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Modeling and Comparative Study between a 250 and 1000kg Wiener Machines for Chocolate Softness

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Abstract: The paper presents a model for chocolate softness using two new design machines (Wieners) given by a polynomial equation of the third or the fourth order. The study aims at upgrading chocolate softness and homogeneity by designing and manufacturing two new machines that would be alternative to the costly current one. The capacity of the smaller one is 250 kg, and 1000 kg of the other. The eventual target is to elevate the present level of chocolate delicacy to match that in the developed countries. The findings of the study are satisfactory; the mixing period in the factory machines has been reduced from 24 to 12 hours in the newly smaller designed machine, while chocolate softness is lowered from 55 to 25 microns, hence increasing or enhancing the chocolate conformity and cohesion. As for the larger machine, time saving in chocolate mixing is 62.5 percent less than that in the primary mixer.

Keywords: Chocolate softness; primary mixer; weiner; grinding; mixing time; chrome marble; modeling.

1. Introduction

Textural properties of chocolate constitute one of the three main acceptability factors used by consumers to evaluate quality, the others being appearance and flavor. Texture is important because the human brain has evolved critical evaluation of mechanical properties and chocolate, like most food products can therefore be accepted or rejected on the basis of this quality factor [1-4]. Chocolate is, a matrix of discrete solid particles (sugar, cocoa and milk) set in a continuous fat medium. This fat makes up about a third of the weight of the chocolate, but because it has a lower density, it occupies almost half the volume. When the fat is solid, the chocolate is harder to bite through, although at higher temperatures it becomes softer and eventually turns into a liquid. This is what happens when chocolate is eaten, as the melting temperature of the fat is below that of the mouth [5-7].

The fat in milk chocolate is a mixture of cocoa butter (derived from cocoa beans) and milk fat. The geographical origin of cocoa beans affects the hardness of the chocolate produced and the rate at which it melts, with the fat from beans grown nearer the equator being harder and slower to melt than those grown further from the equator [8-10].

Reducing fat content causes an increase in the molten chocolate viscosity. This leads to two major issues: difficulties in the process and a loss of eating quality in the final product, reported to have poor in-mouth melting properties, remain hard, and difficult to swallow [11]. Chocolate is highly affected by temperature, a factor that has to

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be reckoned with before and during manufacturing, and in stockpiling and distribution as well.

Chocolate manufacturing greatly depends on how well its components of cocoa mass, cocoa butter, sugar and milk are mixed [12]. At the Philadelphia factories, this process takes about 24 hours daily, and carried out in two 500kg mixers (primary mixers) (Figure 1). The temperature generated by this process should not exceed 45°C. Otherwise, the control unit would stop off the mixer and thus save the chocolate mass.

The chocolate would then be carried by double jacket pipes, at 45°C, to two storage tanks, the capacity of each is 1000 kg. These latter two are also double jacket tanks with 40-45°C though preferably to be at 42°C. After that, chocolate would be carried to the Tempering Unit, where its temperature drops to 29°C, then to the Depositing Unit, which is connected with the control unit, with a view to determining the quantities required for pouring in the molds. By that time, those molds would have been exposed to preheating. Indeed, the temperature of the mold should be very close to that of the chocolate so that chocolate breaking would be avoided when being poured in molds. Then the molds would be carried mechanically to the Vibration Unit, where chocolate is conformed inside the molds. After that, it would be carried to the three-phase Refrigeration unit, then for packing, and finally to the refrigerated stores [5].

2. Advanced mixers (five-roll refiner)

The five-roll refiner (Figure 2) has five barrel-shaped rollers, which are normally between 800 and 2500 mm wide and are approximately 400 mm in diameter. These rolls become parallel under the pressure of operation. The particles are broken by the shearing action between the two counter-rotating rolls. The gap between them becomes narrower until the top gap is the same size as the largest particles within the chocolate, i.e. less than 30µm (micron). The material, with a maximum particle size of around 150 micron, is fed in between the two lower rollers and is transferred up the 'stack' due to the increased speed of the next roller. The film of material becomes thinner by a factor related to the speed difference. The ratio of roll speeds in fact is one of the ways of controlling the particle size of the machine. This is normally between 1.5 and 1.7 with the roll speeds varying from less than 50 rpm to greater than 400 rpm. In some five-roll refiners the rolls have set speeds and in this case the maximum particle size is manipulated by adjusting the feed gap between the first two rolls. The greater this feed gap, the larger will be the particles between the top two rolls. The pressure between the rolls does not control the particle size but is just used to ensure a uniform coating of the rollers by the chocolate. The Bühler Company [14] in Switzerland has produced an automated feedback system, in which a thickness-measuring device on the final roll gives a measurement which adjusts the relative speeds of the first two rollers. The viscosity of the chocolate is critical, however, and, if there is insufficient fat to bind the solid particles into a film, the material may be thrown from the rollers. On the other hand, if the feed material is very thin, because too much fat is present, some of the sugar and milk particles will segregate out in the hopper, resulting in uneven grinding. Temperature has a very large effect on the flow properties of this fat and so accurate cooling and heating of the rolls is required to obtain an optimum particle size distribution within the chocolate [6].

