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# Learning enhancement in Thermodynamics Classroom via use of TEST™ software in design projects and laboratory

**Subha K. Kumpaty**

**Milwaukee School of Engineering, 1025 N. Broadway, Milwaukee, WI 53202**

**Abstract**

Introduced in Spring 1999 into the MSOE's three-quarter Thermodynamics sequence, The Expert System for Thermodynamics (TEST™ software by Subrata Bhattacharjee)[1] has become a great asset and an excellent tool in enhancing students' learning of Thermodynamics fundamentals. The presenter, Dr. Kumpaty encouraged the institution-wide use of the software by obtaining a site license and has personally tested its use in classroom, design projects and laboratory for the last three years. All mechanical engineering (ME) and mechanical engineering technology (MET) students run a 100-kW steam power plant in the laboratory at various part-loads and full load in groups of 10 and conduct thorough, first and second law analyses on the plant employing the user-friendly software. They are also assigned 3 to 4 design projects in the Thermodynamics sequence, the treatment of which has become easier with the parametric studies accommodated superbly by the TEST™ software. The overall experience with this integrated teaching has been very rewarding to both faculty and students. The details of the experience, a sample problem, a sample project, laboratory activities and the effective utilization of the software/courseware are presented.

## Introduction

Milwaukee School Of Engineering is dedicated to excellence in undergraduate education. The goal of the undergraduate curriculum is to produce well-rounded engineers, which is achieved through strong emphasis in a) excellent technical preparation, b) strong laboratory orientation with *faculty teaching labs in small size sections* and c) required Senior Design projects. Accordingly, MSOE graduates are highly sought by industry (over 99% placement). The mechanical engineering students receive a rigorous treatment of Thermodynamics in a three-quarter sequence. Typically, in the fall quarter, they learn to apply the First Law for control masses and control volumes (energy balance). In the winter, they learn to apply the Second Law for control masses and control volumes (exergy/ availability balance). They further apply principles learned to cycles and attempt one credit hour of design projects, for example, designing devices based on power or refrigeration cycles. In the spring quarter, they receive instruction on diverse topics such as IC engines, psychrometry, combustion and compressible flow as well as perform design projects such as cogeneration and air conditioning. The thermodynamics experience is enhanced by one credit hour of laboratory taught in groups of 10 with a lot of quality interaction with the faculty in this last quarter. Currently, Moran and Shapiro text[2] is employed for mechanical engineering sequence and Cengel and Boles text[3] is utilized for mechanical engineering technology program. The presenter introduced the TEST™ software to Spring 1999 class as a means of support for calculations for a design project, which opened the door for its further utilization in the curriculum thereafter. The student feedback has been very affirming and this paper intends to present the sweet story of successful integration of a software tool that has impacted the curriculum immensely.

## TEST™ Software

The Expert System of Thermodynamics is an excellent ***visual*** software tool for thermal engineers, developed by Dr. Subrata Bhattacharjee, Professor at San Diego State University. It follows very closely Cengel and Boles textbook on Thermodynamics[3] and hence can serve as a very attractive courseware as well. The software is very much user friendly and in particular, very methodical utilizing proven problem-attacking techniques. Generally, I let students think of four sequential questions in solving thermo problems.

Q1: Which system? Closed (control mass) or Open (control volume).
Q2. Steady state or time-variant?
Q2: Which pure substance? Two-phase substance or a gas.
Q3: Which units? English or SI?

Listed below in Figure 1 is a thread of selections in the software that establishes how one selects a flow of steam in a system such as a turbine. Daemons are Java applets that are the core of the software. Once a system is chosen, there is a choice for steady state or unsteady operation. The generic control volumes include devices such as turbines, compressors, nozzles, diffusers, heat exchangers while the specific ones are to deal with combustion, psychrometry, compressible flow etc. There is a choice to identify whether single flow, or if multiple, whether or not the flows are mixed or unmixed. Obviously the next selection is the type of fluid. The author has incorporated a host of fluids, both two-phase substances and gases (ideal, perfect, real). The States calculator will indicate the option for unit system and even within a selected unit system all kinds of unit conversions are possible with a touch of a key.


