International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; 9(12): 628-636
www.biochemjournal.com
Received: 04-11-2025
Accepted: 06-12-2025

Dharinkumar Jayswal
Dhudhsagar Dairy,
Mehsana, Gujarat, India

PS Minz
Dairy Engineering Division
ICAR- National Dairy
Research Institute,
Karnal, Haryana, India

Arvind Kumawat
Dairy Engineering Division
College of Dairy Science and
Technolgy, SKNAU
Jobner, Jaipur, Rajasthan,
India

Corresponding Author:
Arvind Kumawat
Dairy Engineering Division
College of Dairy Science and
Technolgy, SKNAU
Jobner, Jaipur, Rajasthan,
India

Cleaning-In-Place test rig for characterization of nozzle performance during cleaning of milk can

Dharinkumar Jayswal, PS Minz and Arvind Kumawat

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i12h.6599

Abstract
A cleaning-In-Place (CIP) test rig was developed to study nozzle spray performance for cleaning milk can. Test rig consisted of a set up on which different solid stream nozzles of orifice diameter 2, 3, 4 and 5 mm were evaluated. Variable parameters were nozzle orifice diameter and pump operating frequency (15-40 Hz). Effect of jet breakup after impingement and surface water distribution along internal wall was measured using patternator. Multi response optimization was applied to maximize impact force and spray jet pressure and minimize nozzle flow rate. The optimization solution with highest desirability function (0.65) was obtained in case of 4 mm nozzle operated at 40 Hz pump frequency. Cleaning time of 30 sec for individual sequences, 1% NaOH solution and hot water at 70 °C resulted in satisfactory cleaning of milk can. Test rig served as a multi-purpose platform for spray performance measurement, optimization and standardization of CIP protocol. These findings may be used for design and improvement of industrial spray jet washing systems.

Keywords: Cleaning-in-place, milk can, nozzle, optimization, test rig, spray performance, washing

Introduction

Cleaning is an important process for production of safe products in food and dairy processing industry. Cleaning operations are characterized with high water and energy requirement and cleaning agents are also required. As a result the target is to minimize use of water, energy and cleaning agents to meet both hygienic and environmental needs (Piepiórka-Stepuk *et al*., 2016; Eide *et al*., 2003) [11, 35]. The efficient cleaning is possible by using Clean-In-Place (CIP) procedures which is a method to cleaning the inner surface of the processing equipment without need for dismantling. It is defined as cleaning of plant or pipelines circuits without dismantling or opening the equipment and with little or no manual involvement on the part of the operator. A CIP protocol involves various cleaning steps in a pre-defined sequence like pre-rinse, hot water rinse, alkali rinse and final water rinse to remove residual cleaning agents (Englezos *et al*., 2019; Li *et al*., 2019) [12, 28].

CIP systems require significant large quantities of water, cleaning agents, and energy. In addition, in-place cleaning generates large quantities of waste water (Fan *et al*., 2018) [15]. Effluents from dairy industry carry protein, carbohydrates and fats from milk which results in higher organic load. Due to presence of high organic matter in the dairy waste stream, makes water treatment a complex process and can pose serious problems especially in the local sewage system in term of organic load (Ahmad *et al*., 2019) [2]. Therefore, cleaning processes are designed keeping environmental issues and regulations in mind (Englezos *et al*., 2019) [12]. Several factors affect the CIP performance, including the type and strength of the cleaning chemicals, the quantity and temperature of the cleaning solution, and the fluid dynamics (Wang *et al*., 2016) [45]. CIP processes are designed using aa combination of: time, chemicals, temperature and mechanical force. Selection of cleaning chemicals and process parameters depend on the nature, chemical properties and volume of the fouling material (Escrig *et al*., 2019) [13].

In Indian sub-continent, milk collection is done through milk co-operative societies where individual farmers or owner of large herd of dairy cattle bring milk to the chilling centre in aluminum or stainless steel cans (Madhavi, 2016). Milk cans are convenient and attractive means of transportation of milk from farms to milk plants or chilling centres (NDDB, 2015). Milk must be handled in milk cans of 40 l capacity, which are clean and free from bacteria.

The cleanliness of milk can is therefore of great importance (Amalanathan *et al*., 2015) [4]. In large capacity milk collection centres, cans have to be cleaned using can washing equipment due to large number of cans. If the quantities are less, then it can be done manually, using can washing trough and mechanically operated brushes and steaming blocks. Can washing is one of the important steps in clean milk production practices (Jacob and George, 2013). Cleaning of milk cans is generally done using automatic can washer in milk collection and chilling centers. Unit operations at high temperatures require more complex CIP processes (Piepiórka-Stepuk *et al*., 2021) [36]. As milk cans are not subjected to elevated temperatures, fouling is not a problem and the primary purpose of CIP is to remove residual milk layer from the interior surface of milk can.

The can washers available now are fully automatic but with the recent development in the fluid engineering and CIP technology there is scope of improvement in terms of minimizing water and chemical use. The objective of this research is to understand the factors which are critical for efficient cleaning of milk can. The developed test rig enables researchers to identify scope for improvement in the CIP procedure with minimal use of energy, water and cleaning solution. Mechanical force generated by nozzle jet is sometimes not enough for getting satisfactory cleaning. The test rig has provision to measure the impact force exerted by the water jet. The purpose of CIP test rig is to study spray nozzle performance and to optimize the cleaning protocols.

