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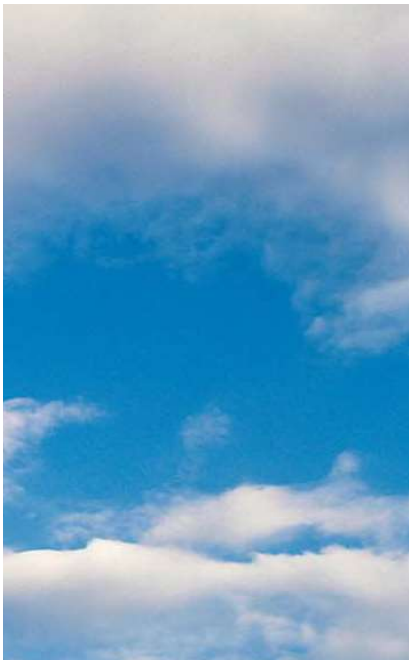


SPX®
WHERE IDEAS MEET INDUSTRY

APV LeanCreme™

MICROPARTICULATION OF WHEY PROTEIN

WITH SPX FLOW TECHNOLOGY





White Paper



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Executive Summary

Whey proteins, once described as a by-product of cheesemaking, are now becoming increasingly popular in their ability to improve health whilst also being highly functional ingredients in dairy and food formulations.

The rising demand from consumers for low fat, creamy taste and high quality foods calls for innovative and cost-effective processing solutions such as APV LeanCreme™. Based on the APV Microparticulation plant, the process uses whey protein concentrate to make a creamy liquid that can be talored to a long line of different products. The APV LeanCreme™ plant is based on the APV Shear Agglomerator (ASA). This groundbreaking technology combined simultaneous heat denaturation of the protein and the formation of protein microparticles under controlled high shear, adding a new, documented functional dimension to whey protein concentrate.

APV LeanCreme™ is white and creamy, rather like coffee cream but without the whey taste. This makes it the ideal starting ingredient for a wide array of innovative and proprietary low fat recipes such as low fat cheeses, fermented milk products, desserts, yoghurt drinks, chocolate drinks, protein boosted drinks, ice creams, spreads etc.

SPX Flow Technology is ready to contribute with its expertise to support your product development projects. You can also take advantage of a short-term project agreement with our Innovation Centre in Silkeborg, Denmark, or rent an APV LeanCreme™ pilot unit to test in your facilities, in order to ensure successful piloting of the APV LeanCreme™ process.

We hope that you will find this white paper inspiring and informative.



Introduction to SPX Flow Technology

VISION AND COMMITMENT

SPX's Flow Technology segment designs, manufactures and markets process engineering and automation solutions to the dairy, food, beverage, marine, pharmaceutical and personal care industries through its global operations.

We are committed to helping our customers all over the world to improve the performance and profitability of their manufacturing plant and processes. We achieve this by offering a complete range of products and solutions from engineered components to complete process engineering and design of complete process plants supported by world-leading applications and development expertise.

We continue to help our customers optimise the performance and profitability of their plant throughout its service life with support services tailored to their individual needs via a finely meshed customer service and spare parts network.

CUSTOMER FOCUS

Founded in 1910, APV, An SPX brand, has pioneered groundbreaking technologies over more than a century, setting the standards of the modern processing industry.

Continuous research and development based on customer needs and an ability to visualise future process requirements drives continued mutual growth.



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Introduction to APV LeanCreme™

The rising demand from consumers for low fat products has given rise to a broad range of natural and synthetic fat replacers. The natural replacers are often produced from protein or protein-polysaccharide complexes[1]. LeanCreme has a proven quality-enhancing ability, especially in the case of low-fat products. LeanCreme is a pure, dairy-based ingredient based on whey protein concentrate, and thus highly acceptable to consumers.

LeanCreme is manufactured using an innovative microparticulation process, in which whey protein concentrate is heated under controlled high-shear conditions, enabling the formation of fine particles with a specific particle size similar to fat globules. The properties of the aggregate are a result of a dynamic balance between shear-controlled aggregate growth and shear-controlled aggregate break up[2].

Whey protein is known to have a high nutritional value with a level of essential amino acids higher than that of most proteins[3], and microparticulation of whey proteins does not result in changes of nutritional value of protein[4].

Microparticulated whey proteins can be produced by different technologies including high-pressure homogenisation of a pre-heated whey protein concentrate and extrusion cooking[5]. The technology applied has great influence on the final product and is basically a matter of the structure of the microparticulated whey proteins formed[6]. The most common process is a scraped surface heat exchanger (SSHE), a proven solution with a successful track record in applications such as soft cheese, semi hard cheese and ice cream[7]. Together with high nutritional value and the characteristic properties such as creaminess, high water binding capacity and foaming stability the application possibilities seem boundless.

1 (Chefel and Dumay, 1993)
2 Steventon et al. (1994)
3 (Schaafsma, 2006)
4 (Erdman, 1990)
5 (Parquin et al., 1993 and Queguiner et al., 1992)
6 (Kulozik et al., 2001)
7 (Spiegel & Kessler, 1998, Koxholt et al., 1999, Steffl et al., 1997, and Schreiber et al., 1998)

HISTORY

Whey proteins, once described as a by-product of cheesemaking, are now becoming increasingly popular in their ability to improve health whilst also being highly functional ingredients in dairy and food formulations.

Traditionally microparticulation of whey protein was performed in two steps employing heat denaturation followed by mechanical creation of microparticles. However, extensive and documented research at Technical University Munich (TUM) in Weihenstephan demonstrated that the most efficient way of making high-quality, microparticulated whey protein was to combine heat denaturation and mechanical shear in one step.

In 2003 APV, An SPX brand, started developing the LeanCreme process based on the conclusions made by the research team from TUM and the process expertise of the APV R&D team. The APV LeanCreme™ process means that SPX Flow Technology can provide a single-step technology that enables the production of high-quality microparticulated whey protein (MPWP) by combining heat denaturation of the protein and the formation of microparticles under controlled shear. It is this synergy between heat and shear that enhances and extends the functional properties of the whey proteins.

INTRODUCTION TO MICROPARTICULATION OF WHEY PROTEIN

The APV LeanCreme™ process is used to produce a highly functional type of microparticulated whey protein. LeanCreme is a creamy, whitish liquid with a viscosity like coffee cream and a mouth feel similar to fat. This mouth feel is retained in the products to which LeanCreme is added, including cheeses, ice cream, fermented dairy products and milk-based drinks.

DEFINITION OF MICROPARTICULATION

" ... if the protein concentrate is heat-treated under shear influence, the shear forces will prevent the formation of a connected gel network so that individual protein aggregates are produced. This process is known as microparticulation" (Spiegel, 1999)

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PROTEIN	% OF TOTAL WHEY PROTEIN
B-LACTOGKOBULIN	48-58
A-LACTALBUMIN	13-25
GLYCOMACROPEPTIDES (GMP)	12-20
IMMUNOGLOBULINS	08-12
BOVINE SERUM ALBUMIN	6
LACTOFERRIN	2
LACTOPEROXIDASE	0.05

Table 1: Typical composition of sweet whey proteins (Belitz and Grosch 1999)

Description of APV LeanCreme™

True microparticulated whey protein particles are very small (typically between 1 – 10 µm), smooth and round. They have the same effect on the tongue as an oil-in-water emulsion. In addition to the particle size, the nature of the protein is also important for the desired mouthfeel when added to products such as cheese, ice cream, yoghurt etc.[1]. This has been confirmed during development and testing of LeanCreme.

CHEMISTRY, PHYSICS

The raw material for LeanCreme is whey concentrate (WPC) from cheese production or from microfiltrated milk (ideal whey). The WPC components influence the properties of LeanCreme.

Whey proteins are a group of functional and nutritional important dairy proteins. Most prominent are the globular β-lactoglobulin and α-lactalbumin representing 60-80% of total whey protein from sweet whey. Table 1 shows the typical composition of whey proteins from sweet whey.

β-lactoglobulin is also the most important protein influencing the properties of the protein aggregates. It determines the overall denaturation kinetics[2]. Denaturation during heat treatment means that the structure of whey proteins with the exception of GMP can change. This explains the changed properties of of microparticulated WPC.

Denaturation is a molecular process illustrated by the simplified reaction scheme in Fig. 1.

In step 1 the native whey proteins are unfolded as a result of the heat treatment. Upon unfolding the thiol groups (-SH) of the whey proteins are exposed and become reactive. In step 2 the thiol groups create thiol bindings (S-S). Thiol bindings are very strong resulting in irreversible reaction, thus creating whey protein aggregates.

