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Corrective Maintenance for Energy Efficiency: A Case Study in a Mineral Water Bottle Production Area

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***Abstract* - Energy efficiency is an effort made with the aim of reducing the amount of energy needed when using equipment or even an energy-related system. Energy efficiency can be achieved by adopting more efficient technologies or production processes. A good maintenance strategy will maximize production efficiency and play an important role in the sustainability of production operations. This study aims to analyze the relationship between energy efficiency and corrective maintenance carried out in the production areas of mineral water companies. The implementation of corrective maintenance is applied to the gallon/bottle washer machine, which is the main equipment in the bottled mineral water production process. Implementation of corrective maintenance is carried out using the Plan, Do, Check, Act (PDCA) cycle for continuous improvement. The results showed that energy consumption decreased after several corrective maintenance tasks were carried out on the washer machine. The energy efficiency obtained is 42.13 kWh/1000 bottles of production, or equivalent to a decrease of 7.2%.**

Keywords: energy efficiency, corrective maintenance, mineral water bottle, PDCA.

I. INTRODUCTION

The manufacturing sector is one of the sectors with the highest energy consumption [1]. Manufacturing companies consume more than half of the world's energy needs, increasing energy demand [2]. Energy demand is getting higher but cannot be matched by sufficient energy supply, and energy production costs are becoming increasingly expensive, encouraging companies to implement energy efficiency. Energy efficiency itself can have a positive impact on companies, both from an economic and environmental perspective [3].

In the manufacturing industry, energy is used in various production processes, such as machinery, transportation equipment, heating and cooling systems, and lighting. Energy sources used in the manufacturing industry can vary, including fossil energy sources such as oil, gas, and coal, as well as renewable energy sources.

The high energy consumption in the industrial sector, which also means increased energy costs, spurred companies to be able to improve their energy efficiency performance [4]. Efficient use of energy is becoming increasingly important in the manufacturing industry to reduce costs and carbon emissions, as well as to comply with energy and environmental-related policies and regulations.

In the manufacturing industry, optimization and energy efficiency can be achieved by several means such as continuous improvement, innovation, or maintenance. Maintenance activities are crucial in all manufacturing system components. This is closely related to aspects such as productivity improvement, quality, and overall operational cost savings including energy [5]. Maintenance is correlated to energy performance. The right maintenance strategy is necessary to achieve optimal energy performance, while energy consumption data is needed for good maintenance management [6].

If the condition of the equipment is known in real terms both when it is functioning well and when it is not, an effective maintenance strategy can be developed. The primary factor that led to the machine's damage or lower performance must be clearly identified and well-defined. Root Cause Analysis (RCA) is a technique that can be used to investigate the primary issues in industrial machinery or facilities that can lead to high energy consumption. RCA is a methodical analysis procedure that looks at an issue from its root cause in order to identify the source [7]. The goal of root cause analysis is to identify the variables that lead to performance problems. The RCA process is used to analyze a problem's performance from the root cause through at least five layers, in order to identify the primary reason and indicate whether or not it needs to be fixed.

The Deming cycle can be implemented as a follow-up to previous RCA activities. The Deming cycle is a strategy that allows the maintenance and improvement of proposed solutions [8, 9]. Development takes place in four processes plan, do, think and act. This tool is used in various TPM proposals to maximize results and create continuous improvement cycles [10,11].

The Deming cycle, on the other hand, is a technique for developing processes and logic programs for the continuousimprovement of various types of industries and machines [12,13]. The application period depends on the size of the company and the degree of standardization of the process. However, in SMEs he sees results after more than 6 months and up to 1 year [14,15].

PDCA can increase the availability of the machine to a higher level than applying TPM and 5S alone, so enhancing this technique enables him to achieve 4% higher availability than before [8,10]. The Deming cycle is advisable to include in the new maintenance models. As a result, a new organizational culture is achieved in both the operator and management areas, which should be measured using indicators that check whether his PDCA is being carried out correctly [15,16].

