The Importance of Liquid Temperature Control

in the Food and Beverage Industry

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TEMPERATURE CONTROL

Abstract

Temperature control is a critical factor in various processes within the food and beverage industry. This whitepaper highlights the significance of liquid temperature control, specifically focusing on distillation, fermentation, rheometry, viscometry, and fat and fiber analysis. The paper discusses the importance of temperature control in each application and provides insights into the equipment and techniques required for accurate and efficient temperature management. Created for scientists and laboratory managers within the industry, this whitepaper will enhance understanding of liquid temperature control's crucial role in ensuring product quality, consistency, and safety.

In this document

Introduction

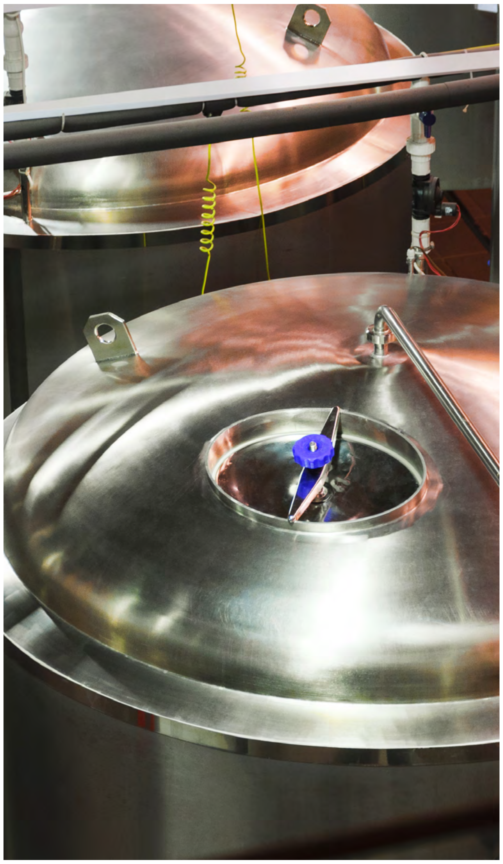
Liquid temperature control is a critical aspect of numerous processes within the food and beverage industry. It ensures product quality, consistency, and safety by maintaining optimal temperatures throughout various applications, including distillation, fermentation, rheometry, viscometry, and fat and fiber analysis. This whitepaper highlights the importance of liquid temperature control in these applications and provides insights into the necessary equipment and techniques for successful temperature management.

The Role of Temperature Control in Distillation

Distillation plays a vital role in the production of alcoholic beverages, essential oils, and other liquid-based products. Precise temperature control is crucial for separating and collecting desirable compounds through vaporization and condensation. Accurate temperature control ensures the separation of components with minimal loss or degradation, resulting in high-quality end products.

As the basics of distillation are directly related to thermodynamics, we want to shed some light on the processes involved. First, distillation is the process of separating groups of molecules from a mixture, reducing entropy. According to the second law of thermodynamics, all spontaneous processes increase the entropy of the universe. However, distillation is not a spontaneous process. We must employ energy in the form of added heat to start this non-spontaneous process. By doing so, molecules from the liquid move faster, and therefore show higher entropy, transforming from a liquid state to vapor– a state known to have even higher entropy content. After cooling the gases down, condensing them and collecting the various contents separated into fractions, the entropy is lower than the previous mixture, which sounds like a paradox.

The Role of Temperature Control in Distillation (continued...)



When separating molecules by different boiling points we make use not of the specific entropy but of the inherent molecule, specific enthalpy. H = E + PV. A molecule with a lower enthalpy will boil more easily and transfer into the receiving vessel earlier than another material with a higher enthalpy content.

Let us take a water/ethanol mixture for example:

Water has a ΔH at vaporization of 40.7 kJ/Mol boiling at 100 °C and Ethanol has a ΔH of 38.7 kJ/Mol boils at 78 °C. So less energy input in the form of heat lets ethanol boil first. When the temperature stays constant, ethanol vapor condenses at a cooler place, i.e., the condenser, cooled by a chiller, runs off the condenser into the receiving flask. When all the ethanol is gone the additional heat increases the temperature until another group of molecules can be vaporized. As with the water/ethanol mixture example, it then forms steam and condenses to form water again with a lower entropy in the fraction than in the previous mixture. A fascinating process of thermodynamics is at play.

What we need to make this process controllable are tunable heating and cooling sources, which, again, according to the zeroth law of thermodynamics (heat flows from the hotter object to the cooler one if in contact until it reaches equilibrium) heat or cool the boiling flask and cool the condenser respectively, precisely adding and extracting the right amount of heat and in a precise fashion.

