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Design and Fabrication of an Industrial Semi-Automatic Label Shrinking Machine for PolyEthylene Terephthalate (PET) Bottles

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Abstract

A company that produce bottled drinking water had been facing issues with manual label shrinking that involve high temperature water and steam. Thus, this project focus on the design of a semi-automatic label shrinking machine to shrink the PVC 40-Micron label around the specially shaped PET bottles. The structure of the machine was designed and analyzed using 3D software. The water tank, heating element and thermal insulator necessary were also properly selected through calculation and analysis. The design of the actuation, bearings and control for the machine were also done through proper steps of selection as well. The machine was fabricated and experiments were done where the best temperature to shrink the label at the satisfaction of the company was determined. The rates of labels shrunk per hour were recorded and it was found that the machine perform better than the theoretical result by 3.54%.

Keywords: *Label shrinking machine, hot water submersion principle, PET bottles, machine design, heat shrink.*

1. Introduction

The trends in the current industrial manufacturing are slowly shifting towards automation whereby all the works are done by automated machine instead of human to increase the efficiency and improve safety. Human being, by nature, is unable to handle repetitive and dull tasks. Under the effect of low labor fees and dull tasks, the workers are often demotivated to work hard for the company. Hence, the productivity of that corporation will decrease despite having a lot of manpower. Besides that, some tasks are also very dangerous and hazardous for workers to be directly involved in it. Thus, automation would be the best solution for those problems and most of the large manufacturing factories already started to imply unmanned manufacturing in order to increase their productivity and efficiency.

A SME from Melaka is a Reverse Osmosis (RO) bottled water distributor. Other than distributing water of their own brand, they also accept orders from customers who request to use their own labels and oddly shaped bottles to increase the bottle's appearance and attract consumers' attention. They tried a lot of techniques to shrink the labels so that the shrink sleeve will fully wrap around the oddly shaped PET bottles without any whitening effects or wrinkles. Currently, the worker of that company shrink the shrinkable sleeve by dipping or submerging the sleeved bottles into the water in a steel container at high temperature. The water in the steel container is heated constantly through the use of gas stove at the range of 80℃ to 90℃.

According to them, they've tried approaching some label shrinking machine's manufacturer regarding the purchase of label shrink machine that fits their needs. However, most of the label shrink machine, which is also name as shrink tunnels, either cost too much or the resulted shrinking does not satisfy them. Other than that, they also have to employ a boiler man to take care of the boiler used by the shrink tunnels. According to them, the purchase of label shrink machine will not bring profit to the company since the loans to buy the machine is too big for the company to bear. They also attempted to complete the tasks by using workers only. However, long period of shrinking will not only cause the worker to feel sleepy and slow down, it is also very dangerous since they are dealing with hot water which will cause injuries if not handled carefully. The heat dissipated from the heated steel container also caused the workers to be unable to work for a long period because of skin's sensitivity. Hence, they've decided to search for alternative options which costs less but will still get the job done.

Therefore, as per their request, this paper will focus on the design and fabrication of a semi-automatic label shrinking machine by using the principle of hot water submersion. Testing and data analyzing will be carry out as well to inspect for potential flaws and problems before actual production. The design of the semi-automatic label shrinking machine will be as simple as possible to ensure that no extra and unnecessary features will be included to reduce the total manufacturing costs of the machine.

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2. Problem Statement

This paper considers the original tasks that were carried out by the workers in mentioned SME. The process of shrinking the labels that include manually dipping the sleeved PET bottles into gas heated hot water and the method of maintaining the water at the desired temperature are considered as well such as Figure 1. The most important aspect to be considered in this paper would be the safety of the worker. In order to reduce the chances of the workers getting hurt due to contact with high temperature water, mechanisms will be designed and the working environment surrounding the machine will be carefully designed as well.

Fig. 1 Original Shrinking Process

3. Literature Review

Shrink sleeves has been among the popular choice of labelling technique for more of the brands especially in beverages industry such as soft drinks and water. The reason why shrink sleeves are able to win against the other labelling method such as adhesive is due to its capability to maximize shelf presence of the product. Shrink labels enable 360 degree of design freedom. This means that the whole bottle, regardless of its shape, can be labelled by using shrink sleeves. Besides that, it is cost effective as well. In terms of recycling, if the material of shrink sleeve is recyclable, the shrink sleeve can be removed fairly easily compared to other attachments.

Sleeves are durable, provide total bottle decoration and can incorporate tamper evident features, while the use of UV flexo allows cost effective production of high quality shorter runs. With advancement in technology and special features, together with relatively low costs, sleeves are now a viable option for most products (Houghton, 2011).

Currently in the market, there are at least five types of shrink systems that can be used to heat shrink the shrink sleeves. In order to make sure the label properly wrap around the PET bottle, it is important to select the appropriate shrink systems since the resulting shrinking would differ according to the systems.

3.1 Heat Guns

The simplest solutions to shrink the shrink sleeves label is by using heat guns. Figure 2 shows one of the type of heat gun application. This type of shrink system is ideal for low speed tamper sealing. If is also often used for sleeve anchoring a base of containers and it has the lowest possible entry cost.

Fig. 2 Heat guns application

The biggest problem with this type of shrink system is the shrinking effect is not uniform when the labels are too tall. The position of heat guns is fixed and the heated air supplied is from one source only, causing some parts of the labels to have different heat applied. Hence, the shrinking result is not very good since some part of the labels will have wrinkles.

3.2 Hot Air Shrink Tunnels

Hot air shrink tunnel was originally used to shrink the loosely-wrapped goods. When PET bottles and shrink sleeves were introduced, hot air shrink tunnel were modified so that it can be used to shrink labels as well.

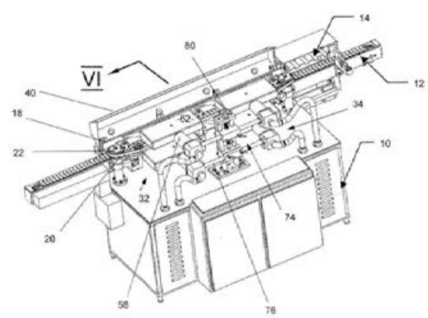


Fig. 3 Hot air shrink tunnel

Figure 3 shows a shrink system for a labelling system includes a return duct and a makeup duct connected to the inlet of a fan. A valve regulates the temperature of air supplied to the inlet by varying the proportion of air flow between the return and make up ducts. The output of the fan is supplied to a nozzle configured to entrain ambient air with the outlet from the nozzle (Martin Malthouse, 2013).

