Cloudy Apple Juice
Influence of Raw Material, Processing and Storage
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1. What is a "naturally cloudy" apple juice?

Product definition (legal, consumer expectation):
A naturally cloudy apple juice is an apple juice in terms of the CODEX GENERAL STANDARD FOR FRUIT JUICES AND NECTARS (CODEX-STAN 247-2005), that has not been clarified and contains the original cloud particles of the freshly extracted juice in sufficient quantity to display a perceivable turbidity. Apple juice with insufficient sedimentation stability as well as blends of clarified with cloudy juices are not naturally cloudy.
(H. Dietrich. Zimmer)

Scientific definition:
Cloudy apple juice is a two-phase system: insoluble particles (solid phase) are suspended in a liquid (serum). The solid particles scatter irradiated light, resulting in the visible impression of turbidity.
2. The cloud particles in naturally cloudy apple juice

2.1 Composition

The cloud particles in centrifuged (= starch-free) juices typically are composed of 35-45 % protein, 20-40 % lipids, 15-25 % polyphenols and 5-10 % sugars (Fig. 2.1).

![Fig. 2.1: Average composition of cloud particles in starch-free naturally cloudy apple juices](image)

Proteins together with lipids form the core of the cloud mass. Both components derive primarily from the cell membranes of the apple. Pectin acc. classical definition (polygalacturonans) is only present in traces. Pectic substances in a broader sense (incl. side chains built up of neutral polysaccharides) make up 5-10% of the cloud mass.
2.2 Origin and formation

In contrast to common belief the cloud particles in naturally cloudy apple juice are not insoluble tissue fragments of the apple cell walls (cellulose, xyloglucans, "proto-pectin") nor starch granules. If insoluble apple pieces are part of the cloudiness at all ("primary cloud particles"), then these are fragments of the cell membranes composed of proteins and lipids. Min. 70 % of the turbidity develops only after disintegration of the apple tissue from components, that were dissolved in the intact apple or at least not recognisable as discrete particles (Fig. 2.2).

![Fig. 2.2: Development of the turbidity after de-juicing with a centrifugal separator](image)

Why do these components which are soluble in the apple become insoluble and precipitate? Three root causes are responsible:

1. Association of membrane fragments
2. Acid denaturation of proteins
3. Polyphenol complexation due to enzymatic browning

During milling the apple cells get torn apart: the well-structured and compartmented tissue is transformed into an unstructured suspension of the solid tissue parts (approx. 3% w/w) in the originally clear vacuole liquid (approx. 97% w/w). Thereby hydrophobic membrane fragments aggregate successively and grow to form visible particles (association of membrane fragments).
At the same time an **acid denaturation of plasma proteins** starts: the pH in the cytoplasma (7.0 - 7.5) drops abruptly due to ingestion of vacuole liquid (pH 3.0 - 3.8); the majority of the plasma proteins becomes insoluble and precipitates.

With disintegration of the tissue the **enzymatic browning** starts because enzymes and substrates get into contact. Monomeric apple polyphenols get oxidised to chinones by the endogenous polyphenol oxidase. The chinones then further react to form highly polymeric structures which are insoluble as such or complex with other polymers (e.g. proteins) to form insoluble aggregates.

### 2.3 Sedimentation stability: fine cloud vs. coarse cloud

The sedimentation of particles with diameters > 0.5 µm according to Stoke’s law is depending on the particle size, the density difference between particle and serum and the serum viscosity. Particles with sizes from 0.1 to 0.5 µm are in the transition phase to a colloidal dispersion; their sedimentation velocity is reduced or completely neutralised by the Brownian movement of the solvent molecules.

Two groups of cloud particles in apple juice can be distinguished:

- **fine cloud** which remains in suspension for months and forms the desired homogeneous cloudiness
- fast sedimenting **coarse cloud**

Both fractions can be separated from each other by centrifugation under defined conditions (15 min at 4’200 g).

