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Plate and Tubular Heat Exchangers in Dairy Processing: A Comparative Perspective on Milk Processing and CIP Performance

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Introduction

Heat exchangers are indispensable components in dairy processing plants, governing critical operations such as milk pasteurization, UHT processing, cream heating, and cleaning-in-place (CIP). Their design and performance directly influence thermal efficiency, product quality, hygienic safety, and operational cost. Among various designs, plate heat exchangers (PHEs) and tubular heat exchangers (THEs) are most commonly employed in milk processing systems. Selecting the appropriate type requires an understanding of milk properties, fouling behavior, and CIP effectiveness rather than heat transfer performance alone (Walstra et al., 2006; Tetra Pak, 2015).

Plate Heat Exchangers in Milk Processing

Plate heat exchangers consist of thin, corrugated stainless-steel plates arranged to form alternating channels for product and heating or cooling media. This configuration creates high turbulence even at low flow rates, resulting in high heat transfer coefficients and excellent energy regeneration efficiency (Kakaç et al., 2012).

In dairy plants, PHEs are widely used for HTST milk pasteurization, where rapid heating to 72–75 °C and immediate cooling are required. Studies have shown that plate heat exchangers can recover up to 90–95 % of thermal energy through regeneration sections, significantly reducing steam and refrigeration demand (Tetra Pak, 2015; Bylund, 2015).

However, the narrow flow channels make PHEs vulnerable to protein and mineral fouling, especially during long processing runs. Research on milk fouling mechanisms indicates that denatured whey proteins and calcium phosphate deposits accumulate rapidly on hot surfaces, leading to reduced heat transfer and increased pressure drop (Changani et al., 1997; Visser & Jeurink, 1997).

Tubular Heat Exchangers in Dairy Applications

Tubular heat exchangers employ straight or coiled tubes arranged in shell-and-tube or concentric configurations. Compared to plate exchangers, tubular systems have larger flow passages and smoother internal surfaces, allowing them to handle high-viscosity and particulate-containing dairy products more effectively (Bansal & Chen, 2006).

Tubular heat exchangers are commonly used in UHT milk, flavored milk, cream, and concentrated dairy products, where processing temperatures may exceed 135 °C. Industrial experience shows that tubular systems can operate for significantly longer production cycles between CIP operations due to their lower fouling sensitivity (Fryer & Asteriadou, 2009).

Although their heat transfer efficiency is generally lower than that of PHEs, tubular exchangers offer superior mechanical strength and are better suited for high-pressure and high-temperature conditions (Kakaç et al., 2012).

Cleaning-in-Place (CIP) Performance and Hygienic Design

Effective CIP is essential to ensure microbiological safety and regulatory compliance in dairy plants. The complexity of plate geometry in PHEs demands precisely controlled CIP parameters, including flow velocity, temperature, and chemical concentration, to ensure complete removal of fouling deposits (Fryer et al., 2011).

Tubular heat exchangers offer advantages in CIP validation due to their simple and predictable flow patterns. Studies on cleaning kinetics have demonstrated that deposit removal in tubular systems is more uniform, making them easier to monitor and optimize (Fryer & Asteriadou, 2009). Consequently, tubular exchangers are often preferred in plants with frequent product changeovers and stringent hygiene requirements.

Impact on Milk Quality and Process Economics

Thermal history plays a crucial role in maintaining milk quality. Plate heat exchangers, with their short residence times and rapid heat transfer, minimize protein denaturation and cooked flavor development in pasteurized milk (Walstra et al., 2006). Tubular systems, while robust, may expose milk to slightly longer heating times, which must be carefully managed during UHT processing to preserve sensory quality.

From an economic perspective, PHEs offer lower energy consumption and compact installation, whereas tubular exchangers provide longer run times and reduced CIP frequency. Many modern dairy plants therefore adopt a hybrid approach, utilizing plate heat exchangers for standard milk pasteurization and tubular units for demanding applications such as UHT and viscous products (Bylund, 2015).

Conclusion

Both plate and tubular heat exchangers play vital roles in dairy processing. Plate heat exchangers excel in energy efficiency and gentle milk treatment, while tubular heat exchangers provide operational robustness and superior CIP reliability. The optimal choice depends on product characteristics, processing conditions, hygiene requirements, and lifecycle cost considerations. A well-informed selection ensures consistent milk quality, efficient plant operation, and compliance with modern dairy safety standards.

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