless steel tank (100 L) containing a heating element which was used to heat the cleaning solution. The spray nozzle (even flat spray VNP series, 30° spray angle, spray capacity code 49, H. Ikeuchi & Co., Ltd., Japan) was used to generate high pressure fluid for cleaning. This cleaning unit can be operated at nozzle pressure varying from 5.2 bar to 7.0 bar and is capable of withstanding contact with detergents and disinfectants at the cleaning temperatures (20 °C–110 °C). During the alkaline wash, food grade industrial brushes, which are either a long handle brush (D9, Hillbrush, United Kingdom), or a guarded machine brush (B1423RES, Hillbrush, United Kingdom) were used to assist cleaning at difficult spots (Fig. 3).

2.3. Cleanability study

The cleaning program for factory X was divided into two sessions; 1) evening cleaning session: after production ended and 2) morning cleaning session: before the production started. Evening

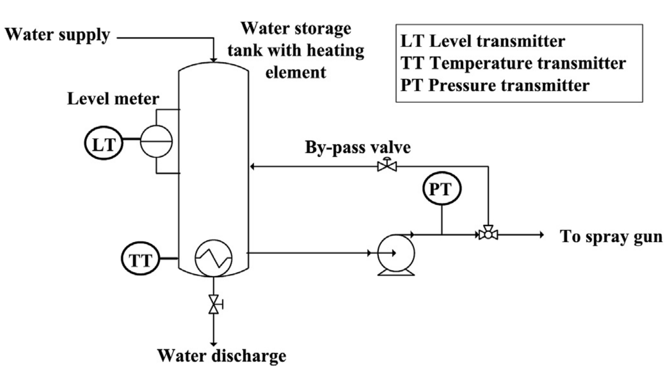


Fig. 2. Portable cleaning unit piping and instrumentation diagram.

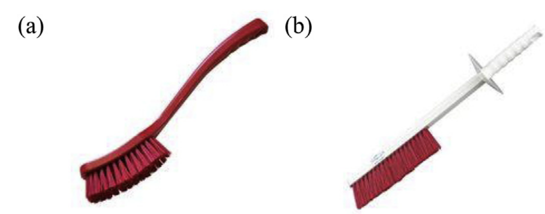


Fig. 3. Industrial brushes used in tested cleaning program: a) long handle brush and b) guarded machine brush.

cleaning was performed immediately after production ended to ensure that the meat patties factory was cleaned physically, while morning cleaning was done as a precaution step to ensure there were no microbes on the food processing surfaces after overnight downtime. There were two types of cleaning programs studied in this work; 1) current cleaning program and 2) tested cleaning program. Table 1 shows the different cleaning parameters carried out during evening cleaning and morning cleaning. Microorganisms can also be killed at relatively low hot temperatures, but longer heat treatment periods will be necessary in such cases (Heinz and Hautzinger, 2007). Treatment temperature of 65 °C and treatment time of 30 s were chosen as tested cleaning parameters using the portable cleaning unit as these are the minimum parameters required to eliminate foodborne pathogens microbes such as *Salmonella* (Ensminger et al., 1993; Heinz and Hautzinger, 2007; Stanga, 2010). Moreover, most animal fat will melt at temperature of 33–47 °C (Moghtadaei et al., 2018). Thus, temperature of 65 °C is sufficient to melt the fat layer accumulated on the equipment surface. Two minutes was chosen as the maximum hot-water rinsing time as Stanga (2010) reported that inactivation of *Salmonella* might vary from 0.2 to 2 min. The portable cleaning unit can be operated at nozzle pressure varying from 5.2 bar to 7.0 bar. Thus, 5.2 bar and 7.0 bar were chosen as water jet pressure. The examined range of nozzle distance (10 cm and 20 cm) were lower and equal with the lowest nozzle distance performed by Leu et al. (1998) which were 20 cm. Thus, temperature of 65 °C, hot water-rinsing time of 30 s and 120 s, water jet pressure of 5.2 bar and 7.0 bar, and nozzle distance of 10 cm and 20 cm were chosen as tested cleaning parameters.

A total of 10 cleaning experiments with different cleaning parameters were conducted (Table 2). The portable cleaning unit was

Table 1
Cleaning parameters chosen during cleaning experiments.

Cleaning Parameter	Evening cleaning – after production	Morning cleaning – before production
Temperature	Room temperature and 65 °C	Room temperature and 75 °C
Nozzle distance	10 cm and 20 cm	10 cm and 20 cm
Cleaning time	30 s and 120 s	120 s
Fluid pressure	5.2 bar and 7.0 bar	With portable cleaning unit (7.0 bar), without portable cleaning unit

Table 2
List of the experimental conditions used for cleaning experiments.

Set	Cleaning Operation	Manipulated Variable				
		The Usage of Portable Cleaning Unit	Rinse Temperature (°C)	Cleaning Time (s)	Nozzle Distance (cm)	Pressure (bar)
1	After production (evening cleaning)	No	35	120	-	-
	Before production (morning cleaning)	No	35	120	-	-
2	After production (evening cleaning)	Yes	35	120	20	5.2
	Before production (morning cleaning)	No	35	120	-	-
3	After production (evening cleaning)	Yes	65	120	10	5.2
	Before production (morning cleaning)	No	35	120	-	-
4	After production (evening cleaning)	Yes	65	120	20	5.2
	Before production (morning cleaning)	No	35	120	-	-
5	After production (evening cleaning)	Yes	65	30	10	5.2
	Before production (morning cleaning)	No	35	120	-	-
6	After production (evening cleaning)	Yes	65	30	20	5.2
	Before production (morning cleaning)	No	35	120	-	-
7	After production (evening cleaning)	Yes	65	120	10	5.2
	Before production (morning cleaning)	Yes	75	120	10	5.2
8	After production (evening cleaning)	Yes	65	120	10	5.2
	Before production (morning cleaning)	Yes	75	120	10	5.2
9	After production (evening cleaning)	Yes	65	30	10	7.0
	Before production (morning cleaning)	Yes	75	120	10	7.0
10	After production (evening cleaning)	Yes	65	120	10	7.0
	Before production (morning cleaning)	Yes	20	120	10	7.0

used during the pre-rinse with water only. The industrial cleaning brushes were used during alkaline/detergent wash and they were only applied during evening cleaning. Table 3 lists the cleaning apparatus involved during each cleaning program. The effectiveness of cleaning for each cleaning program was measured based on the level of microbiological cleaning where swab test was performed. The swab test was only used on selected food processing equipment (Section 2.1).

2.4. Cleaning validation

The pre-cleanliness test of the food processing equipment was executed using Path-Check Hygiene Protein (Microgen, United Kingdom). Path-Check Hygiene Protein was used to detect the presence of protein residue on food contact surfaces. The swab cotton color will change from yellow to green when there is protein residue on the surfaces. This indicates that the surface was not clean. Three different areas were swabbed for each food processing equipment. If only one of the areas was not cleaned, the equipment was considered not clean. Observation and protein swab test were performed for 3 days to get an average data.