**What are the reasons why a particle is fast or slow sedimenting?**

**Density difference particle vs. serum**

The cloud particles have densities between 1.20 and 1.28 g/mL (Fig. 2.3). The density differences between particles and serum range from 0.161 to 0.195 g/mL with an average of 0.175 g/mL. The variations in density difference are relatively small and cannot explain the difference in sedimentation stability between fine and coarse cloud. **It can be concluded that Stoke’s law does not (fully) apply for the relevant fraction of fine cloud.**
The substantial differentiation criterion between fine and coarse cloud is the particle size (Fig. 2.4 and 2.5). The sedimentation stable fine cloud always has an average particle diameter (Sauter diameter $D_{3.2}$) of approx. 0.5 µm. The variation between different juices for this cloud fraction is very small. In contrast, the average particle diameter for all particles of a centrifuged juice (total cloud) typically is between 0.75 und 3 µm. If a juice is not centrifuged, then this value can be as high 25 (!) µm.
Scanning electron microscope (SEM) images of fine and coarse cloud show that the average diameters for cloud particles as measured with laser particle sizers based on laser diffraction can only be regarded as rough approximation as their form, especially for fine cloud, deviates...
largely from a sphere (Fig. 2.6). The majority of the fine cloud is composed of thin fibrilla with a diameter of approx. 40 nm and a length up to several µm. Other particles are globular, vesicle like bodies with smooth surface and a max. diameter of 250 nm. The dimension of the fine cloud particles thus is in the transition range between macroscopic and colloidal suspension. This explains why their sedimentation velocity compared to large particles is very much reduced or even is 0.

Fig. 2.6: SEM image fine cloud particles

Comparing the chemical composition of fine and coarse cloud particles no significant differences can be found in the main constituents proteins, lipids and polyphenols. On the other hand, fine cloud particles almost always contain higher amounts of arabinose and galactose as the coarse particles from the same juice. These two sugars are the main constituents of the neutral pectin side chains which comprise the main part of the cloud particle’s polysaccharides. Obviously, these fragments of the pectin structures are of outstanding importance for the sedimentation stability despite their relatively low mass share (usually 5-7 % w/w). If the SEM images of fine cloud are compared with the respective images of coarse cloud or of coarse cloud that has developed from fine cloud due to pectinase
treatment, then it becomes obvious that the higher pectin amount in fine cloud particles inhibits their aggregation to larger, fast sedimenting complexes. This finding leads to important technological consequences, as will be shown below.

3. Evaluation of naturally cloudy apple juice

3.1 Turbidity intensity

Turbidity is measured with special turbidity photometers (nephelometer) which measure the light scattered by the particles in a certain angle, e.g. 90°, relative to the non-scattered light. In order to largely eliminate the impact of serum colour and for enhancing the measuring range the samples are diluted 1+20 with demineralised and particle free water. The result is expressed in NTU.

How high the turbidity of a cloudy apple juice should be cannot be answered globally. It basically depends on consumer’s expectations. Very common are values between 200 and 1’000 NTU. Higher turbidities give a very thick, sauce-like impression. With lower values the visual impression changes from turbidity to opalescence.

3.2 Sedimentation stability

Even if the preferred turbidity intensity may vary for different markets, it is common sense that the particles that are present shall remain in suspension and shall not sediment. The sedimentation stability of a naturally cloudy apple juice therefore is an outstanding quality criterion and should be determined in every QC laboratory. It is measured by the centrifugation test. Stähle-Hamatschek S (1989) who found a high correlation \( r = 0.991, n = 50 \) between the loss of turbidity during storage of cloudy apple juice in upright stored glass bottles for one year and the turbidity loss due to centrifugation (4’200 g, 15 min) performed a few days after manufacturing. The multiplied gravity acceleration in the centrifugal field simulates within 15 min the sedimentation that appears within a year under standard acceleration of gravity. Thus, the sedimentation stability can be evaluated immediately after processing.

The centrifugation test only requires a laboratory centrifuge and a nephelometer. The turbidity of the juice is measured before and after the centrifugation. The sedimentation stability \( \%T \) is defined as the ratio between both values, expressed in percent:

\[
\text{Sedimentation stability:} \quad \%T = \frac{T_z}{T_0} \cdot 100
\]

with:
- \( \%T \): sedimentation stability
- \( T_0 \): total turbidity before centrifugation
- \( T_z \): residual turbidity after centrifugation
The sedimentation stability should be minimum 50%. Then it is assured that the juice still is sufficiently cloudy after storage for several months and that the sediment is not unaesthetically high.

