Mechanical

PE

Thermal & Fluid Systems

Exam Textbook

Winter 2022 Exam Edition

Updated for Latest CBT Exam

Learn the key concepts and skills necessary to pass the PE Exam

Engineering Pro Guides

by **Justin Kauwale, P.E.**

Mechanical PE: Thermal & Fluids Textbook

by Justin Kauwale, PE

Published by Engineering Pro Guides, LLC
Honolulu, HI 96815

www.engproguides.com

Copyright © 2018-2022 Engineering Pro Guides, LLC

All rights reserved. No part of this book may be reproduced in any form on by any means, electronic, mechanical, photocopying, recording or otherwise, including information storage and retrieval systems, without permission in writing from the publisher, except as permitted by U.S. copyright law.

2022 Edition

ISBN 978-0-9887372-2-8 (ebook)

Thermal & Fluids Textbook

How to pass the PE exam

Table of Contents

TEXTBOOK

www.engproguides.com

1 – Introduction

TEXTBOOK
www.engproguides.com

Section 1.0 - Introduction

Table of Contents

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

1.0 Introduction

One of the most important steps in an engineer's career is obtaining the professional engineering (P.E.) license. It allows an individual to legally practice engineering in the state of licensure. This credential can also help to obtain higher compensation and develop a credible reputation. In order to obtain a P.E. license, the engineer must first meet the qualifications as required by the state of licensure, including minimum experience, references and the passing of the National Council of Examiners for Engineering and Surveying (NCEES) exam. Engineering Pro Guides focuses on helping engineers pass the NCEES exam through the use of free content on the website, http://www.engproguides.com and through the creation of books like sample exams and guides that outline how to pass the PE exam.

The key to passing the PE exam is to learn the key concepts and skills that are tested on the exam. There are several issues that make this key very difficult. First, the key concepts and skills are unknown to most engineers studying for the exam. Second, the key concepts and skills are not contained in a single document. This textbook compiles and teaches you the key concepts and skills required to pass the Mechanical - Thermal & Fluids Mechanical P.E. Exam.

1.1 Key Concepts and Skills

How are the key concepts and skills determined?

The key concepts and skills tested in this sample exam were first developed through an analysis of the topics and information presented by NCEES. NCEES indicates on their website that the P.E. Exam will cover an AM exam (~4 hours) followed by a PM exam (~4 hours) and that the exam will be 80 questions long, ~40 questions in the morning and ~40 questions in the afternoon. The Thermal & Fluids Mechanical PE exam will focus on the following topics as indicated by NCEES. (http://ncees.org/engineering/pe/):

A. Principles (28-44 questions)

1. **Basic Engineering Practice *(5-8 questions)***
   i) Engineering terms and symbols
   ii) Economic analysis
   iii) Units and conversions
2. **Fluid Mechanics *(5-8 questions)***
   i) Fluid properties (e.g., density, viscosity)
   ii) Compressible flow (e.g., Mach number, nozzles, diffusers)
   iii) Incompressible flow (e.g., friction factor, Reynolds number, lift, drag)
3. **Heat Transfer Principles (e.g., convection, conduction, radiation) *(5-8 questions)***
4. **Mass Balance Principles ((e.g., evaporation, dehumidification, mixing)) *(4-6 questions)***
5. **Thermodynamics *(5-8 questions)***
   i) Thermodynamic properties (e.g., enthalpy, entropy)
   ii) Thermodynamic cycles (e.g., Combined, Brayton, Rankine)

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

iii) Energy Balances (e.g., 1st and 2nd laws)
iv) Combustion (e.g., stoichiometric, efficiency)

6. **Support Knowledge *(4-6 questions)***
   i) Pipe system analysis (e.g., pipe stress, pipe supports, hoop stress)
   ii) Joints (e.g., welded, bolted, threaded)
   iii) Psychrometrics (e.g., dew point, relative humidity)
   iv) Codes and Standards

B. Hydraulic and Fluid Applications (21-33 questions)

1. **Hydraulic and Fluid Equipment *(13-21 questions)***
   i) Pumps and fans (e.g., cavitation, curves, power, series, parallel)
   ii) Compressors (e.g., dynamic head, power, efficiency)
   iii) Pressure vessels (e.g., design factors, materials, pressure relief)
   iv) Control valves (e.g., flow characteristics, sizing)
   v) Actuators (e.g., hydraulic, pneumatic)
   vi) Connections (e.g., fittings, tubing)
2. **Distribution Systems (e.g., pipe flow) *(8-12 questions)***

C. Energy/Power System Applications (21-33 questions)

1. **Energy/Power Equipment *(7-11 questions)***
   i) Turbines (e.g., steam, gas)
   ii) Boilers and steam generators (e.g., heat rate, efficiency)
   iii) Internal combustion engines (e.g., compression ratio, BMEP)
   iv) Heat exchangers (e.g., shell and tube, feedwater heaters)
   v) Cooling towers (e.g., approach, drift, blow-down)
   vi) Condensers (e.g., surface area, materials)
2. **Cooling/Heating (e.g., capacity, loads, cycles) *(5-8 questions)***
3. **Energy Recovery (e.g., waste heat, storage) *(5-8 questions)***
4. **Combined Cycles (e.g., components, efficiency) *(4-6 questions)***

Next, each of these broad topics were investigated and filtered for concepts and skills that met the following criteria:

(1) First, the concept and skill must be *commonly encountered* in the Thermal & Fluids field of study. For example, in the Thermal & Fluids field: Power cycles, steam properties, pump sizing, fan sizing, determining friction losses and calculating net positive suction head are regular occurrences in the Thermal & Fluids field.

(2) Second, the skill and concept must be testable in roughly *6 minutes per problem*. There are (40) questions on the morning exam and you will be provided with 4 hours to complete the exam. The same is true for the afternoon portion of the exam. This results in an average of 6

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

minutes per problem. This criterion limits the complexity of the exam problems and the resulting solutions. For example, pressure drop calculations are common in the Thermal & Fluids field, but the calculation is often very lengthy because of the number of steps involved, especially if a unique fluid and flow condition is used. Thus, common fluids like water/air and common pipe/duct materials are used.

(3) Third, the key concepts and skills must be used or be known by practicing Mechanical engineers in the Thermal & Fluids field. This criterion is similar to the first criterion. However, this criterion filters the concepts and skills further by limiting the field to material encountered and used by *practicing engineers*. The HVAC & Refrigeration, Thermal & Fluids and Mechanical Systems & Materials fields are vast and there are many different avenues an engineer can take. Two diverging paths are those engineers involved in research and those who practice. Research engineers are pushing the boundaries of the field and are highly focused in their specific area of the field. The Professional Engineering exam does not cover emerging technologies or highly focused material.

(4) The P.E. Exam must test the *principle or application* of the skill and concept and not the background knowledge of the topic or concept. The exam also does not cover background information on the NCEES topics. The P.E. Exam is meant to prove that the test taker is minimally competent to practice in the Mechanical Engineering field. The exam is less concerned with theory and more with the principle or application of the theory, skill or concept. For example, the P.E. exam is less concerned with the theory of evaporation in a cooling tower and more with the performance and selection of a cooling tower.

In summary, this book is intended to test the necessary skills and concepts to develop a minimally competent, practicing professional engineer in the Mechanical Engineering – Thermal & Fluids field, capable of passing the P.E. exam. This book and the sample exams do this through the following means:

(1) Teaching commonly used skills and concepts in the Thermal & Fluids field.

(2) Providing sample problems that can be completed in roughly 6 minutes per problem.

(3) Teaching skills and concepts used by practicing Thermal & Fluids engineers.

(4) Teaching the application of the skill and concept.

1.2 UNITS

The primary units that are used in the P.E. Exam are United States Customary System Units (USCS). As such, this guide focuses exclusively on the USCS. However, it is recommended that the test taker be very familiar with the unit conversions in the *NCEES Mechanical PE Reference Handbook*, because certain areas of the P.E. Exam may use the International System of Units (SI). For example, the steam tables in the handbook are presented in both SI and USCS units.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

1.3 Computer Based Test (CBT)

As of April 2020, the exam was converted from the paper-pencil/scantron testing method to a computer based platform. This allowed the test to be offered year round instead of twice per year. This also means you will not have the same set of the questions as the next person. The style of the testing interface will be very similar to the fundamentals of engineering (FE) exam that is also administered by NCEES. If you have gone through the computer based version of the FE exam, you should be familiar with the format. The main difference is the number and difficulty of questions and the length of the exam. It is important to review the NCEES Examinee Guide to understand the testing rules and format. Below is a summary of the major content.

(1) Year Round: The exam may be taken any time throughout the year, as long as the testing facility is open. However, you are only allowed to take the exam once per quarter (Jan – March, April – June, July – Sept, Oct – Dec) and at most 3 times per 12 months. The turnaround time from your exam application to test date will be much faster and the results should be received within 7-10 days. The only thing holding you up may be your state approval.

(2) Day of Timeline: The overall time at the testing facility will be 9 hours, with 1 hour allotted for prep time and breaks and 8 hours of actual exam time. You will have a maximum of 4 hours to complete the first half of the exam. Once you submit the first section you cannot return to those questions. You will then have a maximum of 50 minutes of break time, where you are allowed to leave the facility. Finally, you will have a maximum of 4 hours to complete the second half of the exam.

(3) Question Types: One of the main changes in the actual content of the computer-based test is the ability to incorporate different question types. Majority of the questions will be multiple choice with one answer out of four options, but additional question types include (1) multiple answers, (2) selecting a point, (3) drag and drop for matching, sorting, labeling, etc, and (4) fill in the blank. The exam questions are written in a way that can be confusing or meant to trick the examinee, so you can imagine how this can really add to the difficulty of the problem.

(4) NCEES Reference Handbook: Perhaps the greatest consequence of shifting to the computer based conversion is that examinees are no longer able to bring in outside resources. Your only aid during the test is the *NCEES PE Mechanical Reference Handbook*, see the following section for a write-up on the handbook. There are pros and cons to this, aside from no longer needing to lug a suitcase full of books to the test site.

The benefit is that everything is contained and focused towards one resource and that resource is now searchable, see the computer interface section below. The search function is probably one of the biggest benefits of the computer based format, reducing the time spent flipping through resources and giving you the opportunity to search for various topics that may provide hints into solving problems that you may otherwise not know how to begin. You also will not have to worry about having the right table or graphs in your possession, as this will all be provided to you.

The cons are you are no longer able to bring in cheat sheets and unit conversion books to help you with speed or notes that help you to understand concepts that you may struggle with.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Instead, you will have to be completely reliant on the handbook and fully understand how to use the variables in the provided equations. Another major concern is that not all topics may be covered in the handbook, especially the experience type questions that you could normally find in ASHRAE.

(5) Computer Interface: All exam content and references will be on the computer with a 24" monitor. You'll have a split screen with one section for the questions and the other for the *NCEES PE Mechanical Reference Handbook*. The handbook is bookmarked by chapter and has a searchable function to easily find content and equations. There is a calculator on the screen, but it is recommended that you bring your own NCEES approved calculator that you are familiar with. A countdown timer will be located on the upper right corner of the screen. You'll also have the ability to flag and return to problems, as long as you have not exited the section (i.e. morning or afternoon session). The interface only allows you to input answers; your work will be done separately on reusable dry erase sheets. This makes it a little more cumbersome to check your answers, instead of being able to work the problem out right under the question, so you'll just have to be neat about it. For a demo of the computer interface, see the following link http://pearsonvue.com/demo/.

(6) 70 Questions: There will be 80 questions on the exam, but only 70 questions will count towards your score. The extra 10 problems are problems that are being tested and tweaked for future exams. The first number in the range for each section is the number of problems that will count towards your score on the exam. You will have no way of knowing which questions will count and which ones will not count.

Section 2 - Basic Engineering Practice *(5 questions)*
Section 3 - Fluid Mechanics *(5 questions)*
Section 4 - Heat Transfer Principles *(5 questions)*
Section 5 - Mass Balance Principles *(4 questions)*
Section 6 - Thermodynamics *(5 questions)*
Section 7 - Support Knowledge *(4 questions)*
Section 8 - Hydraulic and Fluid Equipment (*13 questions)*
Section 9 - Distribution Systems (e.g., pipe flow) *(8 questions)*
Section 10 - Energy/Power Equipment *(7 questions)*
Section 11 - Cooling/Heating *(5 questions)*
Section 12 - Energy Recovery *(5 questions)*
Section 13 - Combined Cycles *(4 questions)*

1.4 NCEES PE Mechanical Reference Handbook

The *NCEES PE Mechanical Reference Handbook* is the only resource allowed during the exam. As mentioned in the previous section, it will be provided electronically on the same computer screen as the actual test. You may download a free copy of this pdf on your MyNCEES account. It is recommended that you practice doing problems with the electronic version of this resource, so that you may become familiar with its contents and how to navigate through the

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

search and bookmark functions. You should understand the variables and the default units used in the equations and be quick with locating of all major charts and tables.

The same handbook is used for all mechanical exam disciplines: HVAC, Machine Design, and Thermal & Fluids. There will be sections that are not applicable to the Thermal & Fluids exam, so don't waste your time trying to understand sections that are obviously irrelevant. Review the NCEES Thermal & Fluids exam specification alongside the handbook to realize what may be pertinent to the test. For example, most of the Machine Design & Materials chapter does not apply to the Thermal & Fluids test, except perhaps the basic spring deflection equation and thermal deformation equation, which could be used for equipment vibration isolation and thermal expansion of pipes. The more basic fluids equations would be used for the HVAC exam, while the more involved sections, such as impulse momentum and Mach numbers would be used for the Thermal & Fluids exam. The engine and turbine cycles, Brayton and Rankine are also not applicable to the HVAC exam but are applicable to the Thermal & Fluids exam.

Even though your studying will be focused around this handbook for references and equations, you should spend a good amount of time reading other resources to become familiar with background concepts and applications that can be tested, but would not be covered in the handbook. The handbook is more of one large cheat sheet resource and is not intended to provide any explanations. In addition, there are an estimated 10 - 20 experience based problems that cannot be solved with the handbook.

2.0 Disclaimer

In no event will Engineering Pro Guides be liable for any incidental, indirect, consequential, punitive or special damages of any kind, or any other damages whatsoever, including, without limitation, those resulting from loss of profit, loss of contracts, loss of reputation, goodwill, data, information, income, anticipated savings or business relationships, whether or not Engineering Pro Guides has been advised of the possibility of such damage, arising out of or in connection with the use of this document or any referenced documents and/or websites.

This book was created on the basis of determining an independent interpretation of the minimum required knowledge and skills of a professional engineer. In no way does this document represent the National Council of Examiners for Engineers and Surveying views or the views of any other professional engineering society.

3.0 How to use this Book

This book is organized into the topics as designated by the NCEES. These topics include:

- Section 1.0 - Introduction
- Section 2.0 - Basic Engineering Practice
- Section 3.0 - Fluid Mechanics
- Section 4.0 - Heat Transfer Principles

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

- Section 5.0 - Mass Balance Principles
- Section 6.0 - Thermodynamics
- Section 7.0 - Supportive Knowledge
- Section 8.0 - Hydraulics and Fluid Equipment
- Section 9.0 - Hydraulics and Fluid Distribution
- Section 10.0 - Energy/Power System Equipment
- Section 11.0 - Heating/Cooling
- Section 12.0 - Energy Recovery
- Section 13.0 - Combined Cycles
- Section 14.0 - Conclusion

First, it is recommended that the engineer in training gather the recommended references that are presented in the following section.

Second, proceed through the textbook in the order designated. Go through and first read the material of the section, then complete the practice problems designated for that section. If you have trouble with the practice problems, review the material and then read the solutions. The problems at the end of each section are slightly easier and more straightforward than the typical problems you would find in an actual P.E. Exam. These problems are meant only to practice the application of the skill or concept presented in the section. You should also read the recommended resources, search online and also use the NCEES Mechanical PE Reference Handbook when completing these problems. Make sure you know what keywords will allow you to access the correct resource the fastest.

Following the completion of each of the sections, it is recommended that you determine if you are unconfident with any of the NCEES topics. If you are not confident then please go back and revisit the section.

Next, go through the references exam, this will help you to read through all of the recommended resources and will also help you to quickly gain experience. You will not be able to bring in these recommended resources, but it will help you to increase your background practical knowledge.

Finally, set aside an eight-hour block of uninterrupted time to complete a sample exam. Gather a pdf version of the NCEES handbook and your calculator to create a test-like environment. Set a timer and proceed to take the sample exam, which can be purchased separately. Remember that the exam is only 40 problems for the morning and afternoon sessions and does not encompass all the possible items that can appear on an exam, but it should give you an idea of your level of readiness for the exam.

4.0 Sample Exam Tips

Sample exams are not provided in this book, please the engineering pro guides website for sample exams.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Engineering Pro Guides sample exams can be used in multiple ways, depending on where you are in your study process. If you are at the beginning or middle, it can be used to test your competency, gain an understanding and feel for the test format, and help to highlight target areas to study. If you are at the end, it can be used to determine your preparedness for the real exam. Remember that the questions are a sample of the many topics that may be tested and are limited to fit a full exam length and therefore is not comprehensive of all concepts.

Because the exam is written to be similar to the difficulty and format of the NCEES exam, it is recommended that the test be completed in one sitting and timed for four hours per session to simulate the real exam. This will give you a better indication of your status of preparation for the exam.

Review the exam day rules and replicate the environment for the real test as much as possible, including the type of calculator you may use. Keep a watch or clock next to you to gauge your pace for 40 questions in 4 hours.

Based on the NCEES website, the following are general rules for exam day.

Allowed in Testing Room:

1. Religious head coverings
2. Approved calculator
3. Eyeglasses without case
4. Magnifying glass without case
5. Light jacket without hood
6. Pearson VUE provided items (earplugs, tissues).
7. Pearson VUE approved comfort items (medical items, unwrapped cough drops, unpackaged pills, etc). See the complete list linked in the NCEES Examinee Guide.

Prohibited:

1. Cell phones
2. Watches
3. Food/Beverages – *You may access food and beverages during unscheduled breaks during the exam.*
4. Hats and hoods
5. Slide charts, wheel charts, drafting compasses
6. Weapons
7. Tobacco
8. Personal Chairs
9. Eyeglass/Magnifying glass cases
10. Scratch Paper (all writing items will be provided by the test center)

For additional references on exam day policies, exam day processes, and items to bring on your exam day, review the NCEES Examinee Guide:

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

http://ncees.org/exams/examinee-guide/

For best use of your time, answer the questions that you know first and return to the questions that you are unfamiliar with later. Once all the known questions are answered, go through the test again and attempt to answer the remaining questions by level of difficulty. If time allots, review your answers.

If you are stuck on a question, seek the following avenues.

1. Reference Handbook: Use the search function or go through pertinent sections of the NCEES Reference Handbook. During times of uncertainty, this will likely lead you to your answers. Determine the key words/concept that is being asked in the question and do a search. The answer can hopefully be extracted from the handbook.

2. Process of Elimination: There are only four possible choices for each question. Ask yourself if there is an answer that does not make sense and eliminate it. Further narrow down the answer that are derived from equations or concepts that you know are not right and are instead meant to deceive the test taker. See if there are answers that are similar or separated by something like a conversion error. This may be an indication that the correct equation was used.

3. Educated Guess: Remember that there is no penalty for wrong answers. Hopefully with the process of elimination you are able to narrow down as many answers as possible and are able to create an educated guess.

4. Rules of Thumb: Rules of thumb can be used to not only speed up time, but to help lead you in the right direction.

5. If the time is almost up and there are still unanswered questions remaining, determine whether it makes sense to check for mistakes on the problems you do know how to solve, or to tackle the unanswered problems.

Typical Exam Verbiage/Design:

1. Most Nearly: Due to rounding differences, the exam answers will not match yours exactly and in fact may not closely resemble your answer. NCEES uses the term “most nearly” to test your confidence in your solution. When the question prompts you with “most nearly”, choose the answer that most closely matches yours, whether it be greater than or lesser to your value.

2. Irrelevant Information: The exam is intended to test your overall understanding of concepts. At times the question will include unnecessary information that is meant to misdirect you.

3. Deceiving Answers: NCEES wants to know that you are able to determine the appropriate methods for the solutions. There are answers that were intentionally

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

produced from wrong equations to mislead the test taker. For example, you may forget a 1/2 in the formula, KE = $(1/2)*MV^2$ and there would be two answers each off by a factor of 1/2.

4. Do Not Overanalyze: The exam questions are meant to be completed in 6 minutes. Therefore, they are intended to be written as straight forward as possible. Do not be tempted to overanalyze the meaning of a question. This will only lead you down the wrong path.

Review the Solutions:

Once the sample test is completed, grade your results. Measure your aptitude in speed, concept comprehension, and overall score. If you score is above the 75% range then you are in good shape. This 75% score is only applicable if you have prepared completely for the exam. If you are just starting out, then please do not be worried about a low score. This is number is also just a range; there is no finite score to determine passing the test. Instead, NCEES calibrates the results against practicing professional engineers. See this page http://ncees.org/exams/scoring-process/ for a better understanding of how NCEES grades the scores.

Review the answers that you got wrong and use the solutions as a learning tool on how to address these types of problems. Compare the types of questions you are missing with the NCEES outline of topics and determine where you should focus your studying. Finally repeat as many practice problems as you can to get a better grasp of the test and to continually improve your score.

5.0 Recommended References

The following references are recommended to be reviewed prior to the exam but cannot be used during the exam. When reviewing these references, make sure you first understand the content. These references do not go into depth on explaining the equations or concepts but will give you practical knowledge. If you require more theoretical information on any of the information in these references, then you may need to research the information on the internet.

Complete List of References for the Thermal & Fluids Systems PE Exam		
	By Engineering Pro Guides	www.engproguides.com
Engineering Pro Guides provides a technical study guide that teaches the key concepts and skills necessary to pass the Thermal and Fluid Systems PE Exam. If you have any suggestions to this list, please email me, Justin Kauwale, at contact@engproguides.com or comment on the webpage or Google spreadsheet.		

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Section 2.0	**Basic Engineering Practice**		
	Engineering Terms, Symbols and Technical Drawings	All resources	
	Economic Analysis	Economics Factors	
		Compound Interest Tables	
	Units and Conversions	Engineering Unit Conversions	
Section 3.0	**Fluid Mechanics**		
	Fluid Properties (density, viscosity)	Fluid Mechanics with Engineering Applications	
	Compressible Flow (Mach number, nozzles, diffusers)	Fluid Mechanics with Engineering Applications	
	Incompressible Flow (friction, Reynolds, lift, drag)	Fluid Mechanics with Engineering Applications	
Section 4.0	**Heat Transfer Principles**		
	Convection	ASHRAE Fundamentals 2017	Ch. 4 Heat Transfer
	Conduction	ASHRAE Fundamentals 2017	Ch. 4 Heat Transfer
	Radiation	ASHRAE Fundamentals 2017	Ch. 4 Heat Transfer
Section 5.0	**Mass Balance Principles**		
	Evaporation	Thermodynamics an Engineering Approach	
	Dehumidification	Thermodynamics an Engineering Approach	
	Mixing	Thermodynamics an Engineering Approach	
Section 6.0	**Thermodynamics**		
	Thermodynamic Properties	Thermodynamics an Engineering Approach	
	Thermodynamic Cycles	Thermodynamics an Engineering Approach	

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

	Energy Balances (1st and 2nd Laws)	Thermodynamics an Engineering Approach	
	Combustion (Stoichiometric, efficiency)	ASHRAE Fundamentals 2017	Ch. 28 Combustion and Fuels
		Thermodynamics an Engineering Approach	
Section 7.0	**Supportive Knowledge**		
	Pipe System Analysis (pipe stress, supports, hoop stress)	ASHRAE Fundamentals 2017	Ch. 22 Pipe Design
	Joints (welded, bolted, threaded)	ASHRAE Systems 2016	Ch. 46 Pipes, Tubes and Fittings
	Psychrometrics (dew point, relative humidity)	ASHRAE Fundamentals 2017	Ch. 1 Psychrometrics
	Codes and Standards	American National Standards Institute (ANSI)	
		American Society for Testing and Materials (ASTM)	
Section 8.0	**Hydraulic and Fluid Equipment**		
	Pumps (cavitation curves, power, series, parallel)	ASHRAE Systems 2016	Ch. 44 Centrifugal Pumps
	Fans (cavitation curves, power, series, parallel)	ASHRAE Systems 2016	Ch. 21 Fans
	Compressors (dynamic head, power, efficiency)	Hydraulics and Pneumatics - A Technician's and Engineer's Guide	
		https://www.atlascopco.com/en-uk/compressors/compressed-air-tips/compressed-air-manual	
	Pressure Vessels (design factors, materials, pressure relief)	https://www.colorado.edu/engineering/CAS/courses.d/Structures.d/IAST.Lect03.d/IAST.Lect03.pdf	

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

	Control Valves (flow characteristics, sizing)	Hydraulics and Pneumatics - A Technician's and Engineer's Guide	
		ASHRAE Systems 2016	Ch. 47 Valves
	Actuators (hydraulic and pneumatic)	Hydraulics and Pneumatics - A Technician's and Engineer's Guide	
		ASHRAE Systems 2016	Ch. 47 Valves
		https://www.parker.com/literature/Industrial%20Cylinder/cylinder/cat/english/0106c002.pdf	
	Connections (fittings, tubing)	ASHRAE Systems 2016	Ch. 46 Pipes, Tubes and Fittings
Section 9.0	**Hydraulic and Fluid Distribution Systems**		
	Pipe Flow	Hydraulics and Pneumatics - A Technician's and Engineer's Guide	
		ASHRAE Fundamentals 2017	Ch. 22 Pipe Sizing
		ASHRAE Systems 2016	Ch. 46 Pipes, Tubes and Fittings
		Fluid Mechanics with Engineering Applications	
Section 10.0	**Energy/Power Equipment**		
		Power Plant Engineering	
	Turbines (steam, gas)	http://www.klmtechgroup.com/PDF/EGD2/ENGINEERING_DESIGN_GUIDELINES_steam_turbine_systems_rev_web.pdf	
		https://www.netl.doe.gov/File%20Library/Research/Coal/energy%20systems/turbines/handbook/1-1.pdf	
		https://www.gepower.com/content/dam/gepower-	

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

		pgdp/global/en_US/documents/technical/ger/ger-3705-ge-steam-turbine-design-philosophy-techology-programs.pdf	
		https://st-www.gepower.com/content/dam/gepower-pgdp/global/en_US/documents/technical/ger/ger-3434d-ge-gas-turbine-design-philosophy.pdf	
	Boilers and Steam Generators (heat rate, efficiency)	ASHRAE Systems 2016	Ch. 32 Boilers
	Internal Combustion Engines (comp. ratio, BMEP)	http://www.epi-eng.com/piston_engine_technology/engine_technology_contents.htm	
	Heat Exchangers (shell and tube, feedwater heaters)	ASHRAE Systems 2016	Ch. 48 Heat Exchangers
	Cooling Towers (approach, drift, blowdown)	Power Plant Engineering	
		ASHRAE Systems 2016	Ch. 40 Cooling Towers
	Condensers (surface area, materials)	Power Plant Engineering	
		ASHRAE Systems 2016	Ch. 39 Condensers
Section 11.0	**Cooling/Heating**		
	Capacity	Power Plant Engineering	
	Loads	Power Plant Engineering	
	Cycles	Power Plant Engineering	
Section 12.0	**Energy Recovery**		
	Waste Heat	Power Plant Engineering	
	Storage	Power Plant Engineering	
Section 13.0	**Combined Cycles**		

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

	Components	Power Plant Engineering	
	Efficiency	Power Plant Engineering	

Please see the below link to the online version of this spreadsheet for any updates. You can also read below about a majority of the different references. If you have any suggestions or questions on the list, please email Justin at contact@engproguides.com or you can comment on the online version of the spreadsheet.

