Simulation Across the Engineering Curriculum Getting the Most from Your Simulation Systems

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Abstract There is no question that Engineering simulation systems have had a tremendous impact on the Maritime Education and Training in Maritime Training Institutions across the world. The ability to use these systems to economically, efficiently and safely duplicate normal and casualty situations in steam and diesel propulsion simulated ships has been well documented in conferences such like those of the IAMU as well as other international forums more specifically dedicated to the use of such systems.
However, the reality still exists that these systems are not inexpensive, and once the decision has been made by a maritime training institution to purchase or build one, there are still operational and maintenance costs that must be incurred by the institution. This paper will not deal specifically with the design, purchase, installation, or maintenance of the simulator, nor will it try to make a cost justification for this major piece of equipment. It is assumed that these decisions have been made and most institutions are already operating such systems.
This paper and presentation will look for opportunities to use the simulators across the engineering curriculum once the decision has been made to purchase one. The authors will show several benefits from using the simulators in a wide array of engineering and technology courses. Benefits will range from more realistic approaches to otherwise difficult concepts in Thermodynamics and Fluid Mechanics, to de-mystifying the engineering and mathematical processes in the design of such systems, and the closer relationships between the theories involved in energy systems and the operations of those very same systems.
Keyword :

1. Introduction

Merchant and Naval vessels are much more complex than at any time in the history of shipping, and marine engineers must not only be well trained to operate these vessels safely and efficiently, but also educated to understand the complexity of such engineering systems. The Maritime Education and Training (MET) Institutions today are challenged to provide an extensive background in the concepts of Engineering theory and principles, while ensuring these concepts can easily be understood and applied directly to shipboard operational systems.

Maritime Engineering graduates are well known for their prowess in operational and hands-on understanding both shipboard and shore-side. But many of our graduates are either leaving the shipboard environment earlier than ever before or not entering it at all. These graduates go into fields of electrical, mechanical, instrumentation and controls, and industrial engineering and design, and often enter graduate and post-graduate work in these fields as well as pursuing professional engineering licensure. Our stakeholders and employers of these graduates are expecting an engineering graduate that excels not only in the practical aspects of engineering systems and operations, but also graduates who have the theoretical background of engineering principles and practice found in many of the world's best "engineering" programs. This may cause some confusion in our students (and our faculty) as they struggle to grasp both the theoretical and the practical aspects of our profession – along with all other components needed for an educated citizenry – and meet the Standards of Training Certification and Watch keeping (STCW) along with its associated sea-time requirements and certifications - all within a 4-year program.

One well established and effective way to ensure engineering students are prepared for the operation of shipboard and power plant operations is the use of Maritime Engineering Simulation. Systems like this run the gamut of costs and pedagogies ranging from PC Computer based training programs to full scale full mission simulators where students must enter simulated control rooms and associated engine rooms with actual valves and controls that are electronically tied into the simulation system. These systems have proven to be safe and effective systems for a wide range of training for the students from normal operations to start up and shut down of systems to a full load of possible casualties in which the students must address any fault with which the instructor chooses to test the student.

However, there is a significant cost in the design, purchase, installation, operation, maintenance and eventual upgrade and replacement of such systems. Additionally, once the decision has been made to acquire such a system, there are also associated costs with learning the capabilities of the system, and experimenting with this new pedagogy in an attempt to fit it into the curriculum. Often this process is further complicated by adjusting other specific training courses in order to more fully utilize the opportunities that the simulators offer the faculty.

Unfortunately, due to the operational costs and the specific objectives prepared for the use of simulation, the full capabilities of the simulation systems are rarely utilized. It is just not feasible to have all students run the simulators though all of its options and still have time to complete the entire curriculum. Once the system is up and running and the faculty have achieved a comfort level in the operation and use of the systems, there remain many opportunities for incorporating the simulator into a wide range of courses in the Engineering Curriculum. The examples on the following pages are in Heat Transfer, Thermodynamics, Refrigeration, and Instrumentation and Controls, and are intended to simply begin the conversation about these opportunities, and are not intended to exhaust the options.

