Design and Implementation of Washing-Filling-Capping Machine for Small-Scale Reverse Osmosis Water Industry

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Abstract. This paper discusses the design and development of a semi-automated washing, filling and capping machine for 5-gallon bottle used by local reverse osmosis water (RO) refilling supplier. The problem facing by the local supplier is low production capability of RO water as the washing to capping processes were done manually, which were time and energy consuming. This manual procedure also caused back pain and fatigue to the staff. The objective is to design and develop a semi-automated machine (3-in-1 machine) which involves a washing-rinsing module to clean the external and internal of three 5-gallon-bottles simultaneously, a RO water filling module and a bottle capping module. The effluent of filtered RO water is collected and used as the source water for bottle washing-rinsing process. This helps to optimize the water usage. The results show that the productivity of supply has improved. The production per hour has increased by 52.3%. The production cost per unit of bottle has reduced by 28%. The new machine has successfully operated, improving the productivity and ergonomically designed to minimize physical discomfort to the staffs.

1.0 Introduction

In reverse osmosis (RO) water refilling and packaging industry, various types of machines are used to carry out the step by step process from cleaning to transporting the RO water bottled process. However, some variation in terms of machine is possible depending upon the type of container and operation mechanism used in the industry. Mainly, three parts of machines are used to complete the whole processes of refilling RO water in a bottle: washing machine, filling machine and capping machine. The bottle washer machine is a prominent module out of the bottle filling and packaging line, and it is used in the beginning of the processes. The bottle washer machine's functionality will differ depending on the type of container used [1].
Firs Tech Enterprise is one of the fast-growing companies in Terengganu, Malaysia that has been supplying bottled reverse osmosis (RO) water under their own brand; ‘Neutragize’. With fifteen years of experience, their core business has been focusing on providing reversed osmosis (RO) water to local customers such as Tenaga Nasional Berhad (TNB), Kerteh Terminal Sdn Bhd (KTSB), Universiti Malaysia Pahang (UMP) and residential areas near Dungun, Paka, Kemaman and Kuala Terengganu. The bottled water is packaged using a cylindrical-shaped five-gallon polycarbonate transparent container. In current practice, empty bottles are collected and replaced with filled bottles, which will go back and forth between the company’s refilling station and their customers.

In Firs Tech Enterprise, the existing washing process is 100% being done manually by an operator in an area of 3.0 m². However, before the washing process is executed, the collected bottles are required to undergo a screening or sorting process to segregate which bottle could be reused and which could be terminated due to excessive dirt or stain stick on the surface of the bottle. Sometimes, if the bottle no longer represents its original shape or look, i.e. an obvious dent or scratch on any part of the bottle including the cap, it can also be discarded in order to meet the customer’s satisfaction.

Figure 1 shows the flowchart of current practice of washing-filling-capping process.

During the washing process, the bottle is washed inside and out to prevent any contamination that can affect the quality of RO water. Currently, the process is manually performed whereby the operator must hold the bottle with one hand while the other hand is used to wash and rinse inside and out of the bottle. The clean-up process is done whereby the operator scrubbed the outer wall of the bottle using heavy duty sponge and liquid detergent to remove dirt, sand, grease or soil that stick on it. On the other hand, no liquid detergent is used while washing the inner bottle. An amount of running water is used to rinse the bottle inside out. Water is sprayed inside the bottle, and the bottle is shaken vigorously to let any slime detached from the inner part of the bottle. The residue is removed by positioning the bottle mouth in downwards position. The cleaned bottle is now ready to be refilled with RO water.

Currently, the refilling process is carried out using a handheld hose to convey the RO water from a RO water tank to the bottle. This practice is manually done in which the operator needs to open and close the hand valve to refill the RO water in the bottle which being placed on the floor. The bottle is then manually capped using a conventional capping tool and lifted by the operator to the stock area.

![Flowchart of current practice of washing-filling-capping process](image)

**Figure 1.** Flowchart of current practice of washing-filling-capping process
Based on the existing practices, the operators have suffered very much from lower back pain as they must complete the whole processes for approximately one hundred bottles daily using their limited energy. It is no doubt that the pain experienced has caused the employee discomfort. It has caused exhaustion among the operators thus reduced the company's efficiency.

