Shri Guru Gobind Singhji Institute of Engineering & Technology,
Vishnupuri, Nanded (MH), 431606
(Government Aided Autonomous Institute)
Department of Chemical Engineering

PRAGYAA 2026

CHEMTREK 2026: INDUSTRIAL DEFINED PROBLEM (IDP)

Powered by ChemGate Academy

Problem Statement: Optimization of a Sanitary Heat Exchanger for Dairy Pasteurization

1. INTRODUCTION

1.1 Industrial Context

In the dairy processing industry, thermal treatment forms the cornerstone of food safety and product quality. High-Temperature Short-Time (HTST) pasteurization is the gold standard for eliminating pathogenic microorganisms while preserving nutritional and sensory attributes of dairy products.

For high-viscosity cream products (≥10% fat content), **Shell and Tube Heat Exchangers (STHE)** are the industry-preferred choice over Plate Heat Exchangers due to their superior handling of viscous fluids, robust mechanical design, and compatibility with stringent sanitary standards.

1.2 Design Challenge

A regional dairy processing plant in Maharashtra is upgrading its production line to process **high-fat cream (38% fat content)** with a capacity of **9,000 kg/hr**. Your task is to design a Shell and Tube Heat Exchanger that pre-heats the cream from refrigeration temperature (4°C) to pasteurization temperature (75°C) using hot water as the heating medium.

The design must balance three competing objectives:

1. **Thermal Efficiency** - Achieve target outlet temperature with optimal hot water usage
2. **Product Quality** - Minimize pressure drop to prevent fat globule damage
3. **Physical Constraints** - Fit within limited plant footprint (20 m² heat transfer area)

Additionally, the design must comply with **FDA 3-A Sanitary Standards** for dairy equipment, ensuring compatibility with Cleaning-In-Place (CIP) protocols.

2. PROBLEM STATEMENT

2.1 Process Description

The cream pre-heating process operates continuously with the following specifications:

Feed Stream (Cream):

- Flow rate: **9,000 kg/hr**
- Inlet temperature: **4°C** (cold storage)
- Inlet pressure: **1.5 bar(a)** (feed pump discharge)
- Composition: **38% fat by mass** (62% water, 38% milk fat)
- **Fluid allocation:** Cream MUST flow through the **tube-side** for CIP compatibility

Heating Medium (Hot Water):

- Inlet temperature: **90°C**
- Inlet pressure: **3.5 bar(a)** (utility supply)
- Flow rate: **To be determined by participants**
- **Fluid allocation:** Hot water flows through the **shell-side**

Target Performance:

- Cream outlet temperature: **≥75°C** (HTST requirement for high-fat cream per FDA/PMO standards)
- After this heat exchanger, cream proceeds to a holding tube for 15-second residence time (not part of this design)

2.2 Thermophysical Properties

To enable focus on heat exchanger design rather than extensive property research, verified thermophysical data is provided below.

Cream Properties (38% fat, evaluated at mean bulk temperature ≈39.5°C):

Property	Value	Basis/Notes
Density, ρ_c	984 kg/m³	Mass-weighted average
Specific Heat, $C_{p,c}$	3.37 kJ/(kg·K)	$0.62 \times 4.18 + 0.38 \times 2.05$
Dynamic Viscosity, μ_c	12 cP (0.012 Pa·s)	High-fat cream, Newtonian
Thermal Conductivity, k_c	0.48 W/(m·K)	Emulsion correlation

Composition Model: 62 wt% water + 38 wt% triolein ($C_{57}H_{104}O_6$, MW = 885.43 g/mol) as representative milk fat triglyceride

Note: Mean bulk temperature = $(T_{in} + T_{out})/2 = (4 + 75)/2 = 39.5°C$

Hot Water Properties (evaluated at estimated mean temperature ≈72°C):

Property	Value	Notes
Density, ρ_h	978 kg/m³	At mean temp
Specific Heat, $C_{p,h}$	4.19 kJ/(kg·K)	At mean temp
Dynamic Viscosity, μ_h	0.404 mPa·s	At mean temp
Thermal Conductivity, k_h	0.663 W/(m·K)	At mean temp

Important: Hot water enters at 90°C. The properties above are at estimated mean temperature (~72°C). Participants should verify this assumption based on calculated outlet temperature and iterate if necessary.

