



Research Status and Prospect for Vibration, Noise and Temperature Rise-Based Effect of Food Transport Pumps on the Characteristics of Liquid Foods

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In the field of food processing, the processing of liquid foods has always played an important role. Liquid foods have high requirements for the processing environment and equipment. As the core equipment in liquid foods processing, food transport pumps are widely used in liquid foods production, processing and transportation. Most liquid foods are non-Newtonian and vulnerable to vibration, noise, and temperature rise produced by rotary motions of food transport pumps in operation, which can finally affect foods safety. Therefore, this review summarizes the impact of mechanical vibration, noise, and temperature rise on liquid food products, with the aim of ensuring food safety while designing a cleaner, safer and more reliable food transport pumps in the future.

Keywords: vibration, noise, temperature rise, food transport pump, liquid foods

INTRODUCTION

With the continuous development of economy and society, food safety is not only a major public health safety issue (1), but also a major issue related to people's survival and development and nutritional health (2–4). The impact of all links of food production on food safety cannot be ignored, especially in food processing and transportation (5–7). The processing of liquid foods such as peanut butter, beer, and milk makes enormous demands on delivering equipment. Due to the different molecular structures and physical parameters of various liquids, the impact of physical parameters of various equipment operation (mainly including vibration, noise and temperature rise) on liquid foods should be considered during the transportation of liquid foods (8–11). Food transport pumps accelerate the output of liquid food under pressure, thus realizing efficient and stable conveyance of liquid foods. It is the core delivering equipment in the production process of liquid foods. The most used two types of food transport pumps are vane pumps and positive displacement pumps (12–14). Vibration, noise and temperature rise caused by long-term operation are ubiquitous in the use of food transport pumps (15–19).

When delivering liquid foods, pressure pulsation exists in the flow field due to the rotor–stator interaction between the vanes and volutes of the pump. Such pressure pulsations will result in the vibration and noise of the pump (20–23). In addition, local temperature rise of liquid foods in pump impeller and volute will occur during operation of food transport pumps, which will affect the safety of liquid foods (24, 25). Vibration, noise, and temperature rise of liquid foods are inevitable in the process of transfer. Extensive research efforts have been made to investigate the effect of such factors on the quality of liquid foods. This review focuses on the impact of liquid foods in the transfer process in terms of mechanical vibration, noise, and temperature rise.

EFFECT OF VIBRATION-INDUCED FACTORS ON LIQUID FOODS

Vibration in the process of transfer can negatively affect liquid foods (milk, liquor, yogurt, juice, etc.). For example, during yogurt fermentation, the vibration caused by large yogurt transfer pumps will spread to the fermenter (26), and the characteristic frequency of vibrations can affect pH and disturb protein network formation, which can lead to defects in yogurt texture (27). Körzendörfer et al. (28) tested the effect of vibration on the fermentation process of yogurt, and showed that mechanical vibration causes yogurt to produce large particles on the millimeter scale during stirring, while this particle formation is mainly induced by changes in yogurt pH (29). According to particle image velocimetry results, vibration forces the yogurt to undergo vertical back and forth movements, which leads to local protein breakage during aggregation and gelation, making the yogurt more susceptible to syneresis during storage (30). Richmond et al. (31) studied the stability of yogurt during simulated transport in different secondary packaging. Textural defects caused by vibration include whey and cracked or completely destroyed coagulum. In contrast, agitated yogurt might suffer from structural losses (such as hardness) and phase separation in the process of transfer (32, 33). In addition, the vibration can affect the concentration of aldehydes, especially at higher storage temperatures (34). Jaskula-Goiris et al. (10) have studied the beer production process, and found that vibration can lead to intensified collisions between fluid molecules, which can cause beer to undergo oxidative reactions and thus become turbid.

