



# Understanding Haze, Turbidity, and Opalescence in Industrial Manufacturing

## Introduction

Clarity and transparency are critical quality attributes in many industries, from packaging and optics to food, beverages, and pharmaceuticals. Terms like **turbidity**, **haze** (often expressed as Haze %), and **opalescence** describe the loss of clarity in materials or liquids due to light scattering.

This white paper explains what each of these terms means, why they are important in various industrial applications (e.g. clear plastic packaging, films, ophthalmic lenses, beverages, and injectable drugs), how they are applied in these fields, and how they are measured according to industry standards.

We will also compare turbidity, haze%, and opalescence side by side to highlight their differences and relationships.

## Defining Turbidity, Haze, and Opalescence

### Turbidity

**Turbidity** is the cloudiness or haziness of a liquid caused by suspended particles. It essentially quantifies how much particles in a liquid scatter and absorb light, reducing clarity. A turbid liquid appears cloudy or muddy because myriad tiny particles (too small to see individually) scatter light in all directions, like how smoke scatters light in air. Turbidity is a key indicator of water and beverage clarity and quality.

In practical terms, higher turbidity means more suspended solids and less clarity.

Turbidity is typically measured in **nephelometric turbidity units** (NTU) (or the equivalent **Formazin Nephelometric Units** - FNU - in ISO standards) by shining light



into the sample and detecting the scattered light at a 90° angle. The more light that is scattered to the side, the higher the turbidity reading. Very clear water has turbidity <1 NTU, whereas highly turbid, cloudy liquids have much higher values (dozens or hundreds of NTU). Turbidity measurements rely on **nephelometry** (right-angle light scattering detection) or **turbidimetry** (measuring attenuation of light through the sample), calibrated against standard suspensions like Formazin.

For example, the U.S. EPA standard Method 180.1 (white light source) defines NTU, and ISO 7027 (infrared light source) defines FNU; both methods measure 90° scattered light intensity. Turbidity is most commonly discussed for **liquids** (water, beverages, etc.), though the concept can be extended to transparent solids in a general sense (in solids it is usually termed haze, as discussed next).

## Haze (Transmission Haze %)

**Haze** in an optical context refers to the light scattering in a **transparent or translucent solid material** (or sometimes a liquid) that causes a cloudy or milky appearance, reducing the clarity of objects viewed through the material.

Numerically, **haze (%) is defined as the percentage of transmitted light that is scattered more than a specified angle (typically 2.5°) from the incident beam**. In other words, when light passes through a clear plastic or glass, some of it goes straight through (direct transmission) and some is scattered at wide angles; the fraction of light scattered at wide angles is the haze.

According to ASTM D1003 (the standard test for haze in transparent plastics), any transmitted light deviating >2.5° from the incident direction is considered “haze”.

A material with **0% haze** would transmit all light without wide-angle scattering (perfectly transparent), whereas higher haze percentages indicate a cloudy material. Haze causes objects seen through a plastic film or lens to appear fuzzy or obscured.



Note that haze is related to turbidity in concept (both involve light scattering by particles or micro-structure), but haze is usually reported as a relative percentage of light scatter in solid sheets or films, whereas turbidity is an absolute measure of cloudiness in liquids (in NTU).

Lower haze values (for example, <1% haze) correspond to high clarity materials, whereas high haze values (say 30% or more) mean a very translucent or cloudy appearance. Haze in plastics can result from microscopic crystals, additives, or surface roughness that scatter light. This property is crucial in applications requiring transparency, and industries quantify haze to ensure **optical clarity** requirements are met.

## Opalescence

**Opalescence** describes a milky, opal-like shimmer or slight cloudiness in a liquid, often with an **iridescent or bluish tinge**. The term comes from the gemstone opal, which shows a milky, iridescent play of colors. In liquids, opalescence is caused by **light scattering from very small particles or droplets** (colloids) that are just large enough to scatter light but may still allow most light to pass.

An *opalescent* solution may appear clear upon a quick look but exhibits a faint haze or bluish-white glare when light shines through it. Importantly, opalescence usually refers to a **slight or moderate turbidity**, often at levels that might not be picked up as high turbidity numerically but are still visibly detectable under certain lighting. In everyday terms, a liquid described as opalescent is not completely clear, but not fully cloudy either – it has a delicate haze.

Technically, opalescence is an optical effect of *Tyndall scattering*, where sub-micron particles scatter shorter wavelengths of light (blue) more strongly, sometimes giving a bluish cast to transmitted light.



In industrial contexts (especially pharmaceuticals), **opalescence is considered an undesirable attribute if it appears in products that are supposed to be clear**. It can indicate the presence of contaminants, colloidal particles, or incipient instability (e.g. protein aggregates in biopharmaceuticals). However, in some beverage contexts a slight opalescence might be intended (for example, some craft beers or natural juices have an opalescent, unfiltered look for aesthetic or flavor reasons). Opalescence is often assessed qualitatively (e.g. “solution is clear or only slightly opalescent” per pharmacopeia specifications) or quantified in terms of turbidity units if needed. In pharmaceutical quality control, official standards define reference suspensions to categorize opalescence (e.g. reference solutions corresponding to 3 NTU, 6 NTU, etc., as described later).

The key distinction is that **opalescence refers to the visual appearance of slight haze in liquids**, whereas “turbidity” could cover a broad range of cloudiness (from very low to very high), and “haze” is more often used for solids or films.

All three concepts are related – they all involve light scattering phenomena – but their usage and measurement differ by context (solid vs liquid, degree of cloudiness, etc.).

