DESIGN OF A MIXER FOR UNIFORM HEATING OF PARTICULATE SOLIDS IN MICROWAVE OVENS

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ABSTRACT

DESIGN OF A MIXER FOR UNIFORM HEATING OF PARTICULATE SOLIDS IN MICROWAVE OVENS

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The aim of this study is to design a mixer with appropriate parts for uniform treatment of the material in household microwave ovens which can not be achieved with the turntable. The designed mixer's performance was tested by the help of color and surface temperature values.

In the design of the mixer primarily mixing in the vertical and radial directions were sought and for this purpose blades and wings for directing the material especially in these directions were present. The rotational motion of the mixer was provided by a shaft actuated by the motor of the turntable where the motor was replaced by a speed adjustable one.

Couscous macaroni beads wetted with $CoCl_2$ solution were dried for processing in the microwave oven. The initial color values of the samples were L*= 52.0±0.35, a*= 8.8±0.21 and b*= 14.1±0.11 . The studied parameters were microwave power level (10%, 40%, 67% and 100%), processing time (60,90, 120 sec), speed of rotation of the mixer (5,10,15 rpm) , location (4up, 4bt, 6up, 6bt) for the cases of with and without the mixer.

The macaroni beads were well arranged in a mixing container and then put into the microwave oven for operation. Same parameters with coloring experiments were used for the surface temperature determination. After operation the container was photographed by an IR camera.

Whether the designed mixer was present or not, average a* and b* values decreased while temperature increased . All these values were significantly affected by the time and power increase. The L* value became an insignificant parameter to decide for the performance

Location of the particles in the container appeared as a significant parameter affecting the a*, b* and temperature values without the mixer whereas, with the use of the mixer it became an insignificant parameter indicating uniform energy distribution.

Speed of rotation of the mixer was a significant parameter for both cases. However, the color values obtained did not show the same trend with mixer which it showed without mixer.

It is concluded that the designed mixer is effective in providing homogeneity of the product by providing sufficient mixing in the container hence the particles can receive about equal energy.

Keywords: Microwave oven, particulate solids, mixing, mixer design, testing performance, uniform treatment

ÖZ

MİKRODALGA FIRINLARDA TANECİKLİ KATILARIN EŞİT ISITILMASI İÇİN BİR KARIŞTIRICI TASARIMI

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Bu çalışmanın amacı ev tipi mikrodalga fırınlarda dönertabla ile elde edilemeyen eşit düzeyde işleme için uygun parçaları olan bir karıştırıcı tasarımıdır. Tasarlanmış karıştırıcının başarımı renk ve yüzey sıcaklığı değerleri yardımıyla sınanmıştır.

Karıştırıcının tasarımında öncelikle dikey ve çapsal yönde karışım istenmiştir ve bu nedenle nesneleri özellikle bu yönlere yönlendiren bıçaklar ve kanatlar mevcuttur. Karıştırıcının dönel devinimi hızı ayarlanabilen bir motor ile değiştirilen döner tabla motoru tarafından devinime geçirilen bir mil ile sağlanmıştır.

$CoCl_2$ çözeltisi ile ıslatılmış olan kuskus makarnası tanecikleri mikrodalga fırında işlem için kurutulmuştur. Örneklerin ilk renk değerleri L*= 52.0±0.35, a*= 8.8±0.21 ve b*= 14.1±0.11 dir. Çalışılan koşullu değişkenler, karıştırıcının var olduğu ve olmadığı durumda; mikrodalga güç düzeyi (10%, 40%, 67% ve 100%), işlem süresi (60,90, 120 sn), karıştırıcının dönüş hızı (5,10,15 d/dk) , konum (4up, 4bt, 6up, 6bt) ‘dur.

Makarna tanecikleri karıştırıcı kabının içinde düzgün bir biçimde yerleştirilmiştir ve işlem için mikrodalga fırına konulmuştur. Renk deneylerindeki koşullu değişkenlerin aynısı yüzey sıcaklığı saptanmasında da kullanılmıştır. İşlem sonrası kabın üstten IR kamera ile fotoğrafı çekilmiştir .

Tasarlanmış karıştırıcının olduğu ve olmadığı durumda ortalama a* ve b* değerleri sıcaklığın yükselmesiyle düşmüştür. Tüm bu değerler zaman ve güç artışından önemli ölçüde etkilenmiştir. L* değeri başarım için kararı vermede önemsiz bir koşullu değişken olmuştur.

Tanelerin kap içindeki konumu karıştırıcının olmadığı durumda a*, b* ve sıcaklık değerlerini etkileyen önemli bir koşullu değişken olmuştur fakat karıştırıcı kullanıldığında konum önemsiz bir koşulu değişkene dönüşmüştür ki bu da eşit erke dağılımını işaret etmiştir.

Karıştırıcının dönüş hızı iki durum içinde önemli bir koşullu değişkendir fakat karıştırıcı ile elde edilen renk değerleri karıştırıcı kulanılmadığında gözlenen eğilimden değişik eğilim göstermiştir.

Sonuç olarak, tasarlanmış karıştırıcının kap içinde yeterli karıştırmayı sağlayarak tanelerin her birinin yaklaşık eşit erke almasını ve böylece ürünün türdeşliğini sağlamakta etkili olduğu anlaşılmıştır.

Anahtar kelimeler: Mikrodalga fırın, tanecikli katılar, karıştırma, karıştrıcı tasarımı, başarım deneyi, bir örnek işlem

To my family

&

To my grandfather; Fikret Kaftanoğlu

&

To my grandmother; Şaziye Çevik

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CHAPTER 1

INTRODUCTION

1.1 MICROWAVE HEATING

In the industry and houses, the microwave oven has become an important appliance in the past 20 years. There are some benefits of these ovens over conventional cooking methods especially time and energy saving. Microwave technology is newly applied to the processing materails though the use of microwaves for cooking food is widespread. The use of microwave energy for processing materials has the potential to offer similar advantages in reduced processing times and energy savings. (Thostenson, 1999)

While penetrating a food material and microwave energy produces a volumetric heating, due to molecular friction beacuse of dipolar rotation of polar solvents and the conductive migration of dissolved ions. The dipolar rotation is caused by variations of the electrical and magnetic fields in the product. Having dipolar nature, water, as the primary constituent of most food products, is the main source for microwave interactions . Heat is generated throughout the material, leading to faster heating rates and shorter processing times compared to conventional heating, where heat is usually transferred from the surface to the interior(Franca, 2002). However, the application of microwaves can result in uneven heating of certain products, depending on their dielectric and thermophysical properties (Ayappa, Davis, Davis, & Gordon, 1992; Fakhouri & Ramaswamy, 1993).

Because microwaves are electromagnetic waves, they are composed of an electrical and a magnetic field. Microwave wavelengths range from 0.3 to 30 cm (100 MHz to

1 GHz). Microwaves are generated by a device called a magnetron and fed into a cavity, such a domestic microwave oven. The inside walls of the cavity are metallic surfaces that completely reflects the microwaves. A continuous train of reflected waves from the walls combines with the incoming waves from the magnetron to form standing waves inside the cavity, with nodes and antinodes that correspond to the zero and maximum amplitudes of the electrical fields. The cavity sizes and the microwave frequency used are matched to set up a resonant pattern. For microwave heating the energy equation includes a heat generation term, governing equation for heat transport in microwave heating is as the following;

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + \frac{Q}{\rho C_p} \qquad (1)$$

where T is temperature, t is time, α is thermal diffusivity, ρ is density, C_p is heat capacity of the material and Q is the rate of heat generated per unit volume of material.

The heat generated per unit volume of material per unit time (Q) represents the conversion of electromagnetic energy. Its relationship to the electric field intensity (E) at that location can be derived from Maxwell's equation of electromagnetic waves as shown by Metaxas and Meredith (1983):

$$Q = 2\pi \varepsilon_0 \varepsilon'' f E^2 \qquad (2)$$

where the magnetic loses of the food material have been ignored, ε_0 is the dielectric constant of free space, ε'' is the dielectric loss factor of the food, f is the frequency of oven and E is the electric field intensity. electric fields inside the cavity.(Datta, 1990)

Three broad categories of factors influence the heating of foods influence the heating of foods in microwave ovens: oven parameters, food parameters and packaging. The most important and often least understood factors are the dielectric and thermal properties. Dielectric properties refer to the intrinsic electrical properties that affect how materials like foods interact with electromagnetic fields, such as microwaves. (Schifmann, 1993) .The three mathematically linked dielectric properties we need to understand are ε' (the relative dielectric constant (relative to air)) which indicates how well a material will sustain an electric (microwave) field, ε''(the loss factor) which is a measure of its ability to dissipate electrical energy and tan δ (loss tangent) which is related to the material's ability to be penetrated by an electrical field and to dissipate (attenuate) electrical energy as heat.(Mudgett, 1986)

While microwaves heat foods internally, the depth of penetration of the energy varies in different foods. Penetration depth is used to represent the depth at which approximately 63% of the energy has been absorbed. (Schifmann, 1993)

1.2 MIXING AND MEASUREMENT STUDIES IN MICROWAVE PROCESSING

1.2.1 Temperature Distribution and Measurement

Due to the lack of powerful computers and the complicated interactions of electromagnetism with heat and mass transfer, it was nearly impossible to calculate realistic temperature or even electromagnetic field distributions within microwave applicators, especially when products were present. The reason for this is the number of coupled partial differential equations, describing the physical problems of electromagnetism and heat and mass transfer, which have to be solved in a parallel manner.(Knoerzer, 2006)

However, after model calculations, the verification of the simulation is also a very important task, which is not at all simple in the case of microwave applications. The electromagnetic fields are not easily measurable without changing them by the measurement procedure itself. The same is true for the measurement of temperature distributions.(Knoerzer, 2006)

1.2.2 Methods of Measuring Temperature Distribution

• Thermocouples:

Without enormous efforts normal thermocouples cannot be used in microwave devices, since the intense electromagnetic fields which cause heating also disturb the operation of these conventional temperature probes. Furthermore, these probes contain metallic wires and cause unacceptable disturbance of the fields, leading to overheating and possible arcing and destruction of the device, as well as damage to the product. Moreover the method is invasive and only a poor spatial resolution is achievable. (Knoerzer, Regier, Schubert, 2005)

• Fibre Optic Probes:

While the use of fibre optic sensors avoids the problem of a strong interaction with the electromagnetic field, the spatial resolution attainable is often not sufficient. Furthermore, fibre optic thermometers are rather delicate and expensive in comparison to conventional thermocouples and must be placed in contact with the product to be measured. (Knoerzer, Regier, Schubert, 2005)

• Model Substances:

A different approach to determine temperature distributions in microwave devices is the use of model substances that change their properties (e.g. colour, pH value, structure, ete.) after reaching a certain temperature. One published method uses the colour change of the model substance; another uses a coagulation effect of contained proteins. Care has to be taken to match the other important physical properties of the model (e.g. dielectric and thermal properties) to the real product. (Knoerzer, Regier, Schubert, 2005)

- Infrared Thermography:

Infrared thermography provides very good local resolutions and is established for measuring surface temperatures. Even online the infrared sensors provide a reasonably accurate readout of the surface temperature of an object that is in the sensor's field of view. However, in common with conventional contact probes, infrared sensors are metallic and cannot be placed inside the electromagnetic fields of a microwave heating assembly. Furthermore, most measurements have to be done through a shield window because the sensitive electronics inside the infrared sensors require extensive electromagnetic shielding to allow accurate measurements in the presence of electromagnetic (EM) fields. Thus, the efficiency and accuracy of the temperature measurement, which in any case represents only the surface temperature of one part of the heated product, are reduced. (Knoerzer, Regier, Schubert, 2005)

- Microwave Radiometry:

The principle and thus the assets of microwave radiometry are similar to those of infrared thermography, except that the thermal energy detected and used as basis for temperature estimation is in the microwave frequency range rather than the infrared region. As the penetration depth of radiation in the microwave frequency range is much higher than in the IR frequency range, internal temperatures not too far away from the surface can also be observed. But again, especially in volumetric heating methods like microwave heating, the measuring of surface or near-surface temperatures is not sufficient. For information about the whole internal temperature distributions the product has to be destroyed. (Knoerzer, Regier, Schubert, 2005)

- Liquid Crystal Foils and Thermo Paper:

Liquid crystal foils and thermo paper are also established methods for measuring temperature distributions. But methods also provide only surface temperature mapping. Furthermore the use of thermo paper only conveys information about the temperature being above or below a certain threshold. (Knoerzer, Regier, Schubert, 2005)

- <u>Magnetic Resonance Imaging (MRI)</u>

By using magnetic resonance imaging as a tool for temperature measurement, almost all the above-mentioned problems can be avoided. MRI allows a non-invasive three-dimensional measurement of temperature distributions even inline, meaning that the probe does not have to be in contact with the product, the product does not have to be destroyed for information about internal temperature measurements, every wet product can be observed during or after microwave heating, good spatial resolutions can be achieved, and not only surface temperatures but also inner temperature distributions can be measured. The large drawback of this technique is that the costs for an MRI tomograph exceed the costs for all devices mentioned above by orders of magnitude. (Knoerzer, Regier, Schubert, 2005)

1.3 MIXING

1.3.1 Mixing of Solids

Mixing of solids is a widespread and important unit operation in food processing. Some mixes are products themselves, while others are preliminary steps in more complex processes. Historically, mixing of solids has been studied empirically because there seemed to be little fundamental understanding. However, this has changed relatively recently, as physicists and engineering researchers have recognized the importance of solids behavior and the intellectual challenge and satisfaction of solving problems in this area.(Clark, 2004)

Due to the complex nature and high number of parameters involved in the process, the mechanism of mixing is still far from being clear. For each mixing method a characteristic mechanism determines the rate and the attainable degree of mixing. The mixing quality, i.e. the degree of homogeneity is especially important when a relatively small amount of an active ingredient is to be distributed in a large quantity of bulk solids or powders. (Bauman, 2001)

It has been more than 40 years since the action of three different mechanisms was assumed. Namely: (i) convective mixing—which means the transfer of larger particle groups from one location to another, (ii) diffusive mixing—defined as the distribution of particles over a freshly developed surface, and (iii) shear mixing—setting up of slipping planes within the mixture. Later on, it was shown that diffusive-type mixing takes place not only on free surfaces, but within particle beds, too. It has also been revealed that the situation in real systems is more complex, because in the majority of mixers, several mechanisms take place simultaneously (Gyenis, 1999)

1.3.2 Motionless (Static) Mixers

Motionless or static mixers are flow-modifying inserts, built into a tube, duct or vessel. These tools do not move themselves, but using the pressure difference or the kinetic and potential energy of the treated materials, create predetermined flow patterns and/or random movements, causing velocity differences and thus relative displacements of various parts of the moving material. In this way, motionless mixers can considerably improve the process to be carried out. In fluids, motionless mixers work efficiently both in turbulent and laminar regions. Splitting, shifting, shearing, rotating, accelerating, decelerating and recombining of different parts of materials are common mechanisms in this respect, both in fluids and bulk solids.(Gyenis, 2002)

Motionless mixers eliminate the need for mechanical stirrers and therefore have a number of benefits: No direct motive power, driving motor and electrical connections are necessary. The flow of materials (even particulate flow) through them may be induced either by gravity, pressure difference or by utilizing the existing potential or kinetic energy. The space requirement is small, allowing a compact design of equipment in bulk solids treatments. Installation is easy and quick, e.g. by simple replacement of a sectionof tube or by fixing inserts into a tube or vessel. Set-up and operating costs are much lower than those of mechanical mixers, while maintenance is practically superfluous. Motionless mixers are available in a number of different types, shapes and geometries, made from a great variety of materials. The mixer can therefore easily be matched to process requirements and to the features of the processed materials. Physical properties, e.g. flow behavior, particle size, mechanical strength, abrasive effects, safe prescriptions. e.g. for food and pharmaceutical industries, can be taken into account by the proper design of mixers.(Gyenis, 2002)

1.3.3 Techniques for improving heating uniformity

Heating uniformity in microwave processing can be improved in different ways. Among such techniques can be mentioned the modification of relevant food or package parameters in order to optimize the heating uniformity based on modelling and suitable schemes for describing and evaluating the selected optimization parameter. These tools are today important in food product development. The same concept may also be used in microwave oven design. Other complementary aspects related to techniques for improving heating uniformity are, on the other hand, oven devices like rotating turntables in household microwave ovens or moving conveyor belts in industrial appliances, but also mode stirrers which may often result in improved uniformity. There are also several different patents and solutions for exciting the microwaves in a way which results in a more uniform field pattern.

The introduction of a mode stirrer in several types of oven will assist for a selection of the possible modes to exist in the cavity, as determined by the rotational speed of the mode stirrer. Alternatively, or as a combination, movement of the food through the field on a rotating turntable at the bottom of the cavity makes it possible for temperature differences to be partly leveled out, since the field pattern will be affected accordingly. Even if rotating turntables and mode stirrers may to some extent often result in more leveled out heating patterns, the need for a proper design of the food and package, as well as of the relevant oven parameters is still obvious.

Modeling of microwave processes may serve as a tool to learn more about a process, and for improving the heating uniformity by finding the optimal values of relevant food and package parameters, or alternatively relevant oven parameters. In many practical situations it can also be used to reduce the number of experiments needed to find the best design of a food product. The previously empirically based product development of microwave foods has been replaced by numerical modeling, followed by validation, computer simulations and optimization. (Wappling-Raaholt, Ohlsson, 2005)

1.3.4 Previous Designs for Microwave Ovens

- Publication Year/ No: 1988 / JP 63184285 A
  Name: A Removable Drum For Microwave Ovens
  Country: Japan

This design includes a single drum that has two sides one of which is fixed to the base of the oven with a support and the other is placed on the main shaft that rotates the turntable. The flights in the drum were attached to the shaft. This shaft is placed on another shaft responsible for rotating turntable by the help of a gear mechanism. The flights become mobile with the impulse created by the shaft and rotates around the axis perpendicular to the turntable shaft. The food inside is mixed by this movement. No data in the literature is found out that measures the effectiveness of this design . The parts and the whole design are drawn in Figure 1.

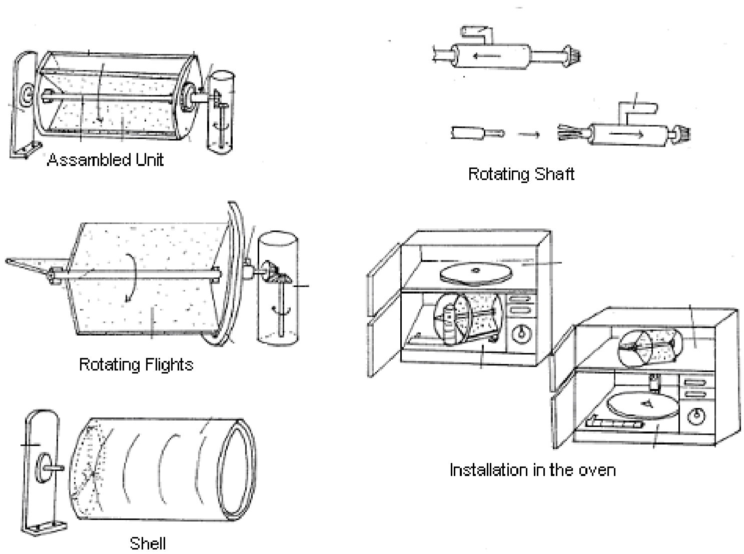

Figure 1 A removable rotary drum for microwave ovens

- Publication Year/ No: 2007 / CN 201087969 Y
  Name: Rotary Microwave Heating Mechanism For Solid Materials
  Country: China

In this design, a magnetron located in the body of a rotary drier causes the solid food to dry while they are going downwards by rotational movement. For this movement another mechanism beside the oven is used. This design is similar to microwave assisted rotary dryer. Its comparison with conventional one was studied and a significant decrease of operation time was observed (Bertelli & Marsailoi, 2005). However, the effect of this design to uneven heating is a mystery. The Fig. 2 displays the original drawing of the design.

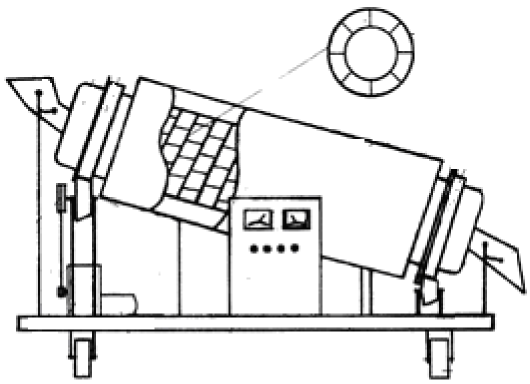

Figure 2 A rotary microwave heating mechanism for solid materials

- Publication Year/ No: 2006 / DE 10 2005 016179 A1
  Name: A Vertical Stirrer Fixed on a Rotating Shaft For Microwave Ovens
  Country: Germany

In this project, an integrated joint bar is fixed to any wall inside the microwave oven. A vertical stirrer (spoon, etc.) is attached to this bar. When the oven is switched on, the turntable turns and this stirrer works. Any measurement about this stirrer is not found yet by the author. The original drawing of the design can be seen in Fig. 3.

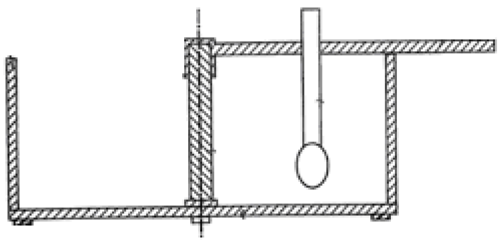

Figure 3 A vertical stirrer fixed on a rotating shaft for microwave ovens

- Publication Year/ No: 1990 / GB 2 230 409 A
  Name: Food Stirrer for Microwave Ovens
  Country: United Kingdom

In this design, there is a mixing bowl with a turntable having a mixing apparatus. The mixing apparatus is attached to the bar fixed to any wall of microwave. When the oven is operating, the bowl is moving with the turntable and the fixed stirrer will mix the food in it. Fig 5. displays the original drawings of the design.

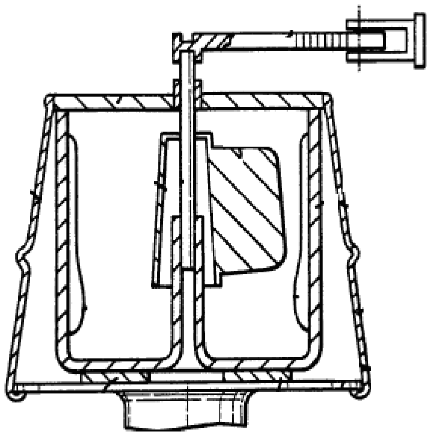

Figure 4 Food stirrer for microwave ovens

- Publication Year/ No: 1998 / GB 2 322 271 A
  Name: Food Stirrer for Microwave Ovens
  Country: United Kingdom

In this design, like the previous one a shaft is mounted on the inner walls of microwave ovens. This design is different from the previous one as the shape of the stirrers are like blender blades and the stirrer have impellers. In the literature, any study about the effect of this stirrer has not been found yet by the author. Fig 5. displays the original drawings of the design.

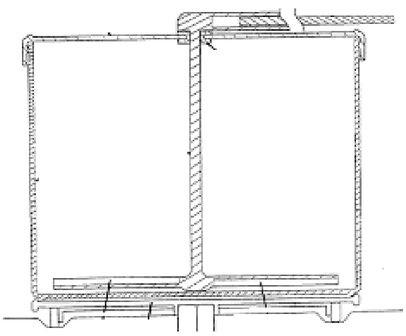

Figure 5 Food stirrer for microwave ovens

- Publication Year/ No: 2007 / GB 2 434 328 A º
  Name: Microwave Stirrer
  Country: United Kingdom

This design is similar with the previous designs in the manner of working principle but the difference is that the apparatus is not fixed on the wall but hang up on the wall by a vacuum filter. The spoon mixing the food is static while the turntable is turning and the food is mixing. The shape in Fig. 6 reflects the design.

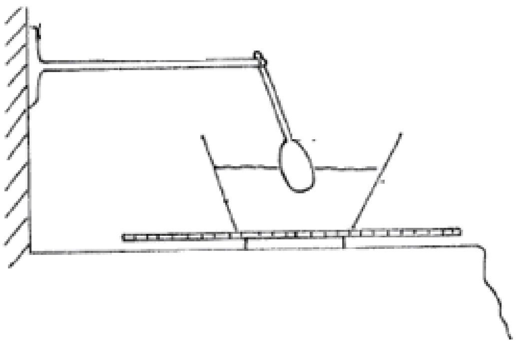

Figure 6 Microwave stirrer

- Publication Year/ No: 1993 / WO 93/10648
  Name: Microwave Stirring Device
  Country: United Kingdom

In this design, different from the others, the apparatus is composed of flights that is on the support mounted on the oven wall and mixing was achieved as the container move with the turntable. The design is given in Fig. 7.

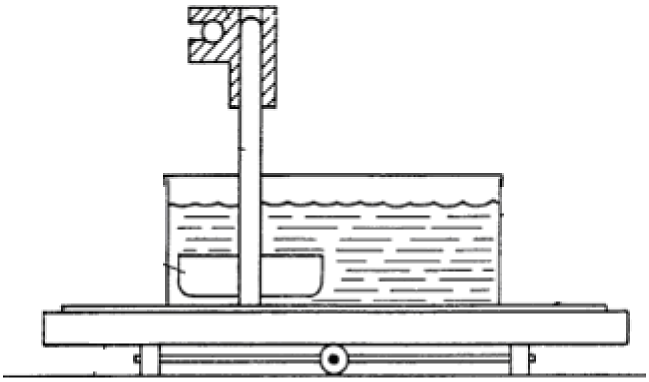

Figure 7 Microwave stirring device

• Glass Agitator

Another mixer designed in the study by Secmeler (2003) was a six-blade impeller manufactured with 6 mm. glass tubes. The blades were fixed to the vertical shaft attached to the mid-point of the overhead support tube. The blades were located to the shaft as seen in the Figure 8.

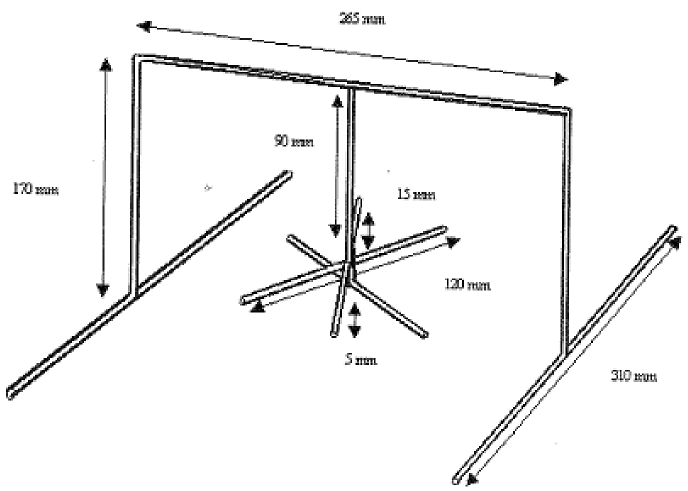

Figure 8 Glass Agitator

- Publication Year/ No: 2009 / TR 2009/015674
  Name: Microwave Oven with Rotating Drums
  Country: Turkey

In the study by Cilvez (2009) rotating drums were placed in a microwave oven These drums were connected to shaft which was als connected to the oven's motor with the connector piece. The rotational motion of these drums was actuated by the turntable motor. The drums roll on a circular path mixing the particle in r axis and with the flights inside the mixing occurs.