Application of mechanical shear forces is necessary to stop the growth of whey protein aggregates. Tight control of the heating and shear force is necessary in order to ensure production of denatured whey protein particles with the desired smooth mouthfeel instead of a sandy or gritty mouthfeel.[3]

LeanCreme microparticles have a loose, porous aggregate structure. This structure provides the flexibility that allows the aggregates to interact with other food components.[4]

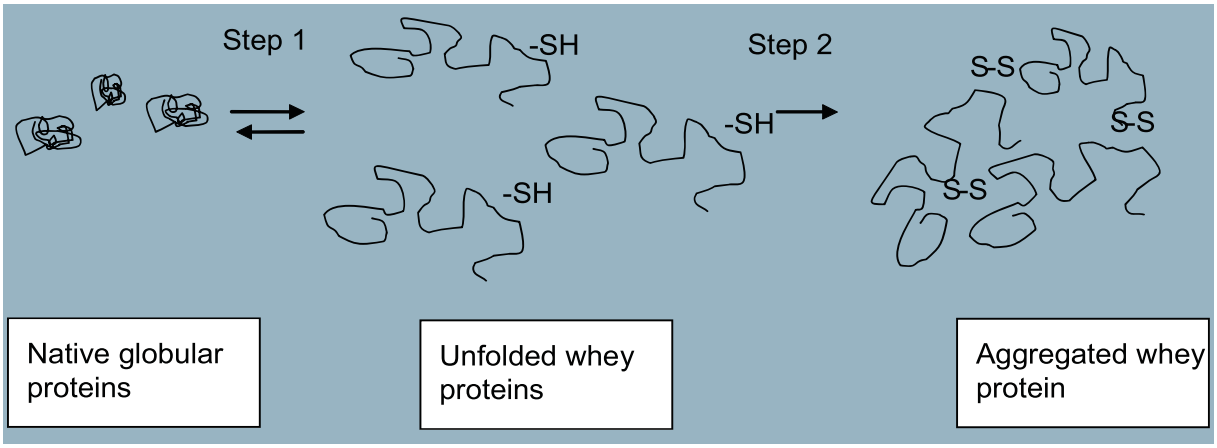


Fig. 1: Schematic drawing of aggregation of whey proteins

1 Tamine, 2009

2 Spiegel, 1999
3 Tamime, 2009
4 Spiegel, 1999

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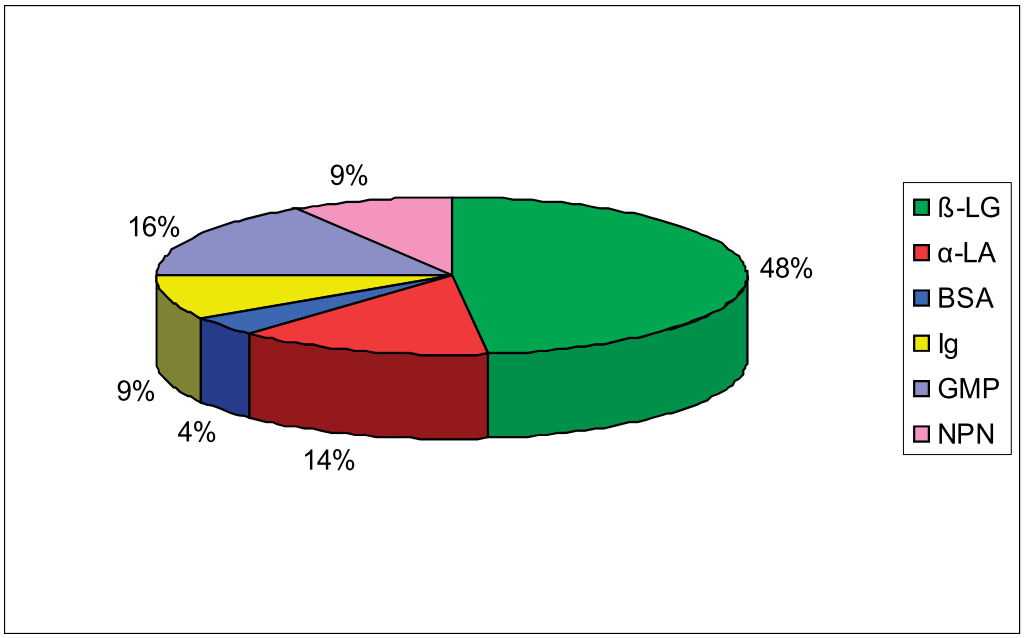


Fig. 2: Typical composition of whey proteins in sweet whey

The scientific explanation is that not every collision of protein molecules result in irreversible aggregation and thus loose and flexible aggregates are formed. The APV LeanCreme™ plant is specially designed to ensure this flexibility. The aggregate structure becomes increasingly compact if temperature and shear is not controlled accurately[1].

1 (Spiegel, 1999)

In general whey proteins denature between 60°C and 85°C (140–185°F) at natural pH. Denaturation can be initiated even faster using various combinations of protein concentration, pH and mineral composition.

GMP is a peptide (a small protein) that is formed during cheese manufacturing and remains in the whey. GMP cannot be unfolded and denaturated.

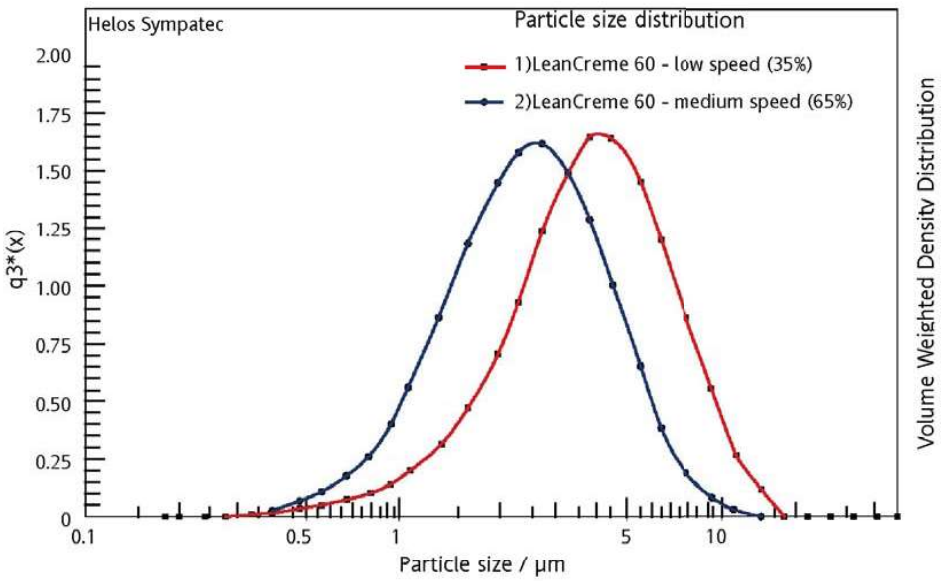


Fig. 3: Particle size distribution of APV LeanCreme™ based on WPC60 with 35% and 65% of max speed respectively

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Because GMP and NPN (non protein nitrogen) cannot be denatured and α-lactalbumin can only partly be denatured, the whey protein composition has an influence on the proportion of proteins that can be microparticulated. In the case showed in Fig. 2 up to 75% of the protein can be microparticulated.

Factors affecting the APV LeanCreme™

By changing the process parameters of the APV LeanCreme™ plant and feed composition it is possible to tailor the required functional properties of the microparticulated whey proteins. Key functional properties are the degree of denaturation, particle size, serum binding capacity (degree of hydration), and sensorical sensation e.g. creaminess and mouth feel[1].

TEMPERATURE

Temperature is an important factor affecting the properties of the LeanCreme particles. A too low temperature slows down unfolding of the proteins, giving the particles time to create a loose, porous aggregates structure. On the other hand a too high temperature, for example around 100°C (212°F), results in a very dense and compact aggregate structure. The smallest particles are, typically produced around 85°C (185°F), depending on other factors[2].

SHEAR

If shear is not applied during the thermal denaturation, a compact gel structure will be formed[3]. The impact of shear is that the shear forces will prevent the formation of a connected gel network so that individual protein aggregates are produced[4]. The property of the microparticles is the result of growth and breakdown of the aggregates and is a balance between these two processes[5]. Thus stringent shear control is essential.

Fig. 3 shows how easily the particle size distribution can be controlled by changing the speed of the dashers in the SSHE in the APV LeanCreme™ plant. In this example the mean particle size was changed from approximately 2.5 µm to 4 µm.

PROTEIN AND LACTOSE

Protein content is important. As an example WPC30 requires higher heat treatment than WPC80 in order to achieve the same degree of denaturation. Aggregation structure and properties can differ, however, even with the same degree of denaturation. Ideal whey from microfiltrated skim milk does not contain GMP, thus enabling denaturation of a higher proportion of the proteins.

The ratio between lactose and protein is also important, since lactose protects the proteins from denaturation.

The influence the particle size as illustrated in Fig. 4[6]. Different heating times were necessary for achieve specific degrees of denaturation, indicated in the figure. In practise the normal lactose content in WPC lies between 2.5 and 5%.

