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UNIT 515: APPLIED THERMODYNAMICS MECHANICS

Lesson 1: Thermodynamic Principles **Suggested Teaching Time:** 2 hours

Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles

Topic	Suggested Teaching	Suggested Resources
Revision of basic concepts	Although there is a certain level of prerequisite knowledge required for entering this course the tutor will benefit from taking time at the beginning of the course to reinforce the basic theorem. Whole-class teaching: as ice breaker, have a quiz where students identify the correct symbols from a given list. Tutor to get the whole class involved in a group discussion to cover the following principles and the meaning of the following terms: • Extensive and intensive properties, the use of capital and lowercase letters (for total and specific quantities) and different material state Develop this discussion further to include the forms of energy involved when discussing thermodynamics. Whole-class teaching should be used to define the terms potential energy (PE) and kinetic energy (KE), flow energy (FE), internal energy (U) and enthalpy (H): • PE: work = mass x g x distance • KE = $mv^2/2$ • FE = pV • U: $\Delta U = mc\Delta T$ (Joule's law) • H = F.E. + U Split class into smaller groups and issue a series of questions covering the energy equations used so far, tutor to circulate and correct as required.	**Books:** *Applied Thermodynamics for Engineering Technologists,* Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Websites:** http://www.freestudy.co.uk/ http://www.s4e2.com/drupal7/content/download http://www.prosim.net/en/software-prophyplus-8.php **Practical equipment:** Equipment to demonstrate thermodynamic and gas laws

Lesson 2: Thermodynamic principles (continued)		**Suggested Teaching Time:** 2 hours
Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles		
Topic	**Suggested Teaching**	**Suggested Resources**
Gas laws	Gas laws: the basic principles should be demonstrated using simple equipment and learners should be given the opportunity to test the principles practically. Whole-class teaching should cover: • Charles's law • Boyle's law • General gas law Use examples from industry where possible to maintain applicability to real world. Illustrate using laboratory experiments where appropriate. The tutor should work through typical examples of calculations covering these laws and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained. Whole-class teaching should then go on to elaborate on the general gas law to bring in characteristic gas constant and the universal gas law while including the definition of a mole. Again use examples from industry where possible. Split class into smaller groups and issue a series of questions covering the energy equations used so far, tutor to circulate and correct as required.	**Books:** *Applied Thermodynamics for Engineering Technologists,* Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Websites:** http://www.freestudy.co.uk/ http://www.s4e2.com/drupal7/content/download http://www.prosim.net/en/software-prophyplus-8.php http://phet.colorado.edu/en/simulation/gas-properties **Practical equipment:** Laboratory equipment to demonstrate thermodynamic and gas laws

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Lesson 3: Thermodynamic principles (continued)	**Suggested Teaching Time:** 2 hours

Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles

Topic	Suggested Teaching	Suggested Resources

Specific heat capacities	Whole-class teaching to cover:
	• Changes in energy levels
	• Discuss principle specific heats
	    ○ Constant pressure (c_P)
	    ○ Constant volume (c_V)
	If possible get the students to conduct experiments to measure SHC of different materials. Or use simulated experiments on the software.
	The tutor should work through typical examples of calculations covering these laws and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.
		Books:
		Applied Thermodynamics for Engineering Technologists, Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383
		Basic and Applied Thermodynamics 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314
		Websites:
		tap.iop.org/energy/thermal/607/file_47502.doc
		http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics
		Practical equipment:
		Laboratory equipment to demonstrate thermodynamic and Gas Laws

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Lesson 4: Thermodynamic principles (continued)	**Suggested Teaching Time: 1** hour

Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles

Topic	Suggested Teaching	Suggested Resources
Changes of state or phase	Whole-class teaching to cover: • Changes in internal energy (U) • Enthalpy (H) This is tabulated as specific internal energy (u) or specific enthalpy (h) in fluid tables. Boiling point or Saturation Temperature: the basic principles should be demonstrated using simple equipment and learners should be given the opportunity to test the principles practically. Whole-class teaching to cover the relationship between boiling point and sensible energy (uf or hf in tables). Cover changes in state from liquid to gas including why and how it occurs. Include the following terms: saturation temperature (ts in tables), saturated liquid, dry saturated vapour, latent enthalpy (hfg in tables) and latent internal energy (ufg in tables). Develop concepts to include the effect of pressure on the boiling point (saturation pressure) again if possible use laboratory equipment to demonstrate these processes. Whole-class teaching to cover the drawing of phase diagrams and how to discover the triple point and critical point and introduce class to concepts of superheated vapour and supercritical vapour.	**Books:** *Applied Thermodynamics for Engineering Technologists,* Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Websites:** tap.iop.org/energy/thermal/607/file_47502.doc http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics **Practical equipment:** To demonstrate thermodynamic and Gas Laws

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Lesson 5: Thermodynamic principles (continued)	**Suggested Teaching Time:** 1 hour	
Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles		
Topic	**Suggested Teaching**	**Suggested Resources**

Changes of state or phase (continued)
 	
Saturation curves
	Discuss:
	• Constant evaporation
	• Wet vapour
	• Dry saturated vapour
	• Superheated vapour
	• Specific volume of:
	  ○ Saturated water (vf)
	  ○ Dry saturated steam (vg)
	  ○ Wet steam
	Split class into smaller groups and issue data for various substances giving values of hf and hg at various temperatures and get students to plot the saturation curve for the material, tutor to circulate and correct as required
	Group discussion on:
	• What their saturation curves illustrate
	• How temperatures and dryness fractions may be drawn on the curve and with the resulting graph
	• How the enthalpy of water, wet, dry or superheated steam may be found
		Books:
		Applied Thermodynamics for Engineering Technologists, Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383
		Basic and Applied Thermodynamics 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314
		Websites:
		tap.iop.org/energy/thermal/607/file_47502.doc
		http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics
		http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics
		Practical equipment:
		To demonstrate thermodynamic and Gas Laws

Lesson 6: Thermodynamic principles (continued)	**Suggested Teaching Time:** 1 hour	
Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles		
Topic	**Suggested Teaching**	**Suggested Resources**
Uses of tables	It is essential that students know how to read fluid tables. The tutor should work through typical examples of calculations using these tables and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books:** *Nbs/Nrc Steam Tables* Lester Haar Illustrated CRC Press, 1984 ISBN: 0891163530, 9780891163534 **Websites:** http://www.spiraxsarco.com/uk/resources/steam-tables.asp http://enpub.fulton.asu.edu/ece340/pdf/steam_tables.PDF

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Lesson 7: Thermodynamic Principles (continued).	**Suggested Teaching Time:** 2 hours	
Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles		
Topic	**Suggested Teaching**	**Suggested Resources**

Laws of thermodynamics	Group discussion to talk through the laws of thermodynamics:
	• First law of thermodynamics to include:
	  ○ Closed systems
	  ○ Non-energy flow equation
	  ○ Systems
	  ○ Steady flow equation
	Reinforce the fact that nett energy transfer = nett energy change in the system
	• Second law of thermodynamics to reinforce the concept that the entropy of any isolated system never decreases. Such systems spontaneously evolve towards thermodynamic equilibrium — the state of maximum entropy of the system
	• Third law of thermodynamics to reinforce the concept that the entropy of a system approaches a constant value as the temperature approaches absolute zero
		Books:
		Applied Thermodynamics for Engineering Technologists, Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383
		Basic and Applied Thermodynamics 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314
		Website:
		http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics

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Lesson 8: Thermodynamic Performance	**Suggested Teaching Time:** 8 hours	
Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles		
Topic	**Suggested Teaching**	**Suggested Resources**
Analyse the thermodynamic performance of **steam-turbine power cycles** (A.C. 1.1)	Group discussion getting students to apply theory already learnt to a theoretical turbine. Discuss with and without friction. Use isentropic efficiency and polytropic efficiency formulas The tutor should work through typical examples of calculations using these tables and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained Group discussion on Rankine cycle: • Draw cycle on presentation screen and discuss various stages • Show how to calculate energy conversions using steam tables • Discuss ideal Rankine cycle and how it would more closely resemble that of the Carnot cycle. Through individual work or group discussion, explore the effect of: • Superheating the steam in the boiler (Rankine cycle with superheating) • Splitting the turbine into two stages and reheating the steam between the two stages (Rankine cycle with reheating)	**Books:** *Applied Thermodynamics for Engineering Technologists,* Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Website:** http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics http://www.freestudy.co.uk/

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Lesson 9: Thermodynamic Performance (continued)	**Suggested Teaching Time:** 4 hours

Learning Outcome 1: Understand how the design of compressible fluid turbo-machines affects performance

Topic	Suggested Teaching	Suggested Resources
Analyse the thermodynamic performance of **steam-turbine power cycles** (A.C. 1.1)	Explore effect of tapping steam off various stages of the turbine and using stages of condenser rather than a single condenser and using this energy to preheat the boiler entry water (Rankine cycle with regenerative feed heating). Undertake this practically if at all possible. Discuss where isentropic inefficiencies lie (turbine and pump) and how they can be overcome by these variation. The tutor should work through typical examples of calculations for each of the different types of system and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained	**Books:** *Applied Thermodynamics for Engineering Technologists*, Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Website:** http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics **Practical equipment:** Working scale model of steam turbine with adjustable tapping off points

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Lesson 10: Thermodynamic Performance (continued)	**Suggested Teaching Time:** 4 hours

Learning Outcome 1: Understand how the design of compressible fluid turbo-machines affects performance

Topic	Suggested Teaching	Suggested Resources
Analyse the thermodynamic performance of **combined heat and power cycles** (A.C. 1.2)	Discuss how we can use the steam for other uses (heating or processes) and how we can have a combined heat and power generation system. Discuss the back pressure turbine cycle and the pass-out turbine cycle and compare efficiencies using calculations. Discuss the application of these two types into a combined heat and Power generation system and discuss efficiencies.	**Books:** *Applied Thermodynamics for Engineering Technologists,* Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Website:** http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics **Practical equipment:** Working scale model of steam turbine with CHP capability

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Lesson 11: Thermodynamic Performance (continued)	**Suggested Teaching Time:** 8 hours	
Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles		
Topic	**Suggested Teaching**	**Suggested Resources**
Analyse the thermodynamic performance of **gas turbine power cycles** (A.C. 1.3)	Group discussion on how a gas turbine varies from a steam turbine. Discuss ideal constant pressure cycle, compressor efficiency as compared to turbine efficiency, constant pressure heating and cooling. Get students to draw p-V p-h and T-s diagrams. Group discussion on: • Efficiency calculation based on first law of thermodynamics • Effect of friction on Joule cycle in both compressor and turbine. The tutor should work through typical examples of calculations for a gas turbine without friction and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained They should then introduce friction into the same calculations to allow students to compare the results the learners should then work through other examples of such calculations. Through individual work or group discussion, explore: • Effect of parallel turbines and effect on efficiency • Advantages/disadvantages of having series turbines • Effect of intercooling on compressor and reheating on turbine • Use and effect of exhaust heat exchangers Discuss where isentropic inefficiencies lie and how they can be overcome.	**Books:** *Applied Thermodynamics for Engineering Technologists*, Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2^{nd} Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Website:** http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics **Practical equipment:** Working scale model of steam turbine with various options of layout etc.