2. Bring Theory to Practice

The authors believe that using the engineering simulators in this way can provide these benefits to MET Institutions and Maritime Universities:

- Better understanding and usage of the simulation systems themselves
- Allow engineering faculty not normally involved in shipboard engineering operations access to the simulators and perhaps a better understanding of the complexities of the operations as compared to principles and theories
- Allow students in engineering theory courses to perform experiments in a system that is "real" to them
- Allow faculty and students almost unlimited change points for lab experiments not possible with typical lab experimental equipment
- Allow faculty and students to calculate "textbook" problems then run similar problems in real or modeled time and compare outcomes from full system with calculated values
- Allow for increased utilization of simulations systems further increasing the benefits relative to the investment costs
- Allow students to perform experiments and see that there are real complications throughout the entire system if individual systems are adjusted or allowed to run out of control

- Allow the students to understand the theory and engineering design that must be incorporated into any engineering system and how such systems must be balanced for optimization and efficiency
- Use the simulators as labs for courses in which lab equipment is difficult to justify for either cost, space or safety reasons

3. Heat Transfer

A typical experiment in Heat Transfer is the use of a Heat Exchanger. This experiment looks at the use of the air heater in the turbo charger system of a diesel engine. Fig 1 shows the heat exchanger in its relationship to the entire turbocharger system.

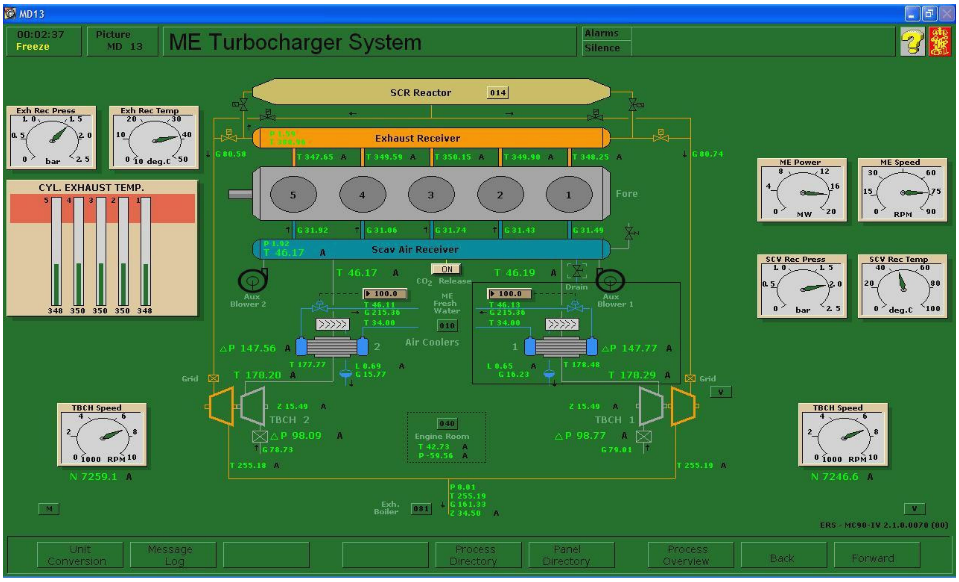

Fig. 1 – Air Cooler Heat Exchanger in Turbocharger system (1)

With this system the faculty can adjust the following parameters of the system:

- *Air flow rate*
- *Pressure drop across the system*
- *Air inlet temperatures*
- *Air outlet temperatures*
- *Cooling water flow rate*
- *Cooling water inlet temperature*
- *Cooling water outlet temperature*
- *Coefficient of heat transfer*

Using the various parameters and using the following formulas, Heat Transfer faculty can teach to the following objectives:

Formulas:

Q = m Cp (To-Ti)

Q = (HTC) A (LMTD) F
Q = Heat transfer rate
M = Mass flow rate
Cp = Specific heat of the fluid
To-Ti – Temperature change across the heat exchanger
HTC = Overall heat transfer coefficient
A = Area of heat exchanger
LMTD = Log mean temperature difference
F = Correction factor for heat exchanger type and condition

By varying the parameters above the following objectives or values can be obtained:

- Calculate the heat transfer rates across the heat exchanger (water and air)
- Calculate the efficiency of the heat exchanger
- Change heat exchanger efficiency and re-calculate heat transfer and flow rates
- Predict flow rate changes needed as load (air flow) increases on engine

4. Thermodynamics

Faculty teaching Thermodynamics can use a Steam Engineering Simulation System to teach the overall efficiency of a steam power plant.