To date, there is no standard bottle cleaning procedure existed in Malaysia. Each vendor practices his own cleaning method or process that they themselves considered as effective and easy to execute. However, it was learned that there are several industrial-scale bottle washer machines commercially available in the market. For instance, Norland International's BWF60 and Triton 450 machines are capable of cleaning three to five containers simultaneously and can also tolerate bottles or containers of distinct sizes [2]. In addition, the standard bottle washer machines used in the beverage industry on a big scale are much more complex in mechanical and control elements and expensive for the beverage industry on a small scale. The large-scale bottle washer machine has a capacity of 10,000 to 150,000 bottles per hour [3]. However, such machines are only suitable for large enterprise, space consuming and not suitable for small scale RO water enterprise.

Nonetheless, there were a few studies that have been conducted to design and develop innovated bottle washer machines for either big or small-scale drinking water industries which purposely custom-made for a specific producer. Fakriza et al. [4] has designed an improvised automated gallon washing machine to minimize musculoskeletal disorder (MSDs) in CV Barokah Abadi using ergonomic function deployment (EFD) approach. Patel et al. [5] has put an added value to a bottle washer machine by developing PLC based process loop control for the machine. In addition, Gajjar et al. [1] has successfully designed and developed a bottle washer machine for Returnable Glass Bottle (RGBs) using Creo Software, embedding it with PLC controller and programmed it with ladder diagram in the SIMATIC Manager. All innovated machines listed have resulted in significant improvements to their client’s factory productivity. Thus, this project aims to design and develop a modular, five-gallon cleaning machine that can be used in much smaller space aligned with Firstech Enterprise’s expectation which is to increase their productivity and serve ergonomically designed machine.

2.0 Research Methodology

The semi-automated machine comprises of three parts which are process part, electrical part and mechanical part. The design and improvising process are described in the next section. Further design is performed by adding ergonomic elements to the concept of design by considering the worker’s comfort, security and health. In applying ergonomics elements to the original idea of the entire method, existing working circumstances are also assessed as a reference [3]. In the hope of reducing the risk of back pain in employees, the addition of ergonomics elements is performed.

2.1 Process flow chart

Figure 2 shows an improvised flowchart of washing-filling-capping process that has been designed and implemented in Firstech Enterprise. Semi-automated washing machine has been developed to replace the previous manual washing process. The developed machine kept the bottle to rotate with the bottle mouth in a downward position during the cleaning process. It cleaned three empty bottles simultaneously whereby the exterior part of the bottles are scrubbed by heavy duty brush and foamed with liquid detergent. While for interior part, water is sprayed all over the inner wall by using the sprinkler nozzle. The rinsing process took place at the same time. The other processes; filling and capping were still being done manually but a few necessary instruments have been invented to ease these processes.
2.2 Electrical parts

The project uses four single-phase AC motors. Two of the motors were used to generate pressurized water up to 10 MPa to clean the inner surface of the bottle through a customized spray nozzle designed to remove stains and dirt. Another pressure washer is employed in a detergent injection mechanism to enhance the cleaning action for the outer surface of the bottle which usually tarnished with oil, sand and dirt. In order to optimize the cleaning action, the rotating mechanism is designed so that the bottle will rotate during the process. This is accomplished by placing another AC motor with gear mechanism to hold the bottle and rotate them simultaneously. The summary of the electrical parts used in the project is tabulated in Table 1.

Table 1. Electrical Components Used in The Proposed Machine

| No | Item                     | Quantity | Specification          |
|----|--------------------------|----------|------------------------|
| 1  | AC Motor                 | 1        | Bottle rotating mechanism |
| 2  | Centrifugal Pump         | 1        | Outer surface cleaning  |
| 3  | Pressure washer          | 1        | Inner surface cleaning  |
| 4  | Pressure washer          | 1        | Detergent injection mechanism |

Figure 3 illustrates an electromechanical relay logic diagram designed for the project. It consists of a master switch (Enable), to enable the whole system, a start push button (Start PB), a stop push button (Stop PB), a control relay (C1), a timer (TD1) and four motors (M1-M4). The machine can only be activated if the enable switch is in active position. When the start button (Start PB) is pressed, control relay coil, C1 will be energized and will activate all C1 contacts. As a result, TD1, M1, M2, M3 will be activated. When the desired operation time is achieved, TD1 contact will break the active connection to M1, M2 and M3 and will stop the washing operation. If the operator wishes to use detergent to enhance the cleaning process, a detergent switch is also provided and can be triggered at any moment during the operation. Besides, Stop PB can also be used if the operator wishes to stop
all operations even though the desired cleaning time has yet to be achieved. It will also serve as the emergency stop button shall any undesired event occurred during the operation.