Lesson 12: Thermodynamic performance (continued)		**Suggested Teaching Time:** 4 hours
Learning Outcome 1: Understand the thermodynamic principles of engineering power and refrigeration cycles		
Topic	**Suggested Teaching**	**Suggested Resources**
Analyse the thermodynamic performance of **vapour-compression cycles**. (A.C. 1.4)	Through individual work and group discussions, explore: • Heating and cooling effects of compression and expansion and application of this to a reversed heat engine cycle • Mediums used within system and use of refrigerants introduce thermodynamic tables for refrigerants • How the vapour compression cycle is similar to gas turbine but is working in reverse (Reverse Rankine Cycle) • Removal of turbine due to impracticalities and use of throttle • Reversed Rankine cycle and effect on power input requirements leading on to coefficient of performance or advantage. Look at this for both refrigeration and heat pump effect • Heat pump effect and application of 1st law of thermodynamics • Isentropic efficiency and effect on the process • Effect of using a flash chamber The tutor should work through typical examples of calculations covering these applications and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained	**Books:** *Applied Thermodynamics for Engineering Technologists,* Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Website:** http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics **Practical equipment:** Working scale model of vapour compression machine

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Lesson 13: Explain how the characteristics of compressible fluid turbo-machines affect performance and evaluate the performance of them using one-dimensional analysis	**Suggested Teaching Time:** 8 hours

Learning Outcome 2: Understand how the design of compressible fluid turbo-machines affects performance

Topic	Suggested Teaching	Suggested Resources

How the characteristics of **compressible fluid turbo-machines** affect performance and evaluate the performance of them using one-dimensional analysis
 	
(AC 2.1 and 2.2)
	Through group discussion, explore:
	• Compressor design
	• Radial flow and axial flow compressors
	  ○ Look at velocity profiles, sources of internal losses
	  ○ Take into consideration overall, single stage and polytropic efficiencies
	
	The tutor should work through typical examples of calculations covering these applications and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained
	
	Lead a group discussion to explore turbine design to cover:
	• Radial in flow and axial flow turbines
	• Velocity profiles
	• Sources of internal losses
	• Overall, single stage and polytropic efficiencies
	• Difference between impulse and reaction turbines
	  ○ Cover velocity profiles and efficiencies
	• Effect of reheat between stages of turbine
		Books:
		Applied Thermodynamics for Engineering Technologists, Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383
		Basic and Applied Thermodynamics 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314
		Website:
		http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics
		Practical equipment:
		Assorted Compressors and Turbines and relevant components some sectioned to show relevant parts and/or features

Lesson 14: The internal combustion engine	**Suggested Teaching Time:** 8 hours

Learning Outcome 3: Understand the performance of internal combustion engines

Topic	Suggested Teaching	Suggested Resources
Introduction to internal combustion engines Air standard cycles (AC 3.1)	Tutor-led instruction to review operation of motors and how all motors require a high level of source energy and must exhaust at a low energy. Discussing the efficiency of Hydraulic and Electric motors. Evolve this discussion to cover the heat engine and how to calculate the efficiency of a heat engine. Whole-class teaching on the practical heat engine and how it developed. Discuss the four processes needed: 1. Heating 2. Expansion 3. Cooling 4. Compression Lead on to how this may be achieved practically: open system as discussed previously with gas and steam turbine systems or a closed system. Discuss the Carnot process and develop the closed system Carnot cycle. Group discussion on the development of the internal combustion engine and the development of spark ignition and compression ignition engines; cover the construction of a spark ignition engine and its operating cycle. Compare it with the closed cycle machines covered so far and draw the Otto cycle Discuss Otto cycle efficiency and effect of compression ratio Whole-class teaching to discuss difference between a spark ignition and a compression engine. Develop the Diesel cycle and the Dual Combustion Cycle.	**Books:** *Applied Thermodynamics for Engineering Technologists,* Eastop, T. D., Pearson Education, 1967, ISBN: 8177582380, 9788177582383 *Basic and Applied Thermodynamics* 2nd Edn, Nag, P. K., Tata McGraw-Hill Education, 2010, ISBN: 0070151318, 9780070151314 **Practical equipment:** Internal combustion engines of assorted designs and relevant components, some sectioned to show relevant parts and/or features **Software** Dynomation-5™ Four-Stroke Simulation **Website:** http://www.tesis-dynaware.com

