Session 1566

Capstone Design Experience in a Thermal-Fluid Applications Course, and Development of an in-house Refrigeration Recovery System.

Ganesh Kudav, Aaron Cain
Youngstown State University, Youngstown - Ohio

Abstract

The Mechanical Engineering curriculum at Youngstown State University (YSU) integrates design and computer aspects throughout the freshmen, junior, sophomore, and senior years. However, some senior year courses have much more intensive capstone design requirements.

Thermal-Fluids Applications, ME – 726, is a late junior/early senior level course. The course deals with design and application of thermal-fluid systems such as heat exchangers, pumping and piping systems, electronic cooling, and other closely related topics presented by the faculty – topics that may be related to a continuing research project, or a consulting problem. One way to get the students involved is to assign the problem as a design and development project that accounts for 20 to 30% of the course grade, the rest from the tests, final exam, and assignments. This paper discusses one such project that was the outcome of the author's consulting activity. The students were assigned to design and develop a refrigeration recovery unit incorporating the acceptable industry and EPA standards.

The EPA is currently requiring a ban on the manufacture of all refrigerants that chlorofluorocarbon-based or the CFC's, thus gradually phasing out the systems that use CFC's. These older systems are serviced by appropriately certified technicians to be carefully recover, recycled, and reuse the CFC's . Unrestricted release of the CFC's from such systems in to the environment is against the EPA ordinance. Many commercial refrigeration recovery/recycling units are available. The author was involved in one consulting project with the recycling system manufacturing and supply company. The experience gained from this project was helpful to come up with a conceptual design that was substantially different from that of the company. The conceptual design was presented to group of students for design of the prototype.

This paper discusses the design procedure from concept to the development and testing of the recovery system. The paper also discusses the experimental data as a result of the system testing. The outcome of this student assignment was the successful implementation of the capstone design component, and a development of a recovery system that has several salient features, is less expensive, and has a better potential for marketability as compared to some currently marketed units.

I. Introduction

According to the Engineering Criteria 2000 (Ref. 1), Criterion 3 requires that the institutions seeking accreditation of an engineering program demonstrate and document

Program Outcomes and Assessment. Some of the elements in this criterion are: a) the ability of their graduates to design a system, component, or a process that meet desired needs; b) the ability to design and conduct experiments, as well as to analyze and interpret data; c) an ability to communicate freely; and d) the broad education necessary to understand the impact of engineering solutions in a global and societal context. Criterion 4 – the Professional Component - requires that the students "be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course...". While the mechanical engineering program at YSU strives to fulfill all of the ABET requirements, each faculty member has the responsibility to incorporate Criteria 3 and 4 into their courses. We attempt to incorporate design component and computer applications throughout the curriculum. However, in the senior courses the design component forms a substantial part of the overall course grade. Thermal Fluids Applications, ME 726, is one such course. After a sequence of fundamental courses in thermodynamics, heat transfer, fluid mechanics, engineering ethics, and engineering economy, students have the necessary background to register for ME 726. Typically, students end up taking this course as seniors or in their last quarter of their junior year. The topics covered in ME 726 are mostly design and application oriented. Topics include heat exchanger design, pumping and piping systems, electronic cooling, thermal energy storage systems, etc. I assign 15% for the design project. The design project involves design, development, and testing of the prototype system whose design objectives are specified by me and handed out at the beginning of the quarter. Three to four students work as a team on any one project. This paper presents one such project that was successfully completed and presented by students. The final outcome was a workable prototype of an R-134a refrigerant recovery system, and a formal written report (Ref. 2) on the prototype which was submitted following an oral in-class presentation.

II. Background

Due to concerns about depletion of earth's protective stratospheric ozone layer, the CFC's such as refrigerants R-11, 12, 113, 114, and 115 are being phased out of production by the year 2000. This EPA regulation was the outcome of the Montreal Protocol on Substances that Deplete the Ozone Layer signed by 24 nations and the European Economic Community on September 16, 1987 (Ref. 3). Thus older system using CFC's have to rely on recovery and recycling of the refrigerants. Many commercially available refrigerant recovery units are employed by certified technicians to recover, clean, and recycle the CFC's for reuse by the system. Systems that use the CFC's are gradually becoming obsolete. The newer refrigeration systems are designed to use "the Ozone friendly" refrigerants that are hydrofluorocarbon-based or HFC's. I undertook a consulting project with Youngstown Research and Development, Inc., YRD, a recycling/recovery system manufacturer and supplier. The current project evolved through my consulting efforts with YRD after which I came up with a conceptual design for the recovery unit (Fig. 1).

