Vortex tube with external cooling for Slush LNG production
A theoretical and experimental study

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Introduction

• Condensing methane using a Ranque-Hilsch Vortex Tube (RHVT) - A new route for LNG production
• Slush is a mixture of liquid- solid methane
• Higher density, more mass of slush in a given volume
Apparatus overview

The vortex tube

\[ \varepsilon = \frac{\dot{m}_c}{\dot{m}_{in}} \]

cold exit: \( p \sim 1 \text{ bar}, T \sim -20^\circ C, \varepsilon \dot{m} \)

hot exit: \( p \sim 1.1 \text{ bar}, T \sim +100^\circ C, (1-\varepsilon) \dot{m} \)

main inlet: \( p \sim 8 \text{ bar}, T \sim 20^\circ C, \dot{m} \)

nozzle, main tube, swirl generator, vortex chamber, plug
Apparatus overview

- LN$_2$ - Liquid nitrogen (cooling fluid)
- Counter-flow HEX with four parallel tubes
- Working gases – CH$_4$ and N$_2$
Apparatus overview

Vortex tube

Working fluid
Apparatus overview

HEX and Heater

LN$_2$

Working fluid

LN$_2$
Theory

Regime 1
$V_\theta = c$

Regime 2
$r V_\theta = \text{constant}$

Regime 3
Solid-body rotation

Location where regime 1 ends (Sonic speed)

Radius of vortex tube

Radius of vortex chamber

$V_\theta (\text{m/s})$

$r (\text{mm})$
Experiments with methane

- $Ma_0$ for all lines $\sim 0.55$
- Good agreement with constant $Ma_0$

$P_{in}$ values:
- $P_{in} = 17.5$ bar
- $P_{in} = 10$ bar
- $P_{in} = 8$ bar
- $P_{in} = 6$ bar

$r_L \sim 2.5$ mm for all lines
Low inlet pressures - Temperature separation

Effect of decreasing $T_c - T_{in}$ with decreasing $T_{in}$ can be compensated by increasing $P_{in}$

Experiments with methane

- $P_{in} = 8$ bar
- $P_{in} = 6$ bar
- $P_{in} = 4$ bar
Measured pressures and adiabatic relations

High Ma₀ (0.75-0.9)

2 phase zone
Conclusions and recommendations

- Thermal separation increases with increasing $P_{in}$ and decreases with decreasing $T_{in}$
- When smaller diameter nozzles are used (large $Ma_0$), condensation possibly occurs in the VC
- Experiments with super-critical methane are recommended
- Experiments with 2-phase methane are recommended
- Numerical (CFD) simulations are recommended
Questions

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