Chapter 16
Designing of a Bulk Dishwasher for Water Conservation in Mega Kitchens

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Abstract Water shortage can be tackled by conserving water to the maximum extend. Efficient usage of water is therefore important in all applications. Dishwashing in mega kitchens results in water wastage as well as time-consuming. The aim of this project is to design a continuous flow bulk dishwasher employing image processing to identify the intensity of strain and control the quantity of water. It is executed by fixing water jets controlled by a controller which sprays programmed quantity of water on the plates on the conveyer belt and suitable angles of jet resulting in effective cleaning, and efficient usage of water as well as reducing human effort, in minimum lead time. If implemented, it will serve as a useful product for all mega kitchens serving large number of people.

Keywords Dishwasher · Bulk dishwasher · Mega kitchens · Continuous flow · Sustainable energy

16.1 Introduction

Water consumption for dishwashing in mega kitchens like buffets and parties is huge owing to the fact that most of them are hand-washed dishes. Hand washing involves more of an individual's time while the conventional dishwasher takes more time as a whole to wash dishes.

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Using heated water for sterilization [1–3] adds an additional hazard for the person. Hand washing plays an important role in small batches but becomes increasingly inefficient with the increment in batch size.

Mega kitchens have huge number of dishes to be washed in a minimum lead time which is a problem that cannot be addressed with hand washing.

Jenny et al. [4] compared the hand washing and dishwashing machines on basis of life cycle analysis and found that hand washing and dishwashing are similar along the dimensions of energy use and greenhouse gas (GHG) emissions but differ in the terms of intensity. It was also found out that hand washing uses more water than dishwashing the same dishes.

Therefore, a mechanism to continuously clean the dishes is proposed, thereby introducing the concept of continuous washing mechanism by the use of belt conveyer to reduce the lead time for washing.

Current designs in dishwasher [5–8] is a box type in which different chambers are provided for keeping dishes which are kept for prolonged duration for washing [9]. Although, these designs are suitable for home or low-scale applications. The required time for washing large number of dishes makes these dishwashers infeasible for mega kitchens.

Reusability of water is the main criterion selected here during the design. Adjustable nozzles and multiple detergent dispensers allowing effective circulation [10] of water are provided for human feedback. It will adjust and improve the quality of cleaning during various loading conditions.

A mechanism for usage of hot water is also proposed for the dual purpose of cleaning and sterilization [11–13]. The hot water used is heated through solar water heater, thereby reducing the conventional energy consumption and carbon footprint.

Energy consumptions for conventional dishwasher in comparison with hand washing was only 9000 J more [4], and the GHG emissions were low for dishwasher in comparison with dishwasher. Hence, dishwasher, specifically designed for bulk dishwashing, can result in significant water savings as well as can be green solution resulting in lesser GHG emissions at almost equivalent energy consumptions.

Different types of dishwashers both market ready and proposed [14] were also studied, and their energy and water requirements have been taken into consideration for the calculation purposes [15, 16].

16.2 Principle of Operation

Bulk dishwasher incorporates conveyer system rather than box type to decrease the lead time of operation. Bulk dishwasher consists of two washing chambers instead of one chamber partitioned into two compartments as in conventional chambers. The input hot water for dishwashing is preferred to be solar water heated so as to have minimum environmental impact.

Flow process is shown in Fig. 16.1. The unclean dishes enter into Chamber 1 and pass on to Chamber 2. Chamber 1 has a set of nozzles which sprinkle pressurized

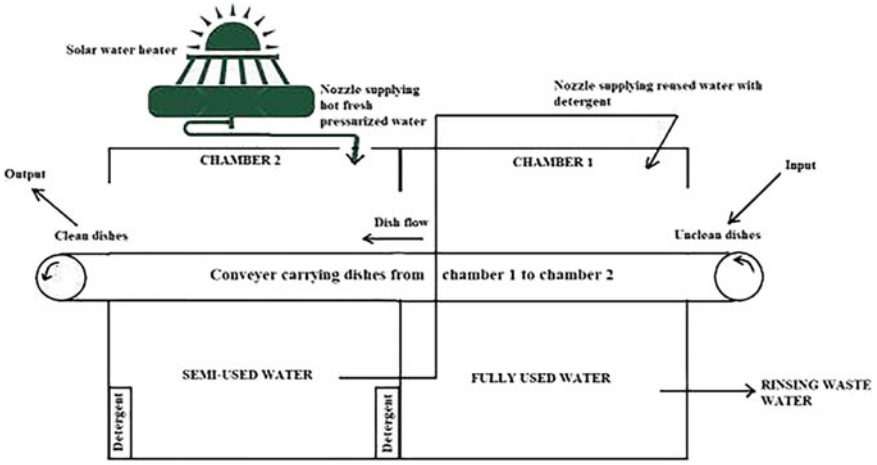

Fig. 16.1 Flow process of the bulk dishwasher

detergent water onto the dishes. This detergent water is supplied via a pump at the base of Chamber 2 which contains semi-used water which is obtained via post-washing of dishes. The used water from Chamber 1 flows down from the conveyer to the fully used water tank which is rinsed periodically.

