Lab Experiment 6: Vapor Compression Cycle

Section 23L

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Experiment Performed: May 8, 2019
Report Submitted: May 21, 2019

Objectives:

To obtain operating data from the chillers in the new Science and Technology building to calculate the COP (Coefficient of Performance) of an operating industrial chiller.

Summary:

Mr. David A. Graham
Facilities - Building Maintenance and Operations
University of Delaware

Mr. Graham,

Team from the Mechanical Engineering Department observed the operation of Chiller # 1 on May 8, 2019. Weather conditions were sunny, an OA temperature of 61.5℉, and an OA wet bulb temperature of .

Based on operating data on the chiller control touch panel and ECUP Monitor displays we calculated the Coefficient of Performance three different ways. The average COP was…

We believe the most accurate value of COP under these conditions is…

Thank you for allowing us to provide this service.

Sincerely,
Team 23LA1
University of Delaware
Mechanical Engineering Dept.

Theoretical Background:

The chillers used at the university's chiller plant operate similar to air conditions, but instead of cooling air, they cool water. This water is chilled and sent to numerous buildings around campus. The fluid used in the chillers is a non-toxic refrigerant, which is cooled from two cooling towers located outside the building. The cooled refrigerant is then put through a chiller, which is a type of heat exchanger that removes heat from the water by transferring it to the coolant, so that it can be recirculated at a cooler temperature.

The data can be evaluated using the equations for evaporator water gain in energy, which finds the heat removed from the building. It also uses the equation for a cooling tower water energy, which finds the heat from the building and heat from the compressor. These equations follow respectively.

$Q_{evap} = m_{evap} c_p (T_{in} - T_{out})_{evap}$ $\qquad$ $Q_{cond} = m_{cond} c_p (T_{out} - T_{in})_{cond}$

These two formulas determine the plant's coefficient of performance.

Equipment:

Procedure:

First, on each of the three separate data sheets, record the date, time of day, weather conditions (sun, rain, cloudy, etc.) and the ambient temperature. Also, record which chiller you are looking at and the type of refrigerant that it uses. Next, identify the key parts of the chiller and relate them to the block diagram. Each chiller has a graphical display. Photograph it for the report preparation. Some data will be found on the Control Room monitor. Then, fill out each of the three data sheets. The first is the thermodynamic COP which will record the refrigerant pressures and temperatures of each point in the refrigeration cycle. The second is the chilled water Flow COP which will record the flow and temperatures of the chilled water leaving and returning. (Temperatures are shown on panel and flows on monitor.) The third is the compressor Power Consumption which will record the three phase motor electrical data for calculation of watts.

Finally, move up the stairs and outside the building to observe cooling tower operation.

Results/Analysis:

Data Sheet 1:

1.	Ck1
P1	-8.9 psig
T1	40.1 f
h1 =hg at P1	90.74
2.	
Tsuper ht	92.5 f
P2=P3	-0.1 psig
h2 (chart est)	100
3.	
P3 = Psat	-0.1 psig

T=	78. 5 f
h3 = hf	28.28
4.	
P4=P1	-8.9 psig
T4	40.0 f
h4 = h3	28.28
COP = (h1 - h4)/(h2-h1)	6.75

Data Sheet 2

	Condenser
Tin	70.9 f
Tout	77.6 f
Flow Rate	3326820 lbm/hr
T_avg	74.25 f
Cp	0.999 btu/lbm-f
rho	62.31 lbm/ft^3
Q_cond	2240142 btu/hr
	Evaporator
Tin	47.4 f
Tout	41.1 f
Flow Rate	3206772 lbm/hr
T_avg	44.25 f
Cp	1.002 btu/lbm-f
rho	62.428 lbm/ft^3
Q_evap	1936993 btu/hr

Qcomp = Qcond- Qevap = 303149 btu/hr

COP = Qcond/Qcomp = 7.29

Data Sheet 3

	Ckt 1
Phases	Amps, Volts
Phase 1	93, 4248
Phase 2	92, 4216
Phase 3	91, 4219
Average Volts	4227.67
Ckt 1 Power = Total Power	538.954 kW
hfg	179.85 J/kg
Mref	373.39 kg/s
cooling	3662.13 kW
COP cooling/power	6.79

Uncertainty Analysis:

For this experiment, there is no singular equation that can be used to determine the uncertainty. However, a reasonable approximation can be obtained by making a conservative estimate for each component (the thermodynamic model, the chilled water model, and the compressor power model). These uncertainties can then be summed to obtain a conservative overall uncertainty.

Measurement	Value	Uncertainty	Summary
P_{evap}	5.8 psia	± 0.1 psia	Expected to stay constant during evaporation
T_{evap}	40.0 F	± 0.5 F	Expected to stay constant during evaporation
Q_{evap}	6411 GPM	± 50 GPM	Fluctuations during observations
P_{cond}	14.6 psia	± 0.1 psia	Expected to stay constant during

			condensation
T_{comp}	92.5 F	± 10 F	Temperature fluctuates greatly as it changes from superheated to saturated liquid
Q_{comd}	6651 GPM	± 50 GPM	Fluctuations during observations
P_{evap}	538.95 kW	± 5 kW	Power fluctuations through the different phases

Discussion and Conclusion:
The coefficient of performance was calculated three different ways. The calculated values were similar. We consider the calculations reliable, as they are within reason when compared so the coefficients of similar vapor chiller units.