The company seeks to set a standard baseline for energy consumption as a reference for energy efficiency performance targets internally. This is also applied to a mineral water company in Indonesia. The company's energy consumption data for 2022 shows that its energy consumption target will always exceed the set baseline, especially in gallon or large bottle production areas. The swelling of operational costs, especially energy costs, is unavoidable. Production line data and energy consumption baselines at the company are presented in Table 1.

Table 1: Energy Consumption Data (kWh/1000 Bottles)

Line	Energy Consumption Target (kwh/1000 bottles)	Energy Consumption January-August (kwh/100 bottles)							
		1	2	3	4	5	6	7	8
Cap Snap	155,19	169,0	171,0	167,3	160,2	162,4	163,7	163,2	159,2
Bardi	116,41	132,2	130,6	134,3	114,1	128,7	122,1	116,6	122,5
Neptune	277,49	263,0	255,2	298,8	246,5	288,5	268,8	268,0	269,2

Therefore, in order to improve the company's energy efficiency, especially in the large bottle production area, corrective maintenance was implemented in the gallon/large bottle washer machine area. This was done especially after it was found that most of the waste that occurred was found in gallon washer machines.

II. METHODOLOGY

This research was conducted in the gallon production area, especially on the gallon washer machine. The Figure 1 is a schematic diagram of the gallon production process. The implementation of corrective maintenance is widely carried out, especially in the washing stage. At this stage there are many leakages which result in energy waste. However, it is alsopossible that leakage may occur in other stages of the gallon production process.

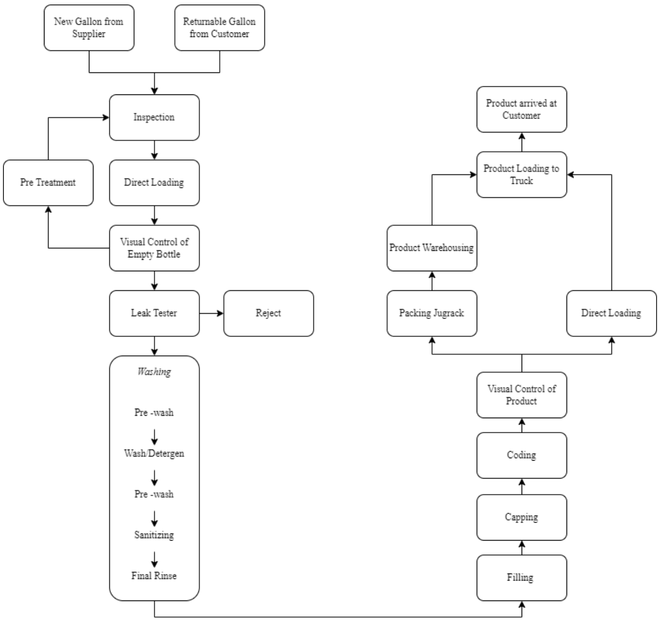


Figure 1: Schematic Diagram of Gallon Bottled Mineral Water Production Process

The main causes of energy waste will be studied using the root cause analysis method. Root cause analysis (RCA) is an analytical method used to determine the main cause of a problem, which is the root of the problem [17]. After finding the root cause of the waste, a series of plans are carried out to solve the problem. At this stage, the plan, do, check, and act method is used, as shown in Figure 2.

Figure 2: Cycle of Plan, Do, Check, Act for Continuous Improvement

In the "plan" stage, planning will be carried out on what to do after the causes of energy waste have been identified. At this stage, a plan will be drawn up to increase the efficiency of energy use in the gallon or large bottle production area. Then the "do" stage is the implementation stage of what was planned at the "plan" stage. Then the next stage is followed by "check", which at this stage is a controlling activity on the implementation of planning at the "plan" stage that has been carried out at the "do" stage. If the results of the "check" process show that the implementation or "do" activity from planning to the "plan" activity does not have any effect, then the planning is carried out again from the beginning or returns to the "plan" activity. If the results of the "check" process on the "do" activity show results that have a good effect on efficiency, then the next step goes to the "act" activity, where the "do" activity will be implemented as a routine activity pattern or an activity pattern that will be standardized in its implementation. Then this cycle ends with the "act" stage, which at this stage is a process of standardizing the implementation of "do" activities that have succeeded in reducing wasted energy consumption.