ISSN 2348 – 7968

United States Patent No. US20130224674 A1, 2013 shows the hot air systems for use in contouring shrinkable films to containers, commonly referred to as shrink systems. The shrink system invented apply heated air to a container with labels. The heated air is recovered and supplied to an inlet of a fan whose outlet supplies the heated air to the containers. The recovered air is combined with an ambient air duct and the proportions of ambient air and recovered are varied to maintain a predetermined temperature as the inlet to the fan (Martin Malthouse, 2013).

Currently on the market, all the hot air shrink tunnels manufactured by different companies are using the same principle. The only difference is the systems integrated with the shrink tunnels. For example, the capability of the system to have adjustable and constant temperature throughout the whole process, the uniformity of the shrinkage of shrink sleeve and also the additional features such as shrink tunnels' height adjustment for more flexible shrinking and shrinking speed. Above all, the applications are the same where heated air are used to heat and shrink the shrink sleeve labels.

This kind of shrink system is very advantageous for some applications because it is versatile and also cost effective. Hot air shrink tunnel has been developed to an extent that it is portable. The portability of the system makes it versatile for many different shrink applications and very cost effective as well since not much machinery systems were infused. Other than that, hot air shrink tunnel is also good for directional heat applications and focused heating. The shrink system is very ideal to focus heating on necks, recesses and grooves of the bottles, causing the sleeve to shrink perfectly around the targeted parts.

The main problem with using such system is the shrink tunnel's poor specific heat capacity. This is because of the design of the tunnel, the air does not transfer heat efficiently, causing more losses on producing heat energy. Besides that, when the products to be shrink are cold/filled, the product can act as heat sink and impede the shrinking result. The probability that the products will have wrinkles are very high when the shrinking is impeding. Other than that, heat shadows will also cause unhelpful distortion and uneven shrinking (Couling, 2012).

3.3 Radiant Heat Tunnel

Radiant heat tunnel uses high level infra-red energy to heat shrink the shrink sleeve label. This shrink system is an alternative to hot air shrink tunnel. The theory behind both systems is quite similar because both uses heat air as well. The only difference between them is that one uses heated air and another uses high level of infra-red energy.

United States Patent No. 4325762 A, 1982, is an invention of heat shrinking tunnel that utilizes high level of infra-red energy to heat-shrink the sleeves in a thermo constrictive operation (Robert J. Burmeistre, 1982). This invention, as in Figure 4, aimed at providing a method for heat-shrinking tubular sleeves of thin, thermoplastic material on either glass or plastic bottles, the sleeves being placed on upright containers while both are conveyed in coaxial vertical alignment (Robert J. Burmeistre, 1982,).

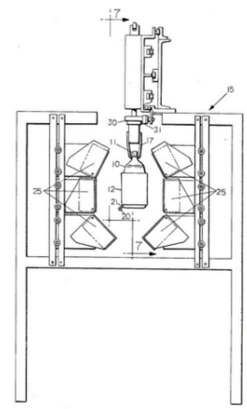


Fig. 4 Radiant heat tunnel

Similar to hot air shrink tunnel, there are several manufacturers provide radiant heat tunnels with different specifications. For example, the number of heat source. The heat source can be a pair of infrared heaters or more than a pair, depending on the demand. Besides that, the flexibility of the radiant heat tunnels also plays a major role in determining the type of radiant heat tunnels. The price of the radiant heat tunnels also varies when more features and specifications were included.

The biggest advantage of using such shrink system is that it can be quite versatile and cost effective as well compared to other shrink tunnels. This is because of its flexibility. For example, Axon Corporation offered a type of radiant heat shrink tunnel that can be mounted directly onto most conveyors, eliminating the need for a floor stand (Axon, 2014). Besides that, it is also possible to have very high energy inputs and it is excellent for pre-heating containers (Couling, 2012).

The disadvantages of radiant heat shrink tunnel are due to its lack of directional discretion. Besides that, similar to hot air shrink tunnel, the shrinking results will be influenced by "heat shadows". The most important of all, the sleeve artwork and color variations can influence the shrinking results (Couling, 2012). This is actually the key points between choosing hot air shrink tunnel and radiant heat shrink tunnel because the current trend of labelling requires a very nice shelf appearance. For that, it is not advisable to use radiant heat shrink tunnel if the bottles require a very nice sleeve artwork and color variations. Other than that, radiant heat shrink tunnel also requires careful use with certain containers due to the possibility of melting those containers.

3.4 Steam Tunnel

Steam tunnel is a type of shrink system that utilizes steam as the heat source to shrink the shrink sleeve labels. This type of system is particularly popular because of its capability to meet the high production rate. Besides that, steam have high thermal mass heat because of the enthalpy of vaporization of steam, making it better in heat transfer efficiency and ideal for obtaining best shrinking result with low wrinkles possibility.

Figure 5 shows a device intended to assist in the accurate and controlled shrinkage of thermo-shrinkable container-jacketing material. Such device is said to produce at least an elevated temperature in a heated processing zone. Heat energy available in said heated processing zone primarily derived from a heat source, which is pressurized steam (Lewis, 2013).

The steam tunnel patented by Graham Louis Lewis is a steam tunnel intended to shrink the sleeve label. In the patent itself, he mentioned that the resulting shrinkage produced by steam tunnel is better than those of hot air shrink tunnel and radiant heat shrink tunnel. This is because steam tunnel has better heat transfer efficiency. However, he also mentioned the dissatisfaction of the appearance of the products after shrinkage due to the whitening of a Polyester film.

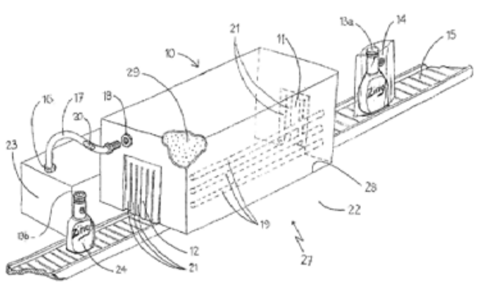


Fig. 5 Steam tunnel

The advantages of using steam tunnel to shrink the shrink sleeve label is the versatility available and also optimum shrink quality and performance. Other than that, the steam tunnel also produces best result in the least line space (Couling, 2012).

The biggest disadvantages of steam tunnel are the additional capital outlay for steam source and associated equipment such as piping, extraction, valve gear, water and drainage (Couling, 2012). If the factory that uses steam tunnel don’t have existing steam source and associated equipment, they will be required to pay for the costs of having those before they can use the steam tunnel. Other than that, the internal and external moisture will have the risk of residual as well. There is also requirement of having another drying equipment such as air-knife or blower to dry or dewater the bottle as well (Couling, 2012).