Fig. 1 Thread of selections of a thermodynamic system in TEST™ software

## Sample Problem

*Steam at 5 MPa and 600 C enters an insulated turbine operating at steady state and exits as saturated vapor at 50 kPa. Take the mass flow rate as 0.1 kg/s. Neglecting potential and kinetic energy changes, determine work developed by the turbine. Repeat the problem a) if the turbine is not well-insulated turbine and there is heat loss at a rate of 10 kW through an enlarged boundary at 25 C. Compare the results with an isentropic expansion in the turbine. Discuss the implications of the second law on these cases.*

State 1 Given ($p$, $T$): 5 MPa, 600 C with mass flow rate 0.1 kg/s

The ***States Calculator*** yields the following (see Figure 2): density $\rho$, specific volume $v$, internal energy $u$, enthalpy $h$, entropy $s$, (default veloctity$V$=0; elevation $z$=0), total energy $e=u+V^2/2+gz$, flow energy $j=h+V^2/2+gz$, mass flow rate $\dot{m}$ (given 1 kg/s), volume flow rate $\dot{V}$ and area $A$.

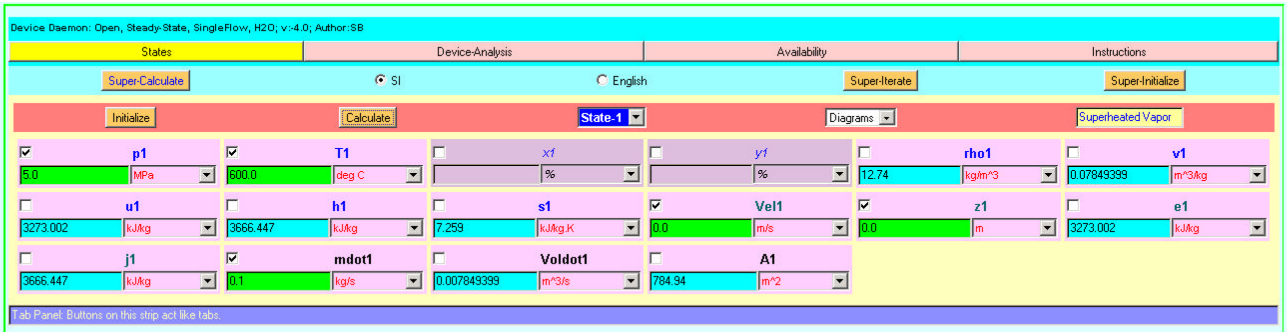


Figure 2a. Properties Determination of State 1 for the Sample Problem

State 2 Given (p, sat. vapor) with the same mass flow rate: The properties are shown below.

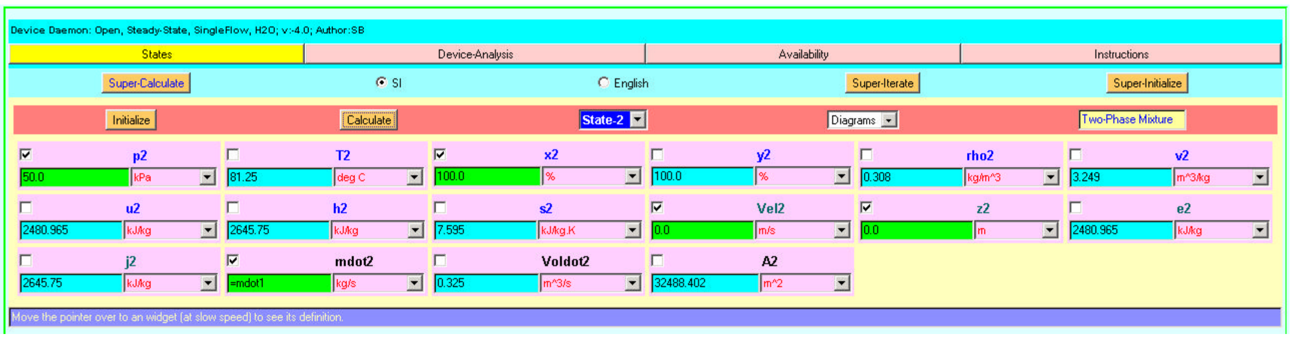


Figure 2b. Properties Determination of State 2 for the Sample Problem

More states can be defined and all the properties calculated for use if a problem warrants several states.