Materials and methods

CIP test rig

The unit operations for milk can cleaning were conducted in a cleaning-in-place (CIP) test rig. This rig resembles a common CIP station (Khalid *et al*., 2014) [22]. A CIP test rig is widely used to investigate the cleanability of food processing equipment (Sundberg *et al*., 2011; Köhler *et al*, 2015) [26, 42]. Various components such as pipe fittings, cleaning spray nozzle and solution tank were designed to provide continuous flow during CIP procedure. In this design, CIP environment was considered and enabled cleaning steps could be carried out on the test rig (Khalid *et al*., 2015) [23]. It was designed to study various process parameters for cleaning of milk can (Fig 1:). The test rig comprised of a solution balance tank, centrifugal pump, spray nozzle, and can loading station. Schematic diagram of the developed test rig is shown in Fig 2: Brief description of various components of test rig is as follows:

Balance tank: Balance tank is required to store and provide a constant feed to the pump. Tank made of SS-304 was used having capacity of 100 l. Tank also consists of float type liquid level controller.

Pump: Pump is required to supply cleaning solution to the nozzle at high pressure. Centrifugal type of pump (capacity 10,000 l/h) was used. The discharge flow from a centrifugal pump is steady.Main advantage of centrifugal pump is that there will be no damage to pump in case discharge end is closed (Kosseva, 2017) [27]. Such situation may occur due to clogging of nozzle.

Discharge pipelines: Pump discharge port was connected to the nozzle adaptor using a pipe (SS 304) of 0.0254 m (1 inch) diameter.A socket was welded at the end of pipe to be used as nozzle adapter. Nozzle adapter facilitates quick switchover of nozzles. Material of construction is SS-304 for all the pipes.

Support stand: Main support stand is needed to support milk can and other accessories. Stand was fabricated out of mild steel as per the required dimensions. Further it was painted with colour to prevent corrosion from water.

Can loading station: Can needs to be placed in inverted position on the nozzle. This stand should be precisely designed and fabricated in such a way that only periphery portion should touch the supporting stand. Main supporting part was circular stainless steel strip / ring. This ring was further supported by frock type leg supports. Leg supports were fabricated out by welding pieces of stainless steel pipe. Angular skirt type leg support ensures better gripping against setup vibration. Four clamps were welded on the periphery of the ring, on the top of the stand. Theses clamps can prevent milk can from slipping away from the stand, which may occur due to vibration. Also the holding of can becomes easy due to clamps. A disc shapedhopper wasplacedbelow the nozzle for collection of drain water.

2.2 Design aspect of spray system for test rig

Nozzle is one of the most important parts of cleaning system. Three forces play important role in cleaning process: mechanical, chemical and thermal force. Mechanical force helps in distribution of cleaning solution and dislodging of particles from the equipment surface. Therefore design and selection of nozzle and spray pattern has prominent effect on mechanical force exerted by the jet or spray droplets.

Spray nozzle were designed and developed in R & D workshop of the Dairy Engineering Division, ICAR-National Dairy Research Institute, Karnal, India. Fabrications of nozzles were carried out on semi-automatic lathe machine by performing series of operations. In first step solid rod (20 mm diameter) made of brass metal was drilled on lathe machine, to make nozzle inlet. Then parting operation was carried out to make nozzle of required length. The tip of the nozzle was drilled to get required orifice diameter (Fig 3:). The outer threading operation was carried out at the bottom part, so that nozzle can be easily attached with nozzle adaptor. The spray system was designed on the basis of following equations (BETE, 2013):

a. Estimating the pressure a pump will have to supply to a nozzle system

P=Pn+P`-->

$$P = P_n + P_p + \frac{\rho h}{144} \quad (1)$$

Where,

P = Pressure (pump), Pa

P_n= Pressure (nozzle), Pa

P_n= Pressure (pipe losses), Pa

ρ=Density of fluid (kg/m^3)

h= Height of nozzle above pump (m)

(h is negative if the nozzle is below the pump)

b. Formula for flow rate through nozzle

$$Q = K\, P_p^{\ x} \quad (2)$$

$$P_p = \left(\frac{Q}{K}\right)^{1/x} \quad (3)$$

$$\frac{Q2}{Q1} = \left(\frac{P2_p}{P1_p}\right)^{x} \quad (4)$$

Where,
Q = Flow rate (m^3/s)
P_p = Pressure (Pa)
K = Constant factor (depends on nozzle type and pipe size)
x = constant (= 0.5)

c. Droplet size calculation

$$\frac{D2}{D1} = \left(\frac{P2_p}{P1_p}\right)^{-0.3} \quad (5)$$

Where,
D = Nozzle orifice diameter (m)
P_p = Pump pressure (Pa)
d. Spray impact

$$I = K\, Q\, P_L^{\,0.5} \quad (6)$$

Where,
I= Total theoretical spray impact (N/m^2)
K = Constant
Q = Flow rate (m^3/s)
P_L = Liquid pressure (Pa)

In case of solid stream nozzle,

$$I = 1.9\, P_L \quad (6)$$

Where,
I = Total theoretical spray impact (N/m^2)
P_L = Liquid pressure (Pa)

Impact pressure is highest in solid stream nozzle. With all other spray patterns, the unit impact decreases as the distance from the nozzle increases, thereby increasing the impact area size.

2.3 Control system

Automated control system like adjustable electric drives are recommended for pump installation to work without exceeding the pressure for any given water flow rates. The major advantage of using VFD is to reduce energy consumption in pumping operations (Khafizov *et al*., 2020; Abdaljlel *et al*., 2020). Use of VFD is considered a technological improvement as it has potential in saving energy compared to the conventional pumping system (Liu *et al*., 2019; Kato *et al*., 2019). The control system of test rig comprised of Direct on Line (DOL) starter and variable frequency drive (VFD). Electrical 3 phase supply (415 V) was provided from available mains to MCB (3-phase 4-pole MCB) as an input. VFD was programmed to match the pump specifications. VFDs mostly have inbuilt frequency variable knob. During preliminary trials it was observed that a small amount of rotation leads to much greater change into frequency. Thus to increase the resolution of the frequency variable knob, an external potentiometer was attached with VFD and bypassing the inbuilt frequency controller.