4. Design

The design of this machine would involve several parts and stages. The first part would be the structural design whereby the water tank and body structure of the machine would be carefully designed. Then, the heating element and thermal insulation will be designed. Heating element is one of the most important element in this machine because it will be used to heat up the water in the water tank up to desired shrinking temperature. Thermal insulation is very important as well to prevent the heat transferred from the water tank to the outer surface of the machine’s body where human contact is possible. Next, the actuator, bearing and control system of the machine will be designed as well. The actuator will be designed in such a way that it will carry the bottles and submerge them into the hot water. Bearings would be designed to hold the actuators and lifting mechanisms. Lastly the control system for both heating element and actuators would be designed to make sure the temperature of the water is in control and the period of submersion can be manipulated at ease.

4.1 Structural Design

The material used to build the body of the machine should be determined and designed properly. The machine’s structure would be dependent on the size of the water tank while the length and width of the water tank would be dependent on the number of PET bottles that will be submerged into the hot water each time. The number of bottles that will be submerged into the water tank will affect the minimum height of the water tank as well. Thus, the design of the water tank would be carried out first.

The size of the water tank can be determined by considering the number of bottles to be submerged into the hot water. Other than that, additional instrumentation such as thermocouple’s position should be taken into consideration as well. Thus, the width and length of the tank can be determined by using Solidworks 2014 where the bottles and thermocouple will be drawn and arranged. Then, the tank's width and length can be approximated. The resulting width and length of the tank can be obtained such as in Figure 6.

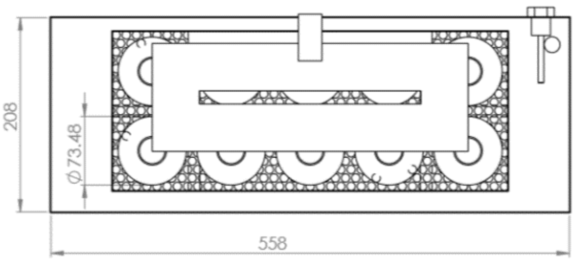


Fig. 6 Top view of water tank with width and length

The height of the tank, however, had to be determined by using Archimedes' Principle. This is because the filled bottles as well as the basket that will be used to contain the bottles have weight. Thus, suitable equations will be derived to determine the necessary height of the tank.

$$Maximum\ height\ of\ water, H_{max} = H_{Initial} + H_{displaced} \quad (1)$$

Where

$$H_{displaced} = \frac{\frac{(m_b+420n)}{1000}}{\rho \times W \times L} \quad (2)$$

The following assumptions will be made:

1. The weight of a filled PET bottle = 420gram
2. The mass of the basket = 1.7kg
3. The density of water, $\rho_{water} = 999.97kg/m^3$

The maximum height of the water will then be

$$H_{max} = 0.2 + \frac{\frac{1700 + (420 \times 10)}{1000}}{999.97 \times 0.208 \times 0.558}$$

$$= 0.2508m \equiv 250.8mm \quad (3)$$

Taking into consideration of the maximum height of the water, the tank should be higher to avoid the water from overflowing. Thus, the tank's dimension can be finalized with dimension of 558mm×208mm×335mm. Also, by obeying the guidelines on "Materials of Construction for Equipment in Contact with Food" by European Hygiene Engineering and Design Group (EHEDG), the material of the water tank should be Stainless Steel type 304.

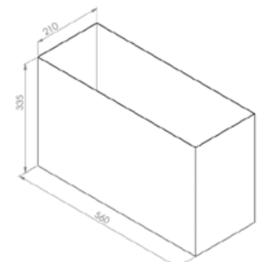


Fig. 7 Isometric view of water tank

Once the water tank's dimension has been determined, the main body structure of the machine can be designed. Figure 8 shows the structural design of the machine. The material for this machine's body structure can be narrowed down to selection between Steel and Aluminum. Table 1 shows the comparison between 2 materials.

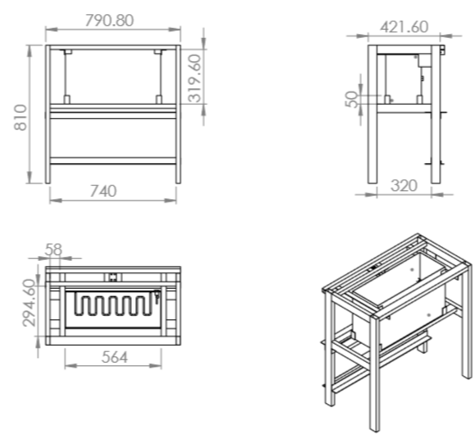


Fig. 8 Body structure of the machine

Table 1: Comparison between Steel AISI 1020 and Aluminum 5052-H32

Properties	Steel AISI 1020	Aluminum 5052-H32
Yield Strength	$3.52 \times 10^8 N/m^2$	$1.95 \times 10^8 N/m^2$
Modulus of Elasticity	$2 \times 10^{11} N/m^2$	$7 \times 10^{10} N/m^2$
Mass Density	$7900\ kg/m^3$	$2680\ kg/m^3$
Prone to vibrations	No	Yes
Corrosion	Yes	No
Price	Cheap	Expensive

From Table 1, it is obvious that the most suitable material for this application would be Steel AISI 1020. This is because even though aluminum is lightweight, it is, however, more prone to vibrations due to its low mass density. Other than that, the price of steel is lower compared to aluminum. The only disadvantages of using steel would be its corrosion issues. This issue can be

ISSN 2348 – 7968

solved easily by applying anti-rust paint such as red oxide onto the steel body. Thus, steel would be selected to build the main body structure of the machine.

4.2 Heating Element and Thermal Insulation

In order to design the heating element that will be used to heat up the water in the tank, the time taken to heat up the water should be determined first. The time taken to heat up the water can be related specific heat capacity of water, mass of water and power supplied to the heating element. Assumptions such as below can be made.

1. The mass of water is constant at 23.2kg.
2. Specific heat capacity of water is $4181\ J/kg$℃
3. Power used by the heating element is single-phase.
4. Current and voltage supply is constant.
5. The voltage supply is 240V.
6. The current supply is 13A.
7. The desired temperature to be reached is 90°C.
8. Ambient temperature is 28°C.

Equation below is derived and simplified from specific heat capacity's equation and power's equation.

$$t = \frac{mc\Delta T}{IV}$$

$$= \frac{23.2\times4181\times(90-28)}{13\times240} = 33.4\ minutes \quad (4)$$

From the equation, it can be determined that at maximum power supplied, the minimum time taken to heat up the water up to 90°C is 33.4 minutes. The acquired time taken is acceptable because the power used is the most common power. Higher voltage such as 440V can be used but not all factories have high voltage supply.