First Law/ Energy balance for the Device (Turbine): Insulated case ($\dot{Q}$=0)
The ***Device-Analysis Calculator*** is shown below. The power produced is 102 kW.

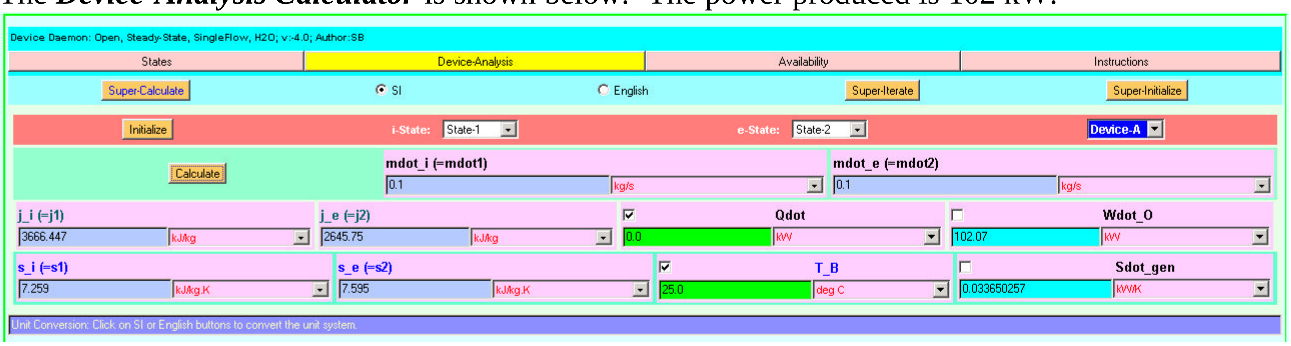


Figure 2c. Device-Analysis for the Sample Problem (Insulated Turbine)

Second Law/ Availability Analysis

Shown in the ***Availability calculator*** is the entropy generation rate, $\dot{S}_{gen}$ which is 0.03365 kW/K

and the exergy destruction rate, $\dot{I}$ is 10 kW using environment as 25 C and 1 atm. The reversible power (isentropic conditions) is 112 kW and hence the second law efficiency, $\eta_{II}$ is 102/112= 0.91.


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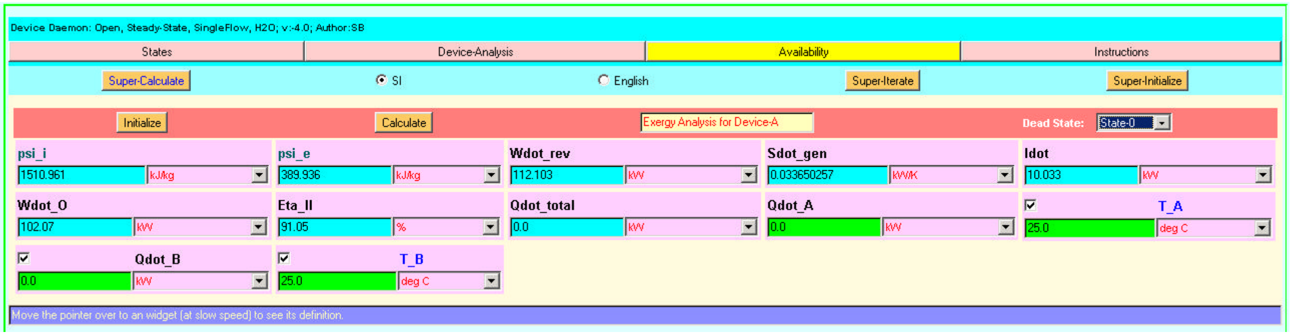

Figure 2d. Availability Analysis for the Sample Problem

First Law for the Device with $\dot{Q}$ = -10 kW
The power produced is obviously 92 kW.