However, studies also have showed that mechanical vibration also positively affects liquid foods. Stoforos et al. (35) examined the effect of vibration on thermal mixing of liquid foods during cooling of several highly viscous foods, potato puree, banana puree, applesauce, and cheese sauce was investigated, and the results showed that thermal mixing of liquid foods was improved under low frequency lateral vibration. Low frequency lateral vibrations can homogenize the temperature distribution of liquid foods while also accelerating food cooling. Kim et al. (36) found that resonance vibration could alleviate the membrane fouling problem of whole milk during filtration process, and resonance vibration could more effectively alleviate the fouling

phenomenon of milk. Salek et al. (37) concluded that mechanical vibration can convert mechanical energy into thermal energy and enhance the hardness, storage modulus, and viscosity of cheese sauce. Warmińska et al. (38) studied the effect of vertical vibration (10–60 Hz, 0.5–2 h) on raw milk, and found that vibration increases electrical conductivity, while also altering the heat and clotting behavior of chymosin. Czerniewicz et al. (39) revealed that vibration decreased the pH of raw milk while increasing the amount of free fatty acids (40).

EFFECT OF NOISE-INDUCED FACTORS ON LIQUID FOODS

Both noise and acoustic wave characteristics have a significant effect on food safety (41–43). Ultrasound has a more pronounced physical effect on milk and dairy products, and related studies have shown that ultrasound has a distinct effect on the degree of emulsification and overall homogenization of milk and dairy products (44, 45). According to this research phenomenon, related researchers made low-fat dairy products by using ultrasound for separating emulsion and removing the fat layer (46, 47). Ultrasound has also been used to enhance the milk curdling ability (48). O’Sullivan et al. (49) found that Ultrasound has been found to reduce micelle size and hydrodynamic volume of sodium caseinate, whey and milk protein isolates. Shanmugam et al. (44) studied flaxseed oils/milk emulsion composition, and found that ultrasound treatment improved the gel properties, gel strength, and elasticity, while reducing the gelation time of emulsions. Gursoy et al. (50) showed that ultrasound can postpone the separation of serum from milk and increase the viscosity of milk. Chandrapala et al. (51) concluded that ultrasound could accelerate the dissolution of powder in milk and the release of individual casein micelles into solution. Sfakianakis et al. (52) found that ultrasonicated milk samples also showed an increase in gel stiffness, clotting strength, final storage modulus, cohesiveness, and water holding capacity.

Aadi (53) found that ultrasound could improve turbidity values, antioxidant capacity, free radical scavenging activity, ascorbic acid of liquid foods such as phenolics, flavonoids and flavonols. Abid (54) found that ultrasound could enhance the concentration values of inactivated polyphenolic compounds and sugars in enzymes (polyphenolase, peroxidase, and pectin methylesterase) and microbial communities. Ultrasound could also effectively reduce the number of microbes in juice (55). Jiang et al. (56) found that ultrasound could enhance the antioxidant activity of liquid foods. Tomadoni et al. (57) found that ultrasound could effectively reduce the number of yeasts and molds in strawberry and kiwifruit juices.

EFFECT OF TEMPERATURE RISE INDUCED FACTORS ON LIQUID FOODS

For most foods, temperature rise implies a deterioration of food quality. Temperature significantly affects microbial reproduction and speeds up food spoilage under appropriate humidity and oxygen conditions (58). Generally, within a certain range of

TABLE 1 | A summary table of all mentioned papers outcomes.

Characteristics	Product	References	Outcomes
Vibration	Yogurt	(28)	Produce large millimeter-sized particles
	Yogurt	(31)	Cause texture defects
	Beer	(10)	Oxidation of beer
	Mashed Potatoes et al.	(35)	Improve thermal mixing of foods
	Whole milk	(36)	Reduce milk scaling
	Cheese sauce	(37)	Increase hardness, storage modulus and viscosity
	Raw milk	(38)	Alter heat and rennet coagulation behavior
	Raw milk	(39)	Decrease pH and increase the amount of free fatty acid
Noise	Milk	(49)	Reduce micelle size and hydrodynamic volume of sodium caseinate, whey and milk protein isolate
	Flaxseed Oil/Milk	(44)	Improve gel properties, gel strength and elasticity
	Milk	(50)	Delay serum separation and increased viscosity
	Milk	(51)	Accelerate the dissolution of powders
	Milk	(52)	Increase gel hardness, coagulation strength, final storage modulus, cohesion and water holding capacity
	Phenols and flavonoids	(53)	Improve food turbidity value, antioxidant capacity, free radical scavenging activity, ascorbic acid
	Enzyme	(54)	Enhance concentration values of inactive polyphenolic compounds and sugars
	Mulberry juice	(56)	Enhance antioxidant activity
	Strawberry and kiwifruit Juice	(57)	Reduce yeast and mold counts
	Temperature rise	Yogurt	(63)
Milk		(64)	Maillard reaction
Milk		(67)	Produce bad odor components
Yogurt		(68)	Reduce viscosity and smoothness
Yogurt		(71)	Negative effects of nutrition, physical properties, and flavor