As shown above, mixing chocolate components is the important section of the production processes as a whole. Chocolate quality depends a lot on the mixing process which takes quite a long time.

Good chocolate is distinguished by taste. Hence to get a better chocolate taste with an elevated delicacy, the mixing process should be developed. In order to obtain the correct flavor and texture, solid particles must be ground to a size smaller than 30 mm, using a highly specialized and costly machine for that purpose [15,16]. However, the mass production of these machines does Like cream, it should melt in the mouth [15]. not fit the needs of the local market, in addition their costly maintenance that is only compatible to developed countries. In these machines, chocolate components are mixed by a group of moving rolls with very high level of softness. So the developing process we seek to achieve is to design an alterative machine at a low cost.

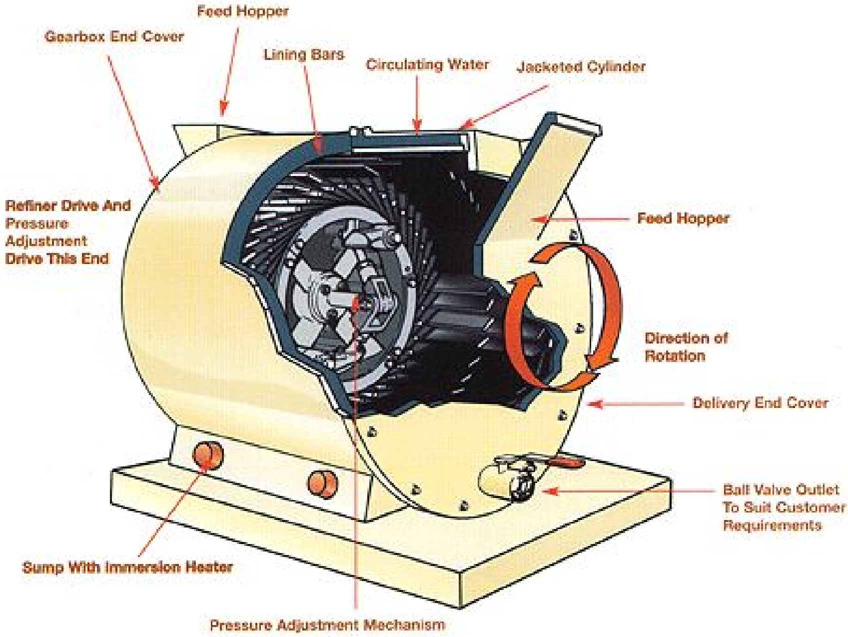

Figure 1. Cross section of primary mixer (pre-mixer) [13]

Figure 2. Advance machine, five-roll refiner [17]

3. The newly designed machine (wiener of 250 kg)

The study is based on milling the chocolate components while being passed and revolved on chrome marbles. These components would be softened by the movement of the weight of the marbles which are operated by on electric motor that is tied to a gearbox. The design incorporates the manufacture of a double jacket tin made up of a stainless steel material with an inner wall thickness no less than 6mm and 5mm for the outer wall, whereas the space between the two walls is about 8cm, and the capacity of the machine is bout 250kg of chocolate. Argon gas is used in the welding so that chocolate would not the affected by any oxidization.

In the middle of the tinplate, an internally moving bar of stainless steel is fixed, with 24 stainless brushes to do the mixing. The bar and brushes are operated by the above mentioned electric motor and the gearbox, which is fixed on a special-made basis above the upper lid of the tinplate.

At the bottom of the tinplate, chrome marbles of different or same diameter (pending availability in the marketplace) are used to help in the mixing and milling process. However, the marbles weight should gradually be increased to reach the proper level of chocolate mixing and softness.

As the chocolate mix is well prepared, and its conformity achieved in the primary mixers of 500kg weight, a special pump at the lower part of the mixer pumps it to the upper part of the wiener (Figure 3). Meanwhile, the chocolate mix at the lower part of the wiener is also drawn by a special pump and pumped to the upper part of the primary mixer. Thus a continued circulation of the mix runs between the primary mixer and the wiener to realize the chocolate's required delicacy.

A special control plate controls chocolate stirring and pumping, and the cooling of the manufactured system is done by a special cooling tower.