Link: http://www.engproguides.com/thermalreferences.html

5.1 Hydraulics and Pneumatics - A Technician's and Engineer's Guide

This reference book contains information on the Hydraulic and Fluid Equipment section including pumps, compressors, control valves and piping.

Amazon Link[i]: Hydraulics and Pneumatics - A Technician's and Engineer's Guide

5.2 Thermodynamics an Engineering Approach

This reference book contains information on a majority of the Thermodynamics topics on the exam including thermodynamic properties, Brayton, Otto, Rankine, vapor-compression, combustion, combined cycles and energy balance. However, your old college thermodynamics books should do just fine.

Amazon Link[i]: Thermodynamics an Engineering Approach

Topics Covered: Thermodynamics, Combined Cycles

5.3 Fluid Mechanics with Engineering Applications

This reference book contains information on a majority of the Fluids Mechanics topics on the exam. However, your old college fluids books should do just fine.

Amazon Link[i]: Fluid Mechanics with Engineering Applications

Topics Covered: Fluid Mechanics

5.4 ASHRAE Handbooks

By ASHRAE

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is the guiding source for primarily the HVAC engineer, however based on input from examinees exam these books may increase your experience with various Energy/Power Equipment like cooling towers, condensers and boilers. These books can also increase your experience with Hydraulic and Fluid Equipment like compressors, pumps, fans control valves and actuators.

The society publishes four handbooks that contain the essential topics and knowledge for practicing engineer: *HVAC Systems and Equipment, HVAC Applications, Refrigeration, Fundamentals*. Each of these handbooks is updated in a four year rotation. Only the HVAC Systems and Equipment and the Fundamentals book are needed for the Thermal and Fluids exam. The handbooks are comprehensive and detailed.

These books will help with the Cooling/Heating, Pumps/Fans, Compressors, Control Valves, Boilers, Heat Exchangers, Cooling Towers and Condensers topics.

Amazon Link[i]: 2016 ASHRAE Handbook: HVAC Systems and Equipment

Amazon Link[i]: 2017 ASHRAE Handbook: Fundamentals

ASHRAE Fundamentals Topics Covered: Fluid Mechanics, Heat Transfer, Mass Balance, Thermodynamics, Supportive Knowledge, Distribution Systems, Cooling/Heating

ASHRAE Systems and Equipment Topics Covered: Hydraulic and Fluid Equipment, Distribution Systems, Energy/Power Equipment, Energy Recovery

6.0 PAST EXAM SURVEYS

After every PE exam, I conduct an online survey with as many PE exam test takers that I can find. I primarily use my website, www.engproguides.com and www.engineerboards.com to find test takers to take the survey. The survey provides insight into an estimated passing score, how well test takers do based on experience and number of hours studied, and which areas of the exam are difficult or easy. The raw results of the survey are shown on the link below. This link shows a summary of the results without any pivot chart analysis.

Link with Latest Analysis: http://engproguides.com/thermalsurvey.html

7.0 QUICK EQUATION CONSTANTS

Throughout the book there are quick equations that are used to enhance your speed on the PE exam. These quick equations make some assumptions on standard air or water conditions. In order to help you to understand the origin of the constants within these equations, the following tables show how the constants can be varied.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

7.1 Power as a Function of Enthalpy for Air Equation

The total heat equation shows power as a function of temperature and air flow rate. The constant at the beginning of the equation is typically 4.5 and this constant encompasses the multiplication of air density and the conversion from minutes to hours.

$$Generic\ Equation: \quad Q_{total}\ [Btuh] = \rho \left[\frac{lbm}{ft^3}\right] * \frac{60min}{hr} * airflow \left[\frac{ft^3}{min}\right] * \Delta H \left[\frac{Btu}{lbm}\right]$$

$$Q\ [Btuh] = Constant * CFM * \Delta H \left[\frac{Btu}{lbm}\right];$$

$$Typically \rightarrow \boldsymbol{Q[Btuh] = 4.5 * CFM * \Delta H \left[\frac{Btu}{lbm}\right]} \quad [Total\ Heat\ Equation\ for\ Air]$$

Total Heat Equation for Air		
Air Density (lbm/ft3)	**Minutes to Hours**	**Constant**
0.086	60.000	5.160
0.085	60.000	5.100
0.084	60.000	5.040
0.083	60.000	4.980
0.082	60.000	4.920
0.081	60.000	4.860
0.080	60.000	4.800
0.079	60.000	4.740
0.078	60.000	4.680
0.077	60.000	4.620
0.076	60.000	4.560
0.075	**60.000**	**4.500**
0.074	60.000	4.440
0.073	60.000	4.380
0.072	60.000	4.320
0.071	60.000	4.260
0.070	60.000	4.200
0.069	60.000	4.140
0.068	60.000	4.080
0.067	60.000	4.020
0.066	60.000	3.960
0.065	60.000	3.900
0.064	60.000	3.840
0.063	60.000	3.780
0.062	60.000	3.720
0.061	60.000	3.660
0.060	60.000	3.600

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

0.059	60.000	3.540

7.2 Power as a Function of Temperature for Air Equation

The sensible heat equation shows power as a function of temperature and air flow rate. The constant at the beginning of the equation is typically 1.1 and this constant encompasses the multiplication of air density, heat capacity ($c_{p,air} = 0.24\, Btu/lbm \cdot F$) and the conversion from minutes to hours.

$$Generic\ Equation: \quad Q_{sens}\ [Btuh] = \rho \left[\frac{lbm}{ft^3}\right] * c_{p,air} \left[\frac{0.24\ Btu}{lbm * F}\right] * \frac{60min}{hr} * airflow \left[\frac{ft^3}{min}\right] * \Delta T[°F]$$

$$Q\ [Btuh] = Constant * CFM * \Delta T[°F];$$

$$Typically \rightarrow \boldsymbol{Q[Btuh] = 1.08 * CFM * \Delta T[°F]} \quad [Sensible\ Heat\ Equation\ for\ Air]$$

Sensible Heat Equation for Air			
Air Density (lbm/ft³)	**Heat Capacity (Btu/lbm-°F)**	**Minutes to Hours**	**Constant**
0.086	0.240	60.000	1.238
0.085	0.240	60.000	1.224
0.084	0.240	60.000	1.210
0.083	0.240	60.000	1.195
0.082	0.240	60.000	1.181
0.081	0.240	60.000	1.166
0.080	0.240	60.000	1.152
0.079	0.240	60.000	1.138
0.078	0.240	60.000	1.123
0.077	0.240	60.000	1.109
0.076	0.240	60.000	1.094
0.075	**0.240**	**60.000**	**1.080**
0.074	0.240	60.000	1.066
0.073	0.240	60.000	1.051
0.072	0.240	60.000	1.037
0.071	0.241	60.000	1.027
0.070	0.241	60.000	1.012
0.069	0.241	60.000	0.998
0.068	0.241	60.000	0.983
0.067	0.241	60.000	0.969
0.066	0.241	60.000	0.954
0.065	0.241	60.000	0.940
0.064	0.241	60.000	0.925
0.063	0.241	60.000	0.911
0.062	0.241	60.000	0.897

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

0.061	0.241	60.000	0.882
0.060	0.241	60.000	0.868
0.059	0.242	60.000	0.857

7.3 Power as a Function of Humidity Ratio for Air Equation

The latent heat equation shows power as a function of humidity ratio and air flow rate. The constant at the beginning of the equation is typically in the range of 4,730 to 4,840 and this constant encompasses the multiplication of air density, heat of vaporization (h_{fg}) and the conversion from minutes to hours. The *NCEES Mechanical PE Reference Handbook* uses a constant of 4840, which comes from using an h_{fg} from 75F, 50% RH to 50F. For the purposes of the PE exam, you should use the NCEES coefficient of 4840. However, the percent difference between 4,730 and 4,840 is only roughly 2%, so unless the answers are very close together, you should be okay with using values within this range.

$$Generic\ Equation: \quad Q_{latent}\ [Btuh] = \rho \left[\frac{lb_{dry}}{ft^3}\right] * h_{fg} \left[\frac{Btu}{lb}\right] * \frac{60min}{hr} * airflow \left[\frac{ft^3}{min}\right] * \Delta W_{lb} \left[\frac{lb_{wet}}{lb_{dry}}\right]$$

$$Q\ [Btuh] = Constant * CFM * \Delta W_{lb} \left[\frac{lbm\ H_2O}{lbm\ dry\ air}\right];$$

$$Typically \rightarrow \boldsymbol{Q[Btuh] = 4,840 * CFM * \Delta W_{lb} \left[\frac{lbm\ H_2O}{lbm\ dry\ air}\right]} \quad [Latent\ Heat\ Equation\ for\ Air]$$

Latent Heat Equation for Air (Humidity Ratio lbm H2O/lbm dry air)

Air Density (lbm/ft3)	Heat of Vaporization (Btu/lbm)	Minutes to Hours	Constant	Air Density (lbm/ft3)	Heat of Vaporization (Btu/lbm)	Minutes to Hours	Constant
0.086	1,080	60	5,573	0.074	1,048	60	4,653
0.085	1,079	60	5,503	0.073	1,045	60	4,577
0.084	1,078	60	5,433	0.072	1,042	60	4,501
0.083	1,077	60	5,363	0.071	1,037	60	4,418
0.082	1,076	60	5,294	0.070	1,031	60	4,330
0.081	1,075	60	5,225	0.069	1,025	60	4,244
0.080	1,074	60	5,155	0.068	1,022	60	4,170
0.079	1,073	60	5,086	0.067	1,019	60	4,096
0.078	1,068	60	4,998	0.066	1,014	60	4,015
0.077	1,062	60	4,906	0.065	1,008	60	3,931
0.076	1,057	60	4,820	0.064	1,001	60	3,844
0.075	**1,052**	**60**	**4,734**	0.063	996	60	3,765
				0.062	990	60	3,683

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

				0.061	984	60	3,601
				0.060	971	60	3,496

This table is used if your humidity ratio is in grains.

$$Generic\ Equation{:}\quad Q_{latent}\ [Btuh]$$

$$= \rho \left[\frac{lb_{dry}}{ft^3}\right] * h_{fg} \left[\frac{Btu}{lb}\right] * \frac{60min}{hr} * \frac{1\ lb_{wet}}{7000\ gr_{wet}} * airflow \left[\frac{ft^3}{min}\right] * \Delta W_{gr} \left[\frac{gr_{wet}}{lb_{dry}}\right]$$

$$Q\ [Btuh] = Constant * CFM * \Delta W_{gr} \left[\frac{grain\ H_2O}{lbm\ dry\ air}\right];$$

$$Typically \rightarrow Q[Btuh] = 0.68 * CFM * \Delta W_{gr} \left[\frac{grain\ H_2O}{lbm\ dry\ air}\right]$$

Latent Heat Equation for Air (grains)				
Air Density (lbm/ft3)	**Heat of Vaporization (Btu/lbm)**	**Minutes to Hours**	**Grains Conversion**	**Constant**
0.086	1080	60	1.429E-04	0.80
0.085	1079	60	1.429E-04	0.79
0.084	1078	60	1.429E-04	0.78
0.083	1077	60	1.429E-04	0.77
0.082	1076	60	1.429E-04	0.76
0.081	1075	60	1.429E-04	0.75
0.080	1074	60	1.429E-04	0.74
0.079	1073	60	1.429E-04	0.73
0.078	1068	60	1.429E-04	0.71
0.077	1062	60	1.429E-04	0.70
0.076	1057	60	1.429E-04	0.69
0.075	**1052**	**60**	**1.429E-04**	**0.68**
0.074	1048	60	1.429E-04	0.66
0.073	1045	60	1.429E-04	0.65
0.072	1042	60	1.429E-04	0.64
0.071	1037	60	1.429E-04	0.63
0.070	1031	60	1.429E-04	0.62
0.069	1025	60	1.429E-04	0.61
0.068	1022	60	1.429E-04	0.60
0.067	1019	60	1.429E-04	0.59
0.066	1014	60	1.429E-04	0.57
0.065	1008	60	1.429E-04	0.56
0.064	1001	60	1.429E-04	0.55

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

0.063	996	60	1.429E-04	0.54
0.062	990	60	1.429E-04	0.53
0.061	984	60	1.429E-04	0.51
0.060	971	60	1.429E-04	0.50
0.059	970	60	1.429E-04	0.49

7.4 Density Factors (Air)

Although you won't be able to bring in the tables above, similar adjustments to the quick equations can be made with the "Temperature and Altitude Corrections for Air" table found in Chapter 7 – Psychrometrics of the *NCEES Mechanical PE Reference Handbook*.

The quick equations above are based on standard air density, 0.075 lbm/ft^3, which is based on 70F dry air at sea level. During non-standard conditions, the density will change due to higher/lower temperatures or altitudes much higher than sea level. To adjust the quick equations, first find the new density, then lookup the density factor (DF) in the NCEES table. The quick equations can then be revised below.

Altitude Changes:

$$Q[Btuh]_{total} = DF * 4.5 * CFM * \Delta H[Btu/lbm]$$

$$Q[Btuh]_{sensible} = DF * 1.08 * CFM * \Delta T[°F]$$

$$Q[Btuh]_{latent} = DF * 4{,}840 * CFM * \Delta W_{lb}\left[\frac{lbm\ H_2O}{lbm\ dry\ air}\right]$$

Temperature Changes:

During temperature changes, note that the heat of vaporization, h_{fg}, for the latent heat equation could also change, so in this case, the full equation should be used.

$$Q[Btuh]_{total} = DF * 4.5 * CFM * \Delta H[Btu/lbm]$$

$$Q[Btuh]_{sensible} = DF * 1.08 * CFM * \Delta T[°F]$$

$$Q[Btuh]_{latent} = \rho\left[\frac{lb_{dry}}{ft^3}\right] * h_{fg}\left[\frac{Btu}{lb}\right] * \frac{60min}{hr} * CFM * \Delta W_{lb}\left[\frac{lb_{wet}}{lb_{dry}}\right]$$

7.5 Power as a Function of Temperature for Water Equation

The sensible heat equation (no phase change) shows power as a function of temperature and water flow rate. The constant at the beginning of the equation is typically 500 and this constant encompasses the multiplication of water density, heat capacity ($c_{p,water} = 1.0\ Btu/lbm \cdot R$) and the conversion from minutes to hours.

$$Generic\ Equation: Q\ [Btuh] = c_{p,water}\left[1.0\frac{Btu}{lbm \cdot °F}\right] * \frac{60min}{hr} * \rho\left[\frac{lbm}{ft^3}\right] * \frac{1ft^3}{7.48\ gal} * GPM * \Delta T[°F]$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$Q\ [Btuh] = Constant * GPM * \Delta T[°F];$$

$$Typically \rightarrow \mathbf{Q}[\mathbf{Btuh}] = \mathbf{500} * \mathbf{GPM} * \Delta\mathbf{T}[°\mathbf{F}] \quad [Heat\ Equation\ for\ Water]$$

As water temperatures start to rise above a certain point, the full equation should be used instead of the quick equation. The only thing that changes is the density, which can be found in the "Properties of Water" table in Chapter 1 of the *NCEES Mechanical PE Reference Handbook.*

Total Heat Equation for Water				
Water Temperature (F)	**Water Density (lbs/ft3)**	**ft3 to Gallons**	**Minutes to Hours**	**Constant**
32.00	62.41	0.134	60	500.65
33.00	62.42	0.134	60	500.67
34.00	62.42	0.134	60	500.69
35.00	62.42	0.134	60	500.70
36.00	62.42	0.134	60	500.71
37.00	62.42	0.134	60	500.72
38.00	62.42	0.134	60	500.72
39.00	62.42	0.134	60	500.72
40.00	62.42	0.134	60	500.72
41.00	62.42	0.134	60	500.72
42.00	62.42	0.134	60	500.71
43.00	**62.42**	0.134	60	500.70
44.00	62.42	0.134	60	500.69
45.00	62.42	0.134	60	500.68
46.00	62.42	0.134	60	500.67
47.00	62.41	0.134	60	500.65
48.00	62.41	0.134	60	500.63
49.00	62.41	0.134	60	500.61
50.00	62.41	0.134	60	500.59
51.00	62.40	0.134	60	500.56
52.00	62.40	0.134	60	500.53
53.00	62.40	0.134	60	500.50
54.00	62.39	0.134	60	500.47
55.00	62.39	0.134	60	500.44
56.00	62.38	0.134	60	500.40
57.00	62.38	0.134	60	500.36
58.00	62.37	0.134	60	500.33
59.00	62.37	0.134	60	500.29
60.00	62.36	0.134	60	500.24

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

61.00	62.36	0.134	60	500.20
62.00	62.35	0.134	60	500.15
63.00	62.35	0.134	60	500.10
64.00	62.34	0.134	60	500.06
65.00	62.33	0.134	60	500.00
66.00	62.33	0.134	60	499.95
67.00	62.32	0.134	60	499.89
68.00	62.31	0.134	60	499.84
69.00	62.31	0.134	60	499.78
70.00	62.30	0.134	60	499.72
71.00	62.29	0.134	60	499.66
72.00	62.28	0.134	60	499.59
73.00	62.27	0.134	60	499.53
74.00	62.27	0.134	60	499.46
75.00	62.26	0.134	60	499.40
76.00	62.25	0.134	60	499.33
77.00	62.24	0.134	60	499.26
78.00	62.23	0.134	60	499.18
79.00	62.22	0.134	60	499.11
80.00	62.21	0.134	60	499.04
81.00	62.20	0.134	60	498.96
82.00	62.19	0.134	60	498.88
83.00	62.18	0.134	60	498.80
84.00	62.17	0.134	60	498.72
85.00	62.16	0.134	60	498.64
86.00	62.15	0.134	60	498.56
87.00	62.14	0.134	60	498.47
88.00	62.13	0.134	60	498.39
89.00	62.12	0.134	60	498.30
90.00	62.11	0.134	60	498.21
91.00	62.10	0.134	60	498.12
92.00	62.09	0.134	60	498.03
93.00	62.08	0.134	60	497.94
94.00	62.06	0.134	60	497.84
95.00	62.05	0.134	60	497.75
96.00	62.04	0.134	60	497.65
97.00	62.03	0.134	60	497.56
98.00	62.02	0.134	60	497.46
99.00	62.00	0.134	60	497.35
100.00	61.99	0.134	60	497.26
101.00	61.98	0.134	60	497.15
102.00	61.97	0.134	60	497.05
103.00	61.95	0.134	60	496.95

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

104.00	61.94	0.134	60	496.84
105.00	61.93	0.134	60	496.73
106.00	61.91	0.134	60	496.63
107.00	61.90	0.134	60	496.51
108.00	61.89	0.134	60	496.40
109.00	61.87	0.134	60	496.29
110.00	61.86	0.134	60	496.18
111.00	61.84	0.134	60	496.07
112.00	61.83	0.134	60	495.95
113.00	61.81	0.134	60	495.84
114.00	61.80	0.134	60	495.72
115.00	61.78	0.134	60	495.60
116.00	61.77	0.134	60	495.48
117.00	61.76	0.134	60	495.36
118.00	61.74	0.134	60	495.24
119.00	61.72	0.134	60	495.12
120.00	61.71	0.134	60	494.99
121.00	61.69	0.134	60	494.87
122.00	61.68	0.134	60	494.74
123.00	61.66	0.134	60	494.62
124.00	61.65	0.134	60	494.49
125.00	61.63	0.134	60	494.36
126.00	61.61	0.134	60	494.24
127.00	61.60	0.134	60	494.10
128.00	61.58	0.134	60	493.97
129.00	61.57	0.134	60	493.84
130.00	61.55	0.134	60	493.71
131.00	61.53	0.134	60	493.57
132.00	61.52	0.134	60	493.44
133.00	61.50	0.134	60	493.30
134.00	61.48	0.134	60	493.17
135.00	61.46	0.134	60	493.03
136.00	61.45	0.134	60	492.89
137.00	61.43	0.134	60	492.75
138.00	61.41	0.134	60	492.61
139.00	61.39	0.134	60	492.47
140.00	61.38	0.134	60	492.32
141.00	61.36	0.134	60	492.18
142.00	61.34	0.134	60	492.04
143.00	61.32	0.134	60	491.89
144.00	61.30	0.134	60	491.74
145.00	61.29	0.134	60	491.60
146.00	61.27	0.134	60	491.45

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

147.00	61.25	0.134	60	491.30
148.00	61.23	0.134	60	491.15
149.00	61.21	0.134	60	491.00
150.00	61.19	0.134	60	490.85
151.00	61.17	0.134	60	490.70
152.00	61.15	0.134	60	490.54
153.00	61.14	0.134	60	490.39
154.00	61.12	0.134	60	490.23
155.00	61.10	0.134	60	490.08
156.00	61.08	0.134	60	489.92
157.00	61.06	0.134	60	489.76
158.00	61.04	0.134	60	489.60
159.00	61.02	0.134	60	489.45
160.00	61.00	0.134	60	489.29
161.00	60.98	0.134	60	489.13
162.00	60.96	0.134	60	488.97
163.00	60.94	0.134	60	488.80
164.00	60.92	0.134	60	488.64
165.00	60.90	0.134	60	488.47
166.00	60.88	0.134	60	488.31
167.00	60.86	0.134	60	488.14
168.00	60.83	0.134	60	487.98
169.00	60.81	0.134	60	487.81
170.00	60.79	0.134	60	487.64
171.00	60.77	0.134	60	487.47
172.00	60.75	0.134	60	487.31
173.00	60.73	0.134	60	487.13
174.00	60.71	0.134	60	486.96
175.00	60.69	0.134	60	486.79
176.00	60.66	0.134	60	486.62
177.00	60.64	0.134	60	486.45
178.00	60.62	0.134	60	486.27
179.00	60.60	0.134	60	486.09
180.00	60.58	0.134	60	485.92
181.00	60.56	0.134	60	485.74
182.00	60.53	0.134	60	485.57
183.00	60.51	0.134	60	485.39
184.00	60.49	0.134	60	485.21
185.00	60.47	0.134	60	485.03
186.00	60.44	0.134	60	484.85
187.00	60.42	0.134	60	484.67
188.00	60.40	0.134	60	484.48
189.00	60.38	0.134	60	484.30

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

190.00	60.35	0.134	60	484.12
191.00	60.33	0.134	60	483.93
192.00	60.31	0.134	60	483.75
193.00	60.28	0.134	60	483.56
194.00	60.26	0.134	60	483.38
195.00	60.24	0.134	60	483.19
196.00	60.21	0.134	60	483.00
197.00	60.19	0.134	60	482.81
198.00	60.17	0.134	60	482.62
199.00	60.14	0.134	60	482.43
200.00	60.12	0.134	60	482.24
201.00	60.10	0.134	60	482.05
202.00	60.07	0.134	60	481.86
203.00	60.05	0.134	60	481.67
204.00	60.02	0.134	60	481.47
205.00	60.00	0.134	60	481.28
206.00	59.98	0.134	60	481.08
207.00	59.95	0.134	60	480.89
208.00	59.93	0.134	60	480.69
209.00	59.90	0.134	60	480.50
210.00	59.88	0.134	60	480.30
211.00	59.85	0.134	60	480.10
212.00	59.83	0.134	60	479.90

[i] Justin Kauwale is a participant in the Amazon Services LLC Associates Program, an affiliate advertising program designed to provide a means for sites to earn advertising fees by advertising and linking to amazon.com

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

2 – Basic Engineering Practice

Engineering Terms, Symbols and Technical Drawings | Economic Analysis | Units and Conversions |

TEXTBOOK
www.engproguides.com

Section 2.0 - Basic Engineering Practice

Table of Contents

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

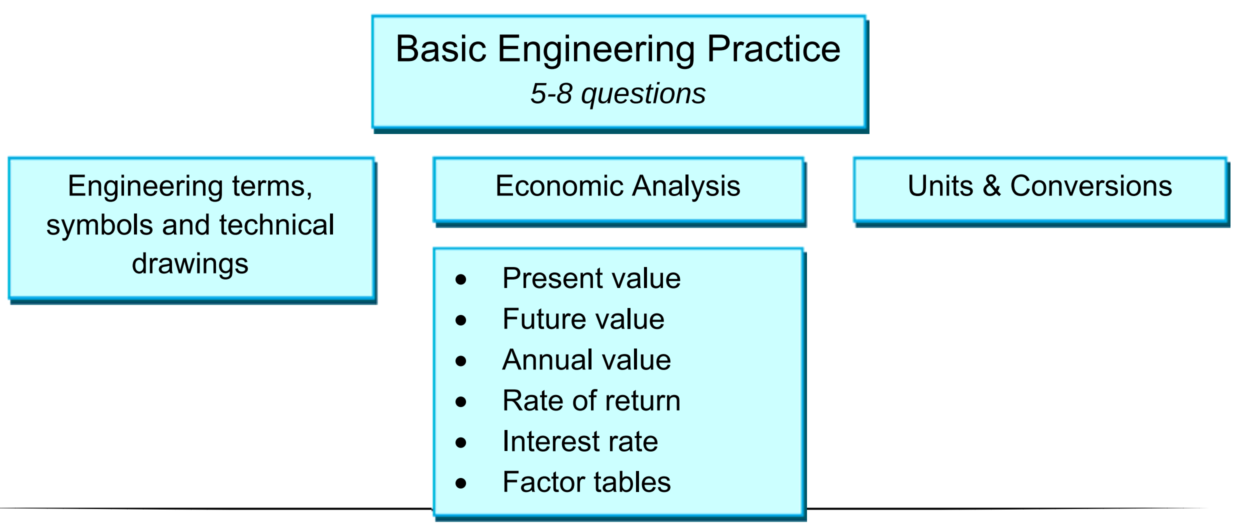
Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

1.0 INTRODUCTION

Basic Engineering Practice accounts for approximately 5-8 questions on the Thermal & Fluids Mechanical PE exam.

