Cellulose Derivatives in Food Applications
Dow Wolff Cellulosics

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Agenda

• Introduction to Cellulose

• Food Approved Cellulose Derivatives
  o Key Properties
  o Functions
  o Common Applications

• Most Widely Used Cellulose Ethers in Food Industry
  o Methylcellulose (MC)
  o Hydroxypropyl Methylcellulose (HPMC)
  o Sodium Carboxymethylcellulose (CMC)

• Q&A
What is Cellulose?

• Worlds most abundant naturally occurring organic substance

• Cellulose comes from plants, trees and vegetable matter

• As such, it has always been part of the human diet and a source of dietary fiber

• In its natural state, cellulose is not soluble in water (chains of cellulose are very tightly bound to each other by H-bonding)
Cellulose Ethers

Water Insoluble → Water Soluble

Water Insoluble

Water Soluble
Cellulose Derivatives for Food

- First cellulosics research work begun in 1920’s in Germany
- Applications in foods (USA) starting in late 1940’s.
- High purity (≥ 95% water-soluble dietary fiber)
- Non-digestible
- Non-fermentable - no gas
  - Related to form of 1,4-β-glycosidic bonds between glucose units
- Non-allergenic
- GRAS status
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• Q&A
Types of Cellulose Derivatives for Food

Physically Modified Cellulose

- Microcrystalline Cellulose (MCC)

Cellulose Ethers

- Hydroxypropylcellulose (HPC)
- Ethylmethylcellulose (MEC)
- Ethylcellulose (EC)
- Methylcellulose (MC)
- Hydroxypropyl Methylcellulose (HPMC)
- Sodium Carboxymethylcellulose (CMC)

3/12/2012
Microcrystalline Cellulose (MCC)

Properties
- Thixotropic
- Shear Thinning – Reversible
- Heat Stable
- Nonionic
- Powdered & Dispersible Grades

Functions/Applications
- Opacifying Agent
- Foam Stabilizer
- Anti-caking agent
- Emulsifier
- Freeze Thaw Stability

Cheese (powdered, shredded)
Beverages, Confections,
Salad Dressings, Sauces,
Whipped Toppings

*Labeled as Microcrystalline Cellulose or Cellulose Gel*
Hydroxypropyl Cellulose (HPC)

**Properties**
- Nonionic
- Surface Active
- Insoluble in Hot Water >40 C
- Soluble in Organic Solvents
- Thermoplastic

**Functions/Applications**
- Foam Stabilizer
- Film Former (Flexible)

*Whipped Toppings, Edible Coatings, Confection Glazes, Extruded Foods*

*Labeled as Hydroxypropyl Cellulose or Modified Cellulose*
Ethylmethyl Cellulose (MEC)

Properties
- Nonionic
- pH Stable
- Precipitates From Solution Above 60°C – (reversible upon cooling)
- Not widely used

Functions/Applications
- Thickening Agent
- Filler
- Anti-Clumping Agent
- Emulsifier

Non Dairy Creams, Low Calorie Ice Creams, Whipped Toppings, Mousse

*Labeled as Ethylmethylcellulose, methylethylcellulose or Modified Cellulose
Ethylcellulose (EC)

Properties
• Nonionic
• Hydrophobic
• Soluble in Organic Solvents
• Thermoplastic

Functions/Applications
• Film Former
• Flavor Fixative
• Limited Food Approval

Flavor Encapsulation, Moisture Barrier Films, Fruit/Vegetable Inks

*Labeled as Ethylcellulose
Methylcellulose & Hydroxypropyl Methylcellulose (MC & HPMC)

Properties
• Reversible Thermal Gelation
• Cold Water Soluble
• pH Stable
• Wide Viscosity Range

Functions/Applications
• Binding
• Boilout Control
• Film Former
• Freeze Thaw Stability

Formed Foods, Fillings, Sauces, Whipped Toppings, Gluten Free Baked Goods

*Labeled as Methylcellulose, Hydroxypropyl Methylcellulose, Modified Cellulose
Sodium Carboxymethylcellulose (CMC)

