

GANACHE THEORY AND PRACTICE

1.0 FOREWORD

When I started getting interested in chocolate confections, I searched far and wide for a document that explained the physics and the chemistry of ganache, but I could not find what I was looking for. Perhaps this will be helpful to someone.

The intended audience for this document is chocolatiers with minimum science and mathematics knowledge.

2.0 INTRODUCTION

A ganache is a suspension of cocoa and other solids in an oil-in-water emulsion.

A suspension is formed when solid particles are dispersed in a liquid medium. For instance, dark chocolate is a suspension of cocoa solids and sugar crystals in cocoa butter. As chocolate crystallizes these solids are then trapped within a cocoa butter matrix.

An emulsion is formed when two immiscible liquids are mixed. In case of ganache, one of the liquids is lipid based and the other is water based. Lipids in a ganache are cocoa butter, dairy fat and other possible oils ranging from nut oils to various vegetable oils. The water-based liquids range from dairy to fruit purees to juices and water.

There are two types of emulsions: Oil-in-water (O/W) or water-in-oil (W/O)¹. When two immiscible fluids are mixed, the type of emulsifier used as well as the process steps that are followed in creation of the emulsion determine whether the final emulsion will be O/W or W/O type.

Since an emulsion is formed by mixing two liquids which cannot be mixed (e.g., oil and water) energy must be added to the system to accomplish the desired mixing. Unfortunately, the resultant mixture will be unstable and will revert to its lower energy state by re-forming the oil and water layers over time. Emulsifiers are necessary to stabilize the emulsions.

When mechanically agitated, one of the fluids forming the emulsion breaks apart into droplets within the other liquid thereby establishing the two phases. The fluid that results as droplets is referred to as *discrete phase* and the other fluid as *continuous phase*. In O/W emulsions oil forms the discrete phase and water is the continuous phase.

An emulsifier stabilizes the emulsion by coating the surfaces of the discrete phase droplets. Once coated with surfactants, the droplets are less likely to combine and coalesce over time providing stability to the emulsion. Whether a given substance will function as a W/O or O/W emulsifier depends on its hydrophilic (water loving) versus lipophilic (fat loving) surface sites ratio.

Being thermodynamically unstable, emulsions generally revert to their lower energy state through phase separation. The separation of phases reduces the overall internal energy of the system by minimizing the contact surface area between the two fluids.

3.0 INTERFACIAL SURFACE AND ITS CHARACTERISTICS

The term *Free Energy* refers to energy available in a system to do work. Free energy of an emulsion system is defined by.

¹ There are also double emulsions (W/O/W and O/W/O), but these do not relate to ganaches.

$$\Delta G = \gamma \Delta A$$

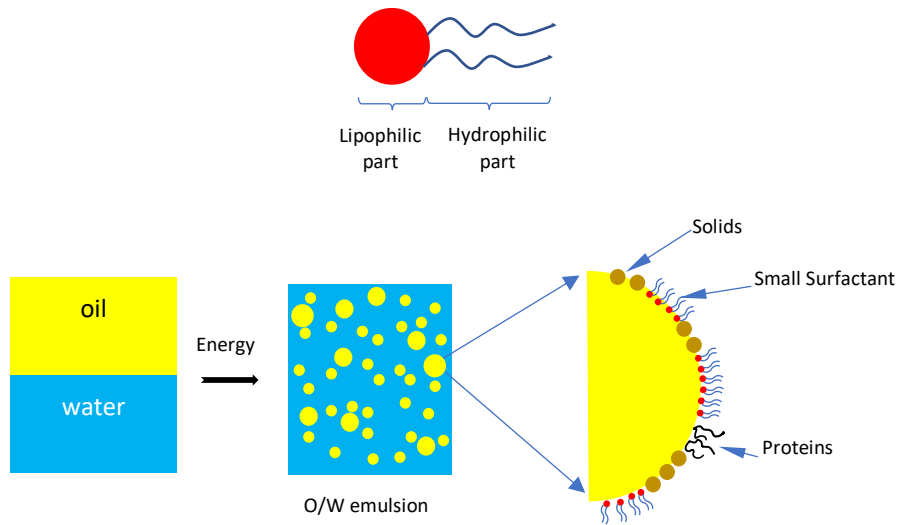
Where γ is the interfacial tension between oil and water and ΔA is the total interfacial area within the system (all units in SI) and ΔG is the free energy of the system. It is simple to see that in the above equation as ΔA is reduced the free energy of the system is also proportionally reduced leading to separation of the phases.

This inherent thermodynamic instability is reduced or even eliminated, leading to a stable emulsion, through the control of interfacial surface area and appropriate emulsifier.

In a ganache, the interfacial area between the discrete and continuous phases can be large. For instance, 1 cm³ of ganache containing 50% volume fraction of discrete phase droplets, with droplet size of 2 microns has interface area of about 1.5-meter square! For this reason, interfacial properties of a ganache have significance to emulsion stability.

Upon mechanical emulsification process the emulsifier molecules/particles migrate towards the interfacial surfaces and cover the surface of the oil droplets. By doing so they prevent droplet aggregation and stabilize the ganache. Emulsifiers that are used in the chocolate industry are small-molecule surfactants, proteins and particulate matter, among others. Emulsions can also be stabilized using thickening agents such as pectin, various gums etc. within the continuous phase. Although some chocolatiers use this method, it is not a common method for ganache stabilization.

A small molecule surfactant can be viewed as a molecule containing hydrophilic (water loving) and lipophilic (oil loving) areas in its structure. An example of such an emulsifier that is common in the chocolate industry is Lecithin. Although the functionality of lecithin in chocolate is somewhat different than similar surfactants in a ganache.



The type of emulsion within a ganache suspension is generally referred to as Pickering Emulsion. These emulsions are stabilized predominantly by particles and proteins. Most chocolatiers do not add small molecule surfactants but depending on the composition of the chocolate being used within the ganache, lecithin or other similar surfactants can end up in the ganache.

In general, a ganache contains the following potential solids and proteins: cocoa solids, casein micelles, whey and casein proteins, milk solids (minerals), solids within fruit purees, solids associated with ground nuts etc. All these various size and population density solids help stabilize the ganache emulsion.

Solids from cocoa beans likely to be the most important factor in the stabilization of the ganache but contributions from other participating proteins, solids cannot be overlooked either.

It is important to realize that discrete phase fat droplet size, within the ganache, range anywhere from 2 – 20 microns. For such a droplet to be “coated” with solids and proteins the size of the emulsifying solids must be smaller than the droplet size.

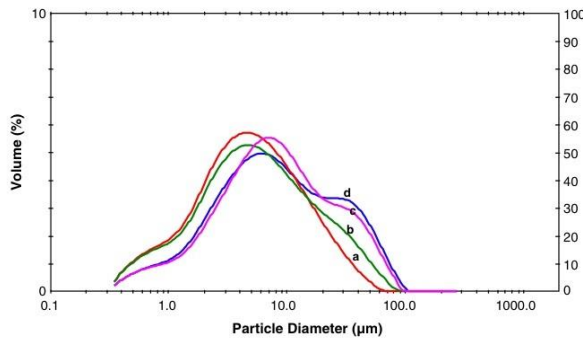


Fig. 1. Particle size distribution of dark chocolate with D_{90} of (a) 18 μm (b) 25 μm (c) 35 μm (d) 50 μm .