2.4 Fabrication of transparent can

In order to ensure a satisfactory cleaning of milk can and to study the nozzle spray pattern, there was a need for visual monitoring. As it was not possible in case of conventional milk can, transparent can was fabricated. Metallic strips (Thickness: 2 mm, Material: galvanized iron) were used for making a supporting frame in cylinder shape. Metal strip was formed into circular ring by cold rolling process with the help of plate bending machine. The strips and rings were welded to form framework with dimensions equal to the conventional can (Height: 0.59 m; Diameter: 0.34 m). LDPE sheet (500 micron) was clipped around the framework (Fig. 3).

2.5 Spray jet impact measurement setup

Impact of spray jet is amount of force which is created per unit surface area by water jet discharged from the nozzle. Suitable modifications were made to support the impact measurement instrument inside the transparent can. Spray jet impact force was measured with help of pressure transducer. Square stainless steel (SS-304) plate (thickness 2.5 mm) was drilled at required positions, and it was attached to the base of transduced assembly. The setup was mounted in an inverted position at the top of transparent can framework (Fig. 4).

2.6 Nozzle performance evaluation parameters

The CIP test rig was used to evaluate performance of four nozzles N1 (D = 2 mm), N2 (D= 3 mm), N3 (D = 4 mm) and N4 (D = 5 mm). The distance between the nozzle outlet and milk can bottom was kept constant L = 0.69 m as employed in industrial can washing equipment. Pump flow rate was controlled using VFD and operated at six different frequency F15 (15 Hz), F20 (20 Hz), F25 (25 Hz), F30 (30 Hz), F35 (35 Hz) and F40 (40 Hz). Various parameters like nozzle flow rate, impact force, jet pressure, and surface water distribution, volumetric rate of non-surface and surface water were experimentally determined according to the experimental plan shown in table 1.

Nozzle flow rate: The volume of liquid flowing through a nozzle depends on fluid pressure difference in upstream and the pressure into which the nozzle discharges. Flow rate through nozzle per unit time was measured for different combinations of nozzle (N1-N4) and pump VFD frequency (F15-F40).

Impact force of water spray jet: Impact force is the amount of force created by water jet per unit surface area. Here impact was indirectly measured by the fabricated setup using weight transducer. There are two main types of water jet: i. In case of droplet jet, jet is transformed into droplets and individual droplets hit the surface. The primary mechanism is atomization of the feed stream. Ii. Coherent jets occurs when a fluid column impinges and spreads out radially. Coherent jet is also known as solid jet. The nozzles used in the present study were of solid jet type. The jet pattern is affected by nozzle diameter, differential pressure, p, and the distance between the nozzle exit and the surface to be cleaned (Köhler *et al*., 2013) [25]. Impact force (N) was measured for different nozzles (N1-N4) under different pump operating conditions.

Spray jet pressure: There are several factors that affect cleaning effectiveness type of residue, cleaning agents, temperature, flow rate, jet pressure, spray pattern, spray angle, spray distance, and rotational velocity of water jet (Sivaramakrishnan *et al*, 2018) [38]. Among them spray jet pressure is the major driving force in removal of the residues from the surface. Nozzle converts high pressure water into high impact water jet. Jet pressure in this case is amount of force created on the plate per unit cross sectional area of water jet. Jet diameter was measured with the help of vernier caliper. Mean jet pressure was determined at inner bottom surface of can. The distance between nozzle and the bottom surface of milk can was 0.69 m.

Surface water distribution: The spray jet after hitting the bottom surface of milk can spreads radially in all direction and flows down long the internal wall. Surface water distribution was determined to determine the uniformity of radial spread of spray jet. The patternator used to measure surface water distribution consisted of eight 100 mm PET cylinders placed side-by-side in a circular arrangement (Fig 6 a). The internal diameter and height of each cylinder were 99.8 mm and 163 mm, respectively. The patternator was designed to collect water droplets at the same locations and the method was similar as proposed by Lundberg *et al*., 2021. A digital weight and timer was used to measure the actual volume of water collected which was dripping along the walls of the transparent can framework.

The plane was represented in angular coordinates, the radius from the center of the spray nozzle r and the angleθ. The center of first cylinder C_1 was at an angle of θ_1 = 22.5° with x axis. The angle for the subsequent cylinder C_2 was$\theta_1 + 45^o$. The angular different between two cylinders was $\Delta\theta = 45^o$ (Fig. 6 b).

Transparent can rinsing operation was carried out on the fabricated test rig. Rinse water dripping down from the inside can surface was collected in a patternator. Circular periphery of cylindrical bottom of can was divided into eight approximately equal parts, and eight PET cylinders (C_1 to C_8) were placed at the bottom of the can in such a way that one cylinder cover one part. Rinsing of can by water was carried out for fixed interval of time. The volume of water collected in containers were measured as V_1, V_2, V_3, V_4, V_5, V_6, V_7 and V_8 for calculation purpose.

Volumetric rate of non-surface water

The spray water that drained off without being collected in the patternator was termed as non-surface water and its volumetric flow rate was measured as V_N (cbm/s).

Volumetric rate of surface water:

The volumetric rate of surface water collected in patternator was determined over time t as:

$$V_S = (V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7 + V_8) / t \qquad (7)$$

Pump discharge pressure

Pump discharge pressure (Pa) was measured with the help of pressure gauge fitted on the pump discharge line.