The Control Room Monitor showed a reading of ___ kW/ton. When converting units to calculate a COP, the result was ___. Comparing this to our calculated values,

As engineers, we believe that the control room monitor is the most accurate reading. Of our calculated COPs, the one derived on Sheet _ was the closest to the monitor reading.

Observing data on a plant scale allows us to see a real world application, which has the potential to show us some complications of a large scale operation that may not be present in a laboratory setting. On the other hand, the error in our analysis could be much larger than in a laboratory setting, as there are more places for errors to propagate.

Design Objective:

Sheet 1 COP: 6.75
Sheet 2 COP: 7.29
Sheet 3 COP: 6.79
Weather Conditions:
High 75 f
Low 42 f

Appendix A: Lab Roles

Lab Section 23 A Experiment # 6 Date 5/8/19

Note: Roles must be agreed on before work starts. Every team member must be represented. It is a commitment. The roles should be rotated for each experiment. Each role in principle has a specific contribution (page or paragraph) to create for the report.

	Name
Team Leader/ Coordinator	KR
Theoretical and Procedure write up	AV
Equipment operation (1 or more)	KR
Data recorder	KR
Equipment diagram (sketch or photo. Include instrumentation)	JK
Graphs, data tables for report (2 people)	BG/JDS
Data & Uncertainty analysis for report (2 people)	BG/JDS
Discussion and Conclusion	JK
Summary Letter	AV
Report typing and compilation	KR
Design Objective Analysis (2 people)	AV / JK

TA initial CK

Appendix B: Data Sheets

DATA SHEET #1

Team 232A1

Thermodynamic state (p, T, h) of the refrigerant at each point in the thermodynamic cycle.

(Convert pressures to psia for properties!)

	Ckt 1	Ckt 2	Average	Caution
1. P1 =	-8.9 psig		0	Not if 1 ckt off
T1 =	40.1 F		0	
h1 = hg at P1	90.74			

5.8 psi

2. Tsuper ht	92.5 F		0
P2=P3	-0.1 psig		0
h2 (chart est)	100		

14.6 p

3. P3= Psat	-0.1 psig		0
T =	78.5 F		0
h3 = hf	28.28		

14.6 psi

4. P4 =P1	-8.9 psig		0
T4=	40.0 F		0
h4 = h3	28.28		

5.8 psi

COP = (h1 - h4)/(h2-h1) $\frac{90.74-28.28}{100-90.74}$ COP= $\boxed{6.75}$

Curve fits

hf= 0.2428*Tsat + 9.17 Btu/lbm 1

hg= 0.144067*Tsat+90.163 Btu/lbm 2

hfg= -0.098733)*Tsat + 81.30208 3

Psat= A + B*Tsat + C*Tsat^2 +D*Tsat^3 4

(A=3, B=.01,C=.0015,D=.000001)

DATA SHEET #3 COP FROM COMPRESSOR POWER INPUT

The Compressors are 3-phase motors

Take the following data from the control panel

	Ckt 1 Amps	Ckt 1 Volts	Ckt 2 Amps	Ckt 2 Volts
Phase 1	93	4248		
Phase 2	92	4216		
Phase 3	91	4219		

Calculate Average volts each: 4227.67

Power factor 0.8

For each Ckt Power = (Vavg/1.732)*PF*(I1+I2+I3)

Ckt 1 Power: 538954.7

Ckt 2 Power: -

Total = 1+2: 538954.7 - watts

Indicated cooling from evaporator water flow

Get from Data Sheet #2

Btu/hr

Convert to same units: (watts)

- watts

COP = Cooling/Power =

DATA Sheet #2

(Monitor display)

COP CALCULATION FORM

CHILLED WATER FLOW & TEMP

Condenser

Temp out	Temp in	delta T
77.6°F	70.9°F	0

gal/min*60min/hr*.1336ft3/gal*62.4lbm/ft3

	gpm	lbm/hr
Flow =	6651	3326820

Evaporator

Temp in	Temp out	delta T
47.4°F	41.1°F	
In	Out	

	gpm	lbm/hr
Flow =	6411	3206772

Btu/hr

Analysis

1. Convert Flows to mass units m (above)

2. Chiller water cooling = Qevap = mevap* cp * (Tin - Tout) — 1936993 Btu/hr

3. Cooling Tower = Qcond = mcond * cp*(Tout-Tin) — 2240142 Btu/hr

4. Energy added by compressor heating = Qcond - Qevap — 403149 Btu/hr

5. COP = Cooling/work = Qevap/ (Qcomp) — Line2/Line 4 — 4.557

Control Panel metric	N/A	kw/ton
Compare to data	1174	Load in tons

42.7% load

OA Temp	59.9 °F
OA wet bulb	57.2 °F

Appendix C: Sample Calculations