Properties
- Anionic
- pH Sensitive
- Interacts with Proteins
- High Water Holding Capacity

Functions/Applications
- Freeze Thaw Stability
- Protein Protection
- Thickener
- Texture Control

*Frozen Foods, Baked Goods, Tortillas, Soups, Sauces, Beverages*

*Labeled as Sodium Carboxymethylcellulose or Cellulose Gum*
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• Introduction to Cellulose

• Food Approved Cellulose Derivatives
  o Structure – Function Relationships
  o Common Applications

• Most Widely Used Cellulose Derivatives in Food Industry
  o Methylcellulose (MC)
  o Hydroxypropyl Methylcellulose (HPMC)
  o Sodium Carboxymethylcellulose (CMC)

• Q&A
Methylcellulose (MC)
Hydroxypropyl Methylcellulose (HPMC)
MC & HPMC Common Applications

- Bakery, Gluten Free
- Fillings
- Sauces
- Formed/Extruded Foods
- Salad Dressings/Marinades
- Whipped toppings
- Batters/Coatings
- Meat/fish preparations
- Beverage Emulsions
MC & HPMC – Advantages

- Broad viscosity range – from very low to extremely high
  - 19 – 250,000 cPs (2 %, Brookfield)

- Always available in high quality (not dependant on harvesting)

- High degree of purity (> 99.5 %)

- Conformity of all standards for food and pharmaceutical applications

- Narrow specifications for all relevant product parameters

- Prepared from wood pulp → GMO free
MC & HPMC - Key Properties/Functions

- **Reversible Thermal Gelation** – (varying gel strengths)
- Wide Viscosity Range
- Thickening
- Moisture Control (Cold Water Binding)
- Emulsification, Encapsulation & Film Formation
- Binding
- Air Entrainment & Foam Stability
- Freeze Thaw Stability
- Provides Soluble Fiber
MC & HPMC Chemistry

- Methylcellulose (MC)
- Hydroxypropyl methylcellulose (HPMC)

Based on the substituent group:

Methyl Group

Methylcellulose (MC)

Hydroxypropyl Group

Hydroxypropyl methylcellulose (HPMC)
MC & HPMC - The Chemistry

Methylcellulose

Hydroxypropylmethyl Cellulose

MC

HPMC
Different chemistries have differences in physical properties

- Dissolution temperature
- Gelation Temperature
- Gel Strength
- Surface Activity

Differences are caused by:

- The substituent group (Ratio of methyl/hydroxpropyl groups)
- Relative numbers of the groups (Degree of Substitution: DS)
- Average chain length of the product (Molecular Weight)
MC & HPMC - Different Viscosities

Thick
~ 50,000 mPa.s

Medium
~ 4000 mPa.s

Thin
~ 50 mPa.s
Viscosity Range

- A rough rule -- For every 1% increase in concentration you will see an 8x increase in viscosity
MC & HPMC

Effect of Concentration
• Viscosity build is not linear

Effect of pH
• Viscosity is stable between pH = 3 and 11

Effect of Temperature
• **MUST** reach set hydration temperatures to become fully functional.

Effect of Salt and Sugar:
• May delay hydration and hinder viscosity development
• May precipitate MC & HPMC out of solution if too much salt or sugar
• May lower gelation temperature
<table>
<thead>
<tr>
<th></th>
<th>Hydration Range</th>
<th>Gelation Range</th>
<th>Gel Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Gel MC</strong></td>
<td>&lt;50°C, 10°C</td>
<td>100 - 114°C, 38 - 44°C</td>
<td>Very Firm</td>
</tr>
<tr>
<td><strong>Conv. MC</strong></td>
<td>&lt;55°C, 13°C</td>
<td>122 - 131°C, 38 - 44°C</td>
<td>Firm</td>
</tr>
</tbody>
</table>
MC & HPMC

REVERSIBLE THERMAL GELATION
MC & HPMC Reversible Thermal Gelation

2% MC & HPMC Solutions

Gels obtained by heating 2% MC and HPMC Solutions
MC & HPMC – Thermal Gelation Benefits