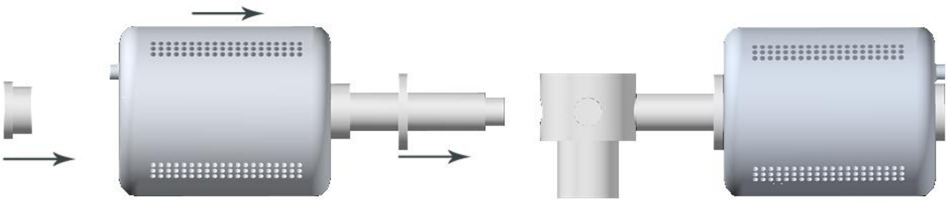

Figure 9 The Rotating Drums

1.4 MATHEMATICAL INTERPRETATION OF THE DESIGN

Conservation of mass, energy and momentum is a rule for all systems. The mathematical form of the conservation equations is given as; (Brodkey & Hershey, 1989)

$$\frac{\partial \psi}{\partial t} + (U \bullet \nabla \psi) = \dot{\psi} + (\nabla \bullet \delta \nabla \psi) - \psi (\nabla \bullet U) \tag{3}$$

When sample is being heated, the property such as color value or temperature is a function of time and three dimensions expressed as;

$$\psi = f(t,3D) \quad (4)$$

where t stands for time and D for dimension.

Considering the domestic microwave ovens, the dimension parameters affecting the distribution become t, r, Θ and z.

$$\psi = f(t,r,\theta,z) \quad (5)$$

With the mixer designed in this study, the sample inside the oven is provided to move in three dimensions mentioned above, then the property will only be a function of time.

$$\psi = f(t) \quad (6)$$

1.5 OBJECTIVES OF THE STUDY

Using microwave ovens in homes and industry is a time and energy saving operation, however non-uniformity in the energy distribution blocks its further usage. In addition to this, it is not possible to achieve more uniform heat treatment without any mixing.

In this study, we aimed to design a new mixer with the required parts to improve the uniformity of the treatment as turntable is not an adequate solution.

The mixer was designed to maintain mixing within the granular bulk solids in the mixing container which was already designed for the mixer to use the motor rotating the turntable. This motor was aso changed with a different motor fits the same location with a control card which enabled the change in speed of rotation.

The need for mixer was verified before testing it by using two different methods. First one was using a thermal marker ($CoCl_2$), and the other was using infrared thermography. In the first method the output examined statistically was the color values L*, a* and b*. The latter gave the surface temperature results to analyze the mixer's performance. Also the determination of the relation between color and temperature values was identified by regression analysis.

CHAPTER 2

MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 Macaroni Beads

The couscous macaroni beads (Selva, Turkey) used in the experiments have an average diameter of 3.54±0.03 mm, an average thickness of 2.23±0.07 mm , an average weight of 0.02g/bead and a shape like short cylinder.

2.1.2 Cobalt Chloride Solution

50 g of cobalt (II) chloride hexahydrate (Riedel-de Haen , Germany) was dissolved in one liter of distilled water. The prepared solution was mixed until no sedimentation occurs. Cobalt (II) chloride hexahydrate changes its color from red to blue as it dries.

2.1.3 Microwave Oven

The home type microwave oven used (BOSCH HMT 872 L, Germany) has a cavity of 21,5 x 36 x 33 cm and maximum power of 900 W. It is operating at 2450 MHz with 5 power levels; 10%, 20%, 40% 67% and 100%. The exact value for these levels were determined by IMPI 2-L test (Buffer,1993). The IMPI 2-L test procedure is given in Appendix A.

2.1.4 Balance

For measuring weights, a portable digital scale (KERN (EW) EW-1500-2M) with a sensitivity of 1/100 g was used.

2.1.5 Oven

For the determination of the relation between color values and temperature, an oven (ST-055, Şimşek Laborateknik) was used .

2.1.6 Infrared Camera

For infrared thermography of the samples, ThermaCam SC640 (FlirSystems) was used.

2.1.7 Color Reader

For obtaining CIE L* a* b* values, a color reader (Konica Minolta CR-10, Japan) was used.

2.1.8 Motor

A motor which has the ability to change its speed by the help of a control card used instead of the original motor of microwave oven which was responsible for rotating turntable.

2.1.9 Control Card

A control card was connected to motor mentioned above for changing its speed.

2.2 MECHANICAL DESIGN

2.2.1 The Scope of the Design

In this study, whole system was designed to use the motor inside the microwave oven giving the motion to turntable for mixing the food inside the mixing container in three axis, namely radial, rotational and vertical. For this purpose, a mixing container and a mixer having 5 different parts are designed. The whole design can be seen in Figure 10. The names of the parts are the main shaft, arm, side scrapper, blade, base scrapper. In construction of all parts, PTFE (Polytetraflouroethylene) was used. The reason of the usage of this material was because it does not reflect microwaves. Because it does not melt easily and absorb microwave energy to itself, it is used for construction of this mixer.

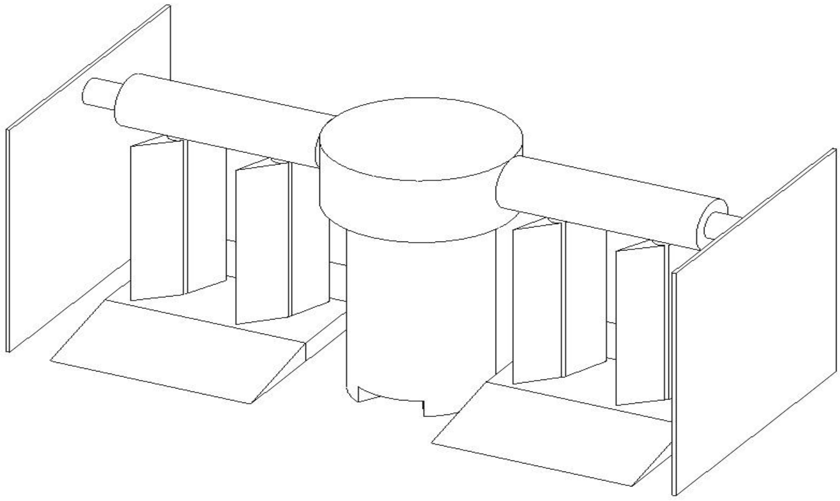

Figure 10 The Mixer

2.2.2 The Working Principles of the Design

The turntable was removed from the microwave oven. Then, the mixing container was put into microwave oven in a position that the mixer could be connectod to the connector. The shaft was connected to the connector placed on the rotator motor of the microwave oven which was responsible for the movement of turntable. The bottom of the shaft was manufactured to fit the connector without any extra effort. When the motor begins to work, the base scrapers causes vertical and rotational, blades cause radial movement while side scrapers avoid agglomeration on the inner surface of the container walls.

2.2.3 The Parts of the Mixer

The Shaft:

The main part that transmits the movement of the motor to the functional parts of the mixer is the shaft (Fig. 11). This cylindrical shaft was easily connected to the connector because the base of the shaft was designed according to the connectors shape. The height of the shaft was higher than that of center funnel of the mixing container in order to fix the arms on the shaft. For this fixing it had two symmetric holes with nearly same diameter with the ends of the arms. The upper part of the shaft which was responsible for connection of arms was thicker than lower part because of the lifting requirements of the other parts which is non-reactive to microwaves due to its molecular stability. PTFE has a high melting point and convenient dielectric properties, which make it an appropriate material for insulation of cables and manufacturing goods for microwave systems.

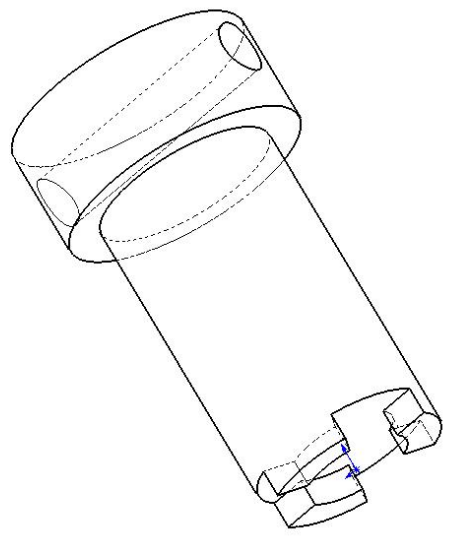

Figure 11 The Shaft

The Arm:

The Arms were responsible for holding the side scrapers and the blades. One end of the arm was designed to connect with shrink-fit joining method to the main shaft whereas the other was to the side scrapers. Also, it has two holes parallel to the main shaft which made the blades connect to the arm. The designed arm was displayed in figure 12 and cylinder in shape.

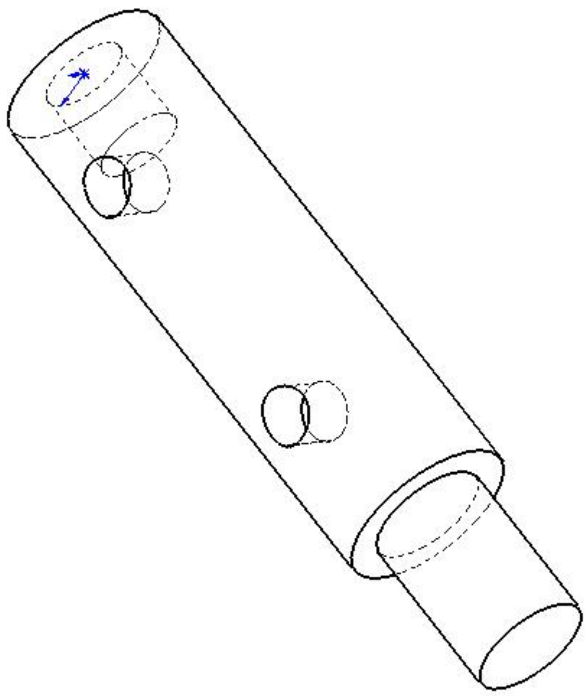

Figure 12 The Arm

The Blade:

The blades were designed perpendicular to arm. It had two central rims at upper and lower surface of blades. The upper rim was connected to arm while the lower was responsible for the connection of base scrapers. It was designed diamond-shaped when it was seen from the upper and lower sides because this type of shape allowed the sample go in the diverted direction easily. This blade cause mixing in radial direction.

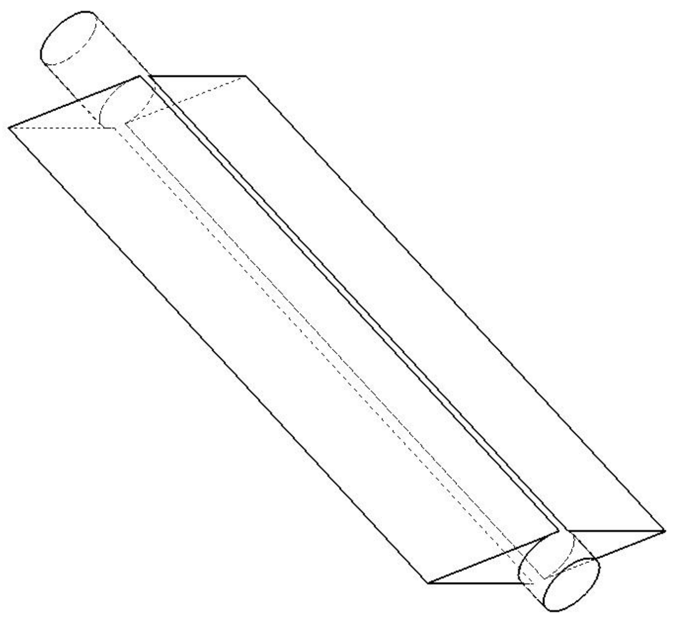

Figure 13 The Blade

The Side Scraper:

The side scraper was in rectangular shape located at the two horizontal ends of the mixer. When the mixing started, some amount of sample agglomerated at the side walls. To avoid the agglomeration and to add these parts of the sample to the mixing, the side scraper was added as a part of the mixer.

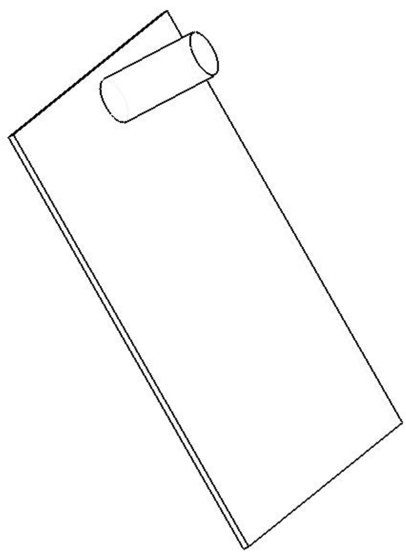

Figure 14 The Side Scraper

The Base Scraper:

The base scraper was a part of the mixer that provided the vertical and rotational mixing. It was designed as an addition of two symmetrical inclined surface to a plain surface. On this plain surface there were two holes for the blades to be connected. When the motion starts, the sample was goingt upwards from these inclined surfaces, and then it got intouch with the blades and changed its radial position. While the sample was moving on the inclined surfaces by the help of the act of the other beads, the sample also moved on the rotational direction.

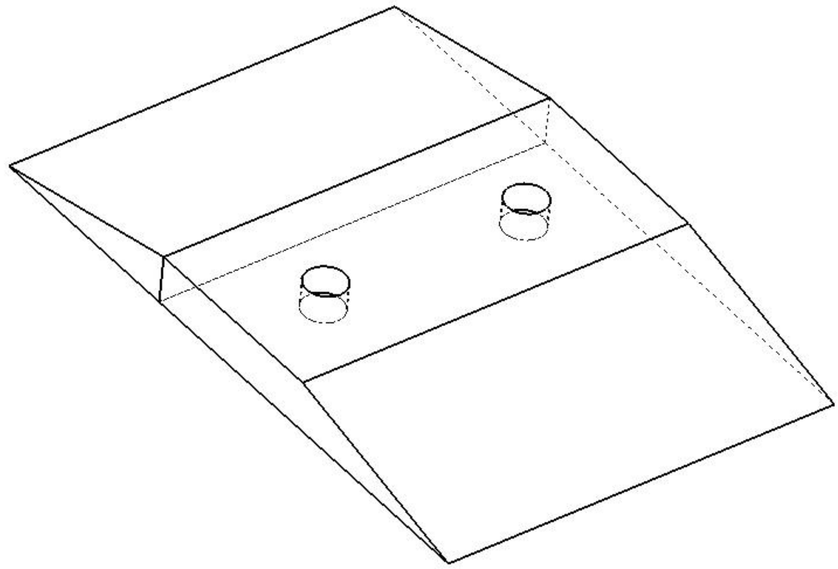

Figure 15 Base Scraper

The Mixing Container:

Besides the conventional containers used in the microwave oven, another mixer was needed for this mixer. Because this mixer used the motor of the turntable at the center, there became a requirement of a funnel for the main shaft to be connected to the connector. The mixing connector was designed and manufactured to meet this requirement with a funnel allowed the shfat go through in it at the center of the mixing container. The mixing container was made up of borosilicate glass that had desirable properties for using in a microwave oven

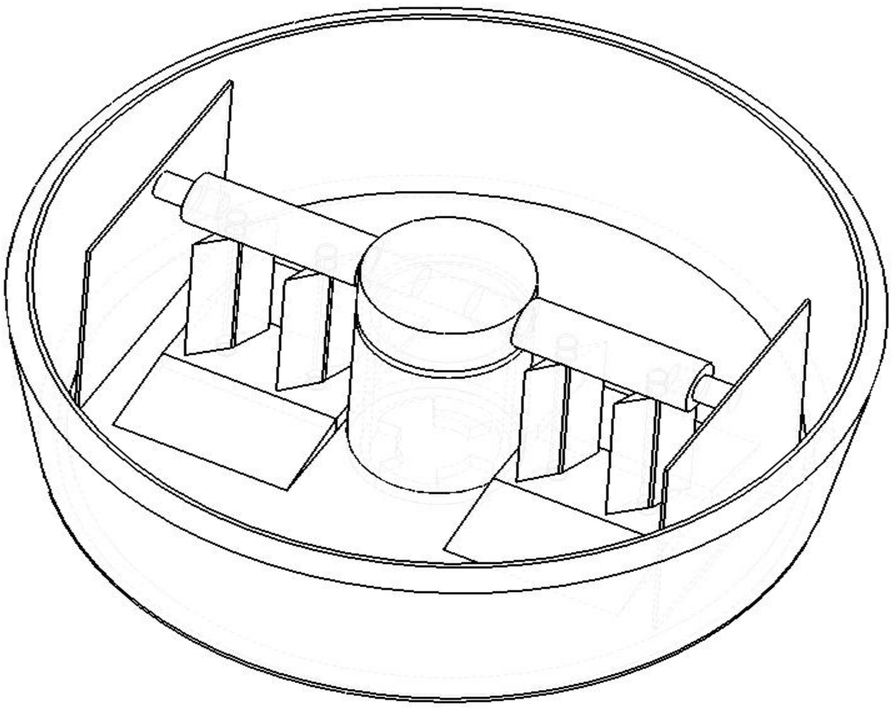

Figure 16 The Mixer and the Mixing Container

2.3 METHODS

2.3.1 Coloring Experiments Performed on Turntable for Verification of the Mixer

60 grams of couscous macaroni beads per layer was weighed and wetted by 30 mL of 5 % (w/w) Cobalt (II) Chloride hexahydrate solution for 30 seconds. The excess solution which was not absorbed was removed and then the sample was dried to maximum 20 % by the surrounding air for preventing cooking in microwave oven. After drying, the macaroni particles will be separeted from each one if sticked and placed in a container, 20 cm. in diameter, in well-arranged position. For bilayer samples, in order to examine the bottom layer, a microwave cling film was positioned between layers. The colored macaroni beads were processed in the

microwave oven for 10, 40, 67 and 100 % power levels for 60, 90 and 120 seconds with three replicates. After the process, the container was taken out of the oven and a board with holes at the 0, 2, 4, 6, 8 cm. far from the center was placed on the container. The color values of the processed sample were measured at these holes. The values were recorded and analyzed statistically.

2.3.2 Coloring Experiments Performed without the Mixer for Testing

240 grams of couscous macaroni beads per layer was weighed and wetted by 120 ml. of 5 % (w/w) Cobalt (II) Chloride hexahydrate solution for 30 seconds. The excess solution which was not absorbed was removed and then the sample was dried to maximum 20 % by the surrounding air for preventing cooking in microwave oven. After drying, the macaroni particles will be seperated from each one if sticked and placed in the mixing container, 20 cm. in diameter, in well-arranged position. The colored macaroni beads were processed in the microwave oven for 10, 40, 67 and 100 % power levels for 60, 90 and 120 seconds at 5, 10 and 15 rpm speed with three replicates. After the process, the container was taken out of the oven and samples taken 4 and 6 cm far from the center and from upper and bottom part was placed on a petri dish. The color values of the processed sample were measured at these Petri dishes and analyzed afterwards.

2.3.3 Coloring Experiments Performed with the Mixer for Testing

240 grams of couscous macaroni beads per layer was weighed and wetted by 120 ml. of 5 % (w/w) Cobalt (II) Chloride hexahydrate solution for 30 seconds. The excess solution which was not absorbed was removed and then the sample was dried to maximum 20 % by the surrounding air for preventing cooking in microwave oven. After drying, the macaroni particles will be seperated from each one if sticked. The turntable was removed from the oven and the mixing container is placed instead. The

mixer is placed on the motor rotating turntable through the hole of the mixing container. After placing the mixer, the sample was placed in the mixing container in well-arranged position. The colored macaroni beads were processed in the microwave oven for 10, 40, 67 and 100 % power levels for 60, 90 and 120 seconds at 5, 10 and 15 rpm speed with three replicates. After the process, the container was taken out of the oven and samples taken 4 and 6 cm far from the center and from upper and bottom part was placed on a petri dish. The color values of the processed sample were measured at these Petri dishes.

2.3.4 IR Experiments Performed without the Mixer for Testing

240 grams of couscous macaroni beads per layer was weighed and placed in the mixing container, 20 cm. in diameter, in well-arranged position. The colored macaroni beads were processed in the microwave oven for 10, 40, 67 and 100 % power levels for 60, 90 and 120 seconds at 5, 10 and 15 rpm speed with three replicates. After the process, the container was taken out of the oven and by an infrared camera sample was photographed thermally for future thermogram analysis.

2.3.5 IR Experiments Performed with the Mixer for Testing

The turntable was removed from the oven and the mixing container is placed instead. The mixer is placed on the motor rotating turntable through the hole of the mixing container. After placing the mixer, the sample was placed in the mixing container in well-arranged position. 240 grams of couscous macaroni beads per layer was weighed and placed in the mixing container in well-arranged position. The colored macaroni beads were processed in the microwave oven for 10, 40, 67 and 100 % power levels for 60, 90 and 120 seconds at 5, 10 and 15 rpm speed with three replicates. After the process, the container was taken out of the oven and by an infrared camera sample was photographed thermally for future thermogram analysis.

2.3.6 Experiments for Determination of the Relation Between L*, a*, b* and Temperature Values

10 grams of sample was placed in a petri dish and left in an oven for a day at 40, 50, 60, 70, 80, 90, 100 ºC in triplicates. The color values were measured by color reader.

2.3.7 Statistical Analysis

Statistical analyses were performed using Minitab Statistical Software (Minitab 13). ANOVA (Analysis of Variance) was used for determining the effects of power, time, speed, location and the mixer designed in a significance level of 0,95.

2.3.8 Thermogram Analysis

For thermogram analysis, the infrared photographs were analysed by using ThermaCam Reseracher Pro program. In this program , the individual temperetaure values were found out at 2, 4, 6, 8 cm from the center and the average temperetaure value with its standard deviation of the whole line passing through these points. These values were further analysed statistically.

CHAPTER 3

RESULTS AND DISCUSSION

Color and temperature values were evaluated and analyzed for testing the effectiveness of the mixer's performance. For this purpose, regression analysis was made to determine the relation between color and temperature.

3.1 COLOR ANALYSIS

The change in the L* value from 0 to 100 indicates the color changes between black to white. A material having a positive a* value is red-purple in color whereas negative a* value in bluish-green. Positive and negative b* values indicate yellow and blue colors, respectively.

The CIE system values of each sample were measured at 5 different points (0,2,4,6,8) in verification experiments, however for testing experiments four data points (4up, 4bt, 6up, 6bt) were used with triplicates.

The $CoCl_2$ hexahydrate particles has dark pink color before mixed with water. After the mixing solution becomes red in color. The particles wetted with this solution becomes blue after heating owing to partial drying.

The wetted particles that would be processed had the initial color values of L* = 52 ± 0.35 , a* = 8.8 ± 0.21 and b* = 14 ± 0.11.

3.1.1 Verification of Mixer

The need for newly designed mixer must have been verified. For this verification, a distribution throughout the location was determined by processing 60 grams of couscous macaroni for 10, 40, 67 and 100 % power levels for 60, 90 and 120 seconds in a well arranged position in a container in both mono and bilayer cases. After the process color values were measured and the following figures (Figure 17-19) were drawn. At 120 sec, the center point began to burn which resulted in a drop in L* value. (Figure 20)

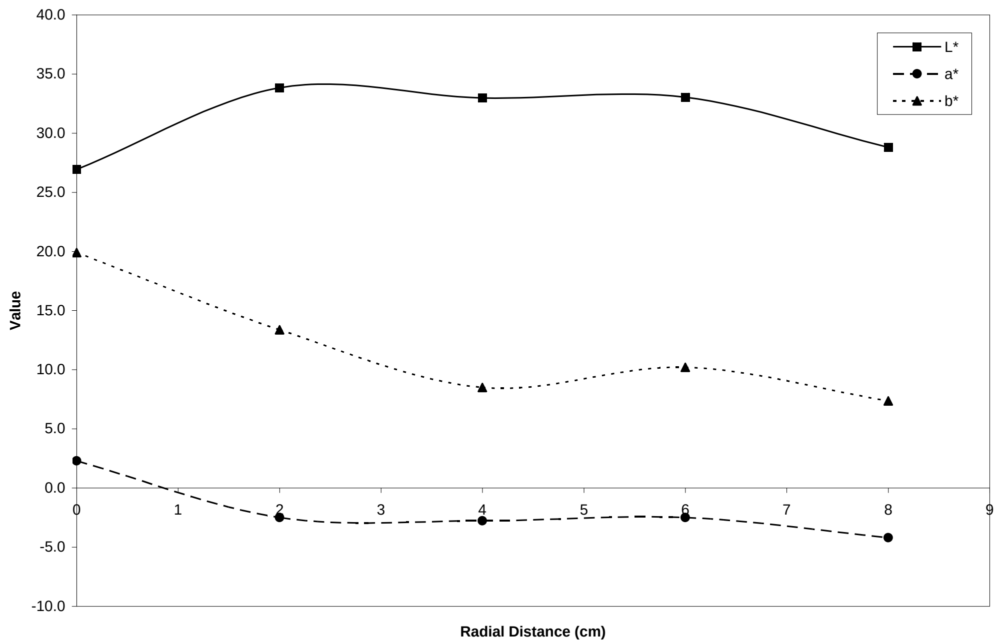

Figure 17 Energy distribution with 100 % power in 120 seconds for the monolayer

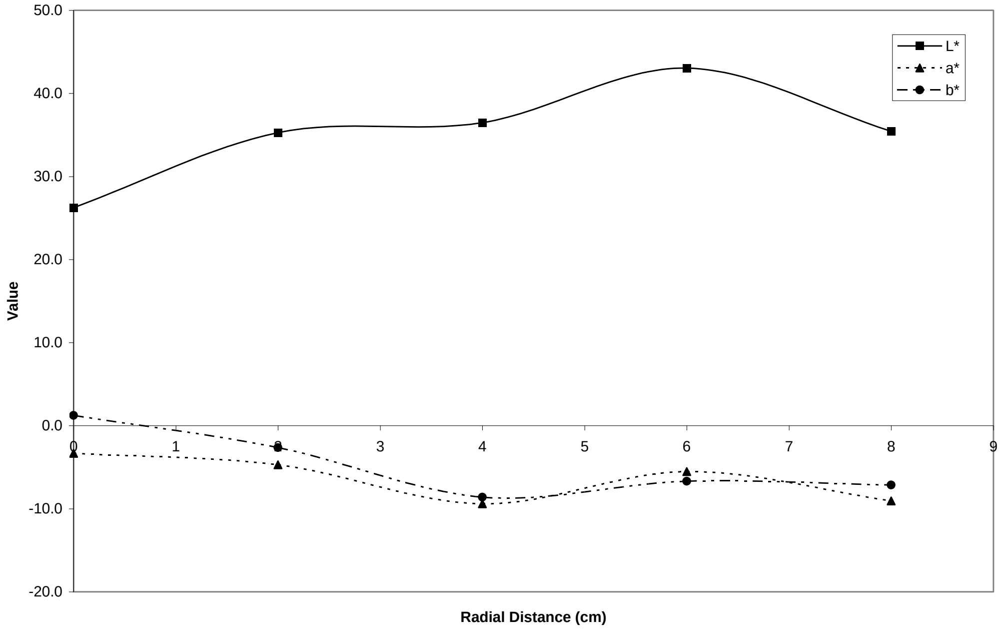

Figure 18 Energy distribution with 100 % power in 120 seconds for the bottom layer when two layers were used

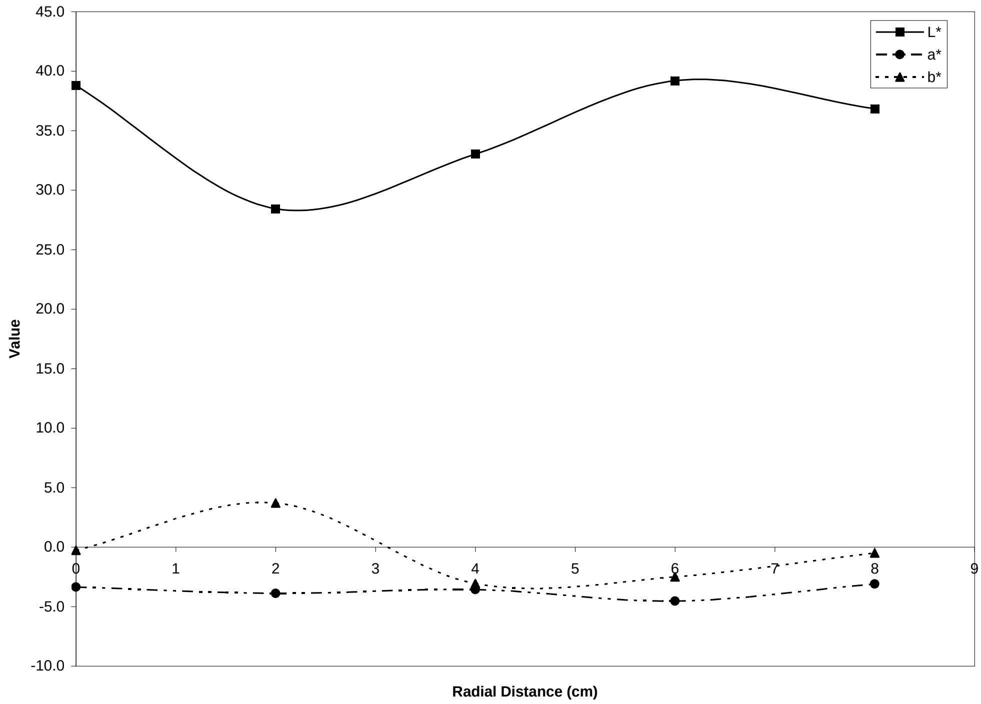

Figure 19 Energy distribution with 100 % power in 120 seconds for the top layer when two layers were used

From the Figures 17-19, it can be said that the energy is not uniformly distributed throughout the sample. In the radial direction, It generally follows a sinusodial path and is sometimes parabolic. It appears that a mixing in the radial way is required to make the distribution homogenous. For a decision on the degree of mixing in vertical direction, the results of statistical analysis is important. Accoding to these analysis; in ANOVA tables (Appendix C) for L* , a* ,b* values all the independent variables were found to be statistically different from each other, except b* value in radial distance. This means by looking at b* value only, it is not possible to decide about the heterogenity in radial distance. As a result, there is a distribution that is non-homogenous, so mixing is required in radial distance in an optimum combination.