1 Kulozik et al., 2001
2 Spiegel, 1999
3 Aguilera, 1995
4 Spiegel, 1999
5 Steventon et al., 1994
6 Spiegel, 1999

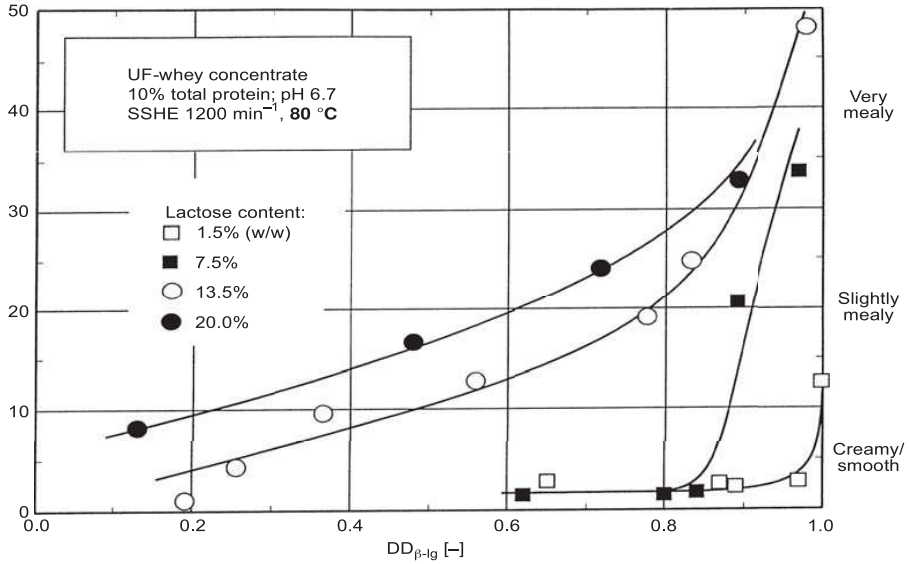


Fig. 4: Effect of the degree of denaturation of β-lg on the aggregate size (Spiegel, 1999)

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CALCIUM

Calcium ions bind strongly with α-lactalbumin and stabilise protein conformation[1] thus playing an important role in structural changes. When the calcium content is low, fouling occurs easily and viscosity and pressure rise. The resulting LeanCreme product tends to become brown or greyish rather than whitish and does not have a smooth mouthfeel. High calcium content, however, reduces fouling, as well as the viscosity and pressure, and the whitish colour will now appear. The calcium phenomena are not fully understood, but WPC obtained from sweet cheese whey usually has a normal calcium content. WPC from rennet casein whey have been tested, but appeared to be highly fouling, possibly due to low calcium content. When calcium was added the fouling disappeared. In general following where noticed when adding calcium to a WPC product of poor quality:

- Viscosity decreases
- The particles get smaller
- Tendencies of easy fouling

RAW MATERIAL

Whey generated from cheese production normally falls into two major groups: sweet whey, with a pH of at least 5.6 and acid whey with a pH of maximum 5.1. Table 2 provides an overview of the typical composition of a range of WPC grades, while Fig. 5 is a graphical representation of the same figures.

.A so called standard LeanCreme is based on WPC60 from sweet whey with a pH between 6.3 and 6.6.

1 Walstra et al., 2006

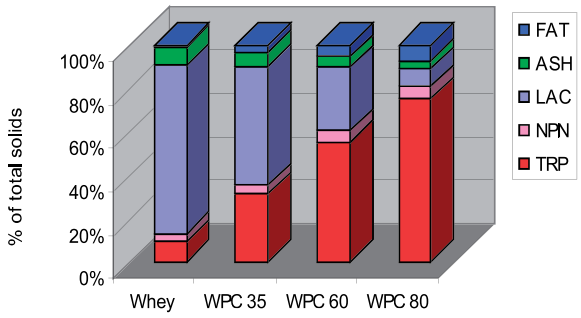


Fig. 5: Typical composition of various WPC grades

Other options exist in addition to traditional WPC based on sweet whey, and acid whey:

- LeanCreme can be based on reconstituted WPC powders. However, good results are obtained only from high-quality powders with low denaturation, high solubility and excellent hydration.
- WPC can be evaporated prior to the APV LeanCreme™ process
- WPC can be mixed with cream prior to the APV LeanCreme™ process
- Sweet WPC can be fermented prior to the APV LeanCreme™ process

pH has a influence on the final properties of the LeanCreme™. It should therefore be identical in each production run.

	WHEY	WPC28	WPC35	WPC50	WPC60	WPC70	WPC80
VOLUME	10,000	2,700	1,850	900	600	340	240
TOTAL PROTEIN %	0.75	2.3	3.3	6.7	10.1	17.2	23.6
TRUE PROTEIN %	0.55	2.0	2.9	6.1	9.2	15.8	22.0
NPN % *)	0.2	0.3	0.4	0.6	0.9	1.4	1.6
NPN/TOTAL PROTEIN %	27	13	12	9	9	8	7
LACTOSE %	4.5	5.0	5.1	5.1	4.9	4.3	2.4
ASH %	0.5	0.6	0.6	0.7	0.8	1.0	1.1
FAT %	0.05	0.2	0.3	0.6	0.9	1.5	2.1
DRY MATTER %	5.9	8.0	9.2	13.1	16.6	24.0	29.1

*) NPN: Non-protein-N (x 6.38), true protein equal to total protein - NPN

Table 2: WPC compositions based on cheese whey having been ultrafiltered

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Properties of APV LeanCreme™

The properties of APV LeanCreme™ can be measured. One key analysis is particle size. It should be noted that there is no particular correlation with serum binding capacity due to the structure of the particles discussed above.

PARTICLE SIZE DISTRIBUTION

Optimal particle size depends on the application and can be varied. The mean particle size must be minimum 0.5-1 micron and maximum 7-10 micron. A narrow distribution and elimination of particles above 10 micron may be more important, however. Particle sizes between 10 and 15 microns can lead to a more gritty and mealy mouthfeel. This is not desirable as it leads to inferior texture than can be experienced in the final product.

When analysing for particle size distribution the samples are diluted, and the instrument detects only the particles and their actual distribution. This analysis does not show the percentage of particles in the sample, i.e. it does not show how many microparticles are formed from the initial whey proteins. The analysis only shows the distribution. Thus a perfect distribution graph does not show the content of these microparticles. There may be 1% microparticles (low or no denaturation) or 70% microparticles (high denaturation). In raw whey/WPC samples with no prior heat treatment, any microparticles detected will typically be whey fat particles or aggregated proteins (cheese fines from casein fractions).

SPX Flow Technology has experienced reliable results using light scattering methods such as Helos Sympatic, Malvern Mastersizer Microplus and Malvern Mastersizer 2000. Use of the same equipment for each analysis is recommended. Results from different equipment will vary basically due to different mathematical calculations and theories. Three different results - Fig. 6, Fig.7 and Fig.8 - based on measurements of the same LeanCreme sample and illustrating why measurement based on the “Fraunhofer” theory is recommended.

Fig. 6 shows an example of a LeanCreme sample measured on Helos Sympatic equipment using the so called “Fraunhofer” theory. For most applications the key is to have a bell-shaped curve, preferably with a narrow particle size distribution. Both instruments calculate various types of mean particle sizes. A key number is the x50 value, in this case is x50 = 3.51 µm. This is an expression of 50% quantile and thereby a one type of mean particle size. Another example of mean particle size is the D4,3 value, which in this case is 3.98 µm. The D4,3 value is an expression of the volume-based mean particle size.

Analysis using the same "Fraunhofer theory" produces almost identical results. Analysis using a Malvern Mastersizer results in a slight change in the bell-shape and slightly different key values e.g. the D4,3 = 4.49 µm.

When analysing on the same Malvern Mastersizer equipment but based on the MIE theory, the particle size distribution changes shape totally. The MIE theory requires estimation of two values: the so called “refractive index” and the “absorption index”. These are not commonly known for LeanCreme particles and this is the main reason why the MIE theory is not recommended for measurement of LeanCreme particle size.

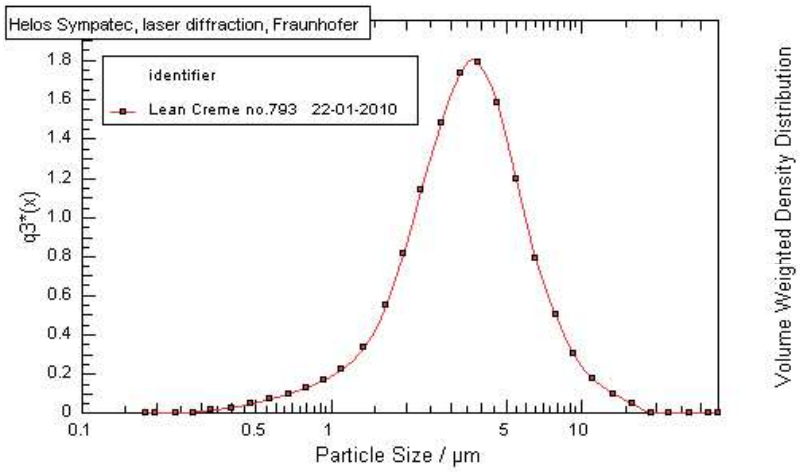


Fig. 6: APV LeanCreme™ sample analysed on Helos Sympatic with Fraunhofer theory

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Particle Name: Fraunhofer	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose (spherical)	**Sensitivity:** Normal
Particle RI: 0.000	**Absorption:** 0	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 5.81 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 0.579 %	**Result Emulation:** Off
Concentration: 0.0023 %Vol	**Span :** 1.604	**Uniformity:** 0.625	**Result units:** Volume
Specific Surface Area: 2.22 m²/g	**Surface Weighted Mean D[3,2]:** 2.700 um	**Vol. Weighted Mean D[4,3]:** 4.492 um	

d(0.1): 1.652 um **d(0.5):** 3.509 um **d(0.9):** 7.280 um

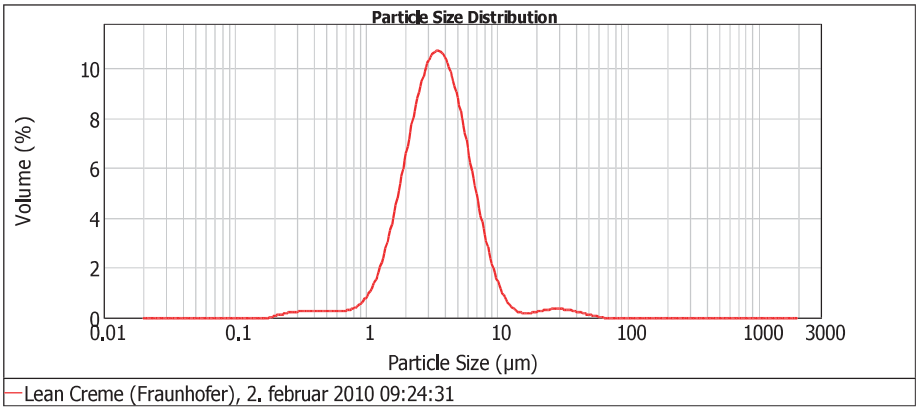


Fig. 7: APV LeanCreme™ sample analysed with Malvern Mastersizer with Fraunhofer theory.