4.2.1 Heating Element

There are a wide variety of heating element. The heating element that would best fit this application is custom-made Nickle-Chromium heating material. The properties of such heating material is stated in Table 2.

Table 2: Ni-Cr Heating Material Properties

Ni-Cr Heating Material Properties	
Standard Chemical Components	Cr: 19~21 Fe: 1 or less Ni: 77 or more
Specific Gravity	$8.4 g/cm^3$
Melting Point	1400℃
Electric Resistivity	$1.08 \pm 5\%\ \mu\Omega - m$
Maximum Service Temperature	1100℃

According to the initial assumptions, the selected heating material would be able to provide heat energy up to 3000W. The heating element is also designed to be tubular shaped such as Figure 9. The tubular shaped heating element is expected to evenly heat up the water in the tank by increasing the heat flux of the heating element. The higher the area of heating element, the higher the heat flux, the faster the water will be heated up.

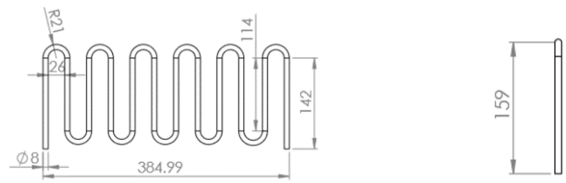


Fig. 9 Heating element design

4.2.2 Thermal Insulation

The thermal insulator that should be used for this machine can be determined by comparing both thickness and thermal conductivity of the thermal insulator. In order to select the thermal insulator, a set of equation is derived from the equation of heat conduction and heat convection. The final equation that can be used to determine the thickness of the insulator that correspond to the thermal conductivity of the insulator is as below.

$$X = k\frac{(T_{hot}-T_{surface})}{\varepsilon\sigma(T_{surface}{}^4-T_{ambient}{}^4)+h_c(T_{surface}-T_{ambient})} \quad (5)$$

Assumptions for equation above is as below.

1. The highest temperature, T_{hot} is 90°C.
2. The expected temperature of the machine's surface, $T_{surface}$ is 30°C.
3. The ambient temperature around the machine, $T_{ambient}$ is 25°C.
4. Emittance of surface of stainless steel tank, ε is 0.2.
5. The Stephen-Boltzmann constant, σ is $5.670373 \times 10^{-8} \frac{W}{m^2K^4}$.
6. The convection coefficient of air is $10 \frac{W}{m^2K}$ (since at minimum convection coefficient, the thickness is maximum)

Applying all the values into the equation above, the final expression that can be used to determine the suitable insulator would be

$$X = 1.0683k \quad (6)$$

The selection of the insulator will be based on the catalogue provided by Rockwool Malaysia Sdn. Bhd. that provides a wide variety of thermal insulator. In this application, RockTech S (Slab) is selected. RockTech S is a durable insulation slab used for industrial applications. It is actually stone wool product made of basalt, a type of volcanic stone. The stone wool products manufactured by Rockwool Malaysia are particularly suited to meet the specification requirements of thermal insulation, fire protection and sound attenuation of both flat and slightly curved surfaces of tanks, vessels, boilers and ducts. Since the water tank is rectangular in shape and have flat surfaces, the RockTech S slab would make the best thermal insulation product for this application. Appendix 1 shows the technical parameters of RockTech S (Slab) products. Table 3 shows the resulting thickness in correspond to different type of RockTech S products.

Table 3: Insulation thickness with corresponding thermal conductivity

Type of Products	Thermal Conductivity at 100°C, W/mK	Density, kg/m^3	Thickness, mm
S350	0.045	60	48.0735
S450	0.045	80	48.0735
S650	0.044	100	47.0052
S850	0.045	110	48.0735

Since most of the products have similar thickness and they met the minimum specifications necessary, it is safe to select S350 as it is the cheapest thermal insulator out of all four suggested products.

4.3 Actuation, Bearing and Control

Automation requires actuation. The actuation that will be used for this application is pneumatic cylinder. The selection of pneumatic cylinder will be discussed. Other than that, bearings that will be used as a support for the lifting mechanism will be designed as well. The final phase of the design would be individual control system for both heating element and actuation.

4.3.1 Pneumatic Cylinder

Pneumatic cylinder that operates via compressed air is one of the most used actuation for automations around the globe. One of the reason for using it is because they come in many sizes at affordable prices. There are mainly two types of pneumatic cylinders, single-acting cylinder and double acting cylinder. Single-acting cylinder are pneumatic cylinders where the air pressure acts on one side of the piston only. A single-acting cylinder relies on the load, springs or other cylinders to push the piston back in the other direction. Different from single-acting cylinder, double-acting cylinders are pneumatic cylinders that have air pressure acted on both side of the piston. This type of cylinder is very suitable for uses where force in both direction is required. It is important to control the speed of submerging and emerging of the lifting mechanism. Hence, single-acting cylinder will not be an option because it depends on the springs to make sure the cylinder's rod is pushed to opposite direction.

In order to determine the double-acting cylinder that is suitable for this application, it is important to first determine the bore size of the cylinder. Figure 10 shows the schematic diagram of a double-acting cylinder while Figure 11 shows the lifting mechanism design of the machine. The selection of pneumatic cylinder can be done by using equation below following the assumptions.

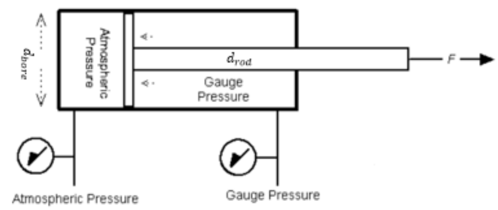


Fig. 10 Double-acting cylinder

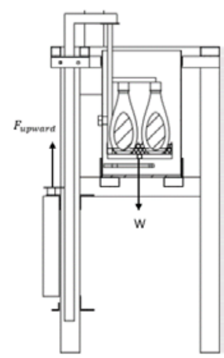


Fig. 11 Lifting mechanism

Assumptions:

1. Number of PET bottles, n is 10.
2. Mass per filled bottle is 420 grams.
3. Total upward force required includes the basket (14.5188N), the lifting mechanism (16.677N) as well as 10 bottles (41.202N).
4. Compressed air pressure is 700kPa.

$$F_{Required} = F_{upward} = \frac{P\pi({d_{bore}}^2 - {d_{rod}}^2)}{4} \quad (7)$$

$$F_{upward} = W = m_{lifting}g \quad (8)$$

Substituting all the values from the assumptions made, the difference between the bore diameter of the cylinder and the rod diameter of the cylinder can be obtained. Table 4 shows the forces that corresponds with the difference between the bore and rod diameter of the cylinder given by CKD Corporation. The types of pneumatic cylinder that will be compared are CMA 2 and CMK 2.