![Electromechanical Relay Logic Diagram](image1)

**Figure 3.** An Electromechanical Relay Logic Diagram

### 2.3 Mechanical Parts

**Figure 4** illustrates the mechanical design of semi-automated washing machine. The module consists of three compartments to wash and rinse three bottles simultaneously. Every compartment uses the same washing and rinsing method. The bottle is placed in downward position and the moving holder that grips the bottle mouth will keep the bottles to rotate continuously when the cleaning process takes place. The static heavy-duty brushes used to scrub the bottles are placed in three positions; attached to the lid which used to wash the bottom part of the bottle, at the middle of the washer which used to scrub the middle part of each bottle, while the other one is located at the neck of the bottle. There is a sprinkler nozzle at every compartment that functions to spray inside of each bottle while it is rotating.

![Semi-automatic Washing Machine](image2)

**Figure 4.** Semi-automatic Washing Machine
Figure 5 illustrates the design of filling module in which the hand valves are opened and closed manually. Previously, the process is conducted handheld while the bottles are placed on the floor. Now, it is ergonomically performed on a bench to avoid uncomfortable posture hence any discomfort on the body of operators such that back pain.

![Figure 5. Filling Module](image)

Figure 5. Filling Module

Figure 6a shows the capping module which is handled manually using a fulcrum capper. The bottle is capped on a bench after being delivered by the rolling conveyor from filling module. Previously, the process is conducted on the floor whereby the operators manually pounded the cap onto the lid of the bottle using capping hammer. Figure 6b illustrates the design of a roller conveyer to convey filled bottles from filling module to capping module and stock area in sequence.

![Figure 6. (a) Capping Module (b) Roller conveyer](image)

Figure 6. (a) Capping Module (b) Roller conveyer
3.0 Result and Discussion

This chapter will discuss and analyse the results obtained from the project done in the previous chapter. The analysis of data is important to evaluate the success of the project. Table 2 shows several tests that have been conducted to evaluate the functionality of the washing machine parts. Most of the features on the machine demonstrated an operative function thus remarked as “Fully functional”. On the other hand, a few features which have shown unsatisfactory functions were further repaired to improve the operation.

Table 2. Functional Test on Washing Machine

| No. | Features            | Description                                                                 | Remarks                                    |
|-----|---------------------|-----------------------------------------------------------------------------|--------------------------------------------|
| 1.  | Start and Stop button | Machine starts to operate when start button is pressed and maintained on operating condition until stop button is pressed | Fully functional                           |
| 2.  | Wash timer          | Timer can be set within 1-30 minutes and will deactivate all operation when desired time is achieved | Fully functional. The time must be set depending on the level of dirtiness of the bottle |
| 3.  | Pressure washer     | Pressurized water is injected to clean the inner surface of the bottle       | The water pressure was unsatisfactory       |
| 4.  | Bottle rotation     | The bottles will rotate during the cleaning process                          | Some bottle fails to rotate during test due to uneven size of the bottle |
| 5.  | Detergent injector  | When the detergent switch is activated, detergent will be injected to the bottle | Fully functional                           |
| 6.  | Exterior sprayer    | Water will be sprayed to the outer surface of the bottle                     | Fully functional                           |
| 7.  | Lid safety switch   | If the machine lid is open, the machine will not operate                     | Fully functional                           |

Table 3 shows an estimated process cycle time took for to complete washing-filling-capping processes. The effluent of filtered RO water is initially collected and used as the source water for bottle washing-rinsing process. Three empty bottles have been washed and rinsed simultaneously in the washing machine which the set timer was 30 seconds. After the washing-rinsing process, the bottles were filled with RO water and being capped using capping instrument. Two filling nozzles and one capping instrument were located side by side in the process line. The capping instrument is connected to a long roller conveyer which used to transfer the refilled RO water to stock area. The estimated total cycle time to complete the whole processes is about 140 seconds.