III. RESULT AND DISCUSSION

3.1 RCA Analysis on Equipment with the Biggest Energy Consumption in the Production Line

Root cause analysis is carried out by mapping five (5) pieces of equipment on each production line that have the highest level of energy consumption. The mineral water company has three (3) production lines, which refers to the existence of three (3) gallon/large bottle washer machines, namely the CapSnap line, Bardi line, and Neptune line. The data for three (3) production lines shows that the equipment that consumes the most energy is the heater in the washer machine for each production line. Figures 3 to 5 show a Pareto diagram of the most consumptive equipment or part mapping on each gallon or large bottle production line where mineral water is produced.

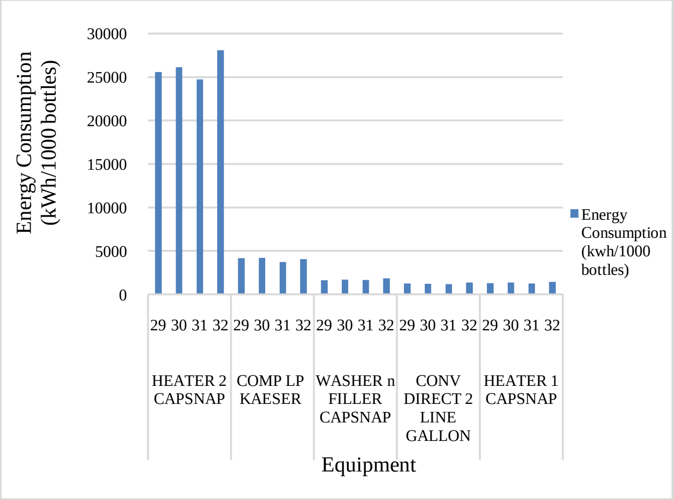


Figure 1: Most Consumptive Area on the CapSnap Line

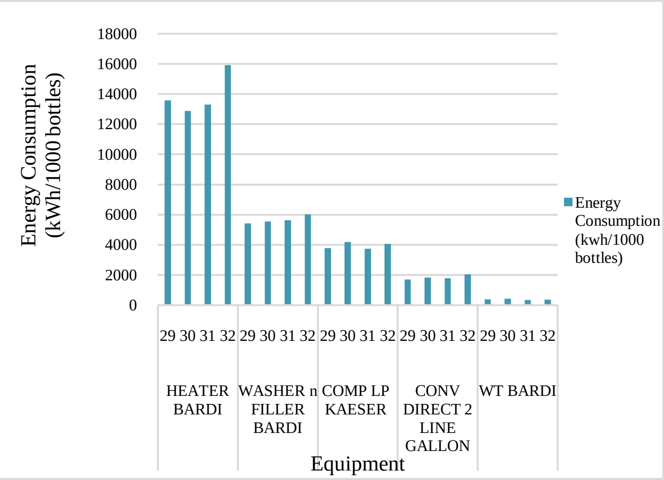


Figure 2: Most Consumptive Area on the Bardi Line

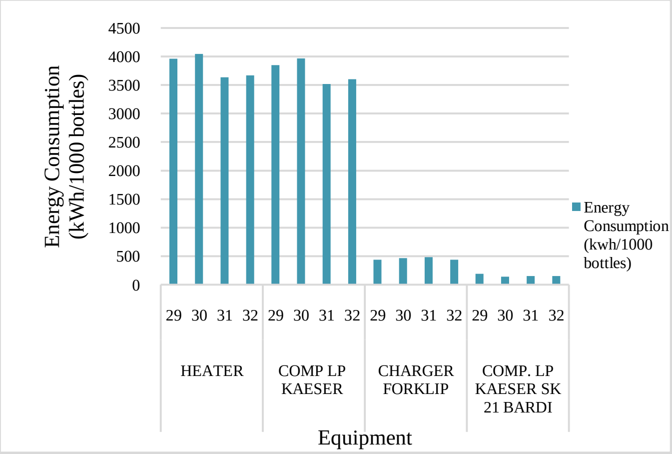


Figure 3: Most Consumptive Area On The Neptune Line

The identification results in the field show that the cause of the high energy consumption in the heater is due to splashing and leakage in the washer machine as shown in Table 2. Splashing occurs in the washer area, especially at the nozzle that sprays towards large