ANOVA (Appendix C Table 6-8) for L*, a *, b* values shows that all the independent variables are statistically different from each other, except vertical distance in a* and b* values. This means by looking at a* and b* values only, we cannot decide about the heterogenity in vertical distance. As a result, there is a distribution that is non-homogenous; mixing is required in vertical direction in an optimum time-power combination.

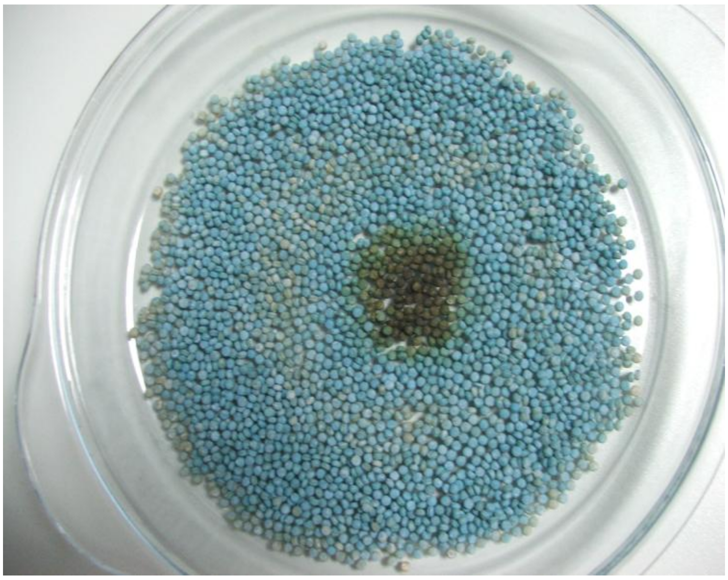

Figure 20 Sample processed at 100 % power level and for 2 minutes

3.1.2 Effect of Power on Color Values Obtained

The effect of power change on the average color values obtained was analyzed statistically in the mixing container for both mixer presence and absence.

<u>A. Analysis of the Experiments Performed Without the Mixer</u>

The samples in the mixing container were processed at 10, 40, 67, 100 power levels, 5, 10, 15 rpm for 60, 90 and 120 sec. The data were taken at four data points (4up, 4bt, 6up, 6bt) in triplicates. The average values were given in Appendix A Table 1

As regard to power level, L* value measurements showed a significant change ($p<0.05$). The trend of L* value is shown in Fig. 21.

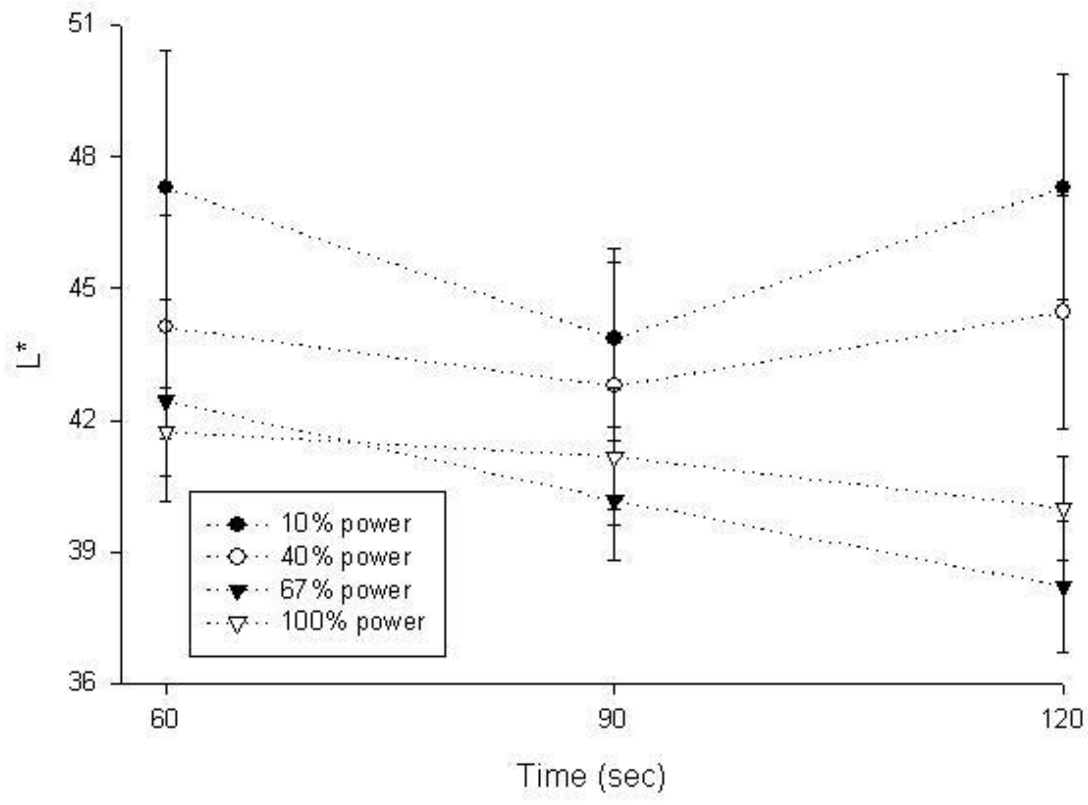

Figure 21 Variation of L* with time without the mixer in different power levels

For all color values power was a significant parameter ($p<0.05$) . Values for a* and b* were in a similar trend, both decreasing by power increase, which was expected because the decrease in a* means the color was changing to bluish green while by decreasing b* the color became blue. These color changed occured during processing. The dependency of a* and b* values were given in Fig. 22 and 23, respectively.

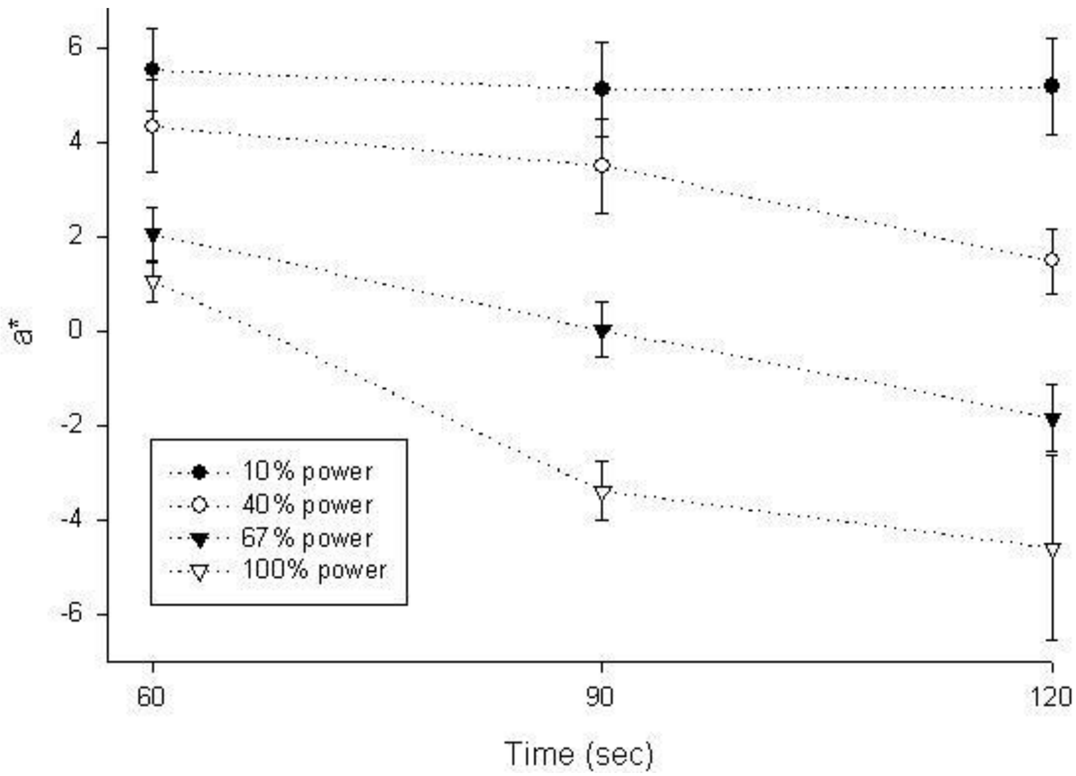

Figure 22 Variation of a* with time without the mixer in different power levels

The increasing power means increase in energy given resulted in more moisture loss. The a* and b* values are the values for making decision about effectiveness.

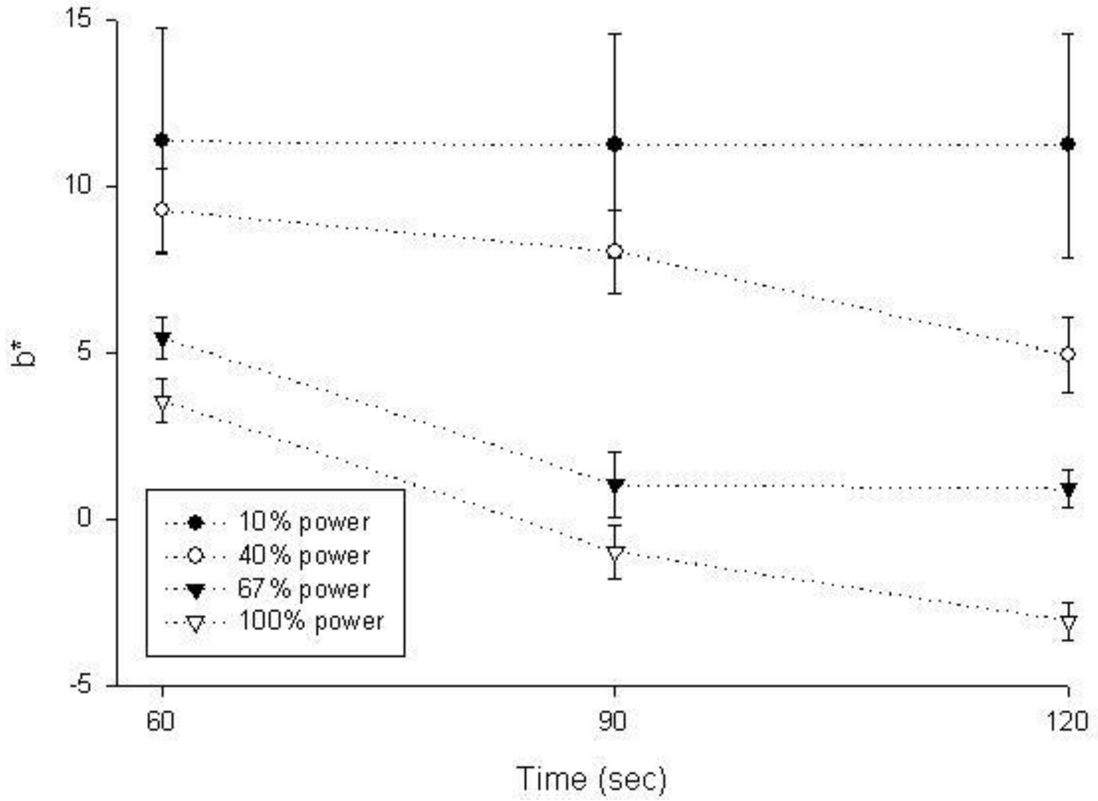

Figure 23 Variation of b* with time without the mixer in different power levels

B. Analysis of the Experiments Performed with the Mixer

The samples were processed with the presence of mixer in the mixing container for the statistical analysis. The mean values obtained from the measurements were listed in Appendix A Table 2. By the use of designed mixer and the funnel at the center of the mixing container, burning of the samples was avoided.

L* value was found to be a significant parameter ($p<0.05$). The L* value was not following a continuous decreasing trend at each power level but at 120 sec all values were lower than that of 60 sec. In the 10 % and 40 % power level, slight increase after a decrease was seen in Fig. 24 because of the regain of moisture whereas the higher power levels had a nearly constant trend till 90 seconds before decreasing sharply.

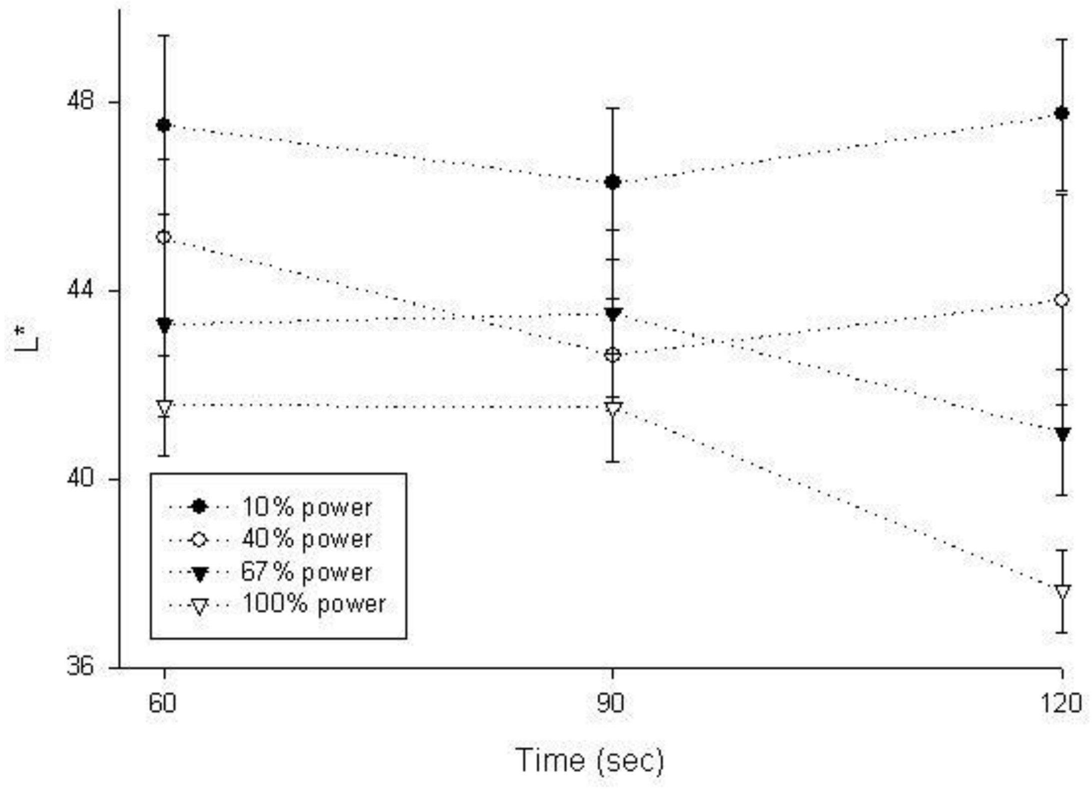

Figure 24 Variation of L* with time with the mixer in different power levels

The results obtained at the end of the statistical analysis showed that a* and b* values are both statistically significant ($p<0.05$). Both values were in the same decreasing trend with increasing time due to drying.

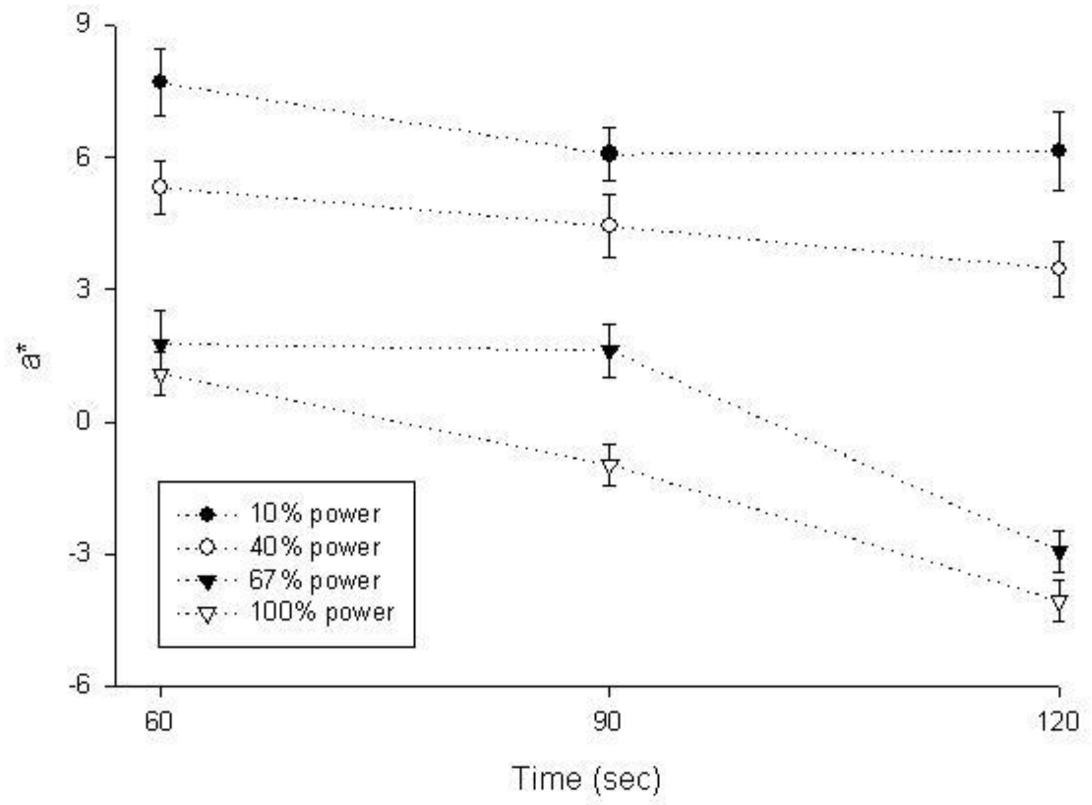

Figure 25 Variation of a* with time with the mixer in different power levels

The a* and b* values were decreasing very much after 67 % and 90 seconds. This was due to the energy given to the samples were increased very much after this point. a* and b* values decreased with the power increase with a decrease. This was an expected behaviour because values for a* and b* were decreasing as the color changes from red to blue. The increased power means increased drying of sample.

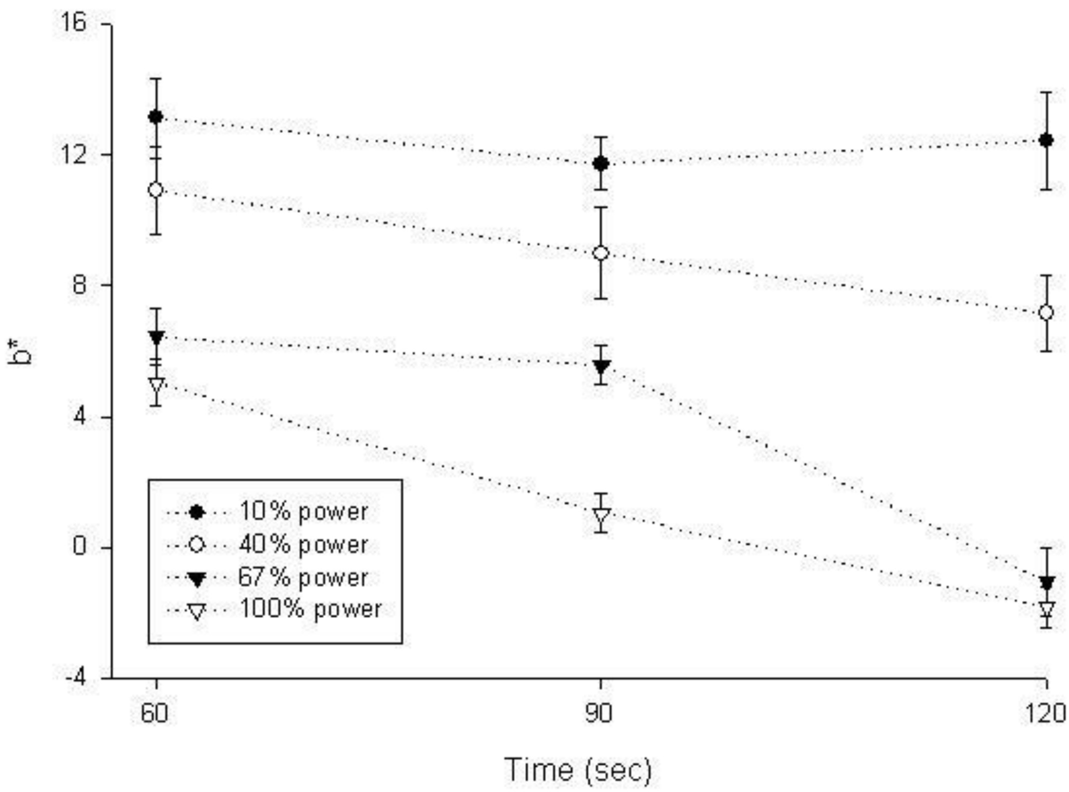

Figure 26 Variation of b* with time with the mixer in different power levels

3.1.2 Effect of Time on Color Values Obtained

The analysis below was performed for determining the effect of time on the color values obtained throughout the experiments.

<u>A. Analysis of the Experiments Performed Without the Mixer</u>

The average values were included in Appendix A Table 1. The statistical analysis was performed and the result obtained showed that L* value was a significant parameter. As can be seen in Fig.27, after 40 % power level the L* value reached an expected trend, higher the time lower the L* value, the inappropriate trend occurred lower than the 40 % power level because of the taken up moisture which was liberated from the sample in the oven.

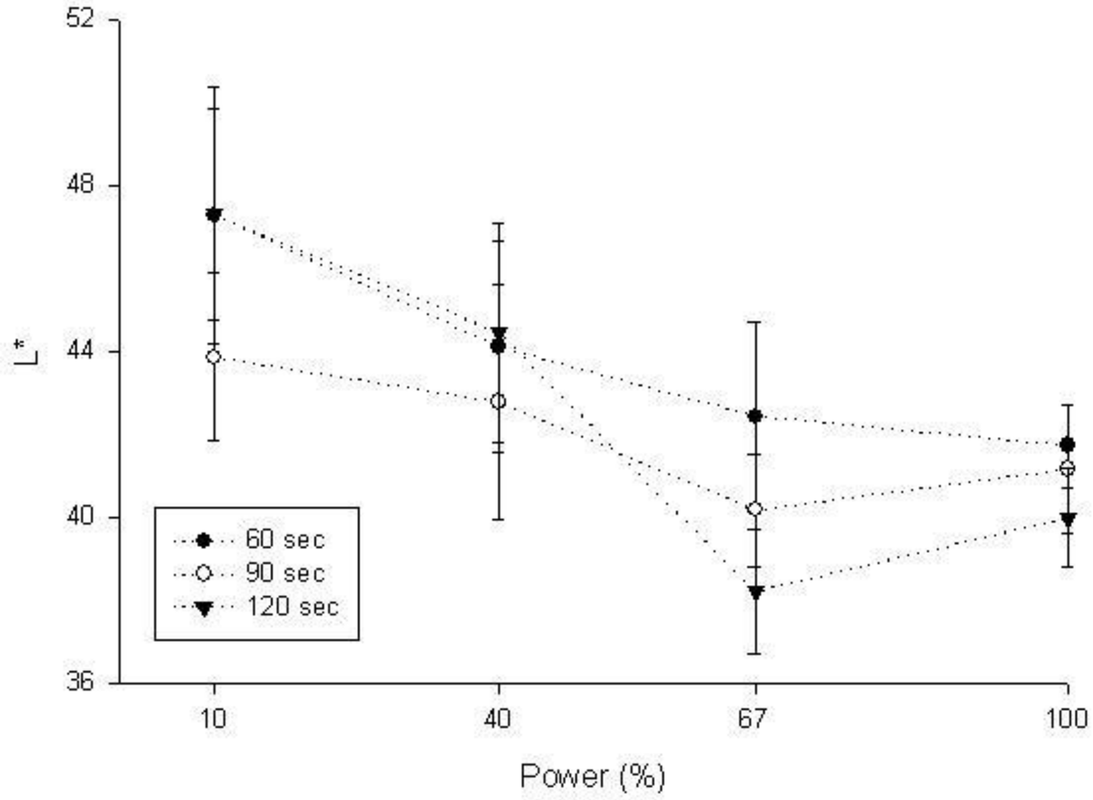

Figure 27 Variation of L* with power without the mixer in different time periods

In the experiments performed without the mixer, dependence of a* and b* values on time were significant ($p<0.05$) with respect to time change. The changes in time with respect t o power level for a* and b* value was given in Fig. 28 and 29.