Figure 3. Newly designed machine (wiener of 250 kg)

4. Experimental data

When chocolate conformity is realized (which usually takes one hour in this factory), softness is measured once every half hour by a gauge device (Figure 4). A chocolate sample is taken by a small-spoon. The grading surface device is varnished by this sample. The grading device involves straight line apertures, the highest grade of which is 185 micron and the lowest is 1 micron. So if the sample is immersed in an aperture, then it is the indication that the sample's grading is identical to that of the aperture. But if the sample is larger than 185 micron, then the chocolate softness can by no means be read. In other words, this softness is out of the grading reach.

As the factory uses the coarse sugar in making chocolate, a comparison has been made on the primary mixer using two separate batches with coarse sugar and powder sugar. Figure 5 explains the curves of softening the chocolate by the coarse sugar and the powder sugar. From the curve of the coarse sugar, it is noted that the mix began gradation after 5.5 hours, and reached the highest delicacy level after 24 hours of mixing, while it has recorded 55 micron only, whereas the powder sugar curve shows that the mix began gradation after 2.5 hours, and the maximum chocolate delicacy was realized after 13 hour mixing. This shows a time saving of 11 mixing hours, with a 40 micron delicacy after 22 hour mixing; an apparently better delicacy level achieved by the powder sugar than that by the coarse sugar.

That is a primary indication for moving away from using coarse sugar. To make sure of that, an experiment was carried on the wiener with powder sugar after having added 210 kg of chrome marbles with a view to facilitating the mixing and milling process.

(Figure 6), which includes the curve mentioned in (Figure 5), i.e. the powder sugar curve used in the primary mixer and the other curve pertaining to the wiener. Hence, it can be noted that the wiener performance by using powder sugar was better than of the primary mixer when using the same sugar. In fact, the required softness, i.e. 25 micron has been achieved after 24 hours of mixing 250 kg of raw chocolate material by the wiener. Given that, and to obtain better results, the mixing method in the factory has been changed. Coarse sugar has been replaced by powder sugar on the one hand, and the primary mixer and the wiener have been connected together so that the softening process will be realized between them by circulation from one to the other. (Figure 7) shows the softness that has been achieved by this experiment of circulation, where the chrome marble maintained its weight, i.e. 210 kg, and the way of mixing was the only thing that has been changed. The figure also shows that the blend started to come into the grading scale only after 3 hours of mixing, and that the required softness, i.e. 25 micron has been achieved after 16.5 mixing hours (for 500 kg of raw chocolate material). This means that the wiener works positively, and that the blend works positively, too.

Given all that, the marbles weight in the Wiener was increased by 10 kg each time up to 260kg as shown in Figure 8 i.e. weights are 220, 230, 240, 250, 260 kg respectively. In all cases, gradation started one hour after the mixing process, excluding the case of 260kg when gradation began immediately.

It is noted that the curves of 240, 250, and 260 kg weights began coming closer to each other after 11 hour mixing. They registered 35, 34 , and 30 micron respectively, and that the required softness of the chocolate started to be achieved by the 12 hour of mixing time, with 28,27, and 25 micron respectively. The curve also shows that 25 micron required delicacy took 16 hours for a 220kg weight, 14.5 hours for 230kg, 14 hours for 250 kg, and 12 hours for 260 kg weights. Eventually, it can be safely said that the required chocolate softness has been achieved in a 12 hour mixing period for 500 kg of chocolate revolved between the primary mixer and the Wiener.