temperature, when the temperature of foods rises by 10°C under constant moisture conditions, the enzymatic and non-enzymatic chemical reaction rate will double, and the rate of food spoilage will increase by 4–6 times (59). The increase in temperature also damages the internal organizational structure of food, thus seriously worsening the quality. Excessive heat can also denature proteins in foods, disrupt vitamins especially vitamin C in watery foods, or change the properties due water loss and deform foods (60). Therefore, the temperature rise of food transport pumps should be strictly controlled during the operation of liquid foods (61). High-protein foods such as milk and soybean milk are highly sensitive to temperature and greatly affected by temperature in the process of production. During yogurt transfer, the temperature should be controlled at around 5°C to avoid spoilage (62, 63). Al-Attabi (64) found that the physical and chemical reactions in heat treatment resulted in changes in milk flavor, which is different from the flavor of raw milk. The temperature increase of milk results in Maillard reaction, lipid degradation and thermal denaturation of whey proteins and milk fat globule membranes (65). In addition, some by-products of Maillard reaction are harmful to human health and can cause allergic reactions when severe (66). Zhang et al. (67) found that the longer the heat treatment time, the higher the heating temperature of milk, and the more extensive the Maillard reaction, which resulted in various unacceptable odor components. Wu et al. (68) found that the yogurt fermentation

temperature might degrade yogurt quality with the growth of microbes, and that culture temperature during production had a significant effect on the physical characteristics of the final product. Higher temperatures exacerbated yogurt whey separation (69), which would result in a weak protein network with coarser microstructures and reduce the viscosity and smoothness of yogurt (70). Yang et al. (71) studied the effect of different fermentation temperatures on the quality of yogurt and metabolites, found that temperature rise caused different degrees of negative effects on the nutritional, physical characteristics and flavor of yogurt. Finally, all the above mentioned papers outcomes are shown in **Table 1**.

CONCLUSION AND PERSPECTIVE

Food safety has been a hotspot and sticking point in research. This review summarized the effect of vibration, noise, and temperature rise in the operation of food transport pumps on the physical, chemical, and structural characteristics of liquid foods. However, machinery vibration and ultrasound are also used for improving the taste of liquid foods, but other hazardous materials will also come with temperature rise. In general, machinery vibration, noise, and temperature rise have both positive and negative effects on liquid foods. Therefore, further research should proceed. At the beginning of food transport pumps

design, it is necessary to take full account of its impact on specific food, such as milk, yogurt, wine, fruit juice, etc., to develop a more adjustable multi-scene food transport pump, which can adjust the rotating speed, flow rate and blade structure according to different liquid foods. Such multi-functional food transport pumps are also the main research and development direction of food machinery in the future. It is also necessary to take into account the material characteristics of food transport pumps, and introduce new technologies and materials, such as carbon nanomaterials, coating technology, which can improve the food transport pumps' damping capacity, sound and vibration absorption capacity, and environmental friendliness. All of this technology will reduce vibration, reduce temperature rise and protect food more safely, when liquid foods are transferred by food transport pumps.

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AUTHOR CONTRIBUTIONS

XJ: methodology and writing-review and editing. SL: formal analysis, data curation, visualization, and original draft. BL: supervision. QD and PG: polish the article. ZZ: conceptualization. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: BL was employed by Hangzhou Weiguang Electronic Co., Ltd., Hangzhou, China.

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