The Thermal & Fluids Mechanical PE exam is designed to ensure that a passing engineer is minimally competent to practice engineering. Being minimally competent does include understanding engineering terms, symbols and technical drawings, unit conversions and economic analysis. However, many of these tasks can be completed without an engineering background and thus the PE exam should provide questions that are complex and that span the skills in this section and other sections. For example, the questions may include an economic analysis but also with thermodynamics. You may also have to decipher a technical drawing and use the information to complete a heat transfer question or you will complete a power cycle question and need to convert units to match the selected answers.

Based on the above reasoning, you should combine your studying of this section with the other sections of this book. The skills learned in the Economic Analysis section may be of sufficient difficulty to be tested by itself on the PE exam.



Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

2.0 Engineering Terms, Symbols and Technical Drawings

2.1 Terms & Symbols

This NCEES topic, terms and symbols, is very vague and provides little information for the aspiring professional. Engineers become more familiar with terms, symbols and technical drawings with experience, as they encounter new things. It is the opinion of the author that a test on your knowledge of *random* terms or symbols, other than those presented in the other topics is not fair nor is an adequate measure of a minimally competent professional engineer. The thermal and fluids field is a large field and it would not be prudent use of your time to memorize terms and symbols. However, you should know the terms and symbols presented in this book, since the exam will cover these topics and you should know the terms and symbols relevant to the topics covered in the exam. Luckily each term and symbol is explained when first introduced in this book.

2.2 Technical Drawings

Technical drawings are a single tool used by engineers to present ideas to others. An engineer should be able to produce technical drawings to accurately communicate ideas and the engineer should also be able to read and interpret technical drawings. Engineering drawings are not typical drawings, sketches or illustrations. These drawings show data like sizes, shapes, angles, tolerances, and dimensions. *On the exam, you may be tested on your interpretation of these engineering technical drawings.*

There are four main types of drawings that each focus on a different point of view.

- Plan/Layout: This is the top view or bird's eye view. If the object is flipped, then the view would be a bottom view.

- Elevation: The elevation view is a side view. There is a distinction between a section view and an elevation view. The section view is a cut into the object and shows a look into the insides of the object, as if the object was cut. The elevation view shows the exterior view of an object.

- Section: The section view is a side view, but there is a distinction between a section view and elevation view. The section view is a cut into the object and shows a look into the insides of the object, as if the object was cut.

- Isometric: The isometric view is a 3D view of an object.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

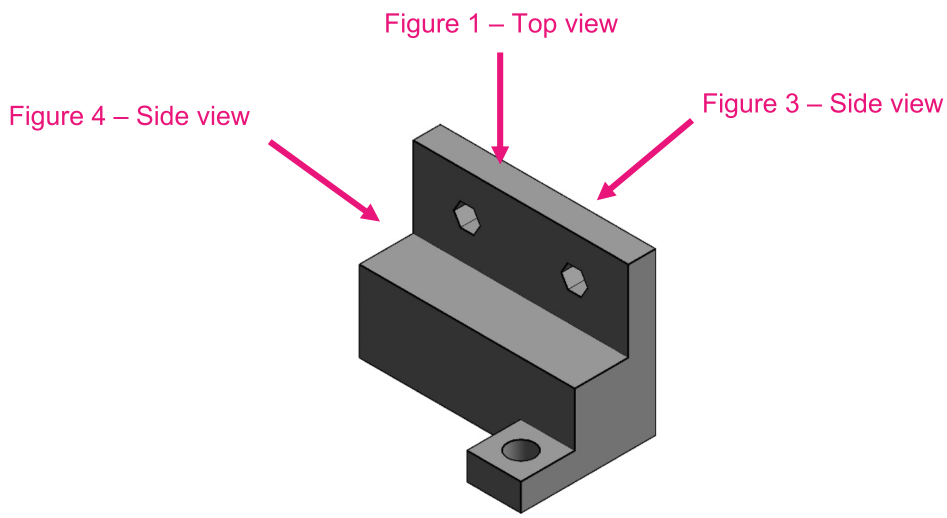


Figure 1: A 3D view, also known as an isometric view of a mechanical object.

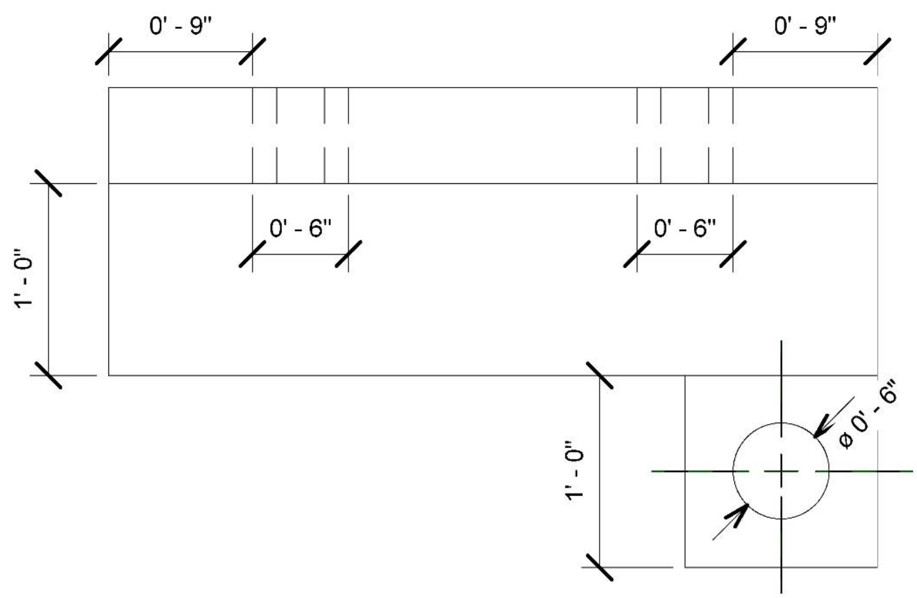


Figure 2: A top view or layout view of the same object, with dimension lines.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

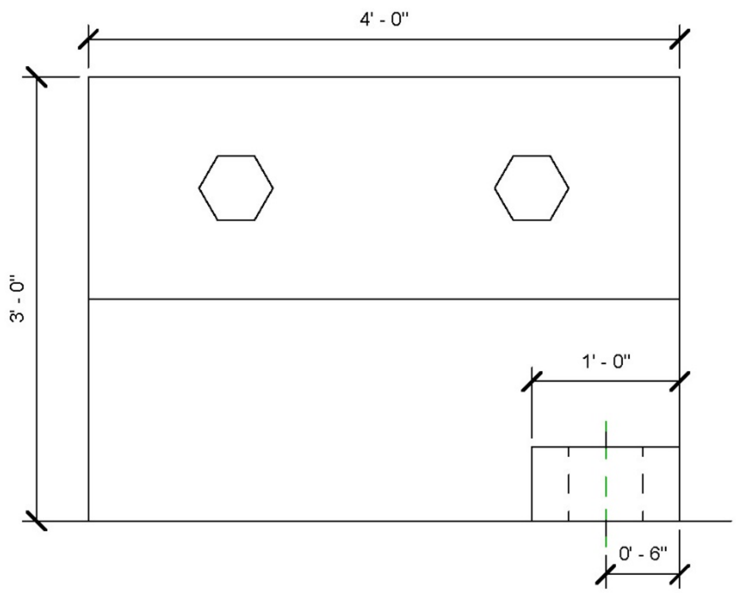


Figure 3: A side view or elevation view of the same object, with dimension lines.

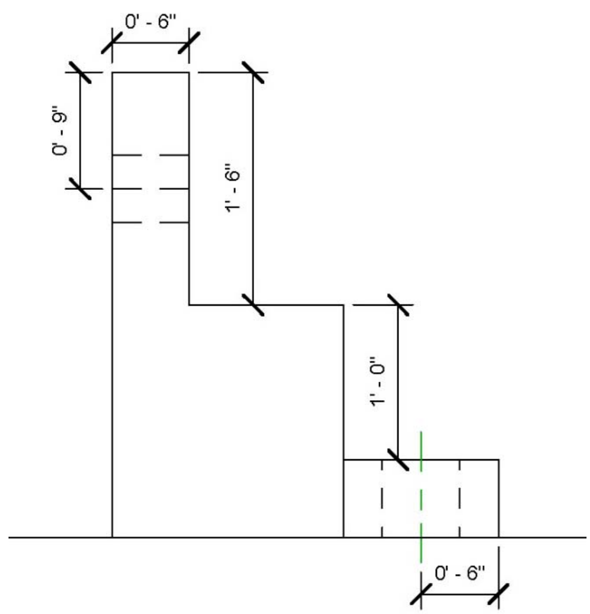


Figure 4: A side view or elevation view of the same object, with dimension lines.

2.3 WELDING TERMS AND SYMBOLS

The exam MAY reference welding terms and symbols based on the standard that is most commonly practiced. The primary welding standard is the American Welding Society (AWS) A2.4:2012 Standard Symbols for Welding, Brazing and Nondestructive Examination. This standard includes information on welding symbols, as well as all the various types of welds like

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

groove, fillet, plug, spot, seam, edge, stud and surface welds. The standard also includes information on brazing symbols and nondestructive examination symbols. However, these topics are not likely to be on the Thermal and Fluids PE exam. The link to purchase this book is shown below, but it is expensive and you should only buy this book if you regularly design or interpret designs with welding. The main reference for welding symbols that you should use are included in Chapter 2.17 Welding of the *NCEES Mechanical PE Reference Handbook*.

A2.4:2012 STANDARD SYMBOLS FOR WELDING, BRAZING, AND NONDESTRUCTIVE EXAMINATION: https://pubs.aws.org/p/1040/a242012-standard-symbols-for-welding-brazing-and-nondestructive-examination

The main concepts you need for the exam on this topic are covered below. First you need to be familiar with the different types of welds and the symbols for each weld. This table provides the symbols for the various types of welds.

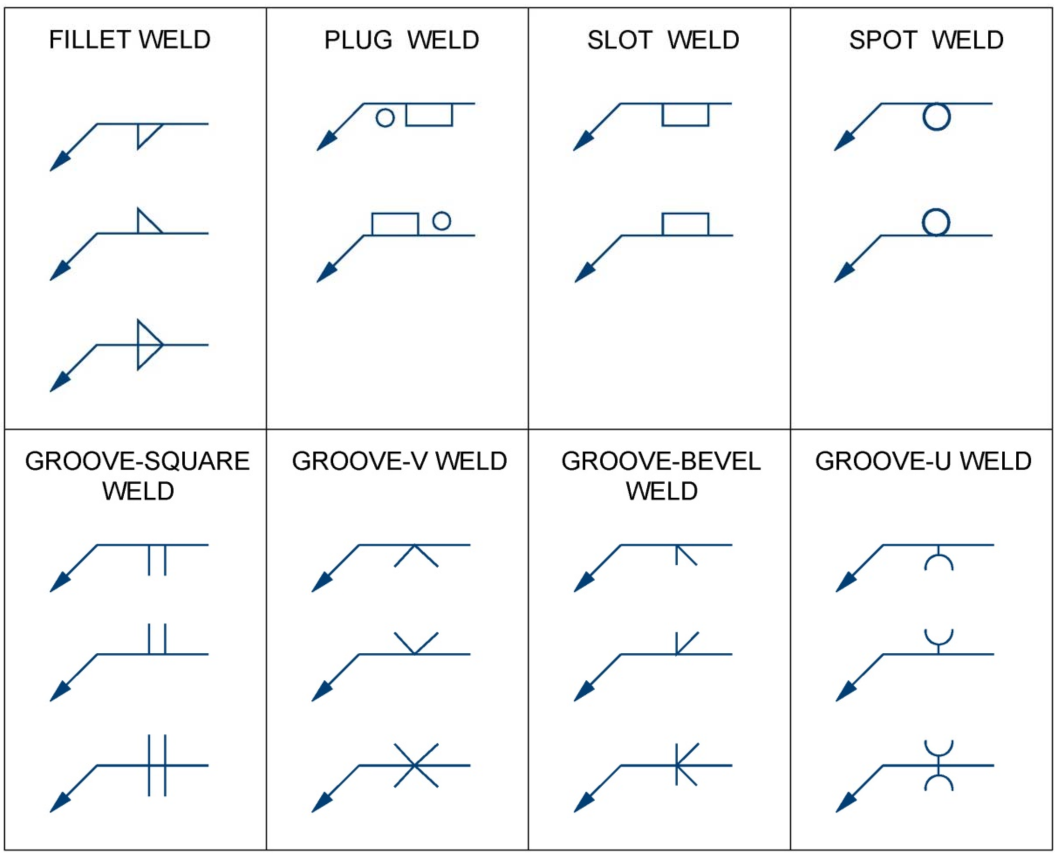


Figure 5: Symbols for the different types of welds.

Fillet Weld: Fillet welds join two parts at right angles to each other. The thickness of the weld can be varied.

Plug Weld: Plug, slot and spot welds are welds used to join two surfaces one atop the other. This is called a lap joint. But unlike a fillet weld, these two surfaces are parallel to one another. A plug weld is a circular weld made through the top surface and joins the bottom surface.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Slot Weld: In a slot weld, a slot shape is made through the top surface and welding fills the slot to join the top surface to the bottom surface.

Spot Weld: A spot weld is made through the top surface to the bottom surface. The top surface is not cut.

Groove-Square Weld: Groove welds are used to join the ends of two parts together. The surfaces of the two parts are butted against each other in parallel. The empty space between the two surfaces is filled with the weld. The shape of this empty space in a groove-square weld is in a rectangular/square shape.

Groove-V Weld: In a V-weld, the empty space is in a shape of a V. The weld fills up this V empty space.

Groove-Bevel Weld: A bevel is the shape of a one-half of a V.

Groove-U Weld: A U weld is the shape of a U.

The next concept that you must understand when reading welding symbols is how the symbol portrays the location of the weld. The symbol type location relative to the leader determines what side the weld must be completed. If the symbol is below the leader, then the weld occurs on the side of the arrow. If the symbol is above the leader, then the weld occurs on the other side of the arrow. You should be familiar with these terms, "arrow side" and "other side". The figure below shows you graphically how the symbols determine the location of the weld. If the welding symbol is above and below the leader, then the weld occurs on both sides.

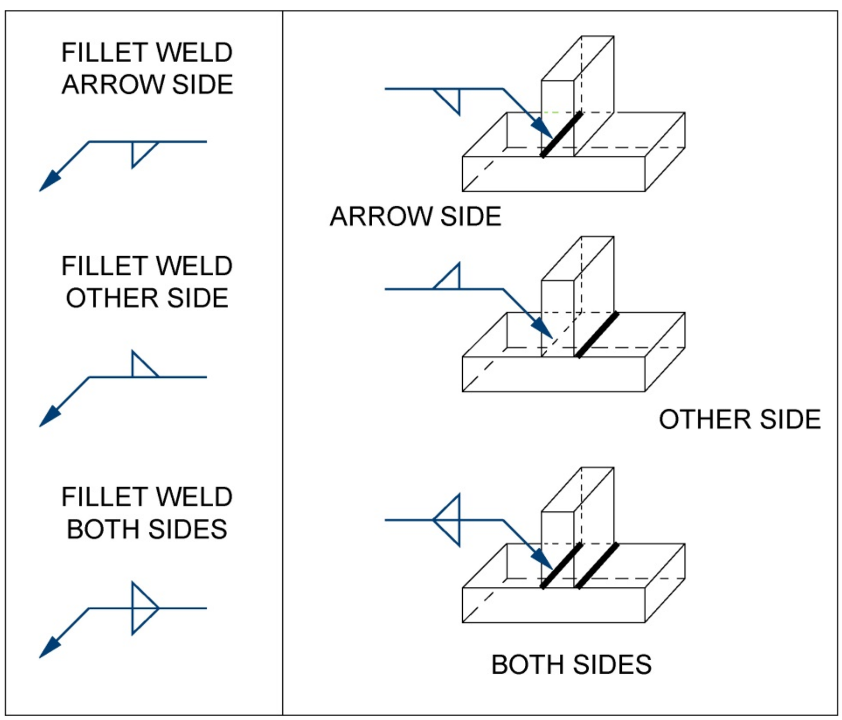


Figure 6: This figure shows the weld location in isometric view, based on the welding symbol.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Next, welding symbols can be added upon another with the following add-on symbols. For example, fillet welds can be added to a groove-bevel weld as shown in the next figure.

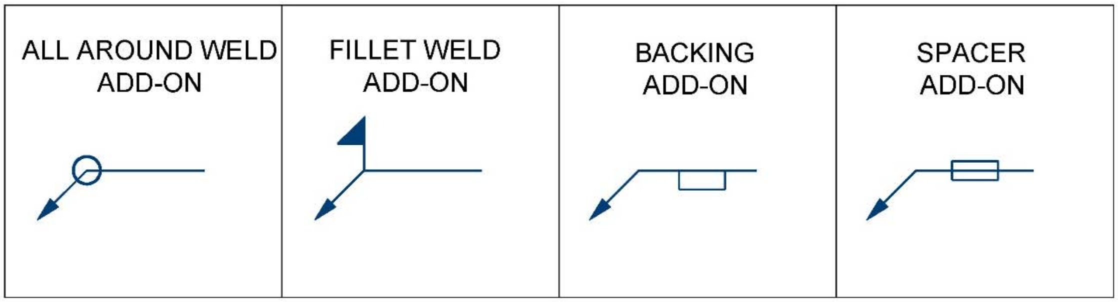


Figure 7: These symbols for add-ons can be included on top another weld.

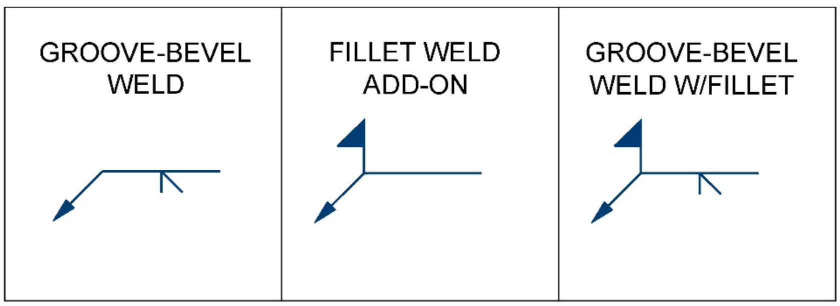


Figure 8: Welding symbols can be added one upon another. In this example you start with the groove-bevel weld on the left and then you add the filet weld add-on. This results in the final figure on the right.

Finally, welds are assigned sizes, thicknesses, lengths, angles and finishes as shown in the following figure and descriptions.

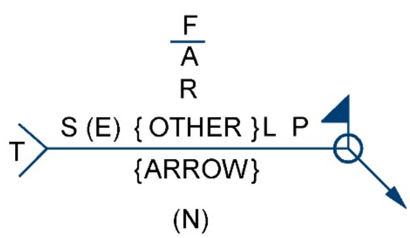


Figure 9: This diagram will help you to understand welding symbols. Use this figure and the following descriptions of each letter.

T: This is the tail of the symbol and may or may not be included. The tail can be used as a reference or to indicate a specific process that is required.

S: This term refers to the size or strength of the welds, for example this could be the depth of a bevel weld.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

E: This is the size of the groove weld.

L: Length of weld.

P: Pitch of the weld.

N: This letter will indicate the number of a certain type of weld like spot or seam.

F: Finishing designation

A: Angle of groove weld or angle of countersink for plug welds.

R: Depth of filling for slot or plug welds.

{Other} and {Arrow}: This is the location for the symbol that describes the type of weld, like bevel, groove, plug, etc. These different types of weld symbols were previously discussed.

2.4 MANUFACTURING DRAWINGS

The *NCEES Mechanical PE Handbook* contains tables on cylindrical fits and tolerances that are used in manufacturing drawings. The fits and tolerances topic is one that is easily tested on the PE exam as a part of interpreting technical drawings. This section will discuss the conceptual information on fits and tolerances, followed by an explanation on how to use the cylindrical fits and tolerances tables presented in Chapter 2.2 Cylindrical Fits and Tolerances of the *NCEES Mechanical PE Handbook*.

During the manufacturing process, *tolerances* are provided to indicate the minimum precision required to allow for a part to operate properly. The *fit* refers to the clearances between two mating parts. The higher the precision, the more costly a part becomes to manufacture. Therefore, the tolerances and fits are usually given as large a value as possible.

2.4.1 TOLERANCES

Tolerances are presented as a part's dimension limits. It can either be shown with +/- values or as a range. The following are examples of tolerance nomenclature which all mean the same thing.

Bilateral Tolerance: $\mathbf{10 \pm 0.05\ in}$, varies 0.05" in either direction away from 10"

Unilateral Tolerance (positive): $\mathbf{9.95\ ^{+0.10}_{-0.00}\ in}$**,** varies 0.10" in the positive direction.

Unilateral Tolerance (negative): $\mathbf{10.05\ ^{+0.00}_{-0.10}\ in}$*,* varies 0.10" in the negative direction

Limits: $\mathbf{9.95in - 10.05in}$, the minimum and maximum dimension.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Tolerance: $\mathbf{0.10in}$, the span between the two limits. The difference between the maximum and minimum size limits of the parts.

The tolerances are often labeled along with nominal sizes on design drawings for the fabricator. The following figure depicts examples of dimensioning various shapes.

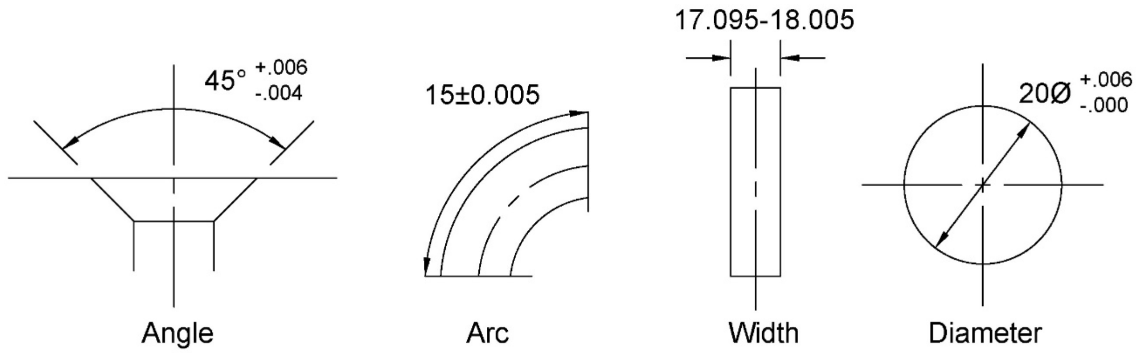


Figure 10: Dimensioning can occur on angles, arcs, lengths, diameters and more.

2.4.2 Fits

Mating two parts together will either require a clearance for smooth movement of one part within another or an interference for a snug, pressure tight fit. Each part is provided with a tolerance. The exam will likely ask you to use a limit dimension from both parts to find a clearance or an allowable dimension for proper operation.

The following image illustrates clearance requirements for a shaft that requires rotation within a hole. If the tolerances were too large, the shaft could potentially be too small to cause unstable rotation or too large causing excessive friction, preventing proper movement.

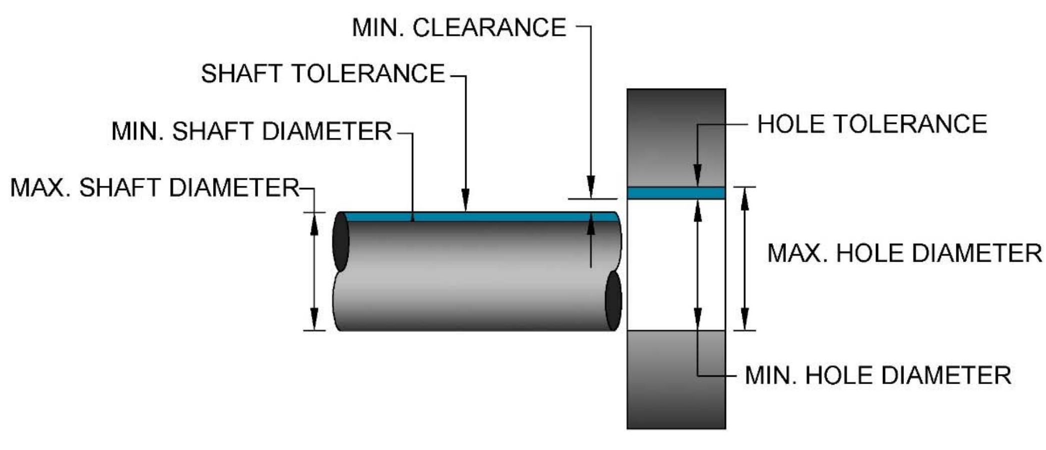


Figure 11: A clearance fit occurs when there is positive clearance between the hole and the shaft.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

The following example of interference is a shaft that has a larger diameter than the hole. In this situation, the rod is forced into the hole for a pressure fit, causing one part to be constrained to the other.