Instantaneous power consumption

Electrical parameters were measured by digital multi parameter meter. Power consumed by induction 3 phase motor was calculated from the equation:

$$\text{Power} = (V \times I \times PF \times 1.732) / 1000 \qquad (8)$$

Where,
P = Power (kW)
V = Voltage (V)
I = Current (A)
PF = Power factor

Optimization of spray performance

Multi response optimization was carried out for selection of nozzle (N1 - N4) and pump operating frequency (F15 - F40) using Design Expert 8.0 software (Stat-Ease Inc, Minneapolis). The optimization module seeks set of response and factor simultaneously that meet the criteria. The goals are merged to determine an overarching feature in terms of desirability function D(X) and the aim is to maximize this function. The objective function D(X) reflects the desirable ranges (0 to 1) for each response (d_i). The simultaneous objective function is a geometric mean of all transformed responses:

$$D(X)=(d_1.\ d_2.\_\ \_\ \_d_n)^{1/n} = \prod_{i=1}^{n} d_i^{1/n} \qquad (9)$$

Where n is the number of responses in the measure. If any of the responses fall outside the desirability range, the overall function becomes zero (Statease, 2021) [41]. Therefore responses showing significant results were included in the optimization study *viz*. impact force, nozzle flow rate, volumetric flow rate of surface water and spray jet pressure.

Standardization of CIP protocol

Cleaning-In-Place (CIP) involved four steps: warm water rinse, washing with alkaline solution (NaOH), a clear rinse with hot water and then sanitizing with Iodophor (25 ppm) an EPA-registered sanitizing agent. Iodophor solution contained 1.6-1.7% iodine. Cleaning effectiveness depends of interdependent parameters like time, temperature, solution concentration, mechanical force of spray jet etc. Increasing these factors beyond certain level will result into losses in terms of energy, utility and result in adverse environmental impact due to higher effluent volume. Thus there is a need to find out the optimum cleaning parameters which lead to satisfactory cleaning with minimum utilization of resources.

CIP protocol was standardized using Taguchi method module of Design Expert 8.0 software (Stat-Ease Inc, Minneapolis). Taguchi method is particularly useful when there is a need to optimize large no of parameters which are also resource consuming (Rangi *et al*., 2019) [37]. Different factors considered for optimization were time (10 - 30 s), NaOH solution concentration (0 - 1%), NaOH solution temperature (60 - 80 °C) and hot water temperature (70 - 90 °C). The experimental design parameters obtained from the software is shown in table 2. Raw milk was kept in stainless steel milk can (capacity 40 L) for 4 h under ambient condition (Temperature: 38±2 °C and RH: 65±5 %). Cleaning sequences for cleaning of milk can was followed as per the Taguchi experimental design. For 0% NaOH treatment clear hot water was used. The cleaning solution at different concentrations of NaOH and temperatures (35 - 70 °C) was prepared in tank before being pumped for can cleaning. To study the effect of individual cleaning treatment on milk can cleaning effectiveness, cleaning solutions were discharged as wastewater immediately after use. After each CIP treatment cycle, cleaning adequacy was determined in terms of total pate count according to the method used by Bremer *et al*. (2006) [6].

Statistical analysis

Multivariate analysis of variance was applied to assess multiple dependent variables simultaneously using SPSS 16.0. The independent variables considered were nozzle type (N1-N4) and pump operating frequency (F15-F40). Performance evaluation parameters were considered as dependent variable. Tukey's HSD post hoc test was used for single-step multiple comparisons between all possible pairs of treatments means.

Results and Discussion

Nozzle flow rate

Flow rates were in the range of 5.31-24.64, 12.75-45.45, 39.28-82.85, 40.62-82.85 and 40.61-131.96 µm^3/s for nozzle N1, N2, N3, N4 and N5, respectively for pump operating at different frequencies (F15-F40). Nozzle diameter and pump frequency had significant ($p < 0.05$) effect on nozzle flow rate. At constant frequency (F = 40 Hz) N5 resulted in 59.27% higher flow rate than N4. While, for N4 it was 82.28% higher than N3 (Fig 7:). Flow rate increased linearly with increase in nozzle diameter as well as pump supply frequency. It is because the increase of the outlet diameter reduced the frictional loss and improved the nozzle flow capacity. Nozzle with larger flow rate yields high amount of water atomization per unit space resulting in better cleaning (Wang *et al*., 2020) [44]. To keep the water and chemical consumption low it is always desirable to keep lower flow rates. In case of nozzles N1 and N2 at lower pump discharge (F15-F20), the nozzle flow rate (5.31-25.36 µm^3/s) may not be sufficient to achieve the required level of surface cleaning.

Impact force of spray jet

The maximum impact force exerted by the jet spay for N1, N2, N3 and N4 nozzles were 0.392, 1.085, 2.947 and 4.804 N, respectively. Higher impact force is desirable as particle removal is strongly connected to the shear stress generated on the target surface by the impinging fluid. The cleaning process involves soil removal by erosion and shear stress generated by the impacting jet (Anglani *et al*., 2017) [5]. Impact force was adversely affected at lower pump operating frequency (F15-F20) and its value was less than 0.788 N for the nozzles tested in test rig (Fig 8:). Mean impact force increased significantly (p<0.05) with increase in nozzle orifice diameter and pump supply frequency. Nasr *et al* (208) also reported significant increases in the rate of cleaning achieved by increasing the product of impact force and mass flux (Nasr *et al*., 2008) [33]. Impact force is amount of force created on a cleaning surface due to the action of the spray jet. It gives an idea how well rinsing will take place on the internal surface of milk can. Nozzles apply the cleaning agent, provide mechanical force for cleaning, and rinse the debris away (Durkee, 2009) [10]. Impact force generated by 2 mm nozzle (N1) was significantly (p<0.05) lower (0.005 - 0.47 N) as compared to other nozzles (N2-N4). Thus, low values of impact force in case of N1 nozzle suggest that it cannot be used for milk can cleaning. CIP test rig was found useful for selection of nozzles (N2, N3 and N4) and to optimize pump operating frequency (> F20) to generate adequate impact force (> 2 N). In a similar study on nozzle performance evaluation, spray impact force was found in the range of 2-5 N for nozzles with orifice diameter 3 mm and 4 mm (Fuchs *et al*., 2019) [17].

