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Improving Productivity of Industrial Soda-Filling Machine using PLC Programming

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Abstract

Soft drinks are in demand because of their sparkling property and refreshing taste. An industrial soda-filling machine is used to fill soda bottles with carbonated solution at certain pressures. This study investigated the soda-filling cycle of an industrial filling machine to improve its productivity and the taste and quality of soft drinks. A programmable logic controller was used to control the different processes of a soda-filling cycle. Different filling pressures of carbonated solution were considered to examine their effects on the productivity of the machine and the taste and quality of the soft drinks. The effects of the different filling pressures on the mean, cumulative, and cycle times in different production cycles were estimated. Filling the soda bottles with carbonated solution at low pressure resulted in an improved productive cycle.

Keywords:

Filling machine, programmable logic controller (PLC), filling pressure

INTRODUCTION

The global soft drink market has grown rapidly in recent decades because of the dramatically increasing demand for soda. Carbonation, which is employed to prepare soda for carbonated drinks, involves dissolving compressed CO_2 in water. CO_2 is not readily soluble in liquids at normal pressure; therefore, it is subjected to high pressure to be dissolved in water. CO_2 reacts with water during carbonation to produce carbonic acid (H_2CO_3), which reduces the pH of carbonated solution [1]. A pH of 3.7 is generally recommended for water solution at atmospheric pressure to produce good-quality carbonated drinks [2].

An industrial soda-filling machine is then used to fill the bottles of various soft drinks with the prepared carbonated soda. The soda-filling cycle of an industrial filling machine generally consists of three major processes, namely, pressing, depressurizing, and releasing [2]. The soda-filling cycle is carried out under atmospheric pressure conditions. During pressing, the carbonated soda solution is introduced into the soda bottle through a nozzle. Pressing forms small bubbles of CO_2 inside the soda bottles. The drastic difference in the air pressures inside and outside of the bottle induces the soda solution to escape from the soda bottle. Depressurizing is executed to release the excess pressure from the soda bottle; without this process, the soda solution can effervesce and overflow. Then, an appropriate time is allotted to reduce the gas bubbles and excess gas in the soda bottle. This process is termed as releasing. These three processes control the soda-filling cycle because they affect the quality and preservation conditions of soda beverages [3].

This study investigated the soda-filling cycle of an industrial filling machine to improve the productivity of the filling machine and the quality of carbonated soda. Programmable logic controller (PLC) programming was used to control the different processes in a soda-filling cycle. The soda-filling processes (i.e., pressing, depressurizing, and releasing) were defined as time-dependent quantities whose time values were controlled by PLC programming [4] [5] [6]. Different filling pressures of the carbonated soda solution were considered to observe their effects on the processes of soda-filling cycle and the taste and quality of soft drinks. The effects of different filling pressures on the mean, cumulative, and cycle times of the different filling processes were investigated in different production cycles to improve productivity of filling machine.

FILLING APPARATUS AND SETUP

Figure 1 shows a prototype of a soda-filling machine that simultaneously can fill two 750 mL soda bottles. A PLC module is connected to the soda-filling machine to control and optimize the filling cycle [7]. A pressure tank containing the soda solution is located at the top of the filling machine. The pressure of the soda solution in the tank can be regulated to observe the effect of pressure on the processes of soda-filling cycle and the taste and quality of soft drinks. Figure 2 presents a schematic of the industrial filling machine operating with

PLC. A complete soda-filling cycle consists of the following processes: bottle insertion, pressing, depressurizing, releasing, and bottle ejection [8].

Figure 1. Prototype of industrial soda-filling machine.

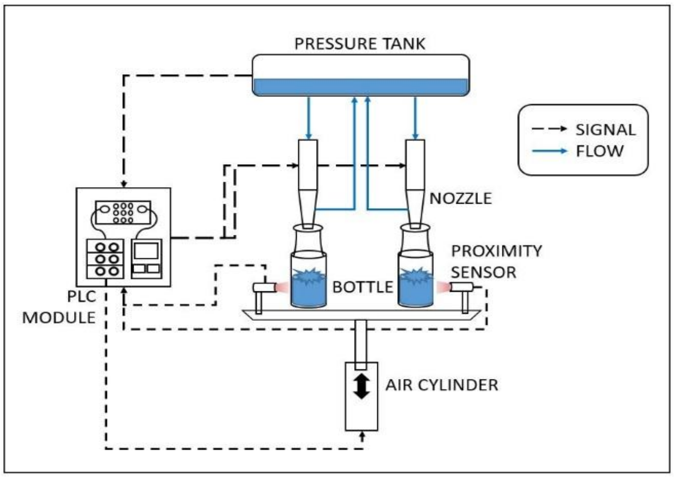

Figure 2. Schematic of the filling machine operating with PLC.