2.3 Design Standards and Guidelines

Material and Construction:

- **Material:** SS 316L (austenitic stainless steel)
- **Surface Finish:** Ra ≤ 0.8 μm (32 μin) for 3-A Sanitary Standards
- **Tube Dimensions:** Standard sizes: 19.05 mm (¾") OD with BWG 14 or BWG 16
  - BWG 14: Wall thickness = 2.11 mm, ID = 14.83 mm
  - BWG 16: Wall thickness = 1.65 mm, ID = 15.75 mm
- **Tube Length:** Typically 3-6 m for dairy applications
- **TEMA Type:** BEM (fixed tubesheet, single shell pass, two tube passes) is standard for sanitary service

Fouling Considerations:

- Cream-side fouling resistance: $R_{f,c} = 0.0003$ m²·K/W
- Water-side fouling resistance: $R_{f,h} = 0.0001$ m²·K/W
- Design must account for fouled condition performance

Typical Performance Range:

- Clean overall heat transfer coefficient: $U_{clean} = 700 - 900$ W/(m²·K)
- Fouled overall heat transfer coefficient: $U_{fouled} = 500 - 700$ W/(m²·K)

3. THE CHALLENGE

3.1 Design Constraints (HARD LIMITS - Must Satisfy All)

1. **Thermal Performance:** Cream outlet temperature $T_{c,out} \geq 75°C$
2. **Pressure Drop Limit:** Cream-side pressure drop $\Delta P_c \leq$ 0.8 bar
    - With inlet pressure 1.5 bar(a), outlet must be ≥ 0.7 bar(a)
    - Excessive pressure drop causes fat globule damage and reduced product quality
3. **Physical Footprint:** Total heat transfer area $A \leq 20$ m²
    - Existing plant layout restricts exchanger size
    - This is a tight constraint requiring optimization
4. **Sanitary Design:** Design must comply with 3-A Sanitary Standards
    - Tube-side cream flow (mandatory for CIP)
    - Drainable configuration
    - Smooth surfaces (Ra ≤ 0.8 μm)

3.2 Heat Duty Calculation

The required heat duty for this process is:

$$Q = \dot{m}_c \times C_{p,c} \times (T_{c,out} - T_{c,in})$$

$$Q = 9{,}000 \text{ kg/hr} \times 3.37 \text{ kJ/(kg·K)} \times (75 - 4)°C$$

$$Q = 2{,}153{,}430 \text{ kJ/hr} = 598 \text{ kW}$$

Design Challenge: With 598 kW heat duty and 20 m² area limit, participants must achieve $U_{fouled} \approx 950 - 1{,}100$ W/(m²·K) depending on LMTD. This requires careful optimization of:

- Tube diameter and BWG selection
- Number of tube passes
- Tube pitch and layout
- Shell diameter and baffle design

4. DELIVERABLES AND EXPECTED OUTCOMES

4.1 Technical Deliverables

Participants must submit a complete heat exchanger design specification including:

1. **Thermal Design:**
   - Hot water flow rate (kg/hr)
   - Hot water outlet temperature (°C)
   - Log Mean Temperature Difference (LMTD) and F-factor
   - Individual heat transfer coefficients: h_i (tube-side), h_o (shell-side)
   - Overall heat transfer coefficient: U_{clean} and U_{fouled} (W/m²·K)
   - Actual heat transfer area (m²) and verification it meets $A \leq 20$ m²
2. **Mechanical Design:**
   - Tube specifications: OD, BWG, ID, length (m)
   - Number of tubes (N_t) and number of passes
   - Tube pitch and layout pattern (triangular/square)
   - Shell diameter (mm)
   - Baffle spacing and design (if applicable)
3. **Hydraulic Design:**
   - Cream-side pressure drop (ΔP_c) - must be ≤ 0.8 bar
   - Shell-side pressure drop (ΔP_h)
4. **Material and Sanitary Justification:**
   - Scientific justification for SS 316L material selection
   - Explanation of 3-A Sanitary Standards compliance
   - CIP (Cleaning-In-Place) protocol compatibility