From Table 4, both CMA 2 and CMK 2 have equivalent difference between square of diameter of piston bore and piston rod. Thus, the final selection will be based on the functionality and prices. CMA 2 series pneumatic cylinder is the most basic type of pneumatic cylinder without any additional switches while CMK 2 series pneumatic cylinder comes with preinstalled switches. Since this machine doesn't require the use of such switches, CMA 2 would be a better choice as it will cost less as well.

Table 4: Selection of pneumatic cylinders

Type	Diameter of Piston Bore, m	Diameter of Piston Rod, m	${d_{bore}}^2 - {d_{rod}}^2$, m^2	$F_{Exerted}, N$	Factor of Safety, $\frac{F_{Exerted}}{F_{Required}}$
CMA 2	0.02	0.010	3×10^{-4}	164.9336	2.28
	0.03	0.012	7.56×10^{-4}	415.6327	5.74
	0.04	0.014	1.404×10^{-3}	771.8893	10.66
CMK 2	0.02	0.010	3×10^{-4}	164.9336	2.28
	0.025	0.012	4.81×10^{-4}	264.4436	3.65
	0.032	0.012	8.8×10^{-4}	483.8053	6.68
	0.04	0.014	1.404×10^{-3}	771.8893	10.66

4.3.2 Bearing

Bearings are used as a sliding support for the lifting mechanism so that the lifting mechanism will only move up and down such as shown in Figure 12. Hence, it is important to design and select the bearings properly so that it will last long enough.

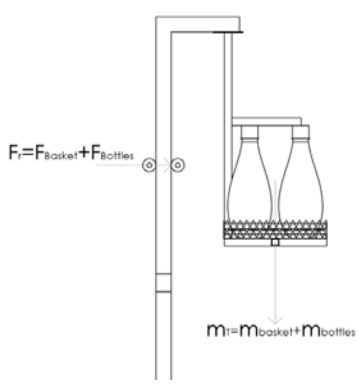


Fig. 12 Bearing as sliding supports

The selection of bearing will start with the calculation of radial and axial forces acting on the bearing. Since the bearing will act as a sliding support for the lifting mechanism, there will be no axial forces. The equivalent dynamic load can then be expressed by considering only radial forces. In order to sustain the weight of the basket and bottles, an equivalent force will be exerted onto the bearings in contact with the lifting mechanism. The assumptions that can be made for the bearings selection are such that:

1. Total radial force is 57.879N (include basket and bottles' weight).
2. There is no axial load.
3. The diameter of the shaft for bearing is 8mm.
4. The designed outer diameter necessary is 22mm.
5. The type of bearing considered is single-row deep groove ball bearings from NSK.
6. X and Y factor of the bearing is 1 and 0 respectively.
7. Speed of the lifting mechanism is 0.2m/s or 173.6234rpm.

The equivalent dynamic load of the bearing is

$$P = XF_r + YF_a = 1(57.879) + 0(0) = 57.879N \tag{9}$$

Where,

P=Equivalent dynamic load, N
F_r=Radial load, N
F_a=Axial load, N

Since the bearing will be used as a lifting supports, the desired life of the bearings can be set at 8000 hours. The expected bearing life in million revolutions can then be determined by using equation below.

$$L = \frac{60nL_h}{10^6} = \frac{60 \times 173.6234 \times 8000}{10^6}$$

$$= 83.3392\ million\ rev \tag{10}$$

Where
L=Bearing life in million revolutions
L_h=Bearing life in working hours
n=speed of rotation, rpm

The final step of bearing selection would be the calculation of dynamic load capacity where

$$L = \left(\frac{C}{P}\right)^p \tag{11}$$

Since p=3 for ball bearing and 10/3 for roller bearing,

$$C = PL^{\frac{1}{3}} = 57.879 \times 83.3392^{\frac{1}{3}} = 252.8158N \tag{12}$$

Appendix 2 shows the catalogue of single-row deep groove ball bearing from NSK. According to the catalogue, the basic load rating associated with bearing of internal diameter of 8mm and outer diameter of 22mm is 3300N. This means that if the mentioned bearing is selected, a safety factor of 13.05 can be achieved. This means that the bearing will unlikely fail. Thus, single-row deep groove ball bearing from NSK with internal diameter of 8mm and outer diameter of 22mm is selected.

4.3.3 Temperature Control

In this project, the machine required controls for both temperature and mechanisms. The temperature of the water can be controlled only via temperature controller by taking feedback from thermocouple and control the heating element. The control board, on the other hand, is important to control the mechanism such as the solenoid, switches and timer.

In order to control the temperature of the water efficiently, a temperature controller must be used. This will allow the temperature controller to control when the heating element should switch on and how long should the heating element switch on. The best temperature controller are the ones that comes with a PID controller. With PID control, the temperature of the water can even maintain at a range of temperature that is favorable for the application.

For this machine, the best temperature controller that can be used would be DTA4848 Temperature Controller by Delta Electronics, Inc. This temperature controller is the best option to control the temperature of the water because it offers embedded PID controller in the temperature controller at lower price compared to other controller. It can only, however, allow only one input and one output. This means the temperature controller is limited to only one input output, causing it to be less sensitive due to the absence of redundant feedback. Figure 13 shows the connection of the temperature controller with thermocouple and heating element.

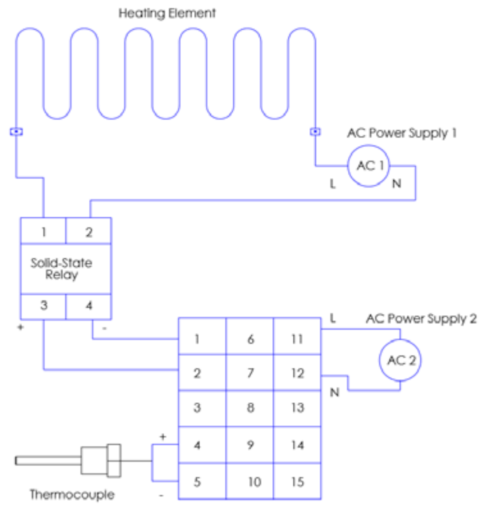


Fig. 13 Schematic diagram for heating system

In order to set up the controller, it is important to follow the steps as shown in Figure 14. Those steps must be adjusted if the machine is running for the first time because every factory have different surrounding conditions. Depending on the surrounding, the PID value of the temperature controller may need to be altered in order to achieve the best heating results.