The industrial soda-filling machine consists of four main components, namely, a pressure tank, two nozzles, a lifting mechanism, and a PLC module (Figure 2). The black dashed lines in Figure 2 show the PLC signals to the components of the filling machine, and blue solid lines show the flow of the carbonated soda solution. The pressure of the carbonated soda solution in the tank is regulated by the PLC module. Two nozzles are employed to fill out the bottles with the carbonated soda solution. The filling nozzles are designed with a series of paths for releasing the extra pressure during depressurizing. This design prevents the soda from fizzing out of the bottle. The nozzle paths must be closed when soda is injected into the bottles (pressing) and open during depressurizing. The timing of the opening and that of the closing of the nozzle paths are controlled by PLC programming to ensure efficiency in a filling cycle. The switching time of the opening and closing of nozzle by the PLC module is approximately 0.1 s.

An air-based hydraulic cylinder is used to enable the unidirectional (up or down) movement to the lifting mechanism. This configuration is necessary for bottle insertion and ejection. The movement of the lifting mechanism is controlled by PLC programming. Pressing must be finished when the soda volume in the bottle reaches 750 mL. Therefore, several proximity sensors are used to detect and ensure the required level of soda in the bottle. The proximity sensor sends a signal to the PLC module when the bottle is filled with soda. The PLC module then closes the nozzle valve, and the bottle is then ejected from the filling machine through the lifting mechanism.

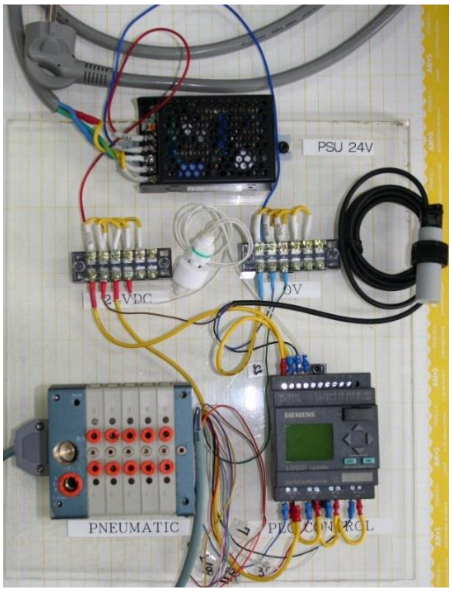

Figure 3. PLC module of the soda-filling machine.

Figure 3 shows a detailed picture of the PLC module of the industrial soda-filling machine. The PLC module is divided into different parts according to their functions: a PLC controller for generating electric signals, a pneumatic device for controlling the opening and closing of the valve switches (i.e., pressure tank, nozzles, and lifting mechanism), and DC power supply for providing electricity to each device. Two filling pressures of carbonated solution (i.e., 1.8 and 2.3 atm) were considered in this study to examine their effects on the productivity of machine and taste and quality of the soft drinks.

RESULTS AND DISCUSSION

Table 1 presents the effects of the two different filling pressures of carbonated solution on the various processes in a soda-filling cycle. The mean time required to complete each process in a single soda-filling cycle was computed, and the computed results were compared to examine the effects of different filling pressures (Table 1).

Table 1. Mean time (s) for the different soda-filling processes

Condition (atm)	Pressing time (s)	Depressurizing time (s)	Releasing time (s)	Total time (s/cycle)
1.8	13.5	11.7	8.7	26.2
2.3	12.6	9.8	9.5	24.8

The pressing time decreases with an increase in the filling pressure from 1.8 to 2.3 atm. High filling pressure expedited the filling of the soda bottles and consequently reduced the pressing time [8]. The soda solution tried to escape immediately from the soda bottle at a filling pressure of 2.3 atm. Therefore, the excess pressure was removed in a shorter time than that at a filling pressure of 1.8 atm, consequently decreasing the depressurizing time by approximately 2 s. The high filling pressure (2.3 atm) formed a large amount of gas bubbles in the soda bottle. Therefore, extra time was consumed to release the bubbles and residue gas from the carbonated solution filled at a pressure of 2.3 atm [9]. The total mean time required to complete a soda-filling cycle at 2.3 atm filling pressure is shorter than that at 1.8 atm filling pressure. These results suggest that a soda-filling cycle was completed in less time when the carbonated solution was injected in a bottle at a filling pressure of 2.3 atm [9].

The cumulative times of different filling processes with various filling pressures of carbonated solution were also computed and presented in Figure 4.