4.2 Presentation Requirements

Teams must prepare a **PowerPoint presentation (15-20 slides)** covering:

1. **Introduction** (2-3 slides)
   - Problem understanding and objectives
   - Design approach overview
2. **Methodology** (4-5 slides)
   - Property estimation methods used
   - Heat transfer correlations selected (with justification)
   - Pressure drop correlations
   - Software/tools used (if any)
3. **Design Calculations** (5-7 slides)

- Thermal design calculations with key equations
- Mechanical design decisions and logic
- Hydraulic calculations and verification
- Step-by-step reasoning for critical design choices

4. **Results and Verification** (3-4 slides)
    - Final design specifications (summary table)
    - Verification against all constraints
    - Performance margins and safety factors
5. **Sanitary and Material Considerations** (2-3 slides)
    - Material selection justification
    - 3-A compliance and CIP considerations
    - Industrial feasibility and maintenance aspects

5. INSTRUCTIONS FOR PARTICIPANTS

5.1 Permitted Methods and Tools

Participants have **complete freedom** in choosing their design approach:

- **Analytical Methods:** Hand calculations using heat transfer correlations (Kern method, Bell-Delaware method, etc.)
- **Simulation Software:** Aspen EDR, HTRI, Aspen Plus, HYSYS, CHEMCAD, or any process simulation tool
- **Spreadsheet Tools:** Microsoft Excel, Google Sheets with custom calculations
- **Programming:** Python, MATLAB, or any programming language
- **Hybrid Approach:** Combination of analytical and computational methods

There are NO restrictions on methodology. Teams are encouraged to use whatever approach they are most comfortable with and can justify technically.

5.3 Submission Requirements

Abstract Submission (26th February 2026):

- 1-page summary (300-500 words)
- Design approach overview
- Preliminary results (if available)

Final Presentation (28th February 2026):

- PowerPoint presentation (15-20 slides)
- 15-minute presentation + 5-minute Q&A
- All team members should be prepared to answer technical questions

5.4 Common Pitfalls to Avoid

- Using properties at wrong temperatures (always check reference temperature)
- Forgetting to include fouling resistances in U_{fouled} calculation
- Not verifying that cream is on tube-side (mandatory requirement)
- Ignoring the 20 m² area constraint during initial design
- Making unrealistic assumptions without justification
- Presenting results without showing calculation methodology

6. EVALUATION CRITERIA

Submissions will be evaluated comprehensively across four dimensions:

Criterion	Weight	Evaluation Focus
Technical Accuracy	40%	• Precision in meeting $T_{out} \geq 75°C$ target • Compliance with $\Delta P \leq 0.8$ bar limit • Compliance with $A \leq 20$ m² constraint • Correctness of heat transfer and pressure drop calculations • Proper use of correlations and equations
Engineering Rigor	30%	• Quality of literature research and correlation selection • Logical decision-making process • Justification of design choices • Understanding of industrial standards (TEMA, 3-A) • Handling of uncertainties and assumptions
Hygienic Design Logic	15%	• Scientific depth in material selection justification • Understanding of 3-A Sanitary Standards • CIP compatibility considerations • Food safety and contamination prevention • Surface finish and drainability aspects
Presentation & Viva	15%	• Clarity of presentation and visual aids • Depth of technical knowledge demonstrated • Ability to answer questions during viva • Team coordination and communication • Professional quality of slides and documentation

7. REGISTRATION AND TIMELINE

7.1 Important Dates

- **Abstract Submission:** 26th February 2026 (11:59 PM)
- **Final Presentation:** 28th February 2026 (Time TBA)

7.2 Participation Details

- **Team Size:** 1 to 3 members per team
- **Eligibility:** Open to all chemical engineering students
- **Registration Fees:** ₹199/- per team

7.3 Contact Information

For queries and clarifications:

Harshit Mengare
Event Coordinator
Phone: 7720950041