III. The Conceptual Design

The schematic in Fig. 1 illustrates the objective operation of the recovery unit. It closely simulates the recovery process from an actual system such as an automobile air-conditioning system. In phase I operation, the high-pressure liquid refrigerant passes through a pressure regulator into a counter-flow heat exchanger. The pressure regulator acts as a throttling device and a pressure reducer. The refrigerant thus enters the heat exchanger as a very low temperature saturation mixture. The liquid boils at the bottom surface of the exchanger, and dry vapor passes through the tubing and enters a compressor. The superheated vapor from the compressor enters the inner tube of the counter flow exchanger and rejects heat to the low temperature outer tube refrigerant. Ideally, the heat exchanger must be designed such that the superheated refrigerant is transformed into subcooled liquid before entering the receiver tank. Phase I continues until the pressure P_1 drops below –10 psig – an indication that the system being serviced is virtually empty of refrigerant. At this point the pressure regulator valve is shut off isolating the air-conditioning system from the recovery system. In phase II operation the recovery unit is run to retrieve any residual liquid refrigerant in the tubing segment between the compressor outlet and the recovery tank. This is done by manually operating two solenoid valves. The first solenoid valve directs the high pressure refrigerant stream into the counter flow heat exchanger inlet and the second solenoid valve cuts off the flow and allows the compressor to pump the vapor directly into the recovery tank. In phase II the residual liquid refrigerant is recovered via the heat exchanger to the compressor, and out to the tank. The entire recovery process is completed when the pressure gage at the compressor inlet reaches at or below -10 psig.