If we would like to achieve distillation by a campfire on the one end and the cool air outside to cool, it could generally work, but the separation would not be good enough to get a pure separation of the mixtures ingredients. There will be a carry-over of water into the alcohol fraction.

Due to the fine-tuning abilities of how much energy is added or subtracted from a system, it is possible to get consistent results quickly with high purity compared to other methods of separation as there are filtration, chromatography, centrifugation or crystallization, which all have their advantages as well in their respective applications.

Equipment and Techniques for Temperature Control in Distillation

Temperature control in distillation is achieved through various equipment and techniques, including reflux condensers, temperature sensors, and heating or cooling systems. The selection and implementation of appropriate equipment, such as jacketed vessels and heat exchangers, allow for precise temperature adjustments during different stages of the distillation process.

To efficiently heat a evaporator vessel as well as cool the condenser, JULABO USA offers the following highly precise instrumentation.

For heating the distillation flask, you may use a **CORIO CD**[1] or **CORIO CP**[2] as two recently cited examples in research literature show. Other appropriate JULABO instruments are the **FP51-SL**[3] and many others from the **DYNEO** or **MAGIO** line.

For cooling the condenser, the **CORIO 300F** for example[4] is a good choice or a recirculating chiller of the JULABO **F-series**[5] or the **PRESTO** line for more demanding applications[6].

1 Ricceri, Francesco, et al. "Understanding the evolution of organic fouling in membrane distillation through driving force and resistance analysis." Journal of Membrane Science (2023): 121993.
2 Carrio, Juan AG, et al. "Gas stripping assisted vapour permeation using graphene membrane on silicon carbide for ethanol recovery." Scientific Reports 13.1 (2023): 9781.
3 Gautam, Ribhu, et al. "On the products from the pyrolysis of heavy fuel and vacuum residue oil." Journal of Analytical and Applied Pyrolysis (2023): 106060
4 Valério, Rita, Carla Brazinha, and João G. Crespo. "Comparative analysis of bio-vanillin recovery from bioconversion media using pervaporation and vacuum distillation." Membranes 12.8 (2022): 801.
5 Lichtinger, Anne, et al. "Nile red as a fluorescence marker and antioxidant for regenerative fuels." Energy Technology.
6 Regueira, Teresa, et al. "Density, compressibility and phase equilibrium of high pressure-high temperature reservoir fluids up to 473 K and 140 MPa." The Journal of Supercritical Fluids 159 (2020): 104781.

Understanding the Impact of Temperature on Fermentation

Fermentation is a fundamental process in the production of alcoholic beverages, vinegar, dairy products, and fermented foods. Temperature control during fermentation is crucial as it directly affects microbial activity, enzymatic reactions, and the production of desirable compounds. Precise temperature control ensures optimal fermentation conditions, resulting in consistent, safe and high-quality products.

What makes fermentation an exciting process is that not only are microbial enzymes are employed to create a plethora of products, but these enzymes also act as catalysts, and this influencing the thermodynamics of the system. The purpose here is to save a lot of energy compared to chemical synthesis. When we look at ethanol again, we know a yeast can produce glucose between 28-33 °C, which needs to be kept constant, compared to a synthesis from ethene at around 300 °C. The product might be purer with the chemical synthesis but for food and beverage purposes we need by-products that add flavor, color, and texture, and modulate hormone levels[7].

7 Montrond Correia, Carla, 2023, Care of, Food that Balance Female Hormones, accessed 9/1/2023, https://www.takecareof.com/articles/foods-that-balance-female-hormones

Equipment and Techniques for Temperature Control in Fermentation

Fermentation temperature control is achieved through various equipment and techniques, such as fermentation chambers, fermenters with cooling jackets, and temperature controllers. These systems allow for monitoring and adjusting fermentation temperatures to maintain ideal conditions for microbial activity and enzyme kinetics. All of these above perform precise temperature control around ambient temperature, i.e., 25 °C to about 37 °C, depending on the microbes or cells utilized. In rare cases, temperatures up to 60 °C are utilized for thermophilic microorganisms.

Fermentation vessels made from glass or stainless steel should have accessory ports to add gases and nutrients and for sampling of probes. The jacketed reactors can be controlled using circulators. For example, the **CORIO CD-200F**[8] or **DYNEO DD-1000F**[9] and for lower temperatures like 10 °C the **F500**[10] or **F1000** in case you are working with mesophilic microorganisms.