Particle Name: Milk Fat (Cow's Milk)	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose (spherical)	**Sensitivity:** Normal
Particle RI: 1.460	**Absorption:** 0.001	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 5.81 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 0.867 %	**Result Emulation:** Off
Concentration: 0.0031 %Vol	**Span :** 2.051	**Uniformity:** 0.758	**Result units:** Volume
Specific Surface Area: 5.46 m²/g	**Surface Weighted Mean D[3,2]:** 1.098 um	**Vol. Weighted Mean D[4,3]:** 4.855 um	

d(0.1): 0.295 um **d(0.5):** 3.926 um **d(0.9):** 8.347 um

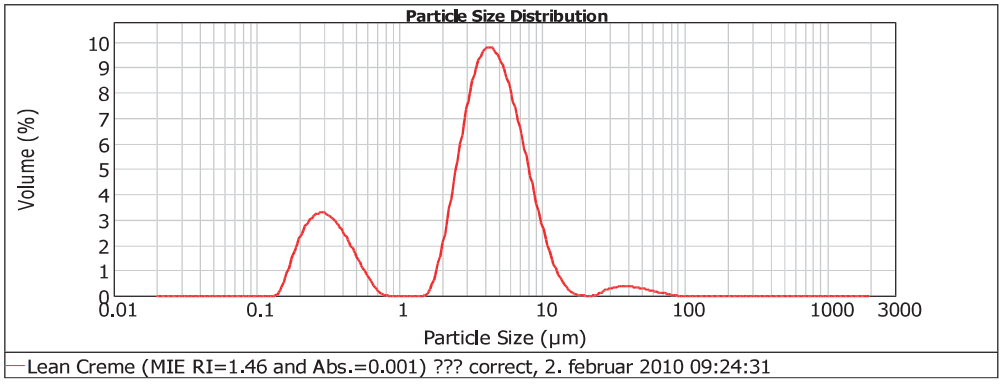


Fig. 8: APV LeanCreme™ sample analysed with Malvern Mastersizer with MIE theory

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DENATURATION DEGREE

As described earlier not all whey proteins can be denatured. GMP, for example, cannot be denatured and typically only 40–60% of α-lactalbumin can be denatured.

Denaturation degree is a key analysis in relation to microparticulated whey protein and can be measured with RP-HPLC which is an advanced and expensive laboratory analysis. However, in practice it is difficult to obtain reliable results, especially for purposes within the normal requirements of LeanCreme. Thus analysis of the functionality of LeanCreme and/or end product should also take account of the fact that denaturation degree is not the only important parameter.

VISCOSITY

In general, the viscosity increases by increasing particle size and protein content.

The viscosity defines the consistency of the products and is an important characteristic in relation to functionality. The creaminess/viscosity created during the APV LeanCreme™ process is preserved in the final product, e.g. cheese, ice cream, drinks etc. and is a key advantage of LeanCreme. An example of viscosity behaviour can be seen in Fig. 9 where the viscosity is increased approximately 10 times. Viscosity is typically increased 4–10 times after LeanCreme treatment. This is strong proof of the functionality of the LeanCreme.

FOAMING PROPERTIES

Due to the unique particle structure created during the APV LeanCreme™ process, excellent foam properties are obtained with boundless opportunities for use in end products, e.g. ice cream and desserts. The photographs below show a typical example of the difference between WPC55 and LeanCreme based on the same WPC55. The total foam volume created with the WPC55 and the LeanCreme based on the same WPC55 is very similar. However, stability increases significantly when WPC is treated using the APV LeanCreme™ process. Stability can even be increased by increasing the solid content. This sample contained only 8% protein and 13% solids.

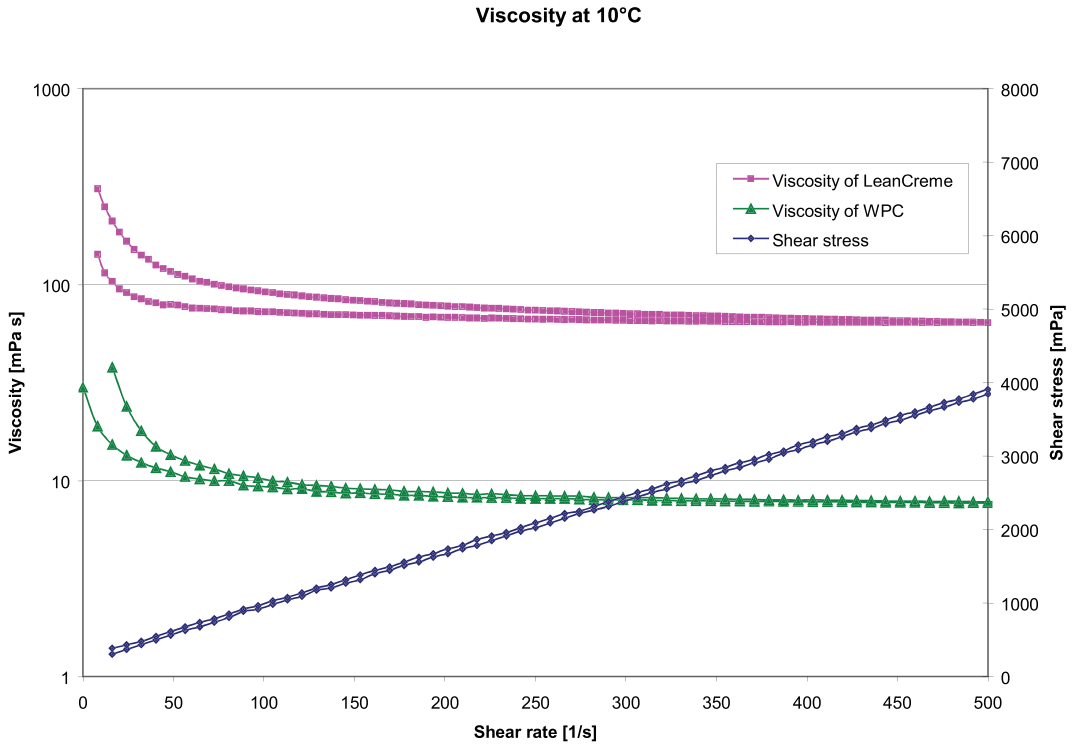


Fig. 9: Viscosity of a WPC65 before and after treatment in an APV LeanCreme™ plant

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SERUM BINDING CAPACITY/DEGREE OF HYDRATION

Serum binding capacity is an expression of the internal structure of the particles created during the microparticulation process. It can be measured by centrifugation e.g. using the method described in Spiegel 1999:

The aggregates are separated by centrifuging[1]. The protein content in the sediment (called Cprotein i.s.) was ascertained enabling the serum binding to be determined as g serum bound per gram protein.

1 20 min, Z = 5000; Omnifuge 2.0 RS, Heraus Sepatec, Osterode











Serum binding capacity:

$$\delta_{serum} = \frac{[g]serum}{[g]protein} = \frac{1 - C_{protein\ i.s.}}{C_{protein\ i.s.}}$$

Fig. 10: Foaming properties

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Decription of APV LeanCreme™ technology

As demonstrated, the ability to control the particle size distribution and structure of the particles is essential. The APV LeanCreme™ plant is designed specifically to control the shear and temperature independently in order to obtain controlled results. LeanCreme plants are very well known to have high reproducibility during a run and between production runs. The design is very robust and is the most proven system in the market.

The APV LeanCreme™ process

APV LeanCreme™ has a high functionality during production in terms of high viscosity, especially when using WPC80, but also when using other WPC grades. This, however, presents no problems for the APV LeanCreme™ plant, which has proved to be able to handle production of LeanCreme with up to 20% protein based on WPC80. This is unique.

The APV LeanCreme™ process is shown in Fig.11.