The cleaning effectiveness of the tested cleaning programs was measured based on the reduction of microbes. Swab test was performed before cleaning (untreated surface) and after cleaning (treated surface). The swab was removed from the tube and rubbed and rolled firmly several times across area of 10 cm × 10 cm on the food processing surfaces. The swab was then transferred into a tube containing 10 ml of 0.1 wt% peptone water. The tube was shaken well and serial dilution was performed. An amount of 0.1 ml of the solution was spread on prepared agar. Plate Count Agar (PCA) was used for total bacterial count, while the presence of pathogens (*Listeria monocytogenes, Escherichia coli, Salmonella enteritidis*) were detected by using PALCAM Listeria-Selective agar (Merck), MacConkey Sorbitol agar (Difco), and Xylose lysine deoxycholate (XLD) agar (Oxoid) respectively.

Table 3
Cleaning programs and cleaning apparatus for case study.

Cleaning program	Evening cleaning	Morning cleaning
Current cleaning program	✗ Cleaning unit ✗ Industrial brushes	✗ Cleaning unit ✗ Industrial brushes
Tested cleaning program	✓ Cleaning unit ✓ Industrial brushes	± Cleaning unit ✗ Industrial brushes

± There were some cleaning programs that used or did not use the cleaning unit.

2.5. Cleaning costs analyses

The cleaning program costs were computed based on the calculation of cleaning costs presented by Palmowski et al. (2005). In this paper, the costs for pre-rinse, hot-water rinse, and post-rinse were calculated based on the details in Table 4, while alkaline rinse was calculated based on the details in Table 5. Tariffs for water, wastewater, and electricity might be different depending on state and country. The costs for cleaning chemicals might also be different depending on the types and brands. In this work, the tariffs for water and electricity usage for Malaysian factory were used. The price of detergent was the price of the detergent brand used in factory X. The total cleaning costs were calculated using Equation (1).

$$\text{Total cleaning costs} = \text{Costs for (pre-rinse} + \text{hot-water rinse} + \text{alkaline rinse} + \text{post-rinse)} \quad (1)$$

Table 4
Calculations of pre-rinse, hot water-rinse and post-rinse costs.

Details	Costs
Water	$\textit{Total water used } (L) \div 1000 \frac{L}{m^3} \times \frac{\$0.50}{m^3}$
Wastewater treatment	$\textit{Total water used } (L) \div 1000 \frac{L}{m^3} \times \frac{\$1.00}{m^3}$
Electric (If related)	$[\text{Electricity used by pump (W)} + \text{Electricity used by heater (W)}] \times \text{cleaning time (hours)} \div 1000 \frac{W}{kW} \times \$0.10/kWh$

Table 5
Calculations of alkaline rinse costs.

Details	Costs
Detergent X	$\textit{Total Detergent X used } (L) \times \frac{\$4.00}{L}$
Detergent X make-up water	$\textit{Total water used } (L) \div 1000 \frac{L}{m^3} \times \frac{\$0.50}{m^3}$
Wastewater treatment	$\textit{Total water used } (L) \div 1000 \frac{L}{m^3} \times \frac{\$1.00}{m^3}$

3. Results and discussions

3.1. Selection of food processing equipment for case study in frozen meat patties factory

In this work, six types of equipment were considered which are: (1) weighing scale, (2) flaker, (3) mincer, (4) bowl cutter, (5) mixer, and (6) burger former. Table 6 shows the cleaning time and level of cleanliness for each food processing equipment. It shows that the mixer and the former took the longest cleaning times of 18 min and 15 min respectively. It took longer time to clean the mixer and the former because their size were bigger than other equipment. In addition, the design of the mixer and the former made it more difficult to clean and sanitize. Due to the height of the mixer and the former, it was difficult for the workers to perform cleaning. Moreover, the mixer tank was quite deep, so it was harder to clean. Operators had to use ladders to clean it. Most of the times, they had to bend down to clean the edge of the mixer tank. It is not a good body posture and might cause backache. Most of the equipment have sharp blades and they were difficult to clean. During the alkaline/detergent wash process, the workers used a kitchen sponge to scrub the blades surfaces. This might cause hand injury to the workers. From interviews with the workers, they mentioned that they reported having backache and several cases of hand injuries during cleaning. The geometry, types of surfaces, and cleaning constraints due to the design of the equipment are shown in Table 7.

All smooth surfaces were more cleanable compared to rough surfaces. All smooth food-contact surfaces like the flaker and mincer were physically clean after cleaning. However, there was still a fat-based layer remaining on the surfaces as shown in Table 6 (based on touch observation). Thus, hot water is needed to melt the fat-based fouling on the surfaces, to assist the cleaning. The mixer also has a smooth type of food-contact surface. However, since the mixer tank is quite deep, the workers sometimes missed the edge of the mixer when cleaning it. Thus the mixer was physically not clean. Cleaning of former equipment was quite challenging as workers had to dismantle and clean between the gaps of the mesh wire conveyer. After cleaning, food residue was often seen between the gaps. Thus, it was physically not clean and it needed different cleaning tools such as brushes or water jet to assist the food residues removal (Salvat and Colin, 1995).

Even though some of the equipment were physically clean, the swab test using Path-Check Hygiene Protein showed that there were protein residue that remained on all of the equipment (Table 6). This shows that the current cleaning procedures cannot clean the food processing equipment properly. Table 8 shows the types of food material that have contact with each equipment. Most of the equipment have contact with meat except for the bowl cutter which is only used to pre-mix the spices. There was still protein

Table 6
Current cleaning time and level of cleanliness for each food processing equipment.

No.	Equipment	Cleaning time, t_c (minutes)				Level of cleanliness		
		Day 1	Day 2	Day 3	Average	Visual inspection	Touch inspection	Protein swab test
1	Weighing scale	3	4	2	3	****	✗	NC
2	Flaker	12	10	14	12	***	✗	NC
3	Mincer	15	17	11	14	***	✗	NC
4	Bowl cutter	10	12	8	10	****	✓	NC
5	Mixer	17	20	18	18	****	✗	NC
6	Burger former	17	16	12	15	**	✗	NC

(Notes: ****** Highest physically clean rank, * Lowest physically clean rank, ✓ Physically clean from fat-based fouling deposit, ✗ Fat-based fouling deposit remained, NC- not clean (protein residue detected), C- clean).

Table 7
Geometry, types of surfaces and cleaning constraint due to the design of the equipment.