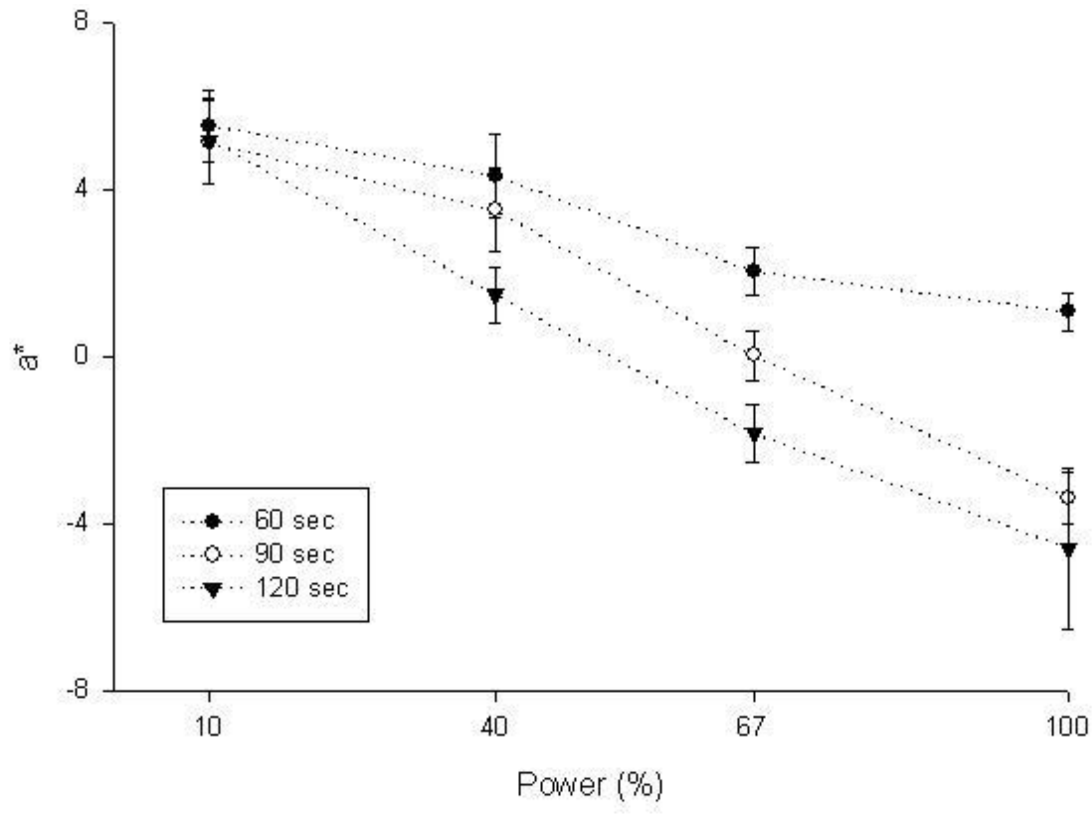

Figure 28 Variation of a* with power without the mixer in different time periods

a* and b* values values showed no mismatch like L* value showed with the general trend, which was decreasing about linearly with increasing treatment. This is again due to prolonged exposure of the material to energy causing more drying .

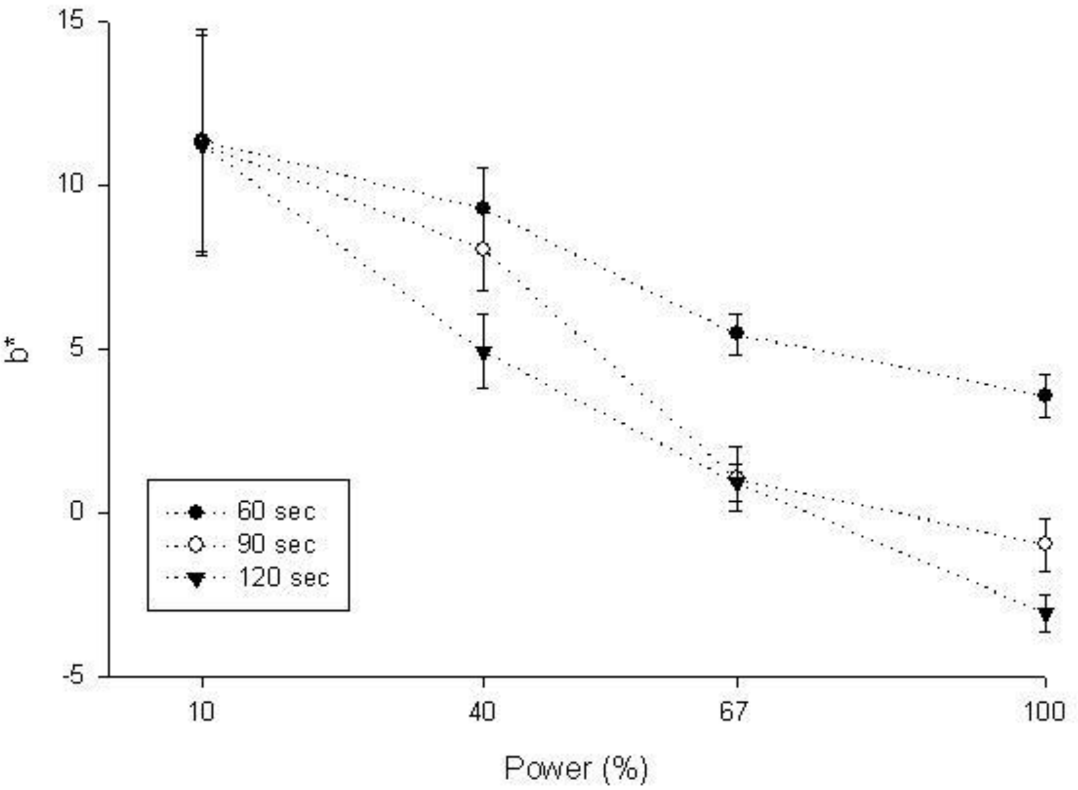

Figure 29 Variation of b* with power without the mixer in different time periods

B. Analysis of the Experiments Performed with the Mixer

The processed material was analyzed and the average data obtained were summarized at Appendix A Table 2. When L* value was taken into consideration, it was a significant parameter ($p<0.05$). The behavior of L* value with the increasing time shown in Fig. 30 was not same for each power level which could be expressed by the humidity gain in the lower power levels.

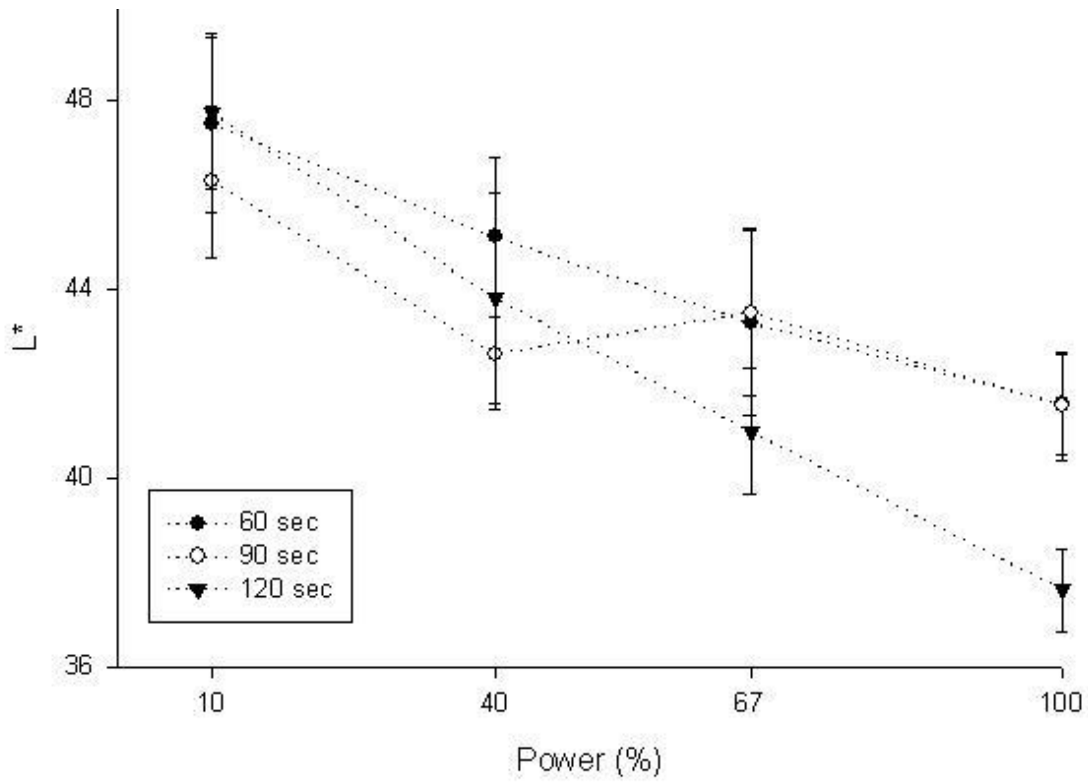

Figure 30 Variation of L* with power with the mixer in different time periods

For the average a* values, significant differences occurs ($p<0.05$). This difference was due to the change of the color of the sample from dark pink to blue. By increasing time, samples processed at higher power levels give lower a* values because beads became much more blue than the others as the energy absorbed by the sample increased. The situation was demonstrated at Fig. 31

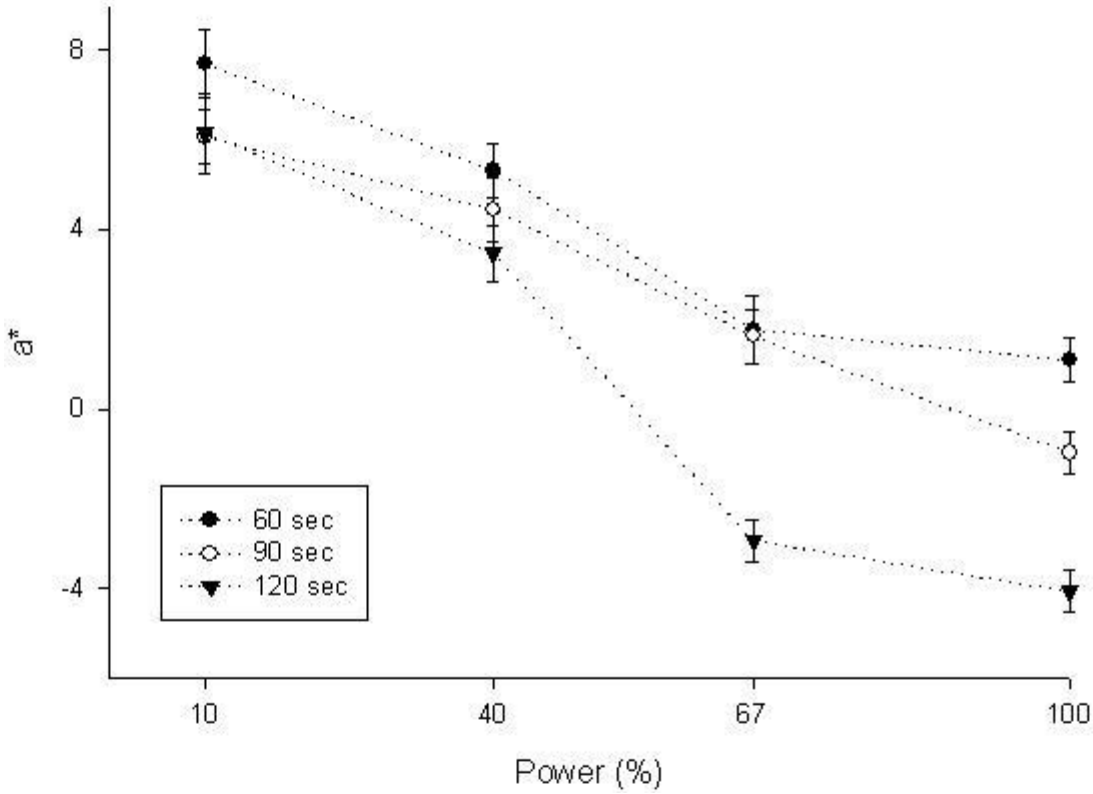

Figure 31 Variation of a* with power with the mixer in different time periods

Further, it was seen that as the energy given was increasing the gradient of the change of the b* values became steeper. All of the changes were significant ($p<0.05$). This is the consequence of increased energy input rate.

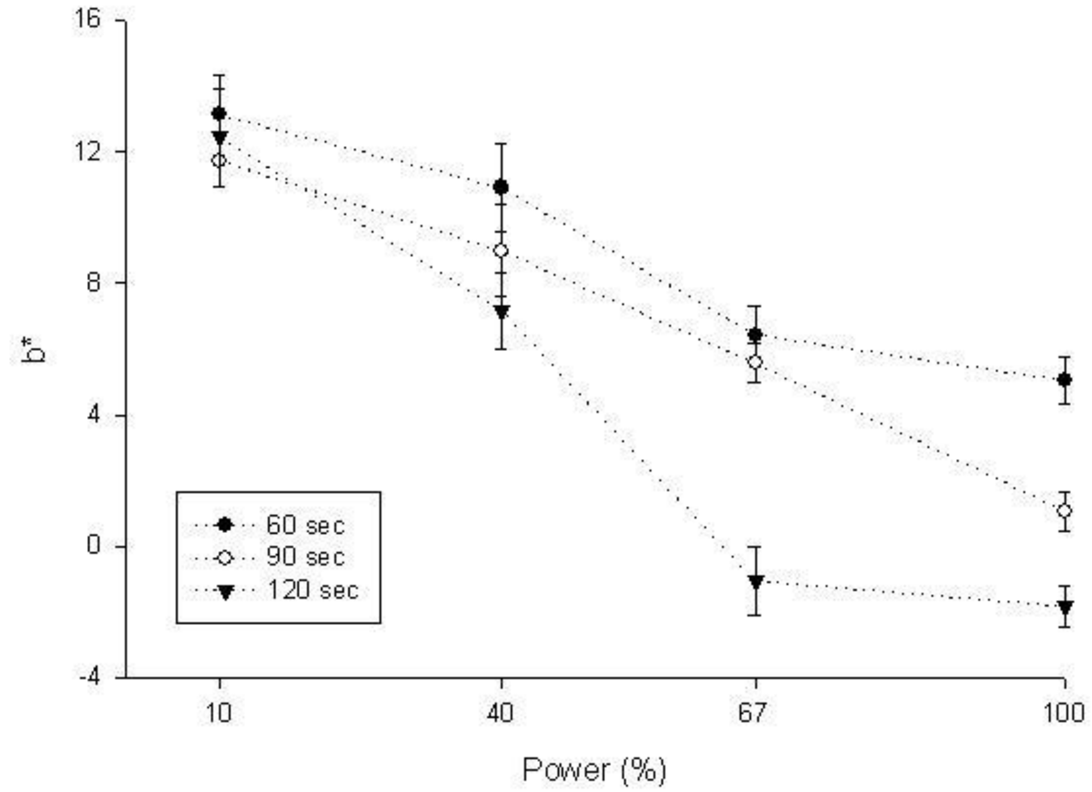

Figure 32 Variation of b* with power with the mixer in different time periods

3.1.4 Effect of Location on Color Values Obtained

<u>A. Analysis of the Experiments Performed without the Mixer</u>

The average values for all color parameters were given in Appendix A Table 1. The analysis done according to these values showed that for L* value, location did not indicate an important effect, whereas for a* and b* values this effect seemed to be important. This effect were demonstrated in Fig.33 and 34.

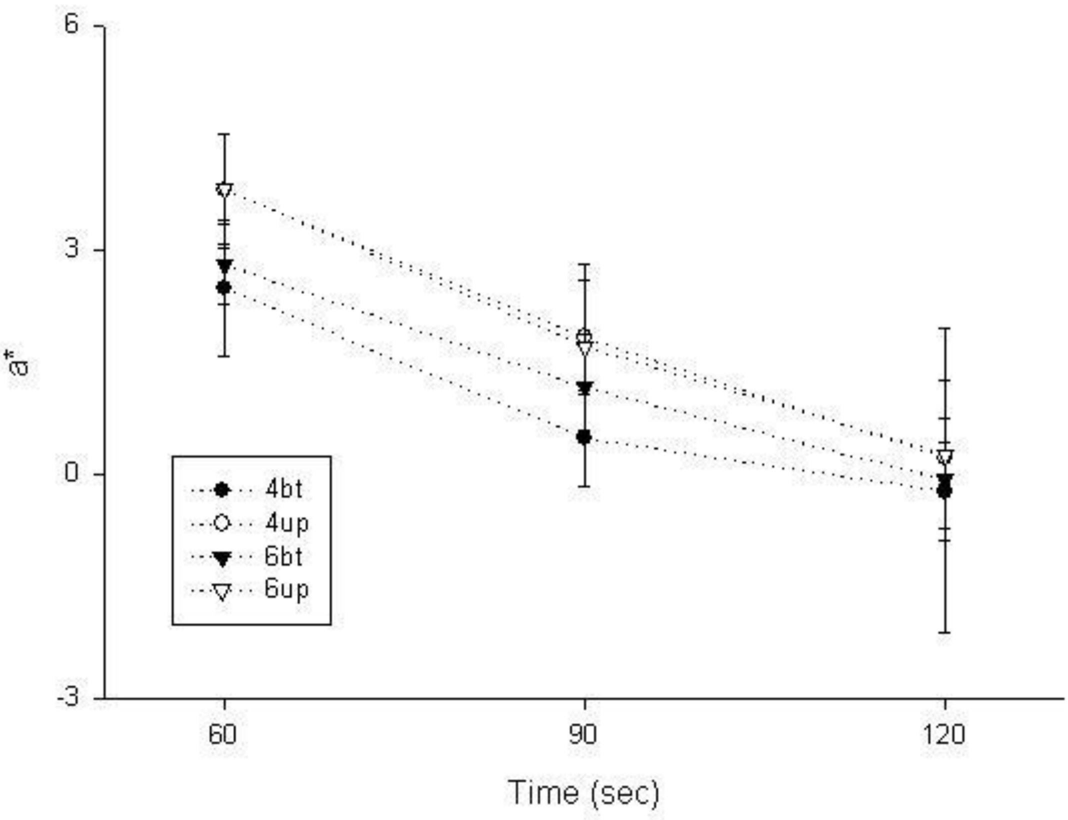

Figure 33 Variation of a* with time without the mixer in different locations

For a* values, upper positions were nearly of the monolayer trend while the bottom parts behaved also in the similar manner. On the other hand, b* values gave random results which was not an ordinary situation. This result can be attributed to an unaccounted mixing effect.

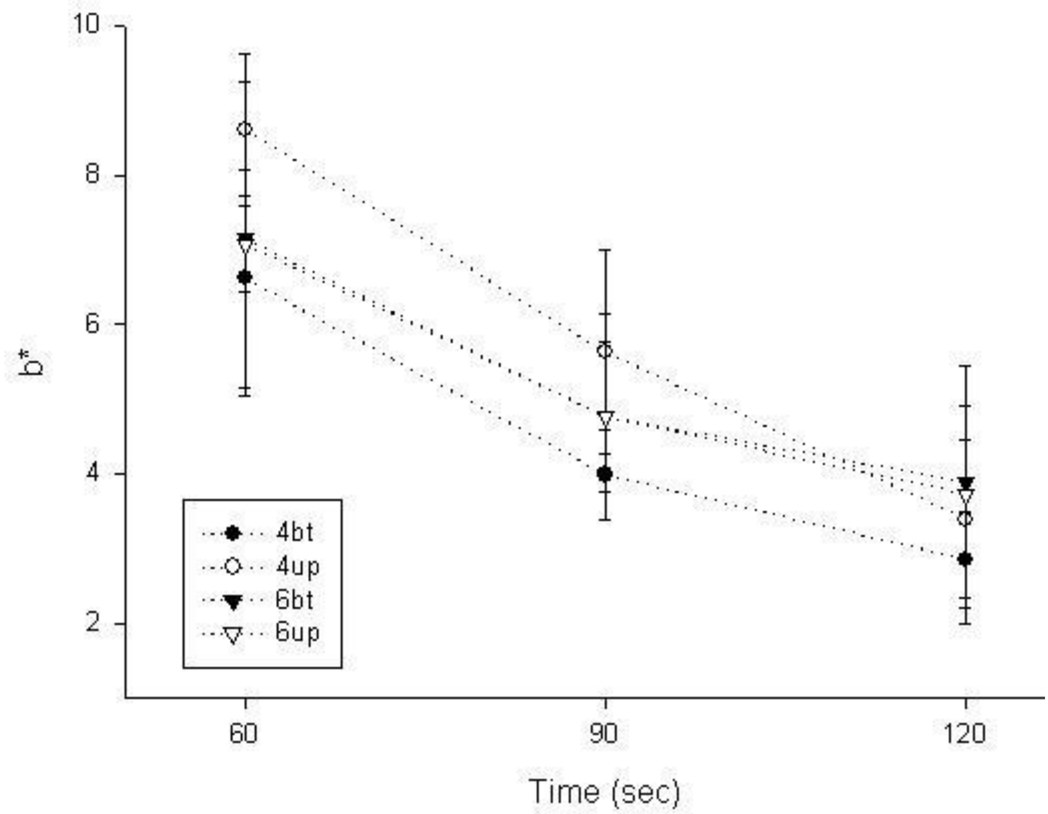

Figure 34 Variation of b* with time without the mixer in different locations

B. Analysis of the Experiments Performed with the Mixer

Primarily it can be stated that, all three color values were found to be insignificant ($p>0.05$) for the effect of location in the experiments performed with the designed mixer. This is merely because of the induced mixing effect in the three directions. That is, it can be claimed that the energy is uniformly distributed to the material receiving the treatment.

3.1.4 Effect of Speed of Rotation on Color Values Obtained

A. Analysis of the Experiments Performed Without the Mixer

After the statistical analysis made on the data given in App A. Table 1, it was seen that all three color values were statistically significant for the speed of rotation effect. For L* values, at the original speed of rotation of the oven which is 5 rpm gave an expected result that was continuous decreasing of L* value due to increased darkness as a consequence of increased drying but at the other two speed of rotation values the trend was unusual. An increase in the randomness of the waves due to the increased speed might be the reason for this situation.

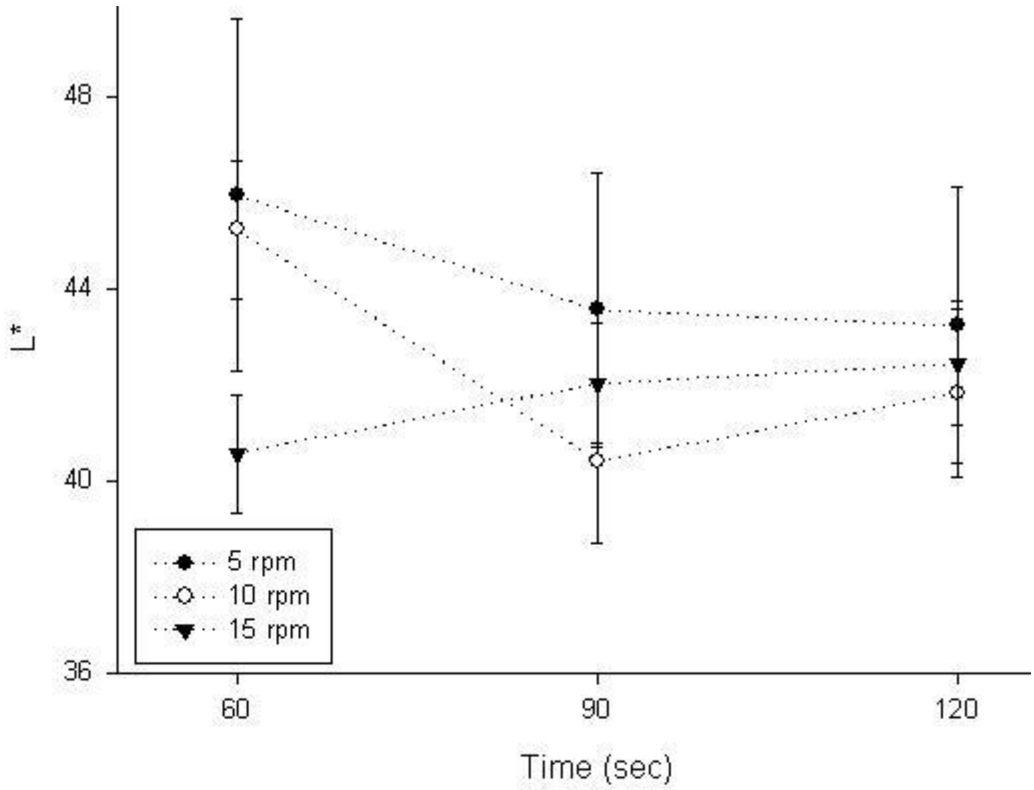

Figure 35 Variation of L* with time without the mixer in different speed of rotations

In contrast to L* value, the a* and b* values had the same trend although there was a disorderness in 60 seconds data that is the increased speed , increases the a* and b* value. This increase was merely because of the beads that were accelerated absorbed less energy than the slower ones.

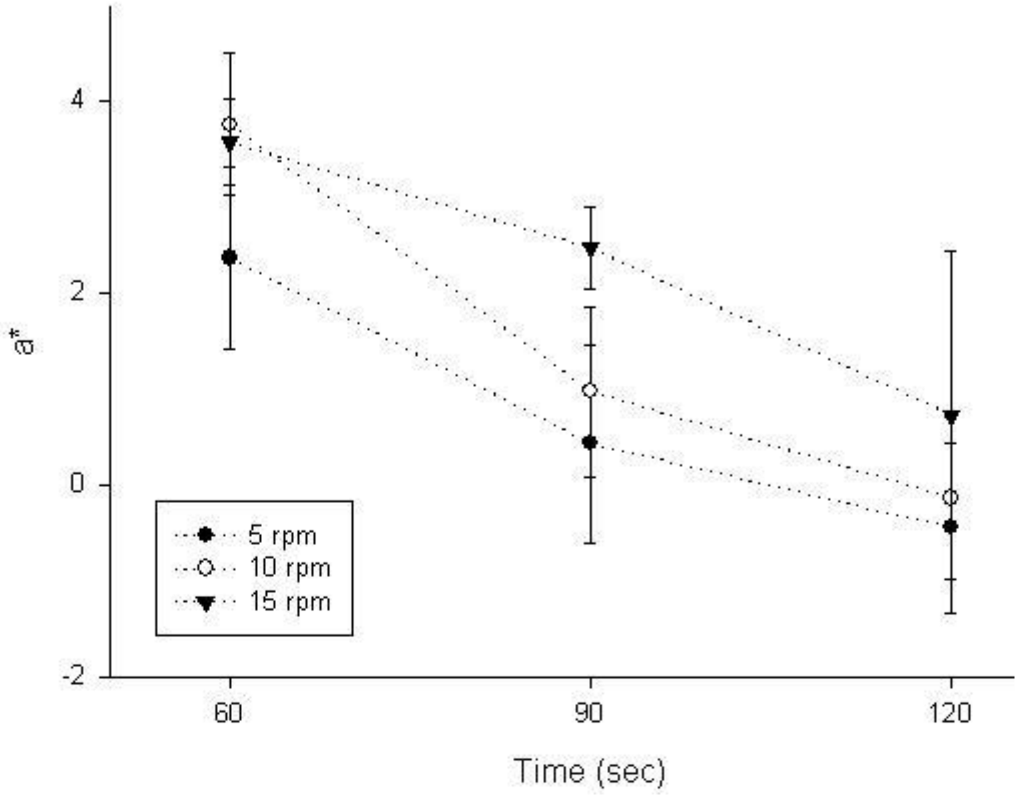

Figure 36 Variation of a* with time without the mixer in different speed of rotations

According to the results portrayed in Figure 36-37, it is possible to state that the speed of rotation of the mixer has a positive effect as all the color values decreased with the decreasing rotational speed. Hence, effectiveness of the contribution of the mixer was proportional with its speed in the studied range.