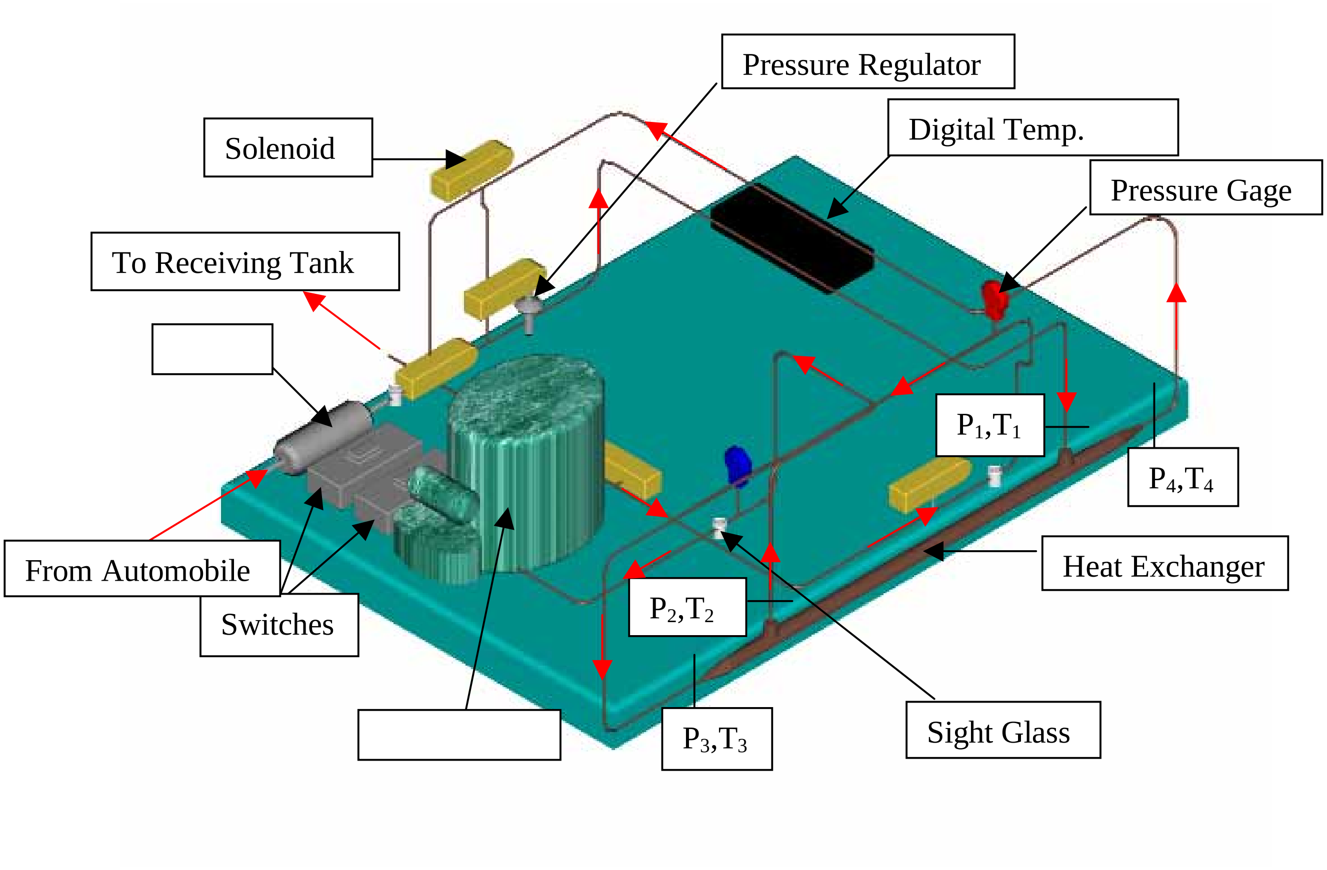

Fig. 1: The Recovery Unit

IV. The Design Objective

With the instructional funds available from the College, I procured a domestic small refrigerator compressor whose performance specifications were obtained from the manufacturer, copper tubing, pressure regulators, thermocouples, valves, and refrigerant 134a. In using R-134a, we made sure that no laws were being broken, should there be any accidental release of the refrigerant during testing of the prototype. Based on these basic components available the students were assigned the task of designing a counterflow heat exchanger. They were required to come up with the design and drawings and submit them to our engineering machine shop personnel. I approved $500.00 for the purchase of any ancillary items for the completion of the design. The certified shop technicians assisted them in the fabrication of the heat exchanger, assembly of the system, and testing.

IV a. The Student Project: Design of a Heat Exchanger and testing of the Recovery Unit

i. Design Procedure

The details of the design are well documented in Ref. 2. For brevity, a few design concepts are summarized in this paper. The heat exchanger design task was accomplished in two phases, one from a thermodynamic standpoint and the other from a heat transfer perspective. On the thermodynamic side initial conditions were first assumed based on supplied design parameters at each heat exchanger inlet and exit. Thus, all other thermodynamic properties could be determined, either directly with the assistance of thermodynamic tables or through the use of conservation of energy and mass flow rate equations. The corresponding state points were labeled 1, 2, 3, and 4 as shown in Fig. 2.

Since the process was time variant, the analysis was further divided by assuming worst- case scenarios. One analysis was performed at time $t = 0$, while another analysis was performed for time $t = \infty$. Aiming at an evacuation of 2.5 lbm of refrigerant from a typical car in fifteen minutes the overall mass flow rate was determined. Heat transfer analysis was performed following a flexible adherence to the NTU heat exchanger analysis method. Comparing the results of the heat transfer analysis for the two scenarios, it required a minimum area 0.685 ft^2, which corresponded to a ¾" diameter of the inside tube of approximately 3.49 ft in length. A double pipe concept was applied in order to maintain simplicity, maximize the area for heat transfer, and utilize readily available materials.