No.	Equipment	Type of surfaces	Length (m)	Width (m)	Height (m)	Design constraint
1	Weighing Scale	smooth	0.32	0.32	0.31	No
2	Flaker	smooth	1.60	1.35	1.18	blade
3	Mincer	smooth	1.23	0.70	1.20	Blade/extruder
4	Bowl cutter	smooth	0.58	1.00	0.90	Blade
5	Mixer	smooth	1.32	0.80	1.52	Blade, high height
6	Burger former	Rough (Mesh wire)	1.00	1.00	1.80	Blade, big size (high height), extruder, mesh wires with small gap

Table 8
Type of food material that have contact with each equipment.

No.	Equipment	Food materials
1	Weighing Scale	Meat
2	Flaker	Meat
3	Mincer	Meat
4	Bowl cutter	Spices
5	Mixer	Spices, meat
6	Burger former	Spices, meat

residues remaining on the bowl cutter's surface. This proved that the current cleaning program in this factory was not effective.

In addition to that, from interviews with operators of factory X, they reported that the equipment that were the hardest to clean were the mixer and the former. Meat processing equipment such as mixer, patty machine, grinder and conveyor are difficult to clean as these equipment have parts that are not easily accessed for cleaning by operators (Hui, 2012). In the meat industry, during preliminary cleaning, dismantling of equipment's parts are necessary to ensure physical (visual) cleanliness (Salvat and Colin, 1995). During cleaning of the former, a mesh wire conveyer need to be dismantled as these mesh wires cannot be cleaned inside the former. This dismantling step took extra few minutes and the operators are facing troubles in brushing the mesh wires using a kitchen sponge. Even after the brushing process, there were still meat residues remaining between the gaps of the mesh wires. For the mixer, as mentioned above, the workers were complaining that they were having a difficult time to clean inside the mixer which is quite deep. They could not reach the edge of the mixer as they were only using a kitchen sponge. Usually, in bigger companies, they use cleaning-in-place (CIP) process to clean the mixer or tank (Etienne, 2006). Thus, these two equipment (the former and the mixer) were chosen to test the effectiveness of the tested cleaning program. The swab test were conducted on the area inside the mixer and the former which were most difficult to access during cleaning.

3.2. Current cleaning program vs. tested cleaning program (evening cleaning)

The current cleaning program at factory X was recorded and its flow chart is shown in Fig. 4. Flow chart of tested cleaning program for evening cleaning is also shown in Fig. 4 for comparison between current cleaning program and tested cleaning program. The current cleaning program was done manually. After the production ended, the remaining minced meat were removed from the food processing equipment (Step 1). Then the equipment surfaces were rinsed using water directly from water source (Step 2). In order to add the mechanical effects, the workers used a water bucket to rinse equipment. The water temperature was at room temperature, which was about 35 °C. Then, the equipment surfaces were washed with alkaline detergent and scrubbed using kitchen sponge (Step 3). Next the surfaces were rinsed again with water to remove the detergent and food residue from the surfaces (Step 4). Finally, the workers removed the minced meat and wastewater on the floor using sweeper and floor squeegee (Step 5). As mentioned above, during current cleaning program, kitchen brushes and common pipes were used to clean the equipment. Our pre-cleanliness test had shown that the current cleaning program was not sufficient as protein residue was detected on the cleaned surfaces and the surfaces remained oily after cleaning (Table 6). Thus, there was potential of foodborne pathogens' growth such as *Listeria monocytogenes*, *Escherichia coli*, and *Salmonella enteritidis* which might contaminate the food-contact surfaces. The remaining of these food residues (protein residue matrix and oil film layer) can protect the microbes from the cleaning detergent.

Therefore, the current cleaning program was improved by developing a new cleaning program. Two types of industrial cleaning brushes were used which were long handle brush to clean the mixer, and guarded machine brush to clean the mesh wire (former). The long handle brush is suitable for equipment with deep tank and equipment with edge which are hard to clean manually, while the guarded machine brush is suitable to clean equipment with blades or mesh wires. It has also a guard that can prevent hand injuries. A portable cleaning unit was used to generate hot water and a high speed water jet (cleaning parameters such as temperature, pressure, nozzle distance, and cleaning time were also investigated). Compared to the current cleaning program, there was one additional step added in the tested cleaning program (Step 3). Step 2 and Step 4 were improved by adding the application of industrial brushes to assist the cleaning.

In this work, the effectiveness of Step 3 for tested cleaning program were investigated at different cleaning parameters: temperature of 65 °C at different distances (10 cm and 20 cm) and cleaning times (30 s and 120 s). The effectiveness and level of cleanliness of Step 3 were defined by microbiologically clean (<2.0 log CFU/cm^2) and physically clean (100% clean) conditions. Fig. 5 shows the images of mesh wire (former) before and after cleaning using the current cleaning program and the tested cleaning program. The mesh wire was physically cleaned when tested cleaning program was applied. Thus, the tested cleaning program with suitable cleaning tools (portable cleaning unit and industrial brushes) were recommended to improve cleaning for factory X.

3.3. Current cleaning program vs. tested cleaning program (morning cleaning)

Morning cleaning was done as a precaution step to ensure that there are no microbes on the food processing surfaces after overnight downtime. This step also included the seventh of the basic cleaning steps by Tamime (2008) which is the disinfection step. In disinfection step, it is common to use chemical agents such as sodium hypochlorite or peracetic acid solution. However, application of hot water at the disinfection stage is a more sustainable disinfection method. The current cleaning program only used water from the water sources and used a water bucket to rinse the equipment, while some of the tested cleaning program used the portable cleaning unit to generate hot water at 75 °C to ensure that all potential foodborne pathogens on the equipment surfaces were eliminated (Heinz and Hautzinger, 2007; Hui, 2012; Tamime, 2008).

3.4. Effect of cleaning temperature (evening cleaning)

The effectiveness of different tested cleaning programs for evening cleaning are shown in Table 9 and Table 10 for the former and the mixer, respectively. A total of 10 sets of cleaning programs were performed. In this work, if the microbial level was more than 2.0 log CFU/cm^2, it is considered not microbiologically clean. During evening cleaning, there were no *Salmonella enterica* detected on the former and the mixer (before and after cleaning). Cleaning of the former by the current cleaning program (Set 1: without hot water) was unable to reduce *Escherichia coli* (3.9 log CFU/cm^2) and *Listeria monocytogenes* (2.7 log CFU/cm^2) to a non-detectable level (Table 9). Then, when the portable cleaning unit was used to generate a water jet at room temperature on the equipment surface (Set 2), it was still not microbiologically clean, as there were still 4.4 log CFU/cm^2 of *Escherichia coli* on the former (mesh wire) surface, while *Listeria monocytogenes* was reduced to non-detectable level. When cleaning the mixer, even without hot water, the number of *Escherichia coli* and *Listeria monocytogenes* remaining was not