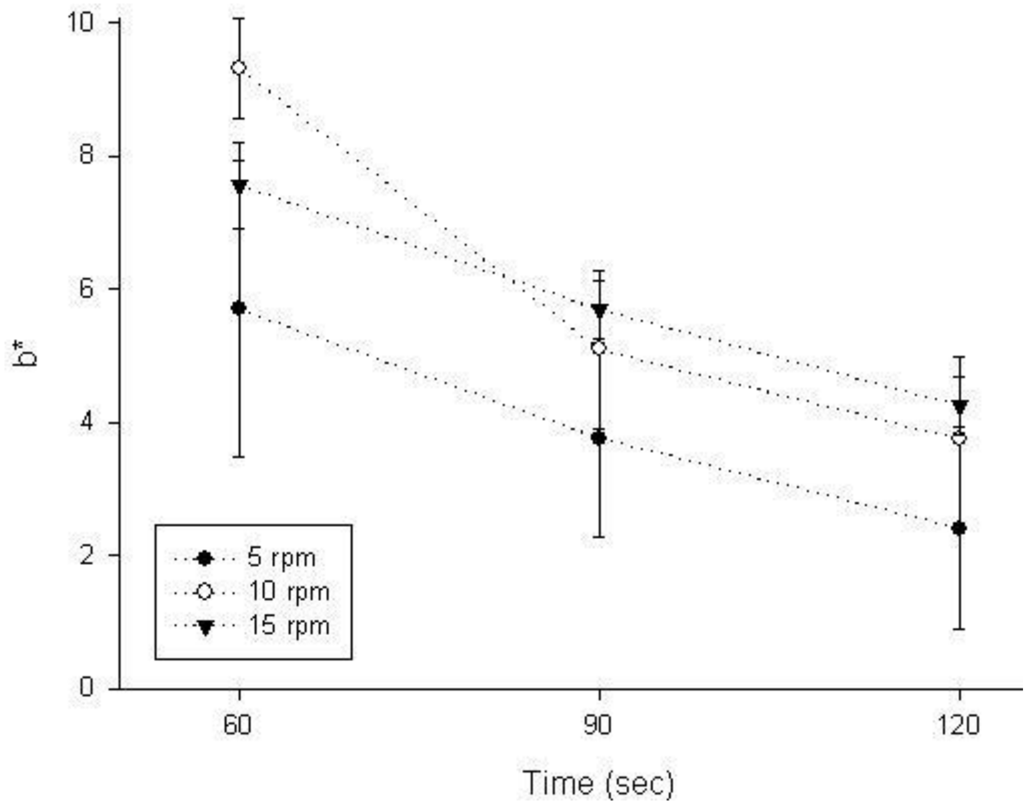

Figure 37 Variation of b* with time without the mixer in different speed of rotations

B. Analysis of the Experiments Performed with the Mixer

Table 2 includes the average values of all color parameters. Like the results obtained in the experiments performed without the mixer, L* values had different trend than that of a* and b* values at a speed of rotation of 10 rpm only. At this value, the trend was upwards (Fig. 38) while the others were downwards. This phenomenon occurs presumably because of the random nature of the microwaves coming from the magnetron.

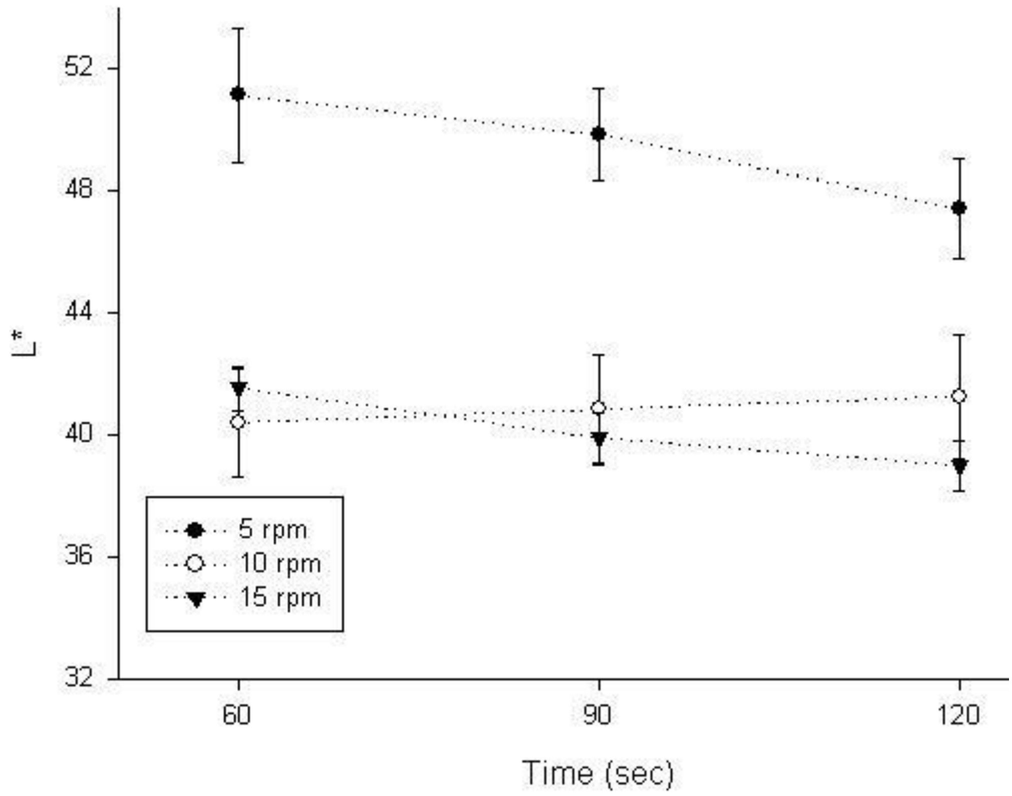

Figure 38 Variation of L* with time with the mixer in different speed of rotations

For a* and b* value, it could be observed from the Fig. 39 and 40 that a general trend was obtained as an increase in the speed decreases the value obtained. This was probably due to the mixing effect.

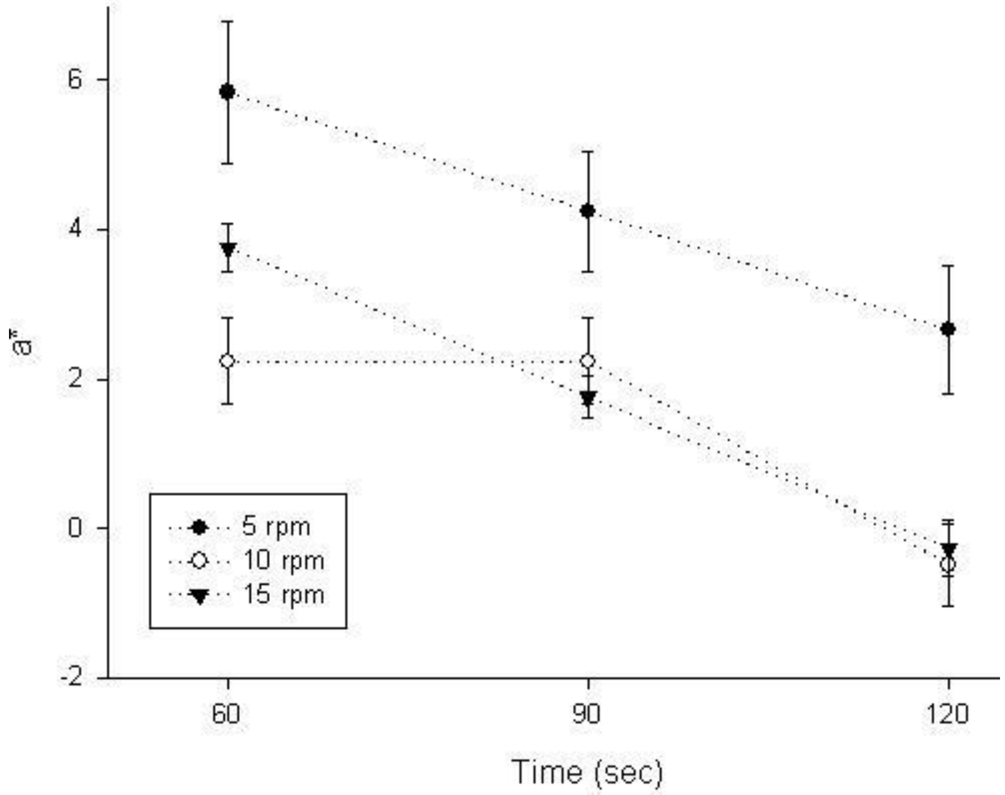

Figure 39 Variation of a* with time with the mixer in different speed of rotations

In the experiments performed with the mixer, it could be observed that the situation in the absense of the mixer was changed totally which made the speed an important parameter for all the values to decrease. This showed that increasing the speed resulted in more uniform heat transfer to the particles.

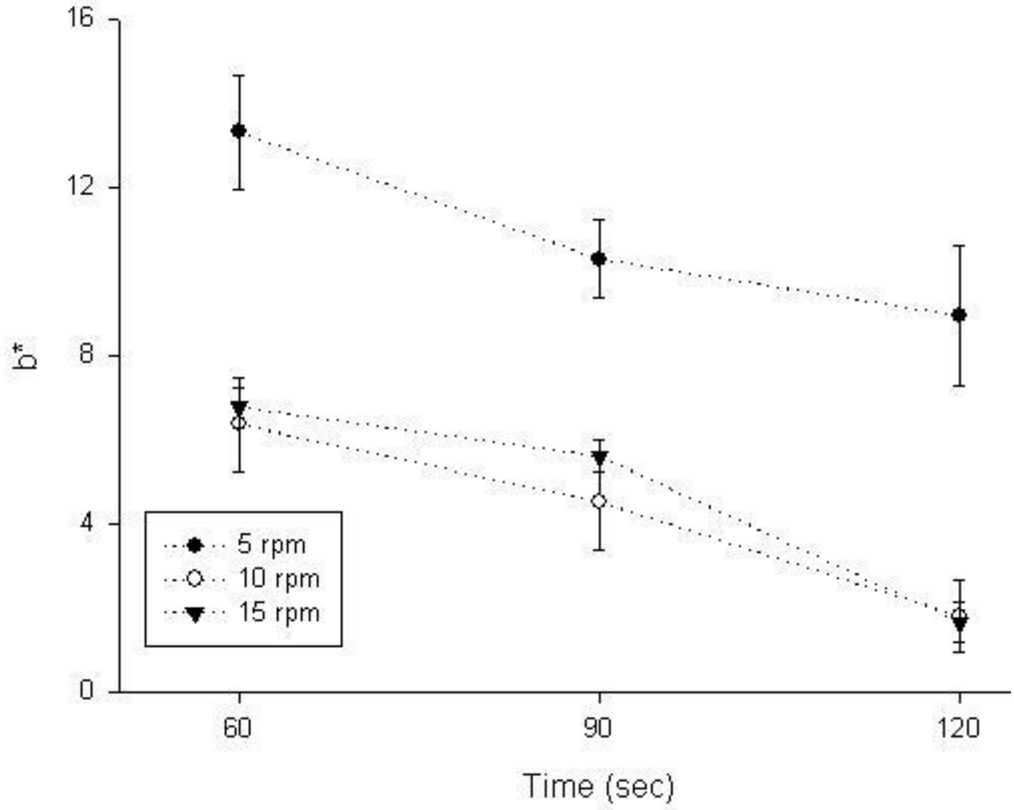

Figure 40 Variation of b* with time with the mixer in different speed of rotations

3.2 SURFACE TEMPERATURE ANALYSIS

The photographs taken by IR camera (Appendix D) was examined. Surface temperature values were read by the help of the software (ThermaCam Researcher Pro 2.0) at four points that were 2, 4,6, 8 cm apart from the center. Also the line passing through these points was averaged and its standard deviation was recorded. The data are given in Appendix B and the sample plots in Fig. 41-46.

3.2.1 Effect of Power on Surface Temperature Values Obtained

A. Analysis of the Experiments Performed Without the Mixer

The average values were summarized at Appendix A Table 3. According to these data, statistical analysis were made and the surface temperature was found to be a significant parameter ($p<0,05$). The behavior of the samples after processing could be seen in Fig. 41. Because by the power increase , the energy absorbed by the sample increases . The increase in power increased the temperatures of the particles in the cavity.

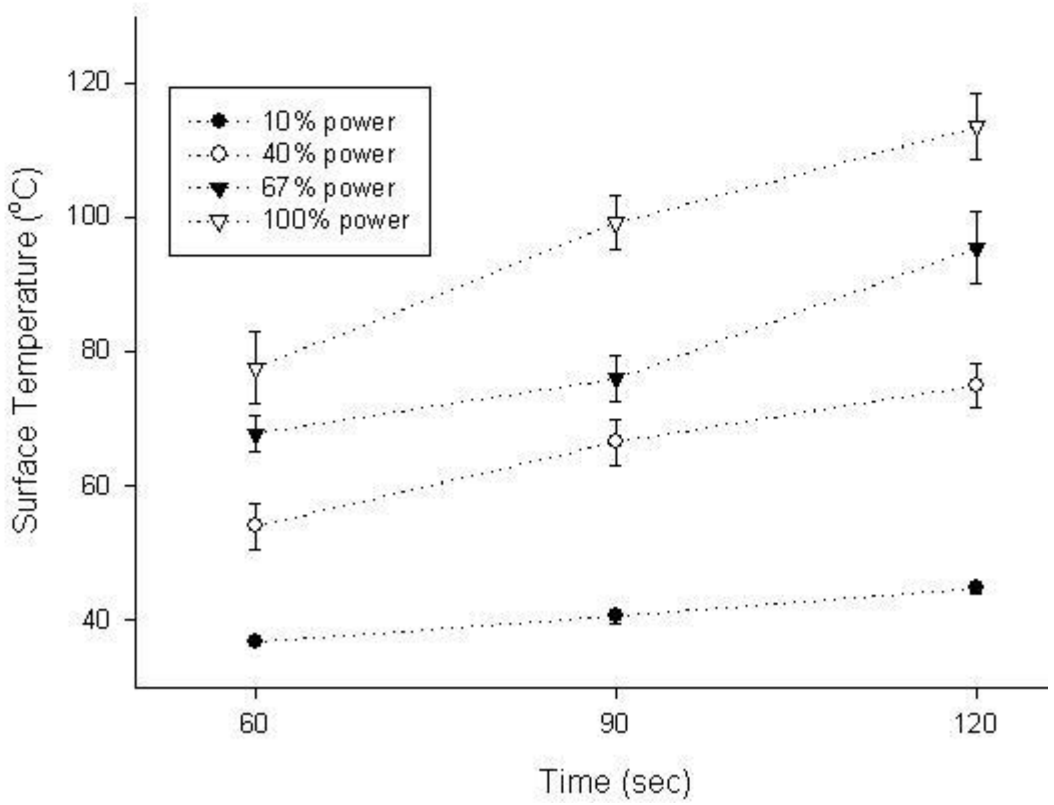

Figure 41 Variation of surface temperature with time without the mixer in different power levels

B. Analysis of the Experiments Performed With the Mixer

The experiments performed with the mixer showed the same trend as it was mentioned above. This was because whether there is the mixer or not, as the rule of thumb, by increasing the power hence the energy input, the internal energy increases. This explains the increase in the temperature.

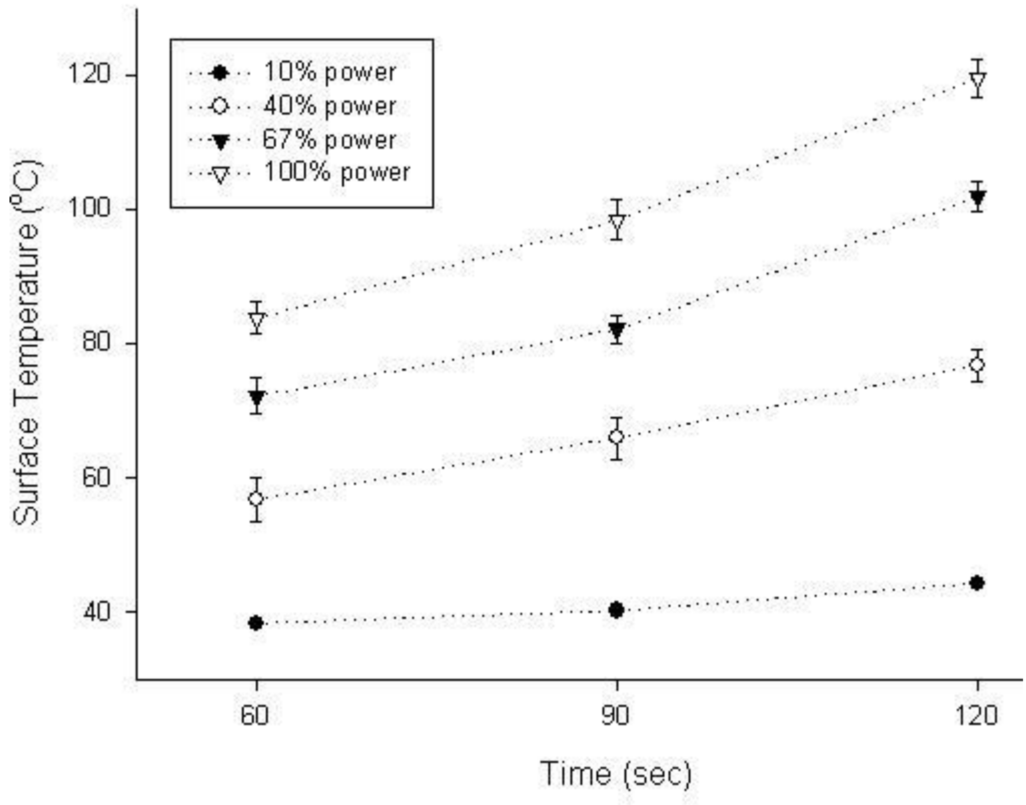

Figure 42 Variation of surface temperature with time with the mixer in different power levels

3.2.2 Effect of Time on Surface Temperature Values Obtained

A. Analysis of the Experiments Performed Without the Mixer

In Appendix A Table 3, the average value of the surface temperature data were found. After the examination by the help of the software provided, the behaviour was plotted in Fig. 43. It could be easily observed from the figure that the more it absorbs energy the more heater the samples were as expected.

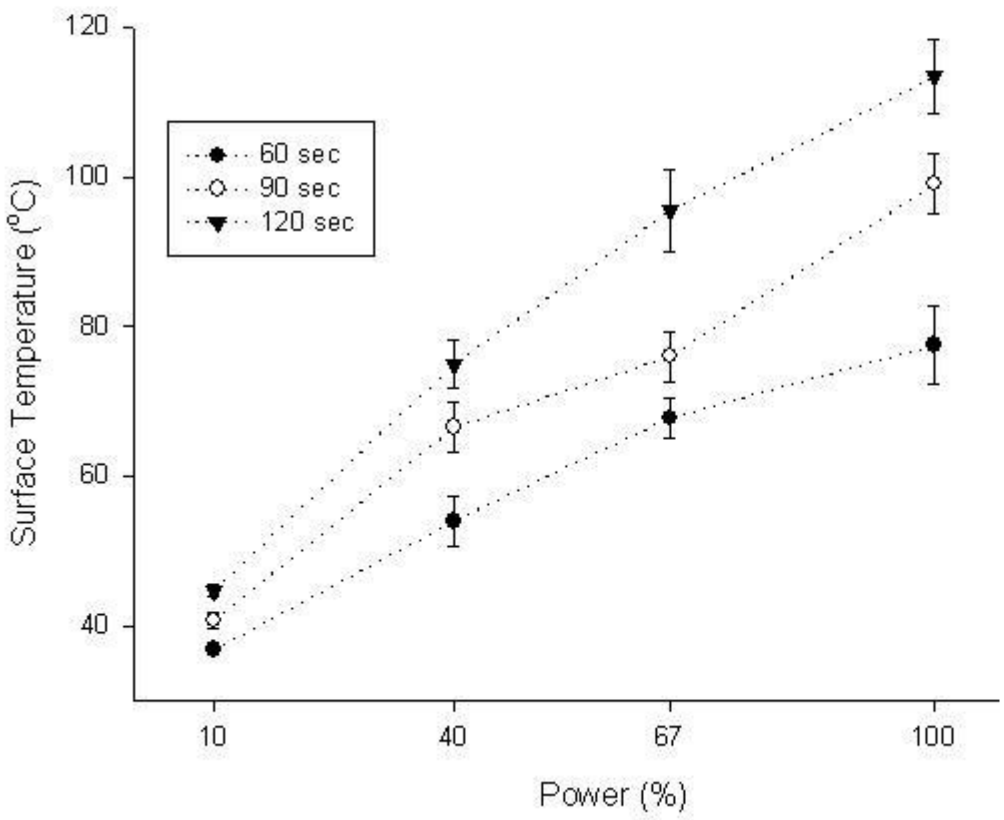

Figure 43 Variation of surface temperature with power without the mixer in different time periods

B. Analysis of the Experiments Performed With the Mixer

Increase in the duration of the treatment to a degree will indicate about the same effect as increasing power, that is the increase in the energy absorbed will increase the temperature.

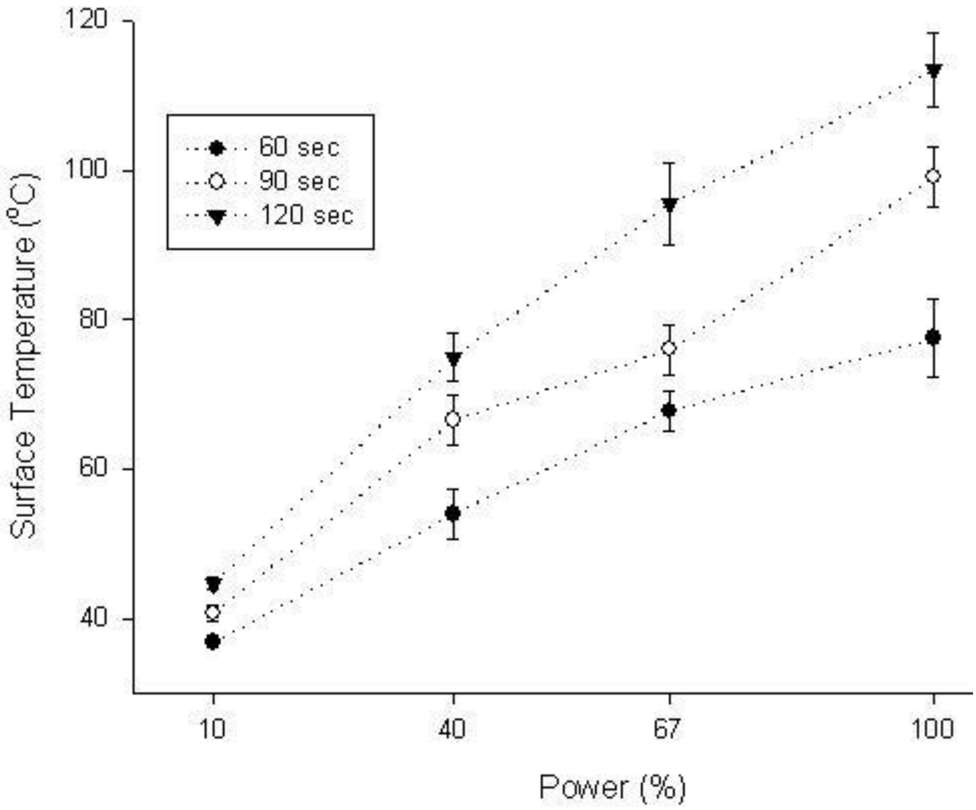

Figure 44 Variation of surface temperature with power with the mixer in different time periods

3.2.3 Effect of Location on Surface Temperature Values Obtained

A. Analysis of the Experiments Performed Without the Mixer

In the case the mixer was not present, i.e. normal microwave oven, the location became a significant parameter where these locations are subject to change as well. Thus, the behavior is unpredictable and unreproducible.

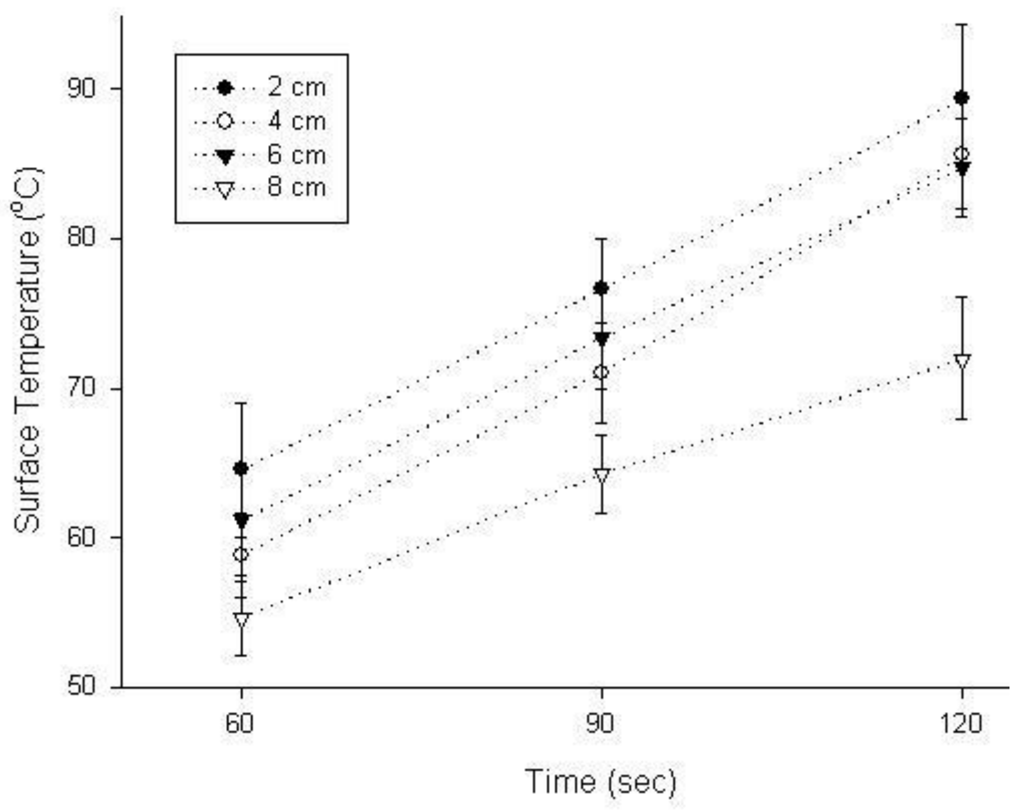

Figure 45 Variation of surface temperature with time without the mixer in different locations

B. Analysis of the Experiments Performed With the Mixer

Because there was mixing location became an insignificant parameter ($p>0.05$) which was an expected result (Appendix C Table 27).

3.2.3 Effect of Speed of Rotation on Surface Temperature Values Obtained

<u>A. Analysis of the Experiments Performed Without the Mixer</u>

As can be observed from Figure 45, increasing the speed of rotation of the mixer decreased the slope dT/dt hence the rate of energy absorption of the sample. This also implies that by decreasing time and increasing the rotational speed of the mixer, an optimum combination can be found.

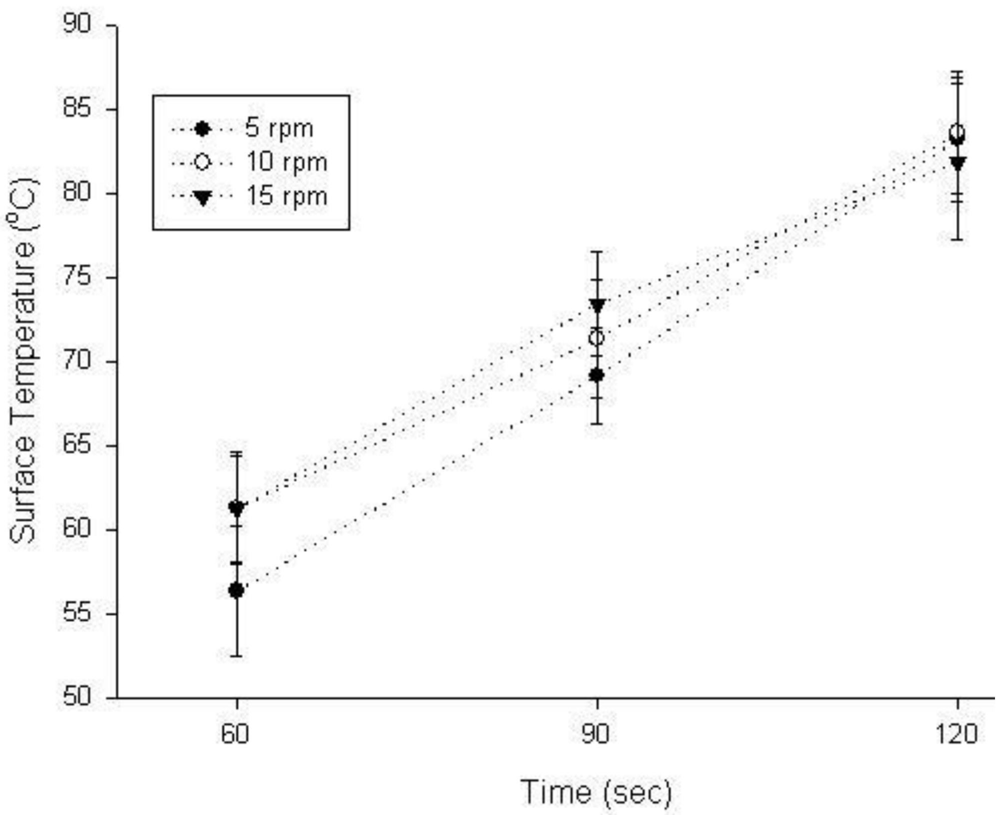

Figure 46 Variation of surface temperature with time without the mixer in different speed of rotations

B. Analysis of the Experiments Performed With the Mixer

As this parameter is insignificant ($p > 0.05$) for the average temperature, every speed value could be taken as giving the same or parallel effect.