The full-mission Steam Plant Simulator at Cal Maritime provides a robust capability for the operational training of marine engineers. Simulator displays provide all of the necessary property data and flow rates to undertake a variety of performance analyses. The following theory-to-practice exercises illustrate how the Simulator can be used to reinforce class room lessons in the thermodynamic principles of propulsion plant design.

- Boiler Efficiency can be evaluated using by comparing the net rate of energy transfer to the working substance during steam generation ($\dot{Q}_{\text{out}}$) to the rate at which thermal energy is released in combustion ($\dot{Q}_{\text{in}}$).

$$\eta_{\text{Boiler}} = \dot{Q}_{\text{out}} / \dot{Q}_{\text{in}}$$

$$\dot{Q}_{\text{out}} = \left(\sum \dot{m}_{\text{steam}} \times h_{\text{steam}}\right) - \left(\dot{m}_{\text{feed}} \times h_{\text{feed}}\right)$$

where the mass flow rates and enthalpies of feed, desuperheated steam and superheated steam are all displayed on the ***Port*** and ***Starboard Boiler*** schematics

$$\dot{Q}_{\text{in}} = \dot{m}_{\text{fuel}} \times LHV$$

where the mass flow rate of fuel to each burner is displayed on the ***Fuel to Burners*** schematic and the Lower Heating Value (LHV) of the selected fuel is displayed in the plant ***Parameters*** table

This analysis may be performed at different power levels to illustrate changes in Boiler Efficiency over the power range.

- Main Engine Efficiency can be evaluated by comparing high and low pressure turbine power outputs ($\dot{W}_{\text{out}}$) to the net rate of energy conversion in the 2-stage turbines ($\dot{Q}_{\text{in}}$).

$$\eta_{\text{Turbine}} = \dot{W}_{\text{out}} / \dot{Q}_{\text{in}}$$

$$\dot{W}_{\text{out}} = \dot{W}_{\text{first-stage}} + \dot{W}_{\text{second-stage}}$$

where the first and second stage turbine power outputs are displayed on the ***Main Turbines*** schematic

$$\dot{Q}_{\text{in}} = \dot{m}_{\text{in}}(h_{\text{in}} - h_{\text{ext}}) + (\dot{m}_{\text{in}} - \dot{m}_{\text{ext}}) \times (h_{\text{ext}} - h_{\text{out}})$$

where the mass flow rates and enthalpies of steam at the turbine inlet, extraction point and outlet are all displayed on the ***Main Turbines*** schematic

- Steam Plant Efficiency can be evaluated by comparing SSTG and Main Engine power outputs ($\dot{W}_{\text{out}}$) to the rate at which thermal energy is released in combustion ($\dot{Q}_{\text{in}}$). This analysis assumes hotel electrical loads are negligible when compared to steam plant auxiliary demands.

$$\eta_{\text{Steam Plant}} = \dot{W}_{\text{out}} / \dot{Q}_{\text{in}}$$

$$\dot{W}_{\text{out}} = \dot{W}_{\text{propulsion}} + \dot{W}_{\text{generators}}$$

where propulsion power is displayed on the ***Main Bearings*** schematic and generator power is displayed on the ***Main Switchboard*** schematic

$$\dot{Q}_{\text{in}} = \dot{m}_{\text{fuel}} \times LHV$$

where the mass flow rate of fuel to each burner is displayed on the ***Fuel to Burners*** schematic and the Lower Heating Value (LHV) of the selected fuel is displayed in the plant ***Parameters*** table.

This analysis may be performed at different power levels to illustrate changes in Steam Plant Efficiency over the power range.

- Regenerative Heating Effects can be demonstrated by observing the position of auxiliary steam regulators at full sea speed with and without extraction. First attain steady-state operation at full sea speed without extraction and record the regulator positions. Then initiate extraction, allow the plant to stabilize, and record the regulator positions again. Following the demonstration, discuss how the reduction in steam flow through the regulators represents fuel savings in the boiler.