Spray jet pressure

The study showed that it was possible to control the spray jet pressure in the CIP test rig. The nozzles with promising results were N2, N3 and N4, demonstrating peak spray jet pressure of 153.62, 234.66 and 244.81 kPa, respectively. Increasing fluid pressure in the spray system, increases the internal energy of the fluid. Conversion of pressure energy is required to atomize the spray, increase momentum and impact. In transferring energy into momentum, solid stream nozzles are most efficient followed by flat fans, hollow cones and full cone nozzles. Full cone nozzles efficiently use internal fluid energy for atomization and are therefore very inefficient at energy transfer (SNP, 2020) [39]. High values of spray jet pressure were observed due to selection of solid jet nozzles. The distance between the nozzle tip and the milk can bottom was 0.69 m. The solid jet nozzle impact at the milk can bottom generates sufficient impact for cleaning of the corners between the bottom and internal wall of can. Study of spray jet pressure helped to further refine the parameters required for cleaning of milk can. The graphical plot between spray jet pressure and pump frequency shows two distinct categories as low and high pressure (Fig 9:). First category is for pump frequency F15, F20 and F25 resulting in jet pressure < 75 kPa which can be grouped as low pressure. In the second or high pressure category, for F30, F35 and F40 jet pressure achieved was above 100 kPa (Fig 9:). Brown *et al*. (2010) [7] studied the impact force created by nozzle on pressure sensitive pad. In case of rotary nozzles, impact force reduces and coverage area increases with increase in distance of nozzle from target. Nozzle operated on rotating mode significantly reduces the impact pressure as compared to static nozzle.

Surface water distribution

Surface water collection significantly increased with increase in pump supply frequency and nozzle orifice diameter (Fig 10:). It was observed that with increase in supply frequency, pump discharge increases leading to more uniform distribution of water in the patternometer. Non uniformity observed in the water distribution in terms of V_1-V_8 may be due to minor problems in the system like change in position of can by the spray jet impact, system vibration, etc. The volumetric rate (nm^3/s) of water collection for N2 (3 mm orifice diameter) nozzle were V_1 = 4360.28, V_2 = 3464.70, V_3 = 2327.54, V_4 = 4375.58, V_5 = 4678.29, V_6 = 6050.58, V_7 = 6059.12, and V_8 = 411.60. Mean water collection in various cylinders of patternometer in case of 3 and 4 mm nozzle were of close values. In case of nozzle N4, the values of V_1-V_8 were in the range of 7772.62 to 18694.33 nm^3/s. Higher quantity of surface water was desirable to have better rinsing of can inner surface. It was observed that at 15 Hz pump operating frequency water jet was just touching the bottom of can, so water spread was poor along the internal walls. With increase the pump supply frequency (F15 to F30), more uniformity in water spread was observed. At higher pump discharge (F35-F40) the spray jet impact was substantial and splashing at the can bottom resulted in non-uniform surface water distribution.

Volumetric rate of non-surface water

Non-surface water is the amount of water collected from the can rinsing process and excludes water drained along the internal walls of the milk can. Non surface water quantity increased significantly ($p<0.05$) with increase in pump supply frequency as well as nozzle orifice diameter (Fig 11:). Higher non surface water quantity indicates less effective surface cleaning on the inner vertical walls of milk can. In such a case most of the water drains off due to splashing. When pump frequency was increased from 15 to 40 Hz volumetric rate of non-surface for N1, N2, N3 and N4 nozzle was in the range of 21218.75 - 42291.66, 27975.35 - 57166.66, 29541.67 - 100083.34 and 76875.09 - 213083.58 nm^3/s, respectively. Spray jet flux is a function of nozzle orifice diameter and increase in jet flux an expansion of the upper limit of the split droplet can be observed. The kinetic energy of droplet increased with diameter, thereby intensifying the degree of splash (Kang *et al*., 2020) [19].

The effect of nozzle orifice diameter on the non-surface water can be explained by the spray jet characteristic. When spray jet droplet impinges on the surface, the drop can stick, rebound, spread, or splash, depending on the impact conditions. Different post-impingement behavior can be observed on the basis of non-dimensional thickness ($h* = h/d_{drop}$) of the liquid film. Deep pool conditions ($h* > 4$) is prevalent as the drop impact pushes the liquid due to effect of thrust. It results in formation of a liquid crater encircled by liquid rim. In case of thin liquid film ($0.1 < h* < 1$) i.e. film thickness is less than the drop diameter, droplet hits the liquid film and spreads out radially forming a crown-like fluid sheet in the direction normal to the liquid surface. This fluid film is unstable and produces many small secondary droplets while radially expanding outwards (Cossali *et al*., 1997; Yarin, 2006; Kim *et al*., 2020) [9, 46, 24]. N2 and N3 nozzle demonstrated thin film characterics in which water moved radially towards the walls and amount of non-surface water was low. N4 nozzle resulted in deep pool conditions resulting in more of splashing and rebound. Formation of water crater with liquid rim was more prominent than the radial movements of liquid film towards the milk can walls. It resulted in higher values of non-surface water in case of N4 nozzle.

3.6 Volumetric rate of surface water

Surface water volumetric rate increased significantly ($p < 0.05$) with increase in pump operating frequency (Fig 12:). Higher volume of surface water is desirable as it is related to wetted area of internal can surface and better rinsing. Wetting rate plays an important role in cleaning. Fuchs *et al.* (2015) [16] found that increasing the wetting rate leads to improved cleaning rate on a stainless steel surface. The maximum volumetric rate of surface water for N1, N2, N3 and N4 nozzles were 24604.16, 45395.83, 82750.1 and 131750.2 nm^3/s, respectively. It was determined as the sum total of individual volumetric rate of cylinders in the patternometer. Spray jet diffuses into the atmosphere due to mass and momentum transfer. Air is gradually entrapped with the progression of jet stream and the whole process helps to disperse the jet. For solid jet sparys, the outward stand-off distance is ~5D from the nozzle exit and the jet loses its cleaning capacity at ~26D (Gua *et al*, 2011) [18]. The internal diameter of the can bottom is 0.335 m on which the spray jet directly impinges and spreads out radially in all directions.