- Controls moisture movement
- Retains shape at high temperatures (Boil out control)
- Reduces oil uptake
- Improves coating adhesion (along with film formation)
- Works alone (no other additives necessary)
MC & HPMC - Thermal Gelation - Binding/Shape Retention
*Note: maximum sugar content must be less than 50%.
0.4% MC–vs- 0.15% Xanthan, 0.15% Guar, and starch control

Before Baking
MC & HPMC – Thermal Gelation – Boil Out Control

After Baking
In French Fry Coatings:

Most important property is gel strength → gel maintains its integrity during frying
- MC has the highest gel strength of the chemistries
- Least surface active

MC will also gel at the lowest temperature
- Ensures film is formed prior to fat being absorbed
Fat Uptake Reduction With Increasing Methylcellulose Solution Strength
Fat Reduction in French Fry Batters

- Achieves ~30% reduction in fat
- Will enable a “Reduced Fat” claim in retail markets
- Note that the batter alone does provide some barrier function ~11%

![Fat Reduction Chart]

<table>
<thead>
<tr>
<th>% Total Fat</th>
<th>Control Non-Battered</th>
<th>Control Battered</th>
<th>2% MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td></td>
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</tr>
<tr>
<td>8.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.00</td>
<td></td>
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</tr>
</tbody>
</table>

3/12/2012
## Cinnamon Buns

### A4M Reverse Emulsion 09/26/11

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Grams</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butter</td>
<td>50.00</td>
<td>19.23</td>
</tr>
<tr>
<td>METHOCEL A4M</td>
<td>2.00</td>
<td>0.77</td>
</tr>
<tr>
<td>Hot Water</td>
<td>48.00</td>
<td>18.46</td>
</tr>
<tr>
<td>Brown Sugar</td>
<td>150.00</td>
<td>57.69</td>
</tr>
<tr>
<td>Cinnamon</td>
<td>10.00</td>
<td>3.85</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>260.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

### Control 09/26/11

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<td>100.00</td>
</tr>
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</table>
Methylcellulose be used to improve the juiciness and mouthfeel of an already lean beef patty (without adding extra fat)

Formulation
- 88.4% Lean beef (90% fat free)
- 10.0% Cold water (<40F)
- 1.2% Methylcellulose
- 0.4% Salt

**Total fat:** 10% fat (from meat) (11.3g fat per ¼ lb patty)

Store bought patty = 20% (22.6g fat per ¼ lb patty) = 50% fat reduction
FILM FORMATION
Surface Activity - 1% Gum Solutions

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Surface Tension (Dynes/cm)</th>
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</thead>
<tbody>
<tr>
<td>Water</td>
<td>72</td>
</tr>
<tr>
<td>Xanthan</td>
<td>69</td>
</tr>
<tr>
<td>CMC</td>
<td>68</td>
</tr>
<tr>
<td>Na Alginate</td>
<td>62</td>
</tr>
<tr>
<td>PG Alginate</td>
<td>58</td>
</tr>
<tr>
<td>MC</td>
<td>53-59</td>
</tr>
<tr>
<td>HPMC</td>
<td>45-55</td>
</tr>
</tbody>
</table>

N. Sakar – CRI Report #823965, 1982
MC & HPMC – Film Formation Benefits

- Improved adhesion of coatings
- Reduced oil pick up (also a function of thermal gelation)
- Increased “hold time” under heat lamp
- Reduced runoff in oven
- Reduced browning
MC & HPMC are very surface active
Tri-colored/tri-flavored film for a coating, as an insert between layers, encapsulation, etc.
Dry mix glaze on chicken breast (applied as a powder to the moist cold chicken)

with METHOCEL and without METHOCEL
FOAM STABILITY
Surface Activity of MC & HPMC

MC & HPMC stabilize emulsions, foams and dispersions by both decreasing the surface tension and increasing the viscosity.

Oil-in-water | Air-in-water | Solids-in-water
---|---|---
No MC/HPMC | With MC/HPMC

Hydrophobic
Hydrophilic
MC & HPMC – Foam Stability

Eggless Meringue
Moisture Control
MC & HPMC – Moisture Migration Control

• MC & HPMC reabsorb moisture when food cools after heating and retains moisture during shelf storage.