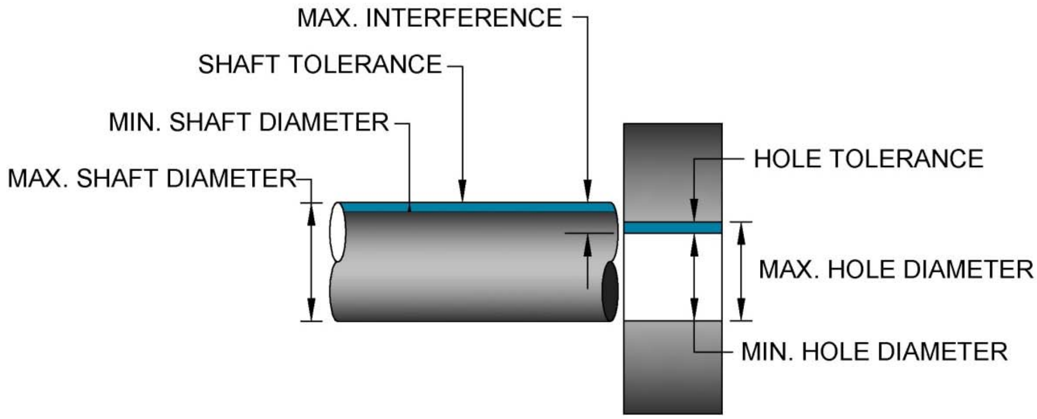


Figure 12: Interference fit in holes occurs when there is a fit with negative clearance between the hole and shaft.

The final type of fit is a transition fit. This type of fit can either have a positive or negative clearance.

2.4.3 Hole Basis and Shaft Basis

In a hole-based system, the size of the hole is kept constant and the shaft size is varied to get a different fit (clearance, transition or interference). The basic size of the hole is taken as the low limit. The high limit of the hole, the low limit of the shaft and the high limit of the shaft are selected to give the required fit. The term basic size is the reference point for the upper and lower limits. Thus if a hole has a minimum value of 25.00, then the basic size is 25.00. If the maximum value is 25.130, then the shaft must be selected to fit into these requirements.

In a shaft basis system, the size of the shaft is constant and the hole-size is varied to achieve the desired fit. The basic size of the shaft is taken as the maximum size of the shaft. The other limit of the shaft is adjusted, along with the limits of the hole to achieve the required fit.

2.4.4 Standard Tolerances

There are various standards for keeping uniform tolerances, one standard is ANSI Standard B4.1, *Preferred Limits and Fits for Cylindrical Parts*. This is a standard of tolerances for mating parts used in typical applications. The tables below are a sample of tables that could be encountered on the exam and a version of this table is shown in Chapter 2.2 Cylindrical

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Tolerances of the *NCEES Mechanical PE Reference Handbook*, although the version in the handbook includes both the I-P units and S-I units versions. For the purposes of the Machine Design PE exam, you would need to be able to quickly decipher this nomenclature but for the purposes of the Thermal & Fluids PE Exam, just a basic understanding should suffice.

Nominal Size		Hole (H11)	Shaft (c11)	Fit
25	Max	25.130	24.890	0.370
	Min	25.000	24.760	0.110

Nominal Size		Hole (H9)	Shaft (d9)	Fit
30	Max	30.052	29.935	0.169
	Min	30.000	29.883	0.065

The tables above show various fits, H11/c11 and H9/d9. You can see that the fit on the H9/d9 is tighter than the fit for the H11/c11. The following table shows how the various fits match up to the descriptions. The fits get tighter as you move down. But before you get to the table below you also be aware of how the fit is determined. The maximum fit is found by finding the difference between the maximum hole and the minimum shaft size. The minimum fit value is found by finding the difference between the minimum hole and the maximum shaft size.

	ISO Symbol		
	Hole Basis	**Shaft Basis**	**Description of Fit**
Clearance Fits	H11/c11	C11/h11	Loose running
	H9/d9	D9/h9	Free running
	H8/f7	F8/h7	Close running
	H7/g6	G7/h6	Sliding fit
	H7/h6	H7/h6	Locational clearance
Transition Fits	H7/k6	K7/h6	Locational transition
	H7/n6	N7/h6	Locational transition
Interference Fits	H7/p6	P7/h6	Locational interference
	H7/s6	S7/h6	Medium drive
	H7/u6	U7/h6	Force

The clearance fits will always have positive fit values or clearance values. The transition fits can have both positive and negative fit values. The interference fits will have negative fit values.

3.5 Geometric Dimensioning and Tolerancing

Geometric dimensioning and tolerancing or GD&T is used primarily in the Machine Design PE exam. For this topic, you need to be familiar with the common symbols and their meanings. The *NCEES Mechanical PE Reference Handbook* gives you a list of the symbols and

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

terminology that you should know but it does not explain how to use or interpret those symbols and terminology. The following section will go into more detail on all of the necessary symbols and terminology that you should know.

3.5.1 Feature Control Frame

Geometric dimensioning and tolerancing provides more control than simply dimensioning and tolerancing. You can add dimensions and tolerances, but by adding in the geometrical component, you can ensure that the design intent is properly manufactured. Geometric dimensioning and tolerancing will be presented with a feature control frame. An example of a feature control frame is presented below. It consists of the geometric characteristic symbol, the tolerance, material condition and the reference datum.

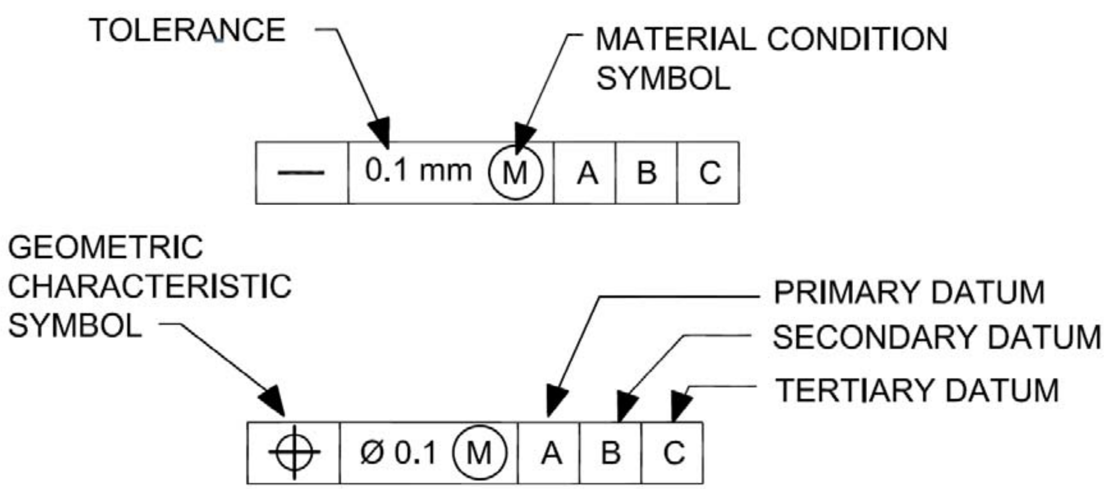


Figure 13: The feature control frame consists of four main sections, the geometric characteristic, tolerance, material condition and datum. The feature control frame will also be coupled with the actual dimension as necessary.

Each part of the feature control frame will be discussed in the following sections in the following order, datums, tolerance zone, material condition modifiers and finally geometric characteristic symbol.

3.5.2 Datums

Datums are a reference plane, axis or point for the dimensions and tolerances. There are a few ways that datums (plane, axis, point) may appear on the exam. First, the datum plane can be placed on a surface directly with a triangle and leader as shown in example (a). The datum plane can also be placed on a surface with a leader and the datum symbol shown on the horizontal portion of the leader as in example (b). Lastly, the datum symbol can be placed on a

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

dimension extension line as in example (c). Please note that in example (c) the datum triangle symbol is not on the dimension arrow.

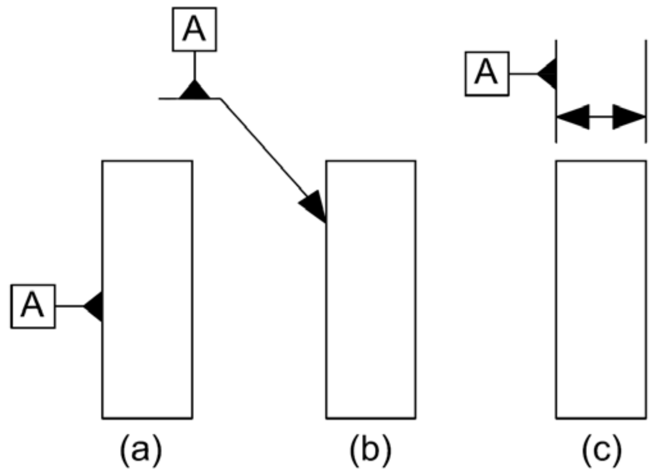


Figure 14: Datums can be applied to surfaces in three different ways. The datum triangle symbol can be filled in or not filled in. The filled in triangle is shown in this figure.

The actual surface is not the datum, but the imaginary plane created at that location becomes the datum. A datum can also be assigned to an axis. The axis is the center line or center plane between two dimension extensions or between two dimensions. The datum must be placed on the dimension line or extension of the dimension line in order for the axis to be the datum.

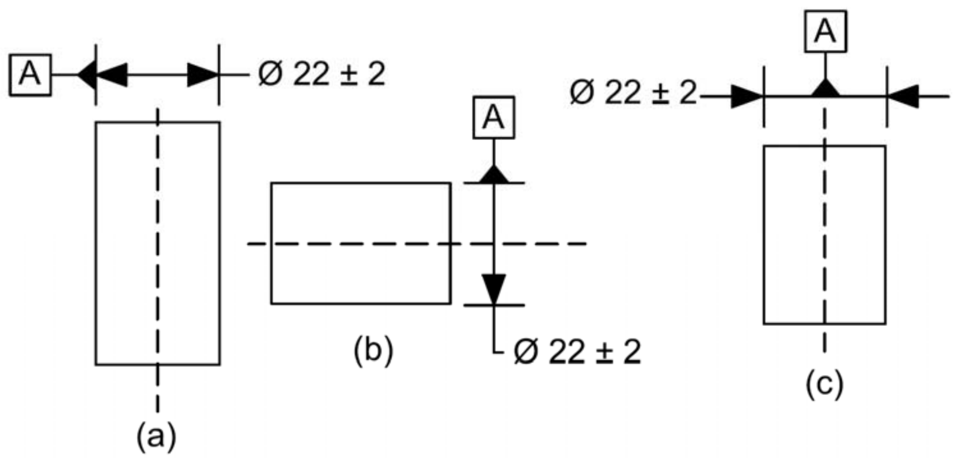


Figure 15: This figure shows three different ways a datum can be assigned to the center plane or axis.

3.5.3 Tolerance Zone

Before discussing geometric characteristic symbols, you need to understand tolerance zones. The feature control frame consists of a tolerance amount. This value creates the tolerance

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

zone. If the tolerance amount has a diameter symbol, then the tolerance zone is the diameter of a cylindrical or spherical zone, where the tolerance amount is equal to the diameter. If there is no diameter symbol, then the tolerance zone is between two straight lines or planes. The distance between those lines or planes is equal to the tolerance amount.

3.5.4 Material Condition Modifiers

Material condition modifiers are used to provide more information and constraints to the tolerance zone. You should be familiar with the following material condition modifiers, (1) MMC, (2) LMC and (3) RFS. These modifiers tell you what is the constraining tolerance and will create the boundary condition for the feature.

Maximum Material Condition (MMC): Maximum material condition is shown by an "M" in a circle. It describes the condition where the maximum amount of material exists. If it is a hole, then it is the smallest hole size. If it is a pin or shaft, then it is the largest size.

Least Material Condition (LMC): The least material condition is shown by an "L" in a circle. It describes the condition where the least amount of material exists. If it is a hole, then it is the largest hole size. If it is a pin or shaft, then it is the smallest size.

Regardless of Feature Size (RFS): Regardless of feature size indicates a geometric tolerance that will be independent of the dimension of the part. Regardless of feature size is the default.

3.5.5 Geometric Characteristic Symbols

The geometric characteristic symbols provide the final part of the feature control frame. The geometry characteristic symbols tell you how to apply the tolerance zone and any material condition modifiers.

3.5.6 Surface Conditions

Surface finishes can be important for the fits and tolerances of components, because the roughness of a component's surface may affect the tolerance of the component. If a tight tolerance is required, then the roughness should be minimized. Also if a figure is rough, then it will affect the straightness of the surface. The following method is used to specify the roughness for a component. The roughness value, #3, is shown in units, μm.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

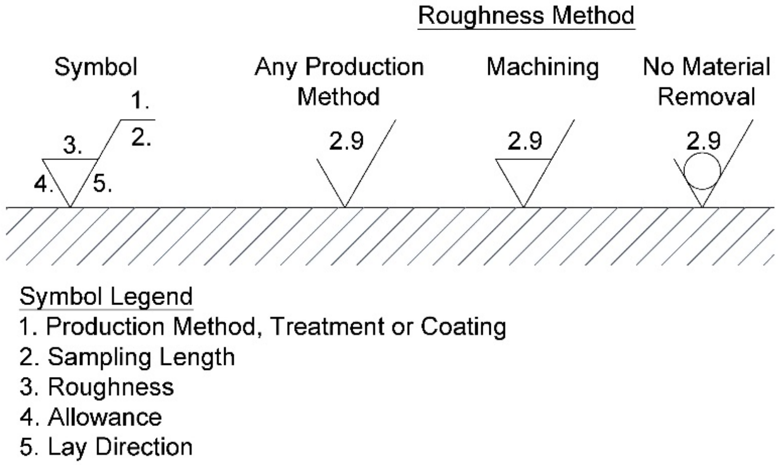


Figure 16: The roughness of a surface can be specified with the above symbology.

4.0 ECONOMIC ANALYSIS

As a professional engineer, you will be tasked with determining the course of action for a design. Often times this will entail choosing one alternative instead of several other design alternatives. *Engineers need to be able to present engineering economic analysis to their clients in order to justify why a certain alternative is more financially sound than another.* The following sub-sections will present the engineering economic concepts that should be understood by the engineer for the PE exam and does not present a comprehensive look into the study of engineering economics.

4.1 INTEREST RATE & TIME VALUE OF MONEY

Before discussing interest rates, it is important that the engineer understands that money today is worth more than money in the future. This is the concept of "time value of money." For example, if you were given the option to have $1,000 today or to have $1,000 10 years from now, you should choose $1,000 today. Why is that? The reason $1,000 today is worth more is because of what you could have done with that money now. In the financial world this is the amount of interest you could have earned with that money. If you took $1,000 today and invested it at 4% per year, you would have $1,040 dollars at the end of the first year.

$$\$1{,}000 * (1 + .04) = \$1{,}040$$

- If you kept the $1,040 in the investment for another year, then you would have $1,081.60.

$$\$1{,}040 * (1 + .04) = \$1{,}081.60$$

- At the end of the 10 years the investment would have earned, $1,480.24.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$\$1{,}000 * (1+.04) * (1.04) * (1.04) \ldots\ldots = \$1{,}000 \; * \; (1.04)^{10} = \$1{,}480.24$$

This means $1,000 today is worth $1,480.24 ten years from now, assuming a yearly interest rate of 4%.

- An important formula to remember is the Future Value (FV) is equal to the Present Value (PV) multiplied by (1 + interest rate, i), raised to the number of years, n.

$$PV * \; (1+i)^n = FV$$

- As an example, what would be the present value of $1,000, 10 years from now, if the interest rate is 4%?

$$PV * \; (1+.04)^{10} = \$1{,}000$$

$$PV \; = \$675.46$$

- Thus in the previous example, receiving $1,000, 10 years from now, is only worth $675.46 today.

It is important to understand present value because when analyzing engineering alternatives, cash values will be presented at many different times. The best way to make a uniform analysis is to *first convert all values to consistent terms, like present value.*

For example, if instead your options were $1,000 today or $1,500 in 10 years (interest rate at 4%), then it would be a much more difficult question than the previous one. With an understanding of present value, you can derive that it is better to accept $1,500 10 years from now, because $1,000 at present value is only worth $1,480 10 years from now, at 4% interest. In this example, the $1,000 today was converted to the "future value," 10 years from now. Once this value was converted, it can then be compared to the future value that was given as $1,500, 10 years later.

4.2 ANNUAL VALUE/ANNUITIES

The previous section described the difference between present value and future value. It also showed how a lump sum given at certain times are worth different amounts in present terms. In engineering, there are often times when annual sums are given in lieu of one time lump sums. An example would be annual energy savings due to the implementation of a more efficient mechanical system. Thus, it is important for the engineer to be able to determine the present/future value of future **annual** gains or losses.

For example, let's assume that a solar hot water project provides an annual savings of $200. Using the equations from the previous section, each annual savings can be converted to either present or future value. Then these values can be summed up to determine the future and present value of annual savings of $200 for four years at an interest rate of 4%.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

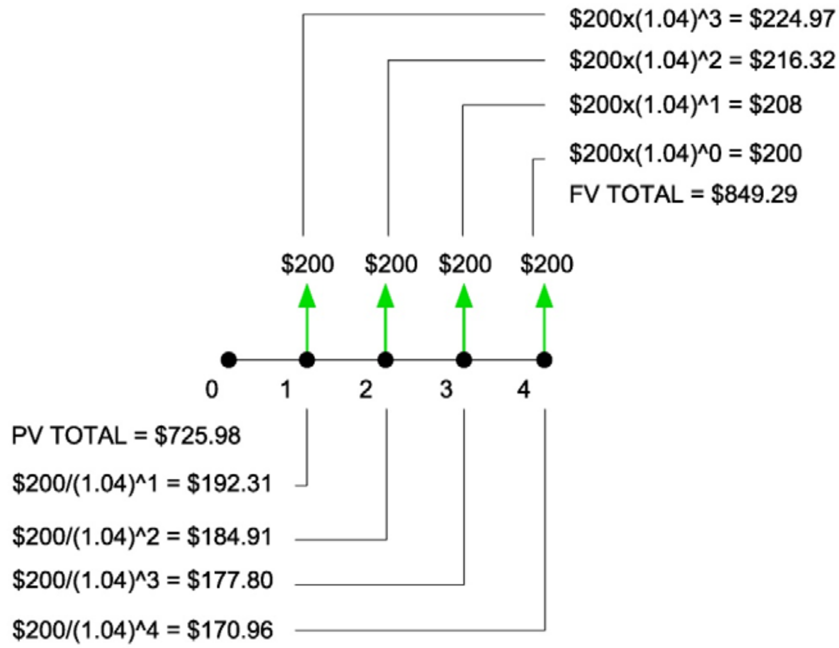


Figure 17: This figure shows an economics cash flow diagram for future annual savings converted to present value and future value.

For longer periods, this method could become tedious. Luckily there is a formula that can be used to speed up the process in converting annuities (A) to present value and future value, based on the interest rate, i, and the number of years, n.

$$\text{Future Value "FV"} = \mathrm{A} * \left(\frac{(1+\mathrm{i})^{\mathrm{n}}-1}{\mathrm{i}}\right)$$

$$FV = 200 * \left(\frac{(1+.04)^4-1}{.04}\right) = \$849.29$$

$$\text{Present Value "PV"} = \mathrm{A} * \left(\frac{1-(1+\mathrm{i})^{-\mathrm{n}}}{\mathrm{i}}\right)$$

$$PV = 200 * \left(\frac{1-(1+.04)^{-4}}{.04}\right) = \$725.98$$

- Reverse Equations, where annual value is solved:

$$\text{Annuities "A"} = \mathrm{PV} * \left(\frac{\mathrm{i} * (1+\mathrm{i})^{\mathrm{n}}}{(1+\mathrm{i})^{\mathrm{n}}-1}\right)$$

$$\text{Annuities "A"} = \mathrm{FV}\left(\frac{\mathrm{i}}{(1+\mathrm{i})^{\mathrm{n}}-1}\right)$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

4.3 Equipment Type Questions

In the Thermal & Fluids field, often times the engineer must develop an economic analysis for purchasing one piece of equipment over another. In the analysis, the engineer will use terms like present value, annualized cost, future value, initial cost and other terms like salvage value, equipment lifetime, rate of return, and payback.

Salvage value is the amount a piece of equipment will be worth at the end of its lifetime. Lifetime is typically given by a manufacturer as the average lifespan (years) of a piece of equipment. Looking at the figure below, initial cost is shown as a downward arrow at year 0. Annual gains are shown as the upward arrow and maintenance costs and other costs to run the piece of equipment are shown as downward arrows starting at year 1 and proceeding to the end of the lifetime. Finally, at the end of the lifetime there is an upward arrow indicating the salvage value.

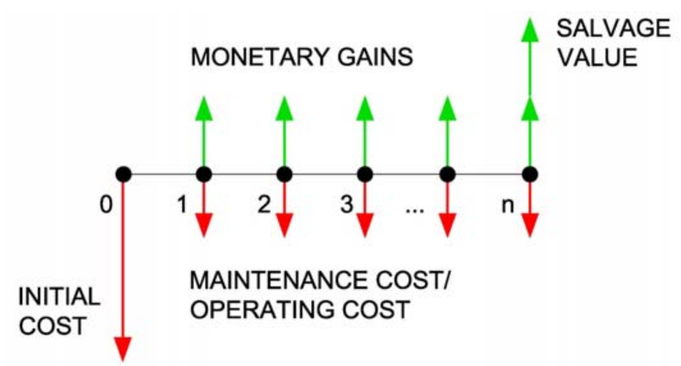


Figure 18: Economic analysis of gains and losses over time.

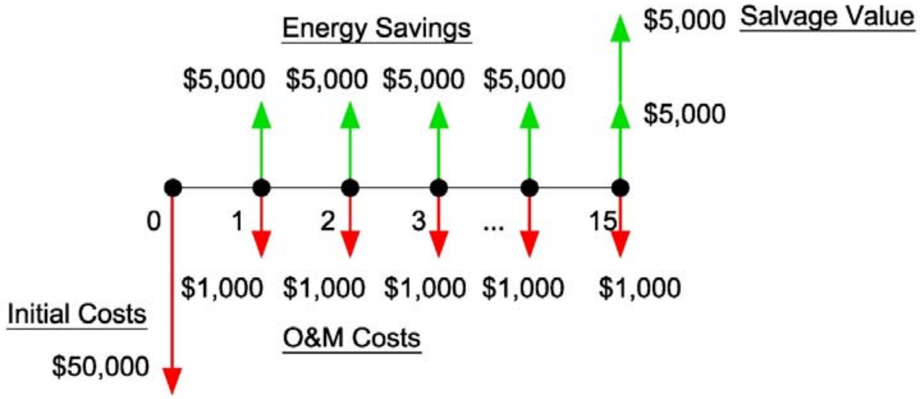
As previously stated, the most important process in an engineering economic analysis is to *convert all monetary gains and costs to like terms*, whether it is present value, future value, annual value or rate of return. Each specific conversion will be discussed in the following sections.

It is also important to note the language and the sign of the values. A “cost” or “loss” is represented as a negative (–) value and is indicated as red downward arrows. Terms like “savings,” “salvage,” or “gain” are represented as a positive (+) value, i.e. money gained, and is indicated in green above. When the question asks, what is the present worth of a piece of equipment over its lifetime, a negative value means there is an overall cost for the equipment, while positive means there was an overall savings. However, when the question directly asks you what the “cost” of an equipment is, the question is already implying that the value is a cost (i.e. negative), so the answer will be given as a positive value. In other words, $10,000 cost is the same as -$10,000 worth. It is important to pay attention to the wording during the exam and not get tricked by the signs.

Each of the sections will use the same example, in order to illustrate the difference in converting between each of the different terms and designating the signs (+ or -).

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Example: A new chiller has an initial cost of $50,000 and a yearly maintenance cost of $1,000. At the end of its 15 year lifetime, the chiller will have a salvage value of $5,000. It is estimated that by installing this new chiller, there will be an energy savings of $5,000 per year. The interest rate is 4%.



4.4 Convert to Present Value

What is the Present Value (Present Worth) of this chiller?

The first term, initial cost is already in present value.

$$PV_{initial\ cost} = -\$50{,}000$$

The second term, maintenance cost must be converted from an annual cost to present value. However, we can add the annual energy savings to this amount to save time.

$$A_{O\&M\ cost} + A_{energy\ savings} = -\$1{,}000 + \$5{,}000 = \$4{,}000$$

$$PV_{O\&M+energy\ savings} = \$4{,}000 * \left(\frac{1-(1+.04)^{-15}}{.04}\right) = \$44{,}473.55$$

The third term, salvage value must be converted from future value to present value.

$$PV_{salvage\ value} = \frac{\$5{,}000}{(1+.04)^{15}} = \ \$2{,}776.32$$

Finally, sum up all the like terms.

$$PV_{total} = \ PV_{initial\ cost} + PV_{O\&M+energy\ savings} + PV_{salvage\ value}$$

$$PV_{total} = -\$50{,}000 + \$44{,}473.55 + \$2{,}776.32 = \$-2750.13$$

A negative Present Value indicates that the investment does not recoup the initial investment.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Side note: If the question had instead asked, what is the present value "cost" of the chiller, the answer would be +$2750.13 because the negative is already implied with "cost." However, the question asks 'what is the present value worth,' so the answer is -$2750.13.

4.5 CONVERT TO FUTURE VALUE

What is the Future Value (Future Worth) of this chiller at the end of its lifetime?

The first term, initial cost is in present value and must be converted to future value.

$$FV_{initial\ cost} = -\$50{,}000 * (1 + .04)^{15} = \$-90{,}047.18$$

The second term, maintenance cost must be converted from an annual cost to future value. However, we can add the annual energy savings to this amount to save time.

$$A_{O\&M\ cost} + A_{energy\ savings} = -\$1{,}000 + \$5{,}000 = \$4{,}000$$

$$FV_{O\&M+energy\ savings} = \$4{,}000 * \left(\frac{(1 + .04)^{15} - 1}{.04}\right) = \$80{,}094.35$$

The third term, salvage value is already in future value.

$$FV_{salvage\ value} = \$5{,}000$$

Finally, sum up all the like terms.

$$FV_{total} = FV_{salvage\ value} + FV_{initial\ cost} + FV_{O\&M+energy\ savings}$$

$$FV_{total} = \$80{,}094.35 - \$90{,}047.18 + \$5{,}000 = \$-4{,}952.83$$

4.6 CONVERT TO ANNUALIZED VALUE

What is the Annual Value of this chiller?