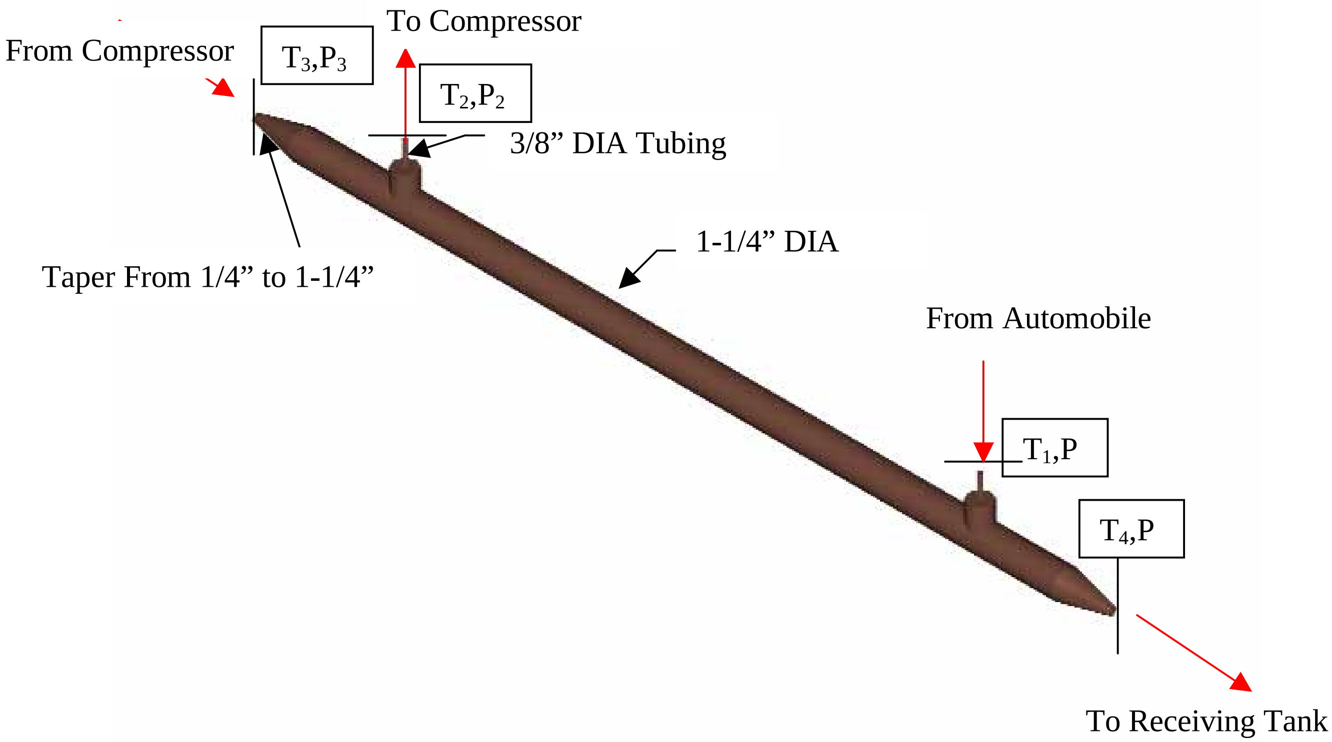

Fig. 2: The Heat Exchanger

ii. Testing Procedure

The heat exchanger was connected to the overall system (Fig. 1) and all the joints were silver-soldered. A vacuum test was conducted on the entire recovery system to make sure that no leaks were present either in the system or in the heat exchanger. This procedure also evacuates the system of any air or moisture that would contaminate the refrigerant. Subsequently, the refrigerant tank was attached to the system and the system was allowed to return to 0 psig. The two pressure gages were mounted to measure pressures P_2 and P_3, i.e. the compressor inlet and exit pressures respectively. The thermocouples were appropriately mounted on the surface of the tubing to enable recording of temperatures T_1, T_2, T_3, and T_4 (Fig. 1). The compressor was turned on and high-pressure refrigerant flow out of the supply tank was initiated. The process was timed and the pressures P_2, P_3, and $T_1 \ldots T_4$ were recorded at 2- minute intervals during the phase I operation. Also, the weight of the recovered R-134a, input voltage, and amperage to the compressor were recorded.

iii. Results

The results of the experiment are tabulated in Table 1, and are graphically presented below. Fig. 3 illustrates that the weight of the refrigerant recovered varies linearly with time and tapers off during the final minutes of phase I operation. Approximately 300 oz. of R-134a can be recovered in 30 minutes. Temperatures T_1 and T_3 are plotted in Fig. 4 as a function of time. Temperature T_1 remains at below-zero Celsius for the most part of phase I, an indication of the throttling effect of the pressure regulator. It gradually increases to the room temperature during the final few minutes due to the depletion of the liquid refrigerant coming in from the automobile. The T_3 trend determined if there was any drastic overheating of the compressor – no apparent overheating occurred. In Fig. 5 the pressures P_2 and P_3 are plotted versus time. Again, as seen from the trend, P_2 remained more or less uniform and gradually reduced to subzero gage during the final seconds of phase I, indicating that virtually all the refrigerant was evacuated from the supply tank. There were no dramatic pressure surges in P_3 and therefore the compressor operated within its operational parameters.