3.3 Colour

Objectively assessing the colour of a cloudy apple juice is much more difficult. Analogous to assessing clarified juices the cloud can be removed by filtration and the colour be measured in the clear serum, e.g. as $A_{420}$. But the serum colour only comprises partially to the visual colour perception of a cloudy juice. The cloud colour can be of much higher relevance for the visual impression. The cloud colour only can be measured with special spectral reflexion colourimeters which define the colour as coordinates in a three-dimensional colour space (red-green-axis, blue-yellow-axis, intensity-axis). These instruments are expensive and still not widely present in QC laboratories (refer also to IFU R09). In addition, uniform and verified measuring methods enabling comparability of results from different laboratories are not yet available.

Alternative to instrument-based assessment of the juice colour remains the subjective visual assessment by experienced panellists. Such assessments should make use of colour standards (e.g. Hellige, Lovibond comparator, NEO-comparator) although no specific standards for cloudy juices are available.

4. Influence of raw material on turbidity and sedimentation stability

Processing of different apple batches with identical conditions can yield naturally cloudy juices with a large variation in turbidity parameters. In a study with 11 apple batches (6x apple blends, 5x single varieties) pressed on a Bucher HP press the total turbidity $T_0$ varied between 390 and 2’646 NTU, so almost by a factor of 7 (Fig. 4.1)! Respectively the sedimentation stable turbidity had a range from 226 to 1’491 NTU. The variation in sedimentation stability %T was from 17 to 65 % with a single variety juices from Elstar showing the lowest value. Studies with cloth-and-rack press or decanter extraction show relative variations in a comparable range.

The major raw material parameters that influence turbidity and sedimentation stability are apple variety, ripeness, starch content and storage time. Generally, fully ripe apples yield higher turbidities and better sedimentation stability than pre-mature fruits. Different apple varieties can produce very good or very bad results. Processing blends of apple varieties (as is common in industrial processing) helps to reduce the variations in the turbidity parameters of the juices. Of course, only fully sound apples shall be processed as enzymes from spoilage micro-organisms or endogenous enzymes from the mechanically damaged tissue of the apple will definitely deteriorate the sedimentation stability.
Starch

The starch topic is closely related to the raw material. In early season the apples grown in moderate climates almost always contain starch as granules with diameters from 2-13 µm. The starch granules can be effectively separated from the press juice with a good centrifuge. If the juice is not centrifuged, then the starch will gelatinise during pasteurisation and form a colloidal solution which cannot be separated mechanically any more.

Fig. 4.2 shows, among others, the average particle sizes of non-centrifuged cloudy apple juices (1). It is obvious that the average particle size in these juices is multiple times larger than in centrifuged juices. Fig. 4.3 shows the glucose content of the cloud fractions from the same juices. It can be detected that the large particles in non-centrifuged juice are composed of up to 80 % starch (“glucose”). The fine cloud from the respective juice on the other hand is virtually starch-free, at least if the mash has not been heated. If the mash is heated to temperatures > 50°C, then also the fine cloud contains significant amounts of retrograded starch. It can be concluded that retrograded starch in a standard process does not positively contribute to the sedimentation stability but only increases unpleasant sediment.

Sediment accumulating after shelf storage caused by the presence of starch and subsequent retrogradation during storage shows a typical unpleasant grey colour.

To summarise it can be stated that the raw material has an enormous impact on the turbidity parameters of naturally cloudy juices. This is also true for colour, aroma and mouthfeel. It is highly recommended to process sound, fully mature apples which provide the required potential for formation of a full bodied aroma and the desired quantity of fine cloud
particles. Fully mature apples also contain sufficient soluble pectin for a viscosity that enhances mouth feeling and sedimentation stability. By selecting the appropriate raw material, a processor therefore can lay the cornerstone for an appealing product but can also effectuate the contrary! It is indispensable that each processor must elaborate for his specific raw material availability the knowhow, which qualities shall be utilised for naturally cloudy apple juice, and which types should be avoided.