## Importance in Key Industries and Applications

Clarity and haze/turbidity levels can directly impact product performance, aesthetics, and regulatory compliance across various industries. Below we discuss why controlling turbidity, haze, or opalescence is critical in several specific fields and how each concept is applied in practice:

### Plastics for Food & Beverage Packaging

In food and beverage packaging, especially with clear plastics (like PET bottles, clear polyethylene films, polycarbonate or acrylic containers), **optical clarity is a major quality attribute**. Consumers expect to see the contents clearly, so excessive haze in



the plastic is undesirable. For instance, a water bottle or clear food clamshell with high haze looks cloudy, which can be mistaken for contamination or old material. **Haze% is the metric typically used for transparent packaging materials** – manufacturers measure the haze of plastic resin samples or finished containers to ensure it stays below a certain specification (often just a few percent for high-clarity packaging).

ASTM D1003 is commonly used in packaging QA/QC to quantify haze and total transmittance of packaging films and sheets, ensuring lot-to-lot consistency. Low haze ensures that the product inside is showcased attractively and that labels or contents are easily visible. In beverage packaging (bottles for water, juices, soda), low turbidity of the *liquid* is important (the drink should look clear if it's supposed to be), **and** low haze of the *bottle* itself is also important so as not to obscure the liquid's appearance. Thus, packaging engineers must consider both the material's haze and how it might change during processing (e.g. some plastics can develop haze if improperly molded or if they crystallize).

**Food packaging films** (such as wrap films or transparent pouches) also require haze control: too much haze (cloudiness) can make the food look unattractive or less fresh. By measuring haze%, packaging manufacturers can verify clarity requirements are met for things like blister packs, salad containers, and bakery packaging.

In summary, **haze measurement in plastics packaging** ensures **consumer appeal and product visibility**, which directly influences purchasing decisions. Furthermore, regulatory standards for food-contact materials might indirectly require clarity (for example, to allow visual inspection of contents for spoilage).

## Clear Plastic Films and Sheets (Industrial and Optical Uses)

Clear plastic films (polyester, polycarbonate, polypropylene, etc.) and sheets are used in applications from **display screens and touch panels to window films and greenhouses**. In these applications, **haze and clarity are critical for functionality**. For



instance, a smartphone screen cover or LCD diffuser needs controlled haze: display covers should be low haze for sharp image quality, whereas a diffuser might intentionally have some haze to scatter backlight evenly.

ASTM D1003 haze testing is widely applied to **architectural and automotive glazing plastics** (like polycarbonate windows, helmet visors, headlight covers) to ensure they meet visibility and safety standards. Automotive headlamp lenses, for example, must have minimal haze so that the light output is not significantly diffused; even a small increase in haze can reduce night-time road visibility. Similarly, **polycarbonate or acrylic sheets** used in building windows or signage are tested for haze and transmittance to guarantee they remain transparent.

**Quality control professionals** in plastics manufacturing regularly measure haze% to catch any process issues (e.g. moisture, improper cooling, or additive dispersion) that could increase haze. If a film shows elevated haze, it might indicate inconsistencies like micro voids or crystallites in the polymer – potentially pointing to processing problems. Thus, haze measurement acts as a diagnostic tool as well as a compliance metric. Some specialized industries also use the concept of **clarity** in addition to haze – clarity often refers to the *small-angle scattering* (near-forward direction) as opposed to wide-angle haze.

For critical optical films, both haze and clarity (a measure of image sharpness through the film) might be specified. In summary, controlling haze in films and sheets is crucial for **optical performance** (clear view or image fidelity) and is ensured by following standards like ASTM D1003 or ISO 14782 during production and incoming inspection.

## Ophthalmic Lenses and Optical Components

In ophthalmic applications (eyeglasses lenses, contact lenses, intraocular lenses) and other precision optical components, **absolute clarity is paramount**. Any haze or turbidity in a lens can scatter light and degrade vision or optical performance.



Ophthalmic lenses are typically made of polycarbonate, CR-39 plastic, or glass, and manufacturers must ensure these lenses have extremely low haze (often well below 1%). Even a haze of a few tenths of a percent could cause noticeable fogging or glare in eyeglasses. For this reason, lens materials are tested for **transmission and haze** similarly to other plastics – ASTM D1003 can be applied to flat samples of lens material or cast plaques to measure haze%. (Finished curved lenses might require specialized setups, but the principle is the same: measure how much light is scattered.)

High-end camera lenses or optical filters also demand essentially zero haze; any light scatter in these can blur the image. Quality assurance engineers track haze as an indicator of material purity and proper curing of lens polymers. For example, if a batch of ophthalmic lens resin had contamination or improper polymerization, it could result in a slight opalescence or haze in the cured lens – which would be unacceptable. Thus, **haze measurement serves as a quality check for optical clarity** in lens manufacturing. Additionally, standards for safety glasses (like ANSI Z87) or for intraocular lenses may specify clarity requirements. Ophthalmic labs will reject lens blanks that show any cloudiness. In this industry, the tolerance for turbidity is extremely low: essentially, lenses must appear water-clear. **Clarity metrics** beyond haze may also be used, such as measuring **light scatter at small angles** (to ensure no “forward haze” that might cause halos).

In summary, controlling haze in ophthalmic and optical products is critical to **ensure safety (clear vision) and performance**, and manufacturers rely on haze tests to maintain these standards.