Chamber 2 is for removal of all sorts of debris and detergent from the plates. Chamber 2 contains a set of nozzles which is fed by hot water from solar water heater or heat exchanger (as available). This water is fresh and is used for final cleaning and sterilization of the dishes. This water after cleaning flows into Chamber 1 tank and is called as semi-used water as it can be used for further cleaning.

Water in Chamber 2 is mixed with detergent available at the base. This is accomplished by using a semi-permeable membrane or a sieve to optimize the usage of detergent in the dishwasher. This semi-used water is fed into Chamber 1 for applying detergent. As the water collected in Chamber 2 is still hot than the normal water. This increases the total thermal efficiency of the dishwasher.

As water is being reused till maximum saturation, this decreases the water consumption and hence has lesser impact on environment.

Dish movement is continuous; hence, the dishes can be washed in minimum lead time without compromising cleaning quality.

16.3 Modelling of Bulk Dishwasher

The hydraulic circuit of the bulk dishwasher is shown in Fig. 16.2. There are two pumps and four nozzles and hose pipes provided for flexible motion of the nozzles. The reused water pump pumps the water from Chamber 2 base which contains semi-

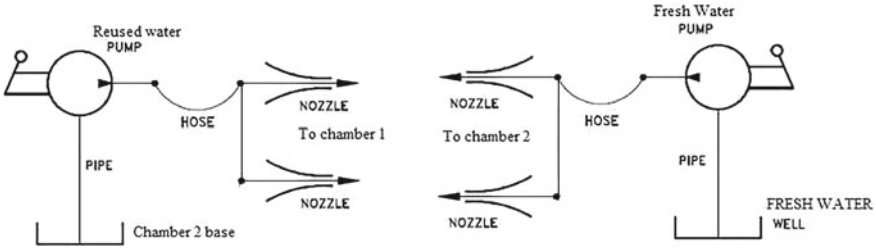

Fig. 16.2 Hydraulic circuit diagram

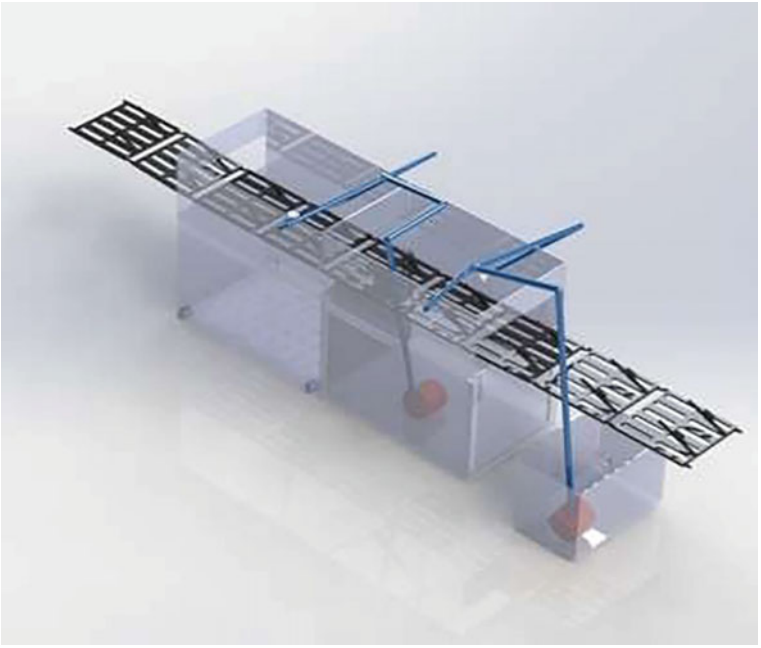

Fig. 16.3 Three-dimensional model of bulk dishwasher

used water (filled with detergent). This water is pumped to Chamber 1 where it is used for applying detergent and for pre-cleaning of dishes. The freshwater pump is used for pumping water from solar water heater source for final cleaning of the dishes via pumping the water to nozzles present in Chamber 2 (Fig. 16.3).

Initially, the dishes are placed on the moving conveyer belt marked with specific dish holders and major soiled plates are sponged off. Conveyer along with the dishes enters into the first chamber where water mixed with the detergent is sprayed on the plates with the help of two nozzles (one nozzle and one shower).