![Fig. 4.2: Average particle size (Sauter diameter) of total and fine cloud](image)

![Fig. 4.3: Glucose content of apple juice coarse and fine cloud](image)
5. **Influence of processing technology**

5.1 **Processes for production of naturally cloudy apple juice**

5.1.1 **Standard process for production of naturally cloudy apple juice and concentrate**

Fig. 5.1a: BFD „classical“ technology for production of naturally cloudy apple juice
5.1.2 Reductive juice extraction with pulper/finisher and centrifuges

Fig. 5.1b: BFD Reductive juice extraction with pulper/finisher and centrifuges
5.2 Mash treatment

Mash enzyme treatment
In processing of clarified apple juice, mash enzyme treatment today is standard for maximising yield and throughput. With the enzyme preparations commercially available in the past this treatment could not be applied. As can be seen from Fig. 4.2 and 5.2 mash enzymation led to formation of very large particles and complete loss of sedimentation stability. Due to the pectolytic enzyme activity the polysaccharides of the cloud particles that are indispensable for sedimentation stability are degraded or modified to an extent that they loose their aggregation inhibiting function and the fine particles aggregate to large complexes ("enzymatic denaturation").

It has to be stressed that sedimentation stability first and foremost is a feature of the cloud particles as such, due to their size and form. That is to say that the loss of sedimentation stability is the result of enzymatic action on the particle-bound polysaccharides and not on the soluble serum pectins, which are responsible for the juice viscosity.

In recent years newly, developed enzyme preparations with high pectinase and very few side activities have become available. An increasing number of industrial processors use these enzyme preparations successfully for production of naturally cloudy apple juices. When the enzyme activity is very well controlled (concentration, temperature, holding time), then the

Fig. 5.2: Influence of mash enzymation on turbidity and sedimentation stability
(n-n-K-....: control; n-n-EZ-....: with mash enzymation)
sedimentation stability of the juices is still reduced to a certain degree, but not completely lost. The economic advantages (higher yield and throughput) obviously prevail as long as internal quality standards for turbidity parameters are met.

**Mash holding time**
If the mash is kept for some time prior to dejuicing, more time is available for the cloud forming processes as described in Chapter 2.2. This leads in the majority of cases to a higher total turbidity and often also to a slightly enhanced sedimentation stability. But this is only valid for mash holding times up to 30 min and also is not true for all raw material qualities. For soft apples stored for a long time the negative effects due to endogenous enzyme activity prevail. In addition, the mash needs to be protected against excessive enzymatic browning by adding ascorbic acid. As the turbidity and sedimentation stability typically is met also without mash holding time, this measure should only be applied for max. 30 min, and only for freshly harvested, crisp fruit.

**Mash heating / pasteurisation**
Also mash heating can influence the cloud formation. Pilot scale trials with mash heating (50°C) and mash pasteurisation (90°C) showed only a small effect when the mashes were extracted with a Bucher press. The respective trials with a decanter on the other hand resulted in increased turbidities and sedimentation stabilities. Industrial scale comparative trials with a decanter showed only small differences between heated and non-heated mashes. Mash heating and especially pasteurisation leads to sensory divergent juices. Due to increasing solubilisation of pectin the juice viscosity increases. Especially with mash pasteurisation the juices become thick (saucy), have a grassy, pear-like aroma and a greyish hue. Also taking into account the cost for the mash heating/pasteurisation this measure cannot be recommended.

The cloud forming reaction (as described in 2.2.) is a temperature dependant reaction. In this regard a processing temperature should be ideally between room temperature and slightly increased temperature, however still below any denaturation temperature of juice / fruit components.

### 5.3 Extraction system
In industrial size fruit juice plants today mostly Bucher HP/HPX presses, belt presses or decanters are applied for apple de-juicing. If the same apple mash is extracted in parallel with an HP/HPX press and a decanter, then the decanter juice typically has approx. twice the turbidity intensity of the press juice. (Fig. 5.4). It can be concluded that the filter effect of the pomace cake inside of the press causes a more pronounced decrease of cloud particles than the centrifugal field inside of a decanter. The turbidities of belt press juices typically are somewhere between HP/HPX press and decanter juices. Decanter juices sometimes have an extremely high turbidity of more than 2’000 NTU, despite downstream centrifugation with a disc centrifuge. Turbidities above 1’000 NTU cannot be distinguished any more by the human eye. In addition, more ascorbic acid (vitamin C) is
required to preserve the light juice colour (cloud particles bind or consume vitamin C!) and the juices sensorially can appear thick and pappy (see also chapter 3.1). Whether such juices fit the consumer expectations needs to be evaluated. On the other hand, such juices can be used for blending with other, low turbidity juices, as is required.