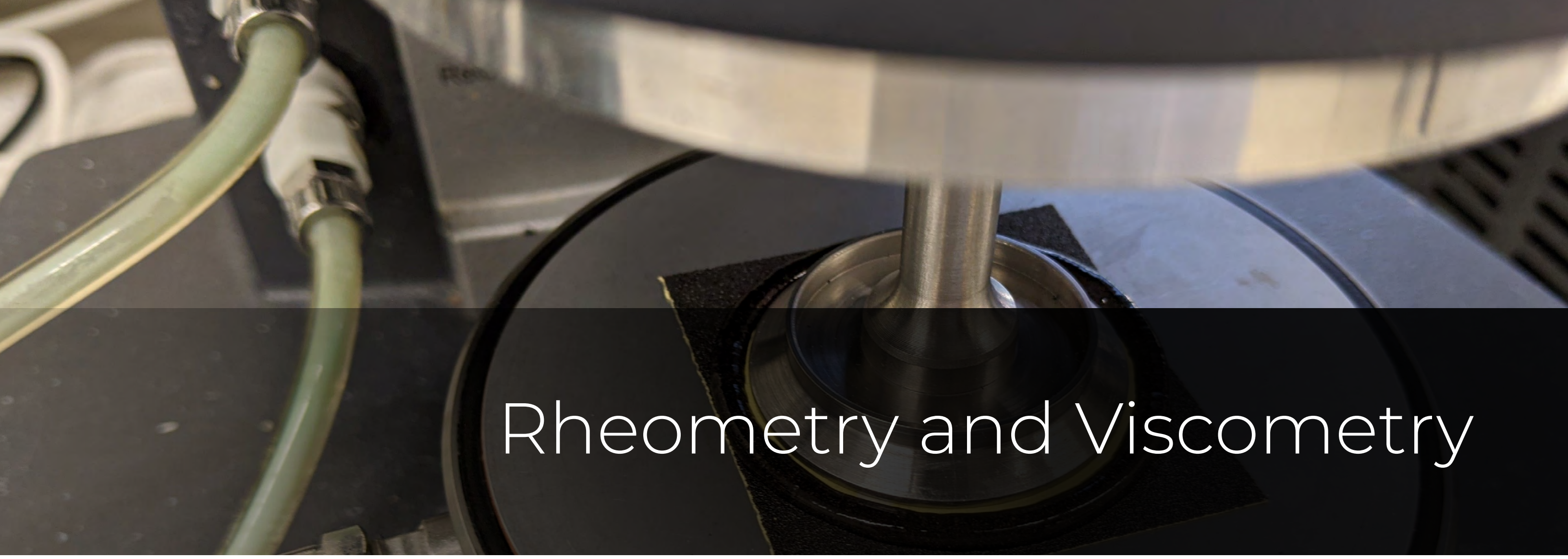
For small scale experiments the shaking water baths as the **SW22**[11] are very effective.

8 van Holst Pellekaan, Nicholas, Michelle E. Walker, Tommaso L. Watson, and Vladimir Jiranek. "'TeeBot': A High Throughput Robotic Fermentation and Sampling System." Fermentation 7, no. 4 (2021): 205.

9 Nemer, Georgio, Nicolas Louka, Paul Rabiller Blandin, Richard G. Maroun, Eugène Vorobiev, Tristan Rossignol, Jean-Marc Nicaud, Erwann Guénin, and Mohamed Koubaa. "Purification of Natural Pigments Violacein and Deoxyviolacein Produced by Fermentation Using Yarrowia lipolytica." Molecules 28, no. 11(2023): 4292.

10 Poblete-Castro, Ignacio, et al. "High-Level Bioremediation of Diesel Contaminated Seawater in Continuous and Batch Bioreactors Using Antarctic Bacterial Consortia: Pollutant Analysis and Microbial Community Dynamics at Cold and Mesophilic Temperatures." Available at SSRN 4183195.

11 Beeck, Regine, et al. "An Advanced Bioreactor Simulating Dynamic Physiological Conditions in the Human Ascending Colon: MimiCol3." Pharmaceutics 14.5 (2022): 1049.



Rheometry and Viscometry

The Difference Between Rheometry and Viscometry

In general, rheology is a physical discipline that studies the flow of matter and viscometry is a measurement of the flow, which in turn is dependent on the forces applied. A rheometer measures how a liquid flows in response to applied forces whereas a viscometer measures the viscosity of a fluid under one flow condition.

In simple terms a spread on a slice of bread is exposed to shear forces by the scraping knife and the forces act in various dimensions compared to the viscosity of honey, which drips from the bottle based on the force of gravity alone. Another good example is cream, which easily flows with a low viscosity, but when it’s exposed to shearing forces like with a mixer, it turns into whipped cream, which has a much higher viscosity and can even hold a spoon upright. In other words, viscosity describes the resistance of a fluid to flow.