gallons of bottles, as happened in the washer machine in the Neptune line. The reason is that there is a leak in the valve area, which causes the sprayer at the final rinse stage not to stop during the transition for changing gallons or large bottles. This causes splashing, which results in water that should return to the final rinse stage reservoir falling into the disinfectant tub, which causes the sensor to read this as an activity of adding water so that it triggers the heater to reheat the water. This is what causes the energy consumption of heaters to always increase.

3.2 Corrective Maintenance for Energy Efficiency

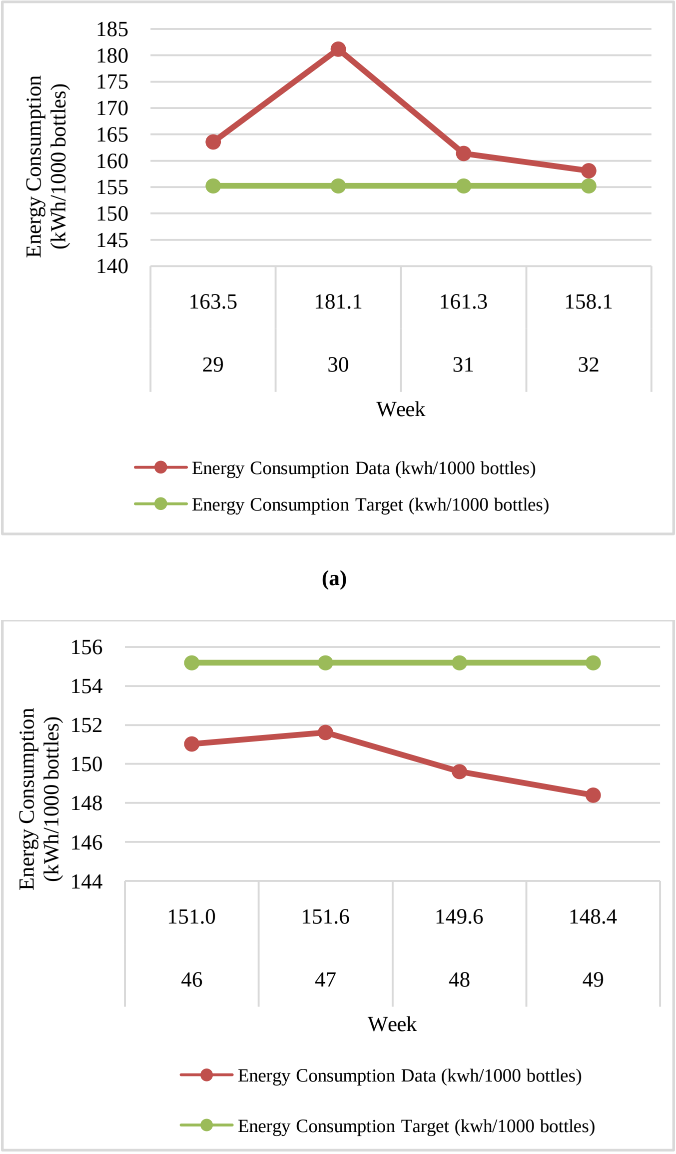
The results of the RCA analysis are then used as input for preparing an improvement plan to restore equipment performance in the production area and improve it again, as well as increase the level of energy efficiency in the production area. Planning for the implementation of corrective maintenance to repair the damage that occurs in the production area is then arranged. Corrective maintenance was chosen because it doesn't cost that much and also because the time available is quite small. Table 2 shows a list of corrective maintenance items in the production area as a result of the RCA study, which was carried out over a period of approximately five months.

