Heat-Transfer-Operations-Ansys-Project

Flow Through a Mid-Rotating Section of a Pipe

Course name: CHE-311

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Project Overview

Introduction:

The project investigates fluid flow and heat transfer behavior inside a pipe system that includes a mid-rotating section. The objective is to understand how the rotation affects flow distribution, pressure drop, and convective heat transfer characteristics.

Why does it matter?

Such systems are found in rotating heat exchangers, rotary coolers, and industrial mixers where enhanced heat removal is critical. Rotation induces secondary flow and mixing, which can increase the heat transfer rate between fluid and wall surfaces.

Objectives

- To model steady-state laminar flow through a rotating pipe segment.
- To evaluate the influence of rotation on temperature and velocity profiles.
- To compare the system's performance with and without rotation.
- To identify design parameters that optimize thermal performance.

Methodology Summary:

Geometry modeled in **ANSYS Discovery / Fluent**.
Two cases simulated:

1. Stationary pipe (no rotation).
2. Pipe with mid-section rotating at constant angular velocity.

Boundary conditions include inlet velocity, outlet pressure, wall heat flux, and convective cooling.

Project Simulation Model Development Overview

Geometry and Meshing:

- The pipe consists of three segments: stationary inlet, rotating mid-section, and stationary outlet.

- Length and diameter selected based on typical laboratory-scale flow.
- The mesh was generated using **ANSYS Mesher** with refinement near walls to capture boundary layers.

Material Properties:

Component	Material	Property Source
Fluid	Water	ANSYS Material Library
Pipe Wall	Stainless Steel	ANSYS Material Library
Rotating Shaft	Aluminum Alloy	Custom material (if required)

Boundary Conditions:

- *Outlet*: pressure = 0 Pa (gauge)
- *Inlet*: velocity = 0.2 m/s, temperature = 300 K

- *Wall heat flux*: 5000 W/m^2
- *Ambient air temperature*: 20°C with convective coefficient 10 $W/m^2 \cdot K$
- *Rotation*: 100 rad/s angular velocity on mid-section wall

Governing Equations and Parameters

Fluid Flow:

The motion of incompressible fluid is governed by the Navier–Stokes equations:

$$\rho(V. \nabla) V = - \nabla P + \mu \nabla 2 V$$

Energy Equation:

$$\rho \, cp \, (V . \nabla T) = k \nabla 2 T + \Phi$$

where Φ represents viscous dissipation — the conversion of mechanical energy to heat due to fluid friction in the rotating section.

Dimensionless Parameters:

Parameter	Expression	Physical Meaning
Reynolds number	$Re = \frac{\rho U D}{\mu}$	Flow regime
Rotational Reynolds number	$Re_{\Omega} = \frac{\Omega D^2}{\nu}$	Rotation strength
Nusselt number	$Nu = \frac{hD}{k}$	Convective heat transfer rate
Prandtl number	$Pr = \frac{\mu c_p}{k}$	Relation between momentum and heat diffusion

Results and Discussion

Flow Field Analysis:

- Without rotation: velocity profile is parabolic; laminar flow is stable.
- With rotation: velocity field exhibits secondary swirling motion due to centrifugal and Coriolis forces.
- The mid-section rotation enhances radial mixing and momentum diffusion

Temperature Distribution:

- Without rotation: higher wall temperature, thicker thermal boundary layer.
- With rotation: improved convective heat transfer reduces maximum fluid temperature.

- Example observation:
    - Max temperature (non-rotating): 354 K
    - Max temperature (rotating): 332 K

Conclusions and Future Work

Conclusions:

- The introduction of a rotating mid-section significantly improves heat transfer due to enhanced fluid mixing.
- The thermal boundary layer becomes thinner, resulting in lower surface and bulk fluid temperatures.
- The overall Nusselt number increases with rotation rate, confirming the heat transfer enhancement effect.
- Viscous dissipation effects become relevant at high angular velocities and must be included in further studies.

Future Work:

- Extend analysis to turbulent regimes using k–ε or SST turbulence models.

- Explore variable fluid properties (temperature-dependent viscosity).
- Conduct experimental validation using a scaled physical model.
- Investigate combined forced convection with external cooling (air fan or coolant flow).

Applications:

- Rotating heat exchangers.
- Cooling of rotating machine parts (motors, turbines).
- Enhanced chemical reactor cooling systems.