## **Beverages (Water, Juices, Beer, etc.)**

The beverage industry is very concerned with **turbidity and clarity** of drinks. For potable water and clear beverages (like soft drinks, clear juices, spirits), **low turbidity is associated with purity and quality**. For instance, drinking water treatment plants



continuously monitor turbidity, since regulations often require turbidity below a certain threshold (e.g. <1 NTU) for safety - higher turbidity can shield bacteria and indicate insufficient filtration. In bottled water or clear sodas, any haze is usually unacceptable to consumers. Thus, turbidity meters are used to ensure the product is visually crystal-clear. In the **juice industry**, clarity is a key quality attribute for many juices (though some juices are intentionally sold as cloudy or “natural”). Apple juice, for example, is traditionally expected to be a transparent golden liquid.

Producers measure the **haze (turbidity)** of apple juice to detect the presence of excess suspended solids or pectins that could make it cloudy. Haze in juice can develop over time due to sedimentation or precipitation of components like tannins or proteins. By quantifying turbidity before and after bottling, manufacturers can determine if a juice is prone to haze formation and take corrective actions (like additional fining or filtration). Notably, **opalescence in beverages** has actually become a desirable trait in some segments - for instance, certain “natural” or organic juices and unfiltered ciders are marketed as slightly cloudy (opalescent) to appear less processed. However, for the majority of mass-market beverages, **consistent clarity is desired**, so turbidity/haze is tightly controlled.

Beer brewing presents an interesting case: **beer haze** can be both a flaw and a feature. Many beer styles (lager, pilsner) are expected to be brilliantly clear, so brewers use filtration and finings to reduce turbidity (chill haze or yeast haze) and will measure beer turbidity in **beer haze units (e.g. EBC units or NTU)** to ensure clarity. On the other hand, some styles like wheat beers or certain ales are intentionally served with a haze (due to yeast or proteins in suspension); in those cases, the haze still needs to be controlled (consistent from batch to batch). Brewers have specialized turbidity standards - for example, the European Brewery Convention (EBC) turbidity unit is measured by a similar nephelometric method (with a conversion roughly such that 1 EBC  $\approx$  4 NTU for beer). In any case, breweries and beverage companies use turbidity



meters as essential QA tools. A **rise in turbidity** in a normally clear beverage can indicate contamination (microbial growth or foreign particles) or process issues, and thus turbidity is also a **health and safety concern**. As one industry article notes, *“haze is sometimes an indicator of contamination”* in beverages and should be monitored for both aesthetic and safety reasons.

Modern beverage QC may employ advanced instruments that can measure both color and haze simultaneously. For example, instead of separately using a turbidimeter for pulp content and a colorimeter for color, spectrophotometer systems can report **Haze % in liquids** along with color in one go. In fact, **haze % measurement can be used as an alternative to turbidity (NTU) for liquids like coconut water**, yielding a number more directly tied to what the human eye perceives.

In one case study, measuring coconut water, researchers found that using a haze percentage (light scatter in transmission) correlated well with visual perception of pulp content and clarity, and could substitute for a separate turbidity reading. This illustrates that the beverage industry sometimes borrows the “haze” concept from solid materials to describe liquid clarity in percentage terms, especially when using spectrophotometric instruments.

**In summary**, turbidity (or haze) measurement in beverages is critical for: ensuring compliance with health standards (in water), maintaining product consistency and consumer appeal (no unexpected cloudiness in juices or sodas), and detecting contamination or instability early. Quality engineers and production managers rely on turbidity specs (NTU limits) as a quick check of filtration efficacy and overall product quality.

## Pharmaceutical Manufacturing

Clarity of solutions is a crucial quality attribute in pharmaceuticals, especially for **injectable and parenteral products**. Any turbidity or opalescence in what is supposed



to be a clear sterile solution can indicate the presence of particulate matter or instability, which could pose serious health risks.

Regulatory pharmacopeias (USP, EP, JP, etc.) have strict guidelines on solution clarity: for example, injections must be “practically clear” and free from visible particles. Often the solution is examined against a black and white background; if a slight opalescence is present, it must not exceed a defined standard. The **European Pharmacopoeia (Ph. Eur.)** defines a method for “**Clarity and degree of opalescence of liquids**”, which includes visual comparison against reference **Formazin opalescent suspension standards**. Specifically, the EP establishes reference suspensions at defined turbidity levels: 3 NTU, 6 NTU, 18 NTU, 30 NTU, etc., corresponding to Reference Opalescence Standards I, II, III, IV. A pharmaceutical solution might be classified as “clear” (no opalescence above that of distilled water, ~0 NTU), “very slightly opalescent” (comparable to Reference I ~3 NTU), “slightly opalescent” (Reference II ~6 NTU), and so on. If an injectable drug shows opalescence beyond an acceptable level (e.g. more than slight), it will fail clarity specifications.

Visual methods are subjective, so instruments are increasingly used for quantification: **nephelometers and turbidimeters** are employed to measure opalescence in NTU for more objective control. The **USP <855>** and Ph. Eur. Section 2.2.19 provide guidelines for **instrumental measurement of opalescence (turbidity)** using turbidimetry (measuring transmitted light loss) and nephelometry (measuring scattered light).

In pharmaceutical water systems (for example, water for injection or purified water loops), turbidity is monitored as a general quality indicator as well, similar to environmental water standards. The limits are usually very tight (e.g. <0.1 NTU), since high purity water should be essentially free of particles.