The figure 1 provides particle size distribution of cocoa solids. The left-hand side of the particle diameter axis in the figure are the cocoa solid fines that participate in creation of an interfacial surface in a ganache. Although the volume % of particles with diameters less than 2 microns make up a relatively small portion of the curve in the graph when looked at not in terms of volume % but in numbers, there will be significantly more small particles than large particles. All these small particles help stabilize the emulsion portion of the ganache. All other larger solids then participate in the overall suspension that is the ganache.

Note: the labels on the 4 plots. 18 μm , 25 μm , 35 μm , 50 μm are the weighted averages of the entire distribution.

The figure above is from Chocolate Alchemy (<https://chocolatealchemy.com>).

A ganache made with white chocolate and dairy elements will have no cocoa solids. In this case the ganache is stabilized by milk solids, casein, and whey proteins as well as other possible solid additions into the ganache (e.g., fruit purees etc.).

So, cocoa solids, although they are dominant, are not the sole contributors to ganache stability.

Molecular structure of proteins plays a key role in their emulsification power. Many proteins are made up of single polypeptide chain. A polypeptide chain consists of large number of amino acids that are linked together. Some proteins have more complicated structures, containing multiple polypeptide chains giving rise to a quaternary structure for the protein. For instance, in milk, both caseins and whey proteins exist in large globular structures called micelles made up of thousands of individual protein molecules. These globular structures are held together by lipophilic interactions as well as protein regions containing calcium phosphate.

Casein micelles are an effective surfactant but when milk is homogenized, the process of homogenization breaks the casein micelles. For this reason, it is preferable to use non-homogenized milk in a ganache where the recipe calls for milk (please note, NOT raw milk).

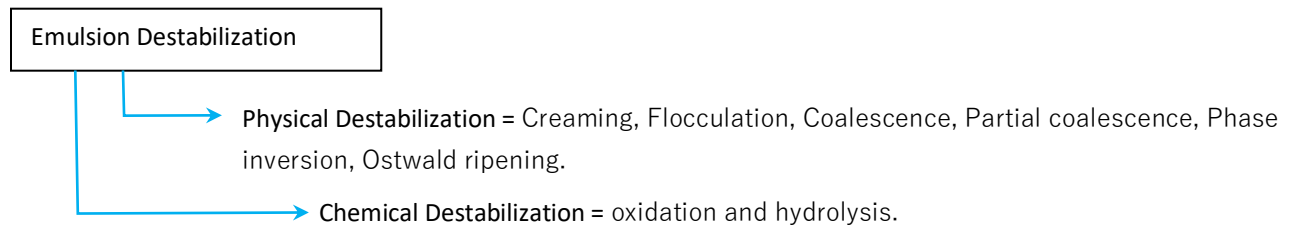
If the solid particles and proteins exist in an emulsion at higher concentrations, which is the common case for most ganaches, then the discrete phase droplet size is usually determined by the power and the design of the homogenizer used in the making of the emulsion. This is the reason why a powerful hand-blender and reasonable duration of homogenization is necessary to produce a high-quality ganache. The other important element in the process is the temperature increase that occurs during homogenization. As the homogenization duration is increased the temperature of the ganache increases which in turn helps create smaller droplets (preferred state for ganache). Whether such droplets within the continuous phase of the ganache will remain intact over time is the next important consideration.

4.0 STABILITY ISSUES IN EMULSIONS

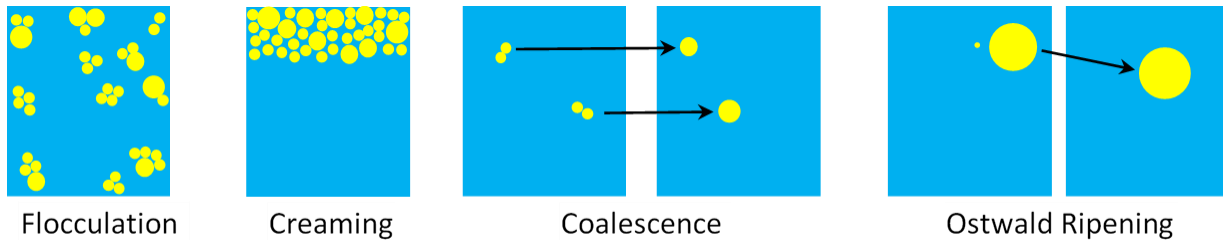
As indicated above the size of the discrete phase droplets can be reduced by application of higher energy onto the water/oil interface, assuming there are adequate number of solids/proteins in the system for emulsion stabilization. The droplet size in a ganache is important since this is one of the key elements which provide the “smoothness” of the ganache on the tongue. As well, smaller the droplets the more stable is the emulsion.

An emulsion can be destabilized over time for two reasons:

- 1) Due to physical processes
- 2) Due to chemical processes.



The fundamental force behind the physical destabilization process is gravity. Gravitational separation of an emulsion is the most common form of instability, driving many different destabilization pathways.



4.1 Flocculation

Flocculation results when droplets begin to aggregate but still maintain a thin layer of continuous phase between them as opposed to coalescence and Ostwald ripening.

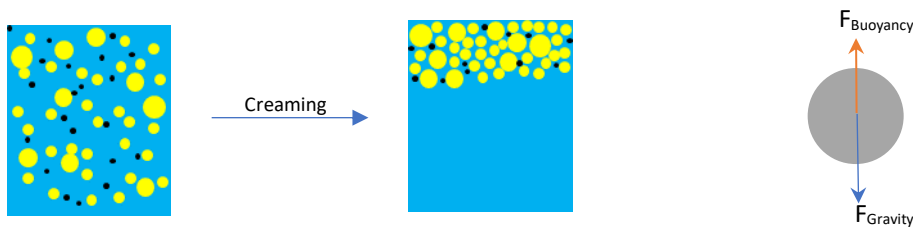
As will be discussed below, different size droplets move at different speeds. This can lead to collisions and result in adhesion between droplets. Mechanisms which lead to droplet motion, especially the small droplets, are combination of Brownian motion, gravity, and shear related motion.

Regardless of the cause of the relative motion of droplets with respect to each other, when droplets collide, they remain in small 3D aggregates. Flocculation can be prevented if the energy barrier associated with interfacial forces is large enough to overcome the collision related aggregation forces (van der Waals forces).

Under certain circumstances flocculation can lead to creaming.

4.2 Creaming

In a ganache suspension there are two types ‘particles’ we need to concern ourselves with; solids that did not participate in stabilization of the ganache and discrete phase droplets of the ganache. Starting with solid particles; their behaviour within the ganache suspension is determined by the balance of several forces affecting on the particle: namely gravity and frictional forces.



If we consider the rigid particles first, the rate at which the emulsion will cream will be dependent on the balance of the Gravitational force and Buoyancy force.

Buoyancy force = (Volume of the particle) x (specific weight of the fluid)

$$F_{Buoyancy} = V * \rho * g$$

Where F = buoyancy force, V = volume of the particle, ρ = density of the fluid, and g = gravitational acceleration

Archimedes Principle states that "the upward buoyant force that is exerted on a body fully or partially submerged in a fluid equals to the weight of the fluid that the body displaces". Therefore, if the particle's weight exceeds the buoyant force then the particle sinks leading to sedimentation. If the particle's weight is less than the buoyant force then the particle floats to the top, leading to creaming.