Table 1: List of Corrective Maintenance Performed

No	Area	*Category*	*Case*	*Action*	Status
1	Conveyor Direct Loading 2	Oil	Oil Leakage	Replacement of Hydraulic Seals	Close
2	Leak tester CapSnap	Air	Cylinder Pusher Unit Leakage	Replacement of *cylinder pusher*	Close
3	Water Treatment CapSnap	Water	Water supply pump motor to filler is leaking	Replacement of seal mechanic	Close
4	Washer Neptune	Water	Disinfectant's Actuator valve is leaking	Replacement of disinfectant *actuator valve*	Close
5	Washer Neptune	Air	Washer Cylinder unloadray is leaking	Replacement of washer unloadray	Close
6	Washer Neptune	Air	Washer Cylinder kicker is leaking	Replacement of washer Cylinder kicker	Close
7	Filler Neptune	Air	The pneumatic hose on the filler unit is leaking	Connecting hoses with shock neeple	Close
8	Filler Neptune	Air	Cylinder neck filling unit is leaking	Replacement of seal cylinder neck filling unit	Close
9	Washer Neptune	Water	The sprayer is still spraying (should be off) because the valve has not fully closed	Replacement of valve	Close
10	Washer Neptune	Water	Prewash Seal valve butterfly prewash is leaking	Replacement of butterfly valve seal	Close

3.3 Analysis of Energy Consumption Data on Each Line Production after Corrective Maintenance Application

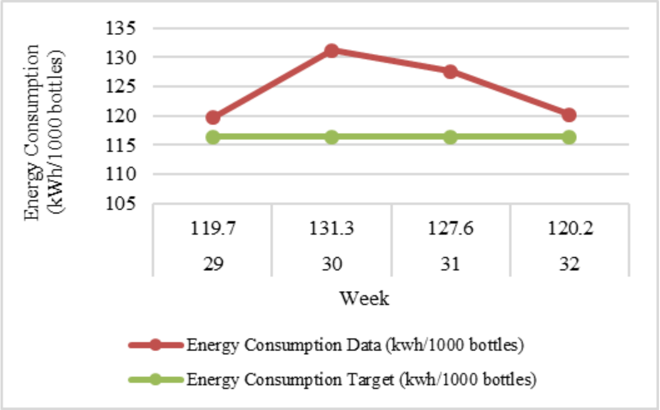
The corrective maintenance planning process and its implementation have been carried out, which means that the "plan" and "do" processes have been carried out. The next stage is the "Check" process, namely the stage to monitor the extent to which the implementation of the corrective maintenance process has been implemented. This "check" or monitoring process is carried out by monitoring the level of energy consumption every week. The monitoring result data after the implementation of the corrective maintenance process is then compared with the energy consumption level data before the implementation of the corrective maintenance. The data being compared is data two months before the implementation is carried out and two months after the implementation is carried out, with production conditions running smoothly and relatively the same. Data from the "check" process, namely comparative data on energy consumption levels on the three production lines, for conditions before and after the implementation of corrective maintenance, are shown in Figure 6 to Figure 8.



(a)

(b)

Figure 4: Energy Consumption Trend in CapSnap Production Line Before Corrective Maintenance Implementation (a) and After Corrective Maintenance Implementation (b)