- Boiler Shrink and Swell in response with maneuvering pressure transients can be demonstrated. Following the demonstration, discuss the cause of these variations in water mass specific volume, and the rationale for two-element (level and steam flow) feed controllers.

5. Refrigeration and Air Conditioning

One of the most important parameters when looking at the overall efficiencies of any refrigeration or air conditioning system is the relationships between the high side and low side temperatures and pressures as compared to the work performed by the compressor. The theoretical efficiency – or Coefficient of Performance (COP) - of a refrigeration system is shown by the following equation:

COP = Heat Transfer in Evaporator/Work of Compressor

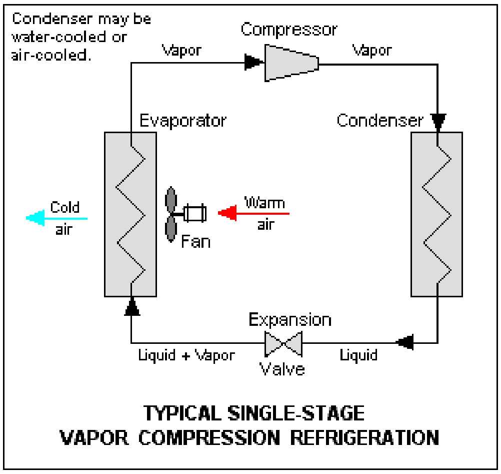

Fig. 2- Typical Refrigeration systems as found in most textbooks (2)

As many marine based refrigeration systems are cooled by the seawater, and the seawater temperature is a variable as ships travel across oceans and seas, this example can help not only in understanding the principles of refrigeration and heat transfer, but can be an important lesson for operating engineers as well.

The system shown in figure 3 is from a diesel simulation system and is a seawater cooled condenser for a ship's service refrigeration system. Compare this figure to that as found in most engineering textbooks when analyzing refrigeration systems (fig 2). The simulator provides a much more detailed picture of what is happening and becomes a laboratory experiment for many individual components of the system or of the system as a whole.

The following parameters of the system can be controlled and monitored:

- *Sea water inlet temperatures and pressures*

- *Sea water outlet temperatures and pressures*
- *Refrigerant inlet/outlet temperatures*
- *Refrigerant mass flow and volumetric rates*
- *Coefficient of heat transfer across the heat exchanger*
- *Condenser (Refrigerant) Pressure*