Another aspect is **biopharmaceuticals (protein therapeutics)**: concentrated protein solutions (like monoclonal antibody drugs) can exhibit opalescence due to protein-



protein interactions forming subvisible aggregates. While the solution may technically remain sterile and usable, opalescence can indicate **suboptimal colloidal stability**, and it's generally considered an undesirable attribute to be minimized. Researchers and formulation scientists measure the turbidity/opalescence of biologic formulations to assess aggregation propensity and stability over time. Opalescence in this context is not just cosmetic; it correlates with phenomena like protein aggregation, which can impact efficacy and immunogenicity. Thus, controlling opalescence is part of ensuring the drug's quality. Modern analytical techniques allow very sensitive turbidity measurements on small-volume samples (even using **90° light scattering detectors in a temperature-controlled setup** to study opalescence and aggregation concurrently).

To summarize, in pharma manufacturing **turbidity/opalescence testing is vital** for: (a) **finished product clarity** (patient safety - no particulates or haze in injections), (b) **process water quality** (turbidity as an in-process control), and (c) **formulation development** (opalescence as a stability/quality indicator for complex drugs). Opalescence that **"indicates contamination or an unsafe product"** must trigger investigation. The industry adheres to standards and uses calibrated reference standards (like the Formazin primary standard of 4000 NTU and its dilutions) to quantify even slight opalescence in a consistent, traceable way. Quality control professionals and regulatory guidelines demand that any turbidity is quantified and within acceptable limits, making turbidity and haze measurement technologies indispensable in pharmaceutical QA/QC.

## Measurement Techniques and Standards

Measuring turbidity, haze, and opalescence reliably requires different techniques and instruments, though all are based on optical scattering principles. Below we discuss how each property is measured and the relevant standards or procedures (including **ASTM D1003 Procedures A and B** for haze, as well as others):



## Turbidity Measurement (Liquids)

**Turbidity** in liquids is typically measured with **nephelometric turbidity meters**, often simply called **turbidimeters** or **nephelometers**. The classic turbidity instrument directs a light beam (traditionally in the visible range for EPA method, or infrared for ISO method) into the sample and uses a photodetector at 90° to the incident beam to capture scattered light. The rationale is that purely clear liquid will scatter virtually no light to the side, whereas a turbid sample with many particles will scatter significant light into the detector. The output is calibrated in **NTU (Nephelometric Turbidity Units)** for EPA Method 180.1 (using a white light source) or **FNU (Formazin Nephelometric Units)** for ISO 7027 (which specifies a near-IR LED source at 860 nm). These units are equivalent in principle (1 NTU  $\approx$  1 FNU when calibrated to the same Formazin standard), and they are defined such that 1 NTU is the turbidity produced by 1 mg/L of *Formazin* polymer in water under standard conditions. **Formazin** is a polymer suspension used as a primary turbidity standard because it is stable and reproducible; a 4000 NTU stock suspension is prepared by a known chemical recipe, then diluted to create lower NTU standards. Many commercial turbidity standards (like StablCal) are based on Formazin or polymer microspheres and come in sealed vials around 0 NTU, 20 NTU, 100 NTU, etc., for instrument calibration.

In addition to 90° nephelometry, some instruments use a **ratio turbidimeter** design: they have multiple detectors at different angles (forward, side, backward) to compensate for particle size effects and sample color. These ratio meters calculate turbidity from a weighted combination of signals, yielding more consistent readings across a range of particle types. If the sample has an intrinsic color that absorbs light, ISO 7027's use of an IR light source helps minimize the influence of color on turbidity readings.

There are also older visual methods: the historical **Jackson Candle Turbidity** (measured in JTU, Jackson Turbidity Units) involved looking through a tube of water at



a candle flame and noting the depth at which the flame just disappears. That method has been largely superseded by electronic instruments but is conceptually an attenuation measure. Another simple field measure is the **Secchi disk**, used in lakes and oceans – a black-and-white disk is lowered into water until it's no longer visible, and the depth is noted as a transparency measure (deep Secchi visibility implies low turbidity). These are useful in situ but not precise in NTU. Modern instruments give a quick digital readout of NTU with high sensitivity (down to <math><0.1</math> NTU for clean water).

Key standards for turbidity measurement include: **ISO 7027-1:2016** (which outlines two methods – nephelometric and attenuation – for water turbidity), **U.S. EPA Method 180.1** (for regulatory drinking water turbidity), as well as guidelines by ASTM (ASTM D7315 for online turbidity, etc.). For beverages and other fluids, industry-specific bodies (like the American Society of Brewing Chemists, ASBC, for beer) have their own standardized turbidity methods, often still in NTU or similar units.

When measuring very **low turbidity** (as in pharmaceutical water or injectables), specialized low-range turbidimeters or **nephelometric instruments** are used, sometimes with a longer path length or a higher sensitivity detector (photomultiplier). USP <855> allows for two approaches: nephelometry ( $90^\circ$  scatter) and turbidimetry ( $0^\circ$  forward attenuation) and suggests using whichever is more appropriate for the expected turbidity level (nephelometry is more sensitive at low turbidities, generally).

It is important for QA/QC labs to properly calibrate the turbidimeter with standards and to keep sample cells (cuvettes) clean and unscratched. Even tiny scratches or residual droplets can scatter light and give false high turbidity readings. Techniques like matching cuvette orientation, use of index-matching oil on cuvette surfaces, and frequent calibration are employed to ensure accuracy. As described by an instrument manufacturer, maintaining and handling turbidity cuvettes requires care: thorough cleaning, avoiding scratches, and sometimes applying silicone oil to mask minor surface defects. Newer integrated systems (for example, a combined density and



turbidity measurement system for pharma use) even eliminate the need for cuvettes by measuring in a closed flow cell, improving reliability and reducing handling errors.