Table 1: Experimental Data

Time, t (min)	Weight of R-134A At time t (lb)	(oz)	Total Weight (oz)	P_i (psig)	P_e (psig)	Voltage (V)	Current (A)	Temp,T1 (deg C)	Temp,T2 (deg C)	Temp,T3 (deg C)	Temp,T4 (deg C)	Temp,T_{amb} (deg C)
0	0	0	0	0	0	0	0	28.1	28.1	28.1	28.1	28.1
2	1	8.5	24.5	15	73	115	6	-2.4	4.2	46.2	22.3	27.8
4	2	12.5	44.5	17	83	115	6	-1.9	4.8	56.1	27.7	27.9
6	3	15.5	63.5	16	90	115	6	-2.3	5.8	61	31.1	27.8
8	5	1.5	81.5	15	95	115	6	-3.2	6.3	64.4	37.2	27.8
10	6	2.5	98.5	15	98	115	6	-3.3	7.1	67.3	35.3	27.8
12	7	1.5	113.5	14	100	115	6	-3.4	7.9	69.9	36.9	27.9
14	8	4	132	15	104	115	6	-3.3	9	72.5	38.5	27.9
16	9	8	152	15	107	115	6	-3.4	20.1	74.9	39.8	27.8
18	11	10	186	14	109	115	6	-3.6	11	77	41.3	28.1
20	12	12.5	204.5	14	111	115	6	-3.4	11.7	79.1	42.4	27.9
22	13	11	219	14	113	115	6	-3.5	12.3	80.6	43.4	28
24	14	11	235	14	115	115	6	-3.4	13	82.9	44.3	28.2
26	15	10.5	250.5	14	116	115	6	-3.5	13.8	84.7	45.2	28
28	16	10	266	14	118	115	6	-3.7	14.4	85.9	46.2	28
30	17	4	276	14	119	115	6	-3.7	14.8	87.4	46.9	27.9
32	17	11.5	283.5	2	122	115	6	-8.7	16.8	87	47.1	27.9
34	18	3.5	291.5	2	130	115	6	6.7	25	84.8	45.3	27.9
36	18	8.5	296.5	1	139	115	6	17.4	30.8	85.2	47.7	28.1
38	18	10.5	298.5	-2.46	141	115	6	23.4	34.9	77.2	47.9	28

