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|---|---|---|
| **Recitation** | **10.213**<br>Spring 2002 | **04/01/02** |

**Refrigeration**

An industrial scale refrigeration cycle runs on *tetrafluoroethane* (thermodynamic data on attached chart and table). Instead of a throttle valve, an *adiabatic expander/turbine* is used to produce some work, which can be used to compensate some of the *adiabatic compressor*'s power requirement.
The *evaporator* operates at –40°F, while the *condenser*'s outlet is at 140°F.

a)
Consider the case where the compressor and expander are *reversible*. For the equipment assigned to you,
i) Describe the inlet and outlet conditions.
ii) Calculate the heat and shaft-work that it produces (in terms of Btu/lbm).

Putting the pieces together with your team, calculate the coefficient of performance of the refrigeration cycle.

b)
Back to the real world where things are often not reversible…
When you look at the cost of such a cycle, you come across this entry in the Freez'it™ catalog that matches the equipment sizes you are considering:

| | *Cost* |
|---|---|
| **Compressor** | |
| 50% efficiency | \$50,000 |
| 80% efficiency | \$85,000 |
| **Expander / Turbine** | |
| 50% efficiency | \$30,000 |
| 80% efficiency | \$65,000 |

*buy any two of these, get one condenser and one evaporator free!*
*free shipping and handling; free refrigerant, piping, and accessories*

You have \$120,000 to spend on this refrigeration cycle.
Your cycle has one condenser, one evaporator, one ______% efficient expander, and one _____% compressor.
Calculate the coefficient of performance of your cycle.

For your cycle configuration, calculate the flow rate of refrigerant required for a cooling rate of 500,000 Btu/hr.

**Tetrafluoroethane**
**All Reversible**

*Italics = estimated value (reading from graph)*

| | **In** | | | | | **Out** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Phase** | **T (F)** | **P (psia)** | **S (Btu/lb R)** | **H (Btu/lbm)** | **Phase** | **T (F)** | **P (psia)** | **S (Btu/lb R)** | **H (Btu/lbm)** | **W (Btu/lbm)** | **Q (Btu/lbm)** |
| **Condenser** | Vapor | 170 | 243.880 | 0.231 | 127 | Sat liq | 140 | 243.880 | 0.117 | 59.764 | | -67.236 |
| **Expander** | Sat liq | 140 | 243.880 | 0.117 | 59.764 | 0.504 | -40 | 7.429 | 0.117 | 48.892 | -10.872 | |
| **Evaporator** | 0.504 | -40 | 7.429 | *0.117* | 48.892 | Sat vap | -40 | 7.429 | 0.231 | 97.050 | | 48.158 |
| **Compressor** | Sat vap | -40 | 7.429 | 0.231 | 97.050 | Vapor | *170* | 243.880 | 0.231 | *127* | 29.950 | |

| | P (psia) | Hliq | Hvap | Sliq | Svap | |
|---|---|---|---|---|---|---|
| -40 F | 7.429 | 0 | 97.05 | 0 | 0.23125 | from table |
| 140 F | 243.88 | 59.764 | 119.72 | 0.1165 | 0.21648 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| W net | 19.1 | Btu/lbm | | | | | |
| Q cold | 48.2 | Btu/lbm | Q hot | 67.236 | Btu/lbm | For 500,000 Btu/hr | 10383 lbm/hr of refrigerant |
| COP | 2.5 | | | | | | |

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**80% Compressor, 50% Expander**

| | **In** | | | | | **Out** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Phase** | **T (F)** | **P (psia)** | **S (Btu/lb R)** | **H (Btu/lbm)** | **Phase** | **T (F)** | **P (psia)** | **S (Btu/lb R)** | **H (Btu/lbm)** | **W (Btu/lbm)** | **Q (Btu/lbm)** |
| **Condenser** | Vapor | *190* | 243.880 | *0.240* | *134* | Sat liq | 140 | 243.880 | 0.117 | 59.764 | | -74.724 |
| **Expander** | Sat liq | 140 | 243.880 | 0.117 | 59.764 | 0.560 | -40 | 7.429 | 0.129 | 54.328 | -5.436 | |
| **Evaporator** | 0.560 | -40 | 7.429 | 0.129 | 54.328 | Sat vap | -40 | 7.429 | 0.231 | 97.050 | | 42.722 |
| **Compressor** | Sat vap | -40 | 7.429 | 0.231 | 97.050 | Vapor | *190* | 243.880 | *0.240* | *134* | 37.438 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| \|W net\| | 32.0 | Btu/lbm | | | | | |
| \| Q cold\| | 42.7 | Btu/lbm | \|Q hot\| | 74.7235 | Btu/lbm | For 500,000 Btu/hr | 11704 lbm/hr of refrigerant |
| COP | 1.3 | | | | | | |

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**50% Compressor, 80% Expander**

| | **In** | | | | | **Out** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Phase** | **T (F)** | **P (psia)** | **S (Btu/lb R)** | **H (Btu/lbm)** | **Phase** | **T (F)** | **P (psia)** | **S (Btu/lb R)** | **H (Btu/lbm)** | **W (Btu/lbm)** | **Q (Btu/lbm)** |
| **Condenser** | Vapor | *275* | 243.880 | *0.275* | *157* | **Sat liq** | 140 | 243.880 | 0.117 | 59.764 | | -97.186 |
| **Expander** | Sat liq | 140 | 243.880 | 0.117 | 59.764 | **0.526** | -40 | 7.429 | 0.122 | 51.067 | -8.697 | |
| **Evaporator** | 0.526 | -40 | 7.429 | *0.122* | 51.067 | **Sat vap** | -40 | 7.429 | 0.231 | 97.050 | | 45.983 |
| **Compressor** | Sat vap | -40 | 7.429 | 0.231 | 97.050 | **Vapor** | *275* | 243.880 | *0.275* | *157* | 59.900 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| \|W net\| | 51.2 | Btu/lbm | | | | | |
| \| Q cold\| | 46.0 | Btu/lbm | \|Q hot\| | 97.186 | Btu/lbm | For 500,000 Btu/hr | 10873 lbm/hr of refrigerant |
| COP | 0.9 | | | | | | |

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