In summary, turbidity measurement uses **optical scattering techniques** to quantify how cloudy a liquid is. The primary unit is NTU, traceable to Formazin standards. **Accuracy and consistency** are ensured by following standards (ISO, EPA) and good measurement practices. These methods yield the data needed to make decisions about water treatment effectiveness, beverage filtration, or injectable solution acceptability.

### Haze Measurement (ASTM D1003 Procedures A & B and ISO equivalents)

**Haze in transparent plastics** is measured by specialized instruments defined in standards like ASTM D1003 *“Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics.”* ASTM D1003 provides two procedures for measuring haze:

- **Procedure A – Using a Haze meter (Direct Haze Meter Method):** This is the traditional method with a dedicated haze meter device. A haze meter typically consists of a light source, an integrating sphere, and detectors arranged such that it can separately measure total transmitted light and the diffused (scattered) light. In one configuration, a collimated light beam is passed through the sample and into an integrating sphere; first the total transmitted light (all light emerging from the sample) is measured at the sphere’s detector. Then a light trap or baffle is introduced to capture the directly transmitted (near-zero-angle) light, so that only the scattered light within the sphere is measured. From these measurements, haze % is computed as: **Haze = (Diffuse scattered light / Total transmitted light) × 100%**. In practice, Procedure A haze meters often use a *pivoting sphere* or a dual-detector setup to get these values. ASTM D1003 defines the geometry carefully – the sample is placed at the



entrance port of an integrating sphere, and the light trap at the exit port subtends an  $8^\circ$  angle (this ensures that only light scattered  $>2.5^\circ$  off-axis is considered diffuse, since  $2.5^\circ$  corresponds to a  $1.3^\circ$  annular exclusion around the direct beam). The haze meter reading directly gives haze % according to that standard geometry. Procedure A is considered the referee method for haze and produces precise results for materials up to a certain thickness and haze level.

- **Procedure B – Using a Sphere Spectrophotometer (Color Spectrophotometer Method):** This procedure allows a regular integrating-sphere spectrophotometer (the kind often used for color measurement with diffuse geometry) to be used for haze measurement. Many modern lab spectrophotometers have an integrating sphere (diffuse illumination) and a means to measure both total transmission and exclude the direct beam via a light trap. ASTM D1003 Procedure B outlines how such an instrument must be configured (e.g. an integrating sphere with  $<4\%$  total port area, diffuse illumination and an  $8^\circ$  viewing angle, etc.). Essentially, the spectrophotometer performs the same sequence: measure total transmittance (with sphere, sample in place, trap closed), then measure diffuse transmittance (with trap open to let direct beam escape or with an internal configuration to subtract it). The instrument's software then calculates haze%. This method is very convenient because one device can measure haze, color, and clarity. However, slight differences in sphere design can lead to small biases compared to a dedicated haze meter. ASTM D1003 acknowledges this: Procedure B spectrophotometers **generally agree closely with Procedure A haze meters**, especially at low haze levels, with at most a small bias (on the order of a couple haze units at higher haze values). For example, one note in ASTM D1003 (Table 4) indicates that at 30% haze, a sphere spectrophotometer might read about 2.5 units different



from a haze meter. To maintain accuracy, it is recommended to validate a Procedure B instrument with known calibrated haze standards.

Both Procedure A and B ultimately provide the same outputs: **haze %** and **luminous transmittance (%)**. Luminous transmittance is simply the total light transmitted ( $I_2$  relative to incident  $I_1$ ) and haze is the percentage of that which is wide-angle scattered. The ASTM standard calls for using CIE Standard Illuminant C (or A as an option) for the light source and a photopic detector response (since haze is defined for visible light). Many haze meters use a white light source approximating daylight and photopic filters.

Other standards similar to ASTM D1003 include **ISO 14782** (International standard for haze of transparent plastics) and **ISO 13468** (which covers luminous transmittance and could be related to haze measurement methods). These international standards use essentially the same principle (and the  $>2.5^\circ$  definition of haze). The ASTM and ISO methods both rely on integrating sphere optics to measure the scattered versus direct components of transmitted light. Some regional standards (JIS K 7105 in Japan, for example) also align with these geometries. Instrument manufacturers often design haze measurement instruments to comply with multiple standards (ASTM, ISO, JIS) simultaneously.

When performing a haze measurement, certain practical steps are taken: calibrating the instrument with an open port and a standard (often a clear glass or DI water with known 0% haze), making sure the sample is flat and free of surface dirt or fingerprints (which can add scattering). Samples are usually measured at a standard thickness (if thinner, often multiple layers are stacked to simulate a thicker sample, as long as multiple internal reflections are negligible) - ASTM D1003 allows samples up to 25.4 mm thick, but for very hazy or very thick materials, sometimes a modified approach is needed.



It's worth noting that **haze meters and clarity**: ASTM D1003 primarily quantifies wide-angle scatter (haze), while some instruments also report "clarity," which corresponds to the amount of light scattered at very small angles (typically  $<2.5^\circ$ ). Clarity is important when you want to know how sharp an image seen through the material would be. Some haze meter instruments (like those with a clarity meter attachment) measure narrow-angle scattering (within e.g.  $0.5^\circ$ ) as a clarity index. ASTM has a separate definition for "**clarity**" in some literature: the percentage of light that is scattered less than a small angle (often  $2.5^\circ$ ) - effectively the complement to haze in the forward direction. While our focus is turbidity/haze/opalescence, it's useful to know that what haze leaves out (the near-forward scatter) affects how well one can distinguish fine details through the material.