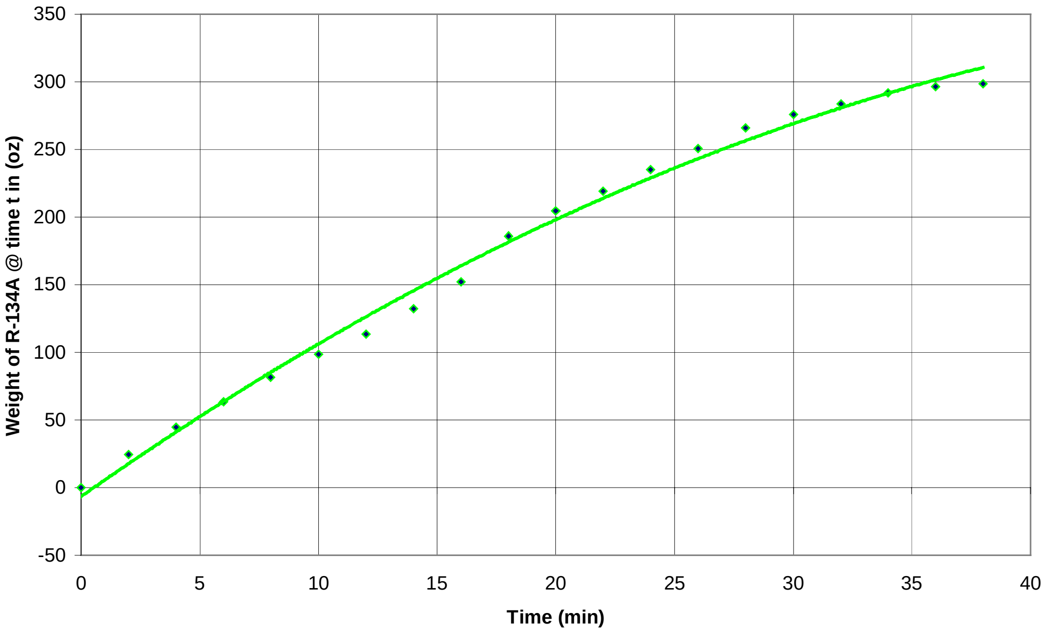

Fig. 3: Weight of R-134A Recovered Vs. Time

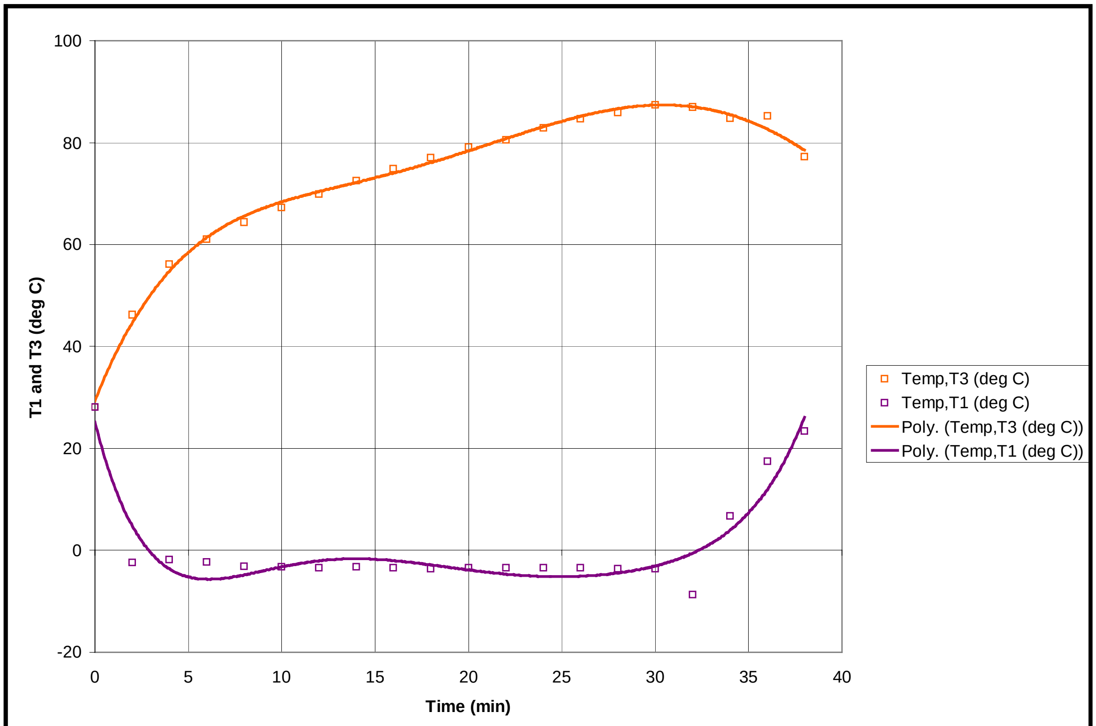

Fig. 4: T1 and T3 Vs. Time

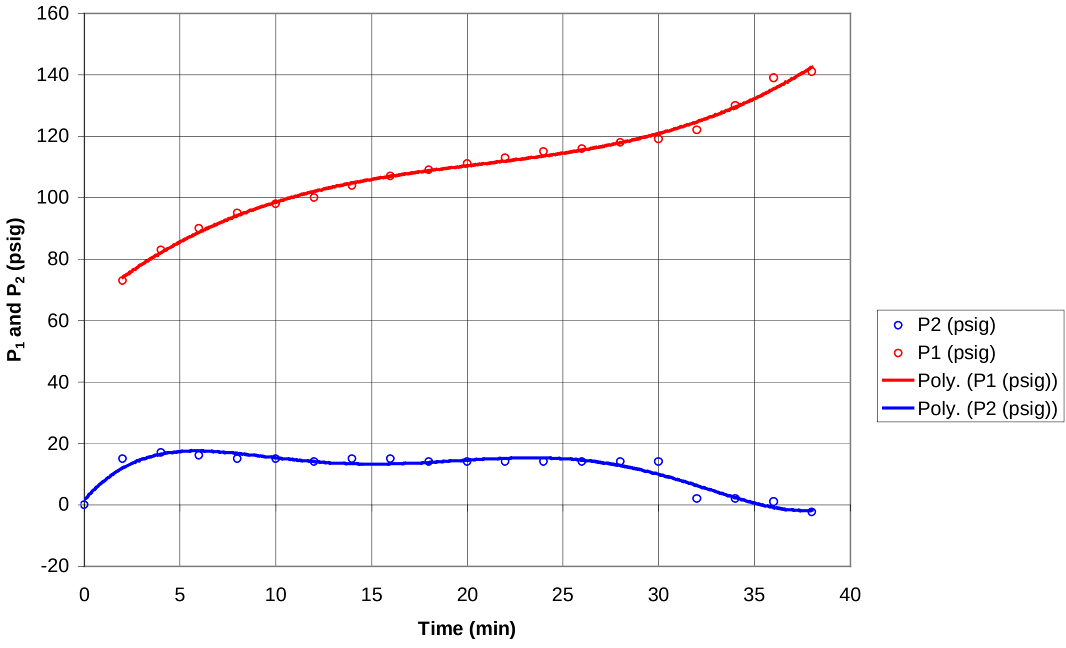

Fig. 5: P_1 and P_2 Vs. Time

V. CONCLUSION

V a. Summary of Student Comments

Much was learned from the design and the construction of the heat exchanger. For example, project management cannot be stressed enough. Goals should be established early on in the design phase. Roadblocks can occur at any time; for instance, unavailability of materials can cause delays. Also, one must plan their work schedule with the resident technician. Plans are worthless if there is no time to proceed through with the construction.

The heat exchanger is very compact and can be mounted in various positions, as the surrounding environment requires. It is also considered simple in that it could be easily mass-produced because of the use of standard copper pipe and fittings; there is no need for specialty parts.

There are only a few disadvantages to this design. The length of the heat exchanger could be considered too long, and a more compact design could probably be found. However, as a prototype, the objective of the heat exchanger had to be made sure to be met with the available resources. Another disadvantage of this design is that the heat exchanger has to be disconnected from the recovery system in order to evacuate the oil/contaminants from the system, although the problem could easily be remedied by installing an oil drain at the outer tube of the heat exchanger.

V a. Outcome