STEP	DESCRIPTION OF THE APV LEANCREME™ PROCESS
1	WHEY FROM CHEESE IS PRE-TREATED BY REMOVAL OF FINES AND FAT, PASTEURISED AT 72°C/15 SEC. (161.6°F/15 SEC.) AND COOLED TO 8–10°C (46.4–50°F)
2	THE CHEESE WHEY IS CONCENTRATED IN A MEMBRANE ULTRAFILTRATION PLANT TO PRODUCE WPC60, FOR EXAMPLE
3	THE WPC IS PRE-HEATED IN A PLATE HEAT EXCHANGER (PHE)
4	STEPWISE HEATING IN A SPECIALLY DESIGNED SCRAPE SURFACE HEAT EXCHANGER (SSHE) WITH A CONTROLLED SHEAR RATE
5	COOLING IN AN SSHE
6	FINAL COOLING IN A PHE

Table 4: The APV LeanCreme process

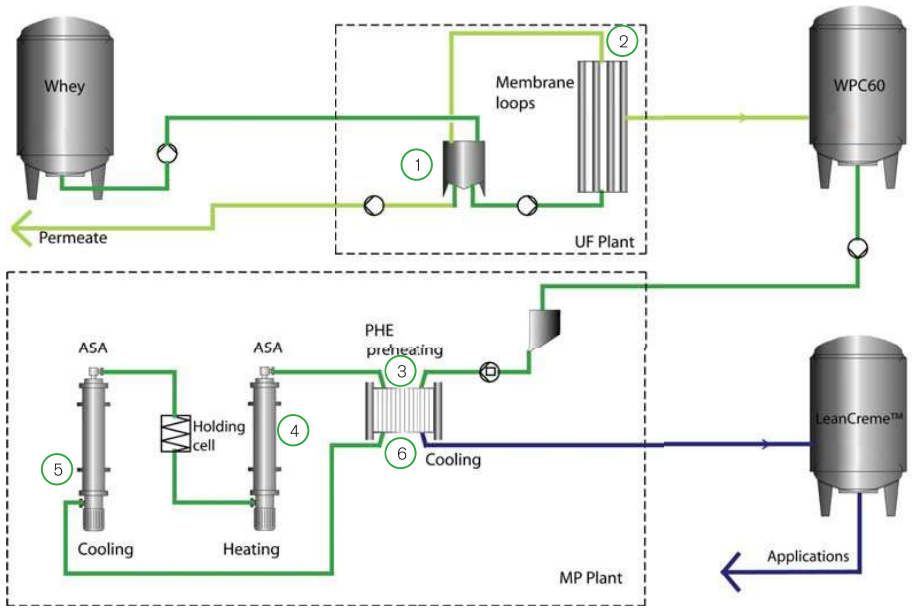


Fig. 11: The APV LeanCreme™ process

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APV Shear Agglomerator (ASA)

The ASA (APV Shear Agglomerator) is the name of the specially designed SSHE. It is designed specifically to create microparticulated whey proteins with unmatched functionality that can only be achieved using the one-step solution[1].

So what is unique about the ASA? It:

- creates very precise and narrow distribution of the particle size
- creates microparticulated whey proteins with constant high quality
- has low degree of fouling, ensuring long production time depending on raw material
- features low wearing of the knives
- has low power consumption
- is easy to service
- has a long service life
- has a low noise level
- employs a significantly improved hygienic design with lower dead volume compared to traditional SSHEs
- is easy to clean and it complies with EU Machinery Directives



1 Spiegel and Huss, 2002

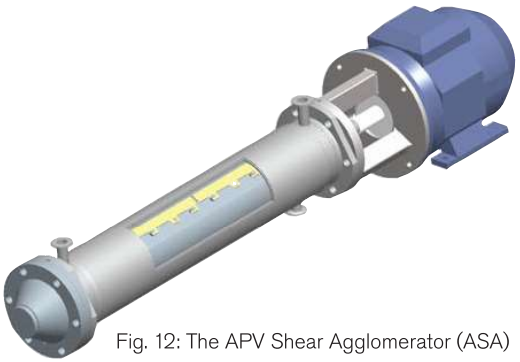


Fig. 12: The APV Shear Agglomerator (ASA)

Operation of the APV LeanCreme™ plant

Achieving the optimal operation and trial conditions requires an understanding of what the APV LeanCreme™ plant actually does.

The main factors influencing the nature of the LeanCreme product have already been discussed. Below is a handy simplified overview:

The three most important conditions influencing the character of the LeanCreme products are:

- Composition and pH of the feed
- Heat treatment (temperatures and holding time)
- Dasher speed

Optimal composition and pH of the WPC depends on the application. Details are available in the chapter "Getting the most out of whey with the APV LeanCreme™ process".

Table 5 provides an overview of the general influence of planned adjustments on the characteristic of the LeanCreme product. Dasher speed is the most efficient way to control particle size and is easy to operate.

ADJUSTMENT OF PARAMETER	VISCOSITY	PARTICLE SIZE DISTRIBUTION	MEAN PARTICLE SIZE
INCREASE PROTEIN LEVEL	INCREASES	-	INCREASES
DECREASE PROTEIN LEVEL	DECREASES	-	DECREASES
INCREASE HEAT TREATMENT	INCREASES	NARROWER	INCREASES
DECREASE HEAT TREATMENT	DECREASES	WIDER	DECREASES
INCREASE DASHER SPEED	DECREASES	NARROWER	DECREASES
DECREASE DASHER SPEED	INCREASES	WIDER	INCREASES

Table 5: An overview of the influence on the APV LeanCreme™ when adjusting protein level, heat treatment and dasher speed

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Fig. 13 shows the effect of particle size adjustment. In both examples the red curve indicates low speed and the blue curve indicates increased speed, resulting in lower particle sizes (left) and narrower particle size distribution (right).

PRACTICAL GUIDELINES

As a consequence of influence of raw material, the WPC, trials should always be conducted prior to production in order to ensure high quality.

As a starting point it is a good idea to focus adjustments on the temperature of SSHE second sections, holding time and dasher speed.

Measurement of particle size distribution should be accompanied by tasting the LeanCreme product. Other measurements are also recommended, depending on the end product. If no rapid measurements are available, the best way of identifying optimal process settings is by tasting and looking at the colour of the LeanCreme product. The observed colour is a consequence of particle size in the same way as skim milk and cream look different due to scattering of light mainly from the fat particles. In most applications LeanCreme should be white and tasting should not give rise to observation of particles. A product with particle sizes between 1 and 10 µm normally requires a high denaturation degree.

If the temperature of the SSHE second section is too high, the product becomes mealy and lumpy due to the presence of particles that are too large.

On the other hand, if the denaturation degree is low, the product will be grey. This results in residual native whey proteins that may be desirable in some applications such as yoghurt drinks, and provides further opportunities for creating interactions in the final product between whey proteins and caseins, or other components. If a LeanCreme product with a high denaturation degree is required, e.g. for cheese applications, the temperature in the SSHE second section should be increased step by step starting, say, at 80°C (176°F), until the colour of the product is as white as possible.

The biggest LeanCreme particles will obviously precipitate eventually during storage. The stable particles mean, however, that large particles can easily be re-stirred. This is important before analysing and before further processing.

PILOT TEST DATA AND DAILY RECORD FORM

Fig. 14 is an example of a form that can be used during trials. It is also possible to log all data in every detail from the plant directly to an Excel spreadsheet ready for further calculations.

STANDARD APV LEANCREME™ CLEANING PROCEDURE

The CIP procedure comprices one caustic and one acid cleaning step.

The cleaning detergents are automatically dosed directly into the feed balance tank on the APV LeanCreme™ plant. The cleaning solutions are recirculated internally in the plant and drained afterwards.

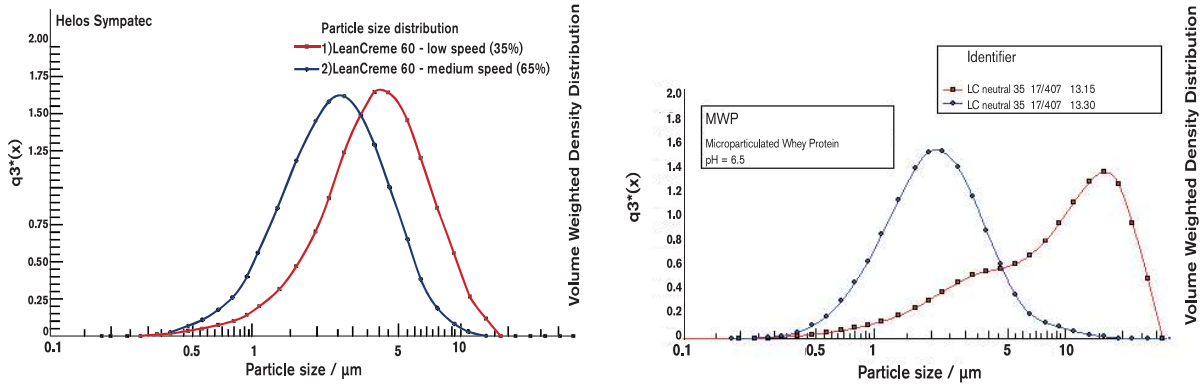


Fig.13: Control of particle size (left) and particle size distribution (right) by changing dasher speed

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Daily Record LeanCreme - Plant

Feed product:			Date:	Remarks:
Operator 1:	from	to	Start time:	
Operator 2:	from	to	Stop time:	
Operator 3:	from	to	Prod. time:	
Operator 4:	from	to	Prod. Quant.:	

Production data:

Time	Feed					PHE Preheating			ASA 02-05				ASA 10-13				ASA 18-19		Holding	PHE cooling	
	pH	°Bx TS	Press. bar	°C	Flow l/h	Ltr. Total	°C prod	°C water	Delta-T	°C Prod.	°C Water	Delta-T	Speed ASA	°C Prod.	°C Water	Delta-T	Speed ASA	°C Prod.	Speed ASA	cell Sec.	°C Prod

Pretreatment:

Prod. type:

Pasteurization: °C Sec.