Beyond lab instruments, there are emerging **imaging-based haze measurement techniques** for situations where integrating spheres are impractical (e.g. measuring haze of installed large glass panels). These use a camera and defined targets to evaluate how contrast is reduced by the sample under diffuse illumination. But for standard QA/QC in manufacturing, ASTM D1003 type sphere instruments remain the workhorse.

In summary, **haze measurement** uses **integrating sphere optics** to separate and quantify scattered light. **Procedure A (Haze meter)** is the primary method, while **Procedure B (Sphere spectrophotometer)** is an alternative that offers additional color measurement capabilities. Both must adhere to the same geometric criteria to produce valid haze values. These methods ensure that manufacturers of transparent products can **numerically quantify "cloudiness"** and verify compliance with specifications for transparency.

## Opalescence Measurement (Pharma and Fine Chemicals)



Measuring **opalescence** in liquids is essentially a low-level turbidity measurement. Pharmacopoeias define both **visual and instrumental methods** to assess the clarity of liquid products:

- **Visual Method (Ph. Eur. 2.2.1 Clarity and Degree of Opalescence):** A sample is compared against prepared reference suspensions under controlled lighting and background. The EP reference suspensions are Formazin-based: for example, Reference Suspension I (very slightly opalescent) is about 3 NTU, II is ~6 NTU, III ~18 NTU, IV ~30 NTU. Distilled water serves as the reference for “clear” (essentially 0 NTU). An operator views the sample and reference in identical tubes – if the sample’s cloudiness is not worse than Reference I, it might be classified as “very slightly opalescent” or essentially clear for most purposes. This visual method is qualitative, but it is part of pharmacopeial standards for release testing. It relies on human observation, which can be subjective, so clear instructions are provided (e.g. view against a black background with specified lighting).
- **Instrumental Method (USP <855> / Ph. Eur. 2.2.19 Nephelometry and Turbidimetry):** Here, one uses a calibrated nephelometer or turbidimeter to measure the sample’s turbidity in NTU, providing an objective number. The pharmacopeial chapters outline that instruments should be calibrated with the primary standard (Formazin 4000 NTU) diluted to the low range of interest. For example, the USP specifies using the Formazin standards corresponding to the EP references. Many pharmaceutical labs now use electronic turbidity meters for opalescence, especially for cloudy injections or complex formulations, as it gives a precise value that can be tracked over time or compared between labs. USP <855> even distinguishes between **turbidimetry (measuring transmitted light loss)** and **nephelometry (measuring scattered light)** and indicates both can be used to quantify opalescence. Nephelometry (90° scatter) is often more sensitive for low opalescence. The results are typically reported in NTU and



sometimes converted or correlated to an “Opalescence Unit” scale equivalent to the EP’s standards (some software can directly give an “EOP (European Opalescence) units” reading for a 10 mm cell pathlength). In fact, instrument makers have implemented algorithms to report “EPO (European Pharmacopoeia Opalescence) units” alongside NTU, since the scale 0, 3, 6, 18, 30 NTU is well-defined by the EP standards.

The technology used for opalescence measurement is essentially the same as turbidity meters described earlier. However, pharmaceutical applications often require instruments that can handle **small sample volumes**, since some drug products are very costly or only available in small quantities. Solutions include flow cells or microcuvette nephelometers. One advancement mentioned in literature is using a **90° light scattering detector with precise temperature control**, enabling measurements on protein solutions with only a few milliliters of sample and allowing detection of subtle changes (since temperature can affect protein aggregation and thus opalescence).

**Standards and calibration:** The **Formazin Primary Opalescent Suspension (4000 NTU)** is prepared by mixing hexamethylenetetramine and hydrazine sulfate solutions (per EP recipe). From this, a **Formazin Standard of Opalescence (60 NTU)** is made by dilution, and then further dilutions yield the reference opalescence levels I-IV. Laboratories can either prepare these fresh (noting that some are only stable for a short time) or purchase stabilized standards from suppliers.

In routine pharmaceutical QC, a product might have a specification like “turbidity < 2 NTU” or “solution clarity = not more opalescent than Reference Standard II” for release. During stability studies, any increase in opalescence over time would be a red flag indicating potential degradation or particle formation. In injectables, **visual inspection for particles** is mandated (to catch any visible foreign particles), but opalescence measurement picks up what the naked eye might not clearly discern (sub-visual haze).



Beyond pharma, **opalescence measurement** can apply in other fine chemical industries - for example, high-purity chemicals or cosmetics, where clarity of a solution is expected. The techniques and standards (NTU via calibrated nephelometer) are the same.

In summary, **opalescence is measured using turbidity techniques** with an emphasis on the low end of the turbidity scale. Pharmacopeial standards guide both the subjective assessment and the quantitative measurement using Formazin-calibrated instruments. The goal is to ensure that liquids that are supposed to be clear indeed have only negligible light scattering. As one instrument provider notes, for most pharmaceutical liquids **"opalescence-inducing particles indicate contamination or even an unsafe product"**, underscoring why these measurements are so critical.

## Side-by-Side Comparison of Turbidity, Haze%, and Opalescence

To clarify the differences and overlap of these three concepts, **Table 1** provides a comparative overview:

**Table 1. Comparison of Turbidity, Haze%, and Opalescence**

Aspect	Turbidity (Cloudiness in Liquids)	Haze % (Transmission Haze in Solids/Liquids)	Opalescence (Slight Haze in Liquids)
Definition	Cloudiness or haziness of a fluid caused by suspended particles. It describes how murky a liquid is due to light scattering by those particles.	Fraction of transmitted light through a transparent sample that is scattered at large angles ( $>2.5^\circ$ ). Essentially the percentage of light deviating from the direct path, causing a cloudy appearance in a clear material.	Milky or pearly appearance in an otherwise clear liquid due to very fine particles scattering light. Opalescence implies a slight iridescent haze (like opal) rather than an overt cloudiness.