The study established that one solid jet nozzle is sufficient for internal cleaning of milk can instead of multiple nozzles fixed at different angles. It is also noteworthy to mention here that the milk cans are used for storage and transport of milk at ambient temperature or chilled milk < 10 ºC. In case of milk can cleaning there is no fouled layer as observed in case of heat exchangers. The can washing system has only to remove the film of milk adhering to the internal surface of milk can. Nozzles N2 (D = 3 mm), N3 (D = 4 mm) and N4 (D = 5 mm) were observed to create radial spread of jet upto the internal walls resulting in adequate cleaning of the walls. Such micromanipulation techniques have been found effective for application in CIP environment (Lui *et al*., 2007) [30]. The results followed the expected trends, indicating an increase in impact force and higher volumetric rate of surface water with an increase in either pump supply frequency or nozzle orifice diameter. The trend is due to the fact that the exit velocity of liquid is increased leading to a greater momentum for impact. Surface water in case of impinging jets is governed by principle of hydraulic jump. This phenomenon occurs, when a liquid jet impinges on a surface at right angle. Immediately after impact, the liquid flow is in radially outward direction. The height of the liquid film increases instantaneously at certain distance from the impinging point causing a circular hydraulic jump. The hydraulic jump is widely observed when the liquid radial momentum is counter balanced by the surface tension force (Kim *et al*., 2020) [24].

3.7 Pump discharge pressure

Pump discharge pressure at different operating frequency F15, F20, F25, F30, F35 and F40 were 19.61 - 29.42, 49.03 - 53.38, 88.26 - 98.06, 117.68 - 127.48, 144.64 - 156.9 kPa, respectively. A control valve in the discharge line is one of the most used control devices for a centrifugal constant-speed pump. This valve helps to manually regulate the pump discharge. Such a device works at the expense of pressure drop resulting in wastage of power and reduced pumping efficiency (Al-Khalifah and McMillan, 2001) [3]. VFD used in the present study enabled semi-automatic control of pump discharge pressure. Pump discharge pressure increased linearly with increase in VFD supply frequency. Frequency had significant ($p<0.05$) effect on pump discharge pressure. Increasing the pressure leads to better cleaning rate. Fuchs *et al*. (2015) [16] reported improvement in cleaning rate with increasing the pressure. If the spray atomizes the spray very efficiently, increase in pressure can lead to better atomization into finer droplets. But in case of solid stream nozzle as used in this study, increase in pump pressure will result in increased flow rate at higher. The impact force and projection will increase in line with pressure (SNP, 2020) [39]. Higher jet pressure will exert more mechanical impact force for cleaning of milk can.

3.8 Instantaneous power consumption

Type of nozzle had no significant effect on power consumption demonstrating no effect with change in nozzle orifice diameter. Power consumption significantly ($p<0.05$) increased with increase in VFD supply frequency. At present high capacity pumps (5-7.5 hp) are being used in straight through type can washing equipment. Results indicate that by reducing the number of nozzles and using solid stream of right orifice diameter pumping power requirement can be significantly reduced. Many centrifugal pump reliability problems are due to oversizing of pumps, which leads to highly restricted discharge valve operation. Improper selection may result to many complex issues like flowrates below the best efficiency point, poor efficiency and high discharge pressures which may not be the requirement of system operation. Development of control technology based on VFD enables to keep the pump operating at its best condition independent of process requirements during different CIP steps (Martins, 2008) [32].

In the present study, 1 hp capacity pump was found to give satisfactory cleaning of internal can surface and the findings were validated using test rig. Instantaneous power consumption (IPC) was minimum (0.07 kW) at 15 Hz and gradual increase was observed upto 40 Hz. IPC was maximum (0.55 kW) at 40 Hz. Performance improvement of the pumps leads to the reduction in power consumption of industrial pumping systems (Thakkar *et al*., 2021) [43]. By observing the trend of IPC, operating VFD frequency in range of 25 to 35 Hz can be recommended for optimum cleaning operation and lower power consumption. Results were in line with the study that established significant correlation between components of the electricity necessary to perform the cleaning process (Piepiórka-Stepuk *et al*., 2017) [34].

3.9 Optimization of spray performance

Multi response optimization enabled maximizing parameters like impact force and spray jet pressure. On the other hand simultaneously it minimizes parameters like nozzle flow rate and volumetric flow rate of surface water. The target for optimization of spray performance was to produce desired mechanical force with minimum consumption of resources. Desirability function value for different solutions suggested by the optimization software was in the range of 0.30 to 0.65 (Table 3). Solid stream nozzle N3 with 4 mm orifice diameter and 40 Hz pump supply frequency was found to yield optimum results with highest desirability score of 0.65. It was observed that nozzle sizes greater than optimal (D = 4 mm) will cause the mechanical forces to weaken and energy to dissipate ineffectively.