• Cold moisture migration – in chilled and frozen storage (ice crystal control)

• Where cold moisture migration control might be used?
  o Baked goods (reduce staling)
  o Frozen doughs and batters (Cookie, Brownie, Rolls & Bread)
  o Frozen Cakes and Muffins
  o Fillings on dough based substrates
Moisture Control and Retention with MC & HPMC
Use of Multiple Properties
MC & HPMC – Using Multiple Properties

Gluten Replacement

- **Medium Viscosity**
  Needs to be able to thicken dough
  Too thick - Will not raise during proving or baking & difficult to work with

- **Gel Strength**
  Weaker Gel to ensure the bread can rise

- **Gelation Temp**
  Higher Gelation Temp (70-90 °C) - to gel later during the baking process

- **Surface Activity**
  Enhances and stabilizes air pocket structure in dough
In Reformed Potato Products:

- Make **mash formable** in the cold (viscosity control)

- **Maintain shape** when fried and re-cooled (thermal gelation & viscosity)

- Dramatically **reduce bursting** leading to improved yields and better safety (thermal gelation, moisture management)

- Make mash slippery reducing starch damage during extrusion

- **Reduce oil uptake** (thermal gelation, film formation)
**MC & HPMC – Using Multiple Properties**

*In Predusts:*
- Increases Batter Pick-up *(Viscosity)*
- Manages moisture migration *(thermal gelation, film formation)*
- Prevents batter blow-offs *(thermal gelation, film formation)*

*In Batters:*
- Reduced fat uptake *(thermal gelation, film formation)*
- Increases “hold time” *(thermal gelation, film formation)*
- Preserves crispiness in oven reconstituted products *(film formation)*
How to Incorporate MC & HPMC in Food Systems
MC & HPMC - Incorporation Methods

• Dry Blending (flour, sugar, salt, spices, etc.)
  7:1 Dispersant/MC or HPMC 😊

• Food Oils (soy, corn, canola, cottonseed)
  5:1-8:1 Oil/MC or HPMC 😊

• Other Liquids (corn syrup, HFCS, glycerin) 😞

• Hot Processing Steps 😊 😊

• Direct Cold Water 😞
MC & HPMC – Delayed Hydration Technique

Add MC or HPMC to hot system
- MC or HPMC won’t hydrate in hot conditions
- Product (dips/soups/etc) will stay thin during hot HTST or UHT; thicken upon cooling

• Improves pumpability of hot filled products

• Better efficiency of heat transfer during processing – lower processing time

• Less burn on
Methylcellulose has a synergistic effect when used in combination with modified waxy maize starches

- Reduce MC and starch levels – save on cost
- Fewer calories
- Increased hot cling
- Greater hot viscosity
- Less “starchy” mouthfeel in sauces
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  o Sodium Carboxymethylcellulose (CMC)

• Q&A
Sodium Carboxymethylcellulose (CMC)
CMC – Common Applications

- Gluten-free and conventional breads
- Pancakes, wraps, tortillas
- Cakes and cookies: Dough and dry mixes
- Bakery creams, fruit preparations
- Glazes, coatings and toppings of bakery products
- Dairy products
- Soups, sauces, dressings, marinades
- Beverages and Wine
- Meat Products
CMC - Advantages

- Broad viscosity range – from very low to extremely high
  - 30 – 60,000 cPs (2 %, Brookfield)

- Always available in high quality (not depending on harvesting)

- High degree of purity (> 99.5 %)

- Conformity of all standards for food and pharmaceutical applications

- Narrow specifications for all relevant product parameters

- Prepared from wood pulp → GMO free
CMC - Advantages

- Absolutely odorless and tasteless (e.g. Guar smells like beans)
- Absolutely clear and transparent solutions in water (unique in the world hydrocolloids)
CMC – Key Properties

• Soluble in Cold and Hot Water
• Thickener
• Increased Plasticity and Elasticity (improved machinability)
• Freeze Thaw Stability
• High Water Binding
• Emulsifier
• Protein protection
• Compatible With Other Hydrocolloids
CMC - Production