Unlike the turbidity intensity, the sedimentation stability %T is much less influenced by the extraction system: for HP/HPX presses and decanters %T is on a similar level for a given mash (Fig. 5.4). Belt presses have not been investigated systematically, but there is no reason to conclude that their %T results should be divergent. With all extraction systems the postulated 50 %T can be achieved, provided that the extracted juices have been sharply centrifuged.

![Fig. 5.4: Influence of extraction system on turbidity intensity and sedimentation stability](image)

(D: Decanter; P: Bucher HP Press)

Recently a new extraction approach with very fast heat inactivation has gained some industrial relevance. It comprises the "cold" extraction of a puree in a pulper/finisher with screen perforations ranging from 1.2 to 2.5 mm, optionally operated under vacuum or inert gas, followed by an almost immediate heat inactivation of the extracted puree. The suspended solids of the puree are then further reduced by a sequence of decanter and disc centrifuges (see also BFD in Chapter 5.1.2).

Due to the fast inactivation of the PPO and optional oxygen reduction the juices obtained by this process are very reductive. To preserve a light colour no or only small amounts of vitamin C are required.

The juices produced with this process are quite different to those produced with the classical method according 5.1.1.
Samples measured were extremely cloudy with total turbidity \( T_0 \) in the range of 4200 NTU. Also, the stable turbidity \( T_z \) was very high with 3400 NTU, resulting in a respectively good sedimentation stability \( \%T \) of > 80%. These juices also still contain extremely high loads of centrifugal pulp: > 20% were measured compared to < 0.5 % for a standard cloudy juice. Finally, the juices have extremely high viscosities with 11.9 mPa*s (but still Newtonian!) at 25°C, as compared to typically < 2 mPa*s for a standard juice. No comparative sensorial evaluations of these juices are available so far.

From the analytical data it can be concluded that these juices will be quite different in sensory perception. They appear to be somewhere between a classical juice and a smoothie. They thus can be regarded as complementary rather than alternative to classical juices, offering alternative marketing positioning and serving different consumer needs.

### 5.4 Oxidation prevention measures

In several investigations it has been confirmed that reducing mash oxidation besides a light juice colour also provides improved sedimentation stability. Technologically prevention of oxidation can be achieved by very fast processing, an inert gas atmosphere, de-aeration and by addition of ascorbic acid (vitamin C).

The easiest and most widely applied method is addition of ascorbic acid. The **vitamin C addition to mash or juice almost always enhances the sedimentation stability in the final juice** (Fig. 5.5 and 5.6). If vitamin C is added already to the mash, the dosage has to be higher as the polyphenol oxidase (PPO) activity in the mash is higher than in the juice, which results in a faster vitamin C consumption. Short mash holding time helps to limit vitamin C consumption.

Also, the processed apples have an impact: the higher the polyphenols concentration and PPO activity, the more vitamin C has to be added. Generally, apples grown for the fresh fruit market require less than wild or cider apples, apples with green or yellow peel less than red peeled apples.
Fig. 5.5: Influence of ascorbic acid addition to mash on turbidity intensity and sedimentation stability (C: control, Asc: with ascorbic acid)

Fig. 5.6: Influence of ascorbic acid addition to juice on turbidity intensity and sedimentation stability (C: control, Asc: with ascorbic acid)
The **ascorbic acid addition** should be limited to the required level for achieving the desired juice colour. Also, storage time and conditions as well as shelf life have to be taken into consideration. For qualities matching the consumer expectations in traditional markets for naturally cloudy apple juice (DE, AT, CH, Eastern Europe) vitamin C addition of 400-500 mg/kg mash or 200-400 mg/L juice typically is sufficient. If more is required, then the raw material or the process does not seem to be appropriate. If significantly higher amounts of ascorbic acid are added, then the juices are too much acidified and undergo accelerated browning upon storage despite initially very light colour. This is especially true if stored as semi-concentrate and/or at elevated temperatures.