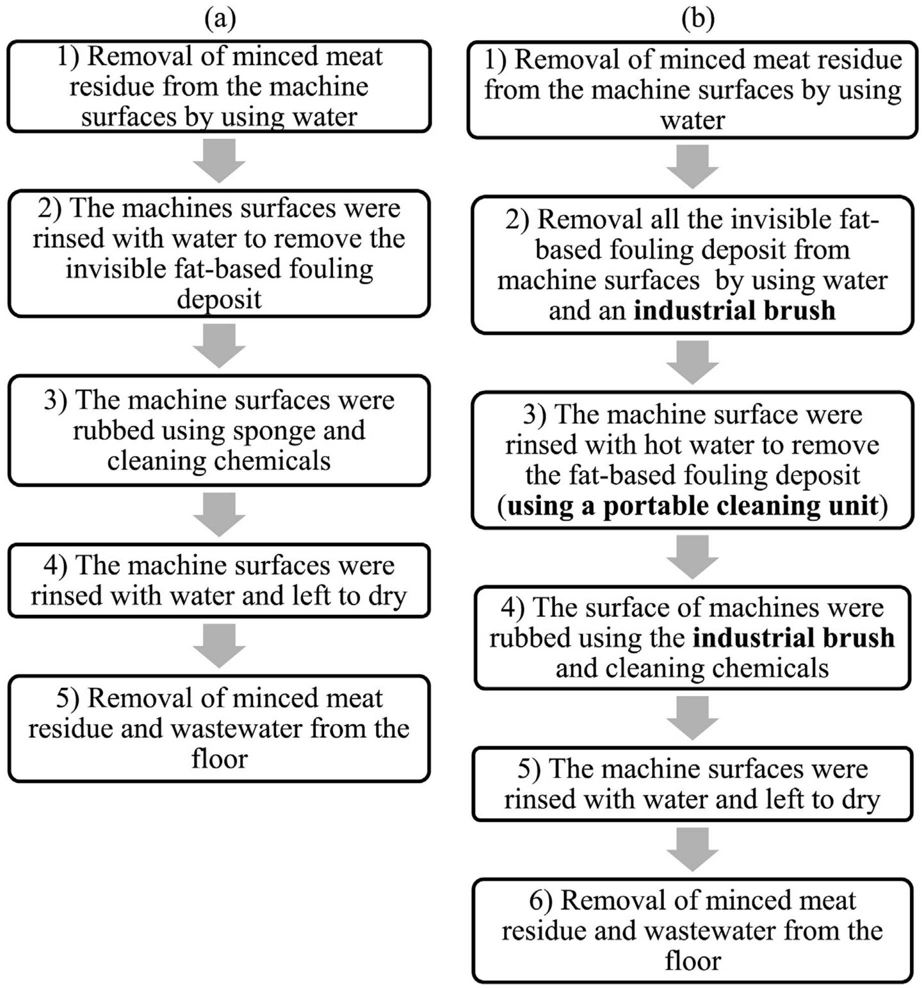


Fig. 4. The flow chart of a) the current cleaning program and b) the tested cleaning program for evening cleaning.

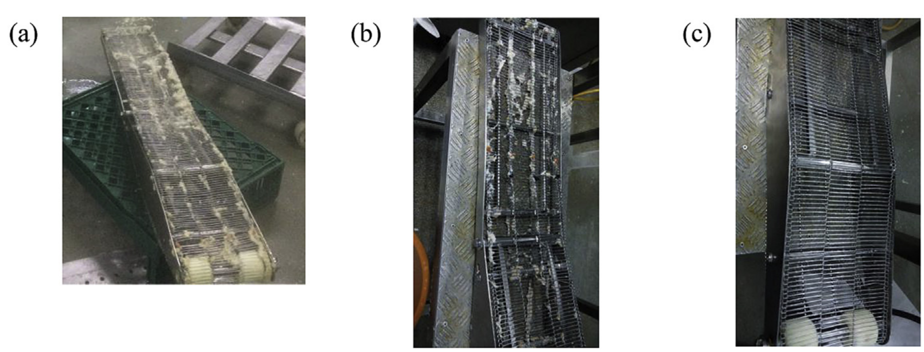


Fig. 5. The mesh wire of the former condition a) before cleaning, b) current cleaning program, c) proposed cleaning program.

detectable (Table 10). However, the total plate count showed that there were still 3.6 log CFU/cm^2 of microbes on the mixer surface. Application of hot water (Set 3) managed to increase the microbial reduction to 2.8 log CFU/cm^2 compared to tap water (Set 1) with 1.9 log CFU/cm^2. Thus, it showed that cleaning with hot water is necessary.

Cleaning efficiency increases at higher temperature (Al-Amoudi and Lovitt, 2007; Khalid et al., 2015, 2016; Piepiorka-Stepuk et al., 2016; Vicaria et al., 2017). Cleaning was improved greatly when hot water was used for rinsing. Hot water were responsible in the fat-based fouling deposit (fat residue from the minced meat) melting process on the food processing surface. When the fat melted, the removal of the fat-based fouling deposit was easier. Due to the high temperature of 65 °C, the adhesive strength between the fat-based fouling deposit and the stainless steel surface was reduced and eventually led to an easier removal. Moreover, the water jet pressure from the portable cleaning unit assisted in removing the fat-based fouling deposit from the surface. In Set 3 to 10, hot water was used. Most of the tested cleaning programs managed to reduce *Escherichia coli* and *Listeria monocytogenes* to

Table 9
Effect of different cleaning programs for evening cleaning on the former.

Set	Total microbial (log CFU/cm^2)		*E. coli* (log CFU/cm^2)		*Listeria monocytogenes* (log CFU/cm^2)	
	After cleaning	Microbial reduction	After cleaning	Microbial reduction	After cleaning	Microbial reduction
1	7.8	0.3	3.9	0.2	2.7	0.4
2	5.3	1.3	4.4	0.8	ND	1.1
3	2.9	2.8	2.2	2.2	ND	1.3
4	5.5	0.5	3.0	2.1	ND	0.0
5	2.2	1.7	ND	1.0	ND	0.0
6	ND	2.0	ND	1.4	ND	0.0
7	ND	2.5	ND	1.3	ND	0.7
8	ND	2.4	ND	0.9	ND	0.0
9	4.5	1.4	2.5	2.1	ND	0.8
10	ND	3.2	ND	2.2	ND	1.2

Notes: ND means non-detectable level which is less than 2.0 log CFU/cm.^{2}.

Table 10
Effect of different cleaning programs for evening cleaning on the mixer.