3.10 Standardization of CIP protocol

CIP was carried using the optimized resulted for spray performance *viz* N3 nozzle (D = 4 mm) and 40 Hz pump supply frequency. It was found that cleaning cycle time and NaOH solution concentration has significant effect (<0.05) on total plate count (TPC) of washed cans. Bacterial reduction was comparatively increasing with increasing the severity of cleaning conditions in terms of time, temperature and chemical concentration. Cleaning time was one of the important parameters and cleaning effect was studied for 10, 20 and 30 s. In nozzle cleaning process, reduction in total plate count is a function of time (Escudero-Gilete*et al*., 2004) [14]. Burfoot and Middelton (2009) [8] studied the effect of operating conditions of high pressure washing on the removal of biofilms from stainless steel surfaces and also concluded that microbial removal increases with cleaning time. Optimum cleaning parameters were: time = 30 s, NaOH solution concentration = 1 %, NaOH solution temperature = 70 ºC, hot water = 70 ºC (Table 4). Treatments E & F can be considered as fairly satisfactory whereas treatment I was found satisfactory in terms of sanitary condition (Fig 15:). Treatment E, F, H and I can be practically followed for milk can cleaning to fulfill the legal sanitary standards. It is recommended to adopt treatment I, keeping in mind the factor of safety even in the adverse conditions of milk receiving.

Conclusion

CIP test rig was found suitable for optimization of spray nozzle performance. The fabricated setup satisfactorily fulfils the purpose of test rig for optimizing can cleaning parameters. Using this test rig different parameters related to milk can cleaning can be varied and its effect on performance related parameters can be measured. It was established that solid stream nozzle having orifice diameter 4 mm is effective for surface wetting and internal cleaning of milk can. VFD based automatic control of pump discharge ensured accurate control of flow rate. It also helped to conserve electrical energy at lower and medium flow rates. Test rig served as a multi-purpose platform for spray performance measurement, optimization and standardization of CIP protocol. The results are helpful in design of various components of CIP system like tank volume, pump capacity, nozzle selection and automatic control unit.

References

1. Abdaljlel IA, Georgi AY, Shaker AH. Study the advantage of variable speed pumps economically in pumping water lines using genetic algorithms. Asso Arab Uni J Eng Sci. 2020;27(3):132-137.
2. Ahmad T, Aadil RM, Ahmed H, Rahman UU, Soares BC, Souza SL, Pimentel TC, Scudino H, Guimarães JT, Esmerino EA, Freitas MQ. Treatment and utilization of dairy industrial waste: A review. Trends Food Sci Technol. 2019;88:361-372.
3. Al-Khalifah M, McMillan GK. Control valve versus variable-speed drive for flow control. 2001. Available from: http://www.idc-online.com/technical_references/pdfs/electrical_engineering/Control%20valve%20versus%20variable.pdf (accessed 13 March 2021).
4. Amalanathan DP, Jaffer DSNM. Distribution channels of milk and the problems encountered by the members of primary dairy co-operatives in Pondicherry U.T. Eduved Glob Manag Res. 2015;2(1):14-19.
5. Anglani F, Barry J, Dekkers W. Development and validation of a stationary water-spray cleaning system for concentrated solar thermal (CST) reflectors. Sol Energy. 2017;155:574-583.
6. Bremer PJ, Fillery S, McQuillan AJ. Laboratory scale clean-in-place (CIP) studies on the effectiveness of different caustic and acid wash steps on the removal of dairy biofilms. Int J Food Microbiol. 2006;106(3):254-262.
7. Brown KJ, Kalata W, Schick RJ, Sami M, Maruszewski A, Parihar A. Impact study of a clean-in-place tank wash system. Proc ILASS-Americas 22nd Annual Conference on Liquid Atomization and Spray Systems; 2010; Cincinnati, United States.
8. Burfoot D, Middleton K. Effects of operating conditions of high pressure washing on the removal of