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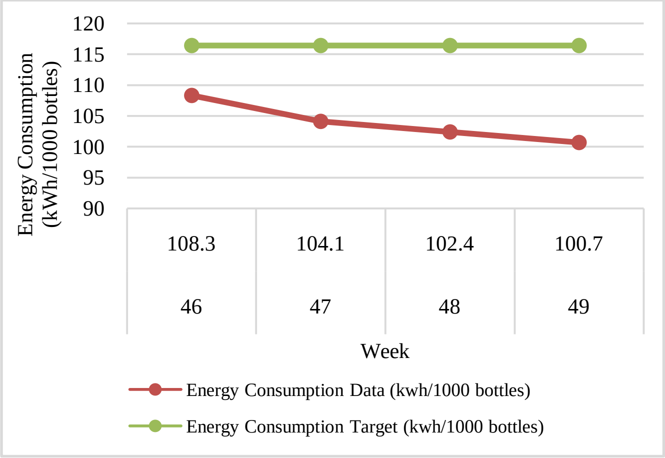
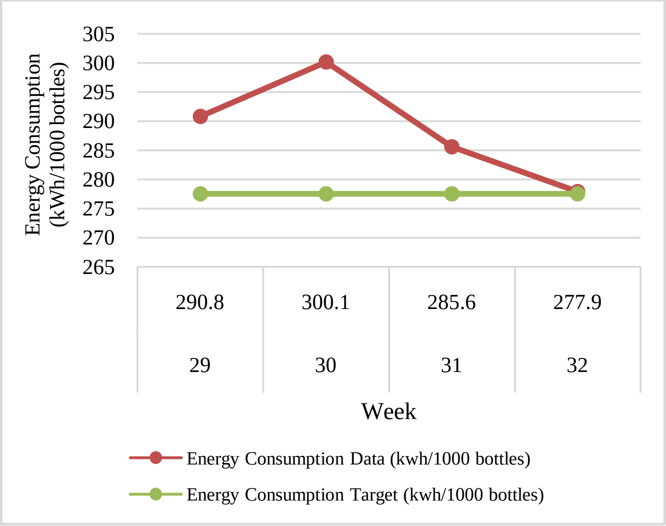


(b)

Figure 5: Energy Consumption Trend in Bardi Production Line Before Corrective Maintenance Implementation (a) and After Corrective Maintenance Implementation (b)



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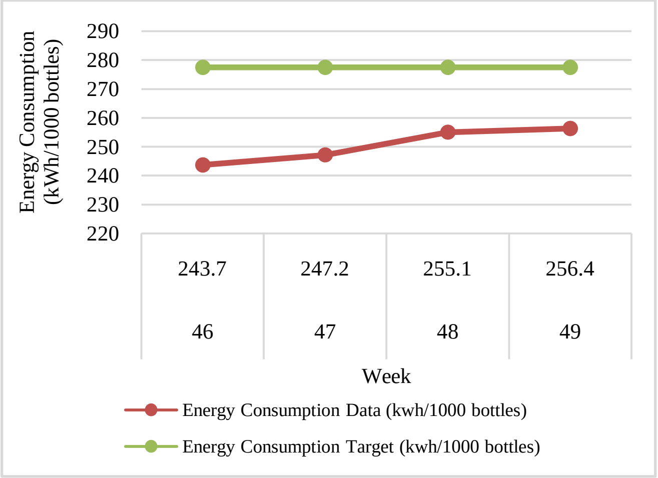

(b)

Figure 6: Energy Consumption Trend in Neptune Production Line Before Corrective Maintenance Implementation (a) and After Corrective Maintenance Implementation (b)

3.4 Analysis of Energy Saving Value

To determine the energy efficiency obtained, monitoring of energy consumption data is carried out 2 months before implementation and 2 months after implementation. Data was taken for the three production lines where the data before implementation was taken in June. The data is presented in Table 3 to Table 5.

Table 1: Energy Consumption Data on the CapSnap Line in June

Equipments Name	Energy Consumption (kWh/1000 bottles)
Heater 2 CapSnap	100.105
Chiller n AHU CapSnap	14.614
Comp LP General Kaeser	13.421
Dehume CapSnap	9.600
Washer n Filler CapSnap	5.704
Conv Direct 2 Line Gallon	4.921
Heater 1 CapSnap	4.048
Conveyor CapSnap	4.905
WT CapSnap	1.821
Charger Forklip	1.320
Comp. LP Kaeser SK 21 CapSnap	684
STP	467
P Dis WWTP M	490
Comp LP Atlas Copco SPS 3	382
CIP	194
WWTP Mizon	69
Boiller CapSnap	37
Total	162.782