Lesson 15: The internal combustion engine	**Suggested Teaching Time:** 8 hours

Learning Outcome 3: Understand the performance of internal combustion engines

Topic	Suggested Teaching	Suggested Resources
The Stirling engine (AC 3.1)	Split class into smaller groups and issue components and plans to build a Stirling engine, tutor to circulate and assist as required. Discuss how the engine operates. Experiment with different factors to discover effect e.g. use of ice on cooling tray, or use of different gases such as helium.	**Books:** *The Air Engine, 1st Edition Stirling Cycle Power for a Sustainable Future*, A Organ, Woodhead Publishing, 2007, ISBN: 9781845692315; eBook ISBN: 9781845693602 *Three Ltd Stirling Engines You Can Build Without a Machine Shop*, Jim R Larsen CreateSpace, ISBN-10 1452806578 ISBN-13 9781452806570 **Practical equipment:** Components to make Stirling engine and plans **Website:** http://www.animatedengines.com/vstirling.html

Lesson 16: The internal combustion engine		**Suggested Teaching Time:** 6 hours
Learning Outcome 3: understand the performance of internal combustion engines		
Topic	**Suggested Teaching**	**Suggested Resources**
Engine efficiency (AC 3.2 and 3.3)	Who-class teaching to cover factors that affect the efficiency of an internal combustion engine: • Ignition timing • Induction • Common rail or direct injection methods • Exhaust systems • Use of turbo and supercharger Split class into smaller groups and use a test bed to demonstrate how individual factors do affect the operation and efficiency of a live engine, for example advancing and retarding the ignition, ideally incorporating a selection of induction manifolds, exhaust systems etc. to show how these affect performance. Tutor-led discussion to look at the practical performance factors achieved by an internal combustion engine to include, power, torque, RPM, mean effective pressure and also specific fuel consumption. Split class into smaller groups and use a test bed to demonstrate practical performance factors of a live engine, recording data for power, torque, RPM, specific fuel consumption etc. Compare test bed data with standard air cycles.	**Books:** *Internal Combustion Engines: Performance, Fuel Economy and Emissions*, Institute of Mechanical Engineers (eds) Woodhead Publishing Print Book ISBN: 9781782421832 eBook ISBN: 9781782421849 **Practical equipment:** Engine test bed

Lesson 17: Reciprocating compressors		**Suggested Teaching Time:** 4 hours
Learning Outcome 4: understand the performance of reciprocating compressors		
Topic	**Suggested Teaching**	**Suggested Resources**
Ideal compressors (AC 4.1) Practical performance (A.C. 4.2)	Whole-class discussion recapping the Otto cycle and the reciprocating piston arrangement and develop this idea into a compressor. Whole-class teaching to cover the definition of and how to calculate the following: • Swept volume • Free Air Delivery • Volumetric efficiency • Isothermal efficiency • Indicated power Tutor-led discussion to discern the effect of cooling on the compressor efficiency and therefore the use of intercoolers. Discuss: • Other methods to improve efficiency such as non-return valves • Input power requirements of various types of compressor • Development of double acting compressors and their effect on efficiency Split class into smaller groups and use a test bed to demonstrate practical performance factors of a reciprocating compressor, recording data and comparing it with the ideal data.	**Books:** *Compressor Handbook: Principles and Practice* Tony Giampaolo Fairmont Press ISBN: 0-88173-615-5 **Practical equipment:** Sectioned compressor and working compressor Test rig for compressor allowing performance figures to be obtained **Website:** http://jensapardi.files.wordpress.com/2010/02/reciprocating_compressor4.pdf