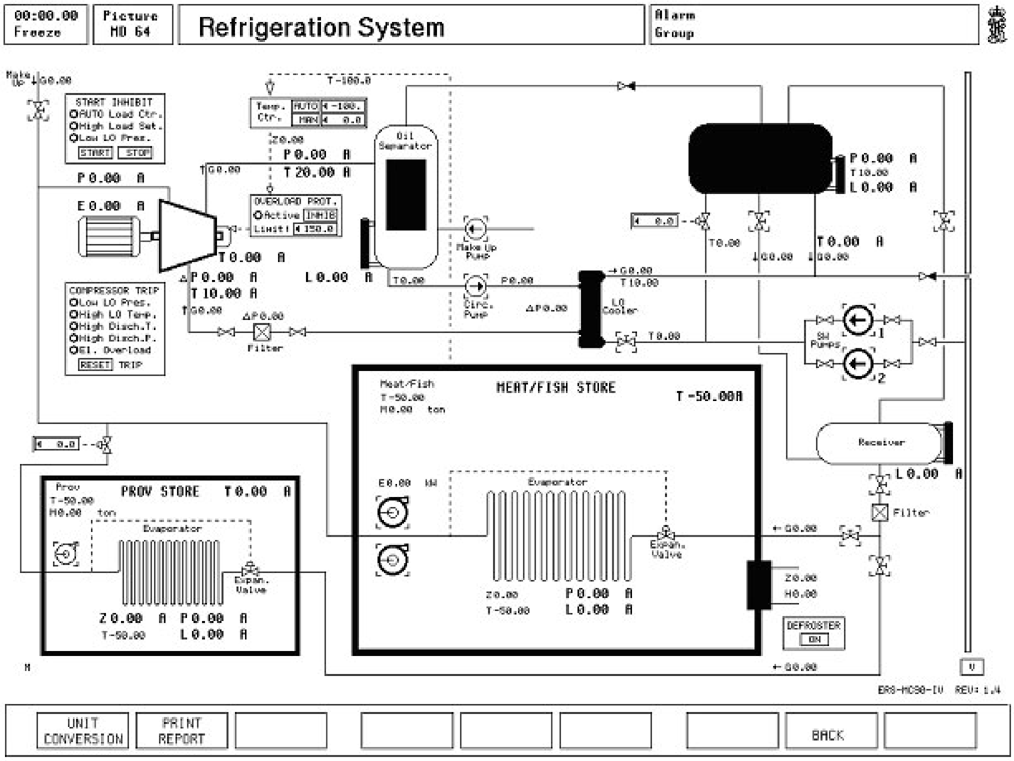

Fig. 3 Marine Refrigeration System (1)

By monitoring pressures and temperatures at various points along the system and determining appropriate enthalpy (h) and entropy (s) values, this lab experiment will allow the student to calculate flow rates, heat transfer rates and temperature changes for various seawater and tube fouling conditions of the system. Efficiencies of the system can be obtained from the information gathered as the parameters are changed.

Additional but similar experiments can be made using the ship's evaporator systems and once high and low side pressures are obtained, overall co-efficient of performances can be calculated. With flow rates, pressures and temperatures, additional experiments can be made on the compressor operations and efficiencies in later experiments.

6. Instrumentation and Controls

In this example of bringing theory to practice, the authors will use a Fuel Oil viscosimeter system to show how a Cascade Control System can work. A cascade-control system consists of one controller (primary, or master) controlling the variable that is to be kept at a constant value, and a second controller (the secondary, or slave) controlling another variable that can cause fluctuations in the first variable. The primary controller positions the set point of the secondary, and it, in turn, manipulates the control valve. (3) In this case, the master controller senses the viscosity, signaling the slave controller which is measuring fuel temperature, finally sending a signal to the control valve which is measuring steam pressure, ultimately controlling the steam flow rate to the fuel oil heater.