Figure 4. The chocolate's gage device

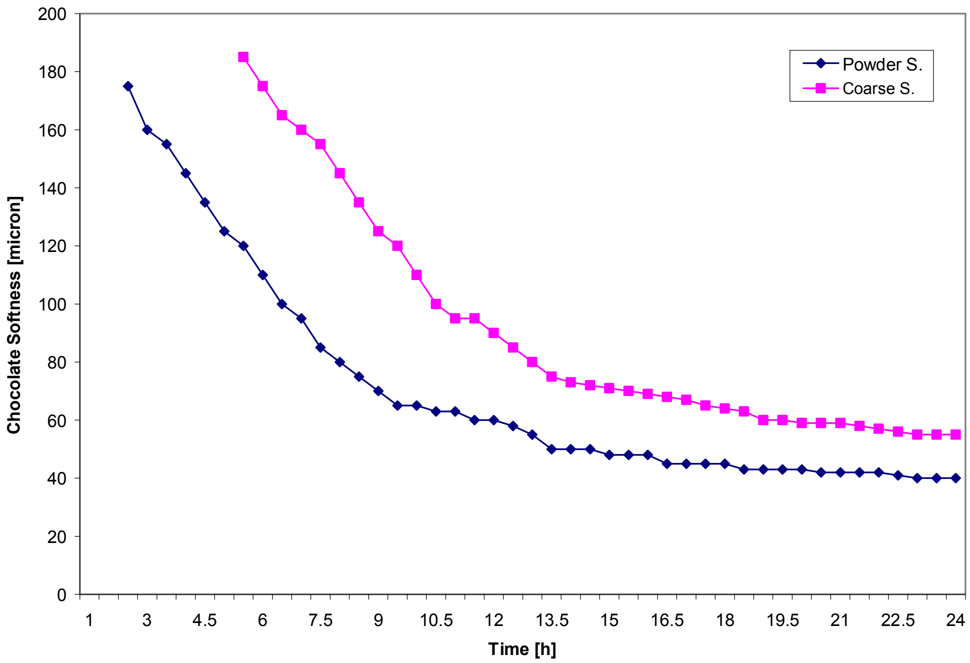

Figure 5. Chocolate softness by the primary mixer using coarse and powder sugar

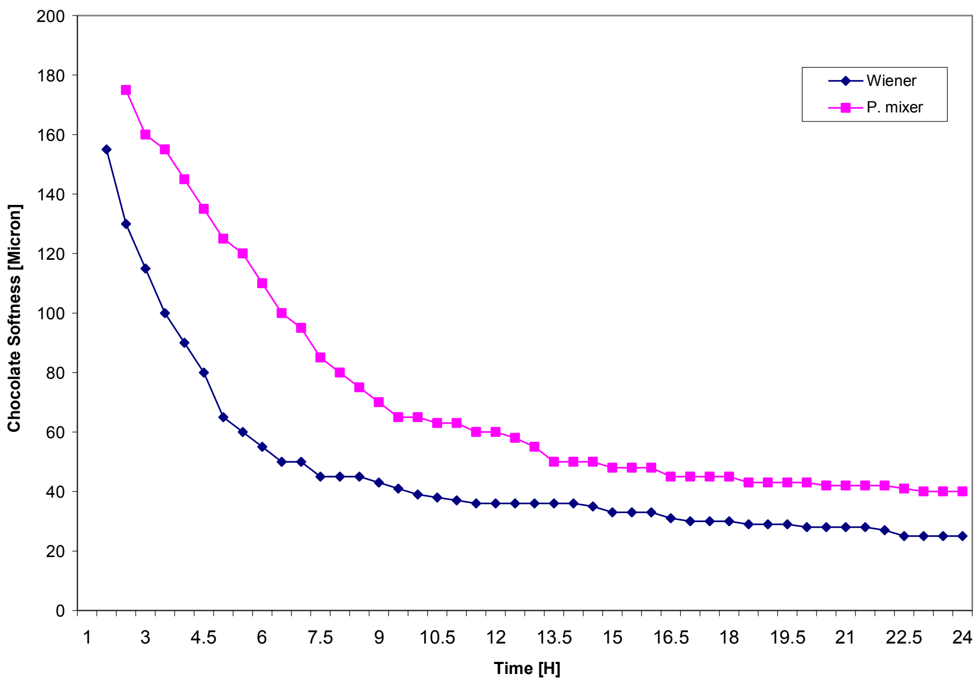

Figure 6. Chocolate softness by the primary mixer and the wiener using powder sugar

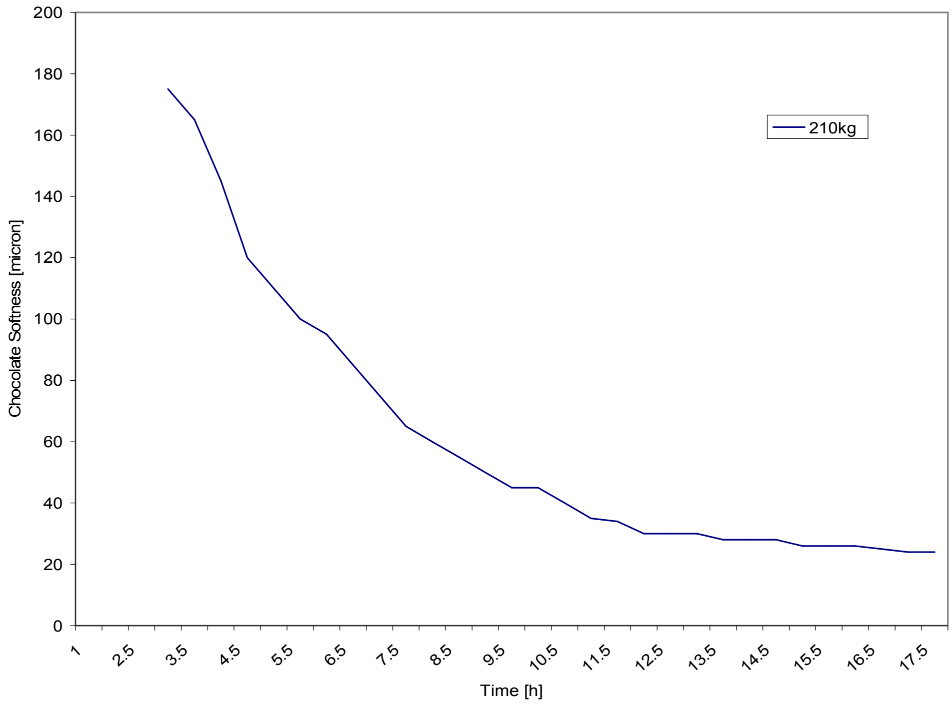

Figure 7. Chocolate softness by the circulation method between primary mixer and wiener of 250 kg using 210 kg of chromic marbles