4.3.4 Control System

For this machine, a control system is very essential as it is part of the lifting mechanism. The control system will consist of electronic parts especially the PIC. The PIC will be used to control the relays that will switch on or off the solenoid that is connected to it. Other than that, the PIC will also receive signals or feedback from switches that act as a limit of the lifting mechanism and decide what to do according to the programs. Figure 14 shows the flow chart of the program. The schematic diagram for the control system are shown in Figure 15.

ISSN 2348 – 7968

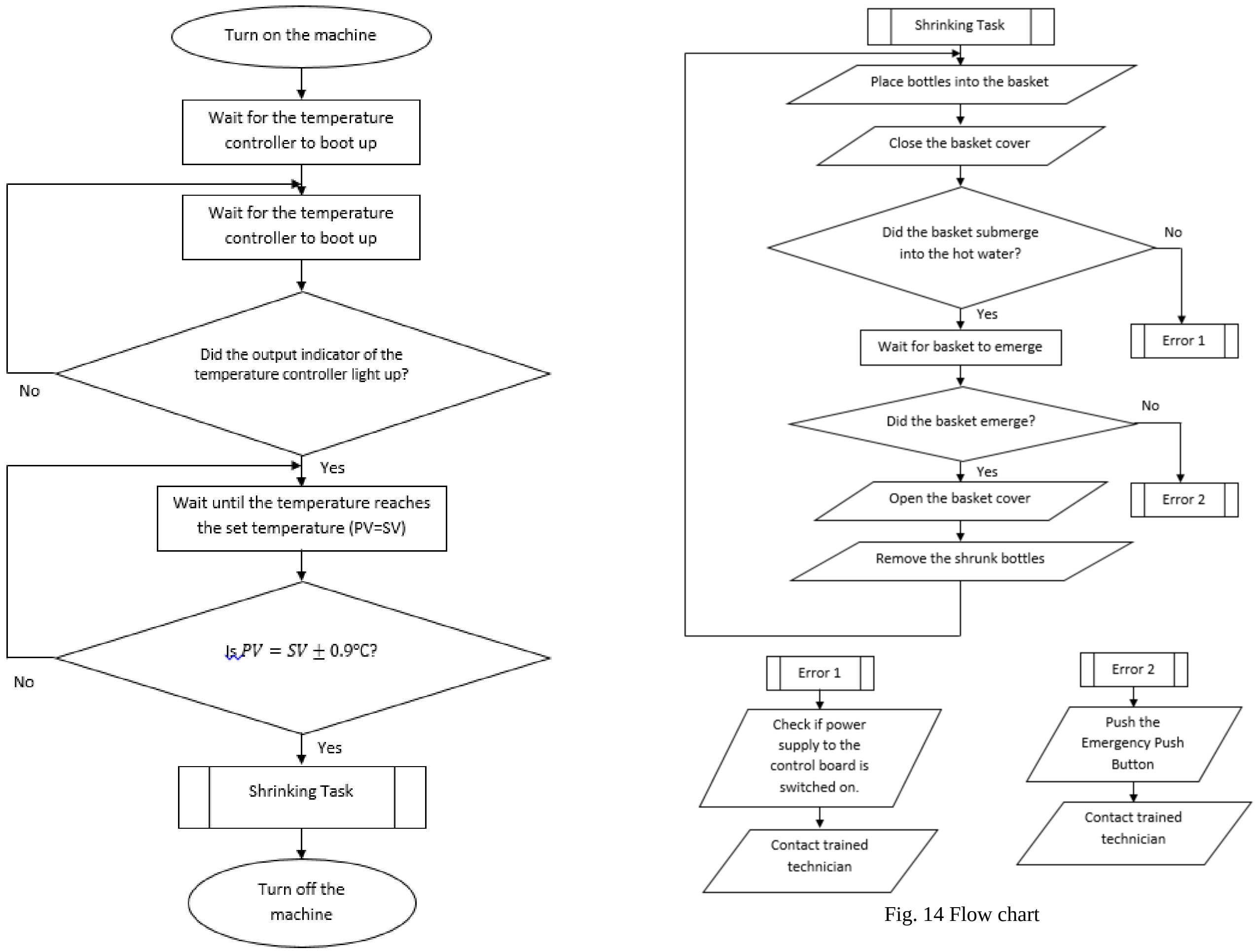


Fig. 14 Flow chart

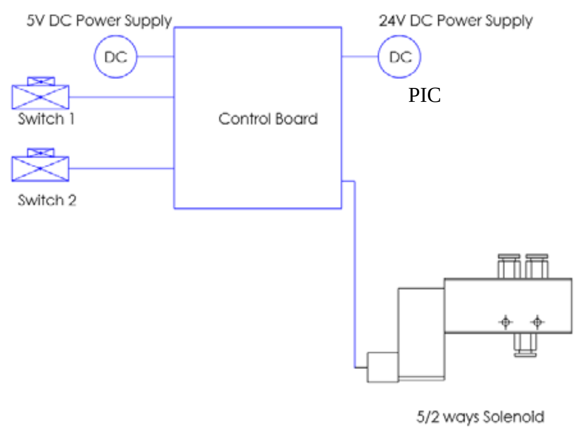


Fig. 15 Schematic diagram for control system

5. Results and Discussions

After the machine's necessary elements were properly designed, the fabrication processes were carried out. The fabricated machine is shown in Appendix 2. There are a few analysis and results that can be carry out and acquired

ISSN 2348 – 7968

from the fabricated machine. The analysis that can be carry out is the best shrinking temperature for heat shrinkable PVC 40 Micron labels and the rates of labels shrunk.