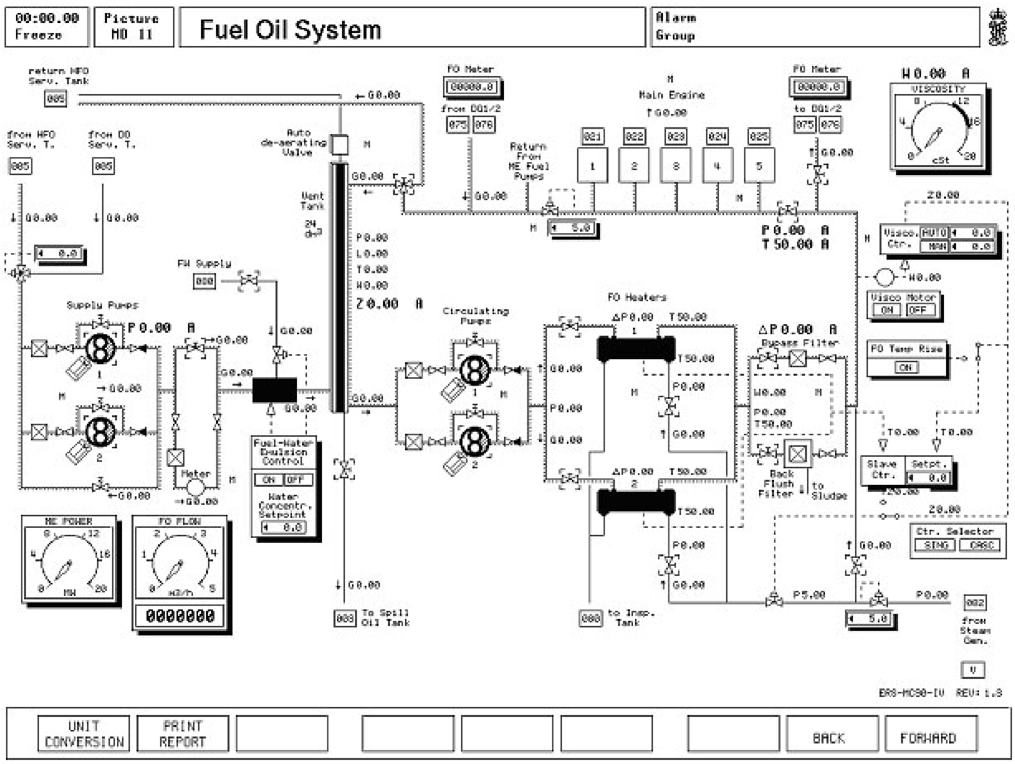

Fig. 4- Fuel Oil System with Heater and Viscosimeter (1)

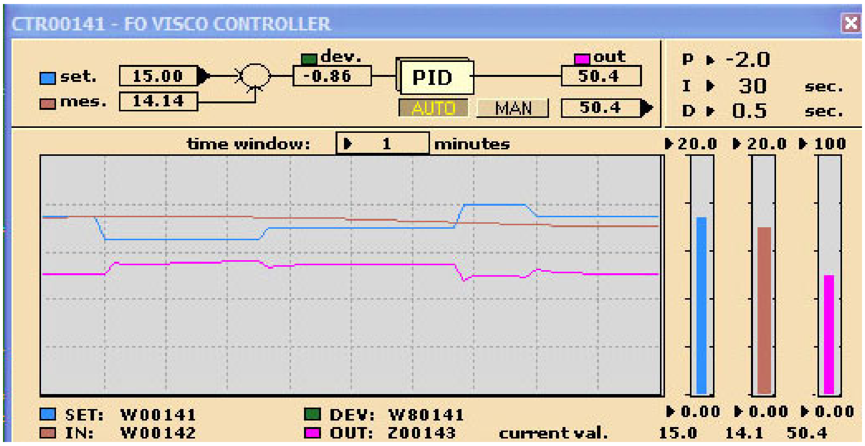

Fig. 5 PID Controller Graph for a Fuel Oil Viscosimeter (1)

Figure 5 shows a PID controller used for this purpose, where:

P = Proportional
I = Integral
D = Derivative

Variables on the system are Pressure, Temperature and Flow rates for both the fuel and the steam. In the Cascade control system, the viscosity of the fuel is the primary objective. Viscosity – a measure of the fluid's ability to flow – is critical to proper operation of the system through the fuel injector pumps and injector tips. Improper viscosity can cause decreased overall efficiency by poor fuel combustion and incorrect fuel flow rates, and can cause increased maintenance and repair.

Controlling the fuel's viscosity is a matter of controlling the temperature of the fuel at a given location. This feedback mechanism causes a steam line valve to adjust to regulate the steam flow to the fuel heaters. The change in steam flow (or in fuel flow) will cause a change in the fuel outlet temperature and therefore in its viscosity.

The operator can adjust the controllers by adjusting the parameters shown below and the student can learn to tune the controllers for a given set of operating conditions. As the operating conditions vary, the students can see how effective the control system remains. As the results of the systems can be given in real time, the student begins to understand how quickly the system can and will react to changes in the system. The student can learn an appreciation how the controller works by inserting his or her own adjustments to the steam control valve to compare human controllers to automatic control systems.

Adjustable parameters of Control systems:

- *Fuel viscosity*
- *Steam Pressure*
- *Fuel Oil Temperature*
- *Gain (magnitude ratio) – the ratio of change in output divided by the change in input that caused it. (3)*

- *Integral control action – Action in which the controller's output is proportional to the time integral of the error in put. (3)*
- *Derivative action – Control action in which the rate of change of the error signal determines the amplitude of the corrective action applied. (3)*

6. Conclusion

This paper gives several examples of how existing maritime engineering simulators can be used to help teach a myriad of engineering principles across the engineering curriculum. While using a system that students already understand, these principles and theories can be brought to practice to better understand the principles themselves as well as the effects of these principles upon a much larger system and the consequences when experiments are run outside the norms of proper operational procedures and practices. The authors encourage engineering faculty of all disciplines to work closely with faculty teaching simulation to help integrate the simulators across the curriculum as a platform for teaching difficult engineering concepts.

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