• CMC products are tailor made

• Main product characteristics are controlled by:
  ➢ degree of polymerisation (DP)
  ➢ degree of substitution ⇒ DS
  ➢ particle size

Sodium Carboxymethylcellulose (CMC)
DP = (Average Chain Length)

- Is controlled by the manufacturing process raw material (cellulose) source
- Determines the viscosity development of the CMC
- Range includes grades from low to extremely high viscosity
CMC - Degree of substitution (DS)

DS $\Rightarrow$ Average Number of CM-groups per Glucose Unit

Impact of increasing DS

- Higher gloss
- Smoother flow behavior, less pseudoplastic
- Clearer solutions (no fibers)
- Higher stability in low water content products
- Higher salt tolerance
CMC - Particle Sizes

Powdered Grades
• Will Clump if attempt to put directly into solution
• Requires dry blending agent

Granular Grades
• Goes into solution without clumping
• Takes longer to hydrate

Instantized Grades
• Very good dispersibility in cold water
• Fast viscosity build up
• No lumping
CMC

Effect of Concentration
- Viscosity build is not linear (doubling will increase viscosity 6-10X)

Effect of Heat
- With increasing temperature the viscosity of the CMC solution decreases (reversible)
- At temperatures above 90°C (194°F) all CMC grades are thin flowing.

Effect of Shear
- The higher the shear, the greater the thinning effect.
- Reverses and builds back viscosity after shear is removed

Effect of Salt Concentration
- Viscosity decreases as salt concentration increases

Effect of pH
- Maximum viscosity between pH 6.5 - 8.5
- Viscosity falls on each side of that range
Relation: CMC concentration and viscosity

CMC - Viscosity

in water, 15 °C, BF LVT
The viscosity decreases during heating process.

→ Reversible Process – viscosity increase again by decreasing the temperature!

Example: WALOCEL® CRT 10000 GA

Brookfield: 2 % SOL.
Spindle no: 3
Speed: 6 rpm
Aqueous CMC-Solutions, Concentration 1.0 % by weight
General behavior in the presence of salts:

- Tolerance is limited
- Viscosity decreases with increasing salt levels
- Higher DS CMCs are more stable than lower

The moment of salt (e.g. table salt) addition is important

- Dissolved CMC is more stable against salts than CMC which is integrated in salt water
- The viscosity development of CMC is suppressed due to salt water
CMC - Effect of pH on Viscosity

- Maximum viscosity between pH 6.5 - 8.5
- Insoluble at pH ≤ 3 (free acid form)
- Strong viscosity decrease at pH < 6
- Slight viscosity drop at pH > 9
Synergistic Combinations of CMC With Other Hydrocolloids
Synergism CMC - Guar without shear stress

Walocel CRT 60000 PA 07 - Guar 5000, concentration: 0.5 % in sum

Amount CMC in the blend [%]

Viscosity [mPas]

- **0.5 % (atro), measured value**
- **Theoretical value**
CMC + Locust Bean Gum

⇒ Improved stability and functionality

Synergism of blends (50 : 50)

• Improved heat resistance compared to pure CMC
• Increased cold functionality compared to pure LBG
• Viscosity win (10 % at low shear)
• Good shear stability
CMC + Gelling hydrocolloids

- Improved stability and functionality

"Synergism" between CMC and classic gelformers such as $\kappa$-Carrageenan, Agar, Starch ...

- Improved gel quality
- Prolonged stability
- No / less syneresis
- Increased elasticity
CMC - Overview on Food Applications

Foods Containing CMC
CMC - Functions in Food

Thickener, Viscosifier (e.g. beverages, soups, dressings, sauces)

→ Gives viscosity to aqueous solutions

Texturizer (e.g. beverages, fruit preparation)

→ Improves body and mouthfeel, keeps consistency stable over storage time

Improve elasticity and plasticity
(e.g. extruded products, bakery products)

→ Good machinability / simplified post-processing
CMC - Functions in Food

Crystallisation control (e.g. ice cream, frozen dough products)
   → Slows down the crystallisation speed, reduced crystal growth/size
   → Delayed retrogradation of amylose (anti staling agent)