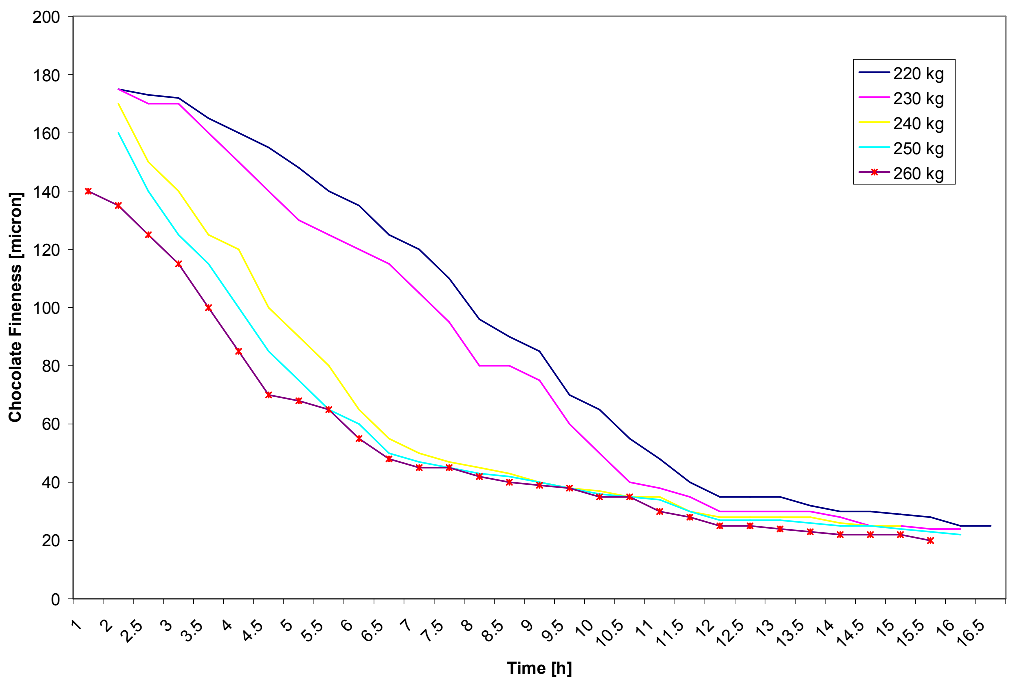

Figure 8. Chocolate softness by the circulation method between primary mixer and wiener of 250kg using (220-260) kg of chromic marbles [5]

5. The wiener of 1000 kg

In view of the success of the 250 kg smaller machines, as well as its positive impact on the elevation of the chocolate delicacy, the factory developed a larger machine of 1000 kg capacity. Figure 9 shows the newly designed machine.

Similar experiments and measurements have been conducted. They all showed positive results. Figure 10 clearly points out that, after raising the marbles weight to 480 and 500 kg, the chocolate softness required (i.e. 25 micron) has been realized after 21 hours of mixing in the 500kg weight, while the 480 kg achieved only 36 micron in the same period of time. However, it should be noted here that, in both curves, chocolate's delicacy level was fixed and increased by five to six consecutive times. This is certainly due to the heavy weight of the mix on the one hand, and to the difficult revolving emanating from friction, on the other. Eventual results demonstrate ample saving in energy consumption and reduction in the cost production due to the reduced mixing time, in addition to improving the quality product.

6. Modeling of a polynomial equation

After undertaking the measurements on different types of chocolate batch, by adding different weights of chrome marble to the Wieners, the idea was about the model of the relationship chocolate softness in and mixing time. The model uses regression analysis that relied on a polynomial function. A polynomial function is one that has the form:

$$y = a_n x^n + a_{n-1} x^{n-1} + \ldots + a_2 x^2 + a_1 x + a_0$$

With n denoting a non-negative integer that defines the degree of the polynomial. A polynomial with a degree of 0 is simply a constant, with a degree of 1 is a line, with a degree of 2 is a quadratic, and with a degree of 3 is a cubic, and so on. Usually, the coefficients a $a_n, a_{n-1}, .., a_1, a_0$ are real numbers [18].