<b>Aspect</b>	<b>Turbidity (Cloudiness in Liquids)</b>	<b>Haze % (Transmission Haze in Solids/Liquids)</b>	<b>Opalescence (Slight Haze in Liquids)</b>
<b>Typical Usage</b>	Primarily for <b>liquids</b> (water, beverages, suspensions, etc.) to indicate clarity/quality. Sometimes used generally for any fluid (including gases) that is not transparent.	Primarily for <b>transparent solids</b> (plastics, films, glass). Also applied to translucent liquids when using haze-meter methods (e.g. measuring haze of juices). Generally used when evaluating <b>optical materials' clarity</b> (packaging, lenses, displays).	Mainly in <b>pharmaceutical liquids</b> (injections, solutions) and some beverages to describe slight, colloidal haze. Used when clarity is expected but a faint haze is observed. Not typically quantified in everyday industrial use except in pharma.
<b>Measurement Unit</b>	<b>NTU (Nephelometric Turbidity Units)</b> or <b>FNU</b> , measured with a calibrated nephelometer (Other units like JTU or Secchi depth are older/qualitative.) Lower NTU = clearer. For example, drinking water <1 NTU, while very cloudy juice could be tens or hundreds of NTU.	<b>Haze Percentage (%) =</b> (Diffuse scattered transmitted light / Total transmitted light) × 100. No unit (percentage of light). Often measured at a specified thickness; values range 0% (optically clear) to 100% (all light highly scattered). Many packaging materials have haze <5%, vs. a frosted plastic may have >50% haze.	Often reported qualitatively (e.g. "slightly opalescent") or in <b>NTU</b> if quantified. Pharmacopeia visual standards correspond to ~3, 6, 18, 30 NTU for different degrees of opalescence. Instruments can measure it in NTU (and some convert to an opalescence scale).
<b>Measurement Method</b>	<b>Nephelometry</b> (90° light scatter detection) and/or <b>Turbidimetry</b> (0° transmission loss). Instruments: turbidimeter with a light source and photodetector at 90°. Calibrated with Formazin or equivalent standards. Standards: e.g. ISO	<b>Integrating Sphere Haze Meter</b> or Sphere Spectrophotometer per ASTM D1003. Measures total transmitted light vs scattered light beyond 2.5° angle. Procedure A: dedicated haze meter (with specified geometry, light trap etc.). Procedure B: spectrophotometer with diffuse/8° geometry	<b>Visual comparison</b> against reference suspensions for qualitative assessment. <b>Nephelometric measurement</b> for quantitative results (using a turbidity meter at 90°). Follows guidelines like Ph. Eur. 2.2.1/2.2.19 and USP <855>. Calibration with low-NTU



<p>Aspect</p>	<p><b>Turbidity (Cloudiness in Liquids)</b> 7027 (IR LED, FNU) and EPA 180.1 (visible light, NTU). Often uses <b>Formazin</b> primary standard and calibrated polymer bead standards.</p>	<p><b>Haze % (Transmission Haze in Solids/Liquids)</b> meeting D1003 specs. Calibrated using haze standard samples (glass or film with known haze %) and open-port calibration. Other standards: ISO 14782 (similar method).</p>	<p><b>Opalescence (Slight Haze in Liquids)</b> standards (Formazin dilutions: 0-30 NTU range). Often measured in a 1 cm cuvette or similar cell. Instrumentation is basically a high-sensitivity turbidity meter.</p>
<p>Importance &amp; Impact</p>	<p><b>Water quality &amp; Beverage clarity:</b> Turbidity is regulated in drinking water (health concerns if high). In beverages, turbidity affects appearance and can indicate spoilage or contamination. Also used in industrial processes (filter monitoring, wastewater treatment). High turbidity can foul equipment and is generally undesirable unless intended (e.g. some unfiltered beers).</p>	<p><b>Product appearance &amp; function:</b> Haze in plastics affects <b>visibility and aesthetics</b> of packaged goods. In optics, haze causes glare and loss of image clarity (critical for lenses, screens). Manufacturers specify max haze to ensure performance (e.g. automobile headlamp covers must have low haze for safety). Haze can also reveal material issues (impurities, poor dispersion, surface texture) so it's a QC indicator.</p>	<p><b>Pharmaceutical safety &amp; stability:</b> Opalescence in an injection can signal unacceptable particulates or instability (aggregates), potentially making a product unsafe. Pharmacopeias require checking opalescence to ensure solutions are "clear" before release. In biopharmaceutical R&amp;D, opalescence is monitored as part of formulation development because it correlates with protein aggregation propensity. In general, any unexpected opalescence in a drug or high-purity chemical triggers investigation and possible rejection of the batch.</p>



As the comparison shows, turbidity, haze, and opalescence are closely related - all involve **light scattering by particles or micro-structures** - but they are distinguished by context and degree. Turbidity is the broad term that is most often applied to **liquids**, haze is a specific quantified measure for **transparent solids (or films)** (expressed in %), and opalescence is a descriptive term for a **very slight haze in liquids**. In many cases the same fundamental instruments (light scattering detectors) are used to measure them, just in different units or scales.