Waterbinding (e.g. meat products, bakery products)
   → Prevents water loss, suppressed syneresis
   → Prolonged freshness

Mouthfeel enhancer (e.g. fat-reduced products like fresh cheese preparations, soups, sauces, beverages)
   → Simulates a "fatty" mouth feel, improved creaminess
Protein protection (e.g. fresh cheese, acidified dairy drinks)

→ CMC protects proteins against the effects of acid and heat

Stabilizer (e.g. soups, dressings, sauces)

→ Keeps molecules stable and suspends particles

"Emulsifier" (e.g. spreadable cheese, dressings)

→ Stabilizes hydrophilic and lipophilic components, support of classic emulsifiers
CMC - Functions in Food

Gelling support (e.g. fresh cheese preps, desserts)

→ CMC improves the quality of gels and supports gel-forming hydrocolloids

Foam stabilization

→ Fixing of foams, constant density, prolonged stand-up

Partial replacement of traditional additives

→ Fat and oil
→ Proteins (Proteins from milk/whey, meat, soy, wheat)
→ Sugar and lactose
Guar Replacement with CMC

Guar Gum

- Guar provides thickening, texturizing, moisture-binding and freeze-thaw stability
- 70-80% of guar gum is being used oilfield applications
  - Gum gum supply short of demand by ~25% in 2012
- Current prices roughly $7/lb
- 1% viscosity = 3500 – 5000 cPs

- CMC is a suitable, cost effective replacement
  - 40,000 or 50,000 viscosity grade – 1:1 replacement
  - Synergy: 20/80 & 35/65 Guar/CMC offers a 2x viscosity gain vs expected value
### Guar Replacement with CMC

<table>
<thead>
<tr>
<th>Properties</th>
<th>Guar gum</th>
<th>Cellulose gum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold and hot water soluble</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Dissolution time</td>
<td>Medium - Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Solution Transparency</td>
<td>Cloudy</td>
<td>Clear</td>
</tr>
<tr>
<td>Flavor</td>
<td>Beany</td>
<td>Neutral</td>
</tr>
<tr>
<td>Viscosity range</td>
<td>5000 - 7000 @1%</td>
<td>30 to 50,000 @ 2%</td>
</tr>
<tr>
<td>Viscosity w/Shear</td>
<td>Shear Thinning</td>
<td>Shear Thinning</td>
</tr>
<tr>
<td>Viscosity w/Heat</td>
<td>Heat Thinning</td>
<td>Heat Thinning</td>
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<tr>
<td>Synergy</td>
<td>Xanthan</td>
<td>Guar, MC</td>
</tr>
<tr>
<td>pH Stability</td>
<td>5 – 7, loss below 3.5</td>
<td>Loss below 3.2</td>
</tr>
<tr>
<td>Moisture Holding</td>
<td>Good</td>
<td>Good</td>
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<tr>
<td>Freeze Thaw Stability</td>
<td>√</td>
<td>√</td>
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<tr>
<td>Ionic</td>
<td>Non Ionic</td>
<td>Ionic</td>
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<tr>
<td>Milk Interaction</td>
<td>Not Known</td>
<td>Protective</td>
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# CMC - Incorporation Methods

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Physical Form</th>
<th>Recommended Preparation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Granular Type (GA)</td>
<td>Powder Type (PA)</td>
</tr>
<tr>
<td>Separate Solution</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Dry Blend Mixture</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Dispersion in organic solvents or oil</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

- **Granular Type (GA)**: +
- **Powder Type (PA)**: –
- **Fine Powder Type (PPA)**: –

**High speed mixer should be used and CMC grades should be added slowly to aqueous solution. The dissolution time is about 30 – 60 minutes.**

**Premix CMC grades with other powder ingredients of the formulation to avoid agglomeration or lumps.**

**CMC grades are dispersed in organic solvents/oil. The CMC dispersion is then added to water while stirring.**

3/12/2012
Thanks for your kind attention!

QUESTIONS??

www.dow.com/dowwolff/en/