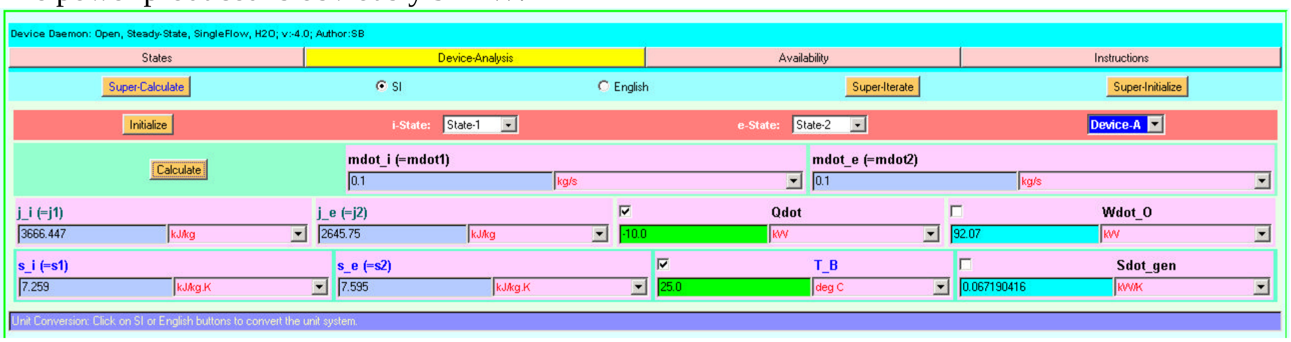

Figure 2e. Device-Analysis for the Turbine with Heat Losses

Second Law/ Availability for the case with $\dot{Q}$ = -10 kW.
Entropy generation rate is 0.06719 kW/K and the exergy destruction rate now is 20 kW. The reversible power (isentropic conditions) is 112 kW as shown before and hence the second law efficiency is 92/112 = 0.82.

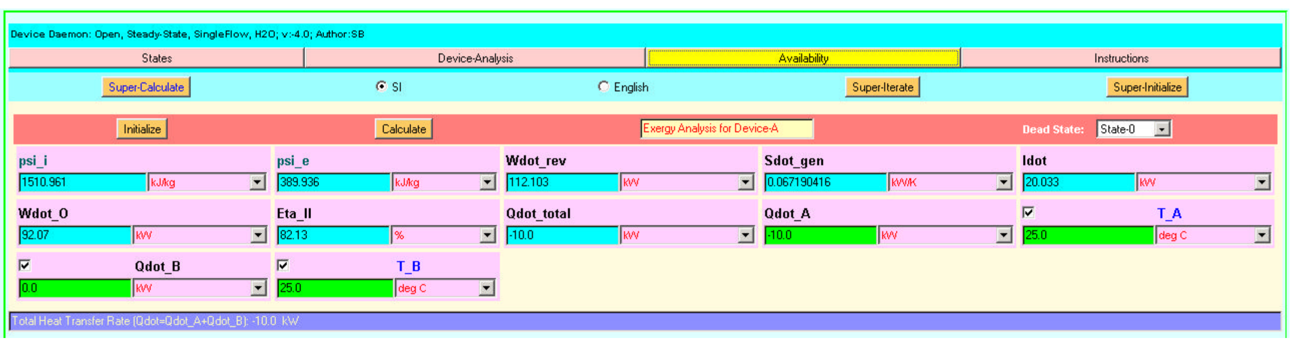

Figure 2f. Availability Analysis for the Turbine with Heat Losses

If we were to attempt a cycle problem, say there are 4 states and 4 devices, TEST™ allows us to define Devices A, B, C and D working between states 1-2, 2-3, 3-4 and 4-1 respectively. Both First and Second Laws can be applied to each device and the cycle can be studied comprehensively with much ease. Once a cycle is designed fully, parametric studies could be conducted. Using the Super-Calculate button, any impact of changing a variable can be readily viewed. The following is one of the projects assigned in the second quarter.