3.3 VARIANCE ANALYSIS

The experiments with and without mixer with all parameters (time, power, speed of rotation and location) were not performed only once. For statistical analysis, the experiments should have to be performed more than once in order to get a variance.
The variance is one of several measures that statisticians use to characterize the dispersion among the measures in a given population. To calculate the variance, it is necessary to first calculate the mean or average of the scores. The next step is to measure the amount that each individual score deviates or is different from the mean. Finally, you square that deviation by multiplying the number by itself. Numerically the variance equals the average of the squared deviations from the mean

In our study, for making decision about the uniformity achieved or the effect on uniformity another tool to analyze were variances of the values obtained at the stated locations. Using ANOVA of these data, the significance of the parameters was also determined to see which value was important to mention.

3.3.1 Effect of the Power on the Variances of the Data Obtained

<u>A. Analysis of Experiments Performed without the Mixer</u>

From the Table in Appendix C it could be stated that L*, b* and surface temperature values changed significantly with the effect of power levels. Except at 6bt for 10 % power (Fig. 47) all the variances were decreasing by increasing power which was expected because the samples that did not absorb enegy in lower power levels would gain energy like the other parts. At all power levels, there were fluctuating trends which was due to the absence of mixing.

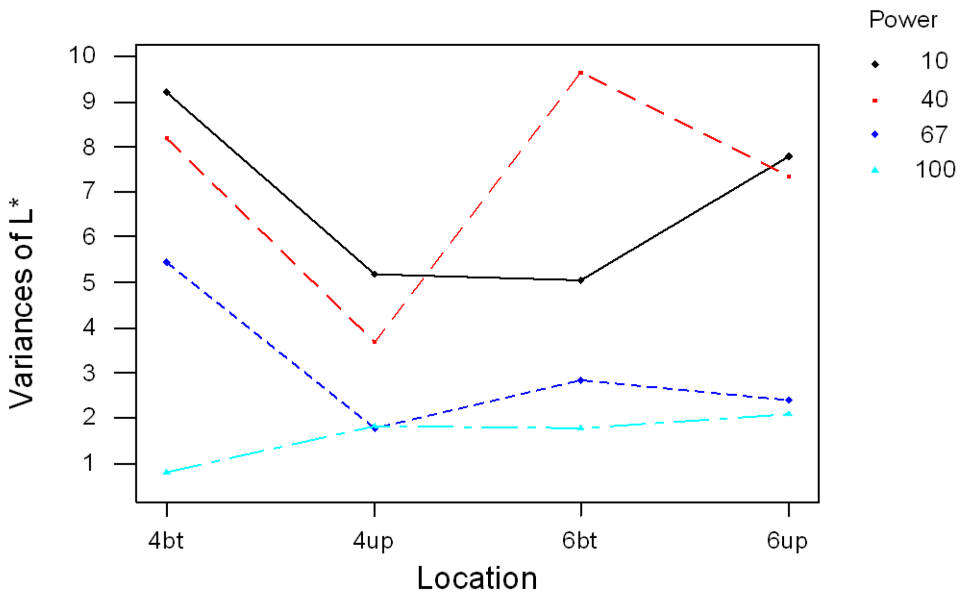

Figure 47 Variation of variances of L* values with location without the mixer in different power levels

After plotting the graph in Fig. 48, it could be observed that variances of b* values decreased and were becoming nearly constant because by the power increase the particles reached the blue color at each power level.

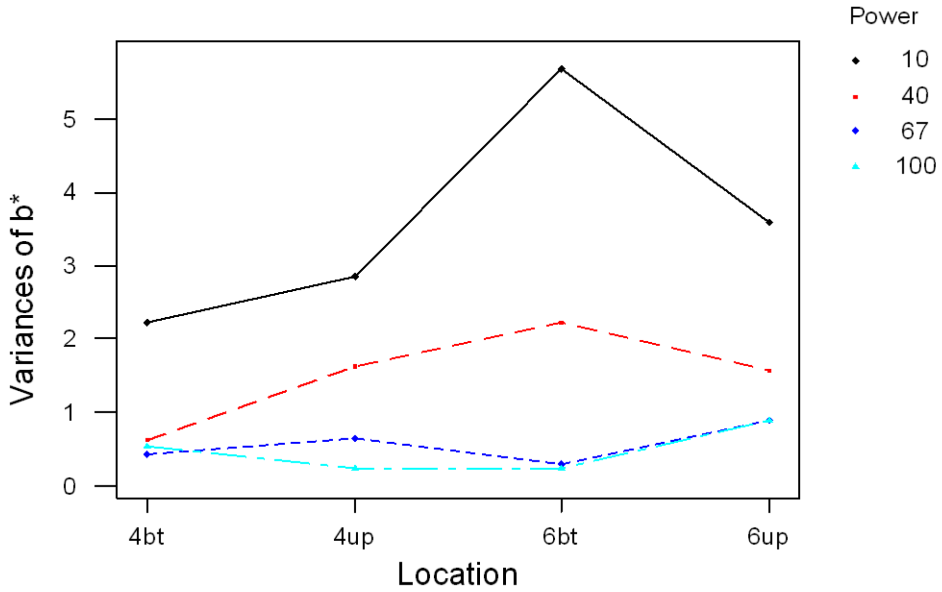

Figure 48 Variation of variances of b* values with location without the mixer in different power levels

The data obtained after the thermogram analysis of photographs taken by IR camera were given in Appendix A Table 3. According to these data the graph in Fig. 49 was drawn to examine the effect of variance of surface temperature. Surface temperature levels were becoming similar and having less variance values by the power level increase because of the increase in adequate heating.

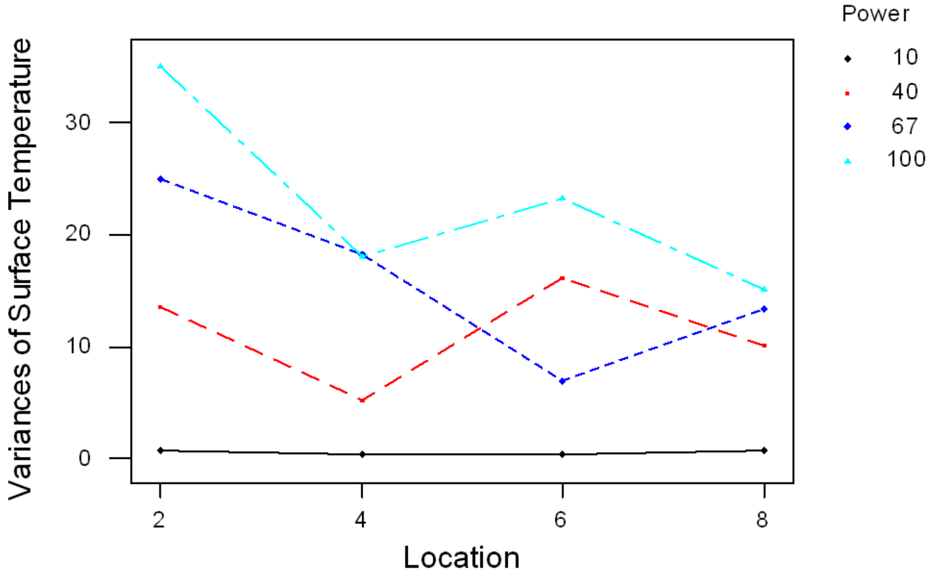

Figure 49 Variation of variances of surface temperature values with location without the mixer in different power levels

B. Analysis of Experiments Performed with the Mixer

After ANOVA examination, L*, b* and surface temperature values were found to be significantly effected by the power level change in the presence of mixer ($p<0.05$). There were fluctuations in the trend of L* value, but by the mixing effect the range of these fluctuations were not as much as the trends in Fig. 47. Because of the nature of the microwaves created by the magnetron, the variances did not follow the same path with power level increase.

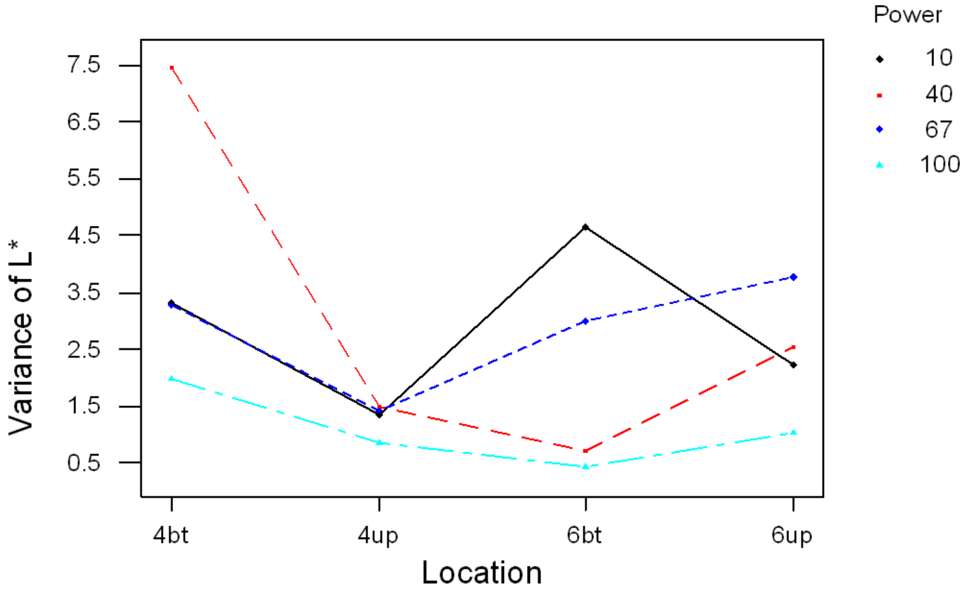

Figure 50 Variation of variances of L* values with location with the mixer in different power levels

Different from the results of the analysis made for the data obtained by not using the mixer, the ups and downs were less by location change which could be attributed to the mixing effect. Also, the value for variances went up to 5 in the mixer absence, whereas as shown in Fig. 51 it never went over 3.

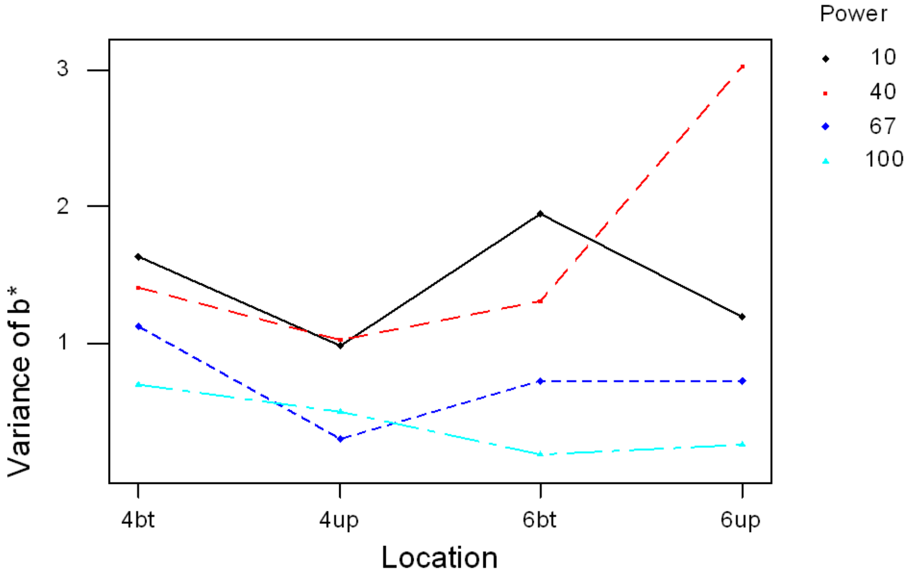

Figure 51 Variation of variances of b* values with location with the mixer in different power levels

Except 40 % power level, for 4 and 6 cm. apart from the center of the container, the behaviour was acceptable as it was not fluctuating. The disorderness occurred might be due to the random nature of microwaves and the unaccounted mixing effect.

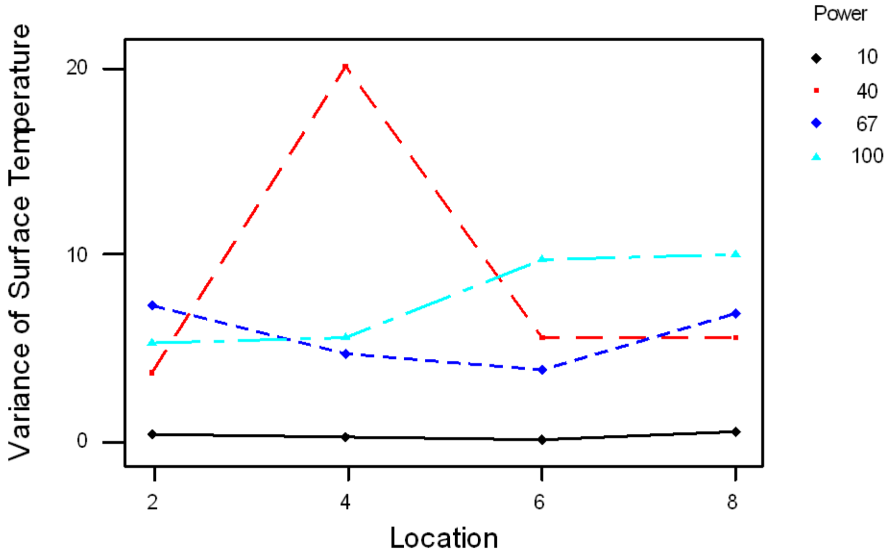

Figure 52 Variation of variances of surface temperature values with location with the mixer in different power levels

3.3.2 Effect of the Time on the Variances of the Data Obtained

Time effect was found to be insignificant ($p>0.05$) for all values in two cases. This is because the operation is not time-bound that is in any time results were not different in all cases.

3.3.3 Effect of the Location on the Variances of the Data Obtained

The color distribution of samples processed with and without the mixer was generally uniform within itself. This uniformity was not significantly affected by all the parameters. Variances of L*, a* and b* and surface temperature values in all 5 locations were not significantly different. ($p>0.05$)

3.3.4 Effect of the Speed on the Variances of the Data Obtained

A. Analysis of the Experiments Performed without the Mixer

The variances given in the Appendix A Table 3 were used to draw the Fig. 53. For L* value, It was seen on the graph that an increase in the speed would decrease the variance and help to get rid of the sinusoidal trend.

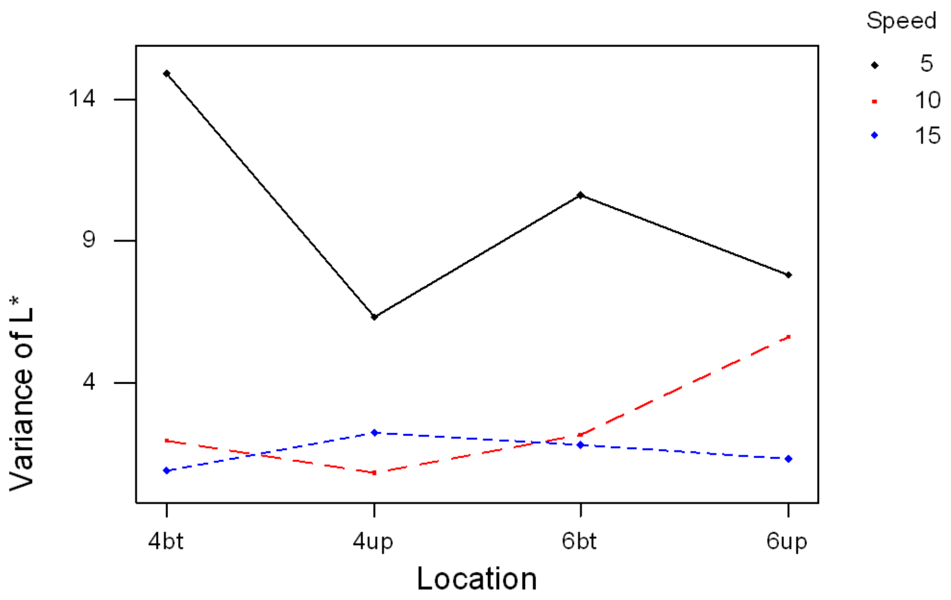

Figure 53 Variation of variances of L* values with location without the mixer in different speed of rotations

In the absence of the mixer, increase in the speed of rotation decreased the variance and made it more constant for L* and b* values. It could be stated that the increase in the speed of rotation caused the particle move faster which resulted in less change in the energy of these particle.

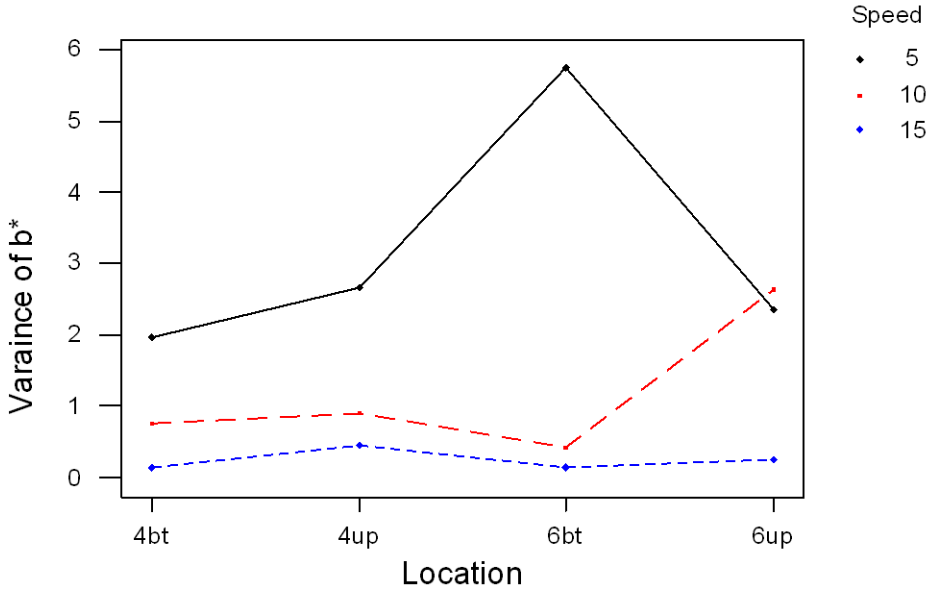

Figure 54 Variation of variances of b* values with location without the mixer in different speed of rotations

B. Analysis of the Experiments Performed with the Mixer

The L* value was a significant parameter for the variance of the results of the experiments performed with the mixer ($p<0.05$). For all locations , the 15 rpm speed of rotation results gave the lowest variance values. Although there were some inconvenient data with the general trend, in general it could be stated that by speed the variance for L* value increase by a decrease in speed.

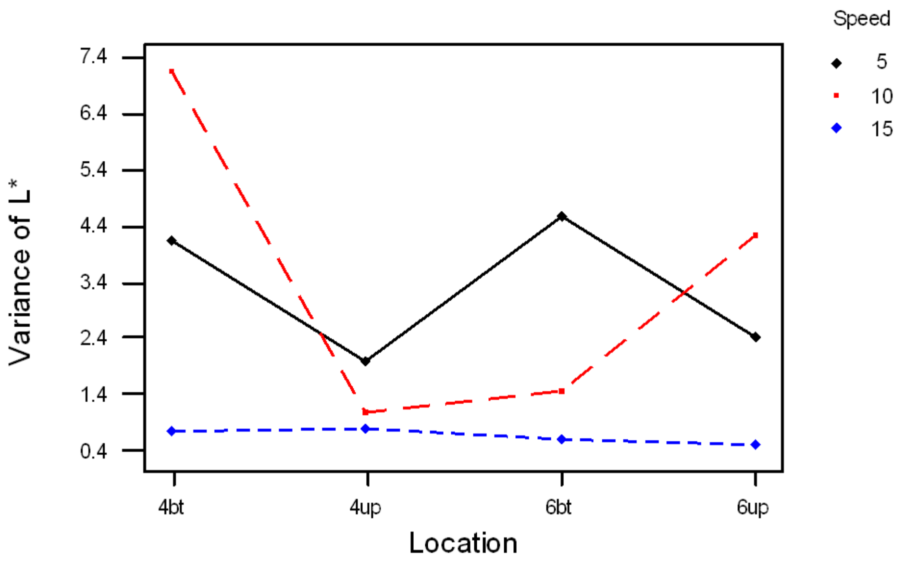

Figure 55 Variation of variances of L* values with location with the mixer in different speed of rotations

For a* and b* values which were statistically significant parameters ($p<0.05$), the same trend was observed except some slight inconsistencies. The variances were decreasing with increase in the speed and also the trend became more constant. This was due to the positive effect of speed increase.

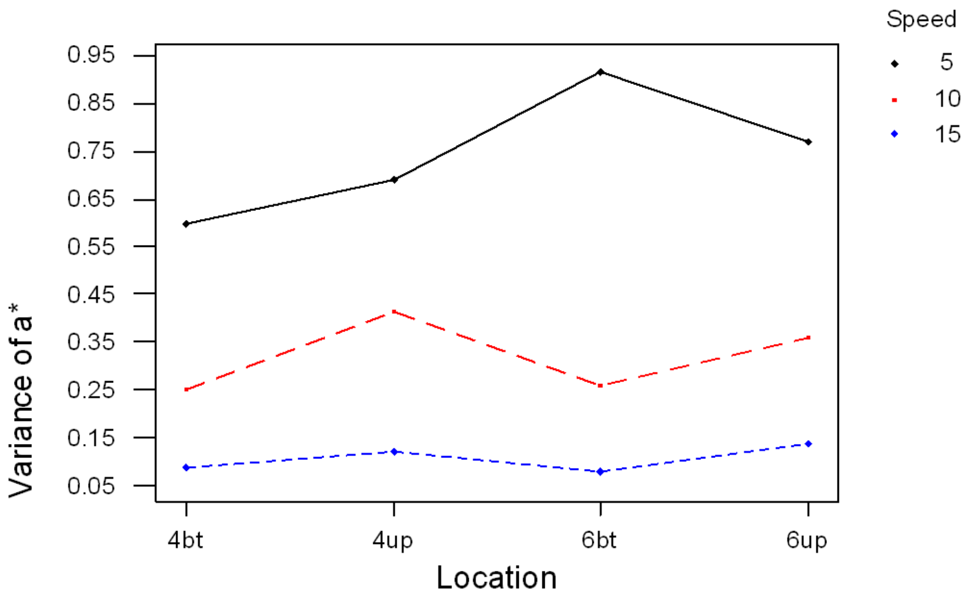

Figure 56 Variation of variances of a* values with location with the mixer in different speed of rotations

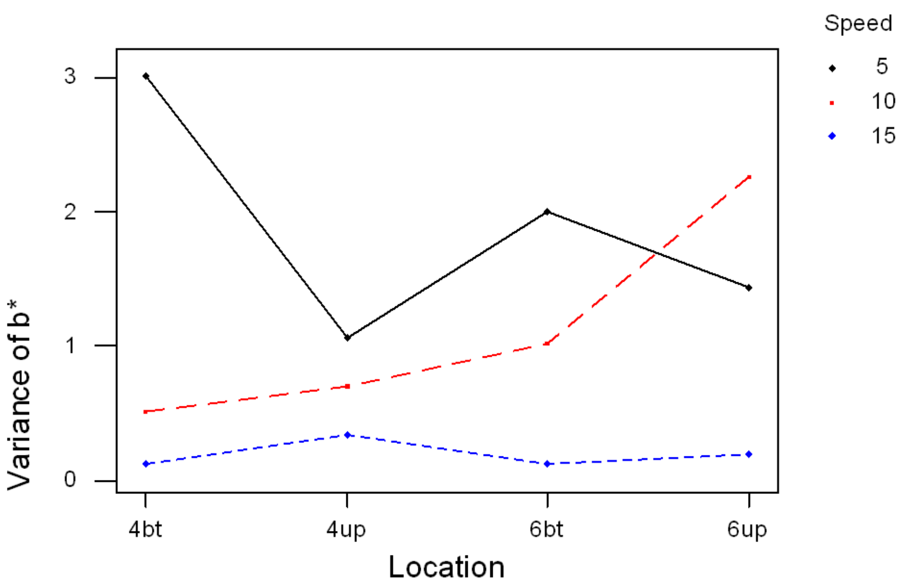

Figure 57 Variation of variances of b* values with location with the mixer in different speed of rotations

3.4 DETERMINATION OF THE RELATION BETWEEN THE COLOR VALUES AND TEMPERATURE

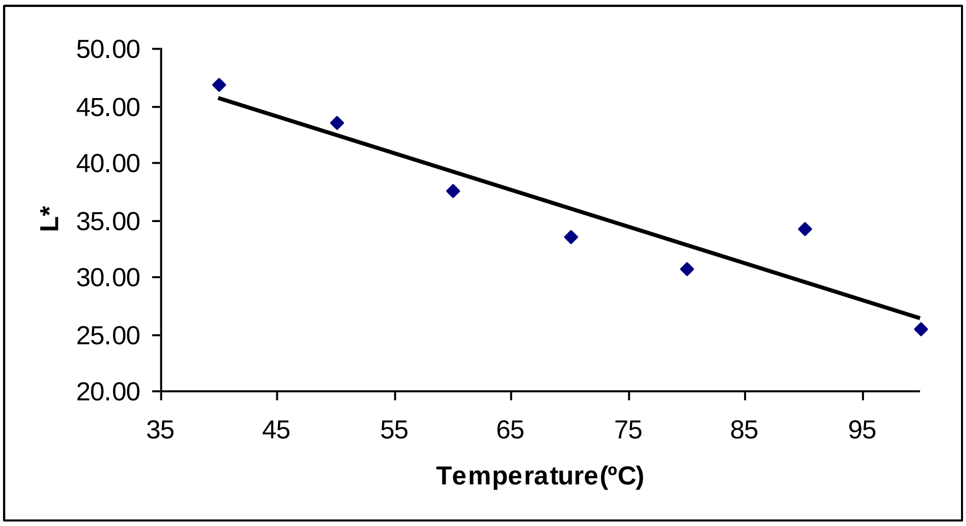

Figure 58 Variation of L* value with temperature

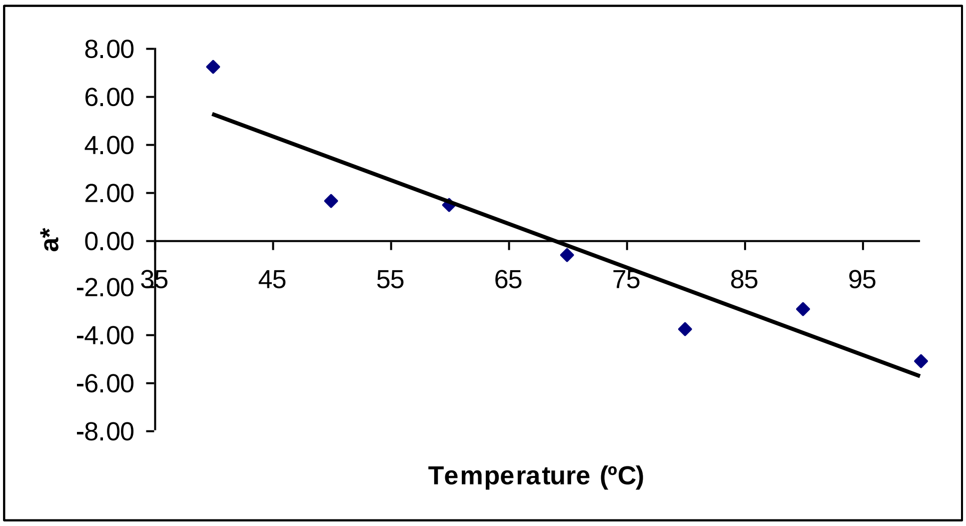

Figure 59 Variation of a* value with temperature

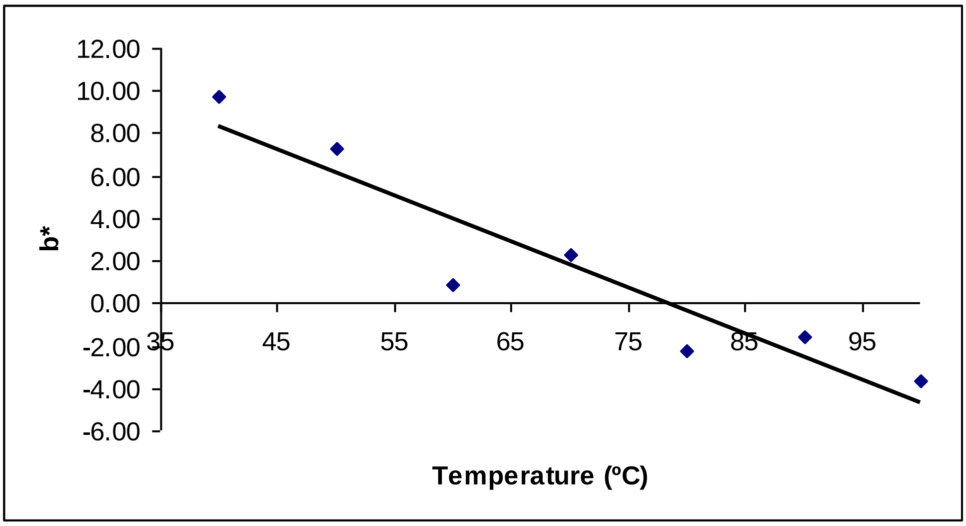

Figure 60 Variation of b* value with temperature

In Figure 58-60, it can be seen that all three color values decrease by the temperature increase. By the regression analysis, the following relations were found to express the relation between the color values and temperature. From these relations, it can be stated that all three color values were decreasing linearly in increasing temperature. The steepest decrease occurred at L* value which was expected as the samples became darker by energy input.