Table 4 shows a summarization of productivity gain measurement before and after the project is executed. Based on the table, it shows that the production cost per bottle has decreased by 28.0% from RM0.25 per bottle to RM0.18 per bottle. The production per hour has increased by 52.3% from 19 bottles to 29 bottles. Regarding the customer’s satisfaction, the delivery accuracy has increased by 25% from 80% to 100%. Overall, the project has demonstrated improvement to the company’s productivity.
### Table 3. Estimated Process Cycle Time

| No. | Sub-process                                    | Process cycle time (s) |
|-----|-----------------------------------------------|------------------------|
| 1   | Open machine lid                              | 3                      |
| 2   | Fix the first bottle                          | 5                      |
| 3   | Fix the second bottle                         | 5                      |
| 4   | Fix the third bottle                          | 5                      |
| 5   | Close and lock machine lid                    | 2                      |
| 6   | Switch on enable button                       | 1                      |
| 7   | Press start button                            | 1                      |
| 8   | Cleaning process                               |                        |
|     | a. Rinsing                                    | 30                     |
|     | b. Detergent                                  |                        |
|     | c. Brushing and rotating                      |                        |
| 9   | Open machine lid                              | 3                      |
| 10  | Unload first bottle                           | 2                      |
| 11  | Unload second bottle                          | 2                      |
| 12  | Unload third bottle                           | 2                      |
|     | Estimated total cycle time for cleaning process for three bottles | 61                     |
| 13  | Fix the first bottle at the filling station   | 3                      |
| 14  | Fix the second bottle at the filling station  | 3                      |
| 15  | Press the fill start button                   | 1                      |
| 16  | Filling process                               | 60                     |
| 17  | Press the fill stop button                    | 1                      |
|     | Estimated total cycle time for filling process for two bottles | 68                     |
| 18  | Bottle transfer to capping station            | 4                      |
| 19  | Capping                                       | 2                      |
| 20  | Bottle transfer to pallet – stock area        | 5                      |
|     | Estimated total cycle time capping process for a bottle | 11                    |
|     | Estimated total cycle time to complete whole processes (seconds) | 140 seconds |

### Table 4. Productivity Gain Measurement

| Metric                                      | Before Project | After Project | Improvement % |
|---------------------------------------------|----------------|---------------|---------------|
| a. Revenue improvement                      |                |               |               |
| Total Sales (RM)                            | 6,309          | 9,800         | +35.6%        |
| Number of staff (pax)                       | 2              | 2             | -             |
| Production cost per bottle (RM)             | 0.25/bottle    | 0.18/bottle   | +28.0%        |
| b. Production/process cycle-time improvement|                |               |               |
| Process Simplification (No. of process)     | 3              | 3             | -             |
| Reject Rate (%)                             | 20%            | 10%           | +50.0%        |
| Average time to complete process (seconds/bottle) | 183 seconds/bottle | 123 seconds/bottle | +32.8%        |
| Production per hour (bottle)                | 19 bottles/hour| 29 bottles/hour| +52.3%        |
| c. Customer satisfaction                    |                |               |               |
| Number of complaints received within the measurement period | 0             | 0             | -             |
| Accurate Delivery (%)                       | 80%            | 100%          | +25.0%        |
4.0 Conclusion

The main points concluded from this research work can be summarized as follows:

1. The semi-automated of washing-filling-capping machine for Firstech Enterprise has successfully designed and implemented.
2. The total sales of Firstech has increased as much as 35.6% after the implementation of the new machines in the refilling station.
3. The production cost per bottle has decreased by 28.0% which from RM0.25 per bottle to RM0.18 per bottle.
4. This existing of new washing-filling-capping module in Firstech Enterprise has increased the productivity of RO water bottle by 52.3% which from 19 bottles per hour to 29 bottles per hour.
5. The new machine has been designed ergonomically for operator’s comfort and safety.

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