**The process line has to be designed in a way to keep the time until pasteurisation short.** With pasteurisation all enzymatic processes, particularly enzymatic browning and pectin degradation by endogenous pectinases, are stopped. **A too fast pasteurisation on the other hand leads to sensory divergent products.** This can be concluded from the results of mash pasteurisation (see chapter 5.2) and lab scale trials with complete removal of any oxygen (unpublished): a certain oxidation is required for formation of the typical apple juice aroma. With appropriate vitamin C addition, a processing time of 30 to 90 min between crushing and pasteurisation can be regarded as acceptable.

If the process starting with grinding consequently provides an **inert gas atmosphere** (e.g. N₂), then extremely light coloured, virtually unoxidised juices can be produced. As for mash pasteurisation, such juices are sensory divergent to the common consumer expectation in Europe but may be matching requirements in other markets (e.g. Japan) or be used to develop new product types.

**Mash deaeration** also helps to limit oxidation as the apple tissue contains approx. 25 % air (v/v) and this air inevitably is mixed into the mash during grinding. However, speed is of vital importance when using deaeraration. Deaerating systems always expose the fruit tissue to mechanical stress and create an additional grinding effect. Doing so, the surface and therefore the opportunity for oxidation is increased. Oxidation is accelerated, unless the removal of air, the deaeration effect is performed faster. Mash deaeration systems for the capacities required in industrial processing are expensive, also in terms of operational costs. Therefore, mash deaeration economically is not very competitive compared to the other measures of oxidation control.

To summarise it can be stated that in processing of cloudy apple juice oxidation does not need to be avoided completely but must be well controlled. The economically and technologically most efficient tool is the addition of small amounts of ascorbic acid to mash or juice. A fast process helps to keep the ascorbic acid demand low. Providing an inert gas atmosphere or mash-deaeration only is viable for special products or markets due to the involved costs and the sensory profile of the juices.
5.5 Coarse cloud removal

Removing the fast sedimenting coarse cloud particles as much as possible is the prerequisite for a good sedimentation stability and prevention of an unappealing deposit. This can be very effectively achieved by a sharp centrifugation of the juice immediately after extraction. With the centrifugation also most of the starch granules are removed, avoiding deposit formation due to retrograded starch. If the juice is pasteurised prior to centrifugation then the starch granules gelatinise and are not effectively removed by the centrifugation anymore. As a result, the total turbidity increases but the sedimentation stability decreases due to retrograded starch (Fig. 5.7; see also Chapter 4 “Starch”). A certain separation of coarse cloud particles also takes place during aseptic storage of the juices in storage tanks. If stored sufficiently long a centrifugation may not be required if the juice is taken out of the tanks through a nozzle above the deposit level. If the cloudy juice is stored as semi-concentrate (see also chapter 5.6) the sedimentation velocity of the coarse particles is significantly reduced and a centrifugation after redilution typically is required.

![Fig. 5.7: Influence of centrifugation before or after juice pasteurisation](image)

(C-P: centrifugation → pasteurisation; P-C: pasteurisation → centrifugation)
5.6 Influence of juice homogenisation

In general juices can be produced with good cloud intensity and stability using above mentioned technologies. An additional homogenisation or more general the use of dispersing technologies is not needed for natural cloudy apple juice.

This is a big difference to other cloudy juices, which are often blended e.g. from purees and clear juices. Here the use of dispersing technologies is mandatory.

In case of natural cloudy apple juice the effect of homogenisation or other dispersing technologies (e.g. based on rotor-stator-systems) shows mixed results.

In case a homogeniser is used, sufficiently high pressure needs to be applied. In general, the structure of the cloud particles (as described above) is destroyed. Based on this cloud stability will decrease, unless the homogenisation effect is strong enough to reduce all particles to a diameter below 1 micrometer. In this case the juice is stabilized, however based on a changed colloidal system. The coarse particles are “milled” to a fine cloud.

