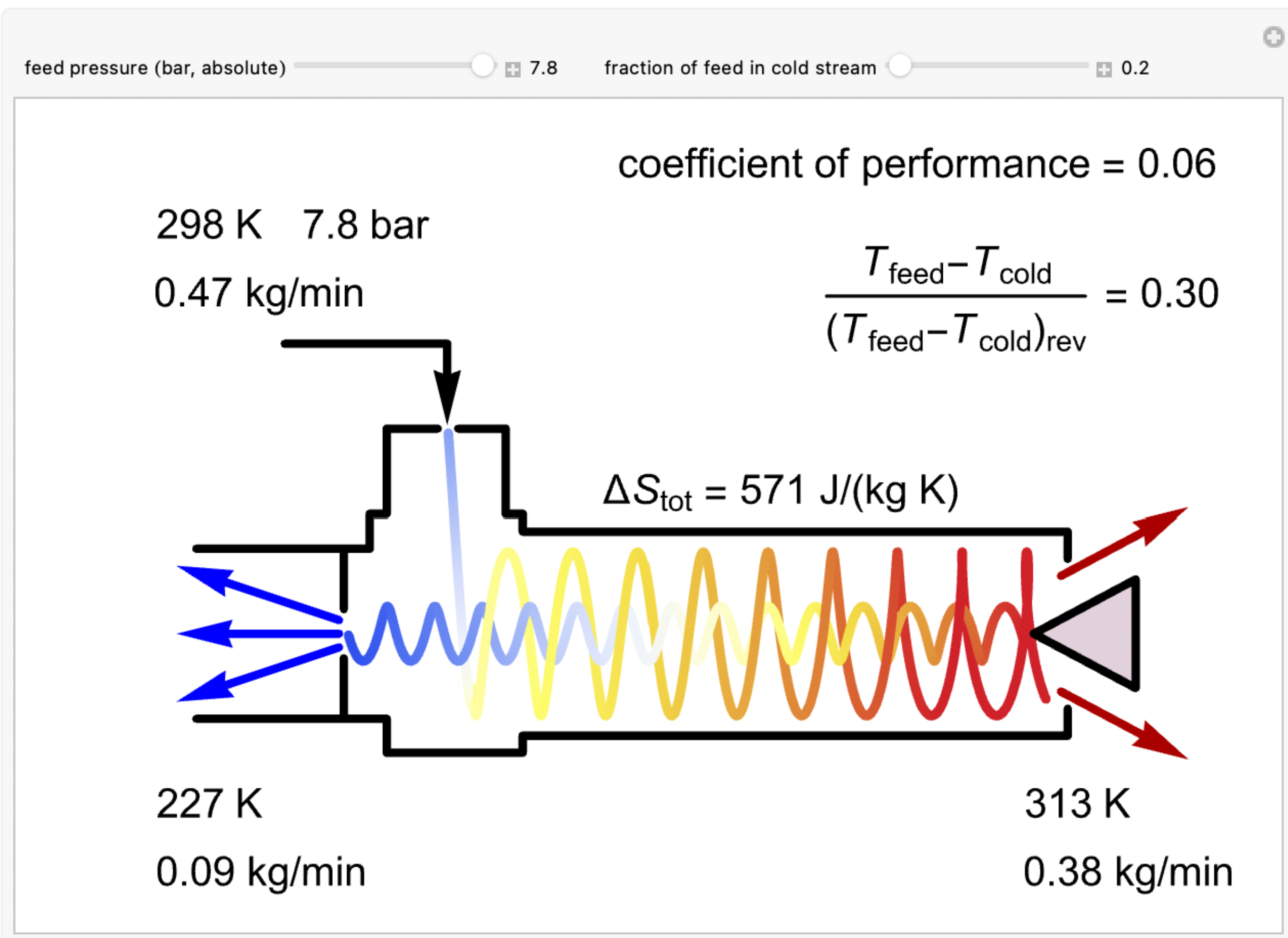
Worksheet: Ranque-Hilsch Vortex Tube

Name(s):____

Student Learning Objectives

1. Apply the first law of thermodynamics to a steady-state, open system by performing mass and energy balances
2. Distinguish between idealized and real system behavior by comparing a reversible, adiabatic model to an irreversible, non-adiabatic system.
3. Quantify deviations from ideal behavior using experimental data from the digital lab and theoretical values
4. Identify possible sources of entropy generation in the vortex tube and explain their thermodynamic consequences
5. Use experimental or simulated data to assess performance metrics, such as temperature separation, isentropic efficiency, and energy partitioning between hot and cold outlets
6. Think critically about real-world engineering design choices and limitations in thermal systems

Schematic and Dimensions (update after digital lab is finished)



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Before running the experiment:

1. Look up Ranque-Hilsch Vortex tube designs and familiarize yourself with the types of designs and performance metrics that one is capable of. Record your findings below.

2. Brainstorm some of the advantages and disadvantages of using a vortex tube over typical refrigeration systems.

Advantages	Disadvantages

3. What assumptions are made when modeling a reversible, adiabatic system?

4. What is an isentropic process, and how do we measure efficiency relative to it?

5. How will the ratio of air in the hot stream vs. air in the cold stream affect the cold-stream and hot-stream temperatures?

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Running the experiment:

1. Turn on the air compressor and wait for the system to reach steady state.
2. Close the nozzle such that air is only flowing out of the cold-side outlet. What do you notice?
3. Open the nozzle to allow different hot/cold stream ratios. Record the data below

cold-side temperature (°C)	cold-side temperature (K)	hot-side temperature (°C)	hot-side temperature (K)	hot-side flow rate (mL/s)