The net force acting on the particle can be written as

$$F_{Net} = \left(\frac{4}{3}\right) \pi r^3 (\rho_{liquid} - \rho_{particle}) g$$

Where

r = radius of the particle

ρ_{liquid} = density of the liquid

$\rho_{particle}$ = density of the particle

g = gravitational acceleration

If $(\rho_{liquid} - \rho_{particle}) < 0$, the net force F will be negative pushing the particle down to the bottom. The particle will sediment. In case of ganache, cocoa particle density is less than the density of the continuous phase making $(\rho_{liquid} - \rho_{particle}) > 0$ hence properly made ganaches do not sediment but particles moving up can result in flocculation and creaming.

As the particle moves up it encounters a hydrodynamic frictional force that acts in the opposite direction retarding their motion. This frictional force can be expressed as

$$F_f = 6 \pi \eta_l r v$$

Where

v is the velocity of the particle moving up towards the surface

η is the shear viscosity, and

r is the radius of the particle.

When $F_{net} = F_f$ the particle moving upwards reaches a constant velocity. Combination of these two equations gives us Stoke's equation for the creaming rate.

$$v_{Stokes} = 2g r^2 \frac{\rho_{liquid} - \rho_{solid}}{9\eta_l}$$

The greater the density difference between the liquid and the solid, higher the creaming velocity of the particle. As well the Stokes equation indicates that the radius of the particle has a large impact on the creaming velocity since this term is squared. Smaller particles move slower hence particle size has a significant impact on creaming.

So, what does all this mean in practice; consider a fruit ganache (or a water ganache). If the discrete phase droplets are some combination of cocoa butter and AMF (Anhydrous Milk Fat) and if we assume cocoa butter and AMF densities to be 0.9 and 0.92 gr/cm³ respectively then the density of the droplet can be assumed to be somewhere around 0.91 gr/cm³. Since the continuous phase density will be a broad mixture of various sugars and water the overall density difference in Stokes equation will be somewhere around 0.2 gr/cm³. Assuming 10-micron droplet size and $\eta = 8.9 \cdot 10^{-4}$ Pa.s and water density of about 1 gr/cm³, a droplet will move towards the surface almost 17cm per hour. This is a surprising and significant first order approximation; albeit with the following considerations.

The Stokes equation is all about isolated rigid spherical particle in an ideal liquid. Despite this, in the example calculation above, a droplet instead of a solid particle was considered. Stokes equation can be modified to account for this and other differences from the ideal. Nevertheless, that topic is too advanced and of no use to a chocolatier. However, it is important to point out some of the reasons for the deviations from the ideal model:

1. Discrete phase droplets are liquid. Movement of two liquids with respect to each other involves much less friction forces than a solid moving through the fluid. Nevertheless, the emulsion portion of a ganache is a Pickering emulsion; meaning each droplet "skin" is covered with solids and proteins. Hence when such an entity is moving through the liquid the friction generated is closer to a solid than a just an oil droplet without emulsifying solids moving through another liquid.
2. Most practical ganaches contain concentrated emulsions. The Stokes velocity can differ significantly between dilute and concentrated emulsion. This leads to reduction of creaming speed in ganaches as compared to other more dilute emulsions (e.g., olive oil lemon juice emulsion or beverage emulsions).
3. As the temperature of the ganache approaches the room temperature ganaches start to crystallize thereby limiting the movements of the droplets
4. Discrete phase droplets in an emulsion are not the same size. As we have seen above; the larger droplets move faster than the smaller droplets within the emulsion. This leads to a range of creaming speeds instead of a single value for Stokes velocity.

4.3 Coalescence

When the interfacial layer of thin film separating the discrete phase droplets from the continuous phase are thinned and/or disrupted then two or more droplets can fuse and become one large droplet. From thermodynamics perspective this is a lower energy state for the system than having multiple individual droplets. Of course, then at the limit of this process a complete separation of the emulsion occurs.

Another phenomenon called **Partial Coalescence** occurs when the fat in the discrete phase crystallizes and punctures the interfacial surface when a droplet is close vicinity of other droplets. Punctured film results in the uncrystallized oil to leak out into the space between the droplets. This is an important phenomenon for ganaches and will be discussed further later in the document.

4.4 Ostwald Ripening

Although the two liquids that make up the emulsion was defined as immiscible, there is still a finite solubility between the two liquids. Smaller droplets will dissolve easier in the continuous phase compared to large droplets. Over time the smaller droplets disappear, and their molecules diffuse through the continuous phase and end up on the more stable larger droplets. As a result, over time larger droplets get larger and the small droplets tend to disappear. Ostwald ripening usually does not occur in O/W emulsions (e.g., ganaches) UNLESS the continuous phase contains alcohol. Since adding alcohol into ganache is a fairly common practice, Ostwald ripening need to be kept in mind during ganache formation.

5.0 CONTROLLING GANACHE STABILITY

Stokes equation can be written in a slightly different format replacing solids with discrete phase droplets, all other variables remaining the same.

$$v_{Stokes} = 2 g r^2 \frac{\rho_{Cont.Ph} - \rho_{Disc.Ph.}}{9\eta_l}$$

Since the emulsion instabilities that apply to a ganache are primarily driven by gravity, reducing v_{Stokes} has a significant effect on the emulsion stability; ideal case being $v_{Stokes} = 0$.

Looking at the Stokes equation, there are three terms in it that can help us in controlling ganache stability:

1. $\rho_{Cont.Ph} - \rho_{Disc.Ph.}$
2. r^2
3. η_l

1. If the density of the continuous phase can be made similar or equal to the density of the discrete phase, then the term $\rho_{Cont.Ph} - \rho_{Disc.Ph.}$ becomes zero or close to zero. This then forces v_{Stokes} to be near zero, which means the droplets stop moving with respect to each other becoming stationary. When the relative velocity of the discrete phase droplets is eliminated then ganache is completely stabilized. Food industry uses this approach through incorporating “weighting agents” that have a higher density than water into the oil phase prior to homogenization. Although different types of weighing agents are available for food scientist, additives into ganache is not a preferred approach for most chocolatiers.

Having said this, it is possible to use equivalency of densities to achieve the zero relative movement goal between the droplets without having to add weighing agents. This is possible since in a ganache the discrete phase does not contain only cocoa butter and AMF. As we have seen earlier solids of vastly different size and density participate in the discrete phase. Continuous phase is also not just water. In a ganache, continuous phase can include diverse array of both crystalline sugars (e.g., sorbitol, dextrose, sucrose) and syrups (e.g., glucose, invert sugar, honey etc.) as well as myriad of solids that can be wetted by water (e.g., fruit puree, fruit pulp etc.).

This situation brings forth an opportunity to balance the ganache ingredients in such a way that the resultant discrete and continuous phases can have same or almost same densities, thereby achieving near zero relative Stokes velocity and hence ideal physicochemical ganache stability.

2. “r” stands for the radius of the droplets in the discrete phase. As mentioned earlier this parameter has a significant effect on the Stokes velocity since in the equation it is squared. This means smaller the droplet size smaller the Stokes velocity and more stable the ganache.

If you recall the free energy of the system is written as follows; $\Delta G = \gamma\Delta A$ where ΔA represents the interfacial area of the system. Smaller droplets mean large resultant surface area which in turn means

large Free energy requirement. This then relates to how a ganache is made, and the type of equipment used in making of the ganache.

3. η_l in the Stokes equation stands for the sheer viscosity of the continuous phase. It is in the denominator of the equation and hence inversely proportional to the Stokes velocity, meaning higher the viscosity of the continuous phase smaller the Stokes velocity. To this end thickening agents can be used in the continuous phase of the ganache. Thickening agents can range from simple starches to various gums to gelatin. There are many other options available for this purpose and indeed are used in the food industry but as far as top quality ganaches are concerned, the use of thickening agents is not a preferable approach but remains available.
4. Let's not forget the fourth parameter in the Stoke's equation " g ". Making ganache in the International Space Station where the gravity is minimal will automatically result in a perfectly balanced ganache.