One additional effect of such a treatment is an increase in absolute measured turbidity. Due to the reduction in particle size the light scattering patterns of the individual particles change in a way, that visually as well as measured with instruments a higher turbidity will be detected.

If a homogenisation takes place prior to pasteurization, it needs to be made sure, that the installation is sealed from air. Otherwise a huge negative oxidation effect will take place.

5.7 Juice-/Semi-concentrate storage

Colour and sedimentation stability of a cloudy apple juice are no constant parameters, in fact they change upon storage.

It is commonly known that juices undergo browning during storage (“non-enzymatic browning”). The browning is accelerated by increasing storage temperature and concentration. Also, high levels of ascorbic acid speed up browning, especially in semi-concentrates.

The reactions that produce this browning are still largely unknown. It is assumed that acid catalysed polyphenol complexing and Maillard reactions are involved. As measures to reduce polyphenols (fining, adsorbents) cannot be applied in cloudy juices and the precursors for the Maillard reactions (sugars, amino acids) cannot be altered at all, the only available measure to limit the non-enzymatic browning is reducing the storage temperature. While the browning of cloudy apple juices stored in aseptic tank farms at maximum 15°C typically is acceptable, semi-concentrates get dark so quickly that they should be stored cold, preferably below 5°C.

Also, the turbidity changes during storage. The turbidity intensity increases during the first one or two years of storage (Fig. 5.8). It can be concluded that even after pasteurisation the cloud...
forming processes (see chapter 2.2) continue to some extent. It is assumed that this process is similar to the post-hazing in clear juices that had not been sufficiently stabilised. With further extended storage the turbidity decreases again, presumably due to aggregation of fine particles to coarser particles which dissipate light to a lesser extent.

The sedimentation stable turbidity typically also increases at the beginning of storage, but less pronounced than the total turbidity (Fig. 5.9). Also, already after one year it normally falls below its starting value.

**Caused by the developments of total and stable turbidity the sedimentation stability %T continuously decreases during storage** (Fig. 5.10). It therefore can beneficial to centrifuge juices from an aseptic tank farm once again before bottling, even if they had been centrifuged already before storage.

![Fig. 5.8: Development of T₀ during storage](image-url)

\[ y = 0.019x^2 + 0.170x \]
\[ r = 0.4695 \]
Fig. 5.9: Development of $T_z$ during storage

Fig. 5.10: Development of $\%T$ during storage
6. Conclusion

As key conclusion from the findings presented in this report it can be stated that selecting and evaluating the right raw material should be set greater store on as is common practise in juice industry. Each apple comprises a certain potential of components for formation of a stable cloudiness. For some varieties this potential is higher (e.g. Boskoop), for others it is lower (e.g. Elstar). By selecting slow browning varieties with light peel colour with the same processing technology a lighter juice will be produced compared to apples rich in phenols and with intensely coloured peel. Finally, the apples should be fully ripe and of course sound in order to provide a full aroma and good pectin structure and avoid release of unnecessary large amounts of starch into the juice.

The applied process technology can preserve the potential for aroma, colour, turbidity and sedimentation stability more or less good, but technological measures cannot replace or create an insufficient potential.

The extraction technology determines to a certain extent the turbidity intensity of the juices: decanter juices in general are more cloudy than press juices. With appropriate process design it has little influence on the sedimentation stability.

Limiting the oxidation, especially the addition of ascorbic acid, enhances the sedimentation stability and is also required for preserving an appealing juice colour. Complete suppression of oxidation produces juices which do not comply with the most widely spread consumer expectations for naturally cloudy apple juice.

Reductive juice extraction by pulper/finisher and centrifuge technology provides complementary juices types with very high turbidities and pronounced mouthfeel.

The quality of cloudy apple juice decreases during storage even if it has been produced from appropriate apples and with adequate process technology: the colour becomes darker and the sedimentation stability declines. Storage temperatures as low as possible, especially for semi-concentrates, actually are the only option to limit these quality deteriorations to an acceptable level.

Reference

Quantitative Erfassung und Bewertung technologischer Einflüsse und Rohwarenparameter auf die Trübungsabszente und Trübungsstabilität in trüben Apfelsäften.
Dissertation University Hohenheim / Germany.