The first term, initial cost is in present value and must be converted to annual value.

$$AV_{initial\ cost} = -\$50{,}000 * \left(\frac{.04 * (1 + .04)^{15}}{(1 + .04)^{15} - 1}\right) = \$-4{,}497.06$$

The second term, maintenance cost is already annualized. However, we can add the annual energy savings to this amount to save time.

$$AV_{O\&M\ cost} + AV_{energy\ savings} = -\$1{,}000 + \$5{,}000 = \$4{,}000$$

The third term, salvage value is in future value and must be annualized.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$AV_{salvage\ value} = \$5{,}000\left(\frac{.04}{(1+.04)^{15}-1}\right) = \$249.71$$

Finally, sum up all the like terms.

$$AV_{total} = AV_{salvage\ value} + AV_{initial\ cost} + AV_{O\&M+energy\ savings}$$

$$AV_{total} = \$249.71 - \$4{,}497.06 + \$4{,}000 = \$-247.35$$

For an even faster method on how to do these calculations with tables, see the following section: Factor Tables.

4.7 Factor Tables

When conducting engineering economic analyses, factor values are used in lieu of formulas. Factor values are pre-calculated values that correspond to:

(1) A specific equation (convert present value to annual, convert present value to future, etc.)

(2) An interest rate, i.

(3) Number of years, n.

Looking up these values in a table is sometimes quicker than using the equations and lessens the possibility of calculator error. It is recommended that the *engineer practice using Chapter 1.6.2 Economic Factor Tables in the NCEES PE Mechanical Reference Handbook*. A summary of the factor values are shown below.

Conversion	Formula	Factor Value (from table)
Present Value to Future Value	$FV = PV * (1+i)^n$	Multiply PV by (F/P, i, n)
Future Value to Present Value	$PV = \frac{FV}{(1+i)^n}$	Multiply FV by (P/F, i, n)
Present Value to Annual Value	$AV = PV * \left(\frac{i*(1+i)^n}{(1+i)^n-1}\right)$	Multiply PV by (A/P, i, n)
Annual Value to Present Value	$PV = AV * \left(\frac{1-(1+i)^{-n}}{i}\right)$	Multiply AV by (P/A, i, n)

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Future Value to Annual Value	$AV = FV\left(\frac{i}{(1+i)^n - 1}\right)$	Multiply FV by (A/F, i, n)
Annual Value to Future Value	$FV = AV * \left(\frac{(1+i)^n - 1}{i}\right)$	Multiply AV by (F/A, i, n)

As an example, let's redo the annual value calculation from the previous example, using the factor tables.

What is the Annual Value of the chiller?

The first term, initial cost is in present value and must be converted to annual value. Look up the A/P factor in the tables for 4% interest at 15 years.

*Tip: The calculation is similar to unit conversions: A = P * (A/P), the P's cancel out to get A.*

$$AV_{initial\ cost} = PV * A/P(4\%, 15)$$

*Extra steps**:** Unfortunately the NCEES Reference Handbook only has values for 2% and 6% interest. Find these two interest rates at 15 years and interpolate to estimate the 4% A/P value. Luckily 4% is right in the middle, so we can just find the average.*

$$\frac{A}{P}(2\%, 15) = 0.0778;\ \frac{A}{P}(6\%, 15) = 0.1030$$

$$\frac{A}{P}(4\%, 15) = \frac{0.0778 + 0.1030}{2} = 0.0904$$

Convert present to annualized cost.

$$AV_{initial\ cost} = PV * A/P(4\%, 15) = -\$50{,}000 * 0.0904 = \$ - 4{,}520$$

Notice that the answer is just slightly off from the previous example. This is because the values are not linear between the 2% to 6% tables, so the interpolation to obtain the 4% values are approximate. If the values are read straight from the tables without needing to interpolate, these answers would be exact.

The second term, maintenance cost is already annualized. However, we can add the annual energy savings to this amount to save time.

$$AV_{O\&M\ cost} + AV_{energy\ savings} = -\$1{,}000 + \$5{,}000 = \$4{,}000$$

The third term, salvage value is in future value and must be annualized. Find the A/F value at 4%, 15 years.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$\frac{A}{F}(2\%, 15) = 0.0578; \ \frac{A}{F}(6\%, 15) = 0.0430$$

$$\frac{A}{F}(4\%, 15) = \frac{0.0578 + 0.0430}{2} = 0.0504$$

$$AV_{salvage\ value} = FV * A/F(4\%, 15) = \$5{,}000 * 0.0504 = \$252$$

Finally, sum up all the like terms.

$$AV_{total} = AV_{salvage\ value} + AV_{initial\ cost} + AV_{O\&M+energy\ savings}$$

$$AV_{total} = \$252 - \$4{,}520 + \$4{,}000 = \$ - 268$$

4.8 Convert to Rate of Return

What is the rate of return on the investment of $50,000 for the new chiller?

The rate of return is a tool used by engineers to describe how profitable or un-profitable an investment is over the equipment's lifetime. The calculation involves determining the equivalent interest rate for a monetary investment and a monetary gain or loss.

In the previous example, $50,000 is invested in a new chiller and the returns on this chiller are $4,000 a year ($5,000 energy savings minus $1,000 O&M) and a salvage value of $5,000 at the end of the 15 years. For the calculation of rate of return (ROR) or return on investment (ROI), **the salvage value is assumed to be $0 only to simplify the problem**.

The ROR is calculated as what "i" value is required in the below equation to make both sides equal. This approach takes trial and error, unless you have a computer or financial calculator.

$$\$4{,}000 * \left(\frac{1 - (1 + i)^{-15}}{i}\right) = \$50{,}000$$

First try, i= .04 (4%).

$$\$44{,}473.55 < \$50{,}000$$

Second try, i= .03 (3%).

$$\$47{,}751.74 < \$50{,}000$$

Third try, i= .025 (2.5%).

$$\$49{,}525 < \$50{,}000$$

Fourth try, i= .023 (2.3%).

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$\$50{,}262 > \$50{,}000$$

Correct answer is approximately, 2.4% ROR. Since, the ROR is less than the interest rate of 4%, this investment is not wise.

4.9 BREAK EVEN ANALYSIS

Break even analysis is the point at which revenues equals cost. This is most commonly used in manufacturing and is discussed briefly. The most common application is finding how many products must be produced until the facility reaches the breakeven point, or until the facility will finally start seeing profits. In this analysis, you use the same principals from the previous section, except there is an unknown variable. First convert all terms to either present, annual, or future, then equate the total sum of all income and expenses to zero and solve for the unknown variable.

In mechanical engineering, this analysis may be more typically done to compare two options, i.e. at which point will option A provide more savings than option B. Convert all terms to present, annual, or future, then equate the sum of all expenses and savings/income from option A and option B to solve for the variable. Again, you will use the same principals, but apply them to solve an unknown variable.

4.10 SIMPLE PAYBACK

Calculating simple payback is similar to a break even analysis. Simple payback is calculated by taking the initial cost and divided it by the yearly savings that will be achieved through the project or the installation of a new piece of equipment. Simple payback is the number of year that will be required to recoup the initial cost. It is called simple because it does not take into account the time value of money.

Example: A new chiller has an initial cost of $50,000 and a yearly maintenance cost of $1,000. At the end of its 15 year lifetime, the chiller will have a salvage value of $5,000. It is estimated that by installing this new chiller, there will be an energy savings of $5,000 per year. The interest rate is 6%. What is the simple payback of the new chiller?

$$Simple\ Payback = \frac{Initial\ Cost}{Profit\ (Income - Expenses)} = \frac{\$50{,}000}{\$5{,}000 - \$1{,}000} = \frac{\$50{,}000}{\$4{,}000} = 12.5\ years$$

4.11 DEPRECIATION

Depreciation is the value that an asset decreases over time. For example, as a building or an equipment gets older, it starts to gradually deteriorate and reduce in useful life over time. Depreciation values can be represented as either a straight line or accelerated form. Please be familiar with Chapter 1.6.3 Depreciation in the NCEES Mechanical PE Reference Handbook.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

4.11.1 Straight Line

Straight line depreciation distributes the depreciation values evenly over the life of the asset. This is the simplest method for calculating depreciation and is represented by the following equation.

$$Straight\ Line\ Depreciation\ (\$/Year) = \frac{Capital\ Cost\ (\$) - Salvage\ Value\ (\$)}{Useful\ Life\ (Years)}$$

For example, a machine is purchased at $100,000 and has a salvage value of $10,000. If the machine has a useful life of 10 years, then the straight line depreciation value is:

$$Straight\ Line\ Depreciation\ = \frac{\$100{,}000 - \$10{,}000}{10\ Years} = \$9{,}000/Year$$

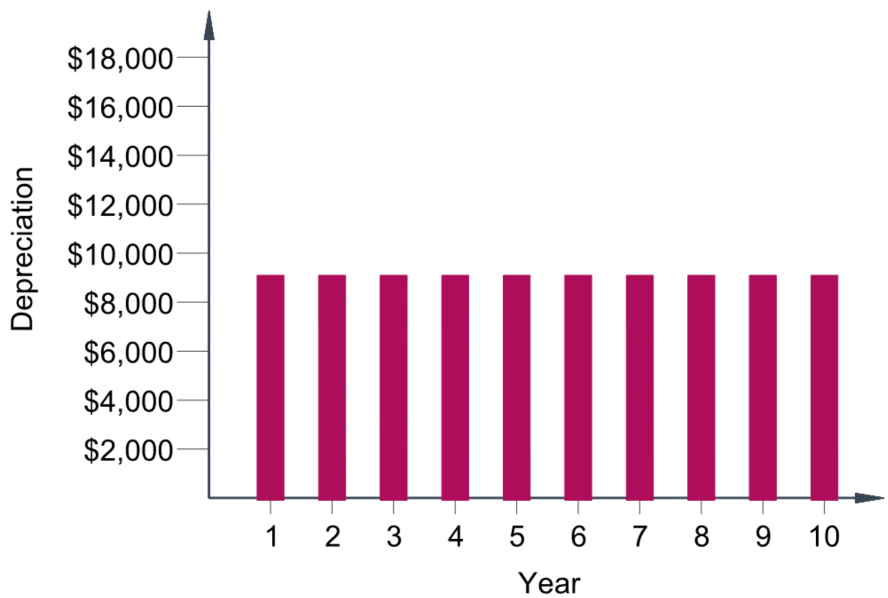


Figure 19: Example of Straight Line Depreciation for an asset with ten years of usable life

4.11.2 Modified Accelerated Cost Recovery System (MACRS)

The modified accelerated cost recovery depreciation system distributes the depreciation to be heavily weighted in the earlier years of the asset's usable life and less weighted in the later years. In other words, it accelerates the depreciation to earlier in the lifetime of the asset. This system is used for taxes in the United States. It allows for the company to take larger depreciation credits in the earlier years, thereby deferring taxes to later in the asset's lifetime.

There are two main differences between this depreciation method and the straight line method. First, the depreciation occurs over n+1 years, where "n" is the lifetime of the asset. In addition, there is no salvage value for MACRS depreciation. At the end of the "n+1" years, the asset will have a salvage value of $0.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$MACRS\ Depreciation_{year,j}\ (\$\ at\ Year\ j) = Recovery\ Rate\ (\%)_{year,j} * Capital\ Cost\ (\$)$$

In practice, the MACRS tables are published by the IRS. For the exam, use the table in Chapter 1.6.3 Depreciation in *NCEES Mechanical PE Reference Handbook* for the recovery rate based on the recovery period. The same equipment used in the straight line example above ($100,000 initial cost, 10 year lifespan) will have a recovery rate at year 2 of 18%, and a recovery rate at year 8 at 6.55%.

$$MACRS\ Depreciation_{year\ 2} = 18\% * \$100{,}000 = \$18{,}000$$

$$MACRS\ Depreciation_{year\ 8} = 6.55\% * \$100{,}000 = \$6{,}550$$

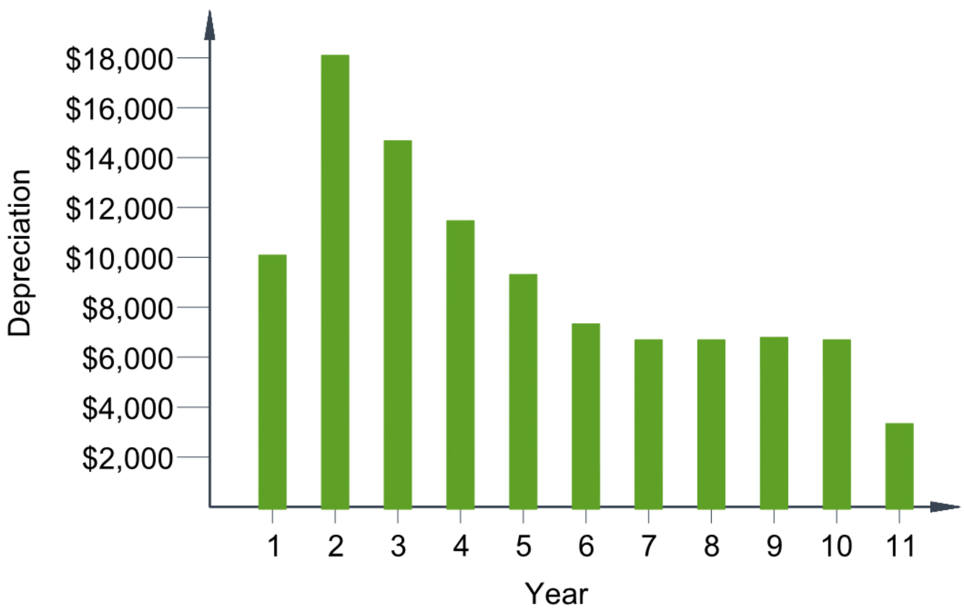


Figure 20: Example of MACRS Depreciation for an asset with ten years of usable life

4.11.3 Sum of Years Digits (SYD)

The sum of the years digits method also uses accelerated depreciation, applying more depreciation in the earlier part of an equipment's life. The difference between MACRS is the amount of depreciation that is distributed throughout the years. SYD is also different to MACRS, but similar to straight line depreciation, in that it incorporates a salvage value and depreciates the equipment over its lifetime, instead of the n+1 years that MACRS uses. SYD is an older method that was used in taxes before MACRS. In present day, it is used for accounting, and is not allowed for taxes.

$$SYD\ Depreciation_{year\ j}(\$\ at\ Year\ j) = \frac{2 * [Capital\ Cost\ (\$) - Salvage\ Value\ (\$)] * (n - j + 1)}{n * (n + 1)}$$

$$n = Useful\ Life\ (years);\ \ j = year\ of\ depreciation$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Using the same example, a machine is purchased at $100,000 and has a salvage value of $10,000. If the machine has a useful life of 10 years, then the "sum of the years" depreciation value at year 2 and year 8 is found below.

$$SYD\ Depreciation_{year\ 2} = \frac{2*(\$100{,}000 - \$10{,}000)*(10-2+1)}{10*(10+1)} = \$14{,}727$$

$$SYD\ Depreciation_{year\ 8} = \frac{2*(\$100{,}000 - \$10{,}000)*(10-8+1)}{10*(10+1)} = \$4{,}909$$

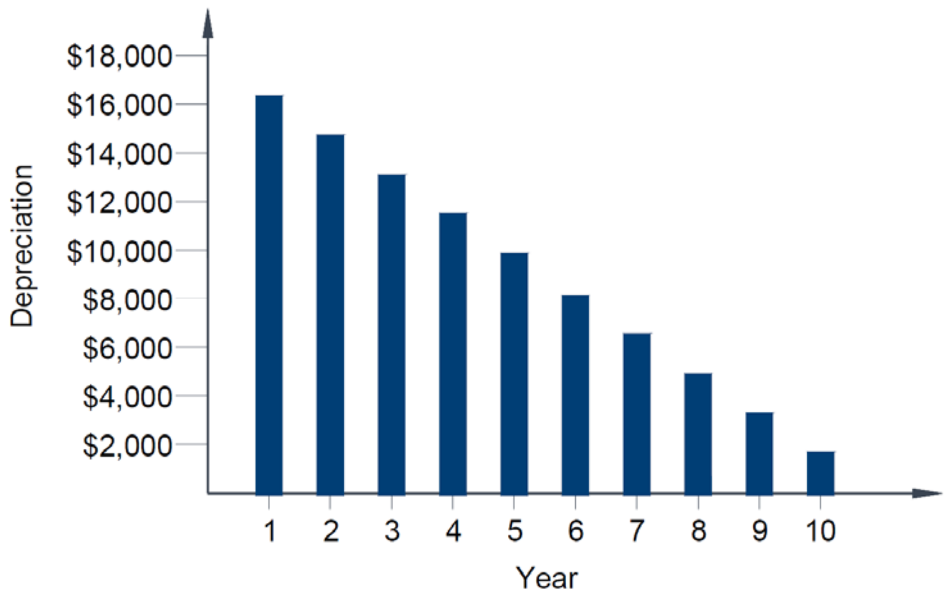


Figure 21: Example of SYD Depreciation for an asset with ten years of usable life.

4.11.4 Depreciation Comparison

The following table compares the straight line, MACRS, and SYD depreciation methods for an equipment with initial cost of $100,000, lifespan of 10 years, and $0 salvage value.

Year (n)	Straight Line		MACRS		SYD	
1	10%	$10,000	10%	$10,000	18%	$18,182
2	10%	$10,000	18%	$18,000	16%	$16,364
3	10%	$10,000	14%	$14,400	15%	$14,545
4	10%	$10,000	12%	$11,520	13%	$12,727
5	10%	$10,000	9%	$9,220	11%	$10,909
6	10%	$10,000	7%	$7,370	9%	$9,091
7	10%	$10,000	7%	$6,550	7%	$7,273
8	10%	$10,000	7%	$6,550	5%	$5,455
9	10%	$10,000	7%	$6,560	4%	$3,636

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

10	10%	$10,000	7%	$6,550	2%	$1,818
11			3%	$3,280		

5.0 UNITS AND CONVERSIONS

Many of the problems on the PE exam will require you to convert units and will have incorrect answers that use different units or wrong conversion techniques. Double check your work and make sure you use the correct units. The exam has switched to computer based testing, so you have to be familiar with the conversions presented in the NCEES Mechanical PE Reference Handbook. Throughout this book, you should also take note of the conversions that occur regularly and commit those to memory.

6.0 ELECTRICAL CONCEPTS

Mechanical and electrical engineers work closely together and there is often a lot of coordination between the two disciplines. Most of the equipment that a mechanical engineer designs will require power. It is important for the mechanical engineer to understand the basics of electrical engineering.

6.1 CURRENT, VOLTAGE AND RESISTANCE

There are three basic terms that mechanical engineers should understand about electrical engineering, current, voltage and resistance.

Current is the measure of the flow of electrons and is measured in terms of amperes (A). Current is represented by the variable (I).

Voltage is best described in mechanical terms as the pressure at which current (flow) is supplied. Voltage is often represented by the variable (V).

Resistance is the opposition to flow. It controls the amount of flow or voltage in a circuit. Resistance is represented by the variable (R) and is measured in ohms (Ω).

These three terms are related by the following equation. In order to solve for another variable, simply re-arrange the equation to solve for the desired variable. This equation is called Ohm's Law.

$$Ohm's\ Law: V = IR$$

6.2 BASIC DC CIRCUITS

A basic direct current circuit consists of a voltage source [battery] and a resistor. The voltage source provides the "pressure" to drive the current (flow) through the circuit.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

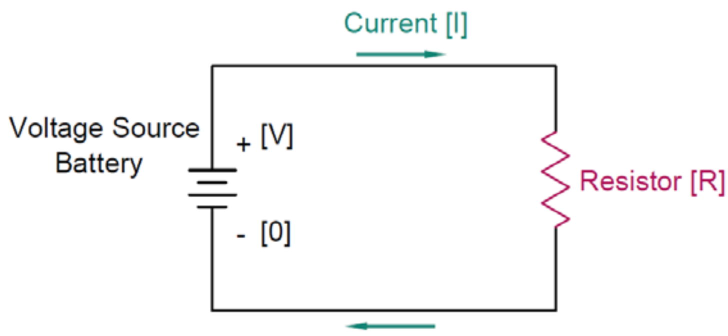


Figure 22: Basic DC Circuit

In order to solve a basic DC circuit question, the following tools must be understood and used properly, 1. Ohm's Law, 2. Voltage around a Closed Loop is Equal to Zero, 3. Current into a Node is Equal to Current Out, 4. Resistors in Series, 5. Resistors in Parallel.

1. Ohm's Law

The amount of current supplied is proportional to the ratio of the Voltage to Resistance. If the Voltage is larger then there will be more current. Also if there is less Resistance then the current will be higher. For example, in the below circuits, the circuit with a resistance of 6 Ω has a current of 2 amps while, the circuit with a resistance of 2 Ω and equal voltage has a current of 6 amps.

$$I = \frac{V}{R}; Ohm's\ Law$$

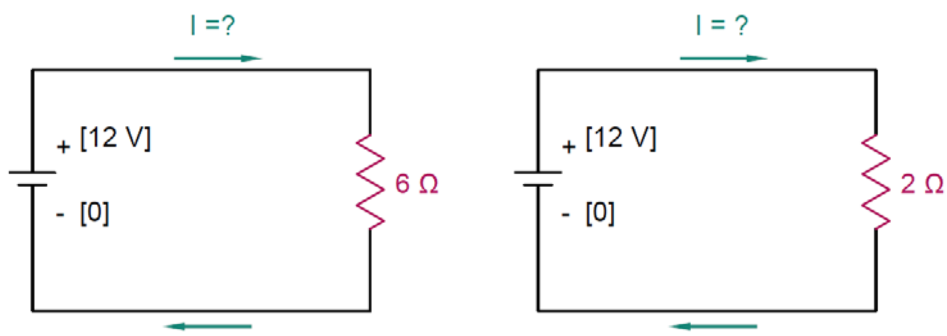


Figure 23: Ohm's Law

$$Left\ Figure: \ I = \frac{12}{6}; I = 2\ Amps$$

$$Right\ Figure: \ I = \frac{12}{2}; I = 6\ Amps$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

2. Voltage

The second thing that must be remembered is that the voltage change around a closed loop is equal to zero. In simpler terms, any path that is returning to the same point must have a voltage change of zero.

In the following example, there is a 12 V voltage source and two resistors of resistance 4 Ω and 2 Ω. Following the current, we see that prior to the 4 Ω resistor the voltage is 12 V, following this resistor the voltage has dropped to 4 V. After the 2 Ω the voltage has dropped to 0 V, but once it reaches the voltage source, the voltage is increased to 12 V.

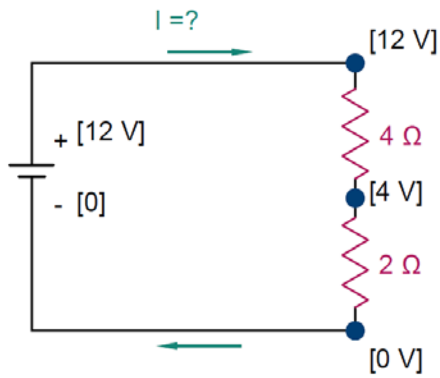


Figure 24: Basic circuit showing voltage drops across resistors in series

The next example shows the same resistors, but they are arranged in parallel. Notice that the voltage change across each loop (inner and outer) is shown to be zero. Then use this fact and Ohm's law to determine the current through each resistor. These currents are shown below in green.

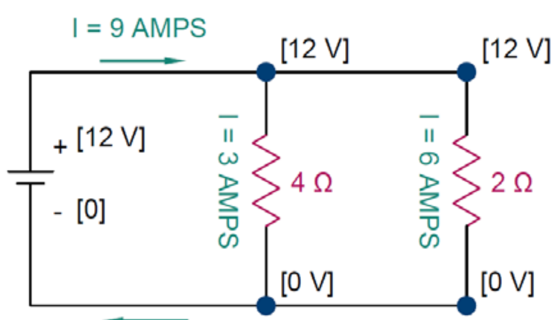


Figure 25: Basic circuit showing Voltage drop across resistors in Parallel.

3. Current

The next rule is that the current into and out of a junction must be equal. In Figure 5, it is shown that the current is 2 amps and the current remains constant through each resistor because at each junction there is only 1 path in and 1 path out.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

In Figure 6, the total current is found to be 9 amps. When the current reaches the 1st junction, the current can travel either through resistor 4 Ω or resistor 2 Ω. Three amps of current travels through the 4 Ω resistor, this leaves 6 amps of current left to travel to the 2 Ω resistor. As shown the current into the junction is 9 amps and the current leaving the junction is 3 amps + 6 amps.

4. Resistors in Series

For resistors in series, the resistors can be converted to an equivalent resistor by simply adding the resistance values together.

$$R_{eq} = R_1 + R_2 + R_3 + R_n$$

In the following example, there are two resistors in series. The equivalent resistance is found by adding the two resistances, $R_{eq} = 6\Omega$. Once the equivalent resistance is found, then the current can be found through Ohm's law. $I = \frac{12V}{6\Omega} = 2\ Amps$.

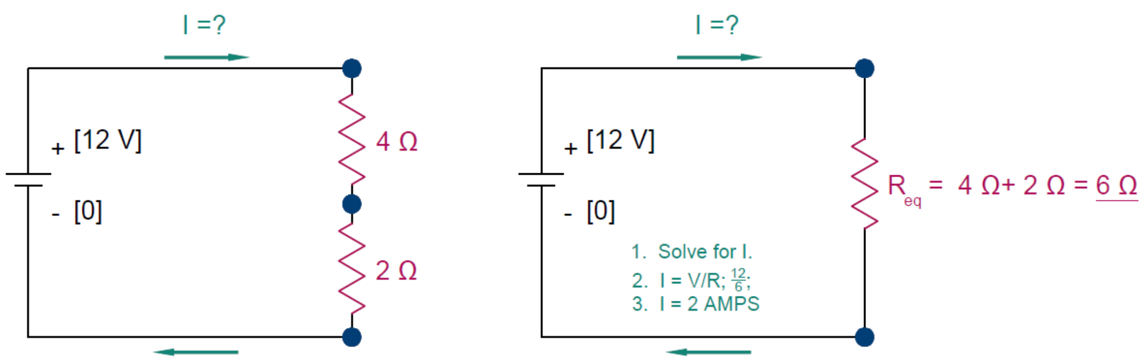


Figure 26: Basic DC Circuit solving for equivalent resistance for resistors in series

Remember that resistors are simply resistances to flow, so if the current has to pass through two resistors then it makes sense that both full values of the resistances need to be taken into account. For resistors in series, the current going through each resistance is equal, but the voltage drop across each resistor is inversely proportional to the resistance value.