This section presents the model of the chocolate softness by polynomial function of the 2nd order up to the 5th order, using MATLAB or Excel Sheet, so we got the same results.

The way to use MATLAB to perform a curve-fitting is by using the function p = polyfit(x, y, n) which takes a vector x (the independent variable, time), y (measured chocolate softness), and n which is the desired order of the resulting polynomial. The function returns a vector of size n + 1 containing the coefficients of the resulting polynomial.

For example: polyfit (Time, Weight220, 5). Below is the polynomial function representing the result of curve-fitting the data points provided in the chocolate-softness experiment. For the case of 220 kg: The output polynomial function is:

f(t) = (-0.0019)*t.^5 + (0.0769)*t.^4 - (1.0036)*t.^3 + (4.1992)*t.^2 - (12.4545)*t + 189.9761

where t, the time of any mixing hour. It is worth noting that the same results were obtained using Excel Sheet.

$y = -0.0019x^5 + 0.0769x^4 - 1.0036x^3 + 4.1992x^2 - 12.455x + 189.98$

where y, the regression of chocolate softness, and x the time of any mixing hour.

Figure 11 and Figure 12 shows for example, but not limited to, some of the results obtained of the regression functions.

The final regression equations and correlation coefficients are presented in the Table 1. From the correlation coefficients (R), we can observe that the regression function of the third and fourth order achieve good results.

From the above, we note that, the model is presented in order to make it easier to dynamically simulate the chocolate softness of any time of mixing by using the Wieners. The advantage of the model is that it allows one to deal the Wiener machines with the polynomial equation to simulate the chocolate softness.

Figure 9. Newly designed machine (wiener of 1000 kg)

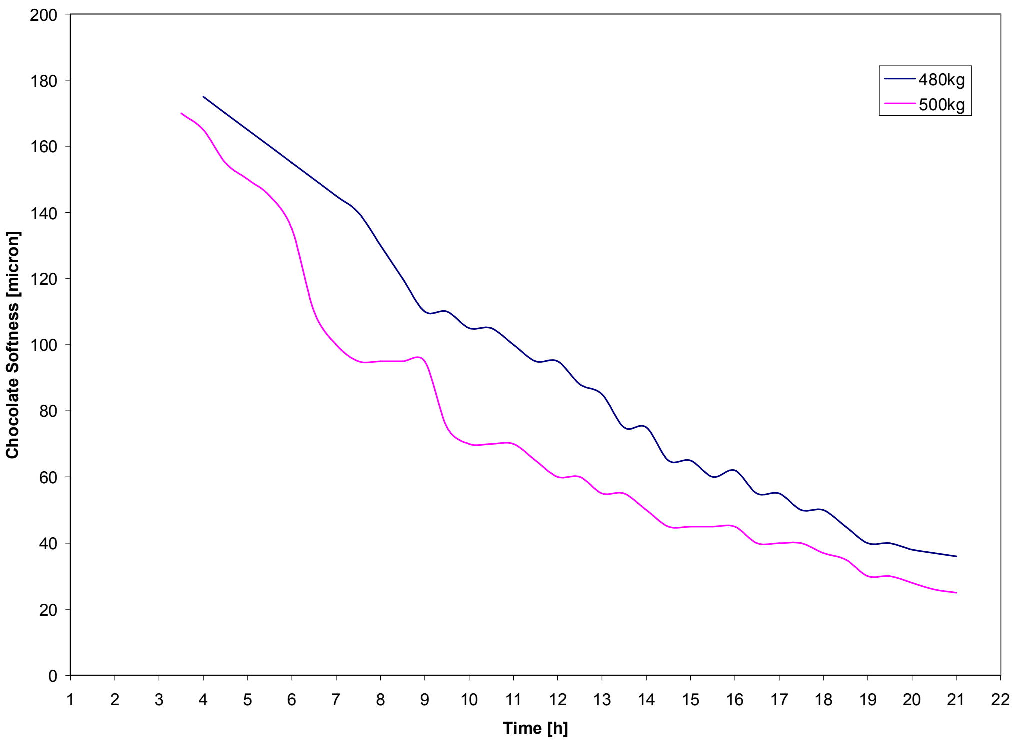

Figure 10. Chocolate softness by the wiener of 1000 kg using (480-500) kg of chromic marbles