Other

Pretreatment remarks:

Aftertreatment remarks:

Cleaning data:	Type	Amount		pH	°C	Analyses of LeanCream			
Agent 1						Time of sample			
Agent 2						protein			
Agent 3						TS			
Agent 4						PS			
Agent 5						PSD			

Fig. 14: Daily record form

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Recommended cleaning procedure for APV microparticulation plant

APV LEANCREME™ PROCESS OF WPC USING APV SHEAR AGGLOMERATORS

	OPERATION	CONC.	AGENT	PH	TEMP.	DURATION
1	PRE-RINSE		WATER/RO PERMEATE		COLD	
2	CAUSTIC	2.5%	NAOH (26-30%)	14	85°C	45 MINUTES
3	RINSE		WATER/RO PERMEATE		COLD	
4	ACID	0.8-1%	HNO3 (62%)	0-1	65-70 °C	15 MINUTES
5	FINAL RINSE		WATER			
FEED PRODUCT			WPC			
DASHER SPEED IN CIP:						
		- VT460		400 RPM		
		-HT640		600 RPM		
		-HT680		600 RPM		

All concentrations are weight percentages, calculated as 100% active substance ($NaOH/HNO_3$)

Never leave the chemicals inside the plant. Always flush with water.

Control cleaning efficiency during routine inspection of the scraper blades is recommended. This could be limited to the dasher providing the most heating load (highest ΔT).

In APV LeanCreme™ pilot plants the dashers must not be opened without the presence of an APV representative.

The water quality complies with drinking water standards

Table 6: Consumption and figures for APV LeanCreme™ standard plants.

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Technical data and guiding consumption figures for APV LeanCreme™ plants

	UNITS	MP500	MP1000	MP1500	MP2000	MP2500	MP3000
CAPACITY OF WPC60	[L/H]	500	1,000	1,500	2,000	2,500	3,000
APPROXIMATE AMOUNT OF WHEY 1)	[L/H]	8,000	16,000	24,000	32,000	40,000	48,000
NUMBER OF ASA	N	3	5	7	9	11	14
INSTALLED MOTOR POWER	[KW]	14	21	32	40	49	63
APPROXIMATE POWER CONSUMPTION	[KW]	9	12	17	22	27	38
STEAM CONSUMPTION DURING PRODUCTION	[KG/H]	32	55	86	125	157	165
ICE WATER HEAT TRANSFER	[KW]	16	35	52	69	85	108
ICE WATER FLOW RATE DURING PRODUCTION	[M3/H]	1.2	1.4	2.2	2.9	4.0	4.4
SEAL WATER CONSUMPTION OF ASA	[L/H]	180	300	420	540	660	840
CAUSTIC 2.5% CONSUMPTION	[L/CLEANING]	1.7	3.3	5	6.7	8.3	10
ACID 1.0% CONSUMPTION	[L/CLEANING]	0.7	1.3	2.0	2.7	3.3	4.0

1) WHEY WITH AN AVERAGE COMPOSITION OF 0.8% PROTEIN, 4.5% LACTOSE, 0.06% FAT, 6.0% TOTAL SOLIDS. FOR OTHER COMPOSITIONS PLEASE CONTACT US. THE CONSUMPTION FIGURES ARE NON-BINDING GUIDELINES ONLY AND ARE SUBJECT TO MODIFICATIONS.

Table 7: Consumption and figures for APV LeanCreme™ standard plants

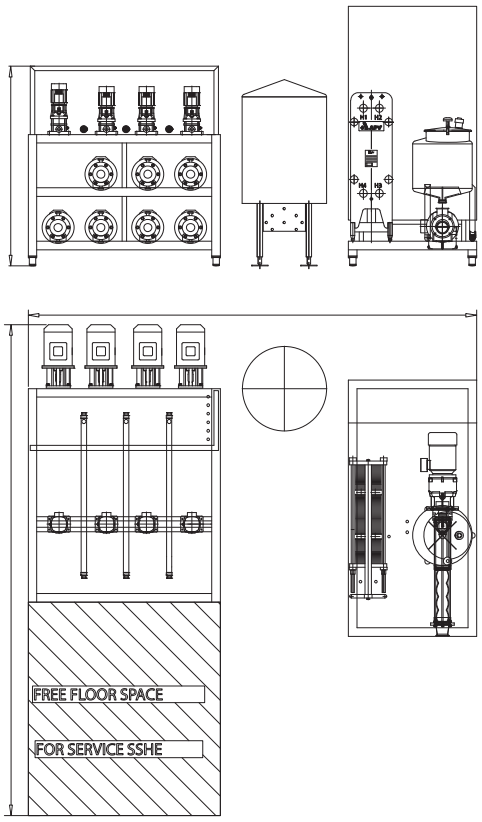


Fig.15: Dimentional sketch of APV LeanCreme™ plant with capacity of 1,500 l/h

The technical specifications in Table 7 are based on processing WPC60 from sweet whey with 17% total solids.

In Fig. 15 shows a dimensional sketch of a MP1500 plant with a capacity of 1,500 l/h. Two metres of floor space are required for service of the SSHE.

The APV LeanCreme™ system is skid-mounted and can be delivered in capacities between 500 and 3,000 l/h. Table 8 shows approximate dimensions for each capacity.

APPROXIMATE DIMENSIONS (METRES)			
CAPACITY (L/H)	A (HEIGHT)	B (WIDTH) 2)	C (LENGTH)
MP500	2.1 M	1.2 + 2.0 M	4.2 M
MP1000	2.3 M	2.6 + 2.0 M	4.4 M
MP1500	2.3 M	2.6 + 2.0 M	4.2 M
MP2000	2.3 M	2.6 + 2.0 M	4.4 M
MP2500	2.3 M	2.6 + 2.0 M	4.8 M
MP3000	2.3 M	2.6 + 2.0 M	6.2 M

2) 2.0 M IS FOR FREE FLOOR SPACE FOR SERVICE OF THE ASA AS ILLUSTRATED ON THE DRAWING

Table 8: Approximate sizes of standard APV LeanCreme™ plants

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Getting the most out of whey with APV LeanCreme™ process

LeanCreme can be added to applications as a liquid or as a powder-based ingredient. Liquid and powder-based LeanCreme products behave differently in the application process. The ability to control temperature and shear independently of one another means, however, that LeanCreme product particle distribution can be tailored to the specific application.

EXAMPLE OF MULTIPURPOSE OF APV LEANCREME™

While justifiably proud of the quality of their cheeses, dairies around the world are also concerned about the environmental impact of excess whey.

APV LeanCreme™ is based on whey protein concentrate (WPC). The whey is concentrated in an Ultrafiltration (UF) membrane plant and the retentate (the WPC) is processed in the microparticulation plant to produce the highly functional LeanCreme product for use in cheeses, yoghurt drinks, sport drinks etc. The APV LeanCreme™ process can also be combined with a Reverse Osmosis (RO) plant to treat the excess UF permeate (by product for UF filtration) to obtain water clean enough to use as flushing water during CIP and that can be safely disposed of down the drain. The RO process is running at reference plants with a return of investment of just two years and with several new products on the market as a result.

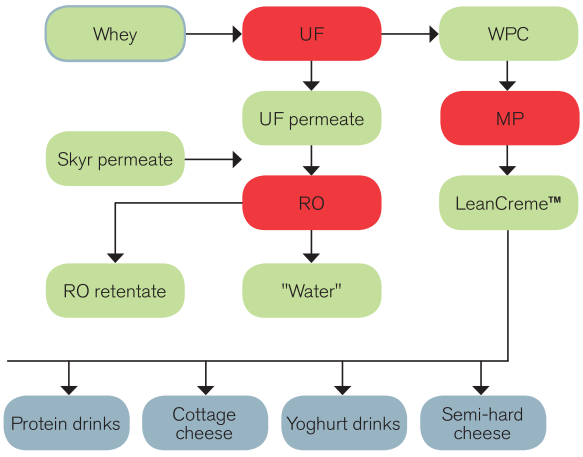


Fig. 16: Diagram of whey treatment plant

CHEESE

The most well known use of LeanCreme is in semi-hard, fresh and soft cheeses. The benefits are remarkable as both cheese quality and economic effectiveness can be enhanced simply by applying a 100% dairy ingredient. LeanCreme particles are perceived by the consumer as creaminess thanks to the particle size similar to fat globules and the particle structure. The creaminess has proved to be caused by increased serum content due to unique high serum binding capacity[1]. The consequences are that LeanCreme particles can simulate fat perception, which is clearly shown by the results in Fig. 17. The creaminess increases with higher fat level. This is no surprise. However, the effect of addition of LeanCreme particles is that the products are perceived to contain more fat at all fat levels. Adding LeanCreme to the cheese results in the following benefits:

- Improved texture for low fat cheeses
- Enhanced cheese sensory properties
- Meltability and flavour preserved
- Enhanced nutrient value
- Increased yield
- Up to 85% microparticulated whey proteins trapped in the curd

Optimal protein-% of LeanCreme to be used for cheese milk

- The optimal proportion of protein-% in the WPC is 9-12%
- The minimum proportion 8%.