6.0 TWO KEY CONCEPTS FOR GANACHE EMULSIONS

6.1 Emulsion Ratio

Emulsion Ratio is defined as the total volume of discrete phase divided by the volume of continuous phase. Although this is a dimensionless number, throughout this document it is the ratio of volumes not weights.

Consider Emulsion Ratio as a dial which lets you tune the overall flavor profile of ganache.

From the perspective of a chocolatier, aroma compounds can be categorized as either water soluble compounds or oil soluble compounds. Once the primary flavour profile of a ganache is determined, whether that flavor is water or oil soluble will be established. If the flavor compound is water soluble then to optimize this flavor's impact on the finished ganache, the water's relative volume with respect to the volume of oil should be increased as much as possible, of course, within the limits of the ganache's desired hardness profile. This means the numerator of the emulsion ratio will be getting smaller while the denominator is getting larger, resulting in a smaller Emulsion Ratio number.

Higher Emulsion Ratio numbers providing a more effective option for the oil-based flavor compounds.

Later, we will touch upon another parameter Emulsion Ratio has an impact on, the "Extent" of the fat crystal network.

6.2 Solid Fat Content and Fat Eutectics

Solid Fat Content (SFC) of a fat or fat mixture can be viewed as a number indicative of how hard the fat is at a given temperature. This is of course experienced by every chocolatier while melting cocoa butter; it does not go from being solid CB to liquid as soon as a specific temperature is reached. During the visual melting phase there is different amount of solid versus liquid at every temperature. For instance, SFC numbers for cocoa butter and AMF, at 20°C, are 78% and 22.5% respectively, (butter is more than three times softer than cocoa butter at 20°C).

What happens to this number when two fats are mixed? For instance, when cocoa butter is mixed with cream, or butter. Let's start with two fats that are mixed at 50:50 ratio (CB and AMF); it could be assumed that the melting point of the mixture will be somewhere between the melting point of the first fat and the second fat. This indeed is NOT the case. The melting point of the fat mixture is lower then the lowest of the two fats. This means the SFC of the mixed fat will be lower than you expect. This effect is called fat eutectics and is clearly not a linear process.

What happens if an oil is added to the above fat mixture. By definition oil is liquid in room temperature so it is expected to reduce the SFC of the fat+oil mixture. This reduction is linear. Meaning oil does not have an eutectic effect on the mixture; it simply dilutes it.

Why is SFC important? It represents the strength of unit-crystals that make up the fat crystal network in ganache.

Having said this, SFC is not the only variable that determines the hardness and elastic modulus of the resultant fat-crystal network. Fine solids, oil soluble proteins as well as the microstructure of the crystal network also has a significant impact on the strength of the fat crystal network; smaller microstructures resulting in firmer networks.

Chocolatiers, take note, tableing your ganache will make it smoother (small fat crystal size) and stronger.

More detailed information on SFC of cocoa butter and AMF combinations as well as the scientific reasons behind why the SFC of the mixture having lower than the average SFC of the two fats that are mixed is covered at “Science of Chocolate” by Stephen T Beckett (2nd addition, page 113); a must-read book for all chocolatiers.

7.0 MICROSTRUCTURE OF GANACHE

Consider a firm ganache for enrobing, after 24 hours of crystallization; and imagine one unit volume of this ganache. If you could look at this volume microscopically, what would it look like? The first thing to notice about this volume is a structural matrix which is made up of fat unit-crystals. The strength of this crystal network depends on its overall structure and is dependent on the strength and size of unit crystal. As mentioned earlier, the relative strength of such crystal networks is given by the SFC number for the ganache. Although, SFC alone does not determine a given ganache’s firmness level. Almost as big a contributor to the firmness level of a ganache is the amount of oil wettable solids and proteins it contains.

The next thing to notice about this crystal lattice is to what extent each segment of the crystal network is “padded” with other oils. Oils are contained around the crystalline structure by the interfacial membrane. The “Extent” can be viewed as “how much of the unit volume is occupied by the crystal lattice and its surrounding oil”, with the remaining volume to be occupied by water (continuous phase) and its elements.

The third thing to notice about this unit volume of ganache is liquids and water wettable solids entrapped within the cavities of the crystal network.

If these three visual images are put together a structure resembling the structure of a wet sponge emerges. A sponge with large, big airy holes will be lower firmness/hardness number (withing the enrobing ganache perspective) and lower Emulsion Ratio. The opposite of this will be a dense sponge with tight little holes, represented by high firmness number and higher emulsion ratio.

Water soluble flavor compounds will be in the “liquid, carried by the sponge” whereas oil soluble flavor compounds will be infused mostly in the oil (Extent”) of the crystal structure.

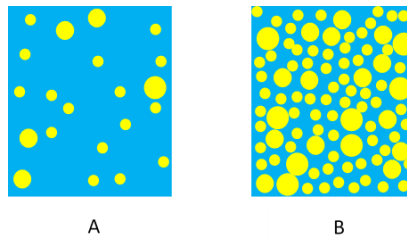
How does this picture serve a chocolatier? Let’s assume a roasted hazelnut paste ganache with cognac (note the oil soluble flavour compound choice). Let’s also assume the desired firmness is at the delicate end of guitar cuttable ganache. This sets the Firmness number thereby setting the strength of the backbone of the crystal network. Next; choice of smaller Emulsion Ratio (ER) or higher Emulsion Ratio? A smaller ER prioritizes the remaining volume of the unit space to liquids and cognac. At its limit, this approach can produce a rather delicate ganache which easily disintegrates in the mouth before it starts to release its high cognac inclusion. Keeping the same hardness level and opting out for nuttier flavor with only cognac overtones leads to higher ER values for the ganache.

On the other end of the scale, perhaps with water soluble flavour compounds; low Firmness Number and low ER, passion fruit ganache becomes a generously fruit flavored ganache perfect for filling dark chocolate shells with. Or creamier version higher ER version of the passion fruit filling can be used with white chocolate shells.

In the above picture the strength of the crystal network is set by the Firmness Number. The ER number controls the balance between oil soluble flavor compounds and water-soluble compounds. This presents itself as the Extent of the crystal structure. More or less Extent determines how much remaining volume is left for water and water-soluble compounds.

8.0 PARTIAL COALESCENCE AND BUILDING OF THE CRYSTAL LATTICE

What does the droplet concentration look like in a ganache? is it like figure A or B below?

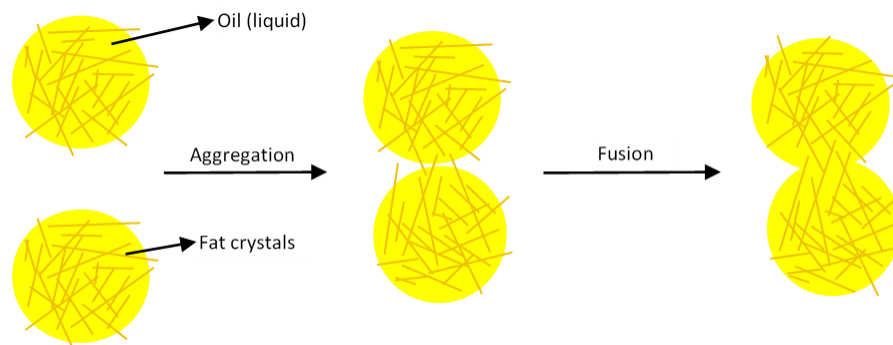


A real ganache is much closer to B than A. In fact, the droplet density is even a little higher than depicted in picture B. In general, Emulsion Ratio of around 1 is same as droplet concentration of 0.5 and when the ER reaches around 2, the droplet concentration goes up to 0.66. At higher droplet concentrations there is a risk of emulsion inversion, but this could be managed with the use of additional surfactant proteins and most critically through the use of correct method in making of the ganache. Please note droplet concentration = total volume of droplets divided by the total volume.