For example, a plastic bottle's clarity might be reported as 2% haze (per ASTM D1003), the water it contains might be 0.5 NTU turbidity (EPA method), and a pharmaceutical injection in that bottle should be essentially 0 NTU with "no opalescence" (per EP visual inspection). Each measure tells us about the quality and suitability of the material or fluid for its intended use - clear vision, appealing appearance, or safe injection into a patient.

## HunterLab Solutions for Measuring Haze, Turbidity, and Opalescence

HunterLab's family of high-precision spectrophotometers provides standardized, traceable, and repeatable measurements of color, haze, turbidity, and opalescence across liquids, solids, and translucent materials. The **Vista**, **UltraScan VIS**, and **UltraScan PRO** each meet or exceed ASTM D1003, ISO 14782, ISO 7027, and pharmacopeial clarity requirements, offering scalable options for both production QA and advanced research.

### Vista™ (d/0° Sphere Geometry - Transmission)

The Vista spectrophotometer combines color and haze measurement for transparent and translucent materials in a compact, spill-resistant design. Using diffuse illumination



and 0° viewing geometry (d/0°), it accurately quantifies appearance attributes that align with human visual perception.

**Applications:** Beverages, purified and processed water, flavor extracts, clear pharmaceutical solutions, cosmetics, and other transparent or slightly opalescent liquids; translucent and transparent plastic films, sheets, ophthalmic lenses, and bottles.

**Key Capabilities:**

- Measures color and haze % in transmission per ASTM D1003 Procedure B, producing results equivalent to a dedicated haze meter.
- Simultaneously reports CIELAB (and other color metrics) and haze %, streamlining clarity and color evaluation in one test.
- Accepts cuvettes, test vials, and flat films/sheets, supporting both liquid and solid transparent samples.
- Exceptional sensitivity (<0.1 haze %) enables early detection of turbidity or opalescence in otherwise clear materials.

**Typical Use:** Ensuring clarity and consistency in bottled water, juices, and injectables, as well as evaluating haze and optical uniformity in transparent packaging materials, ophthalmic lenses, and polymer films.

**UltraScan VIS™ (d/8° Integrating-Sphere Spectrophotometer)**

The UltraScan VIS delivers precision measurement of haze %, total transmittance, and color in both solid and liquid samples. It is fully compliant with ASTM D1003 Procedure B and ISO 14782, making it the benchmark for optical quality control.



**Applications:** Plastic films, PET preforms, bottles, display lenses, and transparent packaging components.

**Key Capabilities:**

- Measures total and diffuse transmittance to quantify wide-angle scatter causing haze.
- Operates in both reflectance and transmittance modes for complete optical profiling.
- Provides stable, repeatable results for materials used in automotive, electronics, and consumer packaging applications.

**Typical Use:** Evaluating haze and clarity uniformity in liquids, polymer films, molded parts, and packaging where optical transparency and surface quality directly affect appearance and function.

**UltraScan PRO™ (d/8° Integrating-Sphere Spectrophotometer / UV-VIS-NIR High-Resolution Spectrophotometer)**

The UltraScan PRO provides the highest level of analytical precision for research-grade optical, pharmaceutical, and advanced materials applications. Its extended wavelength range (350 – 1050 nm) allows precise measurement of color, haze, transmittance, and opalescence even in highly pure or photoactive samples.

**Applications:** High-transparency polymers, ophthalmic materials, coatings, and pharmaceutical or biopharmaceutical liquids.

**Key Capabilities:**



- Measures haze %, color, and transmission with spectral accuracy exceeding ASTM D1003 Procedure B.
- Detects very low-level opalescence (< 1 NTU equivalent), ideal for clarity testing per USP <855> and Ph. Eur. 2.2.1 / 2.2.19.
- Optional UV control filters enable evaluation of optical brighteners, UV-active coatings, or photo-stability.

**Typical Use:** Assessing color, clarity, and stability of injectables, diagnostic reagents, and advanced optical polymers where trace haze or opalescence indicates product quality.

Together, HunterLab's Vista, UltraScan VIS, and UltraScan PRO provide a unified platform for haze, turbidity, and opalescence measurement across every form of material—from clear beverages and pharmaceuticals to transparent films and optical components. By combining colorimetric precision with haze and clarity quantification, these instruments enable manufacturers to maintain product quality, ensure regulatory compliance, and enhance visual appeal through objective, traceable measurement.

## Conclusion

In industrial manufacturing and quality control, understanding **turbidity, haze%, and opalescence** is crucial for maintaining product quality and consistency. These properties, while related, apply to different scenarios - from the clarity of a drink or drug solution (turbidity/opalescence) to the transparency of a plastic film or lens (haze). They are important because they directly impact **performance (optical function), aesthetics (consumer perception), and even safety (contaminants in water or injectables)**. Technical standards such as **ASTM D1003** for haze in plastics and **pharmacopeial methods for opalescence** in liquids provide frameworks to measure and control these properties. Modern technologies (integrating spheres, laser nephelometers, etc.) enable precise quantification without reliance on subjective



observation, which helps industry professionals in QA/QC roles ensure that materials and products meet stringent specifications. By comparing turbidity, haze, and opalescence side by side, we appreciate that all three describe **loss of clarity due to light scattering**, yet each term has its domain of relevance and method of measurement. A clear understanding of these concepts allows engineers and scientists to troubleshoot processes (e.g. finding the source of haze in a plastic or the cause of turbidity in a beverage) and to innovate better products (such as ultra-clear packaging, stable protein solutions, or brilliantly clear beverages) that meet the high expectations of both regulators and consumers.