The author believes that ME-726 in its present format of instruction has met all of the requirements of ABET Criterion 3. The students learned the spirit of team-work, formulated the design procedure based on the given constraints, made appropriate assumptions, and used the principles of heat transfer and thermodynamics. The end result was a well presented written report, a working prototype, and an oral in-class presentation. This project has laid the foundation for further refinement in the design such as inclusion of filters and oil separators within the recovery system, or alternatively as a model for a performance comparison of the refined heat exchanger design.

Bibliography

1. 1999-2000 Criteria for Acreditating Engineering Programs – Engineering Criteria 2000; URL: ž HYPERLINK http://www.abet.org ‑http://www.abet.org .

2. Cain, A., Goodman, G., Sikora, S., & Utterback**, G., Design of a Heat Exchanger,** a report submitted in partial requirement for completion of ME 726 course, Youngstown State University, Spring 1999.

3. *Refrigeration Service for the 90's,* Published by Refrigeration Service Engineers Society, 1991.

GANESH V. KUDAV, Ph.D., P.E.

Ganesh V. Kudav is currently an Associate Professor of Mechanical Engineering at Youngstown State University. He teaching undergraduate and graduate courses in the areas of energy, fluid mechanics, systems dynamics, and heat transfer. His research interests are in computational and experimental fluid dynamics, neural networks, and energy systems. He received is Ph.D. degree from Texas Tech University and is a Registered Professional Engineer in the State of Ohio.

AARON C. CAIN

Aaron C. Cain is currently an undergraduate student in Mechanical Engineering at Youngstown State University and is also seeking a Bachelor's Degree in Computer Science concurrently. He expects to graduate in Spring 2000. He is a member of the University's Honor Program, and a recipient of University Trustees' Scholarship, and McDermott International Inc. Engineering Scholarship. He is a member and serves on the executive committees of Tau Beta Pi, and ASME.