When the mechanical agitation of the two immiscible liquids ends, the discrete phase is fully established as small droplets of liquid fat suspended in the continuous phase of the ganache along with larger solids.

The discrete phase droplets contain fine solids which mostly reside on the interfacial membrane that keeps the liquid fat droplets intact.

The oil in the droplets contain cocoa butter and AMF. Both lipids crystallize at certain temperature range and have many different possible crystal structures, resulting in liquid fat droplets covered with fine particles and proteins containing fat crystals.



When a fat crystal within a droplet grows they can protrude from the droplet and penetrate another droplet. These droplets then join and remain in aggregate because such a geometry leads to a thermodynamically more stable system. The reason for the increased stability is because hydrophobic fat crystals prefer to be surrounded by oil molecules due to the reduction in interfacial energy.

Over time the droplets tend to partially merge because this further reduces the unfavorable contact area of oil exposed to water. Hence, the junctions holding the partially crystalline droplets together often become stronger and more difficult to break after an emulsion has been aged. This leads to a crystalline network surrounded by non-crystalline fats. (For more in-depth treatment of the subject see Food Emulsions; Principles, practices, and techniques (Third addition) by David Julian McClements)

During shearing of emulsions, several physicochemical mechanisms contribute to the increased rate of partial coalescence:

1. Shearing results in increased collision frequency
2. It also increases collision efficiency between droplets since a crystal protruding from a droplet is more likely to penetrate another during the rolling motion of droplets by shearing forces.
3. Shearing leads to smaller “unit crystal” structure as ganache cools below crystallization temperatures of dominant crystal forms for CB and AMF

Upon shearing and cooling of the ganache, a crystal network is formed by random connection of unit crystals that are surrounded by non-crystalline CB, AMF, and oils (for a ganache this depends on the environment temperature)

The technique referred to as “tableing” by chocolatiers is in-fact a shearing action.

In the previous section two key terms were mentioned associated with the visual depiction of a solidified unit volume of ganache: Crystal network and the Extent of the network. These refer to the network formed by penetrating crystals and the resident crystal structure of the droplets. The term Extent refers to the oils (non-crystalline lipids) within the connected droplets.

9.0 WHAT IS A BALANCED GANACHE

Although every chocolatier has heard of the term “balanced ganache” it is very difficult to find a clear definition of what exactly is being balanced and to what purpose.

A balanced ganache is an emulsion where the density of the discrete phase is equal or very close to the density of the continuous phase

When this condition is achieved, forces acting on the oil droplets floating in water are *balanced* and the droplets do not float to the top surface of the ganache. In the terminology used in section 5.0; a balanced ganache has the Stokes velocity for the droplets zero or close to zero.

So what does this mean from the perspective of a chocolatier?

1. Ingredient weights and volumes in a recipe should be arranged in such a way that when a ganache emulsion is formed the resulting density of the discrete phase and continuous phases are equal.
2. A balanced ganache is much less likely to separate than otherwise but it is not the only thing that prevents ganache separation. It is also critical that the emulsion formation steps outlined in section 10 below should be adhered to. Under certain circumstances it is possible to end up with a balanced but broken ganache if continuous phase is mixed into the discrete phase which is reverse of the correct way of establishing an oil-in-water emulsion.
3. A balanced ganache does not ensure long shelf life. Shelf life is impacted by a concept called Water Activity. Please read the Appendix of this document for some info on Water Activity.

4. Mouth feel. A balanced ganache will always have a smoother mouthfeel than an unbalanced ganache. This is because the distribution of the oil droplets within the ganache will be uniform while the ganache is solidifying and crystallizing.

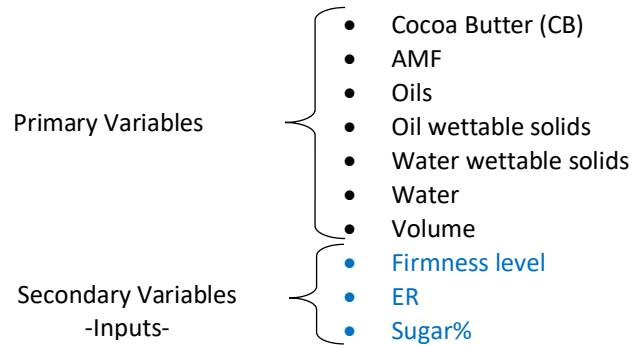
10.0 HOW TO MAKE GANACHE

Assuming you already have a ganache recipe which provides density equivalence between the discrete and continuous phases along with reasonable ER and Firmness values; what is the correct way to establish an O/W emulsion?

1. Melt Chocolate(s) and additional CB (if needed – both chopped into small pieces) either using bain-marie or a microwave with short bursts and stirring between heating. Ensure that the temperature reaches 120 F (50 C) but does not go above.
2. If the recipe contains nut-butter/paste, then warm it up to same temp as the molten chocolate and mix it in the molten chocolate (nut paste into chocolate or vice versa does not make any difference). Ensure thorough mixing by hand.
3. If there is an oil addition (e.g., nut oils or olive oil etc.) bring it up to the same temp as the chocolates and nut paste and mix it by hand into the chocolate mixture.
4. In a separate bowl hand mix all other **liquids** (all dairy except butter, water, flavored water, fruit puree, syrups, and all other additional sugars etc.).
5. Heat up the liquids above 95 F (35 C) or higher (as needed) for the purpose of melting all the crystalline sugars and melting dairy fat. Mix well by hand. Ensure that the temperature does not exceed about 130F (54 C) since casein micelles start disintegrating around that temperature. Please remember to use non-homogenized dairy products so that casein and whey micelles remain intact. (Note: do not use raw milk or cream due to potential health hazards)
6. Let both the **chocolate/nut-paste/oil mixture** and other **liquids** come down to around 95 F (35 C) in separate containers. This is because at around 92 – 93 F cocoa butter crystals start to form; the liquids at this point should be crystal free. As well, the mechanical homogenization will add significant energy into the emulsion resulting in elevated temperatures. The temperature of the ganache at the end of the homogenization cycle should not go above approximately 120 F (50 C). If we begin mixing chocolate and other liquids at higher temperature, then at the end of the homogenization the temperature of the emulsion will be too high.
7. Once the **liquids** reach around 95F (35 C) add the room temperature alcohol if the recipe has any.
8. If the recipe contains butter then warm it up to 95F (35C) and have it handy.
9. Prepare to use a hand blender (more powerful the better); if available, one with an emulsifying attachment or a powerful food processor.
10. Immerse the hand blender into the **liquids** (continuous phase of ganache) and start blending.
11. While blending, pour the **chocolate/nut-paste/oil mixture** (Discrete phase) in a thin ribbon INTO the **liquids** mixture.
12. Continue blending for 3 minutes (keep a timer, it feels much longer than one imagines) for batches up to 1 kg total ganache weight and longer if the ganache weight is higher. At around mid way point add in the softened **butter** continue blending until 3 minutes is reached.
13. If the desired ganache has higher H and ER, then the emulsification will be more challenging due to the higher viscosity of the emulsion. This might be a difficult for small hand blenders or blenders with complex emulsification attachments. If the blender is stalling replace the emulsification head with a simple blade.
14. Once the emulsion is thoroughly homogenized pour it on a flat surface (quartz, granite, marble. Steel) and using the chocolate crystallization technique, sheer mix the ganache. Keep an eye on the temperature; once ganache reaches around 87F (30 C) then the it is ready to use.

