Incorporation of Condensation Heat Transfer in a Flow Network Code

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Introduction

- Pure water is distilled from waste water in International Space Station
- Distillation assembly consists of evaporator, compressor and condenser
- Vapor is periodically purged from the condenser to avoid vapor accumulation
- Purged vapor is condensed in a tube by coolant water prior to entering purge pump
- The paper presents a condensation model of purged vapor in a tube
UPA Distillation Assembly

- Demister (rotates)
- Stationary Bowl (stationary)
- Centrifuge (rotates)
- Liquid Level Sensor (stationary)
- Brine Pickup Tube (stationary)
- Distillate Pickup Tube (hidden) (stationary)
- Motor
- Feed Tube (stationary)
- Compressor (rotating lobes in stationary housing)
- Evaporator (rotates)
- Condenser (rotates)
Wastewater Tank

Urine from Node 3

Fluids Pump

Distillation Assembly (Distills wastewater)

Recycle Filter Tank Assy. (accumulates & stores brine for disposal)

Purge Pump (removes gases from Distillation Assy.)

Coolant (promotes condensation within purge pump)

Separator (separates water from purge gases)

Purge Gas to Node 3 cabin

Product water to Water Processor Assembly
Problem Description

Superheated Water Vapor
\[ P_{\text{inlet}} = 0.95 \text{ psia} \]
\[ T_{\text{inlet}} = 101^\circ\text{F} \]

\[ T_{\text{outer wall}} = 65^\circ\text{F} \]

Saturated Water Vapor
\[ P_{\text{outlet}} = 0.5 \text{ psia} \]

Inner Tube Diameter = 0.125 inch
Outer Tube Diameter = 1 inch
Length = 4 inches
Material is Titanium

Calculate the Quality and Heat Transfer Properties of the Water as it Condenses in the Pipe

Model consists of 2 Boundary Nodes and 28 Internal Nodes and Models Conduction through the Tube Wall
Generalized Fluid System Simulation Program (GFSSP)

GFSSP calculates pressure, temperature, and concentrations at nodes and calculates flow rates through branches.

H₂ + O₂ + N₂
Finite Volume Method

- Finite Volume Method is based on conservation principle of Thermo-Fluid Dynamics
- In Classical Thermodynamics we analyze a single control volume
- In Finite Volume Method, flow domain is discretized into multiple control volumes and a simultaneous analysis is performed
- Finite Volume Method can be classified into two categories:
  - Navier-Stokes Solution (Commonly known as CFD)
  - Network Flow Solution (NFS)
GFSSP
Finite Volume Method

Network Flow Solution (NFS)

Navier-Stokes Solution (CFD)
GFSSP Process Flow Diagram

Solver & Property Module
- Equation Generator
- Equation Solver
- Fluid Property Program

Output Data File
- Time dependent process
- non-linear boundary conditions
- External source term
- Customized output

User Subroutines

Preprocessor
- Command line preprocessor
- Visual preprocessor

Input Data File
Coupling of Thermodynamics & Fluid Dynamics

- $p$ - Pressure
- $m$ - Flowrate
- $h$ - Enthalpy
- $c$ - Concentration
- $\rho$ - Density

Error

Iteration Cycle
GFSSP Solution Scheme

**SASS** : Simultaneous Adjustment with Successive Substitution

**Approach** : Solve simultaneously when equations are strongly coupled and non-linear

**Advantage** : Superior convergence characteristics with affordable computer memory
Condensation Heat Transfer

Diagram showing the relationship between heat transfer rate ($q'$, MW/m²) and temperature difference ($T_s - T_w$, K) for different gas velocities ($v_g$, m/s). The diagram includes curves for Dropwise and Transition regimes, as well as a dashed line for Filmwise heat transfer.
Heat transfer correlations

Akers, et al, 1959 – Annular Correlation
Boyko and Kruzhulin, 1967 – Annular Correlation
Chato, 1962 – Stratified Correlation

Chose Soliman correlation for its stability and generality
Soliman Correlation for Heat Transfer Coefficient for Annular Flow Condensation

\[ h = 0.036 \text{Pr}^{0.65} F_0^{0.5} \left( \frac{k \rho_l^{0.5}}{\mu_l} \right) \]

\[ F_0 = F_f + F_m \pm F_a \]

\[ F_f = 0.045 \text{Re}^{-0.2} \left[ \frac{\pi^2 \rho_v D^4}{8W_T^2} \right] \left[ x^{1.8} + 5.70 \left( \frac{\mu_l}{\mu_v} \right)^{0.0523} (1 - x)^{0.470} x^{1.33} \left( \frac{\rho_v}{\rho_l} \right)^{0.261} + 8.11 \left( \frac{\mu_l}{\mu_v} \right)^{0.105} (1 - x)^{0.400} x^{0.660} \left( \frac{\rho_v}{\rho_l} \right)^{0.522} \right] \]

\[ F_m = 0.5 \left( \frac{D}{dz} \left[ \frac{\pi^2 \rho_v D^4}{8W_T^2} \right] \right) \left[ 2(1 - x) \left( \frac{\rho_v}{\rho_l} \right)^{2/3} + \left( \frac{1}{x} - 3 + 2x \right) \left( \frac{\rho_v}{\rho_l} \right)^{4/3} + \left( 2x - 1 + \beta x \right) \left( \frac{\rho_v}{\rho_l} \right)^{1/3} + \left( 2 \beta - \frac{\beta}{x} - \beta x \right) \left( \frac{\rho_v}{\rho_l} \right)^{5/3} + 2(1 - x - \beta + \beta x) \left( \frac{\rho_v}{\rho_l} \right) \right] \]

\[ F_a = 0 \]

\( F_f \): Effect of two-phase friction
\( F_m \): Effect of momentum changes in the flow
\( F_a \): Effect of axial gravitational field on the wall shear stress
Solid-to-fluid heat transfer

\[ T_{\text{solid}} = T_{\text{coolant}} \]

\[ Q_{\text{condensation}} = h A (T_{\text{fluid}} - T_{\text{solid}}) \]
Plot of Quality vs. Pipe Location for Selected Heat Transfer Correlations

For Grid Size = 20 and R = 1
Heat Transfer Coefficient vs. Pipe Location
Soliman Correlation for Grid Size 40 and R Value 1
Quality Comparison for Different Tube Grid Resolution
(Soliman Correlation)

Quality

Distance (in)

0 0.5 1 1.5 2 2.5 3 3.5 4

1 0.95 0.9 0.85 0.8 0.75 0.7

10 grid
20 grid
30 grid
40 grid
50 grid
Outer Wall Temperature Comparison for Different Tube Grid Resolution
(Soliman Correlation)
Conclusions

- A condensation heat transfer model was successfully incorporated in a general purpose flow network code.
- The numerical model considers solid-to-fluid heat transfer.
- Soliman et al.’s correlation of condensation heat transfer is recommended due to its generality and stability.
References & Acknowledgements

References:


Acknowledgement:

Authors would like to acknowledge Mr. Bruce Tiller and Mr. Richard Schunk of MSFC for their suggestions and comments.