The LeanCreme particles are incorporated into the matrix of the cheese. It is often said that the LeanCreme particles are trapped physically into the cheese matrix. Additionally it is most likely that weak bindings contribute to retaining the LeanCreme particles.

1 Kulozik et al., 2001

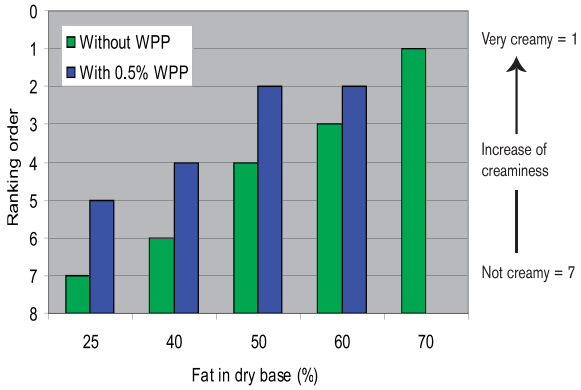


Fig. 17. Creaminess of a soft cheese (Camembert type) at different fat levels (Kulozik et al., 2001)

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LeanCreme particles are recognised as acting similarly to integrated milk fat globules due to the particle structure and particle size[1]. To obtain this effect it is essential to control the temperature and shear force specific to the applied feed type. This enables a very high quality with remarkable cheese texture to be obtained, especially in low fat cheeses.

If the microparticles do not have an optimal shape and surface the particles will be drained out with the whey and the fat simulation will not be obtained. The consequences are poor yield and cheese texture.

Yield may be calculated from:

$$\text{Yield} = \frac{m_{cheese}}{m_{milk}} \times 100$$

The incorporation of whey proteins can be calculated by entering the mass of whey proteins in both milk and cheese in the above equation. The improved yield is attributable to two conditions:

- Increased retention of cheese milk serum
- Incorporation of whey proteins

The first condition results from the high water binding capacity of LeanCreme particles. In fact the water binding capacity is so high that it has to be taken into consideration when producing cheeses to achieve the required final cheese texture.

As explained previously in Fig.2, not all of the protein in cheese whey can form LeanCreme particles. Normally around 75% of the proteins can form LeanCreme particles. This means that a maximum of 75% of the whey proteins can be typically recovered in the cheese when adding LeanCreme to the cheese milk.

Typically a yield increase of 6-7% can be obtained, depending on the WPC type and quality, the LeanCreme plant process settings, and finally the cheese process. Optimal particle size and particle size distribution are essential to enable trapping of the particles in the casein network like fat globules[2]. Undenatured whey proteins are roughly less than 1 nm and will be lost in the whey.

One concern of a cheese maker is the consequence for taste when adding LeanCreme, especially a bitter taste. It is well known that bitter taste is attributable to protein digestion of casein. Whey protein may inhibit the proteolyses and thus the breakdown of casein. However, it has not been proved that microparticulated whey protein inhibits the proteolyses. This may be due to the fact LeanCreme particles are very stable particles, partly due to a high degree of denaturation.

It is worth noting that SPX has no recorded cases of bitter taste caused by microparticulated whey protein produced using APV LeanCreme™ technology.

HOW TO PRODUCE TASTY LOW FAT EPC AND GOUDA TYPE CHEESES

It is well known that high-quality low-fat, semi-hard cheeses are challenging to produce. The texture can often be rubbery. LeanCreme particles have proved to be perfect as a means of overcoming this is a natural and simple way.

The LeanCreme ingredient based on WPC60 has showed to have the optimal composition for creating microparticles for semi-hard cheeses. Microparticulated WPC60 is added to the cheese milk before pasteurisation. Table 9 shows typical volume ranges of LeanCreme to achieve a tasty, semi-hard cheese. As can be seen, low-fat cheese can incorporate most LeanCreme particles.

The high water binding capacity of LeanCreme particles has to be compensated for during the cheese process to achieve texture properties in the final product similar to the reference. The most common adjustments in the cheese process (compared to high fat cheeses) are:

- Increasing the renneting temperature of the cheese milk by 1-2°C (2-4°F) after adding hot water. The purpose is to improve renneting properties[3].
- Prolonging total stirring/agitation by 2-5 minutes. The purpose is to compensate for high moisture in the curd.

FAT CONTENT (FAT IN DRY MATTER IN THE FINAL CHEESE)	TYPICAL ADDITION OF LEAN-CREME BASED ON WPC60 OF CHEESE MILK VOLUME
10+	5 - 8%
20+	4 - 5%
35+	2 - 4%
45+	1 - 3%

Table 9: Typical ranges of volume of LeanCreme of the cheese milk for EPC and Gouda type cheeses.

1 Steffl et el., 1997
2 Steffl, 1999
3 Hinrichs 2001

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EPC AND SOFT CHEESES		
FAT LEVEL IN THE FINAL CHEESE		
FAT/DRY MATTER	5-20%	20-50%
CHEESE MILK		
STANDARDISED CHEESE MILK	95%	98%
LEANCREME™ BASED ON WPC60 ADDITION	5%	2%
PROCESS DATA		
RENNETING	NORMAL	NORMAL
HIGHER TEMPERATURE - FINAL HEATING (°C)	+2°C (4°F)	+2°C (4°F)
LONGER FINAL STIRRING BEFORE WHEY DRAINAGE	5 MINUTES	5 MINUTES

Table 10: Recommend process for producing EPC and soft cheeses

Table 10 shows the recommended process for using LeanCreme in EPC and soft cheeses.

OTHER TYPES OF CHEESES

The same recommendation for additional volume and cheese process adjustment can typically be used for other types of cheeses such as cottage cheese, fresh cheese, quark, cream cheese, soft cheese, blue cheese, pizza cheese and cheddar cheeses. Improved yield and increased creaminess are the most common benefits. LeanCreme can also be used in cottage cheese to help avoid syneresis.

APV LeanCreme™ as a powdered ingredient

LeanCreme as a powdered ingredient constitutes the ideal starting ingredient for a wide range of markets and applications such as slimming milk products with delicious taste, cheeses, food, chocolate, confectionary, ice cream etc.

The whey can be based on sweet whey from cheese. After standard pre-treatment, the whey dry matter is increased by RO/NF (nanofiltration) before the whey is concentrated in a UF system to produce WPC. Alternatively the dry matter can be increased by evaporation after UF. The WPC with high solids is

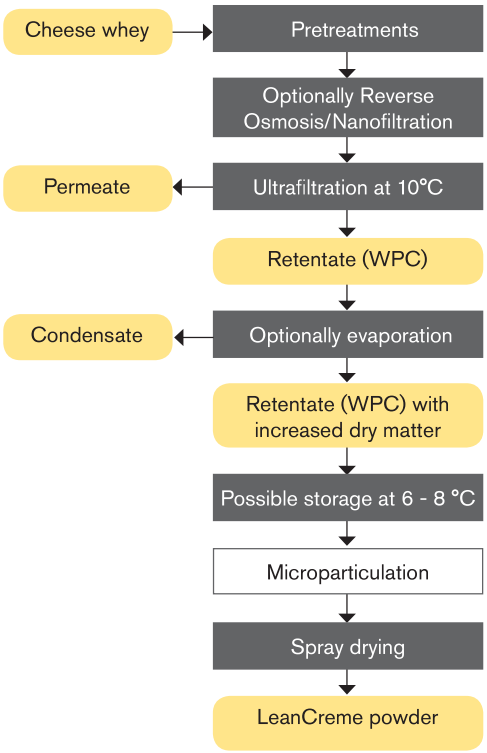


Fig. 18: Diagram of manufacturing of LeanCreme powder

treated by the APV LeanCreme™ process including cooling to 50°C. The LeanCreme can proceed directly to the spray dryer. Fig. 18 shows a diagram of the process.

Table 11 shows examples of WPC grades and dry matter that can be processed on a LeanCreme plant. Dry matter with up to 25% moisture can normally be processed. As a consequence of this, the WPC80 needs to be diluted from typically 29% to 25% dry matter.

As usual when processing highly functional proteins it should be a matter of handling with care. Drying LeanCreme is no exception

.