5. Resistors in Parallel

When resistors are in parallel, the current has multiple paths to go through. Each path will have a current that is inversely related to the resistance in that path. However, the voltage drop across each resistor will remain constant. Use the following equation to find the equivalent resistance value of multiple resistors in parallel.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_n}$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

In the following example, the equivalent resistance is found to be $R_{eq} = 1.33\Omega$. The current through the equivalent resistance is then found to be 9 amps.

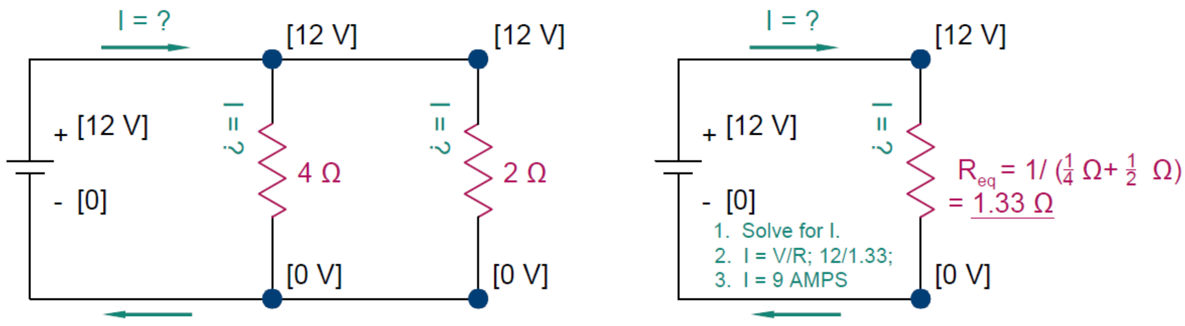


Figure 27: Basic dc circuit for equivalent resistance for resistors in parallel

6.3 D/C Power

The next important electrical equation to remember is the DC electric power equation as shown below. Real power is typically expressed in units, Watts and apparent power is expressed in volt-amperes. Current is represented by the variable "I" and is expressed in amperes and voltage is represented by the variable "V" and is expressed in volts.

$$Real\ Power \rightarrow P = IV(volt - amperes);$$

$$Apparent\ Power \rightarrow S = IV\ (volt - amperes);$$

Variations of the equation can be shown by substituting "I" and "V", through the use of Ohm's law.

$$P = \left(\frac{V}{R}\right) * V = \frac{V^2}{R}$$

$$P = I * IR = I^2 * R$$

6.4 A/C Power

The previous electrical sections have dealt with DC power or direct current electricity. This allows for a basic understanding of common electrical terms. However, for the P.E. exam, the mechanical engineer should also be aware of alternating current (AC) power terms and equations.

Alternating current is most commonly used on the PE exam and in most power applications. Alternating current describes the alternating directions of flow in a circuit. Current quickly alternates flow direction from positive to negative many times a second. In the figure below,

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

positive current is shown flowing in a clockwise direction in the figure on the right and this flow direction corresponds to the positive portions of the graph on the left.

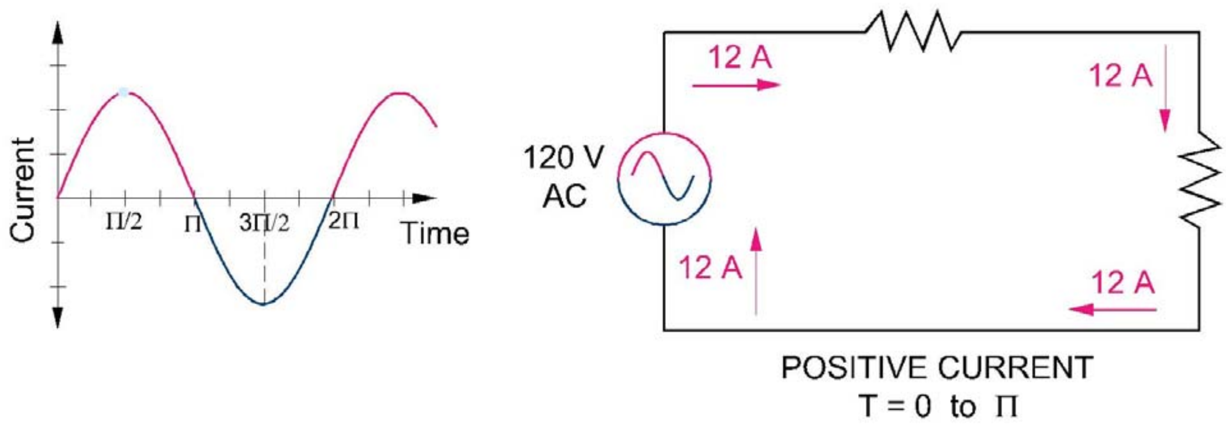


Figure 28: Alternating current consists of positive and negative flowing current. This figure shows positive current flow.

In this next figure, negative current is shown flowing in a counter-clockwise direction. The current flow in the figure on the right corresponds to the negative portions of the graph on the left.

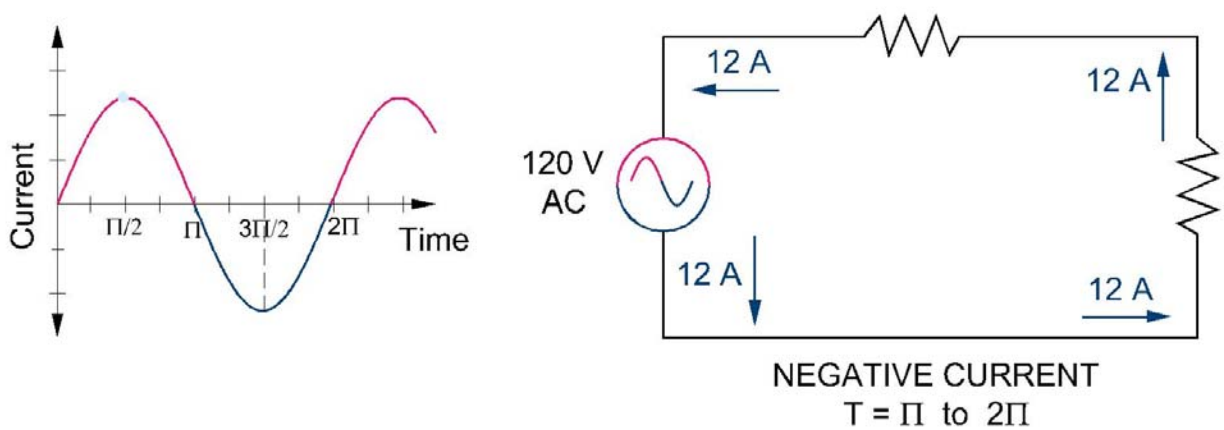


Figure 29: Alternating current consists of positive and negative flowing current. This figure shows negative current flow.

6.4.1 Frequency

The frequency of an alternating current wave is the number of cycles completed in one second and is given in units of hertz. For example, in the USA, the standard frequency for alternating current is 60 hertz (HZ). This means that 60 cycles are completed in one second. In Europe,

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

the standard is 50 hertz (HZ). In the previous figures, 1/60 seconds would correspond to the value for one cycle is completed at 60 Hz. 1/50 seconds would complete one cycle for 50 Hz.

$$frequency\ f\ (HZ) = \frac{cycles}{second}$$

Another term that is closely related to frequency is angular frequency. Angular frequency is the rotational frequency of alternating current and is given in terms of radians per second. Essentially you are converting a cycle into angular units. For example, if one rotation is completed in one second, then the angular frequency is 2π radians per second. If 60 rotations were completed in one second, then the angular frequency is 120π rad/s. Remember that a generator rotates to produce the frequency in current. That is why the current can be represented as a waveform and angular frequency is useful in analyzing these waveforms. Angular frequency is related to physical frequency through the following equation.

$$angular\ frequency\ \ \omega\ (radians/sec) = 2\pi f$$

6.4.2 RMS AND MAX

In an AC circuit, the voltage and current are constantly varying in magnitude over time. The RMS method is used to find the average or effective value of a constantly varying value. You may want to simply calculate the average of the value over time to get the effective value of the current or voltage, but in a simple AC circuit, the average will be zero because there are both positive and negative values. The term root mean square is found by taking the sum of "n" number of points along the waveform, squaring each value, summing all "n" values and then taking the square root of the sum.

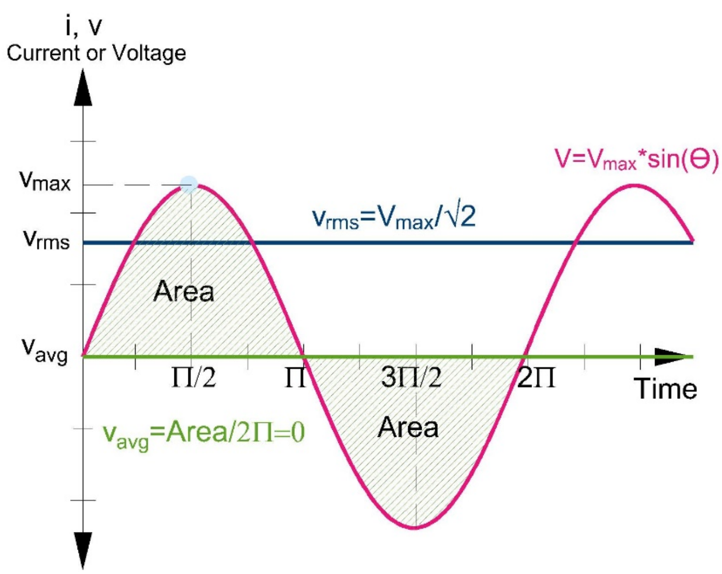


Figure 30: This figure shows the relationship between average, root mean square and maximum values in a sine wave.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

The fundamental equation for calculating RMS is shown below. The variable "V" is used for voltage but this variable can also be exchanged for "I" for a current waveform.

$$RMS = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 \ldots + V_n^2}{n}}$$

The RMS equation can be written for a continuous function, "f(t)" by taking an integral, in lieu of summing, across an infinite number of "n" points along the time period T. The equation is summarized below.

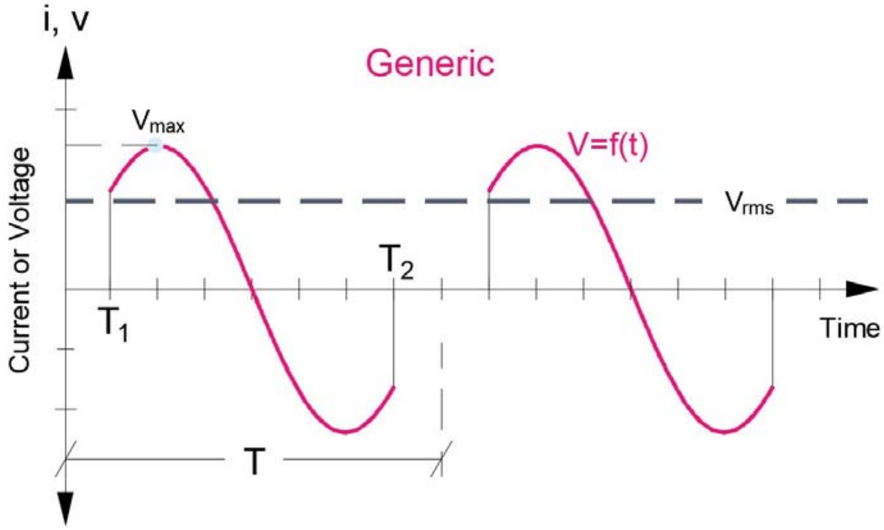


Figure 31: For a function, f (t), the RMS is the square root of the integral of the square of the function across time period T.

$$RMS_{generic} = \sqrt{\frac{1}{T}\int_{T_1}^{T_2} f(t)^2 dt}$$

The following is a summary of the RMS equations for the most common waveforms. The equations were all derived from the generic equation above.

Perhaps the *most important RMS equation* you should know is the RMS equation for a sinusoidal waveform. This is most commonly used for the analysis of AC circuits. In a basic sinusoidal waveform, as shown in the figure below, the RMS value is 0.707 times the peak value of the sinusoidal graph.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

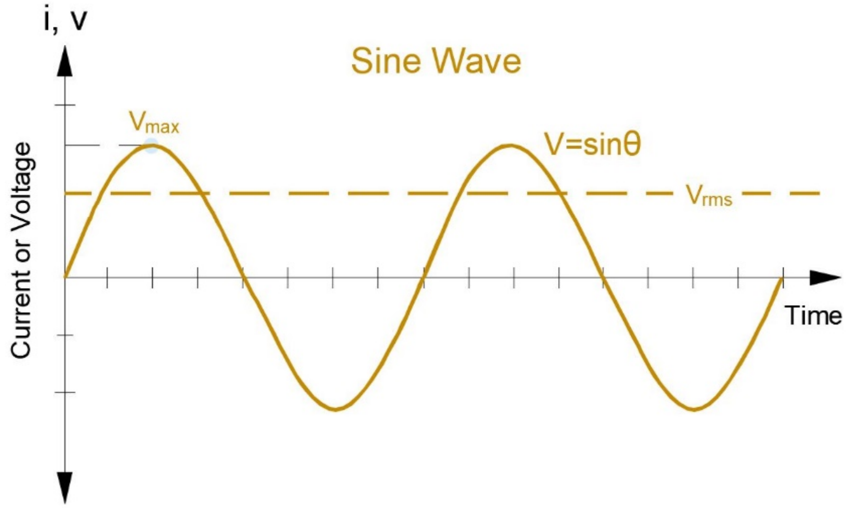


Figure 32: The RMS value of a sinusoidal waveform is the most important RMS equation for AC circuit analysis.

$$RMS_{sine\ wave} = \frac{V_{max}}{\sqrt{2}}$$

The common voltages used for mechanical equipment in the USA are 120 V, 208 V, 240 V, 277 V and 480 V. The smaller voltages are for single phase equipment and the larger voltages are used for three phase equipment. In mechanical engineering, you will encounter both single-phase and three-phase equipment and you should be familiar with the differences in both single-phase and three-phase for the exam. In application, single-phase is used for low power loads and/or short distances. Single-phase often powers residential loads, lighting loads, receptacles, small motors (less than 1 HP), office loads, etc. Three-phase is used for higher power loads and/or long distances. Three-phase is used for power generation, utility loads, transmission & distribution, larger motors (greater than 1 HP).

6.4.3 SINGLE-PHASE

A single-phase power circuit is shown on a circuit as having a single "hot" line and a return path "neutral" line. If you have done some electrical work in your house, then you should be familiar with single-phase power. In a home, electrical power is typically routed from the utility, which is shown as "AC" in the next diagram. A single wire, called the hot line, is routed to a power panel. This panel provides power to individual circuits that are protected with a circuit breaker. From the circuit breaker, a hot line is routed to a load and a neutral line is routed back to the panel and then continued back to the power source (AC), which then completes the circuit.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

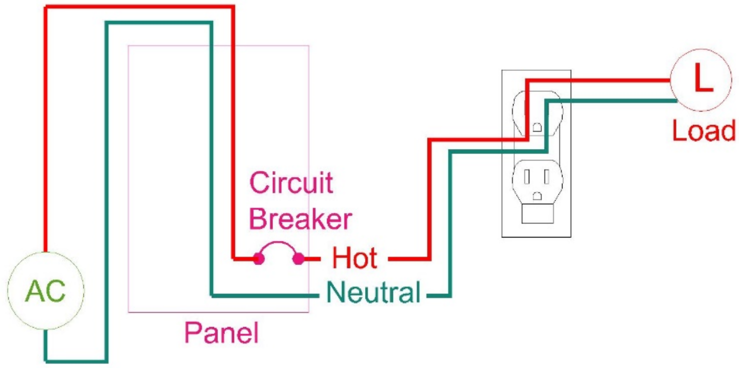


Figure 33: Single-phase circuit has a hot line and a neutral line.

6.4.4 Three-Phase

A three-phase power circuit has either three or four power wires. Three wires provide the three phases of power to a load and the fourth wire is sometimes used as a neutral to return unbalanced current back to the source. Three-phase power is used because of its efficiency in amount of wires, versus the amount of power it can carry. In a single-phase circuit, you need 1 wire to provide the power and 1 wire to complete the circuit to carry the power back to the source. In a three-phase circuit, you have 3 wires (3 phases), each providing power and no return circuit.

Three-phase power accomplishes this feat by using alternating current and the difference in frequencies to provide power to a load. Three wires with current traveling at the same alternating current frequency are offset by 120 degrees or 1/3 of their period. In order to illustrate this point, assume the total length of a period is 3 seconds, meaning that current reaches its positive peak at time 0 sec and then its negative peak at 1.5 sec and the end of its period at its positive peak at 3 seconds. Now assume that the second phase or second wire starts at time 1 sec and its negative peak at 2.5 sec and the end of its period at 4 seconds. The third wire starts at 2 sec and its negative peak is at 3.5 sec and the end of its period is at 5 seconds. From the load's perspective, it sees current moving through its circuit.

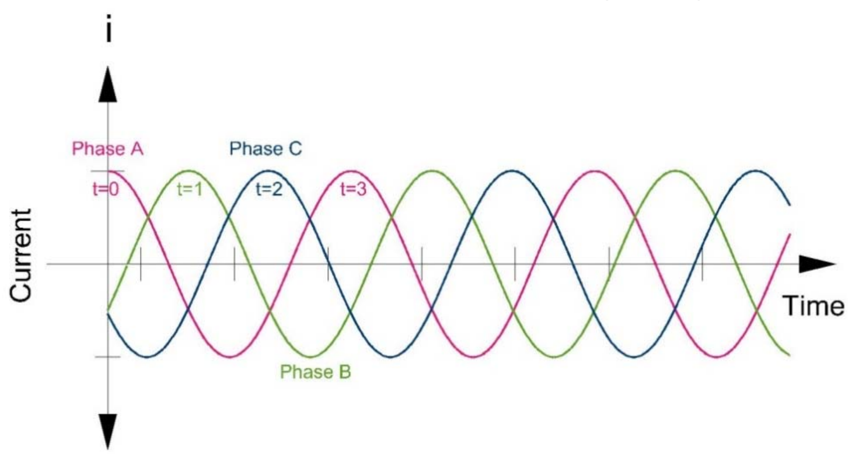


Figure 34: Three-phase power waveform

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$Total\ Electricity\ Supplied \rightarrow Apparent\ Power \rightarrow S_{1ph} = I * V\ (volt - amperes)$$

$$Total\ Useful\ Power \rightarrow Real\ Power \rightarrow P_{1ph} = I * V * PF\ (watts)$$

6.4.5 Power Factor

The term power factor describes the relationship between the apparent power (S) and real power (P). Power factor describes how much of the apparent power provided is being used for real power. Real power can best be understood by remembering that power is the multiplication of current and voltage. If you imagine a waveform, where current and voltage are perfectly in sync, then current and voltage will always be positive at the same time and will always be negative at the same time. Thus, the multiplication of current and voltage will always be positive. This is best shown in the next waveform section. Apparent power is the multiplication of the current and voltage at all times.

In the following graph, current and voltage are in phase. This corresponds to a power factor of 1.0. The current and voltage waveforms cross the X-axis at the same time. In this graph the real power is 100% of the apparent power.

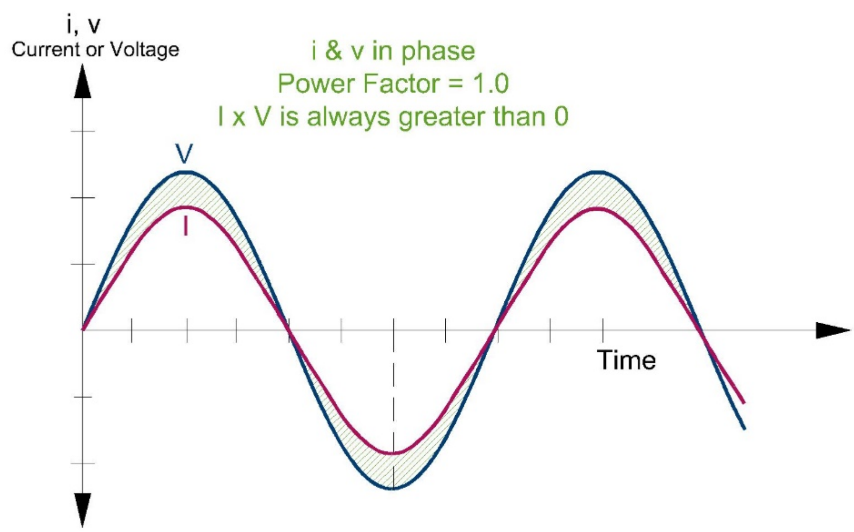


Figure 35: Current and voltage waveforms with a power factor of 1.0.

In the following graph, current and voltage are out of phase by a factor of 0. This corresponds to a power factor of 0. The current waveform is negative when the voltage is positive for 50% of the time. Thus, the multiplication of the current and voltage will be negative for 50% of the time and positive 50% of the time. The real power will be 0% of the apparent power and the reactive power will be 100% of the apparent power.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

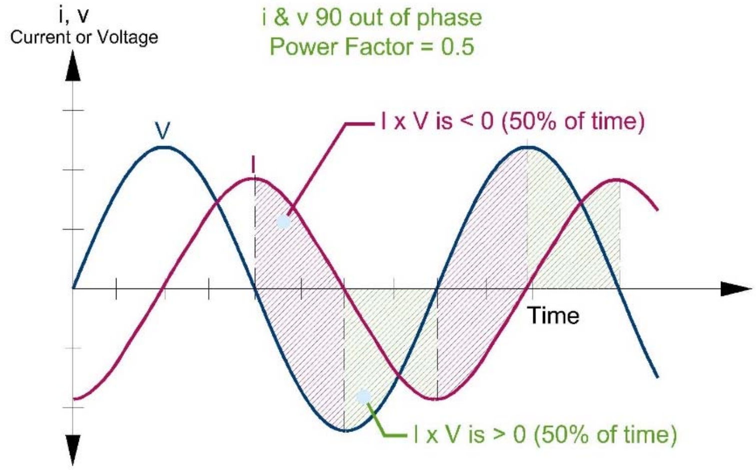


Figure 36: Current and voltage waveforms with a power factor of 0.

The next graph shows a negative power factor. When the voltage waveform crosses to the negative, the current waveform crosses to the positive. Thus, the multiplication of current and voltage will always be negative. This corresponds to a power factor of -1. In this scenario, the real power will be 100% of the apparent power and the reactive power will be 0% of the apparent power, similar to a power factor of 1. The only difference is that power is flowing the opposite way. With a power factor of 1, the load is completely resistive. But a power factor of -1 means that the load is now generating power and the power is 100% real.

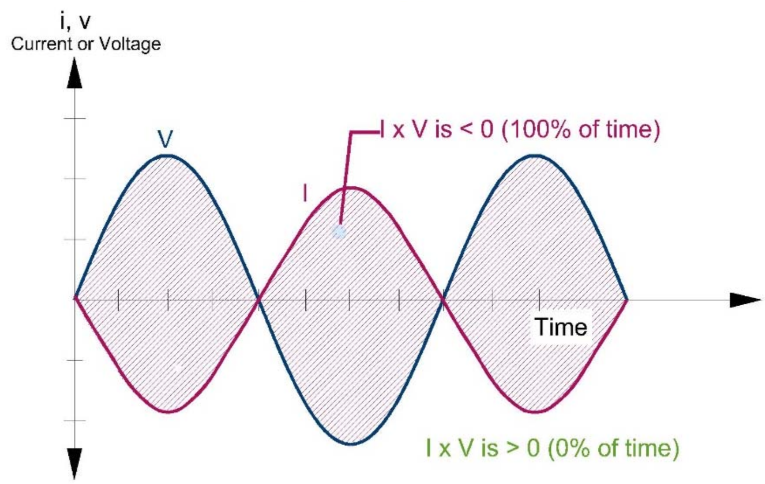


Figure 37: Current and voltage waveforms with a power factor of -1. The load is now generating power.

Chapter 1.10.2 Power Factor of the NCEES Mechanical PE Reference Handbook provides the basic equation for power factor. In equation format, power factor is described as the ratio between apparent power (S) and real power (P).

$$Power\ Factor\ (pf) = \frac{P\ (Watts, kW\ or\ MW)}{S\ (volt - amperes, KVA\ or\ MVA)}$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

6.4.6 Apparent Power and Real Power

Real power is the power that is used for useful, actual work. This could be used to turn a motor, turn on a light or to power a computer. Real power is given in units of kilowatts (kW), watts (W) or megawatts (MW) and is designated by the variable, "P". The three phase and single phase real power equations are shown below. Real power is found by multiplying the current and voltage values by the power factor. The three phase real power equation includes the root 3 term.

$$P_{1ph} = I * V * (pf)$$

$$P_{3ph} = \sqrt{3} * I * V * (pf)$$

$$I = RMS\ of\ current\ waveform; V = RMS\ of\ voltage\ waveform;\ pf = power\ factor$$

Apparent power is found by multiplying the current and voltage values. The three phase apparent power equation includes the root 3 term.

$$S_{1ph} = I * V$$

$$S_{3ph} = \sqrt{3} * I * V$$

$$I = RMS\ of\ current\ waveform; V = RMS\ of\ voltage\ waveform;$$

6.4.7 Motor Equations

Chapter 1.10.1 Efficiency in the NCEES Mechanical PE Reference Handbook shows the efficiency equation for a motor. The electrical input to the motor is the real power and is shown on the denominator. The motor output is the rated horsepower or the operating horsepower. There is a conversion to convert the horsepower into kW, since the denominator is in units of kW.

$$Motor\ Efficiency = \frac{Motor\ Output\ (HP) * \frac{.746\ kW}{1\ hp}}{Real\ Power\ Input\ (kW)}$$

Chapter 1.10.2 Power Factor rewrites the equation in terms of apparent power. Apparent power is equal to the Real Power divided by the power factor.

$$Real\ Power\ (P) = Apparent\ Power\ (S) * \ pf$$

$$Motor\ Efficiency = \frac{Motor\ Output\ (HP) * \frac{.746\ kW}{1\ hp}}{Apparent\ Power\ Input\ (S) * \ pf\ (kW)}$$

Chapter 1.10.3 Full Load Current and 1.10.6 Motor phases, again rewrites the equation and solve for current by substituting the apparent power equation.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$S_{1ph} = I * V; \; S_{3ph} = I * V * \sqrt{3}$$

$$1\,ph\,Motor \rightarrow Motor\,Efficiency = \frac{Motor\,Output\,(HP) * \frac{.746\,kW}{1\,hp}}{I * V * pf\,(kW)}$$

$$3\,ph\,Motor \rightarrow Motor\,Efficiency = \frac{Motor\,Output\,(HP) * \frac{.746\,kW}{1\,hp}}{I * V * \sqrt{3} * pf\,(kW)}$$

6.5 Mechanical Equipment Motor Rating

When selecting mechanical equipment, the mechanical engineer must coordinate the power requirements with the electrical engineer. This is done through the following steps: (1) Determine Mechanical Horsepower, (2) Determine Fan/Pump Brake horsepower, (3a) Determine Motor Horsepower, (3b) Determine Electrical Input Power, and finally (4) Apparent Power.