Set	Total microbial (log CFU/cm^2)		*E. coli* (log CFU/cm^2)		*Listeria monocytogenes* (log CFU/cm^2)	
	After cleaning	Microbial reduction	After cleaning	Microbial reduction	After cleaning	Microbial reduction
1	3.6	1.9	ND	1.3	ND	1.2
2	3.4	2.5	ND	1.6	ND	1.4
3	ND	2.8	ND	1.8	ND	1.7
4	5.0	−1.4	ND	1.0	ND	1.5
5	2.3	1.4	ND	0.4	ND	1.0
6	ND	2.2	ND	0.0	ND	0.9
7	3.3	0.6	ND	1.3	ND	1.1
8	ND	1.7	ND	0.5	ND	0.0
9	ND	2.6	ND	1.8	ND	1.1
10	ND	2.6	ND	1.8	ND	0.7

Notes: ND means non-detectable level which is less than 2.0 log CFU/cm.^{2}.

non-detectable level. An excessive cleaning temperature will generate higher energy consumption without increasing the cleaning efficiency (Piepiorka-Stepuk et al., 2016). Thus, rinsing temperature of 65 °C was sufficient enough to reduce *Escherichia coli* and *Listeria monocytogenes* to non-detectable level for all types of food-contact surfaces and equipment in factory X.

3.5. Effect of cleaning time (evening cleaning)

Sufficient cleaning time is important to ensure that the cleaning medium has enough contact time with the dirty cleaning area or equipment (Khalid et al., 2015; Tamime, 2008; Vicaria et al., 2017). Excessive extension of cleaning time will increase energy consumption without obtaining a better cleaning quality (Piepiorka-Stepuk et al., 2016). In this work, the effectiveness of rinsing time using the portable cleaning unit were investigated at two different rinsing times of 30 s (Set 5, 6, 9) and 120 s (Set 2, 3, 4, 7, 8, and 10). Adequate rinsing time with hot water allows enough time for the fat-based fouling deposit to melt. Longer cleaning time and higher cleaning temperature provide higher fouling deposit removal (Madaeni and Mansourpanah, 2004). Cleaning the former at 65 °C, 7.0 bar, 10 cm nozzle distance, 120 s cleaning time (Set 10) compared to 30 s (Set 9) showed a higher reduction of total number of microbes (3.2 log CFU/cm^2 vs. 1.4 log CFU/cm^2 respectively (Table 9)). Moreover, when cleaning at 120 s (Set 10), the number of *Escherichia coli*, *Listeria monocytogenes,* and *Salmonella enterica* was less than 2.0 log CFU/cm^2, compared to 2.5 log CFU/cm^2 of *Escherichia coli* remaining after cleaning at 30 s. However, for the mixer, 30 s of rinsing time using the portable cleaning unit was enough to reduce the *Escherichia coli*, *Listeria monocytogenes,* and *Salmonella enterica* to non-detectable level (Set 6 and Set 9). This is shown in Table 10. Thus, 120 s rinsing time using hot water of 65 °C is suggested for the former and 30 s for the mixer.

3.6. Effect of mechanical action (using different nozzle pressure) (evening cleaning)

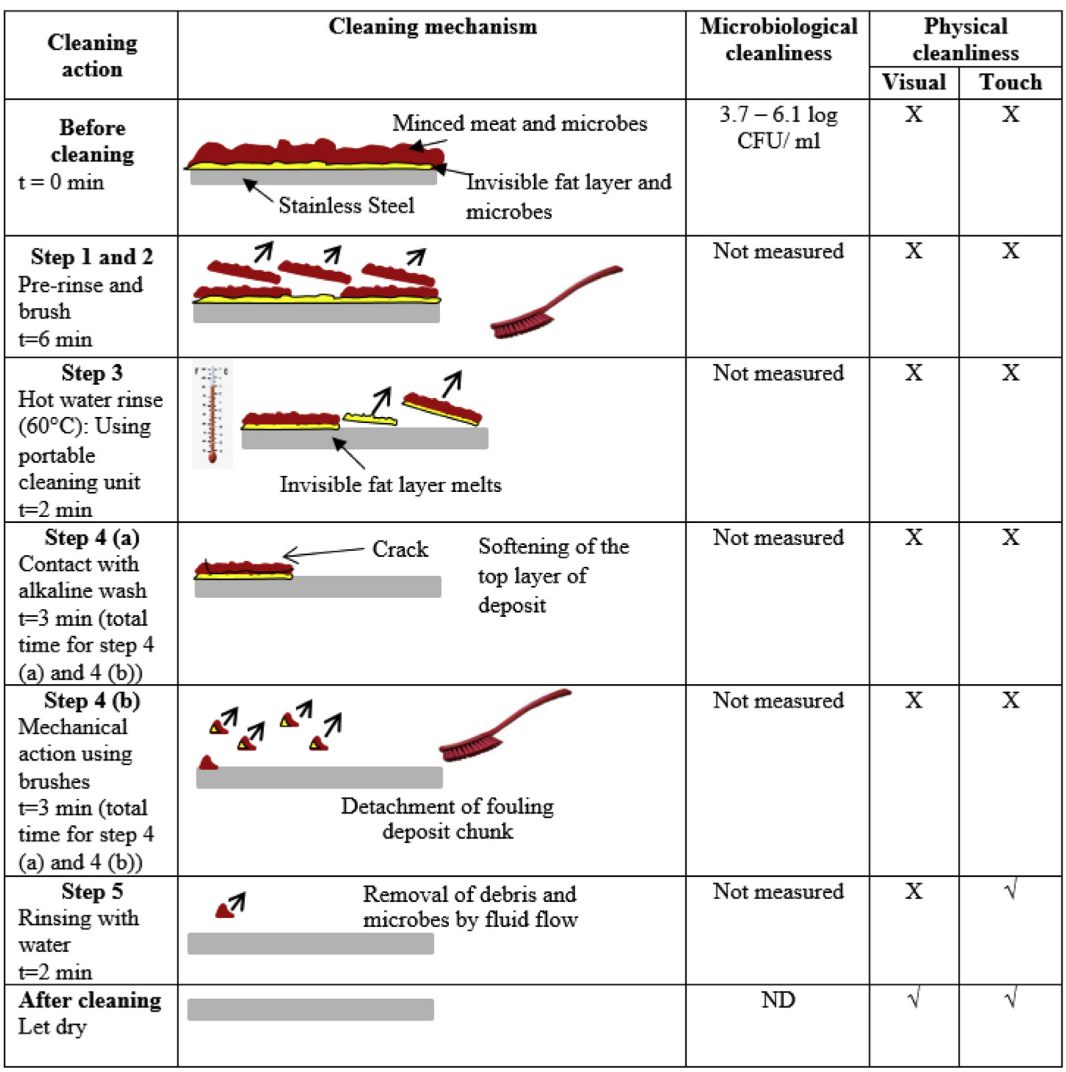
During the evening cleaning, cleaning was performed using two different pressure nozzles which were 5.2 bar (Set 2 to 8) and 7.0 bar (Set 9 and 10). Cleaning the former, with a cleaning time of 120 s, 10 cm nozzle distance, 65 °C, and 7.0 bar (Set 10) showed better cleaning performance with a reduction of 3.2 log CFU/cm^2 compared to cleaning performed at 5.2 bar (Set 7) with a reduction of 2.5 log CFU/cm^2. However, both of these sets managed to reduce the number of the microbes to less than 2.0 log CFU/cm^2 (microbiologically clean). Cleaning time of 30 s, 10 cm nozzle distance, at 65 °C and 7.0 bar (Set 9) cannot reduce *Escherichia coli* to less than 2.0 log CFU/cm^2. Due to the high pressure nozzle, the food residue detached from the food processing surfaces splashed and landed on other clean surfaces. Then, the high pressure impact caused heavy aerosol (water, steam, mist, dirt, and microbes) to remain suspended for a long time (Stanga, 2010) which led to a contamination of clean surfaces. This might be the reason for non-microbiological clean condition for Set 9 experiment, even though high pressure nozzle of 7.0 bar was used. Therefore, increasing nozzle pressures has no positive effect on the removal of microbes. It was concluded that 5.2 bar was sufficient to clean all food processing equipment in factory X. At 5.2 bar, cleaning can be done effectively and at the same time aerosols formation are minimal. This will minimize the potential cross contaminations to other clean surfaces.