11.0 STATE MODEL FOR GANACHE

As described earlier a ganache is a suspension of cocoa and other solids in an oil-in-water emulsion. Although ingredients such as chocolate, cream, fruit purees and/or nut pastes etc. are used in creating a ganache, none of these elements are fundamental enough to describe a complicated suspension as a ganache. The use of more fundamental parameters is necessary to mathematically describe a ganache. The set of variables that describe the state model of a ganache are as follows.



A state model is a set of equations (consider state equations as governing rules) when solved simultaneously (when all the rules are adhered to) the solution represents set of primary parameters that satisfied all the rules, meaning a ganache recipe derived from this set of primary variables will adhere to all the ganache theory described in this document.

The variables indicated in blue will be the system inputs (knowns) that will be provided into the system; and the system equations, when solved simultaneously will provide the primary variables set which will result in a ganache recipe that satisfies the required system inputs of for firmness, Emulsion Ratio, and overall sugar % while satisfying all the ganache rules.

The state equations for ganache are as follows.
(Note: all Primary ganache variables are in %)

$$1. F + S_o + S_w + W + S = 1$$

Where F= Lipids = CB + AMF + Oils

S_o = Oil wettable solids

S_w = Water wettable solids

W = water

S = Sugar, all values for these variables are in percentages of unity

$$2. aF + bS_o + bS_w + cW + dS = g$$

Where $a = 1/\rho_a$ where ρ_a is the average density of lipids used in the ganache

$b = 1/\rho_b$ where ρ_b is the average density of solids used in the ganache

$c = 1/\rho_c$ where ρ_c is the density of water used in the ganache

$d = 1/\rho_d$ where ρ_d is the average density of sugars used in the ganache

g = volume of the ganache

$$3. ER = (aF + bS_o)/(cW + dS + bS_w)$$

Where ER is the emulsion ratio (discrete phase VOLUME)/Continuous phase VOLUME)

$$4. H = (SFC(1 - O) + xS_o)/(cW + dS + bS_w)$$

Where H is the required firmness of the ganache
SFC is the Solid Fat Content of CB+AMF combination
O is the added oil
x is a coefficient indicating what percent of fine solids participates within the crystal network

$$5. \rho_{discrete\ phase} = \rho_{continuous\ phase}$$

Where ρ is the density of the discrete and continuous phases of the emulsion

A solution set to state equations will be in terms Primary Variables; not the ingredients a chocolatier uses to make a ganache. For instance, a piece of milk chocolate contains CB, AMF, crystalline sugars, and oil wettable solids potentially along with various inclusions and emulsifiers commercial chocolates might contain. Furthermore cream, butter, milk also contain AMF as well as Oil wettable solids, proteins, and other solids. It is not a trivial matter to develop a ganache recipe starting from the Primary Variables.

These equations succinctly incorporate all the physicochemical concepts discussed in this paper and describe them in mathematical language. Here is what they mean in plain language.

Equation 1 is a mass unity statement. It says, if I add all the percentages of a substance's building blocks then I get 1.

Equation 2 is a similar concept to #1 above but in the context of volumes of comprising elements of the ganache. It basically says; if you add the volumes of all fats, all solids, all liquids, all sugars you will get the ganache volume.

Equation #3 is a definition statement; it defines a term "Emulsion Ratio" as volumes of all lipids and oil wettable solids divided by the volumes of the rest of the ganache elements.

Equation #4 is also a definition for the variable Hardness. Firmness (Hardness – interchangeable term) of a ganache is directly proportional to the final SFC diluted by oil, as well as the oil wettable solids. The multiplier for oil wettable solids, x, is a number less than 1 and is there to account for the fact that certain percentage of oil wettable solids are too large to participate in the building of the fat crystal network and hence they become the contributing element of the overall suspension.

The denominator of the hardness equation is the volume of the rest of the ganache primary variables. This means firmness of a ganache is determined by total SFC of the lipids plus a certain size oil wettable solids per unit volume of the rest of the ganache elements.

The symmetry between ER and H (equations #3 and #4) is highly apparent. ER relates to volume of hardness causing materials to the rest of the ganache components and H relates to hardness generating fats and oil wettable solids upon solidification to room temperature.

Equation #5 forces the densities of the discrete phase and continuous phase of the emulsion to have the same value. As covered earlier, this condition eliminates most of the causes which lead to emulsion destabilization. In fact, having the same density for these two elements of a ganache leads to a smooth mouth feel on the tongue as well.

11.1 Solution Volume For The State Equations.

Any set of Primary Variables that can simultaneously satisfy all five state equations is called a "solution set". Known values (i.e. initial values that are used as input parameters to the system equations) for the state equations are.

1. H = Hardness or firmness of the ganache
2. ER = Desired emulsion ratio
3. S = Overall sugar percentage of the ganache.

Note that S denotes sugar percentage and S_o and S_w indicate oil wettable solids and water wettable solids, respectively.

For a given set of values for H, ER, and S it is possible to determine whether the simultaneous solution of the state equations will yield values for primary variables that are within valid ranges. For instance negative values for any of the primary variables will have no meaning in physical reality. If there is a valid solution then it can be stated that for the flavor profile and the chosen H, ER, and S values will lead to a ganache formulation that is physico-chemically balanced.

If a chocolatier desire to create a say medium firmness ganache with certain flavor profile and sweetness then the solution to the state equations, with these inputs, provide the set of values for CB, AMF, S_o , S_w and W, which constitutes a solution set. Note that the remaining parameter, ganache volume, is also identified in the solution set but it does not have taste analogue so although it impacts the mathematics of the solution, it does not relate to the recipe as an ingredient.

A solution set means a balanced ganache recipe.

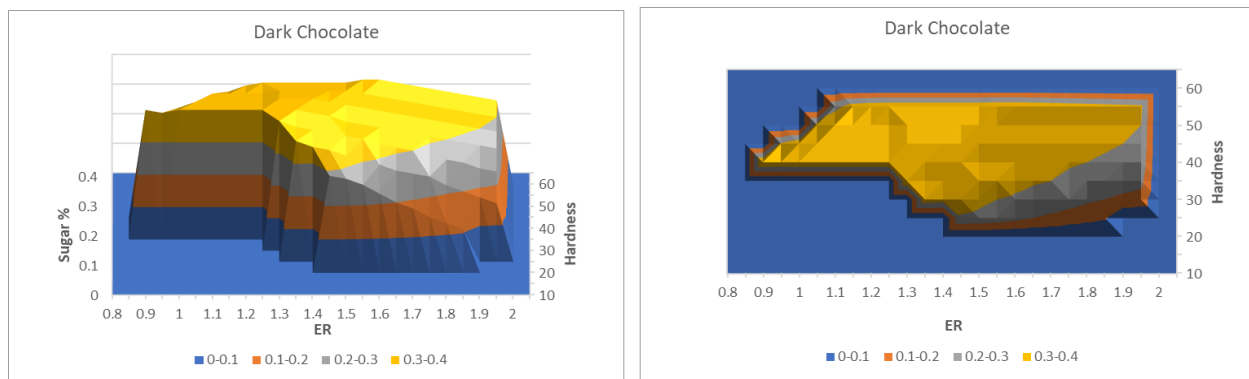
It is then possible to iterate through all reasonable H, ER and S values and seek solutions to state equations and subsequently identify ALL balanced ganache formulations for the selected flavor profile.