1) Determine Mechanical Horsepower. Mechanical HP is defined as the amount of power required to meet the needs of the system in question. For example, if the mechanical equipment was a pump, then the mechanical HP would be the amount of power generated by a certain GPM at a certain pressure. For a fan, the mechanical work would be the amount of power generated by a certain amount of CFM at a certain pressure. These equations can be found below.

$$\boldsymbol{P_{mech\,work,pump[HP]}} = \frac{\boldsymbol{h_{ft} * Q_{gpm} * (SG)}}{\boldsymbol{3956}};$$

$$h = hydraulic\,head[ft], Q = flow\,rate\,[gpm], SG = specific\,gravity$$

$$\boldsymbol{P_{mech\,work,fan[HP]}} = \frac{\boldsymbol{Q_{cfm} * TP_{in\,wg}}}{\boldsymbol{6356}};$$

$$TP = total\,pressure\,[in\,wg], Q = flow\,rate\,[cfm]$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

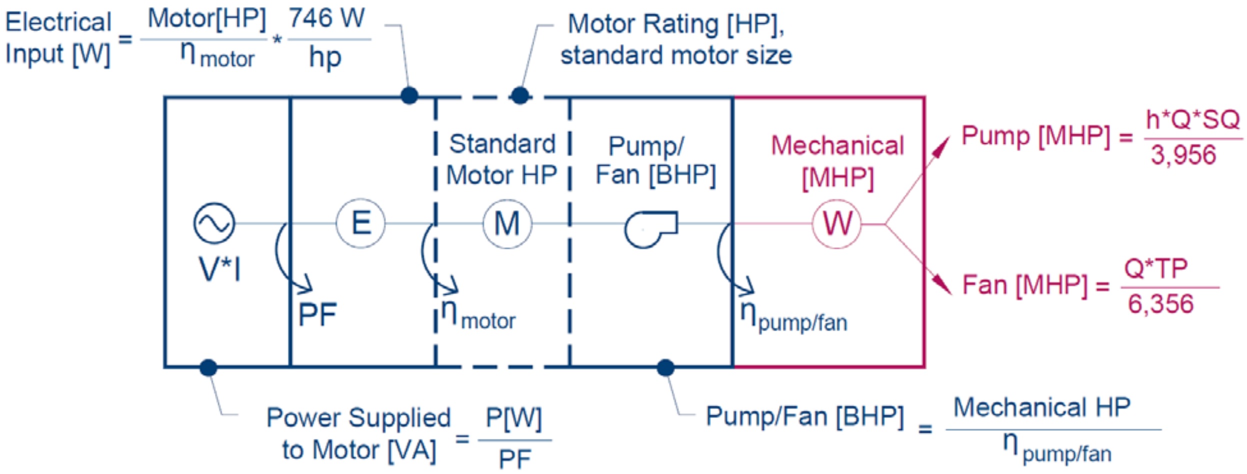


Figure 38: Determining mechanical horsepower

In the figure above, mechanical horsepower is shown on the right in red. Two equations are shown for solving for the mechanical horsepower for a fan and pump, based on flow and pressure. *There are other Mechanical horsepower formulas presented in the NCEES Mechanical PE Reference Handbook based on other given data. You should have these equations ready for the exam.*

<u>2) Determine Fan/Pump Horsepower</u>. In order to blow air or pump a fluid, a pump or fan is required. This pump/fan is not perfect and cannot supply the mechanical HP required without losing energy due to friction and inefficiencies in the equipment design. Thus the Pump/Fan Horsepower is found by dividing the Mechanical HP by the efficiency of the Pump/Fan. This is the size of the pump or fan required. Often times the fan/pump horsepower is called the brake horsepower or BHP.

$$\boldsymbol{P_{fan/pump[BHP]}} = \frac{\boldsymbol{P_{mech\,work[MHP]}}}{\boldsymbol{\eta_{fan/pump}}};$$

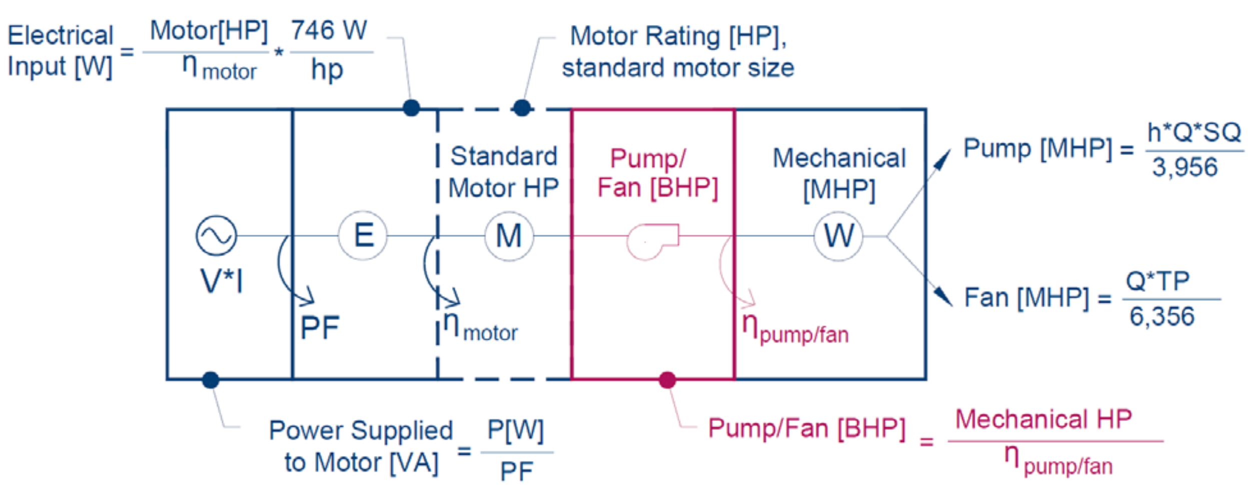


Figure 39: Determining Pump/Fan Horsepower

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

In the figure above, pump/fan horsepower is shown in the middle in red. Given the mechanical horsepower required, the pump/fan horsepower is found by dividing the Mechanical Horsepower by the efficiency of the Pump/Fan. Typical efficiencies for pumps and fans can range from 60% to 90%. The efficiencies depend on the design of the equipment and the operating point.

3a) Determine (Standard) Motor Horsepower Rating [OPTIONAL]. In order to power the pump/fan, a motor is required to supply the power to the equipment. The horsepower rating of the motor is based on the available motor sizes from the manufacturer, which are given in standard increments. These standard motor ratings are discussed in the next section, "Motor Ratings." If the question does not explicitly ask for the standard horsepower rating, you may typically skip this step.

- **Standard Rating Excluded**: If the standard motor horsepower rating is not accounted for, the power calculated is the actual power consumed during operation. This is typically done for energy calculations, where the engineer is concerned about actual electrical consumption, and not rated criteria.
- **Standard Rating Included**: If the standard motor horsepower rating is accounted for, the question is typically asking for a motor selection. Standard horsepower ratings are also used in cooling load calculations when usage and load factors are given, see *Heating & Cooling Loads* chapter of this book.

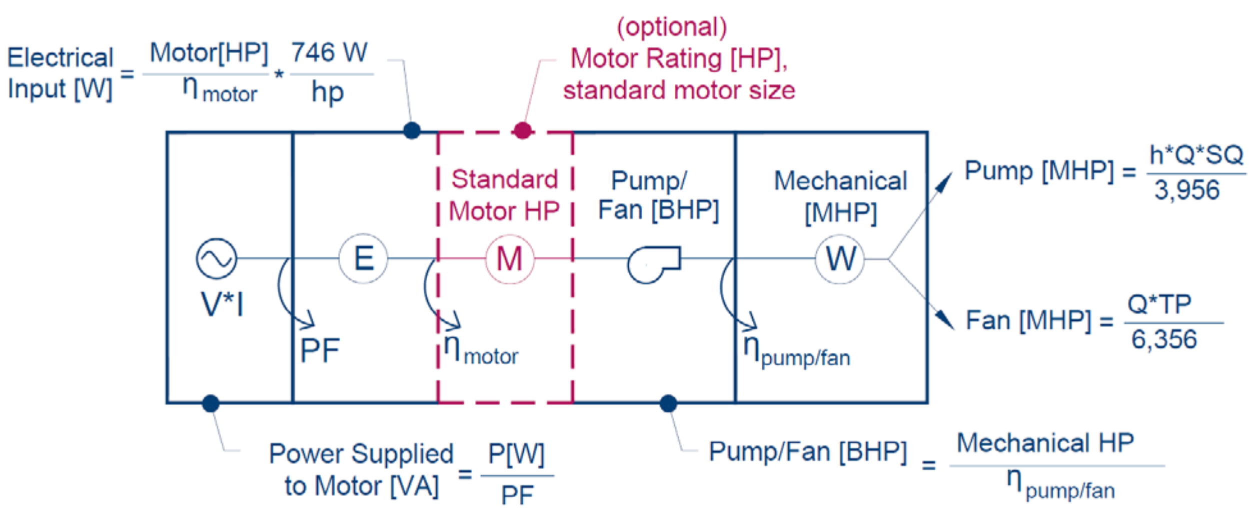


Figure 40: Determining Standard Motor Horsepower

3b) Determine Electrical Input (Watts). The motor is not perfect, similar to the pump/fan and some power is lost due to friction. The electrical power delivered to the motor is found by dividing the standard motor horsepower (or the Pump/Fan brake horsepower if the standard rating is not used) by the efficiency of the motor. This is also known as the real, or usable,

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

electrical power. Real electrical power is typically given in watts, typical efficiencies of motors are around 90%.

$$\boldsymbol{P_{electrical[W]}} = \frac{\boldsymbol{P_{motor[HP]}}}{\boldsymbol{\eta_{motor}}} * \frac{\boldsymbol{746W}}{\boldsymbol{hp}} [standard\ motor\ HP\ used]$$

$$\boldsymbol{P_{electrical[W]}} = \frac{\boldsymbol{P_{fan/pump[BHP]}}}{\boldsymbol{\eta_{motor}}} * \frac{\boldsymbol{746W}}{\boldsymbol{hp}} \ [standard\ motor\ HP\ not\ used]$$

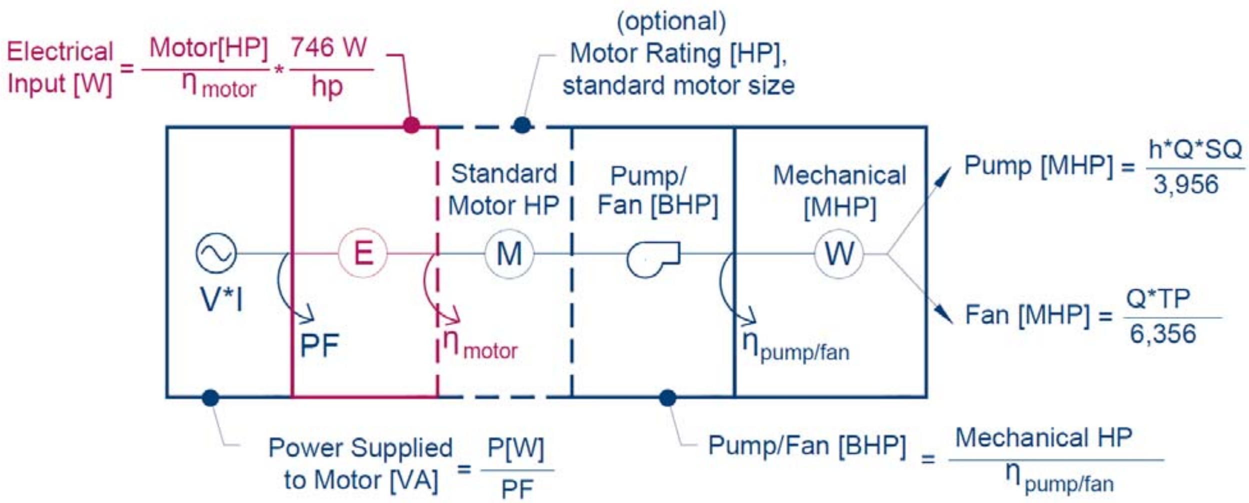


Figure 41: Determining (Real) Electrical Input Power

<u>4) Determine Electrical Power</u>. In order provide power to the motor, electrical wiring is connected to the motor from a power source. This power source provides the necessary current at the correct voltage of the motor. However, as mentioned in a previous section, the current and voltage supplied to the equipment is not completely in phase, so not all of the power supplied is useful (real power). The amount of electrical apparent power required is found through the use of the power factor. Apparent power is given the variable, “S” and units VA. Real power is given the variable, “P”.

$$\boldsymbol{Apparent\ Power} \rightarrow \boldsymbol{S_{supplied\ to\ motor[VA]}} = \frac{\boldsymbol{P_{electrical[W]}}}{\boldsymbol{PF}}$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

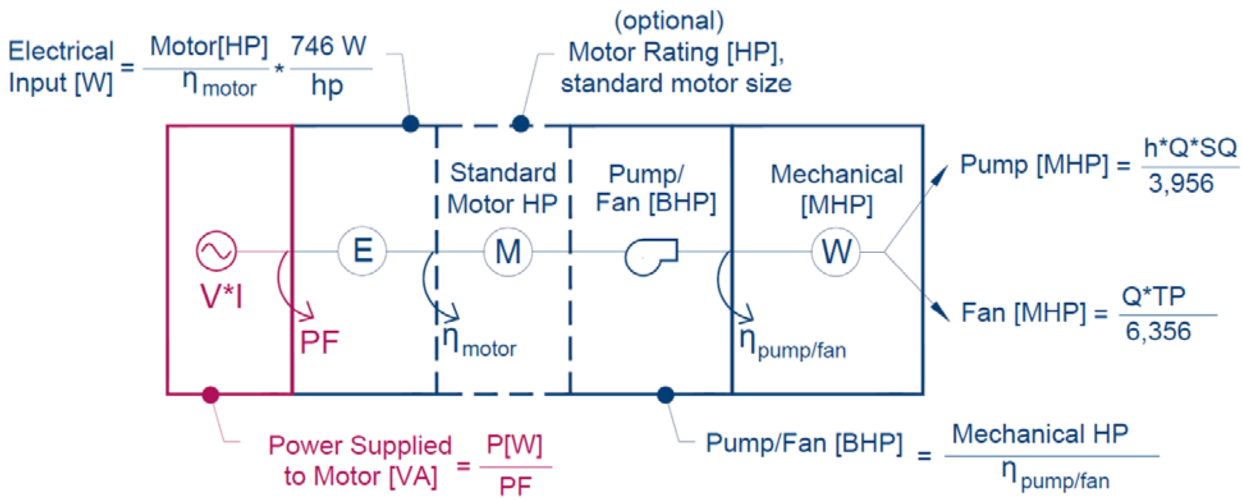


Figure 42: Determining electrical power.

In the figure above, the power supplied to the motor is shown on the left in red. The power supplied to the motor is greater than the "real" electrical input because of the power factor term. Not all of the power supplied to the motor is useful, thus additional power must be provided. The actual power supplied to the motor is found by dividing the electrical input by the power factor in order to get the apparent power value.

The electrical amperage can be determined from the following equations, depending on whether or not the problem indicates you have a 3-phase or 1-phase motor.

$$1 - Phase\ Motor \rightarrow S\ (VA) = \frac{P(W)}{PF} = Amperage\ (A) * Voltage(V)$$

$$3 - Phase\ Motor \rightarrow S\ (VA) = \frac{P(W)}{PF} = Amperage\ (A) * Voltage(V) * \sqrt{3}$$

6.6 Motor Ratings

For the purposes of the PE exam, you should be familiar with the following different motor ratings, (1) Horsepower ratings and (2) Enclosure ratings. There are other ways that motors are rated but those ratings are geared towards the Electrical Power PE exam and are not relevant to the Thermal & Fluids PE exam.

First, motors are provided at standard horsepower values. Motors are not provided at any horsepower value. Thus if a problem asks you to select a motor that meets a certain set of requirements, then the possible answers will only have the standard horsepower values and you must select the size that can meet the requirements without going excessively over the requirement. For example, if you find out that you need 4.5 HP, then you would select the 5 HP

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

motor and not the 3 HP or 7.5 HP motors. The following table shows all the standard horsepower motor values.

1 Phase Motor Horsepower Table			
1/6 HP	1/2 HP	1-1/2 HP	5 HP
1/4 HP	3/4 HP	2 HP	
1/3 HP	1 HP	3 HP	

3 Phase Motor Horsepower Table			
½ HP	7.5 HP	40 HP	150 HP
¾ HP	10 HP	50 HP	200 HP
1 HP	15 HP	60 HP	250 HP
2 HP	20 HP	75 HP	
3 HP	25 HP	100 HP	
5 HP	30 HP	125 HP	

Secondly, mechanical engineers must be able to select a motor enclosure that best suits the environmental conditions. For example, if a motor will be located outside in a corrosive environment then you may want to install a NEMA 4X enclosure. If the motor is in a location with flammable fumes, then you may be required to install an explosion proof enclosure. The motor enclosures are rated in accordance with NEMA standards as shown in the link below. NEMA stands for National Electrical Manufacturers Association. The most common types of enclosures are open drip proof and totally enclosed fan cooled. These descriptions correspond to the following NEMA classifications as shown in the table below.

NEMA Type	**Description**
Type 1	General purpose indoor
Type 2	Drip-proof indoor
Type 3	Dust tight, rain tight, ice resistant, outdoor
Type 3R	Rain proof, ice resistant, outdoor
Type 3S	Dust tight, rain tight, ice proof, outdoor
Type 4	Watertight and dust tight, indoor or outdoor
Type 4X	Watertight, dust tight, corrosion resistant, indoor and outdoor
Type 6	Submersible, Dust tight, rain tight, ice resistant, outdoor
Type 7	Class 1, Group A, B, C, D, indoor hazardous location, air break
Type 8	Class 1, Group A, B, C, D, indoor hazardous location, oil immersed
Type 9	Class 2, Group E, F, G, indoor hazardous location, air break

Link: http://www.nema.org/Products/Documents/nema-enclosure-types.pdf

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

6.7 MECHANICAL EQUIPMENT HEAT OUTPUT

The NCEES outline indicates the final topic under electrical concepts is motor heat output. This topic is covered under Heating/Cooling Loads. The basic concept to understand for this topic is that power is supplied to a motor, which is ultimately converted to mechanical power in the form of moving air or water. Along the way, the power supplied is lost due to inefficiencies that result in heat. In addition, the Heating/Cooling Loads will classify this heat further depending on whether or not the heat is seen by the air conditioning system. For example, if the motor is located in a non-air conditioned space, then the heat at the motor will not be seen by the air conditioned space. However, if the fan that is powered by the motor is located in an air conditioned space, then the heat output at the fan will be seen by the air conditioning system. The inefficiencies at the motor will cause heat that will not be seen by the air conditioning system, but the inefficiencies at the fan will cause heat that will be seen by the air conditioning system.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

7.0 PRACTICE PROBLEMS

7.1 PROBLEM 1 - ECONOMICS

Background: A client is contemplating on purchasing a new high efficiency pump and motor, with an initial cost of $10,000. The pump has a lifetime of 15 years and is estimated to save approximately $1,000 per year. There is an additional maintenance cost of $300 per year associated with this new pump. The pump will have a salvage value of $0 at the end of its lifetime. Assume the interest rate is 4%.

Problem: What is the annual value of the pump?

(a) -$499

(b) -$199

(c) $199

(d) $499

7.2 PROBLEM 2 - ECONOMICS

Background: A client is contemplating between two separate turbines. Turbine 1 has a life of 25 years, an initial cost of $50,000, an ongoing maintenance/electricity cost totaling $1,000 per year. Turbine 2 has a life of 25 years, an initial cost of $35,000 and an ongoing maintenance/electricity cost totaling $1,500 per year. Assume interest rate is equal to 4%.

Problem: What is the present worth of the two turbines?

(a) Turbine 1 = -$91,646 ; Turbine 2 = -$116, 866

(b) Turbine 1 = -$65,622 ; Turbine 2 = -$58,433

(c) Turbine 1 = $65,622 ; Turbine 2 = $58,433

(d) Turbine 1 = $91,646 ; Turbine 2 = $116,866

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

7.3 PROBLEM 3 - ECONOMICS

Background: An existing A/C control system is inefficient and you are researching whether or not to replace system. You develop a new system that will cost $30,000 and require an ongoing maintenance of $1,000 per year, but it will save $4,000 per year in energy savings. The new A/C control system will have a lifetime of 30 years.

Problem: If the minimum rate of return is 8%, what will be the annual cost of the new system? Economically, should the new system be installed?

(a) -$665, Yes, it provides a negative annual cost at the minimum rate of return.

(b) -$335, No it provides a negative annual cost at the minimum rate of return

(c) $335, Yes, it provides a positive annual cost at the minimum rate of return.

(d) $665, No, it provides a positive annual cost at the minimum rate of return.

7.4 PROBLEM 4 - ECONOMICS

Background: A new high efficiency chiller with a lifetime is planned on being purchased. It has an initial cost of $200,000 and an ongoing maintenance cost of $2,000. However, this chiller will provide an energy savings of $10,000 per year. The chiller has a lifetime of 25 years and the minimum attractive rate of return is 4%. At the end of its lifetime, the chiller will have a salvage value of $25,000.

Problem: What is the annual cost of the chiller at the minimum attractive rate of return? What is the simple payback?

(a) -$8,210, 25 years

(b) -$4,202, 25 years

(c) -$4,202, 20 years

(d) -$2,820, 20 years

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

7.5 PROBLEM 5 - ECONOMICS

Background: A new boiler is planned on being purchased. It has an initial cost of $10,000 and an ongoing maintenance cost of $500 per year. This new boiler is much more efficient than the existing boiler and will have a yearly energy savings of a$1,500 per year. The boiler has a lifetime of 15 years and the minimum attractive rate of return is 5%. At the end of its lifetime, the boiler will have a salvage value of $1,000.

Problem: What is the present value of the boiler at the minimum attractive rate of return?

(a) -$860

(b) -$380

(c) $380

(d) $860

7.6 PROBLEM 6 – UNIT CONVERSIONS

Background: A boiler is sized at 10 boiler horsepower. The input to the boiler is 10 boiler horsepower. It is found that the boiler outputs 300,000 BTU/H of heat to produce steam.

Problem: The efficiency of the boiler is most nearly?

(a) 79%

(b) 81%

(c) 84%

(d) 89%

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

7.7 Problem 7 - Electrical

Background: A 460 V, 1 phase, 60 HZ, 20 BHP pump. The motor has an efficiency of 75%. There is a power factor of 0.85.

Problem: What is the current in amperes supplied to the motor?

(a) 29

(b) -38

(c) 44

(d) 51

7.8 Problem 8 - Electrical

Background: A 10 BHP fan operates for 4000 hours in the year. The motor is 85% efficient and the power factor is 0.85. Energy cost is $0.25 per kilowatt-hour.

Problem: How much does it cost to operate the fan in one year?

(a) $7,460

(b) $8,770

(c) $10,320

(d) $12,140

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

7.9 Problem 9 - Electrical

Background: A new electrical circuit has 3 resistors in series. Each resistor has a resistance of 4 Ω. The circuit is powered by a 12 V battery.

Problem: What is the current through the circuit?

(a) 0.5 amps

(b) 1.0 amps

(c) 2.0 amps

(d) 3.0 amps

7.10 Problem 10 - Electrical

Background: A new electrical circuit has 2 resistors in parallel. One resistor has a resistance of 4 Ω. The resistance of the other resistor is unknown. The circuit is powered by a 12 V battery.

Problem: If the total current through the circuit is 8 amps, what is the resistance of the 2^{nd} resistor?

(a) 1.2

(b) 1.6

(c) 2.0

(d) 2.4

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

7.11 Problem 11 - Electrical

Background: You are sizing a fan to deliver 500 CFM at a static pressure of 2.0 in wg. The fan efficiency is 85% and the motor efficiency is also 85%.

Problem: What is most nearly the input size of the motor?

(a) ¼ HP

(b) ½ HP

(c) 1 HP

(d) 1.5 HP

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

8.0 Solutions

8.1 Solution 1 - Economics

Background: A client is contemplating on purchasing a new high efficiency pump and motor, with an initial cost of $10,000. The pump has a lifetime of 15 years and is estimated to save approximately $1,000 per year. There is an additional maintenance cost of $300 per year associated with this new pump. The pump will have a salvage value of $0 at the end of its lifetime. Assume the interest rate is 4%.

Problem: What is the annual value of the pump?

First convert all terms to annual values. Maintenance cost and cost savings are already annual values.

$$A_{maint} = -\$300; \ A_{savings} = \$1{,}000$$

Convert initial cost (present value) to annual value.

$$A_{initial\ cost} = -\$10{,}000 * (\frac{A}{P}, 4\%, 15)$$

Refer to 1.6 Economics Analysis in the NCEES Mechanical PE Reference Handbook for the corresponding value.

$$A_{initial\ cost} = -\$10{,}000 * (.0899)$$

$$A_{total} = A_{maint} + A_{savings} + A_{initial\ cost}$$

$$A_{total} = -\$300 + \$1{,}000 - \$899$$

$$A_{total} = -\$199$$

The correct answer is most nearly, (b) -$199.