**Sample Project**

*Ocean Thermal Energy Conversion power plant generates power by exploiting the naturally occurring decrease of the temperature of the ocean water with depth. At a particular location in the Atlantic near Hampton, Virginia, the temperature near the surface is 80 F and the temperature at a depth of 1500 ft. is 45 F. A power plant is to be designed which utilizes this naturally occurring temperature gradient to produce electric power. The net output desired is 125 MW.*

*First, you may design a cycle using ammonia as the working fluid. You should specify boiler/evaporator and condenser temperatures, operating pressures, mass flow rate of the fluid, power required by the pump, thermal efficiency and any other details that are relevant. Also, estimate seawater flow rates through the boiler and condenser. You may assume the properties of seawater as those of pure water. The seawater enters the boiler at 80 F and leaves at 77 F. The seawater enters the condenser at 45 F and leaves at 46.5 F. You may further consider the issues related to the plant efficiency taking into account the fact that the pumps for the ocean water flows and other auxiliary equipment typically require 15% of the gross power generated.*

*Second, consider replacing the working fluid. You may choose R-134a, for example and/or any other fluids. How will it affect the plant? Can the same pump be used? Will the boiler be enlarged? How will the equipment related to the ocean water flows be affected? Compare the designs and discuss advantages and disadvantages. You can consider factors such as safety, reliability, cost, size and all other good stuff! When all is said and done, you are to choose the* best *option with an appropriate justification.*

This project is developed out of design and open-ended problem 6.4D out of Moran and Shapiro text.[2] Here's how one student, Andrew Krajnik (2001 Winter) summarized the results he obtained using TEST™ software in an AutoCAD drawing, shown in Figure 3:

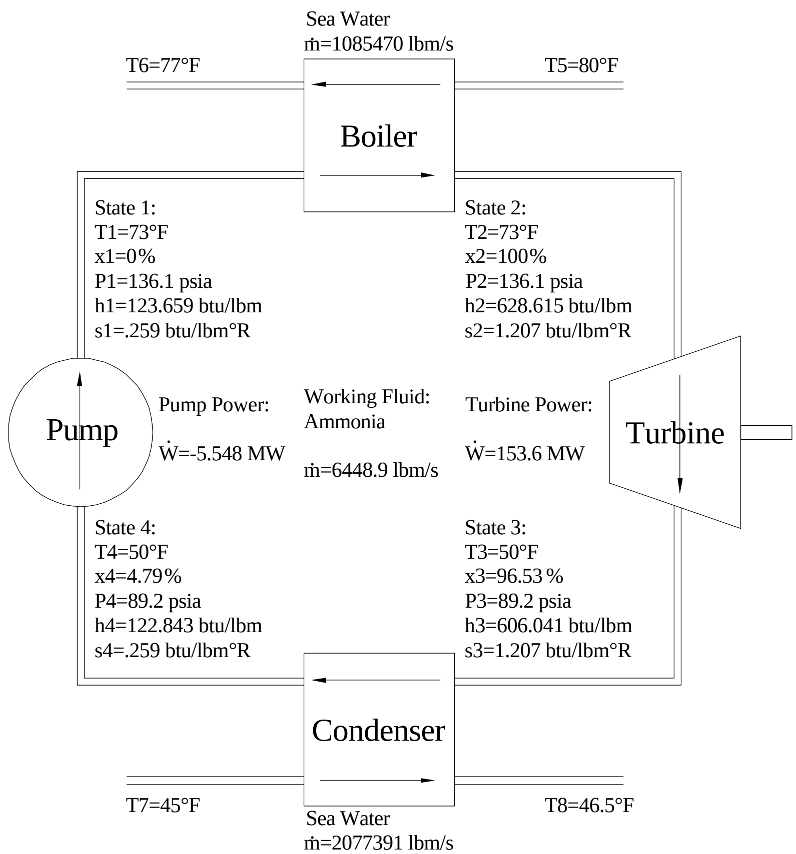


Figure 3a. Design Calculations of OTEC Power Plant using Ammonia as the working fluid