Table 2: Energy Consumption Data on the Bardi Line in June

Equipment Name	Energy Consumption (kWh/1000 bottles)
Heater Bardi	59.687
Washer n Filler Bardi	23.622
AHU n Chiller Bardi	15.370
Comp LP General Kaeser	16.748
Conv Direct 2 Line Gallon	7.352
Charger Forklip	1.817
WT Bardi	1.505
Comp. LP Kaeser SK 21 Bardi	665
STP	454
P Dis WWTP M	489
Comp. LP. Atlas Copco SPS 3	369
CIP	189
WWTP Mizon	67
Boiller Bardi	36
Total	128.370

Table 3: Energy Consumption Data on the Neptune Line in June

Equipment Name	Energy Consumption (kWh/1000 bottles)
Heater	149.311
Comp LP General Kaeser	134.939
Charger Forklip	1.826
Comp. LP Kaeser SK 21 Neptune	632
STP	404
P Dis WWTP M	494
Comp LP Atlas Copco SPS 3	372
CIP	188
WWTP Mizon	68
Total	288.234

Data from the three production lines taken after the corrective maintenance implementation process was taken in November. Energy consumption data for the three production lines, namely the CapSnap, Bardi and Neptune lines, are shown in Table 6 to Table 8.

Table 4: Energy Consumption Data on the CapSnap Line in November

Equipment Name	Energy Consumption (kWh/1000 bottles)
Heater 2 CapSnap	93.353
Chiller n AHU CapSnap	13.614
Comp LP General Kaeser	13.150
Dehume CapSnap	9.587
Washer n Filler CapSnap	5.657
Conv Direct 2 Line Gallon	4.910
Heater 1 CapSnap	3.129
Conveyor CapSnap	5.086
WT CapSnap	1.891
Charger Forklip	1.389
Comp. LP Kaeser SK 21 CapSnap	711
STP	490
P Dis WWTP M	498
Comp LP Atlas Copco SPS 3	375
CIP	250
WWTP Mizon	90
Boiller CapSnap	30
Total	154.210

Table 5: Energy Consumption Data on the Bardi Line in November

Equipment Name	Energy Consumption (kWh/1000 bottles)
Heater Bardi	50.270
Washer n Filler Bardi	21.562
AHU n Chiller Bardi	14.620
Comp LP General Kaeser	14.303
Conv Direct 2 Line Gallon	6.378
Charger Forklip	1.750
WT Bardi	1.477
Comp. LP Kaeser SK 21 Bardi	560
STP	458
P Dis WWTP M	325
Comp. LP. Atlas Copco SPS 3	329
CIP	120
WWTP Mizon	67
Boiller Bardi	36
Total	112.255

Table 6: Energy Consumption Data on the Neptune Line in November

Equipments Name	Energy Consumption (kWh/1000 bottles)
Heater	138.311
Comp LP General Kaeser	127.939
Charger Forklip	1.810
Comp. LP Kaeser SK 21 Neptune	632
STP	454
P Dis WWTP M	440

Comp LP Atlas Copco SPS 3	320
CIP	228
WWTP Mizon	76
Total	270.210

Total energy consumption in June and November is presented in Table 9. Table 9 data shows that overall, in all three production lines, the energy consumption rate decreased, namely in June by 579,386 kWh/1000 bottles to 537,675 kWh/1000 bottles, or reduced by 41,711 kWh/1000 bottles. If this figure is used in %, there will be a decrease in energy consumption by:

$$\text{Total Energy Saving} = \left(\frac{579.386-537.675}{579.386}\right) \times 100\%$$

$$= 7.37\%$$

Table 9: Data on Total Energy Consumption in Production Lines in June and November

Line Production	Energy Consumption (kwh/1000 bottles) June	Energy Consumption (kwh/1000 bottles) November
CapSnap	162.782	154.210
Bardi	128.370	112.255
Neptune	288.234	270.210
Total	**579.386**	**536.675**

IV. CONCLUSION

From the results of the RCA analysis, further action is taken by planning and implementing corrective maintenance as part of the "plan" and "do" stages, which are then followed by the "check" step which indicates a decrease in energy consumption levels reaching 7.37%, then the process next as the "act" step is to create a standard system for caring for components in the washer machine so that component failure does not occur which results in leakage which has an impact on increasing the level of energy consumption in the production area.

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