Rheometers can either be rotational, which applies shear stress onto the fluid, or extensional ones, which apply extensional stress. Viscometers on the other hand either move an object through the fluid, measuring the friction of the object, or move the fluid through an object like a capillary, measuring the friction experienced by the fluid by passing the object.

The Influence of Temperature on Rheology

In food, the texture and rheological properties are important for the product's shelf life and the overall consumer experience. For example, a cheese spread needs to achieve and maintain the proper consistency to delight a customer. Rheometers are used to measure this physical property, using an off-line capillary or a rotational measurement. A circulator such as the Julabo **DYNEO DD-1000F** or **CORIO CP-200F** or **CORIO CD-600F** can be employed to keep the temperature constant[12], [13], [14].

Equipment and Techniques for Measuring Viscometry of Fluids

Viscometry analyzes the characteristics of the flow of liquids, such as honey or ketchup that need to maintain the same characteristics over time. As liquids tend to flow quicker when they get warmer, it is critical to test products under various environmental conditions. Viscometers, which also use a capillary system, can measure the speed of the liquid flowing through an obstruction. For this type of viscometry measurement, the JULABO **CORIO CD-BC4**[15] can be used, or it measures the rotational force resisting a paddle stirred in a beaker, Julabo equipment as the **DYNEO DD** can be utilized effectively[16].

12 Nilsson, Klara, Mathias Johansson, Corine Sandström, Hanna Eriksson Röhnisch, Mikael S. Hedenqvist, and Maud Langton. "Pasting and gelation of faba bean starch-protein mixtures." Food Hydrocolloids 138 (2023): 108494.
13 Seighalani, Fariba Zad Bagher, Donald J. McMahon, and Prateek Sharma. "Determination of critical gel-sol transition point of Highly Concentrated Micellar Casein Concentrate using multiple waveform rheological technique." Food Hydrocolloids 120 (2021): 106886.
14 Mateen, Abdul, and Gurmeet Singh. "Evaluating the potential of millets as blend components with soy protein isolate in a high moisture extrusion system for improved texture, structure, and colour properties of meat analogues." Food Research International (2023): 113395.
15 Laranjo, Mayara Rocha, Bernardo de Sá Costa, and Edwin Elard Garcia-Rojas. "Stabilization of gelatin and carboxymethylcellulose water-in-water emulsion by addition of whey protein." Polímeros 29 (2020).
16 Nemer, Georgio, et al. "Purification of Natural Pigments Violacein and Deoxyviolacein Produced by Fermentation Using Yarrowia lipolytica." Molecules 28.11 (2023): 4292.

Fat and Fiber Analysis

Significance of Temperature Control in Fat and Fiber Analysis

Accurate fat and fiber content analysis is essential for product labeling, nutritional information, and quality control in the food and beverage industry. Temperature control is a critical factor in these analytical processes as it ensures sample preservation, reaction efficiency, instrument calibration, and method standardization. Proper temperature control enhances the accuracy and reliability of fat and fiber analysis, enabling manufacturers to make informed decisions about product composition and quality.

Equipment and Techniques for Temperature Control in Fat and Fiber Analysis

Temperature control in fat and fiber analysis is achieved through specialized equipment, including analytical machines with built-in temperature control mechanisms like the ones from ANKOM[17]. These machines allow for precise temperature regulation during the analysis process. Additionally, sample preparation techniques, temperature-controlled storage, and calibration procedures contribute to accurate temperature control and reliable analysis results[18]. For example, for artificial meat products, where there is a higher demand to analyze these nowadays, Julabo circulators as the 600F are used for precise fat and fiber analysis[19].

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17 Urrego, Maria Isabel Gonzalez, et al. “Nutritional composition and evaluation of different methodologies for fat determination in wet feed for dogs and cats.” Brazilian Journal of Veterinary Research and Animal Science 54.4 (2017): 398-406.
18 McCleary, Barry V., and Ciara McLoughlin. “Determination of Insoluble, Soluble, and Total Dietary Fiber in Foods Using a Rapid Integrated Procedure of Enzymatic-Gravimetric-Liquid Chromatography: First Action 2022.01.” Journal of AOAC International 106.1 (2023): 127-145.
19 Zahari, Izalin, et al. “Extrusion of high-moisture meat analogues from hempseed protein concentrate and oat fibre residue.” Journal of Food Engineering 354 (2023): 111567.

Conclusion

Liquid temperature control is paramount in the food and beverage industry for distillation, fermentation, rheometry, viscometry, and fat and fiber analysis applications. Accurate temperature management ensures the production of high-quality products, consistency in process outcomes, and compliance with regulatory standards. By employing appropriate equipment and techniques specific to each application, scientists, and laboratory managers can enhance their ability to achieve reliable and precise temperature control, improving product quality and safety.

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