3.7. Effect of mechanical action (using industrial brushes) (evening cleaning)

In this work, industrial brushes were added to assist in the removal of food residues remaining on the food-contact surface in factory X. The application of a kitchen sponge in the current cleaning program was not efficient enough to remove food residues especially the fat-based fouling deposit. Furthermore, application of industrial brushes can solve problems regarding potential injuries such as hand injuries and back pain during cleaning. Without industrial brushes, it was hard to achieve a physically clean condition. If there are no fouling deposit or food residue remaining, the potential of microbial growth will be reduced. Cleaning without industrial brushes cannot reduce the total number of microbes to non-detectable level (Set 1 and Set 2). Fig. 6 shows the cleaning mechanism, cleaning time, and cleanliness level (physical and microbiological) of the tested cleaning program for the former. For other processing unit (mixer, mincer, flaker etc.), cleaning time and cleanliness level might be different. The use of industrial brushes assists in removing the remaining fouling deposit which cannot be removed by heat and chemical action. Removal of fat-based fouling deposit depends on (1) the energy to overcome the adhesive force between the surface of food processing equipment with the fat-based fouling deposit, and (2) the energy to transport the fat-based fouling deposit away from the food processing surface. The industrial brushes help in overcoming the adhesive force between surface and fat-based fouling deposit, thus making it easier to rinse the surface.

3.8. Effect of nozzle distance (evening cleaning)

Shorter distance between the nozzle and the surface will give higher fluid velocity with higher impact of water jet which can remove the fouling deposit more efficiently (Leu et al., 1998; Meng et al., 1998). However, results of microbial reduction when different nozzle distances were used have shown a lack of consistency. In contrast with claims by Leu et al. (1998) and Meng et al. (1998), reducing the nozzle distance gave no significant improvement on the microbiological cleanliness of equipment surfaces for both the former and the mixer. The examined range of nozzle distance (10 cm and 20 cm) were lower and equal with the lowest nozzle distance performed by Leu et al. (1998) which were 20 cm. Studies by Köhler et al. (2013) showed that nozzle distance has no significant effect on the cleaning. However, the nozzle distance used were also lower (1.6–18.4 cm) compared to other studies by Leu et al. (1998) and Meng et al. (1998). For future study using the portable cleaning unit, a higher nozzle distance should be used. Thus, it can be concluded that nozzle distance in this work has no significant



Notes: ND means non-detectable level which is less than 2.0 log CFU/cm^2

Fig. 6. Cleaning mechanism of fat-based fouling deposit from stainless steel surface using the proposed cleaning program for the former.

effect on the cleaning effectiveness. Shorter nozzle distance of 10 cm gave a better visual monitoring for operators to observe the physical cleanliness during cleaning. Moreover, this generated less splash which can prevent cross-contamination to other clean surfaces, as the unit operation arrangement in the premise was quite congested. Some of the aisle width was very narrow, about 40 cm–280 cm. Hence, 10 cm nozzle distance was suggested for the proposed cleaning program.

3.9. Disinfection step before production (morning cleaning)

Tables 11 and 12 show the results for morning cleaning (the former and the mixer) respectively. Rinsing using water only (Set 1–6) was compared with usage of portable cleaning unit (Set 7–10). For Set 7 to 9, hot water of 75 °C at different water pressure (5.2 bar and 7.0 bar) was studied. As for Set 10, water at room temperature and 7.0 bar was used for morning rinsing. A higher temperature of 75 °C was suggested in the morning cleaning for disinfection purposes (Tamime, 2008). High temperature water can replace chemical agents (Heinz and Hautzinger, 2007; Hui, 2012; Tamime, 2008). Disinfection in the morning cleaning is a precaution step to remove any potential of microbes' growth that might happen during overnight when there was no production. Tables 11 and 12 show that there was microbial growth during the overnight downtime. During morning cleaning, there were no *Salmonella enterica* were detected on the mixer (before and after disinfection step), but there were *Salmonella enterica* detected on the former (for some set) before disinfection step. However, the disinfection step using the tested cleaning program was able to reduce the microbes to non-detectable level. Set 8 and Set 9 used different water pressure of 5.2 bar and 7.0 bar respectively. Disinfection (morning cleaning) at 75 °C, 120 s, 10 cm nozzle distance, and 5.2 bar (Set 8) can reduce *Escherichia coli*, *Listeria monocytogenes*, and *Salmonella enterica* to non-detectable level for both the former and the mixer. However, at 7.0 bar (Set 9), there were still 2.4 log CFU/cm^2 *Escherichia coli* on the former surface (Table 11). Thus, 5.2 bar was sufficient enough to reduce the microbes to non-detectable level and it can save more energy. Cleaning using 7.0 bar can create more mist compared to 5.2 bar. Aerosol (water, steam, mist, dirt, and microbes) formation in the food industry is a main concern (Stanga, 2010). High pressure impact causes a heavy aerosol to remain suspended for a long time (Stanga, 2010). High pressure generated will take the fouling deposit and microbes transferred to another surfaces. Mist can attach to the ceiling and lamps, and can become a habitat for microbial growth which can cause contamination to food products. Set 10 (at 7.0 bar without using hot water) shows that number of *Escherichia coli* remaining after morning cleaning was 2.4 log CFU/cm^2. Thus, it showed that hot water at 75 °C was needed. For cleaning of the mixer, rinsing with water only was enough to ensure that the number of total microbes remained were not detectable. However, 75 °C, 120 s, and 5.2 bar were suggested as a precaution step.