Once we determine all of the solution sets for reasonable ranges of input values for the H, ER, and S then it is possible to plot these values and establish a three dimensional volume which contains all of the physico-chemically balanced ganache formulation for that specific flavor profile

Question: what would such a solution volume look like?

If I re-cast the above concepts and the question in chocolatiers' terminology; lets assume a ganache using a single dark chocolate as the chosen flavor profile. Also let's also assume that we want to see all valid solutions regardless of Harness, ER and Sugar percent values before deciding on a single recipe; what would the resultant shape look like?

Figure below shows the solution volume created by flavor profile of a dark chocolate ganache. Axes are labelled. The height of the structure indicates the sugar percent value. For instance, the yellow colour indicates the sugar percent range between 30% to 40%.



For now, visualize the solution space much like a mountainous island. Where water is there are no valid ganache recipes. Any point on (or in) this volume is a valid recipe.

In this example the valid Hardness value ranges are between 10 and 60. A low value for hardness represent a soft ganache for filling shells and higher values are for enrobed ganaches.

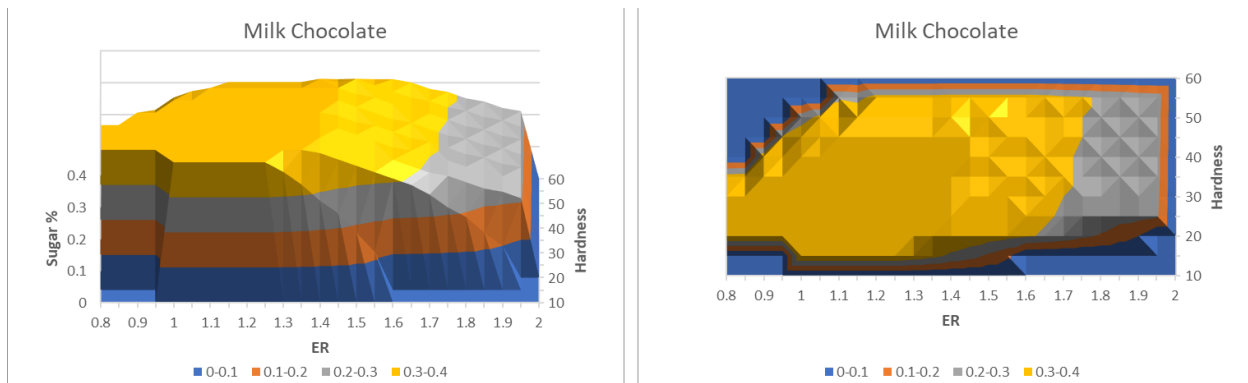
For instance, in the above flavor profile example, if you are considering a ganache with hardness = 20 and Emulsion Ratio of 1.2 will not lead to a valid solution set or in other words there will not be a possible well balanced recipe resulting in such a hardness and ER values.

A word of caution; current version of Ganache Master will provide slightly different values since the chocolate couverture that was used to establish these results is no longer available in the market and hence chocolate selections in the Ganache Master are now reflect current market options. But the science remains the same.

But if $H=35$, $ER=1.5$ are selected then there are many recipes that can be chosen from; one such recipe can have sugar value between 20 and 30% (grey coloured height). Ganache Master web page will provide the valid sugar range (minimum and maximum sugar values) after entering specific H and ER inputs.

An important point to highlight is as follows; if you selected $H=30$ and $ER=1.8$ but would like to have sugar values say 35% then there will not be a valid recipe for this selection of inputs. Being off the solution volume ("island") means both the sea and the sky.

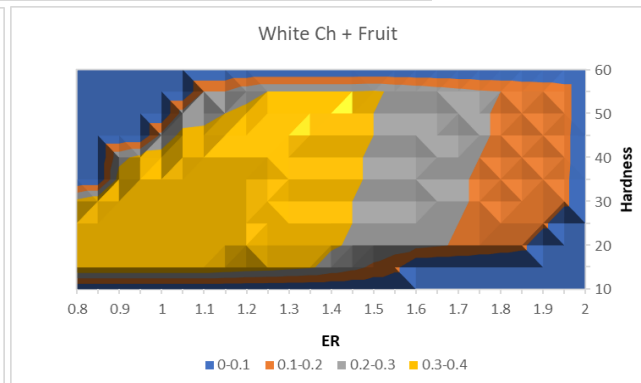
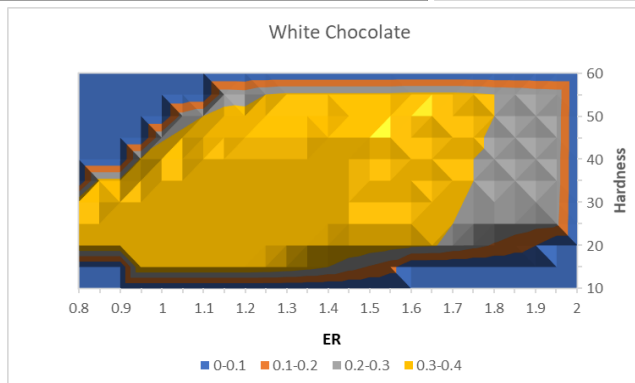
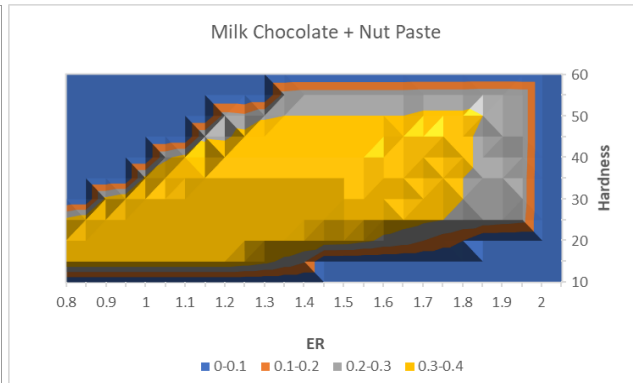
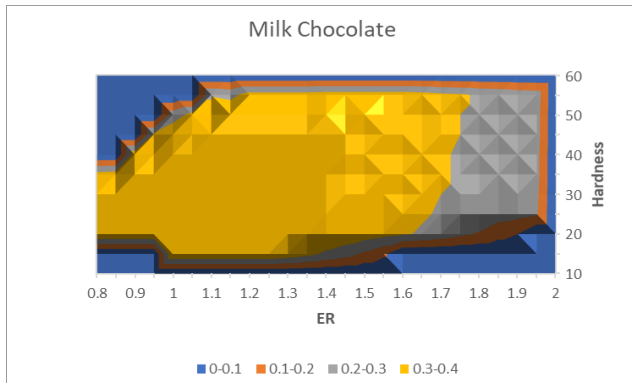
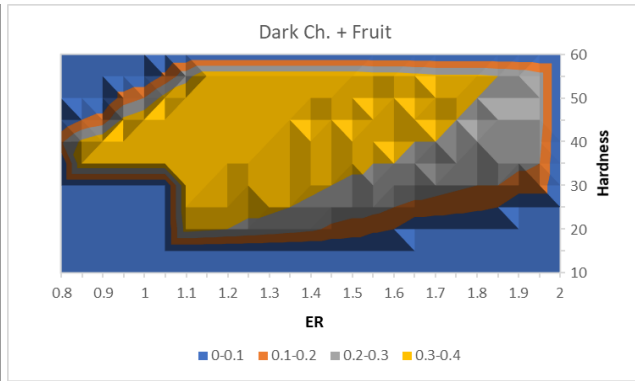
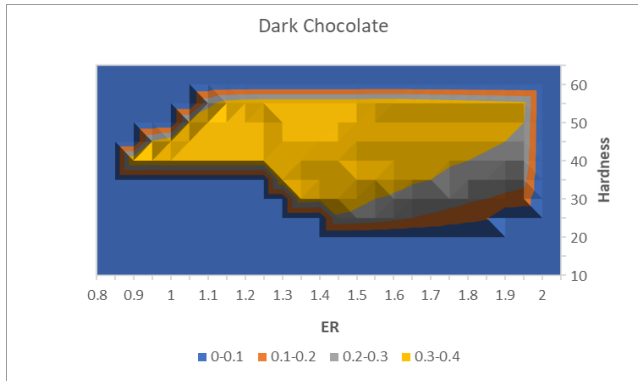
Size and shape of this solution volume changes with the flavor profile selected. For instance, if a milk chocolate is selected as a flavor profile instead of dark chocolate then the solution space would look like as follows.