The pressurized detergent-mixed water serves the dual purpose of removing the lightly soiled stains and emulsifying the strongly soiled parts. The nozzles are kept adjustable so as to facilitate its orientation as per the need.

Two-nozzle arrangement is preferred over one nozzle because the shower arrangement shall cover more area of the plate and emulsifying majority of stains. The nozzle part shall deliver the water with high kinetic energy, thereby removing light stains and some freshly emulsified stains in the initial stage itself, thereby reducing the load in second stage.

After passing through the first chamber, the plates are moved to the second chamber. Here, the preheated water (through a solar heater arrangement) is drawn through a pump and sprayed on the plates with the help of two-nozzle arrangement (one nozzle and one shower), thereby removing the leftover stains. Using heated water (70–80 °C) in the process also sterilizes the plates, thereby eliminating the need for any post-processing operation other than drying.

The chief highlight of this method is water reusability as the water used in Chamber 2 (freshwater) for rinsing the plates is collected in the tank below and is concentrated with the detergent by using the immersed detergent containers equipped with semi-permeable membranes allowing the slow but steady mixing of detergent with water.

The concentrated water is then pumped to nozzles in first chamber with the help of a submersible pump of the required rating, thereby reusing the water and reducing the water consumption by a factor of 2.

Pumping the water from second chamber also ensures higher water temperature (>50 °C), thereby increasing the emulsifying capacity of concentrated detergent mixed water and also increasing de-soiling capacity of water at the given kinetic energy (Table 16.1).

16.4 Life Cycle Assessment (LCA) Study [17]

16.4.1 Goal and Scope

The goal of this study is to determine whether or not a bulk dishwashing machine is more efficient than hand washing for both energy and water consumption.

The analysis aims to see which method has a larger environmental impact as measured by carbon dioxide (CO_2). The scope of this life cycle assessment (LCA) is limited to the phase when the dishwasher is being used. The stages of manufacturing and disposing are not considered for this LCA study.

Table 16.1 Bulk dishwasher specifications

Parameter	Specifications
Conveyer speed	5 inch/s
Time to transverse (1 dish)	50 inch/5 inch per second = 10 s
Time in freshwater chamber	10/2 = 5 s
Nozzle output (for 1 unit)	0.15278 L/s
Total output (2 nozzles)	0.305 L/s
Total freshwater used (per dish)	0.305 l/s * 5 s = 1.5 L
Power used by one pump	18 W
Total power used by 2 pumps	36 W
Weight of conveyer	0.3 * 25 = 7.5 kg
Weight of standard SS plates	0.25 * 10 = 2.5 kg
Total load on conveyer motor	10 kg
Conveyer motor type	BLDC
Conveyer motor power	1 KW
Continuous motor torque	3 Nm
Motor peak torque	14 Nm
Motor operating voltage	48 V

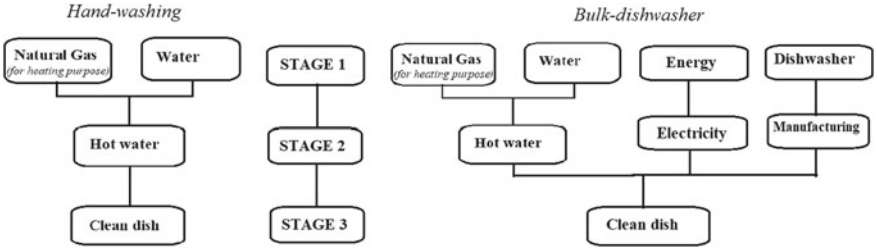

Fig. 16.4 Different stages of dishwashing

16.4.2 Function Unit of Analysis, Impact Categories, and System Boundary

Function units taken for analysis are the maximum dishes and cutlery which can be washed in dishwasher.

The impact categories that will be examined are CO_2 emissions, total water use and total energy use.

The system boundary includes stage 1 and stage 2 of washing. Soaps and sinks are excluded as inputs. (Natural Gas if applicable) (Fig. 16.4).

Table 16.2 Hand washing energy consumption data

Hand washing inputs (per dish)			
		Units	Base values
Phase1	Water	Water used (L)	1.18 (L)
Phase2	Water supply	Energy (J) to distribute water	8520
	Heated water	Natural gas (J) to heat water	99,161

16.4.3 Methodology

Water and energy consumption analysis of hand washing is referred from [4] and compared with theoretically calculated for the proposed bulk dishwasher. The formula used for energy calculation is Eq. 16.1:

$$Q = m \cdot c \cdot \Delta T \tag{16.1}$$

where Q is the heat consumed in the dishwashing process, m is the mass of water and c is the specific heat of water and Δ is the temperature loss/gain of water.