EXAMPLES OF WPC GRADES AND DRY MATTERS:	
WPC28-35	30% DRY MATTER
WPC60	28% DRY MATTER
WPC80	25% DRY MATTER1)

1) Please note that for WPC80 it is necessary to dilute to a dry matter of 25%

Table 11: Examples of WPC grades and dry matter

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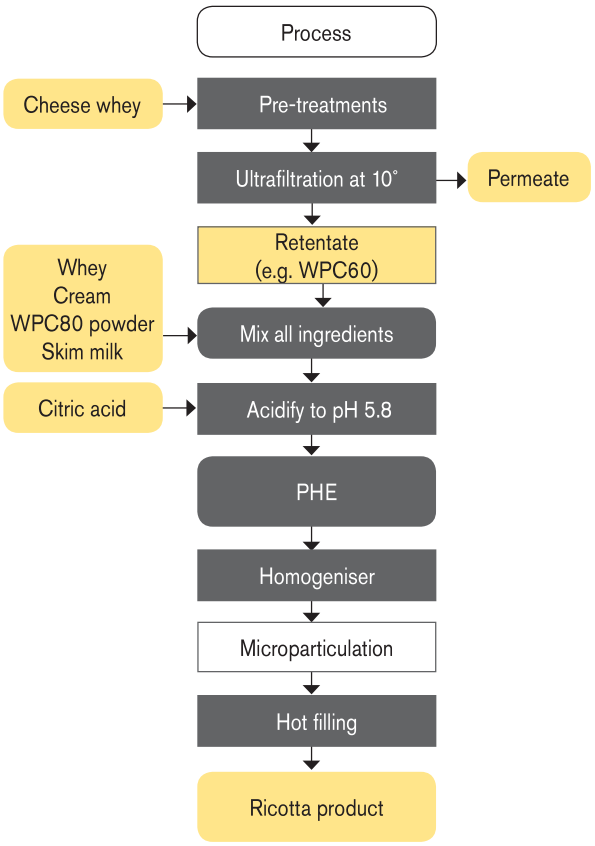


Fig. 19: Diagram of manufacturing Ricotta and similar products

RICOTTTA/MASCAPONE

Ricotta originates from Italy and is a soft creamy cheese with a slight flavouring of caramel. The ratio of casein and whey protein together with the process parameters is important for the texture of the final product. For example, a ratio of 1/3 of casein and 2/3 of whey proteins can result in an excellent Ricotta product. The process steps below result in optimal benefits from the LeanCreme plant. The ingredients are mixed and acidified before the pre-heating step, followed by homogenisation and microparticulation in the LeanCreme plant.

This gives less volume during processing as the unwanted components of permeate are removed in the very beginning of the process. The quality of the Ricotta is improved with creaminess and mouth feel. Control of temperature and shear rate for each heating and the cooling step is essential in this product.

DAIRY BEVERAGES

Now, for the first time ever, healthier low-fat and low-carbohydrate dairy drinks that taste and look like traditional dairy drinks are now available to consumers. With APV LeanCreme™ the milk can be replaced entirely or partly by microparticulated whey proteins.

Drinking yoghurts vary all over the world from high viscous creamy products to very low-viscosity milk-like products. The ability to control the viscosity very precisely with APV LeanCreme™ is extremely important in producing microparticulated whey proteins with high functionality. SPX Flow Technology has experience based on a significant number of studies conducted on how the addition of LeanCreme impacts viscosity, taste and texture of drinking yogurts. LeanCreme particles can be based on sweet whey from cheese, lactic whey from cottage cheese, or on other fermented products.

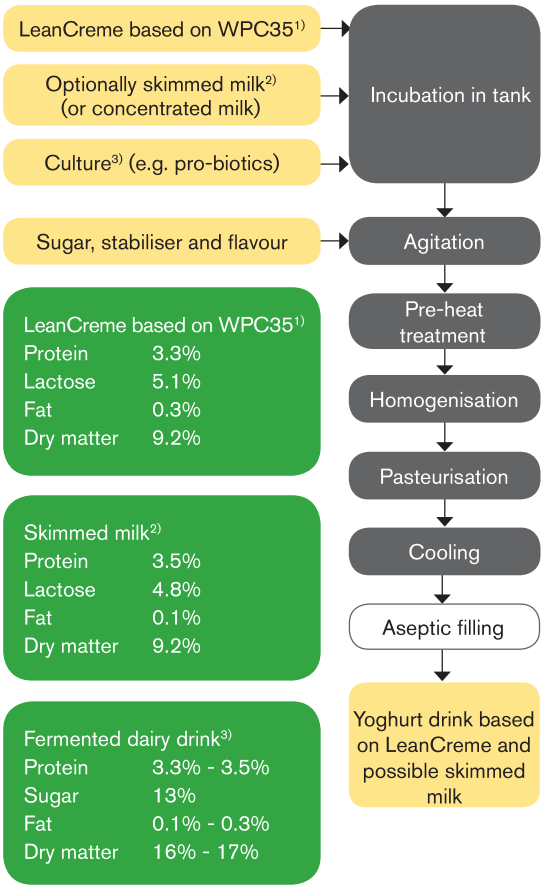


Fig. 20. Diagram of acidified dairy drinks manufacture based fully or partly on APV LeanCreme™

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The benefits of using APV LeanCreme™ in acidified drinks compared to milk-based drinks are:

- Creaminess increased with maintaining low viscosity
- Increased stability
- Less acidic and dry taste, more round and mild taste
- Higher nutritional value due to low fat content and content of whey proteins

More than 98% of trained panellists preferred the taste and consistency of acidified dairy drink based on 100% APV LeanCreme™ over milk-based controls.

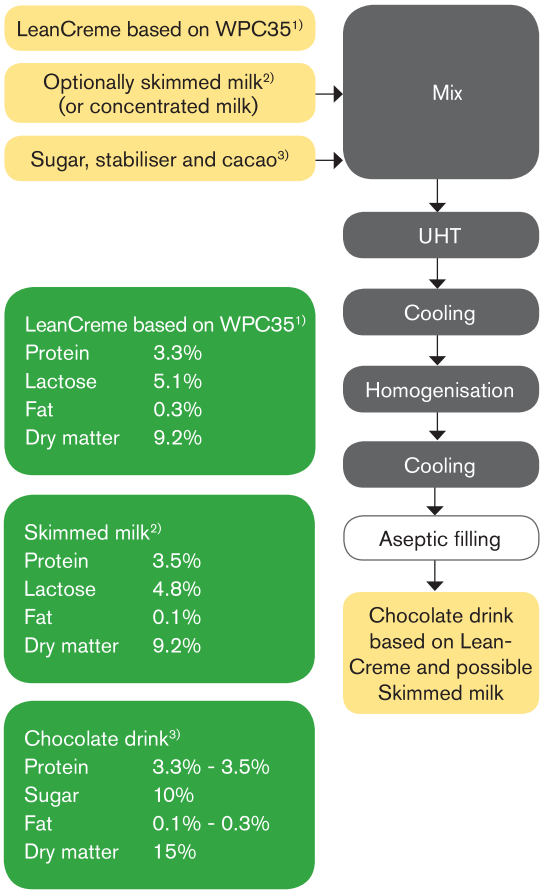


Fig. 21: Diagram of chocolate flavoured protein drink manufacture.

After pre-treatment the whey is concentrated in a UF system to produce WPC. The WPC is then treated in the APV LeanCreme™ microparticulation process before being used to manufacture of any drinking yoghurt or flavoured drink. For details, see process diagrams in Fig. 20 and Fig. 21. WPC35 was used in these examples as the composition is similar to skim milk and provides a great opportunity to use the lactose in a natural way.

Additional opportunities include:

- yoghurt drink with pro-biotic culture, short or long shelf life,
- sports/protein drink with high whey protein content based in e.g. WPC60 resulting in approximately 9% of protein.

YOGHURT

Studies have documented that microparticles are able to act as effective fat replacer in low-fat yoghurt with similar texture to full-fat yoghurt[1]. The degree of denaturation of the microparticulated whey protein and the particle size distribution had significant influence on textural behaviour. Currently the optimal process is not determined. Promising results have been obtained with a process mixing LeanCreme powder with skim milk powder and following the traditional yoghurt process.

ICE CREAM

SPX Flow Technology has learned via a large installed base of APV LeanCreme™ plants in the ice cream industry that LeanCreme particles can replace up to 50% of skim milk in ice cream formulation without altering the melting stability. The best whey product for ice cream applications is WPC30 due to its high lactose content. The particle size has an influence and smaller particles give the best results[2].

1 Torres et al., 2009
2 Kulozik et al., 2001

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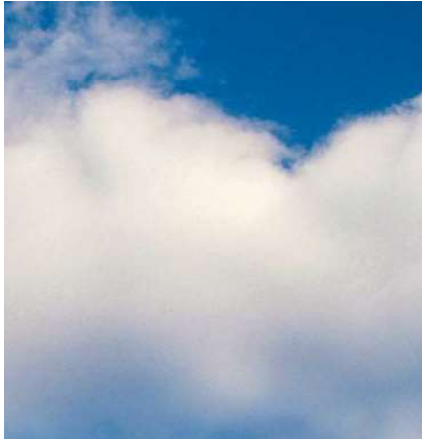
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ABOUT SPX

Based in Charlotte, North Carolina, SPX Corporation (NYSE: SPW) is a global Fortune 500 multi-industry manufacturing leader.

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STATE OF Texas }

COUNTY OF Hunt }

The foregoing instrument was subscribed and sworn before me this date of 02/12/2025, by Tanya Zeif

This notarial act was an online notarization.

Document Notarized using a Live Audio-Video Connection



(Notary Seal)

Notary's Signature Heather Mayo

Registration No.: 134814539

Commission Expiration Date: March 20, 2028