The first thing to notice is that the solution space is significantly broader and higher percentage sugar is possible for a lot more H, ER selection options. Why is there such a change in the solution volume.

One reason is mathematical (combinations). Easiest way to visualize the reason is perhaps through an example. Let's say you are preparing loot bags (for friends who do not live in North America; a loot bag is a collection of candy pieces given to small children who came around during the Halloween night, dressed as something scary, for trick or treat). Let's also assume that each bag should have the same number of candies and for fun let's say we want each bag to be unique (no two bags should have the same candies). If you have two types of candy to make loot bags with (e.g. Mars bars and Bounty bars) then you can only have 3 unique combinations: 2 mars bars, a mars bar, and a bounty bar or two bounty bars. There is no forth possibility. But if you had 6 different types of candies to start out with and two candies per unique loot bag rule, you then can have 15 unique bags.

Based on the above analogy, a ganache made with only a single dark chocolate will have a smaller number of unique solutions (hence a smaller solution volume) than a ganache containing two different chocolates, an alcohol selection and a nut-paste. Before taking a closer look at this phenomena let's look at a broader picture.



Above solution volumes are plotted by seeking solutions to the state equations at all different H and ER values with highest possible sugar values. As a note, I limited the maximum sugar at 40% since beyond this value the resultant ganache will be too sweet for most taste buds.

When solution spaces for Dark chocolate and milk chocolate are compared it is clear that milk chocolate based ganache has a larger solution volume than dark chocolate ganache. As mentioned earlier the limited number of mathematical combinations resulting from limited flavor profile inputs is one reason; but not the only one.

How do we explain milk chocolate solution volume being larger than milk chocolate with nut paste?

The second and perhaps more important reason originates from the 5th state equation.

$$\rho_{discrete\ phase} = \rho_{continuous\ phase}$$

Some of the primary variable combinations for milk chocolate + nut paste fail to satisfy the state equation #5. Indeed these two constraints go hand in hand. Therefore although there are more potential mathematical combinations resulting from broader selection options not all of these satisfy the 5th state equation and hence a different shape for the solution volume.

What are the implications of failure to satisfy the 5th state equation? This means the densities of the discrete phase will differ from the density of continuous phase resulting in motion of discrete phase droplets towards the surface of ganache. So, from practical point of view the resultant ganache will not be as silky on the tongue as it should. But would it split? Unlikely. For all intents and purposes it will become a ganache (especially if you follow the ganache making steps discussed above) but it will not be the best that can be achieved.

12.0 CONCLUSION

This brings us to the essence of this study. If you are going to make a ganache why not start with a physico-chemically balanced foundation providing for you a perfect springboard to shine the specific flavor profile you are creating.

Mel Ogmen

Appendix:

Water Activity

Water activity is a critical concept for chocolatiers. It regulates food safety and shelf life as well as flavor and texture characteristics of chocolate confections. Both the mathematics and the chemistry of this topic is rather complex. Here is a simpler and more practical summary of what it is and how to control it during the formulation of your ganache.

What is it?

Formal definition of water activity involves ratio of partial pressure of water vapour in the confection to that of pure water. It is a dimensionless number between 0 and 1. 0 is the no water activity end of the scale whereas 1 is the water activity of pure water.

Low water activity leads to longer shelf life, less risk with food born pathogens, more stable confection (taste and mouth feel) under changing shipping and/or storage environment.

High water activity results in short shelf life. Chocolatier must be confident that the high-water activity confection will not result in food borne illnesses in customers.

Should I avoid producing higher water activity confections?

Absolutely not. Many ganache filled confections fall into this category. These can be very punchy fruit flavors or delicate herb or tea infused ganaches. Instead, you can improve the odds by following some of the guidelines in this document.

What are the key concepts and how do I control water activity?

Water content, available water (free water), bound water, and the strength of the bond between water and various other elements and compounds are the key concepts that help to modify the water activity of a given ganache recipe.

Water content of a ganache can be gleaned from its recipe. If you add percentages of skim milk, milk, cream, fruit juices, fruit purees and other water source in the recipe you will get a good idea. Higher water content in a ganache might lead to higher water activity. Related concepts of “**free water**” and “**bound water**” although they are appealing from the perspective of visualizing water activity, are inadequate description of the underlying chemistry. Nevertheless, they provide a reasonable path forward.

When the water is in contact with solid surfaces and other compounds it chemically and/or physically binds to them through surface tension and hydrophilic surface regions. These bonds make the water “**bound water**” and the probability of such water being available for microbial activity is reduced.

So, what are those things in a ganache recipe that “bind” water. It is mostly sugar. Sugars come in in a wide variety of molecular shapes and sizes. Different sugars bind water not only slightly differently but also in different amounts and different binding strength. This is the reason for use of multiple different types of sugars in Ganache Master’s recipes.

Although low sugar content became a desirable trend, it is important to point out that one of the reasons for many high volumes produced confections contain high sugar content is the issue of shelf life (as well sugar is cheap). Such confections also contain other “preservative” chemicals again to impact the shelf life.

Another aspect of ganache chemistry that can impact shelf life and microbial load is the pH of the resultant emulsion. Lower pH (acidic) leading to lower water activity and microbial load. Some fruit ganaches can be rather low pH and if they are also made with variety of sugars then although such a ganache might show high water

content this does not necessarily translate to high water activity and shorter shelf life. Although caution and diligence is always urged for health and safety reasons.

To improve shelf life:

- Keep overall water content of the ganache low. This is achieved by keeping the emulsion ratio as high as possible while still getting a balanced recipe from Ganache Master
- Use a mixture of different types of sugars and syrups in the formulation and keep the sugar content high
- If possible, use acidic components. Add a little citric acid (citric acid is a natural acid found in fruits such as lemons, limes, peaches, plums, grapefruit, and oranges.)
- Allow filled cavities of ganache to fully crystallize and “dry out” before capping them.