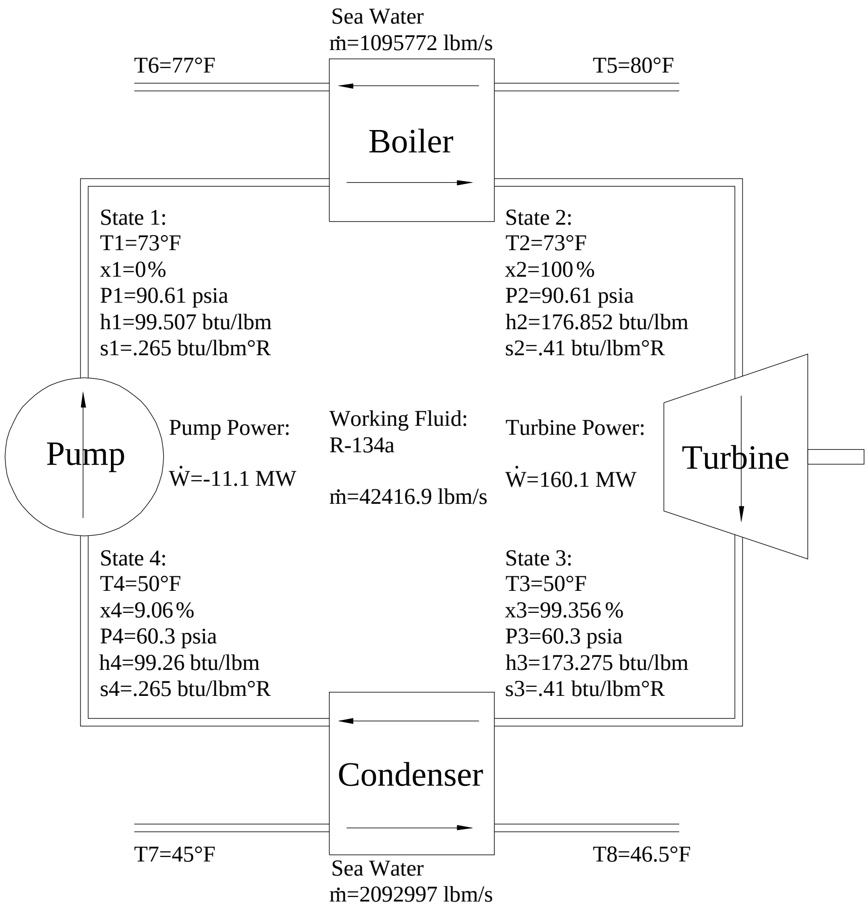


Figure 3b. Design Calculations of OTEC Power Plant using R-134a the working fluid

A typical discussion on the results obtained at the second quarter stage by a student in this class would run as follows. Comparing the mass flow rates necessary to meet the power requirement, it takes more than six times the amount of R-134a to do the same work as ammonia. If one considers the volume flow rates through the turbine, the above ratio may not be that drastic, however, the increase in mass flow rate is too great to deselect R-134a over ammonia. Also, the pump required for the system with R-134a would need to be twice as big as that required for the ammonia system. Another factor to consider is the operating pressures of the fluids. The higher the operating pressure of the working fluid, the stronger the piping needs to be to contain it. The ammonia operates at higher pressures (136 and 89 psia), as opposed to R-134a (91 and 60 psia); however, the pressure ratio is 1.5 for both. From a safety standpoint, both of these fluids are considered to be safe for the environment. The flow rates of seawater in both designs are very close, and therefore do not serve to make one alternative more appealing than the other. However, in the overall design consideration for a plant of this size, the enormous flow rates present a challenge, roughly 900 million gallons per hour. Flow rates of this magnitude are virtually unheard of, and even if these flow rates could be achieved and maintained, the size of the piping would be enormous and costly. In addition, such high flow rates could potentially cause major disruptions in the marine life surrounding the facility. Care would also have to be taken that aquatic plant and animal life would not be drawn into the system and cause harm to the aquatic life or damage to the power plant. Although the initial cost of the plant would be

extremely large, the fact remains that there are no fuel costs for running a plant of this type. The power is generated using naturally occurring thermal gradients, and the plant would more than likely pay for itself within a very short amount of time. If the obstacles cited could be met and overcome in a safe and environmentally manner, then ammonia would be the best alternative based on cost and size. From efficiency standpoint comparing with other sources of energy, this OTEC power plant does not fare well. Both plants designed above have an efficiency of 4.3% while the maximum efficiency possible is 6.6% for the temperature range available.
The usefulness of the TEST™ software in design calculations is self-evident.