16.4.4 Lifecycle Inventory Analysis

Manual Hand Washing: The general trend in hand washing is to wash dishes with running water rather than using pool of water. The water used for dishwashing is heated from 15 to 35 °C in colder regions. Heating above 50 °C results in scaling which is undesirable [18]. As majorly, dishwashers are used in developed countries, unlike India. Hence, hand washing data from the US households is referred to [4]. Here, the underlying assumption is that water is not heated or heated via sustainable sources like solar water heater. Hence, energy consumption for both hand washing and bulk dishwasher is ignored as shown in Table 16.2.

The total energy consumed was 107.6 kJ for dishwashing dishes by hand washing. This will be compared by commercial and proposed bulk dishwasher.

Commercial dishwasher: This data was considered for older dishwashers with lesser efficiency because dishwashers have a lifetime of 15 years [19]. Dishwashers have become efficient over time [20], hence older dishwasher study reflects a more reasonable study.

Consumption study of commercial dishwashers [4] was done with various assumptions like the water heater was set to 50 °C as shown in Table 16.3.

The dishwashers use 9000 J more energy than hand washing owing to the fact of requirement of electricity for dishwasher operation.

Table 16.3 Commercial dishwasher consumption data

Commercial dishwasher inputs (per dish)			
Phase 1	Water used	Litres used	18.9 (L)
Phase 2	Heated water	Energy to heat water	2,767,716 (J)
	Water supply	Energy for distribution	1,340,000 (J)
	Manufacturing	Manufacturing energy	110.4 (J)

Table 16.4 Proposed Bulk dishwasher consumption data

Bulk dishwasher inputs (per dish)			
Phase 1	Water used	Litres used	1.5 (L)
Phase 2	Heated water	Energy to heat water	220,000 (J)
	Water supply	Energy for distribution	1,137,240 (J)
	Manufacturing	Manufacturing energy	Not available

Bulk dishwasher: Bulk dishwasher inputs were theoretically calculated as shown in Table 16.4. Water consumption per dish was calculated as 1.5 L (Table 16.1). Energy to heat water was calculated as 220,000 J which is considerably lower than commercial dishwashers. Water supply energy was found to be 15% less than the existing commercial dishwashers. Manufacturing energy consumption data is unavailable as the proposed dishwasher is currently in design phase.

Comparative analysis of LIA: The comparative analysis was done for energy consumption for heating water and supplying water for hand washing, commercial dishwasher and bulk dishwasher (Fig. 16.5). Heated water for both hand washing and bulk dishwasher is less due to the fact that bulk dishwasher derives its heated water from external sources like solar water heater. Water supply energy is comparatively lower for hand washing as compared to dishwashers. It was observed that bulk dishwasher used significant lesser water supply energy than commercial dishwashers.

In Table 16.5, Comparison of time consumption for dishwashing was done for hand washing, Commercial dishwasher and bulk dishwasher. The bulk dishwasher will use considerably less time to wash the dishes than hand washing and commercial dishwashers. The time taken by bulk dishwasher is 10 s which is 12 times faster than hand washing.

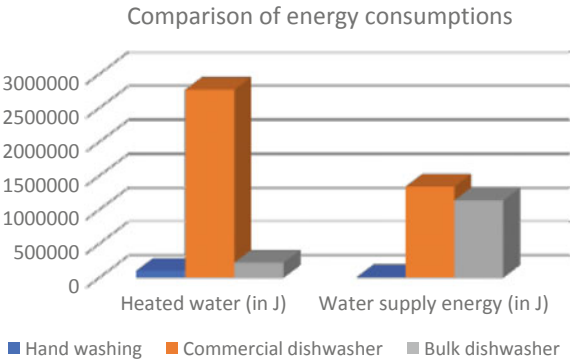

Fig. 16.5 Comparison of energy consumption of LIA

Table 16.5 Comparison of time consumption under various considerations (Hand washer Vs Dish washer Vs Bulk dish washer)

Water (L)	Per dish	Per loading (10)	Per day	Time per dish (s)
HW	1.18	11.8	94.4	120
DW	1.83	18.3	146.4	60
BDW	1.52	15.2	121.6	10

16.5 Conclusion

The idea for development of bulk dishwasher was pitched to us by ISKCON Trust due to the issue of overuse of water and time wastage in dishwashing during large religious feasts. The problem was solved by designing a belt-conveyer-based dishwasher which uses water twice, firstly for rinsing and secondly by collecting and concentrating the semi-used water with detergent and then using it again for initial rinsing of other plate and then finally discarding it, thereby reducing the water usage by a factor of 2.

The energy required for transporting the water has been reduced by approximately 15%. The water heating element in the dishwasher had been eliminated as it uses completely solar heated water, thereby considerably reducing the electrical energy usage.

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