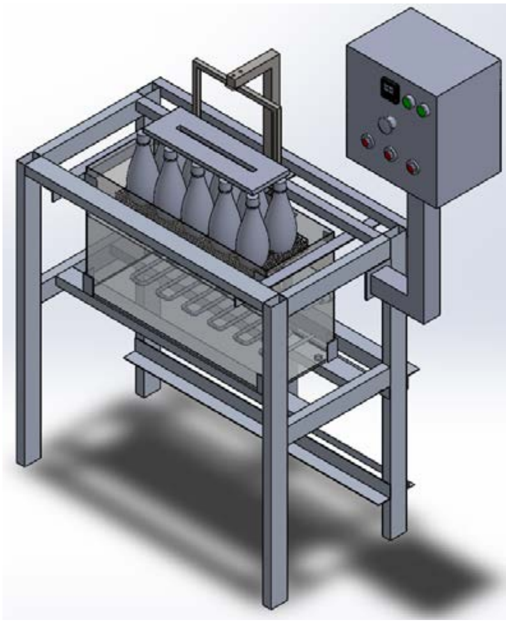


Fig. 16 3D drawing of label shrinking machine

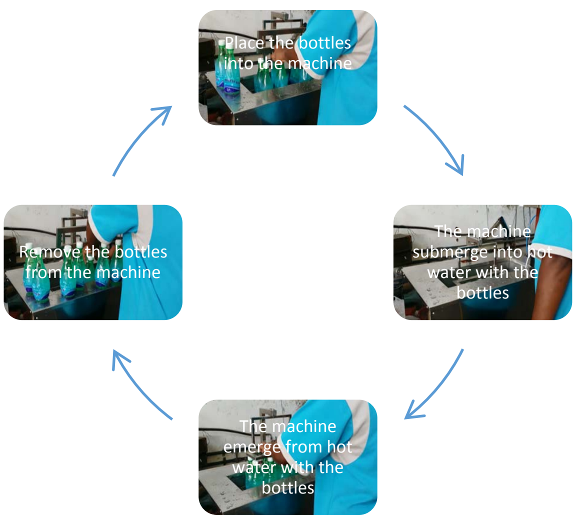


Fig. 17 The process of label shrinking using the machine

5.1 Best Shrinking Temperature

The labels used are shrinkable labels that are sensitive to heat. In order to determine the best shrinkage, the best shrinking result had been acquired by manipulating the temperature of water. The determination method was through the satisfaction of the company towards the shrinking results. Figure 18 shows the effects of temperature towards the shrinkage of labels. Note that unsatisfied shrinkage has wrinkles indicated by circles.

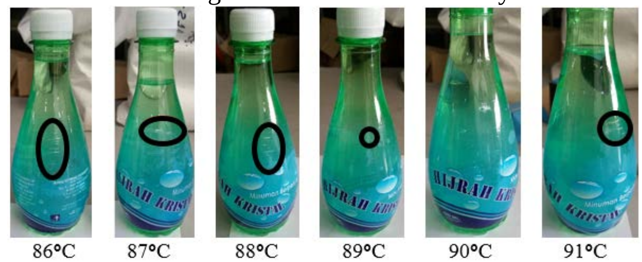


Fig. 18 Effects of temperature towards the shrinkage of labels.

At 86℃, a large area of wrinkles can be spotted on the bottle after shrinking. At 87℃, the wrinkles remain visible even though the area of wrinkles reduced. The same goes to labels shrunk at 88℃ with smaller area of wrinkles. At 89℃, the area of wrinkles became less visible to the extent where the company deemed acceptable. The best shrinking results occurred at 90℃ where no wrinkles are found around the bottles. At 91℃, the wrinkles are spotted again even though it is less visible.

The results concluded that the best shrinking result would only happen when the temperature range is between 89℃ and 91℃. The possible reason behind the difference in shrinking effect when the temperature is different is because of the type of label used. The labels used by company are PVC 40-micron heat shrinkable labels. The shrink temperature of PVC 40-micron is unknown because it is dependent on the manufacturer. When the content of PVC in the label differs, the shrink temperature differs. Thus, for this particular label, it is found that they shrink best when the temperature of the water is between 89℃ and 91℃. Labels shrunk at temperature out of the temperature range are deemed unusable and will be rejected.

5.2 Rate of Labels Shrunk

The rate of labels shrunk by the machine were tested and the average time were taken in table below. The process was carried out by putting in 4 bottles for each movement, 2 bottles in one hand. This means that there are a total of 3 movements to arrange the bottles into the basket. Then, the lifting mechanism will drop the basket into the water and lift it up after some time. Immediately after that, another 3 movements to take out all the bottles from the basket, every movement involve 2 bottles on each hand.

The actual rates of labels shrunk and the estimated rates of labels shrunk have a small percentage error. From the 10 trials, the average time taken to shrink 10 bottles is 19.3 seconds. This marks the shrinking rates at 1866 bottles per hour. The rates of labels shrunk via manual labor is approximately 7 seconds per bottle, which marks 515 bottles per hour. It is obvious that the rates of labels shrunk increased more than 3 times by replacing machine with manual labor.

Table 5: Time Taken to Shrink 10 Bottles.

Trial	Time taken, (s)
1	20.70
2	20.95
3	19.94
4	20.23
5	18.55
6	19.88
7	17.91
8	18.10
9	18.51
10	18.23

Note that the rates of labels shrunk is highly dependent on the worker's performance. If the worker is paying attention to the work, he/she can obtain higher rates of labels shrunk. However, if he/she is constantly affected by external works and unnecessary movements, then the rates will reduce.

From the 10 trials, it can be observed that the time taken to complete the whole process gets shorter as the number of trial increased. This is because the worker's movement in handling the process become smoother and faster as they repeat the same task. Therefore, the average time improved. This indicate that if the worker is given training and time to make themselves comfortable with the work, they will be able to further improve the efficiency with the aid of the machine.

6. Conclusions

The design and fabrication of the label shrinking machine was successfully carried out. The fabricated machine was also tested and analyzed for efficiency as well. It was found that the machine would be able to increase the production of the process by more than 3 times the original process. Other than that, the machine would be able to electrically heat up the water and keep the temperature of the water constant at an acceptable temperature range instead of using gas and stove.

6.1 Research Limitations

This research is limited to budget. Due to budget limitations, the machine can only be designed in such a way that it will be able to keep the workers out of hazardous environment. However, manual placing of bottles into the basket were still required. This means the process is not continuous. It's a stop and place process whereby every cycle involves manual placing and removal of bottles into and from the basket.

6.2 Future Research

The label shrinking machine that were designed are not the most optimized one due to the limitation in budgets. This particular machine has great potential to be further improved in terms of performance. The possible future works that can be carried out are listed as below.

1. Integration of robotics hand to place the bottles into the basket instead of using manual labours.
2. Improve the control system so that more feedbacks can be obtained from the machine.
3. Improve the time taken to heat up the water up to desired temperature to reduce waiting time.
4. Improve the rates of labels shrunk by designing a continuous submerging mechanism.