biofilms from stainless steel surfaces. J Food Eng. 2009;90(3):350-357.
9. Cossali GE, Coghe ALDO, Marengo M. The impact of a single drop on a wetted solid surface. Exp Fluids. 1997;22(6):463-472.
10. Durkee J. Cleaning times: Spray nozzles play critical role in aqueous, solvent cleaning machines. Met Finish. 2009;107(6):80-82.
11. Eide MH, Homleid JP, Mattsson B. Life cycle assessment (LCA) of cleaning-in-place processes in dairies. LWT Food Sci Technol. 2003;36(3):303-314.
12. Englezos V, Rantsiou K, Cravero F, Torchio F, Giacosa S, Segade SR, Gai G, Dogliani E, Gerbi V, Cocolin L, Rolle L. Minimizing the environmental impact of cleaning in winemaking industry by using ozone for cleaning-in-place (CIP) of wine bottling machine. J Clean Prod. 2019;233:582-589.
13. Escrig J, Woolley E, Rangappa S, Simeone A, Watson NJ. Clean-in-place monitoring of different food fouling materials using ultrasonic measurements. Food Control. 2019;104:358-366.
14. Escudero-Gilete ML, González-Miret ML, Heredia FJ. Multivariate study of the decontamination process as function of time, pressure and quantity of water used in washing stage after evisceration in poultry meat production. J Food Eng. 2005;69(2):245-251.
15. Fan M, Phinney DM, Heldman DR. The impact of clean-in-place parameters on rinse water effectiveness and efficiency. J Food Eng. 2018;222:276-283.
16. Fuchs E, Boye A, Murcek R, Majschak JP. An experimental comparison of film flow parameters and cleaning behaviour of falling liquid films for different tilt angles. Food Bioprod Process. 2015;93:318-326.
17. Fuchs E, Köhler H, Majschak JP. Measurement of the impact force and pressure of water jets under the influence of jet break-up. Chem Ing Tech. 2019;91(4):455-466.
18. Guha A, Barron RM, Balachandar R. An experimental and numerical study of water jet cleaning process. J Mater Process Technol. 2011;211(4):610-618.
19. Kang T, Qin Q, Yao X, Yu Q. Characteristics of splash formed by the impact of liquid jet on a thin liquid film. J Phys Conf Ser. 2020;IOP Publishing, UK. pp.032028-032029.
20. Kato H, Fujimoto H, Yamashina K. Operational improvement of main pumps for energy-saving in wastewater treatment plants. Water. 2019;11(12):2438.
21. Khafizov I, Gafforov K, Shuxrat M, Abdullo J. Energy saving when using a variable frequency drive in pump installations. J Crit Rev. 2020;7(12):99-102.
22. Khalid NI, Ab Aziz N, Nuraini AA, Taip FS, Anuar MS. Alkaline cleaning-in-place of pink guava puree fouling deposit using lab-scale cleaning test rig. Agric Agric Sci Procedia. 2014;2:280-288.
23. Khalid NI, Nordin N, Abdul Aziz N, Ab Aziz N, Taip FS, Anuar MS. Design of a test rig for cleaning studies and evaluation of laboratory-scale experiments using pink guava puree as a fouling deposit model. J Food Process Eng. 2015;38(6):583-593.
24. Kim H, Choi H, Kim D, Chung J, Kim H, Lee K. Experimental study on splash phenomena of liquid jet impinging on a vertical wall. Exp Therm Fluid Sci. 2020;116:110111.
25. Köhler H, Stoye H, Mauermann M, Majschak JP. Optimization approach for efficient cleaning with impinging jets—influence of nozzle diameter, pressure and nozzle distance. Proc Int Conf Heat Exchanger Fouling and Cleaning; 2013; Hungary. pp.421-428.
26. Köhler H, Stoye H, Mauermann M, Weyrauch T, Majschak JP. How to assess cleaning? Evaluating the cleaning performance of moving impinging jets. Food Bioprod Process. 2015;93:327-332.
27. Kosseva MR. Chemical engineering aspects of fruit wine production. In: Science and Technology of Fruit Wine Production. Academic Press; 2017. p.253-293.
28. Li G, Tang L, Zhang X, Dong J. A review of factors affecting the efficiency of clean-in-place procedures in closed processing systems. Energy. 2019;178:57-71.
29. Liu M, Ooka R, Choi W, Ikeda S. Experimental and numerical investigation of energy saving potential of centralized and decentralized pumping systems. Appl Energy. 2019;251:113359.
30. Liu W, Aziz NA, Zhang Z, Fryer PJ. Quantification of the cleaning of egg albumin deposits using micromanipulation and direct observation techniques. J Food Eng. 2007;78:217-224.
31. Lundberg J. Characterization of a medium velocity deluge nozzle for offshore installations. J Loss Prev Process Ind. 2021;104510.
32. Martins G. How to improve reliability in centrifugal pump systems through the automatic tuneup of pumps within their best operational condition. Proc 24th Int Pump Users Symposium; Texas A&M University, Turbomachinery Laboratories; 2008.
33. Nasr GG, Yule AJ, Burby M, Zekria M, Clarke J, Woodall D. Understanding the cleaning performance of high pressure sprays at long stand-off distances. Proc 22nd European Conf on Liquid Atomization and Spray Systems (ILASS); 2008; Italy.
34. Piepiórka-Stepuk J, Diakun J, Jakubowski M. The parameters of cleaning a CIP system affected energy consumption and cleaning efficiency of the plate heat exchanger. Chem Process Eng. 2017;38(1):111-120.
35. Piepiórka-Stepuk J, Diakun J, Mierzejewska S. Poly-optimization of cleaning conditions for pipe systems and plate heat exchangers contaminated with hot milk using the cleaning in place method. J Clean Prod. 2016;112:946-952.
36. Piepiórka-Stepuk J, Diakun J, Sterczyńska M, Jakubowski M, Kalak T. Mathematical modeling and analysis of the interaction of parameters in the clean-in-place procedure during the pre-rinsing stage. J Clean Prod. 2021;297:126484.
37. Rangi P, Minz PS, Deshmukh GP, Subramani P, Singh R. Application of image analysis technique to determine cleaning of ohmic heating system for milk. J Food Sci Technol. 2019;56(12):5405-5414.
38. Sivaramakrishnan AS, Abubaker H, Münsch M, Delgado A, Murcek R, Boye A. Experimental and numerical investigation of a nozzle at different operating conditions for a clean in place system. Proc Appl Math Mech. 2018;18(1):e201800248.
39. SNP. Guide to spray properties Part 5: Impact and reach. 2020. Available from: https://www.spray-nozzle.co.uk/home/resources/engineering-resources/guide-to-spray-properties/5--impact-and-reach (accessed 14 March 2021).

40. Stanchev P, Vasilaki V, Egas D, Colon J, Ponsá S, Katsou E. Multilevel environmental assessment of the anaerobic treatment of dairy processing effluents in the context of circular economy. J Clean Prod. 2020;261:121139.
41. Statease. Optimization module. 2021. Available from: https://www.statease.com/docs/v11/contents/optimization/optimization-overview/ (accessed 15 March 2021).
42. Sundberg M, Christiansson A, Lindahl C, Wahlund L, Birgersson C. Cleaning effectiveness of chlorine-free detergents for use on dairy farms. J Dairy Res. 2011;78(1):105.
43. Thakkar S, Vala H, Patel VK, Patel R. Performance improvement of the sanitary centrifugal pump through an integrated approach based on response surface methodology, multi-objective optimization and CFD. J Braz Soc Mech Sci. 2021;43(1):1-15.
44. Wang P, Han H, Liu R, Gao R, Wu G. Effect of outlet diameter on atomization characteristics and dust reduction performance of X-swirl pressure nozzle. Process Saf Environ. 2020;137:340-351.
45. Wang X, Puri VM, Demirci A, Graves RE. Mathematical modeling and cycle time reduction of deposit removal from stainless steel pipeline during cleaning-in-place of milking system with electrolyzed oxidizing water. J Food Eng. 2016;170:144-159.
46. Yarin AL. Drop impact dynamics: splashing, spreading, receding, bouncing. Annu Rev Fluid Mech. 2006;38:159-192.