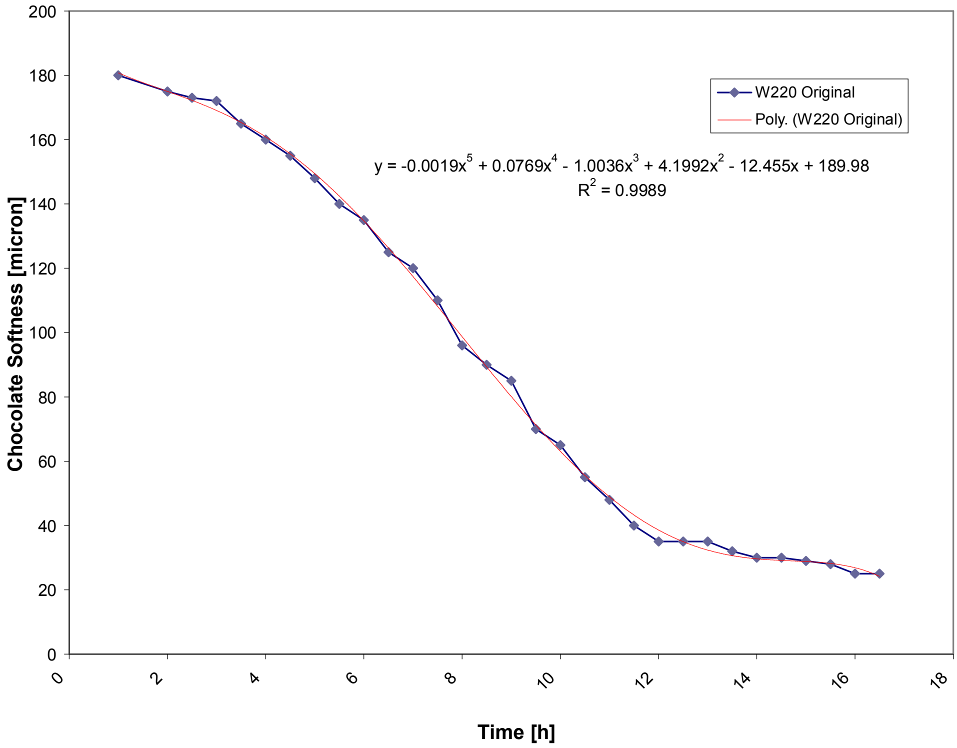

Figure 11. The regression function of chocolate softness of W220

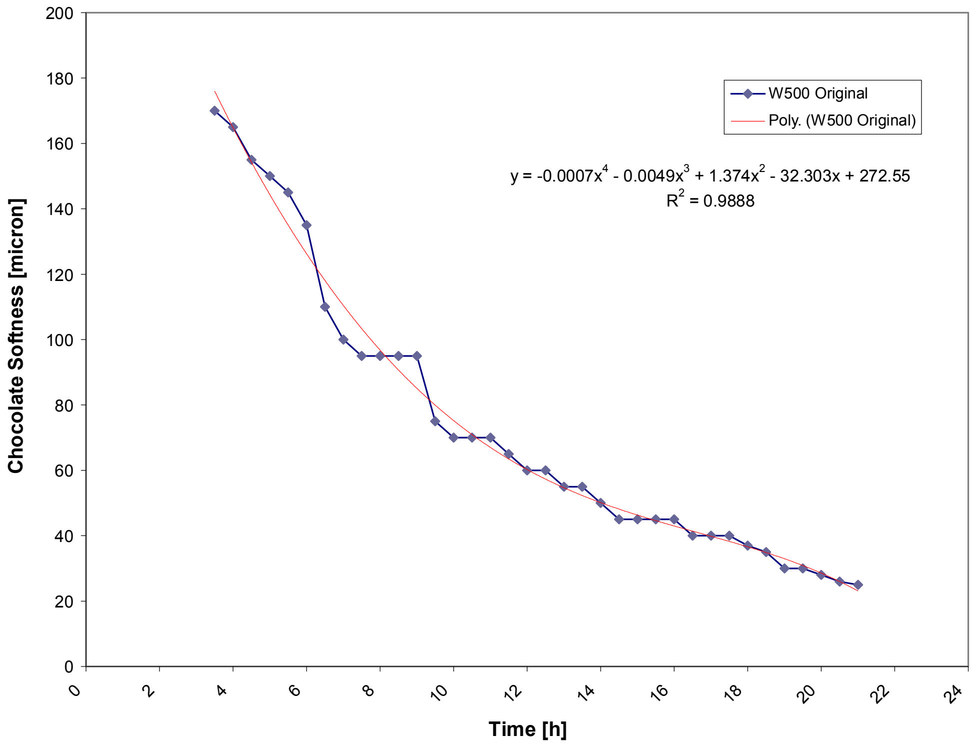

Figure 12. The regression function of chocolate softness of W500

Table 1. The regression equation of chocolate softness and the correlation coefficients