Appendices

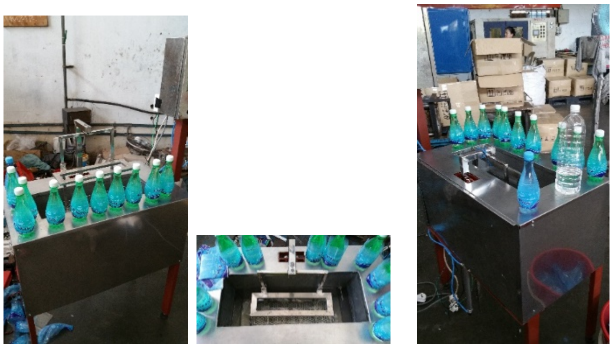
RockTech S (Slab)

Technical Parameters

	S350	S450	S650	S850	Standards
Density	60kg/m³	80kg/m³	100kg/m³	110kg/m³	EN1602
Length x Width	1200mm x 600mm				EN882
Thermal conductivity					ASTM C177
50ºC	0.037W/mK	0.038W/mK	0.038W/mK	0.038W/mK	
100ºC	0.045W/mK	0.045W/mK	0.044W/mK	0.045W/mK	
150ºC	0.053W/mK	0.054W/mK	0.050W/mK	0.054W/mK	
200ºC	0.060W/mK	0.061W/mK	0.057W/mK	0.060W/mK	
250ºC		0.074W/mK	0.065W/mK	0.072W/mK	
300ºC			0.075W/mK	0.083W/mK	
350ºC			0.088W/mK	0.099W/mK	
400ºC				0.115W/mK	
450ºC				0.131W/mK	
Hot surface performance	350ºC	450ºC	650ºC	850ºC	ASTM C411/ ASTM C447
Linear shrinkage, max % at maximum use temperature	0%	0.2%	0.5%	0.02%	ASTM C356
Compressive strength	Min 4 kPa, Max 30 kPa at 10% relative deformation				EN826
Surface burning characteristic					ASTM E84
FSI	0				
SD	Max 30				
Water absorption (partial immersion)	Min 0.12kg/m², Max 0.30kg/m²				BSEN1609
Water vapor sorption	0.040% by weight	0.042% by weight	0.050% by weight	0.031% by weight	ASTM C1104
Corrosion to stainless steel	Conforms to the stainless steel corrosion specification as per ASTM C692 and C871 test method				ASTM C692/ ASTM C795
Health & Safety:					
Odor emission	No perceptible odour present				ASTM C665-06
Fungi resistance	Does not encourage growth of fungi				ASTM C1338
Compliance to standard	ASTM C612 "Standard specification for mineral fibre board and board thermal insulation" Type IA to IVB				

Appendix 1 Technical parameters of RockTech S (Slab) from Rockwool Sdn Bhd

ISSN 2348 – 7968



Appendix 2 Front view, top view and side view of the fabricated label shrinking machine.

d (mm)	D (mm)	B (mm)	B_1 (mm)	r [1] min. (mm)	r_1 [1] min. (mm)	C_r (N)	C_{0r} (N)	C_r (kgf)	C_{0r} (kgf)	(min^{-1})	(min^{-1})	(min^{-1})	
5	8	2	—	0.1	—	310	120	31	12	53 000	—	63 000	MR 85
	8	—	2.5	—	0.1	278	131	28	13	53 000	—	63 000	—
	9	2.5	3	0.15	0.15	430	168	44	17	50 000	—	60 000	MR 95
	10	3	4	0.15	0.15	430	168	44	17	50 000	—	60 000	MR 105
	11	—	4	—	0.15	715	276	73	28	48 000	—	56 000	—
	11	3	5	0.15	0.15	715	281	73	29	45 000	—	53 000	685
	13	4	4	0.2	0.2	1 080	430	110	44	43 000	40 000	50 000	695
	14	5	5	0.2	0.2	1 330	505	135	52	40 000	38 000	50 000	605
	16	5	5	0.3	0.3	1 730	670	177	68	36 000	32 000	43 000	625
	19	6	6	0.3	0.3	2 340	885	238	90	32 000	30 000	40 000	635
6	10	2.5	3	0.15	0.1	495	218	51	22	45 000	—	53 000	MR 106
	12	3	4	0.2	0.15	715	292	73	30	43 000	40 000	50 000	MR 126
	13	3.5	5	0.15	0.15	1 080	440	110	45	40 000	38 000	50 000	686 A
	15	5	5	0.2	0.2	1 730	670	177	68	40 000	36 000	45 000	696
	17	6	6	0.3	0.3	2 260	835	231	85	38 000	34 000	45 000	606
	19	6	6	0.3	0.3	2 340	885	238	90	32 000	30 000	40 000	626
	22	7	7	0.3	0.3	3 300	1 370	335	140	30 000	28 000	36 000	636
7	11	2.5	3	0.15	0.1	455	201	47	21	43 000	—	50 000	MR 117
	13	3	4	0.2	0.15	540	276	55	28	40 000	—	48 000	MR 137
	14	3.5	5	0.15	0.15	1 170	510	120	52	40 000	34 000	45 000	687
	17	5	5	0.3	0.3	1 610	710	164	73	36 000	28 000	43 000	697
	19	6	6	0.3	0.3	2 340	885	238	90	36 000	32 000	43 000	607
	22	7	7	0.3	0.3	3 300	1 370	335	140	30 000	28 000	36 000	627
	26	9	9	0.3	0.3	4 550	1 970	465	201	28 000	22 000	34 000	637
8	12	2.5	3.5	0.15	0.1	545	274	56	28	40 000	—	48 000	MR 128
	14	3.5	4	0.2	0.15	820	385	83	39	38 000	32 000	45 000	MR 148
	16	4	5	0.2	0.2	1 610	710	164	73	36 000	28 000	43 000	688 A
	19	6	6	0.3	0.3	2 240	910	228	93	36 000	28 000	43 000	698
	22	7	7	0.3	0.3	3 300	1 370	335	140	34 000	28 000	40 000	608
	24	8	8	0.3	0.3	3 350	1 430	340	146	28 000	24 000	34 000	628
	28	9	9	0.3	0.3	4 550	1 970	465	201	28 000	22 000	34 000	638
9	17	4	5	0.2	0.2	1 330	665	136	68	36 000	24 000	43 000	689
	20	6	6	0.3	0.3	1 720	840	175	86	34 000	24 000	40 000	699
	24	7	7	0.3	0.3	3 350	1 430	340	146	32 000	24 000	38 000	609
	26	8	8	(0.6)	(0.6)	4 550	1 970	465	201	28 000	22 000	34 000	629
	30	10	10	0.6	0.6	5 100	2 390	520	244	24 000	—	30 000	639

Appendix 3 Single row deep groove ball bearing from NSK bearing.

Acknowledgments

We would like to express our gratitude to the Reverse Osmosis bottled water company for their kind corporation for the fabrication of the machine.

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