3.10. Cleaning costs

From the findings from Section 3.4 to 3.9, the following cleaning parameters were proposed:

- For the former: evening cleaning (65 °C, 120 s, 10 cm, and 5.2 bar), morning cleaning (75 °C, 120 s, 10 cm, and 5.2 bar)
- For the mixer: evening cleaning (65 °C, 30 s, 10 cm, and 5.2 bar), morning cleaning (75 °C, 120 s, 10 cm, and 5.2 bar)

Table 13 and Table 14 show the cleaning time, cleaning costs, and water usage for the former and the mixer, respectively. This data only shows the total cleaning costs for two selected food

Table 11
Effect of different cleaning programs for morning cleaning on the former.

Set	Total microbial (log CFU/cm^2)		*E. coli* (log CFU/cm^2)		*Listeria monocytogenes* (log CFU/cm^2)	
	After cleaning	Microbial reduction	After cleaning	Microbial reduction	After cleaning	Microbial reduction
1	4.4	1.6	3.1	0.6	ND	0.7
2	4.7	2.2	3.3	0.4	2.3	1.8
3	3.5	0.9	2.7	1.5	ND	0.0
4	5.5	0.0	3.7	1.1	ND	0.0
5	2.2	4.1	3.7	1.3	3.0	0.9
6	ND	1.0	ND	0.0	ND	0.0
7	ND	0.0	ND	0.0	ND	0.0
8	2.6	0.2	ND	1.6	ND	0.0
9	2.9	1.2	2.4	0.4	ND	0.0
10	2.4	2.0	2.8	0.9	ND	0.0

Notes: ND means non-detectable level which is less than 2.0 log CFU/cm.^{2}.

Table 12
Effect of different cleaning programs for morning cleaning on the mixer.

Set	Total microbial (log CFU/cm^2)		*E. coli* (log CFU/cm^2)		*Listeria monocytogenes* (log CFU/cm^2)	
	After cleaning	Microbial reduction	After cleaning	Microbial reduction	After cleaning	Microbial reduction
1	3.6	2.5	ND	1.7	ND	1.4
2	ND	1.8	ND	0.0	2.3	−0.3
3	ND	1.3	2.3	−0.3	ND	0.0
4	3.3	1.8	ND	0.0	ND	0.0
5	ND	0.0	ND	0.0	ND	0.0
6	ND	0.0	ND	0.0	ND	0.0
7	ND	0.0	ND	0.0	ND	0.0
8	ND	0.0	ND	0.0	ND	0.0
9	ND	0.0	ND	0.0	ND	0.0
10	ND	0.0	ND	0.0	ND	0.0

Notes: ND means non-detectable level which is less than 2.0 log CFU/cm.^{2}.

Table 13
Cleaning time and costs for different cleaning program for the mixer (evening cleaning).

Cleaning program	Current cleaning program				Proposed cleaning program			
Type of process	Water flow rate (L/min)	Quantity of water used (L)	Cleaning time (min)	Cleaning cost ($)	Water flow rate (L/min)	Quantity of water used (L)	Cleaning time (min)	Cleaning cost ($)
Pre rinse	9.6	28.80	3	0.04	9.6	19.20	2	0.03
Rinse (Hot water)	-	-	-	-	8.3	4.15	0.5	0.02
Alkaline rinse	-	1.00	6	0.07	-	1.00	6	0.07
Post rinse	9.6	76.80	8	0.12	9.6	57.60	6	0.09
Total	**-**	**106.60**	**17**	**0.23**	**-**	**85.95**	**14.5**	**0.21**

Table 14
Cleaning time and costs for different cleaning program for the former (evening cleaning).

Cleaning program	Current cleaning program				Proposed cleaning program			
Type of process	Water flow rate (L/min)	Quantity of water used (L)	Cleaning time (min)	Cleaning costs ($)	Water flow rate (L/min)	Quantity of water used (L)	Cleaning time (min)	Cleaning costs ($)
Pre rinse	9.6	76.80	8	0.12	9.6	57.6	6	0.09
Rinse (Hot water)	-	-	-	-	8.3	16.6	2	0.06
Alkaline rinse	-	1.00	3	0.07	-	1.00	3	0.07
Post rinse	9.6	28.80	3	0.04	9.6	19.2	2	0.03
Total	**-**	**106.60**	**14**	**0.23**	**-**	**94.4**	**13**	**0.25**

processing equipment in factory X. The result showed that the proposed cleaning program decreased and increased the total cleaning costs for the mixer and the former, respectively. The total cleaning costs for the mixer decreased by 8.7%. The proposed cleaning program not only can achieve a physically and microbiologically clean state, this program can also reduce the cleaning costs for the mixer which can benefit food manufacturers. As opposed to the former, the cleaning costs increased by 6.3%. However, it has to be emphasized that the proposed cleaning program can achieve a physically and microbiologically clean condition which the current cleaning program could not achieve. Investment on a good cleaning program will lead to a better hygienic factory environment, decrease the number of rejected products, and increase the product quality. Tables 13 and 14 show that the total cleaning time was reduced by 2.5 min (14.7%) and 1 min (7.1%) for the mixer and the former, respectively. They also show a higher cleaning rate for the tested cleaning program compared to the current cleaning program. A shorter total cleaning time will reduce the labor work.

The proposed cleaning program uses water more sustainably as the post-rinsing time can be decreased up to 25%–33% (the mixer and the former, respectively) compared to the current cleaning program. The quantity of water used for the mixer and the former decreased by 23% and 11% respectively. Less wastewater was generated which is more environmentally friendly.

4. Conclusions

This study shows that critical analysis of the cleaning program of an SME food factory (meat patties factory) can lead to the definition of appropriate cleaning tools (portable cleaning unit, industrial cleaning brushes) and a tailored cleaning program to help plant managers and food industry operators manage daily cleaning operations more efficiently. The portable cleaning unit provides hot water rinse and the industrial cleaning brush allows mechanical action which enable effective cleaning. Overall, the tailored cleaning program has shown good improvement on the level of cleanliness. The physical and microbiological cleanliness is the indicator to test the effective cleaning program. The cleanliness of most of the food processing equipment in factory X was under the desired level. The mixer and the former which are difficult to clean were chosen for the case study to test the tailored cleaning program.

The critical analysis of the current cleaning program opened the way to the revision of the whole cleaning program, by adding hot water rinsing after the pre-rinse step (evening cleaning). For morning cleaning, a disinfection step using hot water was suggested. The proposed cleaning program not only resulted in a hygienic cleaning environment but also in a safe and healthy working environment for workers. The suggested cleaning program can reduce water consumption up to 23%, cleaning time up to 14.7%, and cleaning cost up to 8.7%. However, this study had not focused on the improvement of cleaning performance at each cleaning step. Hence, the potential of minimizing the cleaning costs (cleaning chemical, water, time, and wastewater) at every cleaning step should be investigated in future work.