L* = 58,43 - 0.321T (R^2 = 0,88)

a* = 12,52 - 0.183 T (R^2 = 0,89)

b* = 17,05 - 0.218 T (R^2 = 0,88)

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

On the basis of the experimental results and their discussion it is possible to conclude that, in the conventional microwave ovens the energy distribution is non-uniform. Hence a non-homogenous product with respect to the sought property is inevitable.

As L* value is a parameter for lightness, it may be regarded as not very important for the effectiveness of mixing as compared to the real color values a* and b*. These latter values are the real color values indicating the effectiveness and uniformity of energy distribution.

The surface temperature value measurements are quite in accordance with the trend of a* and b* values. This improves the robustness of the conclusion made after the color experiments and can be used as a verification.

The speed of roation of the mixer contributes highly to mixing, however it must be considered with time and power to achieve an optimum setting.

In the light of the findings it is possible to claim that the mixer designed is a good solution for reaching more uniformly heated particulate solids .

4.2 RECOMMENDATIONS

The techniques that can be used to determine the effectiveness may be more elaborate to reach more detailed results. MRI can be a solution to this problem that it could reach the values in three dimensions not in 2-D. Also a combination of microwave and conventional heating could be used to measure its effect also. The effect of this mixer to a liquid of varying thicknesses or liquid-solid slutions may also be observed by detailed arrangements.

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APPENDIX A

AVERAGE COLOR AND SURFACE TEMPERATURE DATA

A.1 Average Color Value Data

Table 1 Average color L*, a* and b* values with its variances for samples processed without mixer

Power (%)	Time(sec)	Location	Speed (rpm)	Average			Variance		
				L*	a*	b*	L*	a*	b*
10	60	4up	5	50.53	6.8	13.77	13.04	0.49	3.77
10	90	4up	5	51.57	4.03	11.9	2.86	4.32	9.07
10	120	4up	5	52.43	5.13	12.77	26.56	1.4	9.17
40	60	4up	5	50.37	4.67	8.67	0.44	1.7	4.5
40	90	4up	5	45.9	1.4	7.33	16.47	1.33	0.94
40	120	4up	5	38.8	0.8	3.77	6.03	0.63	0.4
67	60	4up	5	42.3	1.07	4.87	4.41	0.1	0.49
67	90	4up	5	40.77	0.03	0.3	0.5	0.05	2.91
67	120	4up	5	41.67	-3.97	-1.33	3.1	0.1	0.06
100	60	4up	5	40.9	-2.1	-0.03	0.13	0.03	0.16
100	90	4up	5	44.37	-6.23	-5.8	0.7	0.01	0.28
100	120	4up	5	46.87	-5.23	-2.27	1.54	0.05	0.12
10	60	4bt	5	49.33	5.93	14.6	56.8	3.05	14.89
10	90	4bt	5	47.87	5.53	11.4	11.96	0.5	1.48
10	120	4bt	5	49.13	5.5	11.43	5.3	2.91	0.02
40	60	4bt	5	47.8	1.5	3.9	13.72	1.99	0.13
40	90	4bt	5	39.27	0.2	3.1	25.3	2.71	0.76
40	120	4bt	5	42.57	-0.83	1.27	25.02	1.05	0.6
67	60	4bt	5	39.6	0.1	-0.07	34.83	0.25	1.92
67	90	4bt	5	39.1	-2.57	-0.37	2.41	0	0.05
67	120	4bt	5	39.13	-0.17	-0.13	1.86	0.02	0.44
100	60	4bt	5	48.97	-0.27	3	0.44	0.04	2.73
100	90	4bt	5	44.97	-4.47	-1.97	0.81	0.02	0.17
100	120	4bt	5	40.47	-3.67	-1.6	0.14	0.25	0.43
10	60	6up	5	50.9	6.1	8.4	2.77	1.83	0.57
10	90	6up	5	49.57	3.97	7.97	19.44	0.44	2.89
10	120	6up	5	49.03	4.83	10.3	5.24	0.9	14.77

Table 1. (Cont'd)

40	60	6up	5	44.97	2.63	6.5	27.64	2.14	0.93
40	90	6up	5	38.93	3.27	6.93	2.54	3.94	1.14
40	120	6up	5	42.07	1.47	6.23	21.64	1.4	0.12
67	60	6up	5	40.87	0.33	4.87	5.58	0.1	0.16
67	90	6up	5	42.47	-0.47	3	1.85	0.1	5.11
67	120	6up	5	33.1	-3.77	-2.67	6.01	0.64	0.25
100	60	6up	5	50.07	0.57	-4.57	0.16	0.21	0.32
100	90	6up	5	41.27	-4.5	-5.33	0.56	0.49	1.65
100	120	6up	5	38.07	-3.9	-1.37	0.1	0.28	0.32
10	60	6bt	5	51.97	4.63	11.37	26.89	1.7	41.77
10	90	6bt	5	50.67	5.97	14.33	2.06	1.32	5.86
10	120	6bt	5	47.83	3.47	6.07	10.56	1.42	1.86
40	60	6bt	5	46.53	4.3	7.97	19.61	0.09	6.52
40	90	6bt	5	42.37	3.27	6.47	37.62	0.69	2.12
40	120	6bt	5	45.53	1.63	2.2	18.04	0.56	8.13
67	60	6bt	5	38.37	2.43	5.17	7.37	0.24	0.56
67	90	6bt	5	41.43	1.03	2.87	0.44	0.09	1.04
67	120	6bt	5	42.5	-3.27	-2.57	0.79	0.24	0.1
100	60	6bt	5	41.63	-1.13	1.37	0.44	0.1	0.56
100	90	6bt	5	36.03	-3.63	-2.77	2.86	1.08	0.1
100	120	6bt	5	42.57	-5.07	-3.37	0.02	0.42	0.3
10	60	4up	10	41.67	5	12.6	1.04	0.01	0.04
10	90	4up	10	43.67	5.23	10.97	0.2	0.14	0.65
10	120	4up	10	45.37	5.8	13.87	0.25	0.07	0.82
40	60	4up	10	48.73	6.4	15.27	0.2	2.73	0.33
40	90	4up	10	42.27	6.5	12.63	5.29	0.25	6.96
40	120	4up	10	39.23	1.33	4.73	0.3	0.09	0.14
67	60	4up	10	43.87	3.43	7.4	1.65	0.7	0.03
67	90	4up	10	40	2.47	5.9	0.13	0.01	0.13
67	120	4up	10	33.37	-2.6	-2.07	0.04	0.21	1.44
100	60	4up	10	49.53	3.6	7.3	0.04	0.01	0.04
100	90	4up	10	39.2	-3.1	0.67	0.01	0.09	0.14
100	120	4up	10	37.4	-5.37	-5.7	0.19	0.02	0.19
10	60	4bt	10	49.17	3.13	10.4	4.66	0.54	2.73
10	90	4bt	10	45.47	5.1	12.03	0.16	0.28	0.34
10	120	4bt	10	43	4.6	8.7	0.21	0.13	0.13
40	60	4bt	10	52.7	4.1	10.23	3.99	2.47	1.86
40	90	4bt	10	42.67	0.63	4.93	0.46	0.25	0.64
40	120	4bt	10	48.13	-2.9	2.33	3.45	0.01	1.34
67	60	4bt	10	39.23	1.07	6.37	0.85	0.41	0.5
67	90	4bt	10	39.4	1.37	2.47	0.31	0.17	0.26
67	120	4bt	10	43.4	-1.27	1.57	5.67	0.17	0.32
100	60	4bt	10	43.83	1.37	7.43	0.46	0.24	0.24
100	90	4bt	10	38.5	-4.4	-2.23	2.11	0.09	0
100	120	4bt	10	42.1	-4.57	-3.5	1.12	0.02	0.73
10	60	6up	10	52.63	6.33	12.93	2.9	0.05	0.14
10	90	6up	10	41.23	4.2	11.33	6.6	4.03	0.1
10	120	6up	10	45.37	3.23	10.07	28.3	5.24	13.61

Table 1. (Cont'd)

40	60	6up	10	48.27	5.53	9.33	9.9	0.02	0.58
40	90	6up	10	36.57	4.53	8.6	0.66	2.25	5.07
40	120	6up	10	44.63	5.93	6.53	0.46	0.92	4.44
67	60	6up	10	43.87	2.63	7.63	0.09	0.8	0.12
67	90	6up	10	36.2	-0.53	2.6	3.49	1.82	1.63
67	120	6up	10	39.43	-0.93	3.73	0.3	1.14	0.65
100	60	6up	10	41.47	3.43	7.67	1.29	0.24	0.16
100	90	6up	10	35.8	-4.73	-3.2	11.37	0.9	4.53
100	120	6up	10	38.57	-4.83	-3.6	1.6	0.14	0.49
10	60	6bt	10	47.3	6.97	12.43	2.19	0	0.08
10	90	6bt	10	36.53	5.97	10.83	1.45	0.06	0.81
10	120	6bt	10	53.63	7.7	15.6	0.16	0.19	0.01
40	60	6bt	10	39.83	3.17	7.57	0.58	0.04	1.8
40	90	6bt	10	45.73	0.7	6.03	4.64	0.27	0.66
40	120	6bt	10	46.03	0.4	6.3	5.61	0.21	0.25
67	60	6bt	10	40.4	0.5	5.4	1.11	0.03	0.19
67	90	6bt	10	37.2	-4.03	-1.33	7.09	0.57	0.34
67	120	6bt	10	29.03	-2.43	4.8	0.66	2.4	0.19
100	60	6bt	10	40.77	3.27	7.27	1.42	0.56	0.06
100	90	6bt	10	45.87	-4.57	-1.33	0.92	1.37	0.56
100	120	6bt	10	39.77	-6.43	-3.87	0.02	0.32	0.25
10	60	4up	15	43.77	5.6	11.4	1.16	0.21	1.57
10	90	4up	15	43.17	5.13	12.9	0.94	0.16	0.39
10	120	4up	15	40.73	6.03	11.23	0.44	0.1	0.1
40	60	4up	15	42.87	5.23	11.83	1.2	0.04	0.44
40	90	4up	15	50.5	6.2	11.57	1.81	0.21	0.5
40	120	4up	15	41.63	3.63	8.13	1.34	0.04	0.37
67	60	4up	15	44.7	0.97	2.77	3.31	0.56	0.44
67	90	4up	15	35.17	-0.43	-5.1	2.77	0.2	0.31
67	120	4up	15	34.63	-0.1	1.47	0.16	0.07	0.12
100	60	4up	15	43.8	4.8	8.53	2.29	0.21	0.69
100	90	4up	15	44.53	0.63	4.8	1.74	0.02	0.21
100	120	4up	15	44.23	-2.9	-4.03	9.61	0.39	0.41
10	60	4bt	15	43.67	4.97	11.47	2.44	0.04	0
10	90	4bt	15	42.57	6.2	12.5	1.01	0.13	0.19
10	120	4bt	15	46.93	5.17	10.23	0.46	0.02	0.22
40	60	4bt	15	34.3	3.47	8.63	0.79	0.1	0.16
40	90	4bt	15	41.4	3.6	9.37	0.43	0.21	0.02
40	120	4bt	15	51.03	4.9	7.23	0.54	0.07	0.04
67	60	4bt	15	43.17	5.37	5.03	1.08	0.42	0.16
67	90	4bt	15	41.4	-1.37	-4.2	0.37	0.66	0.19
67	120	4bt	15	38.47	-2.9	2.47	1.49	0.43	0.04
100	60	4bt	15	30.4	-1.07	-1.03	0.43	0.16	0.2
100	90	4bt	15	35.47	-4.2	0.37	1.26	0.19	0.02
100	120	4bt	15	32.7	-6.8	-5.87	0.27	0.12	0.32
10	60	6up	15	43.87	5.63	7.73	0.97	0.81	0.04
10	90	6up	15	35.63	5.3	10.57	2.4	0.49	0.01
10	120	6up	15	42.23	4.6	11.37	1.44	0.07	0.14
40	60	6up	15	37.33	7.3	12.93	0.22	0.07	1.84

Table 1. (Cont'd)

40	90	6up	15	47.13	7.13	9.73	1.77	0.06	0.06
40	120	6up	15	51.43	-0.57	4.67	1.34	0.34	0.09
67	60	6up	15	48.43	4.77	8.63	1.02	0.14	0.02
67	90	6up	15	42.5	3.5	1.43	1.12	0.04	0.06
67	120	6up	15	37.17	-1.03	0.63	2.24	0.22	0.02
100	60	6up	15	33.77	0.4	3.63	2.82	0.13	0.14
100	90	6up	15	41	-1.1	3.47	0.37	0.13	0.04
100	120	6up	15	31.83	-1.83	-1.33	0.34	0.37	0.44
10	60	6bt	15	42.83	4.97	9.57	1.32	0.06	0.14
10	90	6bt	15	38.5	4.37	8.23	0.39	0.1	0.17
10	120	6bt	15	52.03	5.83	13.37	0.52	0.17	0.42
40	60	6bt	15	35.87	3.27	9	0.02	0.06	0.39
40	90	6bt	15	40.8	4.5	9.47	0.16	0.07	0.06
40	120	6bt	15	42.33	1.6	4.97	0.49	0.07	0.04
67	60	6bt	15	44.37	1.7	6.87	2.64	0.07	0.09
67	90	6bt	15	45.7	0.77	3.4	1.24	0.1	0.07
67	120	6bt	15	45.73	0.2	3.7	4.09	0.04	0.16
100	60	6bt	15	35.53	-0.5	2.67	1.84	0.28	0.04
100	90	6bt	15	46.57	-0.47	1.3	6.8	0.02	0.13
100	120	6bt	15	45.37	-4.4	-0.67	1.77	43.33	0.09

Table 2 Average color L*, a* and b* values with its variances for samples processed with mixer

Power (%)	Time(sec)	Location	Speed (rpm)	Average			Variance		
				L*	**a***	**b***	**L***	**a***	**b***
10	60	4up	5	53.97	8.37	17.53	1.86	0.58	2.72
10	90	4up	5	53.63	5.57	11.93	2.12	0.14	0.10
10	120	4up	5	52.50	7.93	17.57	3.04	1.00	1.21
40	60	4up	5	55.70	7.23	13.67	6.84	0.32	1.36
40	90	4up	5	47.87	5.97	11.70	1.49	1.77	3.25
40	120	4up	5	49.83	7.43	14.57	0.32	0.72	0.86
67	60	4up	5	58.10	3.97	12.30	0.07	0.04	0.04
67	90	4up	5	46.93	2.77	7.77	2.14	0.54	0.08
67	120	4up	5	43.93	0.00	5.13	4.40	0.21	0.04
100	60	4up	5	49.23	6.37	12.40	0.02	1.20	2.17
100	90	4up	5	48.83	1.43	4.40	0.65	1.20	0.79
100	120	4up	5	42.97	-1.50	4.33	1.05	0.57	0.22
10	60	4bt	5	56.03	7.70	19.80	19.06	0.97	6.07
10	90	4bt	5	57.63	6.63	17.33	0.49	0.69	0.01
10	120	4bt	5	49.70	6.03	12.00	2.77	0.54	4.84
40	60	4bt	5	54.17	7.33	13.40	5.76	0.94	1.03
40	90	4bt	5	50.50	7.40	13.83	2.71	0.48	0.94

Table 2. (Cont'd)

40	120	4bt	5	45.40	5.60	13.60	3.49	1.33	9.61
67	60	4bt	5	44.83	4.20	10.03	2.12	0.12	4.60
67	90	4bt	5	46.27	1.40	6.07	1.84	1.57	0.69
67	120	4bt	5	41.60	-2.53	0.30	1.39	0.04	2.71
100	60	4bt	5	46.70	2.33	6.73	6.37	0.44	1.44
100	90	4bt	5	51.43	1.43	6.40	1.56	0.00	2.29
100	120	4bt	5	43.97	-0.87	3.20	1.86	0.06	1.89
10	60	6up	5	55.00	8.20	18.47	9.03	2.59	0.09
10	90	6up	5	52.73	7.57	17.83	1.40	0.17	0.54
10	120	6up	5	51.60	5.60	15.20	0.03	4.00	5.23
40	60	6up	5	54.90	6.83	16.23	0.73	0.06	0.90
40	90	6up	5	50.60	6.40	12.77	3.97	0.84	0.94
40	120	6up	5	51.63	4.90	12.93	6.10	0.21	2.33
67	60	6up	5	47.37	2.50	11.33	1.32	0.13	0.54
67	90	6up	5	40.77	0.53	4.00	0.46	0.10	0.43
67	120	6up	5	45.57	-0.17	4.87	0.37	0.16	4.92
100	60	6up	5	42.80	5.13	8.63	0.19	0.09	0.74
100	90	6up	5	49.57	0.60	6.33	4.76	0.52	0.41
100	120	6up	5	48.97	-1.00	3.93	0.80	0.37	0.25
10	60	6bt	5	50.87	7.27	18.10	4.62	0.12	3.33
10	90	6bt	5	55.30	7.83	16.80	13.03	0.20	3.43
10	120	6bt	5	50.77	6.50	13.70	15.29	0.43	8.31
40	60	6bt	5	53.00	6.57	13.77	0.25	0.44	3.05
40	90	6bt	5	50.50	6.90	14.87	0.64	2.01	0.24
40	120	6bt	5	50.70	5.43	13.57	0.52	1.26	0.72
67	60	6bt	5	47.40	3.97	9.13	18.01	5.74	2.26
67	90	6bt	5	47.30	3.40	7.83	0.31	0.01	0.17
67	120	6bt	5	42.50	0.37	5.83	0.91	0.66	2.50
100	60	6bt	5	48.57	5.43	11.83	0.24	0.04	0.01
100	90	6bt	5	47.40	1.53	5.50	0.01	0.00	0.01
100	120	6bt	5	46.80	-1.40	3.17	0.97	0.07	0.01
10	60	4up	10	40.60	5.60	10.70	0.79	0.04	0.16
10	90	4up	10	43.80	5.57	9.23	3.00	2.50	1.21
10	120	4up	10	42.77	4.83	10.53	0.46	0.64	2.90
40	60	4up	10	39.23	1.63	5.20	0.57	0.37	0.19
40	90	4up	10	40.53	2.13	4.93	0.82	0.14	0.04
40	120	4up	10	46.57	3.37	1.90	0.54	0.08	0.49
67	60	4up	10	48.43	0.20	6.00	2.94	0.13	0.04
67	90	4up	10	46.00	0.87	6.70	0.84	0.24	0.28
67	120	4up	10	38.13	-5.67	-3.73	0.21	0.00	1.84
100	60	4up	10	34.93	-0.73	1.97	2.25	0.66	0.34
100	90	4up	10	38.07	-1.37	-5.33	0.42	0.00	0.09
100	120	4up	10	35.23	-6.50	-5.03	0.20	0.19	0.82
10	60	4bt	10	41.33	6.23	10.67	0.85	0.25	0.16
10	90	4bt	10	44.17	4.83	7.60	2.54	0.32	1.03
10	120	4bt	10	52.83	5.90	12.83	2.90	0.97	2.33
40	60	4bt	10	36.00	4.10	4.57	13.87	0.27	0.17
40	90	4bt	10	42.73	3.37	4.53	2.41	0.06	0.37
40	120	4bt	10	39.27	0.40	5.43	35.44	0.03	0.12

Table 2. (Cont'd)

67	60	4bt	10	40.13	0.63	3.50	0.41	0.05	0.01
67	90	4bt	10	41.07	1.17	5.47	12.82	0.54	1.36
67	120	4bt	10	43.83	-2.90	-1.97	9.85	0.25	0.44
100	60	4bt	10	31.67	-1.70	2.27	3.45	0.07	0.26
100	90	4bt	10	38.57	-1.53	-4.10	0.20	0.04	0.01
100	120	4bt	10	33.50	-6.10	-5.53	1.24	0.19	0.00
10	60	6up	10	47.07	5.17	11.23	2.76	1.14	4.20
10	90	6up	10	35.80	5.63	10.37	0.21	0.06	0.24
10	120	6up	10	46.57	6.43	13.13	4.01	0.09	0.16
40	60	6up	10	38.53	5.07	10.50	2.01	1.40	5.56
40	90	6up	10	39.97	4.33	6.13	2.46	0.10	15.30
40	120	6up	10	44.40	3.27	6.13	7.41	0.30	0.26
67	60	6up	10	35.17	1.73	4.43	16.12	0.12	0.16
67	90	6up	10	43.80	2.17	6.07	14.56	0.56	0.40
67	120	6up	10	41.07	-4.43	-4.87	0.52	0.24	0.04
100	60	6up	10	40.97	-0.33	3.97	0.04	0.12	0.74
100	90	6up	10	32.50	-2.10	0.30	0.39	0.07	0.07
100	120	6up	10	32.47	-6.63	-4.30	0.56	0.12	0.04
10	60	6bt	10	49.50	5.50	11.00	0.13	0.07	0.67
10	90	6bt	10	46.97	7.83	12.97	6.52	0.04	0.25
10	120	6bt	10	46.77	7.13	12.10	0.66	0.81	1.08
40	60	6bt	10	36.13	2.67	10.30	2.24	0.30	7.03
40	90	6bt	10	36.23	2.00	5.00	0.60	0.25	0.64
40	120	6bt	10	41.83	2.10	1.97	0.08	0.57	0.06
67	60	6bt	10	42.50	1.57	4.73	2.47	0.02	0.82
67	90	6bt	10	45.00	2.10	2.63	2.47	0.37	0.10
67	120	6bt	10	38.57	-4.17	-4.63	1.36	0.02	0.22
100	60	6bt	10	42.23	-2.07	0.77	0.34	0.10	0.06
100	90	6bt	10	36.57	-1.43	-0.97	0.34	0.14	0.24
100	120	6bt	10	35.27	-5.27	-4.43	0.44	0.44	1.04
10	60	4up	15	38.40	4.20	10.13	0.49	0.81	0.30
10	90	4up	15	42.90	3.63	7.47	0.31	0.04	0.17
10	120	4up	15	42.53	4.50	9.00	0.20	0.07	0.04
40	60	4up	15	42.17	7.40	12.70	0.22	0.03	2.28
40	90	4up	15	37.00	2.37	6.73	0.19	0.10	0.22
40	120	4up	15	42.03	4.37	7.73	2.30	0.04	0.54
67	60	4up	15	44.33	-0.17	4.77	1.00	0.02	0.30
67	90	4up	15	44.53	0.00	6.30	0.30	0.01	0.13
67	120	4up	15	36.33	-5.90	-5.53	0.81	0.13	0.01
100	60	4up	15	43.53	-0.83	3.37	0.09	0.02	0.02
100	90	4up	15	41.60	-3.37	1.23	3.01	0.04	0.09
100	120	4up	15	32.63	-3.07	-2.37	0.22	0.16	0.02
10	60	4bt	15	41.17	5.97	9.97	0.17	0.02	0.04
10	90	4bt	15	42.87	5.50	6.60	0.30	0.07	0.21
10	120	4bt	15	46.53	4.30	10.70	0.69	0.04	0.09
40	60	4bt	15	43.40	7.33	12.40	0.57	0.06	0.03
40	90	4bt	15	34.73	3.53	7.70	1.01	0.02	0.07
40	120	4bt	15	34.77	1.37	1.43	1.86	0.02	0.36
67	60	4bt	15	37.30	0.73	3.33	0.01	0.06	0.04

Table 2. (Cont'd)

67	90	4bt	15	37.50	1.93	5.23	0.19	0.02	0.20
67	120	4bt	15	40.67	-3.00	-2.37	0.80	0.07	0.06
100	60	4bt	15	38.20	-0.73	1.60	0.84	0.12	0.04
100	90	4bt	15	46.33	-1.03	1.57	1.10	0.32	0.17
100	120	4bt	15	32.37	-5.93	-3.03	1.20	0.22	0.20
10	60	6up	15	43.77	6.23	8.50	1.86	0.04	0.19
10	90	6up	15	36.33	4.43	9.70	0.57	0.16	0.13
10	120	6up	15	42.10	6.13	12.00	0.31	0.49	0.01
40	60	6up	15	43.63	4.73	9.77	0.00	0.02	0.06
40	90	6up	15	43.63	6.93	12.40	0.02	0.02	1.83
40	120	6up	15	43.00	2.27	2.57	0.07	0.12	0.04
67	60	6up	15	32.83	0.90	3.43	0.26	0.07	0.04
67	90	6up	15	40.80	0.70	5.43	0.19	0.21	0.06
67	120	6up	15	42.57	-3.60	-3.67	0.24	0.21	0.00
100	60	6up	15	43.43	0.07	2.67	0.01	0.04	0.02
100	90	6up	15	30.80	-3.50	-2.20	2.17	0.13	0.01
100	120	6up	15	37.77	-5.60	-5.60	0.44	0.13	0.07
10	60	6bt	15	51.30	5.30	10.77	1.21	0.01	0.14
10	90	6bt	15	42.17	7.17	11.73	0.17	0.04	0.08
10	120	6bt	15	47.20	7.47	10.90	0.37	0.04	0.28
40	60	6bt	15	43.67	2.63	8.37	1.21	0.04	0.02
40	90	6bt	15	37.40	1.33	7.40	0.49	0.02	0.03
40	120	6bt	15	35.70	0.63	4.47	0.49	0.04	0.06
67	60	6bt	15	40.60	0.83	3.30	0.37	0.10	0.04
67	90	6bt	15	41.90	1.43	2.73	0.52	0.02	0.37
67	120	6bt	15	36.53	-3.83	-3.13	0.72	0.37	0.14
100	60	6bt	15	35.83	-0.50	3.67	0.02	0.13	0.02
100	90	6bt	15	36.57	-3.27	-1.13	1.14	0.04	0.10
100	120	6bt	15	30.03	-4.53	-6.43	0.32	0.09	0.16