**Laboratory Use of TEST™**

Housed in Johnson Controls Laboratory on campus is a 100-kW steam power plant, which is run periodically so that all ME and MET students, while taking Thermodynamics will study the plant thoroughly in groups of 10. A three-hour laboratory is utilized in preparation: to identify the components of the plant, decide on how the plant is run, what data is to be recorded and how the First Law and the Second Law analyses are to be processed etc. The following week, the plant is run at four loads- 25%, half, 75% and full load. The students take responsibility and coordinate how they would work with the licensed operator and how they would confirm the sequential recording of all the data necessary before the load is changed, and study various minute details of our plant and its practical variations from the cycle they see in the textbooks. They will come for a stimulating discussion the following week, showing some of the results, asking questions, understanding the value of the steam power plant experiment in illustrating the thermodynamic principles and illustrating the use of exergy/ availability analysis in an actual energy conversion system. Within a few days from that lab discussion, they submit a comprehensive report on the Steam Power Plant Analysis. Also, they study the exhaust gas composition from the gas analyzer data they collect while running the plant. Combustion Analysis is performed at all four loads as well. The MSOE faculty find their students being very appreciative of the time allotted for a thorough study of the plant. The students over the years have seen this experiment as an opportunity to experience the culmination of their learning of the energy and the availability balances. They study exergy accounting systematically and make suggestions for the plant improvement. While looking at several states in each load case and repeating the calculations for four loads, the TEST™ software has made their experience worthwhile and enjoyable. Instead of being lost in the calculations of properties from the tables using interpolation technique and complaining why they should be repeating the calculations for four load conditions, they are now able to focus their attention on critical issues such as availability accounting, comparison of results from different load conditions and possible improvement of plant performance. It is fitting to recognize the tremendous role TEST™ has played in the presenter's course offering of Thermodynamics sequence.

**Student Feedback**

"I wish I had known this software exists a year earlier."
"I will certainly use the software in my workplace after I graduate."
"TEST has made my learning easier and I will continue to use it in my engineering practice."
"Thanks for introducing me to such a fantastic tool to solve thermo problems."
"This software is not just an interpolator of properties. It guides your thinking on how to attack thermodynamics problems correctly and efficiently."
"Could you give us more take-home exams so that we can take the help of TEST?"

"I don't know how I would have handled the Power Plant Lab without TEST software."

The above are just a few statements that describe the positive influence of TEST™ software on student learning of Thermodynamics concepts. Out of 120 students that have been introduced to TEST™ software by the presenter in the past three years, none have said they disliked its use. In stead, all have voted for its greater utility as courseware. Several students that felt they needed more practice benefited a great deal from following the sample problems provided within the software. It can be safely stated that the introduction of TEST™ software has and will continue to enhance student learning of Thermodynamics at MSOE. The use of TEST™ software for special topics such as combustion, psychrometry and compressible flow is not dealt with in this paper; however, the preliminary results have been more than promising. The results will be disseminated in future.

## Conclusion

'The Expert System for Thermodynamics' software has proved to be an effective multi-media tool in enhancing the learning environment for Thermodynamics course sequence in the presenter's classrooms at Milwaukee School Of Engineering. The author presented its use as a great asset in a variety of assignments such as homework problems, projects and laboratory. The positive feedback from students affirms this assessment of the presenter. In conclusion, the use of TEST™ software is highly recommended since it will facilitate the student centered learning of Thermodynamics become a rewarding experience for all involved- both faculty and students.


## Acknowledgment

The author wishes to thank Dr. Bhattacharjee and his family for the excellent visual tool that they have gifted the thermal engineers across the globe. Its use in the thermodynamics classroom is not only worthwhile but a convincing reality that teaching and learning thermodynamics can be fun and non-intimidating.


### References Cited


1. http://kahuna.sdsu.edu/testcenter
2. Fundamentals of Thermodynamics, 4th Edition by Moran & Shapiro, John Wiley & Sons, 1999.
3. Thermodynamics: An Engineering Approach, 3rd Edition by Cengel & Boles, McGraw Hill, 1998.


### Biographical Information


Dr. SUBHA K. KUMPATY is an associate professor of mechanical engineering. He teaches courses mainly in the thermal area along with courses such as numerical modeling, vibrations, finite element analysis. He is the principal investigator of NSF sponsored grants- Research Experiences for Undergraduates and Aid to the Disabled Grant. He is active in research involving undergraduates for over 10 years. He obtained his doctoral degree at the University of Mississippi in August 1991.