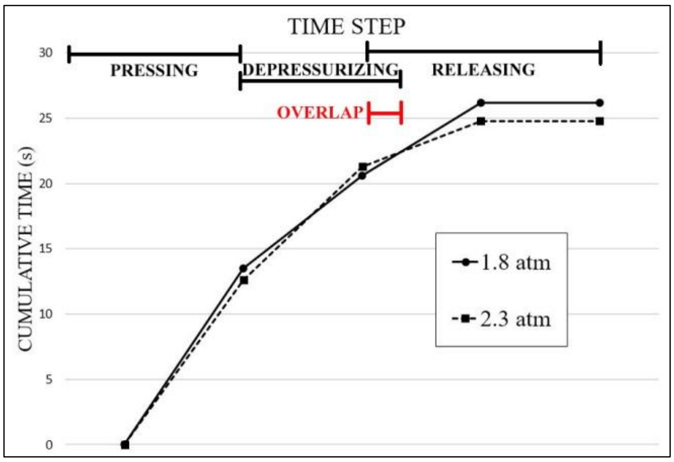

Figure 4. Cumulative time (s) graph for the different soda-filling processes.

The cumulative pressing time was longer when the carbonated solution was filled at 1.8 atm than that at 2.3 atm. The soda solution tried to fizz out from soda bottle at a filling pressure of 2.3 atm because of the considerable formation of gas bubbles and residue gas. Consequently, a longer time was required to settle the soda level in the bottle by reducing the gas bubbles and residue gas. Therefore, depressurizing and releasing overlapped. The overlap time is the time consumed to settle the soda level in the bottle. The overlap time was slightly longer when the filling pressure was 2.3 atm. The cumulative releasing time for 2.3 atm filling pressure was likewise long because of the formation of more gas bubbles [9]. These results imply that the total filling cycle time was reduced when the filling pressure of the carbonated solution was 2.3 atm. However, the quality and taste of soft drinks were unaffected by an increase in the filling pressure.

Figure 5 shows the effects of different filling pressures of carbonated solution on the cumulative and cycle times in different production cycles. The cumulative and cycle times were computed for 30 production cycles to examine the effect of filling pressure on soda productivity further. The cumulative time for 30 production cycles was approximately 5.4% shorter when the carbonated solution was filled at a pressure of 2.3 atm than that at a pressure of 1.8 atm. However, more irregular fluctuations in the cycle time occurred at a filling pressure of 2.3 atm. The irregular fluctuations in the cycle time were caused by the formation of a large number of gas bubbles in the soda solution [9]. Therefore, a longer releasing time was required to reduce the gas bubbles for the carbonated solution filled at a pressure of 2.3 atm than that at a pressure of 1.8 atm. These irregular fluctuations also affected the productivity cycle. The cycle time was comparatively smoother for the carbonated solution filled at 1.8 atm. Moreover, no change occurred in the quality and taste of the soda by changing the filling pressures of the carbonated solution. Therefore, the productivity of the soda-filling cycle is better when the filling pressure is 1.8 atm because of the less variation in the cycle time.

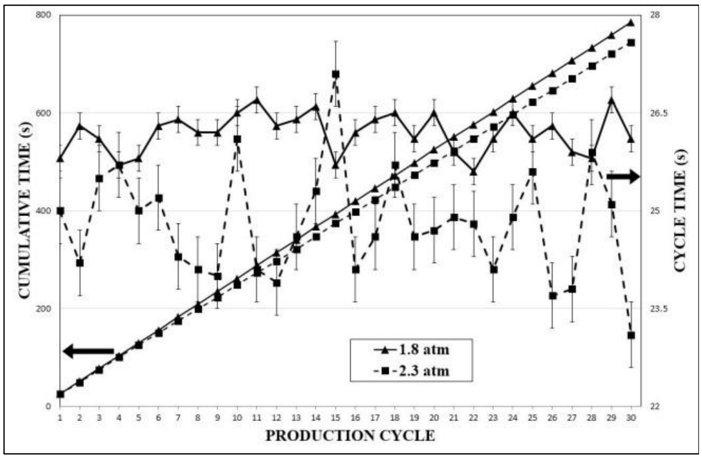

Figure 5. Cumulative time (s) and cycle time (s) in different production cycles for different filling pressures (atm).

CONCLUSION

The present study investigated the soda-filling cycle of an industrial filling machine. PLC programming was used to control the different processes in a soda-filling cycle. The productivity of the machine and the taste and quality of soft drinks were observed at different filling pressures of the carbonated solution. The mean, cumulative, and cycle times in different production cycles were computed for different filling pressures. An increase in the filling pressure of the carbonated solution also increased the pressing time. Filling the bottle with carbonated solution at high pressure formed more gas bubble; consequently, the soda was induced to fizz out of the bottle. Therefore, the releasing time was increased, and depressurizing and releasing overlapped. Large irregular fluctuations in the cycle time were found when the filling pressure was 2.3 atm. Increasing the filling pressure of the carbonated solution does not affect the taste of soft drinks. Thus, the productivity of the soda-filling machine can be improved by applying a lower filling pressure (i.e., 1.8 atm).

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