A.2 Average Surface Temperature Data

Table 3 Average surface temperature values with its variances for samples processed without mixer

Power (%)	Time (sec)	Location	Speed (rpm)	Average Temperature	Variance
10	60	2	5	35,43	0,06
10	90	2	5	38,80	4,03
10	120	2	5	46,87	0,16
40	60	2	5	50,77	2,80
40	90	2	5	70,57	0,64
40	120	2	5	78,47	11,76

Table 3. (Cont'd)

67	60	2	5	68,37	7,26
67	90	2	5	86,93	8,86
67	120	2	5	102,43	9,14
100	60	2	5	77,87	58,96
100	90	2	5	109,70	1,51
100	120	2	5	121,73	46,92
10	60	2	10	36,07	0,04
10	90	2	10	40,17	0,16
10	120	2	10	48,97	0,66
40	60	2	10	60,80	34,33
40	90	2	10	67,53	4,62
40	120	2	10	87,40	8,19
67	60	2	10	81,70	4,63
67	90	2	10	84,87	35,02
67	120	2	10	106,83	3,16
100	60	2	10	86,57	57,84
100	90	2	10	109,60	20,92
100	120	2	10	127,53	35,32
10	60	2	15	35,63	0,25
10	90	2	15	41,33	1,61
10	120	2	15	41,77	0,04
40	60	2	15	61,93	2,57
40	90	2	15	79,00	28,21
40	120	2	15	85,57	29,29
67	60	2	15	85,57	39,76
67	90	2	15	83,17	10,44
67	120	2	15	96,70	105,87
100	60	2	15	91,67	36,69
100	90	2	15	106,20	18,84
100	120	2	15	130,03	38,17
10	60	4	5	37,13	0,06
10	90	4	5	40,53	0,34
10	120	4	5	44,03	0,40
40	60	4	5	55,00	5,71
40	90	4	5	67,37	7,70
40	120	4	5	74,10	2,77
67	60	4	5	63,27	1,86
67	90	4	5	75,40	1,39
67	120	4	5	102,47	75,22
100	60	4	5	69,23	40,05
100	90	4	5	90,50	7,51
100	120	4	5	136,00	0,43
10	60	4	10	36,80	0,01
10	90	4	10	41,00	0,13
10	120	4	10	47,27	0,92
40	60	4	10	54,17	10,32
40	90	4	10	67,33	5,49
40	120	4	10	78,60	1,33
67	60	4	10	63,83	1,37

Table 3. (Cont'd)

67	90	4	10	74,00	22,63
67	120	4	10	97,83	7,34
100	60	4	10	85,27	18,29
100	90	4	10	109,43	61,62
100	120	4	10	110,83	21,84
10	60	4	15	36,87	0,10
10	90	4	15	39,90	0,28
10	120	4	15	43,53	0,81
40	60	4	15	55,20	2,52
40	90	4	15	73,27	6,22
40	120	4	15	76,17	5,69
67	60	4	15	63,40	0,43
67	90	4	15	74,70	18,03
67	120	4	15	94,40	35,56
100	60	4	15	82,60	9,19
100	90	4	15	100,03	0,58
100	120	4	15	123,40	2,41
10	60	6	5	37,70	0,16
10	90	6	5	41,00	0,27
10	120	6	5	41,97	0,14
40	60	6	5	50,17	40,01
40	90	6	5	61,50	63,61
40	120	6	5	74,97	1,74
67	60	6	5	69,83	12,20
67	90	6	5	78,57	0,17
67	120	6	5	105,03	1,36
100	60	6	5	77,30	14,53
100	90	6	5	94,23	2,94
100	120	6	5	125,20	2,59
10	60	6	10	37,80	0,28
10	90	6	10	40,57	0,01
10	120	6	10	47,93	0,86
40	60	6	10	56,30	0,63
40	90	6	10	69,03	0,57
40	120	6	10	76,03	27,37
67	60	6	10	71,70	0,91
67	90	6	10	78,57	2,40
67	120	6	10	95,67	17,24
100	60	6	10	84,73	32,36
100	90	6	10	108,80	12,13
100	120	6	10	119,93	44,24
10	60	6	15	38,53	0,17
10	90	6	15	40,00	0,12
10	120	6	15	43,97	1,20
40	60	6	15	61,40	7,72
40	90	6	15	79,63	0,02
40	120	6	15	80,33	3,89
67	60	6	15	67,03	4,44
67	90	6	15	79,97	14,60

Table 3. (Cont'd)

67	120	6	15	98,57	9,69
100	60	6	15	79,30	44,41
100	90	6	15	108,40	40,44
100	120	6	15	111,37	15,06
10	60	8	5	36,03	0,02
10	90	8	5	41,43	4,44
10	120	8	5	38,50	0,91
40	60	8	5	43,63	23,26
40	90	8	5	53,57	15,37
40	120	8	5	68,93	10,70
67	60	8	5	61,90	8,17
67	90	8	5	69,90	0,76
67	120	8	5	84,10	41,13
100	60	8	5	68,03	19,36
100	90	8	5	85,33	10,66
100	120	8	5	90,17	12,64
10	60	8	10	37,30	0,12
10	90	8	10	42,53	0,66
10	120	8	10	49,13	0,52
40	60	8	10	50,50	2,77
40	90	8	10	57,80	1,81
40	120	8	10	62,33	10,12
67	60	8	10	61,73	1,26
67	90	8	10	70,40	22,51
67	120	8	10	88,63	11,61
100	60	8	10	74,27	9,56
100	90	8	10	80,73	9,72
100	120	8	10	96,50	13,89
10	60	8	15	36,20	0,43
10	90	8	15	37,87	0,04
10	120	8	15	39,80	0,09
40	60	8	15	53,07	6,54
40	90	8	15	63,60	7,09
40	120	8	15	66,83	13,32
67	60	8	15	62,77	1,12
67	90	8	15	64,90	1,56
67	120	8	15	85,87	33,01
100	60	8	15	67,77	1,00
100	90	8	15	103,07	6,45
100	120	8	15	93,63	52,12

Table 4 Average surface temperature values with its variances for samples processed with mixer

Power (%)	Time (sec)	Location	Speed (rpm)	Average Temperature	Variance
10	60	2	5	39,40	0,03

Table 4. (Cont'd)

10	90	2	5	39,20	0,61
10	120	2	5	43,63	1,05
40	60	2	5	45,63	0,21
40	90	2	5	64,40	1,75
40	120	2	5	73,17	6,96
67	60	2	5	62,90	2,47
67	90	2	5	78,73	14,20
67	120	2	5	107,97	0,12
100	60	2	5	81,17	1,04
100	90	2	5	94,17	14,84
100	120	2	5	121,33	4,85
10	60	2	10	37,70	0,37
10	90	2	10	40,20	0,57
10	120	2	10	43,30	0,43
40	60	2	10	69,20	13,93
40	90	2	10	60,50	0,76
40	120	2	10	75,73	1,42
67	60	2	10	69,63	16,65
67	90	2	10	81,40	1,11
67	120	2	10	94,20	24,49
100	60	2	10	83,17	0,60
100	90	2	10	95,97	3,42
100	120	2	10	118,43	9,06
10	60	2	15	38,80	0,07
10	90	2	15	40,73	0,05
10	120	2	15	45,30	0,28
40	60	2	15	57,77	0,44
40	90	2	15	64,77	2,50
40	120	2	15	75,67	4,82
67	60	2	15	71,33	0,44
67	90	2	15	83,43	1,26
67	120	2	15	98,13	5,37
100	60	2	15	80,10	1,47
100	90	2	15	96,40	4,44
100	120	2	15	119,97	8,16
10	60	4	5	39,53	0,17
10	90	4	5	40,37	0,74
10	120	4	5	45,13	0,46
40	60	4	5	47,87	1,24
40	90	4	5	64,23	74,70
40	120	4	5	74,90	0,39
67	60	4	5	70,67	18,89
67	90	4	5	73,63	0,41
67	120	4	5	109,70	0,49
100	60	4	5	81,53	8,16
100	90	4	5	94,47	2,96
100	120	4	5	118,50	7,84
10	60	4	10	37,30	0,16
10	90	4	10	39,40	0,03

Table 4. (Cont'd)

10	120	4	10	43,90	0,21
40	60	4	10	65,47	89,74
40	90	4	10	62,47	2,96
40	120	4	10	77,93	2,40
67	60	4	10	71,17	0,49
67	90	4	10	82,23	0,97
67	120	4	10	95,97	6,52
100	60	4	10	81,20	0,73
100	90	4	10	92,43	6,25
100	120	4	10	111,23	11,44
10	60	4	15	39,13	0,76
10	90	4	15	40,97	0,04
10	120	4	15	44,90	0,03
40	60	4	15	56,83	0,25
40	90	4	15	67,97	2,44
40	120	4	15	72,80	7,32
67	60	4	15	69,97	4,00
67	90	4	15	80,63	3,42
67	120	4	15	99,87	7,41
100	60	4	15	80,70	1,47
100	90	4	15	97,47	7,46
100	120	4	15	127,73	3,76
10	60	6	5	38,93	0,10
10	90	6	5	40,93	0,49
10	120	6	5	43,73	0,09
40	60	6	5	47,47	0,52
40	90	6	5	64,73	9,21
40	120	6	5	78,40	8,31
67	60	6	5	69,80	5,59
67	90	6	5	79,63	6,20
67	120	6	5	100,73	0,06
100	60	6	5	85,60	22,57
100	90	6	5	99,47	8,05
100	120	6	5	115,63	14,89
10	60	6	10	37,20	0,09
10	90	6	10	38,80	0,07
10	120	6	10	42,40	0,07
40	60	6	10	61,33	11,61
40	90	6	10	65,00	10,99
40	120	6	10	75,20	2,17
67	60	6	10	71,50	0,81
67	90	6	10	82,77	5,69
67	120	6	10	98,10	1,47
100	60	6	10	78,57	6,77
100	90	6	10	100,37	2,09
100	120	6	10	111,63	0,57
10	60	6	15	38,53	0,05
10	90	6	15	40,97	0,09
10	120	6	15	45,00	0,03

Table 4. (Cont'd)

40	60	6	15	57,90	1,21
40	90	6	15	66,50	1,46
40	120	6	15	77,17	4,33
67	60	6	15	71,90	5,07
67	90	6	15	82,00	1,11
67	120	6	15	102,30	8,59
100	60	6	15	84,67	21,29
100	90	6	15	102,73	1,37
100	120	6	15	122,97	9,85
10	60	8	5	39,73	0,10
10	90	8	5	40,20	1,69
10	120	8	5	42,80	0,31
40	60	8	5	47,80	0,09
40	90	8	5	69,23	2,96
40	120	8	5	80,80	7,77
67	60	8	5	83,60	9,25
67	90	8	5	77,97	8,26
67	120	8	5	100,60	0,07
100	60	8	5	84,60	0,73
100	90	8	5	100,63	10,70
100	120	8	5	112,70	10,51
10	60	8	10	36,57	0,02
10	90	8	10	38,80	0,12
10	120	8	10	41,47	1,84
40	60	8	10	56,07	17,52
40	90	8	10	63,03	3,10
40	120	8	10	74,17	3,86
67	60	8	10	71,50	13,08
67	90	8	10	85,97	2,76
67	120	8	10	100,83	2,36
100	60	8	10	82,73	0,65
100	90	8	10	92,20	46,27
100	120	8	10	115,10	11,59
10	60	8	15	38,60	0,21
10	90	8	15	40,90	0,37
10	120	8	15	43,80	0,21
40	60	8	15	56,83	1,85
40	90	8	15	65,70	2,37
40	120	8	15	77,73	10,66
67	60	8	15	69,50	9,67
67	90	8	15	81,70	9,25
67	120	8	15	98,30	7,24
100	60	8	15	88,53	1,54
100	90	8	15	98,60	0,21
100	120	8	15	114,77	8,04

APPENDIX B

POWER MEASUREMENT BY IMPI 2-L TEST

The oven was operated at the highest power level with load of 2000±5 g water placed in two 1-L Pyrex beakers. Initial temperature of water was 20±2 °C. Final temperatures of water were measured immediately after 2 min and 2 s of heating. The power was calculated from the following formula:

$$P\ (W) = (70(\Delta T_1 + \Delta T_2))/2 \qquad (7)$$

where ΔT_1 and ΔT_2 are the temperature rises of the water in the two beakers calculated by subtracting the initial water temperature from the final temperature.

The power measurement should be run three times, with the oven power is the average of the three readings. If any individual measurement is more than 5% from the average, the complete test should be repeated. (Buffer, 1993)

Table 5 Results of IMPI 2-L Test

Run	**ΔT_1**	**ΔT_2**	**Power (W)**
1	10.5	10.0	717.5
2	10.5	10.0	717.5
3	10.5	10.0	717.5
Average			**717.5**

APPENDIX C

RESULTS OF STATISTICAL ANAYSIS

C.1 Statistical Analysis of Color Value Data Obtained From Verification Experiments

Table 6 ANOVA (G.L.M.) table for the effects of power level, time, vertical and radial direction on L* value in verification experiments

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	2393.72	2393.72	797.91	81.65	0.000
time	2	1748.59	1748.59	874.30	59.64	0.000
vertical direction	1	271.00	271.00	271.00	18.49	0.000
radial direction	4	423.54	423.54	105.89	7.22	0.000
Error	260	3811.23	3811.23	14.66		
Total	270	8648.09				

Table 7 ANOVA (G.L.M.) table for the effects of power level, time, vertical and radial direction on a* value in verification experiments

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	2685.48	2685.48	895.16	20.07	0.000
time	2	562.46	562.46	281.23	0.02	0.000
vertical direction	1	0.11	0.11	0.11	40.81	0.900
radial direction	4	553.23	553.23	138.31	194.86	0.000
Error	260	1791.61	1791.61	6.89		
Total	270	5592.88				

Table 8 ANOVA (G.L.M.) table for the effects of power level, time, vertical and radial direction on b* value in verification experiments

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	5699.77	5699.77	1899.92	212.24	0.000
time	2	737.92	737.92	368.96	27.48	0.000
vertical direction	1	2.35	2.35	2.35	0.18	0.676
radial direction	4	468.13	468.13	117.03	8.72	0.000
Error	260	3491.25	3491.25	13.43		
Total	270	10.399.42				

C.2 Statistical Analysis of Color Value Data Obtained From Experiments without the Mixer

Table 9 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on L* value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	2411.94	2411.94	803.98	35.95	0.000
time	2	286.03	286.03	143.01	6.39	0.002
speed	2	504.61	504.61	252.30	11.28	0.000
location	3	79.41	79.41	26.47	1.18	0.316
Error	421	9415.03	9415.03	22.36		
Total	431	12697.01				

Table 10 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on a* value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	3587.12	3587.12	1195.71	35.95	0.000
time	2	735.90	735.90	367.95	6.39	0.000
speed	2	156.20	156.20	78.10	11.28	0.000
location	3	84.28	84.28	28.09	1.18	0.000
Error	421	1602.45	1602.45	3.81		
Total	431	6165.95				

Table 11 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on b* value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	8505.9	8505.9	2835.3	350.03	0.000
time	2	1178.9	1178.9	589.5	72.77	0.000
speed	2	375.3	375.3	187.7	23.17	0.000
location	3	111.2	111.2	37.1	4.58	0.004
Error	421	3410.1	3410.1	8.1		
Total	431	13581.5				

C.3 Statistical Analysis of Color Value Data Obtained From Experiments with the Mixer

Table 12 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on L* value in experiments with the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	2648.4	2648.4	882.8	55.67	0.000
time	2	233.4	233.4	116.7	7.36	0.001
speed	2	7916.1	7916.1	3958.1	249.58	0.000
location	3	74.1	74.1	24.7	1.56	0.199
Error	421	6676.5	6676.5			
Total	431	13581.5				

Table 13 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on a* value in experiments with the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	4379.53	4379.53	1459.84	194.13	0.000
time	2	806.70	806.70	403.35	53.64	0.000
speed	2	720.15	720.15	360.07	47.88	0.000
location	3	27.67	27.67	9.22	1.23	0.300
Error	421	3165.93	3165.93	7.52		
Total	431	9099.98				

Table 14 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on b* value in experiments with the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	8188.8	8188.8	2729.6	419.88	0.000
time	2	1573.1	1573.1	786.6	120.99	0.000
speed	2	3994.0	3994.0	1997.0	307.19	0.000
location	3	31.7	31.7	10.6	1.63	0.183
Error	421	2736.9	2736.9	6.5		
Total	431	16524.6	16524.6			

C.4 Statistical Analysis of Color Values Based on Mixer Presence

Table 15 ANOVA (G.L.M.) table for the mixer presence analysis based on L* value

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Mixer Presence	1	88.87	88.87	88.87	2.53	0.112
Error	862	30245.55	30245.55	35.09		
Total	863	30334.42				

Table 16 ANOVA (G.L.M.) table for the mixer presence analysis based on a* value

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Mixer Presence	1	177.13	177.13	177.13	10.00	0.002
Error	862	15265.93	15265.93	17.71		
Total	863	15443.06				

Table 17 ANOVA (G.L.M.) table for the mixer presence analysis based on b* value

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Mixer Presence	1	405.36	405.36	405.36	11.61	0.001
Error	862	30106.12	30106.12	34.93		
Total	863	30511.48				

C.5 Statistical Analysis of Surface Temperature Values Obtained from Experiments Without Mixer

Table 18 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on surface temperature value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power	3	192893	192893	64298	1052.06	0.000
time	2	39776	39776	19888	325.42	0.000
speed	2	627	627	313	5.13	0.006
location	3	10093	10093	3364	55.05	0.000
Error	421	25730	25730	61		
Total	431					

C.6 Statistical Analysis of Surface Temperature Values Obtained from Experiments With Mixer

Table 19 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on surface temperature value in experiments with the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power	3	204889	204889	68296	1805.77	0.000
time	2	36948	36948	18474	488.46	0.000
speed	2	168	168	84	2.23	0.109
location	3	36	36	12	0.32	0.810
Error	421	15923	15923			
Total	431	257965				

C.7 Statistical Analysis of Variance of Obtained Color Values Data Without the Mixer

Table 20 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on variance of L* value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	821.77	821.77	273.92	4.88	0.003
time	2	64.78	64.78	32.39	0.58	0.563
location	3	145.65	145.65	48.55	0.87	0.461
speed	2	1974.58	1974.58	987.29	17.59	0.000
Error	133	7464.09	7464.09	56.12		
Total	143	10470.86				

Table 21 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on variance of a* value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	21.47	21.47	7.16	0.51	0.675
time	2	22.67	22.67	11.34	0.81	0.447
location	3	29.67	29.67	9.89	0.71	0.549
speed	2	3.90	3.90	1.95	0.14	0.870
Error	133	1860.71	1860.71	13.99		
Total	143	1938.43				

Table 22 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on variance of b* value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	224.48	224.48	74.83	4.70	0.004
time	2	14.66	14.66	7.33	0.46	0.632
location	3	26.95	26.95	8.98	0.56	0.639
speed	2	215.63	215.63	107.81	6.78	0.002
Error	133	2115.82	2115.82	15.91		
Total	143	2597.53				

C.8 Statistical Analysis of Variance of Obtained Color Values Data With the Mixer

Table 23 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on variance of L* value in experiments with the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	93.73	93.73	31.24	1.63	0.186
time	2	13.72	13.72	6.86	0.36	0.700
location	3	138.10	138.10	46.03	2.40	0.071
speed	2	241.28	241.28	120.64	6.28	0.002
Error	133	2554.26	2554.26	19.20		
Total	143	3041.10				

Table 24 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on variance of a* value in experiments with the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	2.05	2.05	0.68	1.51	0.216
time	2	0.13	0.13	0.07	0.15	0.863
location	3	0.29	0.29	0.10	0.22	0.885
speed	2	10.09	10.09	5.04	11.09	0.000
Error	133	60.52	60.52	0.46		
Total	143	73.09				

Table 25 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on variance of b* value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	38.90	38.90	12.97	3.58	0.016
time	2	4.38	4.38	2.19	0.61	0.547
location	3	7.61	7.61	2.54	0.70	0.554
speed	2	68.23	68.23	34.11	9.42	0.000
Error	133	481.66	481.66	3.62		
Total	143	600.77				

C.9 Statistical Analysis of Variance of Obtained Surface Temperature Values Data Without the Mixer

Table 26 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on variance of surface temperature value in experiments without the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	9414.8	9414.8	3138.3	12.38	0.000
time	2	889.2	889.2	444.6	1.75	0.177
location	3	1752.2	1752.2	584.1	2.30	0.080
speed	2	82.2	82.2	41.1	0.16	0.851
Error	133	33726.4	33726.4	253.6		
Total	143	45864.8				

C.10 Statistical Analysis of Variance of Obtained Surface Temperature Values Data With the Mixer

Table 27 ANOVA (G.L.M.) table for the effects of power level, time, speed and location on variance of surface temperature value in experiments with the mixer

Source	DF	Seq SS	Adj SS	Adj MS	F	P
power level	3	1503.4	1503.4	501.1	4.31	0.006
time	2	48.6	48.6	24.3	0.21	0.812
location	3	253.7	253.7	84.6	0.73	0.538
speed	2	307.0	307.0	153.5	1.32	0.271
Error	133	15469.9	15469.9	116.3		
Total	143	17582.6				

APPENDIX D

INFRARED PHOTOGRAPHS OF THE ANALYSED SAMPLES

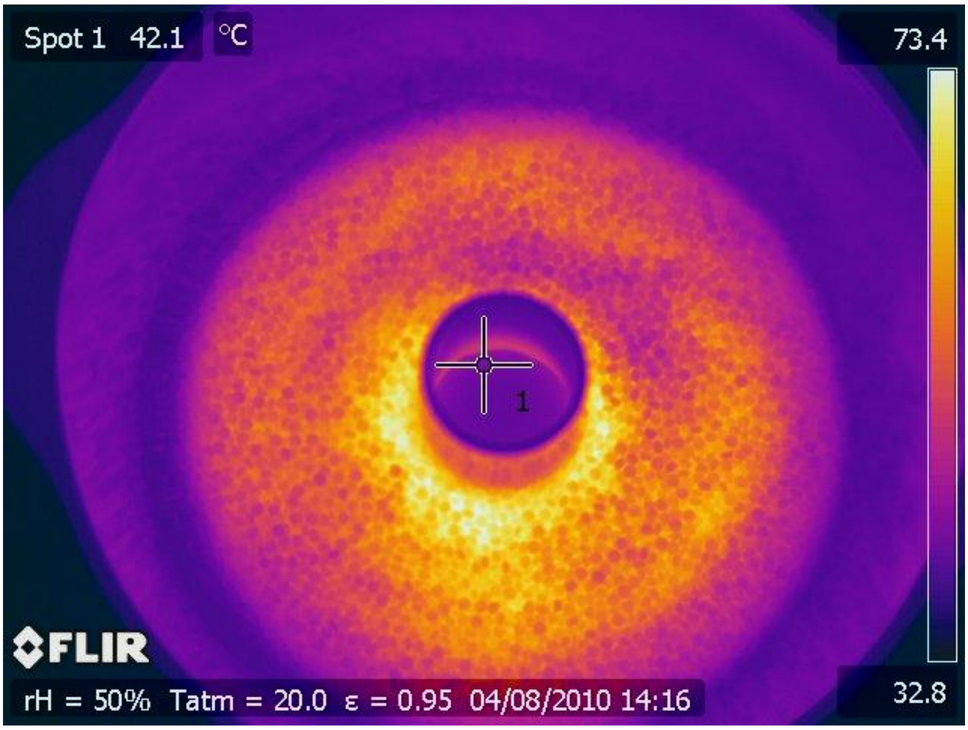

Figure 61 An infrared photograph of a sample without the mixer

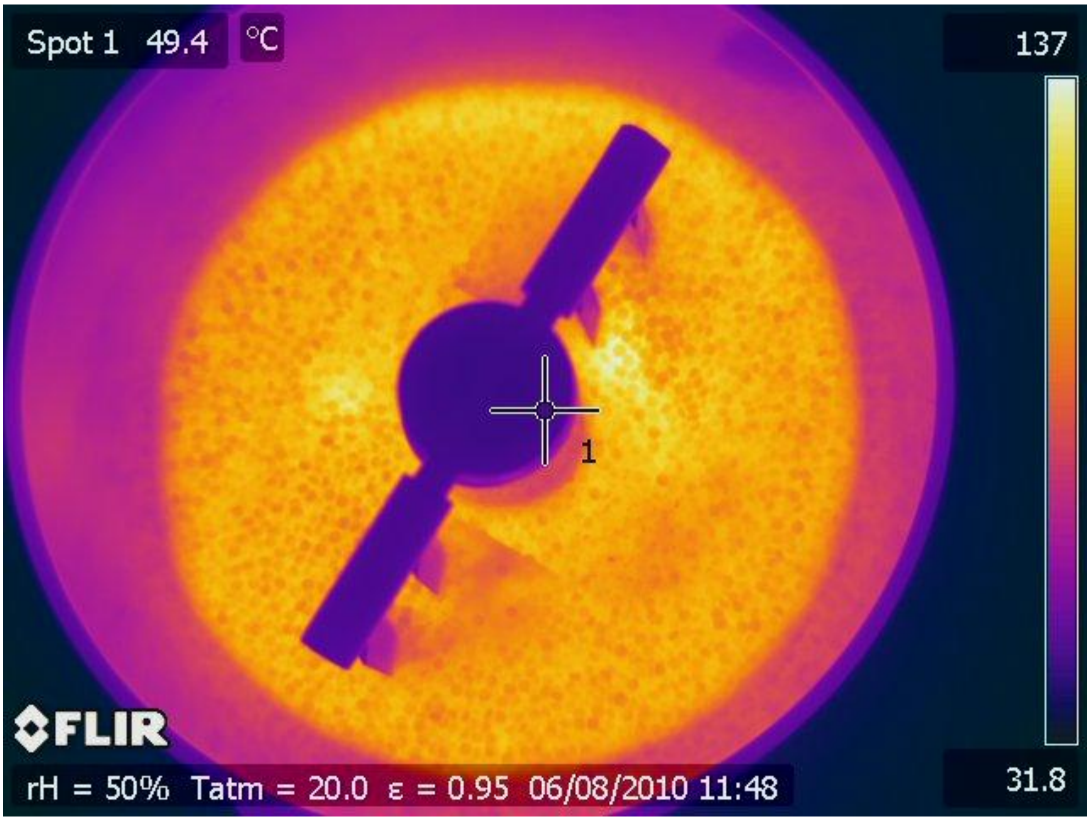

Figure 62 An infrared photograph of a sample with the mixer

APPENDIX E

PHOTOS OF THE DESIGNED SYSTEM

Figure 63 The mixer inside the mixing container

Figure 64 The placement of the design inside the oven

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