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Appendix

In this paper, an example calculation for the proposed cleaning program for the former is presented. Water rinsing costs (pre-rinse, hot water-rinse and post-rinse) were calculated using the equations in Table 4, while alkaline wash costs were calculated using the equations in Table 5. These calculations were also used to calculate the current cleaning program. For current cleaning program, hot water-rinsing cost was excluded. Tariff for water, wastewater, and electric might be different depending on state and country. The costs for cleaning chemicals might also be different depending on the types and brands.

Pre-rinse costs

For pre-rinse and post rinse, the water flow rate was measured based on the pipe water flow rate used in the factory. Readings over three days were taken and the average water flow rate were 9.6 L/min.

$$\textit{Total water used } (L) = \textit{water flow rate x total cleaning time}$$
$$= 9.6\,\frac{L}{min}\,x\ 6\ minute\ (Pre\_rinse\ time)$$
$$= 57.6\ L$$

$$\textit{Water costs } (\$) = \textit{Total water used } (L) \div 1000\,\frac{L}{m^3} \times \frac{\$0.50}{m^3}$$
$$= 16.6\ \ L \div 1000\,\frac{L}{m^3} \times \frac{\$0.50}{m^3}$$
$$= \$0.01$$

$$\textit{Wastewater costs } (\$) = \textit{Total water used } (L) \div 1000\,\frac{L}{m^3} \times \frac{\$1.00}{m^3}$$
$$= 16.6\ L \div 1000\,\frac{L}{m^3} \times \frac{\$1.00}{m^3}$$
$$= \$0.02$$

$$\textit{Electric costs} = [\text{Electricity used by pump (W)} + \text{Electricity used by heater (W)}] \times (\text{cleaning time})\ (\text{hours}) \div 1000\,\frac{\text{W}}{\text{kW}} \times \$0.10/\text{kWh}$$
$$= [750\,\text{W} + 7500\,\text{W}] \times 0.033\ \text{hours} \div 1000\,\frac{\text{W}}{\text{kW}} \times \$0.10/\text{kWh}$$
$$= \$0.03$$

$$\textit{Costs of hot water\_rinse } (\$) = \textit{Water cost} + \textit{Wastewater cost} + \textit{Electric cost}$$
$$= \$0.01 + \$0.02 + \$0.03$$
$$= \boldsymbol{\$}0.06$$

$$\textit{Water costs } (\$) = \textit{Total water used } (L) \div 1000\,\frac{L}{m^3} \times \frac{\$0.50}{m^3}$$
$$= 57.6\ \ L \div 1000\,\frac{L}{m^3} \times \frac{\$0.50}{m^3}$$
$$= \$0.03$$

$$\textit{Wastewater costs } (\$) = \textit{Total water used } (L) \div 1000\,\frac{L}{m^3} \times \frac{\$1.00}{m^3}$$
$$= 57.6\ L \div 1000\,\frac{L}{m^3} \times \frac{\$0.50}{m^3}$$
$$= \$0.06$$

$$\textit{Costs of pre\_rinse } (\$) = \textit{Water cost} + \textit{Wastewater cost}$$
$$= \$0.03 + \$0.06$$
$$= \boldsymbol{\$}0.09$$

Hot water - rinse costs

For hot water-rinse, the flow rate of the portable cleaning unit was used. At 5.2 bar, the flow rate was 8.3 L/min.

$$\textit{Total water used } (L) = \textit{water flow rate x total cleaning time}$$
$$= 8.3\,\frac{L}{min}\,x\ 2\ minute\ (Hot\ water\_rinse\ time)$$
$$= 16.6\ L$$

Post-rinse costs

$$\textit{Total water used } (L) = \textit{water flow rate x total cleaning time}$$
$$= 9.6\,\frac{L}{min}\,x\ 2\ minute\ (Post\_rinse\ time)$$
$$= 19.2\ L$$

$$\textit{Water costs } (\$) = \textit{Total water used } (L) \div 1000\,\frac{L}{m^3} \times \frac{\$0.50}{m^3}$$
$$= 19.2\ \ L \div 1000\,\frac{L}{m^3} \times \frac{\$0.50}{m^3}$$
$$= \$0.01$$

$$\textit{Wastewater costs } (\$) = \textit{Total water used } (L) \div 1000\,\frac{L}{m^3} \times \frac{\$1.00}{m^3}$$
$$= 19.2\ L \div 1000\,\frac{L}{m^3} \times \frac{\$0.50}{m^3}$$
$$= \$0.02$$

$$\textit{Costs of post - rinse } (\$) = \textit{Water cost} + \textit{Wastewater cost}$$
$$= \$0.01 + \$0.02$$
$$= \boldsymbol{\$}0.03$$

Alkaline rinse costs

This company used alkaline detergent X with ratio of 1:60 of water, where the operators mixed 0.1 L detergent X with 6 L water daily. It was assumed that the same amount of detergent were used for each machine (total of 6 machines). The alkaline rinse step is a batch cleaning and longer cleaning time will not affect the cleaning costs (water, wastewater, cleaning chemical). Thus, if the amount were divided to six machines equally, one machine used 0.017 L detergent X with 1 L water as shown below. Table 5 was used to calculate the cost of the alkaline step.

$$Detergent\ X\ volume = \frac{0.1\ L}{6\ machines} = 0.017\ L\ detergent\ X$$

$$Water\ volume = \frac{6\ L\ water}{6\ machines} = 1\ L\ water$$

$$\begin{aligned} Cost\ of\ detergent\ X &= Total\ detergent\ X\ used\ (L) \times \frac{\$4.00}{L} \\ &= 0.017\ L \times \frac{\$4.00}{L} \\ &= \$0.07 \end{aligned}$$

$$\begin{aligned} Cost\ of\ make\_up\ water &= Total\ water\ used\ (L) \div 1000 \frac{L}{m^3} \times \frac{\$0.50}{m^3} \\ &= 1\ L \div 1000 \frac{L}{m^3} \times \frac{\$0.50}{m^3} \\ &= \$0.0005 \end{aligned}$$

$$\begin{aligned} Cost\ of\ wastewater &= Total\ water\ used\ (L) \div 1000 \frac{L}{m^3} \times \frac{\$1.00}{m^3} \\ &= 1\ L \div 1000 \frac{L}{m^3} \times \frac{\$1.00}{m^3} \\ &= \$0.001 \end{aligned}$$

$$\begin{aligned} Cost\ of\ alkaline\ rinse &= \$0.07 + \$0.0005 + \$\ 0.001 \\ &= \boldsymbol{\$}0.07 \end{aligned}$$

$$\begin{aligned} Total\ cleaning\ cost &= Cost\ of\ (pre\_rinse + hot\_water\ rinse \\ &\quad + alkaline\ rinse + post\_rinse) \\ &= \$0.09 + \$0.06 + \$0.07 + \$\ 0.03 \\ &= \boldsymbol{\$}0.25 \end{aligned}$$

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