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After the experiment:

1. Given a feed stream at 22°C and 6 bar, calculate the minimum possible cold stream temperature, given by the following equation for reversible, adiabatic expansion:

$$(T_f - T_c)_{rev} = T_f \left[\left(\frac{P_f}{P_{atm}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]$$

$T_{c,rev} =$ ________________

2. Calculate the reversible cold and hot-stream temperatures for the following molar flow rates using the energy balance below, given that the molar heat capacity for an ideal diatomic gas at constant pressure is $C_p = \frac{7}{2}R$. Use the equation above for reversible, adiabatic expansion to determine T_c. Assume that $T_f = 22°\text{C}$.

$$\dot{n}_h C_p \left(T_{h,rev} - T_f \right) + \dot{n}_c C_p \left(T_{c,rev} - T_f \right) = 0$$

$\dot{n}_c$ (mol/s)	$\dot{n}_h$ (mol/s)	$T_{c,rev}$ (°C)	$T_{h,rev}$ (°C)
0.05	0.01		
0.04	0.02		
0.03	0.03		
0.02	0.04		
0.01	0.05		

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3. The vortex tube efficiency η is the ratio of actual temperature drop to the temperature change of a reversible (isentropic) adiabatic expansion. The coefficient of performance (COP) is the ratio of cooling rate to work input. Calculate $(T_f - T_c)_{rev}$, then calculate η and COP for each of your experimental measurements using the equations below.

$$\eta = \frac{T_f - T_c}{(T_f - T_c)_{rev}} \qquad COP = \frac{Q_c}{W} \qquad Q_c = \dot{n}_c C_p (T_f - T_c)$$

$$W = \dot{n}_f C_p T_f \left[\left(\frac{P_f}{P_{atm}} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]$$

$(T_f - T_c)_{rev} =$ ____________________________

Measurement #	$\dot{n}_c$ (mol/s)	Q_c (W)	W (J)	COP	η
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

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Questions to answer

1. What are some possible sources of entropy generation in the vortex tube? How might this affect vortex tube performance?

2. When designing a vortex tube, what metrics might be important to consider besides COP and η?