Weight	The Regression Equation	$R^2 =$
W220	$y = 0.3691x^2 - 18.709x + 221.49$	0.971
	$y = 0.1178x^3 - 2.7645x^2 + 4.7115x + 177.94$	0.9963
	$y = -0.0052x^4 + 0.3012x^3 - 4.9032x^2 + 13.969x + 166.61$	0.9971
	$y = -0.0019x^5 + 0.0769x^4 - 1.0036x^3 + 4.1992x^2 - 12.455x + 189.98$	0.9989
W230	$y = 0.5936x^2 - 22.412x + 224.0$	0.979
	$y = 0.0893x^3 - 1.7808x^2 - 4.6651x + 191.05$	0.994
	$y = -0.0073x^4 + 0.3463x^3 - 4.7785x^2 + 8.3104x + 175.18$	0.9957
	$y = -0.0012x^5 + 0.0431x^4 - 0.4543x^3 + 0.8069x^2 - 7.9033x + 189.51$	0.9964
W240	$y = 1.1142x^2 - 29.11x + 211.42$	0.9781
	$y = -0.0612x^3 + 2.7428x^2 - 41.283x + 234.06$	0.9879
	$y = -0.0091x4 + 0.2587x^3 - 0.9876x^2 - 25.135x + 214.3$	0.9915
	$y = 0.0028x^5 - 0.13x^4 + 2.1802x^3 - 14.392x^2 + 13.776x + 179.89$	0.9969
W250	$y = 1.0671x^2 - 27.416x + 196.41$	0.9668
	$y = -0.0934x^3 + 3.5515x^2 - 45.984x + 230.94$	0.9935
	$y = -0.0002x^4 - 0.0847x^3 + 3.4502x^2 - 45.546x + 230.4$	0.9935
	$y = 0.0021x^5 - 0.0928x^4 + 1.3857x^3 - 6.8075x^2 - 15.769x + 204.07$	0.9972
W260	$y = 0.7852x^2 - 21.129x + 162.35$	0.969
	$y = -0.0557x^3 + 2.2668x^2 - 32.203x + 182.95$	0.9828
	$y = -0.0022x^4 + 0.0211x^3 + 1.3716x^2 - 28.328x + 178.2$	0.9832
	$y = 0.0026x^5 - 0.1149x^4 + 1.8118x^3 - 11.121x^2 + 7.9357x + 146.14$	0.9913
W480	$y = 0.2892x^2 - 15.686x + 236.39$	0.9953
	$y = 0.0029x^3 + 0.1819x^2 - 14.475x + 232.44$	0.9954
	$y = -0.0006x^4 + 0.0324x^3 - 0.3331x^2 - 10.827x + 223.76$	0.9954
	$y = 0.0005x^5 - 0.0317x^4 + 0.7689x^3 - 8.4862x^2 + 30.937x + 145.41$	0.9959
W500	$y = 0.5381x^2 - 20.854x + 233.84$	0.9791
	$y = -0.038x^3 + 1.9349x^2 - 36.12x + 281.12$	0.9888
	$y = -0.0007x^4 - 0.0049x^3 + 1.374x^2 - 32.303x + 272.55$	0.9888
	$y = 0.0005x^5 - 0.031x^4 + 0.6934x^3 - 6.0953x^2 + 4.2393x + 208.11$	0.9895

7. Conclusions

The obtained results are summarized as follows:

(1) The model presented relates the chocolate softness and mixing time using tow new design Wieners given by a polynomial equation of the third or the fourth order.

(2) The improved chocolate softness, has simultaneously improved the viscosity and homogeneity of the mixture, and accordingly made the chocolate taste much better than before.

(3) The results of the design and manufacture of the Wiener machine, and the use of circulation method have led to the satisfactory results by reducing the chocolate softness from 55 to 25 microns thus, improving the quality of the product.

(4) The best softness that was realized by the primary mixer by using powder sugar was 40 micron after 22 hours of blending, whereas it was achieved after 9.5 hours by the small wiener.

(5) The curves show that 25 micron required delicacy took 16 hours for a 220kg weight, 14.5 hours for 230kg, 14 hours for 250 kg, and 12 hours for 260 kg weights.

(6) The undertaken measurements show that the smaller wiener has reduced the mixing time from 24 to 12 hours for 500kg chocolate (i.e. 50 percent of the time consumed by the primary mixer, and that the larger wiener has shortened it to 21 hours for a 1000kg chocolate mix. This means that, like the smaller machine, larger machine has also saved mixing time by three hours of the mixing time, i.e. when time counting is measured for a double size of the smaller machine. Hence the larger machine should be considered as reducing as 62.5 percent of the time of the primary mixer.

(7) The curves of the larger machine, i.e. the 1000kg wiener, show a notable consistency of the chocolate softness several times in stages of gradation, while that was not the case in the smaller machine.

(8) As a result of the design and manufactured of the wieners, achieve a financial savings of the factory.

(9) Due to the reduced mixing time, eventual results demonstrate ample saving in energy consumption and reduce the cost production.

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