(a) -$499

(b) -$199

(c) $199

(d) $499

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

8.2 SOLUTION 2 - ECONOMICS

Background: A client is contemplating between two separate turbines. Turbine 1 has a life of 25 years, an initial cost of $50,000, an ongoing maintenance/electricity cost totaling $1,000 per year. Turbine 2 has a life of 25 years, an initial cost of $35,000 and an ongoing maintenance/electricity cost totaling $1,500 per year. Assume interest rate is equal to 4%.

Problem: What is the present worth of the two turbines?

First convert all terms to present worth, Turbine 1.

$$P_{turbine\ 1} = P_{initial\ cost} + A_{maint/elec} * (\frac{P}{A}, 4\%, 25)$$

$$P_{turbine\ 1} = -\$50{,}000 - \$1{,}000 * 15.6221$$

$$P_{turbine\ 1} = -\$65{,}622$$

Second convert all terms to present worth, Turbine 2.

$$P_{turbine\ 2} = P_{initial\ cost} + A_{maint/elec} * (\frac{P}{A}, 4\%, 25)$$

$$P_{turbine\ 2} = -\$35{,}000 - \$1{,}500 * 15.6221$$

$$P_{turbine\ 2} = -\$58{,}433$$

The correct answer is most nearly, (b) Turbine 1 = -$65,622; Turbine 2 = -$58,433.

(a) Turbine 1 = -$91,646; Turbine 2 = -$116, 866

(b) Turbine 1 = -$65,622; Turbine 2 = -$58,433

(c) Turbine 1 = $65,622; Turbine 2 = $58,433

(d) Turbine 1 = $91,646; Turbine 2 = $116,866

8.3 SOLUTION 3 - ECONOMICS

Background: An existing A/C control system is inefficient and you are researching whether or not to replace system. You develop a new system that will cost $30,000 and require an ongoing maintenance of $1,000 per year, but it will save $4,000 per year in energy savings. The new A/C control system will have a lifetime of 30 years.

Problem: If the minimum rate of return is 8%, what will be the annual cost of the new system? Economically, should the new system be installed?

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

First convert all terms to annual values. Maintenance cost and energy savings are already annual values.

$$A_{maint} = -\$1{,}000; \; A_{savings} = \$4{,}000$$

Convert initial cost (present value) to annual value.

$$A_{initial\ cost} = -\$30{,}000 * (\frac{A}{P}, 8\%, 30)$$

Refer to 1.6 Economics Analysis in the NCEES Mechanical PE Reference Handbook for the corresponding value.

$$A_{initial\ cost} = -\$30{,}000 * (.08883)$$

$$A_{total} = A_{maint} + A_{savings} + A_{initial\ cost}$$

$$A_{total} = \$4{,}000 - \$1{,}000 - \$2{,}664.90$$

$$A_{total} = \$335$$

The correct answer is most nearly, (c) $335; yes, it provides a positive annual cost at the minimum rate of return.

(a) -$665, Yes, it provides a negative annual cost at the minimum rate of return.

(b) -$335, No it provides a negative annual cost at the minimum rate of return

(c) $335, Yes, it provides a positive annual cost at the minimum rate of return.

(d) $665, No, it provides a positive annual cost at the minimum rate of return.

8.4 SOLUTION 4 - ECONOMICS

Background: A new high efficiency chiller with a lifetime is planned on being purchased. It has an initial cost of $200,000 and an ongoing maintenance cost of $2,000. However, this chiller will provide an energy savings of $10,000 per year. The chiller has a lifetime of 25 years and the minimum attractive rate of return is 4%. At the end of its lifetime, the chiller will have a salvage value of $25,000.

Problem: What is the annual cost of the chiller at the minimum attractive rate of return? What is the simple payback?

First convert all terms to annual values. Maintenance cost and energy savings are already annual values.

$$A_{maint} = -\$2{,}000; \; A_{savings} = \$10{,}000$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Convert initial cost (present value) and salvage value (future) to annual value.

$$A_{initial\ cost} = -\$200{,}000 * (\frac{A}{P}, 4\%, 25)$$

Please refer to 1.6.2 Economics Factor Tables for the value corresponding to the 4% interest rate tables, A/P column and n=25 row.

$$A_{initial\ cost} = -\$200{,}000 * (.06401)$$

$$A_{salvage\ value} = \$25{,}000 * (\frac{A}{F}, 4\%, 25)$$

$$A_{salvage\ value} = \$25{,}000 * (.02401)$$

$$A_{total} = A_{maint} + A_{savings} + A_{salvage\ value} + A_{initial\ cost}$$

$$A_{total} = -\$2{,}000 + \$10{,}0000 + 600.25 - \$12{,}802$$

$$A_{total} = \$ - 4{,}202$$

$$Simple\ Pay\ Back = \frac{initial\ cost}{yearly\ gain} = \frac{\$200{,}000}{\$10{,}000 - \$2{,}000} = 25\ years$$

The correct answer is most nearly, (b) $-4,202; 25 years.

(a) -$8,210, 25 years

(b) -$4,202, 25 years

(c) -$4,202, 20 years

(d) -$2,820, 20 years

8.5 Solution 5 - Economics

Background: A new boiler is planned on being purchased. It has an initial cost of $10,000 and an ongoing maintenance cost of $500 per year. This new boiler is much more efficient than the existing boiler and will have a yearly energy savings of a $1,500 per year. The boiler has a lifetime of 15 years and the minimum attractive rate of return is 5%. At the end of its lifetime, the boiler will have a salvage value of $1,000.

Problem: What is the present value of the boiler at the minimum attractive rate of return?

First convert all terms to present value.

Maintenance cost and energy savings can be combined and converted to present value.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$A_{maint} = -\$500;\ A_{savings} = \$1{,}500$$

$$P_{maint/savings} = \$1{,}000 * (\frac{P}{A}, 5\%, 15)$$

$$P_{maint/savings} = \$1{,}000 * (10.3797) = \$10{,}380$$

Convert salvage value (future value) to present value.

$$P_{salvage\ value} = \$1{,}000 * (\frac{P}{F}, 5\%, 15)$$

$$P_{salvage\ value} = \$1{,}000 * (0.4810) = \$481$$

$$P_{initial\ cost} = -\$10{,}000$$

$$P_{total} = P_{maint/savings} + P_{salvage\ value} + P_{initial\ cost}$$

$$P_{total} = \$10{,}380 + 481 - \$10{,}000$$

$$P_{total} = \$861$$

The correct answer is most nearly, (d) $860.

(a) -$860

(b) -$380

(c) $380

(d) $860

8.6 SOLUTION 6 – UNIT CONVERSIONS

Background: A boiler is sized at 10 boiler horsepower. The input to the boiler is 10 boiler horsepower. It is found that the boiler outputs 300,000 BTU/H of heat to produce steam.

Problem: The efficiency of the boiler is most nearly?

First convert boiler horsepower to BTU/H by using the unit conversions presented in the NCEES Mechanical PE Reference Handbook, 1.1 Engineering Terms and Symbols.

$$1\ boiler\ horsepower = 33{,}479\ Btu/h$$

$$10\ boiler\ horsepower * 33{,}479 = 334{,}790\ Btu/h$$

There are other boiler efficiency equations, but in this example problem the simplest efficiency is found, which is just output energy divided by input energy.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$Efficiency = \frac{output}{input}$$

$$Efficiency = \frac{300{,}000\ Btu/h}{334{,}790\ Btu/h} = 89.6\%$$

The correct answer is most nearly, (d) 89%.

(a) 79%

(b) 81%

(c) 84%

(d) 89%

8.7 Solution 7 - Electrical

Background: A 460 V, 1 phase, 60 HZ, 20 BHP pump. The motor has an efficiency of 75%. There is a power factor of 0.85.

Problem: What is the current in amperes supplied to the motor?

The brake horse power shown is the output of the motor (input to the pump). You need to use the motor efficiency to find the electricity input to the motor.

$$P_{motor[HP]} = \frac{P_{pump[BHP]}}{\varepsilon_{motor}}$$

$$P_{motor[HP]} = \frac{20\ BHP}{0.75} = 26.7\ HP$$

The motor input is the electricity provided, but this electricity is only the real power. You need to use the power factor to find the apparent power.

$$S_{apparent\ power} = \frac{P_{motor[HP]}}{PF} = \frac{26.7\ HP}{0.85} = 31.4\ HP$$

Once you have the apparent power, you can then solve for current. Make sure you confirm whether or not you have a single phase or three phase motor.

$$P_{supplied\ to\ motor,watts} = I * V$$

Make sure to convert horsepower to watts.

$$P_{supplied\ to\ motor,watts} = 31.4\ HP * \frac{0.7457\ KW}{HP} * \frac{1000\ volt - amperes}{KW} = 23{,}395\ VA$$

$$23{,}395\ VA = I * 460\ V$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

$$50.9\ amps = I$$

The correct answer is most nearly, (d) 51 Amperes.

(a) 29

(b) -38

(c) 44

(d) 51

8.8 SOLUTION 8 - ELECTRICAL

Background: A 10 BHP fan operates for 4000 hours in the year. The motor is 85% efficient and the power factor is 0.85. Energy cost is $0.25 per kilowatt-hour.

Problem: How much does it cost to operate the fan in one year?

The brake horse power shown is the output of the motor. You need to use the motor efficiency to find the electricity input to the motor.

$$P_{motor[HP]} = \frac{P_{pump[BHP]}}{\varepsilon_{motor}}$$

$$P_{motor[HP]} = \frac{10\ BHP}{0.85} = 11.8\ HP$$

$$11.8\ HP * \frac{0.7457\ KW}{HP} * 4{,}000 \frac{hrs}{year} = 35{,}197\ kwh$$

Find the cost ($) with the electricity cost.

$$35{,}197\ kwh * \frac{\$0.25}{kwh} = \$8{,}799$$

The correct answer is most nearly, (b), $8,770

(a) $7,460

(b) $8,770

(c) $10,320

(d) $12,140

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

8.9 SOLUTION 9 - ELECTRICAL

Background: A new electrical circuit has 3 resistors in series. Each resistor has a resistance of 4 Ω. The circuit is powered by a 12 V battery.

Problem: What is the current through the circuit?

$$R_{eq,series} = 4 + 4 + 4 = 12$$

$$I = \frac{12}{12} = 1\ amp$$

The correct answer is most nearly, (b) 1 amp.

(a) 0.5 amps

(b) 1.0 amps

(c) 2.0 amps

(d) 3.0 amps

8.10 SOLUTION 10 - ELECTRICAL

Background: A new electrical circuit has 2 resistors in parallel. One resistor has a resistance of 4 Ω. The resistance of the other resistor is unknown. The circuit is powered by a 12 V battery.

Problem: If the total current through the circuit is 8 amps, what is the resistance of the 2nd resistor?

Determine the current through the 1st resistor.

$$I = \frac{12}{4} = 3\ amp$$

Determine the current through the 2nd resistor.

$$Total\ current - current\ through\ 1st\ resistor = current\ through\ 2nd\ resistor$$

$$8\ amps - 3\ amps = 5\ amps$$

Determine the resistance of the 2nd resistor.

$$R = \frac{12}{5} = 2.4$$

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

The correct answer is most nearly, (d) 2.4 Ω.

(a) 1.2

(b) 1.6

(c) 2.0

(d) 2.4

8.11 Solution 11 - Electrical

Background: You are sizing a fan to deliver 500 CFM at a static pressure of 2.0 in wg. The fan efficiency is 85% and the motor efficiency is also 85%.

Problem: What is most nearly the input size of the motor?

Find fan mechanical power through the Fan Power equation presented in 9.3.8 Fans.

$$P_{fan[MHP]} = \frac{CFM * SP}{6356} = \frac{500 * 2}{6356} = 0.16\ MHP$$

Convert fan mechanical horsepower to fan brake horsepower. The fan mechanical horsepower is the output of the fan. The fan brake horsepower is the input power to the fan.

$$P_{fan[BHP]} = \frac{P_{fan[MHP]}}{\varepsilon_{fan}} = \frac{0.16}{.85} = 0.19\ BHP$$

The input power to the fan is also equal to the motor output. Use the motor efficiency to find the motor input (electricity).

$$P_{motor[HP]} = \frac{P_{pump[BHP]}}{\varepsilon_{motor}} = \frac{0.19}{.85} = 0.22\ HP$$

The correct answer is most nearly, (a) .25 HP.

(a) ¼ HP

(b) ½ HP

(c) 1 HP

(d) 1.5 HP

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

3 – Fluid Mechanics

Fluid Properties (e.g., density, viscosity) | Compressible Flow (e.g., Mach number, nozzles, diffusers) | Incompressible Flow (e.g., friction factor, Reynolds number, lift, drag) |

TEXTBOOK
www.engproguides.com

Section 3.0 – Fluid Mechanics

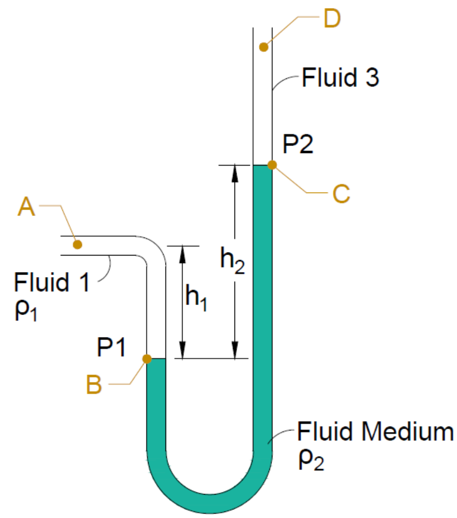
Table of Contents

1.0 INTRODUCTION

Fluid Mechanics accounts for approximately 5-8 questions on the Thermal & Fluids Mechanical PE Exam. These questions can cover fluid properties, compressible flow, incompressible flow, friction loss, etc. Fluid properties describe the density, viscosity, kinematic viscosity, specific gravity and much more. Other properties are described in other sections of this book. In order to be prepared for questions on Fluid properties you need to understand what these properties describe, its units and where to find the properties of common fluids. Finally in this section you need to understand the difference between compressible and incompressible flow and when you can use compressible equations versus incompressible equations. The majority of the exam, which basically includes all sections in this book except for the compressible flow section, will assume incompressible flow.

2.0 FLUID PROPERTIES

During the exam you will need to be able to find and use fluid properties to complete many problems. You should be very familiar with the NCEES Mechanical PE Reference Handbook and where to find these fluid properties. As you go through these descriptions of the important fluid properties, look through your NCEES Mechanical PE Reference Handbook. Tag the locations that contain these properties and be mindful of the units. You should be able to quickly find air properties for various temperatures, water properties, steam properties and ideal gas properties (nitrogen, oxygen, etc.). *The key is to not waste time looking for fluid properties and to not make mistakes when solving a problem due to incorrect units.*



In the figure above, use the equation, ΔP=ρgh to calculate pressure changes from one point to another. Starting from point A and traveling to point B of the tube. Using the density of fluid 1, the pressure difference from point A to point B can be calculated.

$$P_B = P_A + \rho_1 g h_1$$

Notice that the height at point B is lower than point A, so the pressure will be greater at point B and therefore the pressure shall be added. Now, traveling up from point B to point C, the pressure at point C can be found as the following.

$$P_C = P_A + \rho_1 g h_1 - \rho_2 g h_2$$

If fluid 3 is air exposed to atmosphere, then fluid 3 and therefore point C and D have a pressure of 14.7psia. The pressure at point A becomes the following.

$$P_A = 14.7psia + \rho_2 g h_2 - \rho_1 g h_1$$

Manometers can have various configurations, but the principals behind the calculation are the same. Start at one point and add or subtract the pressures based on the vertical height difference of the fluid multiplied by the fluid density and gravity.

4.3 FORCES ON SUBMERGED SURFACES (LIQUIDS)

The following topic discusses how to find the resultant force due to the pressures of a fluid when a flat plat is submerged. The first concept to understand is that the fluid creates a pressure gradient along the plate, which linearly increases as the depth of the submergence, y increases. See the figure below for an illustration of the pressure gradient along a flat plate.

5.3.2 Converging-Diverging Nozzle

A more complex, converging-diverging nozzle consists of a converging portion that is used to raise the pressure of the fluid and then a throat section, followed by a diverging section. The diverging section is a location of low pressure and in application the fluid in the diverging section is typically released into ambient conditions or a tank.

The pressure in the chamber is the starting point of the fluid. At the chamber, the fluid is at a certain pressure, temperature and density and is labeled with the subscript *"o"*. The chamber in reality can be a tank, pipe or any vessel that is much larger than the nozzle.

The velocity through the nozzle is controlled by the pressure difference between the chamber and the ambient conditions. If the pressure in the chamber is increased then the velocity through the nozzle will be increased, but up to a certain point. This point is Mach 1. Once the fluid reaches this point, any increase in the chamber pressure, will not result in an increased velocity through the nozzle, because the fluid is choked at the nozzle.

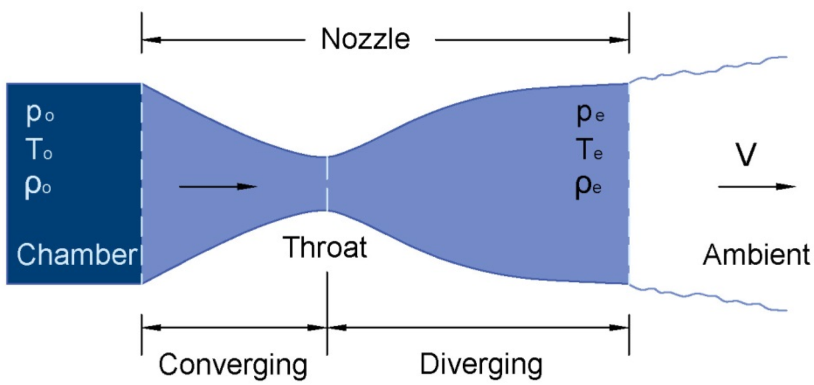


Figure 15: Converging diverging nozzle

5.4 DIFFUSERS

Diffusers are the opposite of nozzles. Diffusers decrease the pressure of the fluid by reducing the velocity.

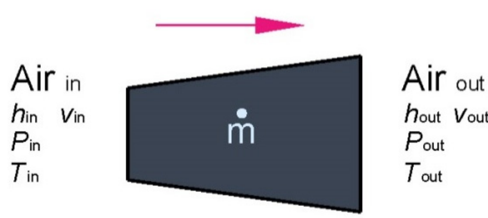


Figure 16: A diffuser decreases the velocity, decreases velocity pressure and thus increases the static pressure of the fluid.

On the exam, use the same equations to solve diffuser problems as you would for nozzle problems.

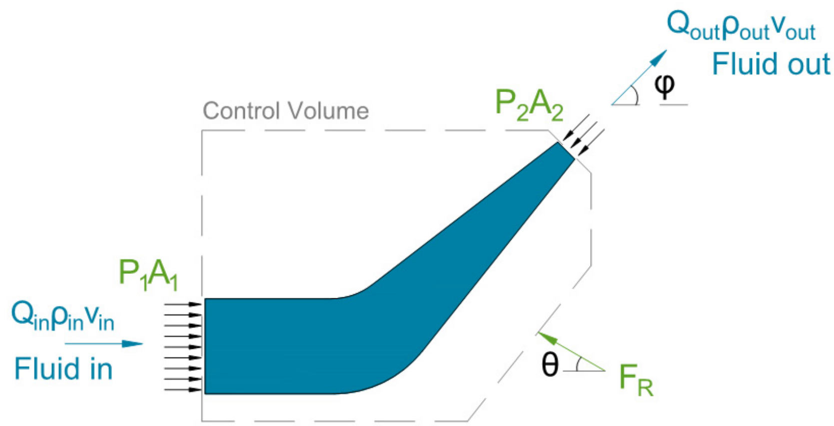
Copyright © 2022 Engineering Pro Guides, LLC. Licensed for individual use only.

In the equation above, Q is the volumetric flow rate (m^3/s or ft^3/s), ρ is the density (kg/m^3 or $(lbm/ft^3)/g_c$), and v is the velocity (m/s or ft/s). The equation can also be represented in terms of mass flow rate, $\dot{m}$ (kg/s or $(lbm/s)/g_c$). *Remember that density or mass in terms of lbm in English units need to be divided by g_c in order to convert the units to lbf.*

$$\sum F_{ext} = \sum \dot{m}_{out} v_{out} - \sum \dot{m}_{in} v_{in}$$

In these problems, break out the forces and momentum equations into each coordinate and solve for the resultant forces.

Example: Water enters a reducing elbow that diverts the incoming fluid by angle φ. Find the reactive force acting on the elbow in order to keep it from moving.



To solve this problem, a control volume is taken around the elbow as shown above. The sum of all the forces acting on the control volume will equal the momentum entering and leaving the elbow. The force on the intake is found from the pressure acting on the intake of the control volume, which is positive, and the pressure on the outlet is found from the pressure acting on the outlet of the control volume, which is negative. The force from the pressure is equal to the pressure multiplied by the area that the pressure is acting on. Therefore the sum of the external forces can be calculated below

$$\sum F_{external} = P_1 A_1 - P_2 A_2 - F_R$$

Then equating the external forces to the difference in momentum gives the following.

$$P_1 A_1 - P_2 A_2 - F_R = Q_{out} \rho_{out} v_{out} - Q_{in} \rho_{in} v_{in}$$

To solve the problem, separate the equation into x, y components.

X-Component:

$$P_1 A_1 - P_2 A_2 \cos\varphi - F_{R,x} = Q_{out} \rho_{out} (v_{out} \cos\varphi) - Q_{in} \rho_{in} v_{in}$$

8.0 PRACTICE PROBLEMS

8.1 PROBLEM 1 - REYNOLDS NUMBER

A fluid has is traveling at a velocity of 8 ft/sec through a 6" pipe. The fluid has a density of 60 lb/ft^3 and has a kinematic viscosity of 1.5×10^{-5} ft^2/sec. What is the Reynolds number?

The Reynolds number is most nearly,

(a) 270,000

(b) 540,000

(c) 1,115,000

(d) 3,200,000

8.2 PROBLEM 2 - MACH NUMBER

An object is moving at a velocity of 738 ft/sec through air. The conditions of air are 0.5 atmospheres and -70 °F. What is the Mach number?

The Mach number is most nearly,

(a) 0.5

(b) 0.75

(c) 1.0

(d) 1.25

9.0 SOLUTIONS

9.1 SOLUTION 1 - REYNOLDS NUMBER

A fluid has is traveling at a velocity of 8 ft/sec through a 6" pipe. The fluid has a density of 60 lb/ft^3 and has a kinematic viscosity of 1.5 x 10^{-5} ft^2/sec. What is the Reynolds number?

$$Re = \frac{V * D}{\upsilon}$$

$$V = \frac{ft}{sec}; D = diameter\ (ft); \upsilon = kinematic\ viscosity\ (\frac{ft^2}{\sec})$$

$$Re = \frac{8\frac{ft}{sec} * \frac{6\ in}{12\frac{in}{ft}}}{1.5 * 10^{-5}\frac{ft^2}{sec}}$$

$$Re = 266{,}667$$

The correct answer is most nearly (a) 270,000

(a) 270,000

(b) 540,000

(c) 1,115,000

(d) 3,200,000

9.2 SOLUTION 2 - MACH NUMBER

An object is moving at a velocity of 738 ft/sec through air. The conditions of air are 0.5 atmospheres and -70 °F. What is the Mach number?

$$M = V/\sqrt{k * g_c * R * T}$$

$$k = 1.4\ for\ air; g_c = 32.2\frac{ft * lbm}{lbf * sec^2};$$

$$R = 1545.3\ \frac{ft * lbf}{lbmol * R}; from\ MERM$$

$$Need\ to\ remove\ the\ lbmol\ term\ with\ the\ molar\ mass\ of\ air, 29\frac{lbm}{lbmol};$$

$$R = 1545.3\ \frac{ft * lbf}{lbmol * R} \div 29\frac{lbm}{lbmol} = 53.3\frac{ft * lbf}{lbm * R}$$

4 – Heat Transfer Principles

Conduction | Convection | Radiation

TEXTBOOK
www.engproguides.com

Section 4.0 – Heat Transfer Principles

Table of Contents

1.0 INTRODUCTION

Heat Transfer accounts for approximately 5-8 questions on the Thermal & Fluids Mechanical PE exam.

The heat transfer principles tested on the Thermal & Fluids exam are used throughout other sections of the exam, specifically in heat exchangers, cooling/heating cycles and distribution systems. There are three main types of heat transfer: conduction, convection and radiation. Conduction is the transfer of heat through contact. In this type of heat transfer, common skills needed include finding overall heat transfer coefficients, finding insulation values and temperature transitions through materials. Convection is the transfer of heat through a moving fluid. This is most commonly seen in heat exchangers as moving hot fluids transfer heat to cool fluids. The main skill needed in this area include finding the convective heat transfer coefficient.

The final type is radiation, which will require finding the radiative heat transfer coefficient and finding the temperature difference between two objects.

2.0 Conduction

Conduction is the method of heat transfer through material(s) in physical contact. The driving force in conduction is a temperature difference on either side of the material(s). For example, if the end of a metal rod is placed in a fire, heat will be conducted through the metal rod to the other end. In the Thermal & Fluids field, heat transfer due to conduction is most commonly calculated through equipment insulation or through heat exchanger materials. However, it is easier to visualize heat transfer through a building wall or roof. The formula for calculating heat transfer due to conduction through a uniform material is as follows:

$$Q_{cond,flat\ plate} = \frac{k * A * (T_{hot} - T_{cold})}{t}$$

$$where\ Q_{cond,flat\ plate} = quantity\ of\ heat\ transfered\ through\ flat\ surface\ \left[\frac{Btu}{hr}\right]$$

$$k = thermal\ conductivity\ of\ material\ \left[\frac{Btu}{hr * ft * °F}\right]$$

$$T_{hot} - T_{cold} = temperature\ difference\ [°F]$$

$$t = thickness\ of\ material\ [ft];\ A = area\ of\ heat\ transferl\ [ft^2]$$

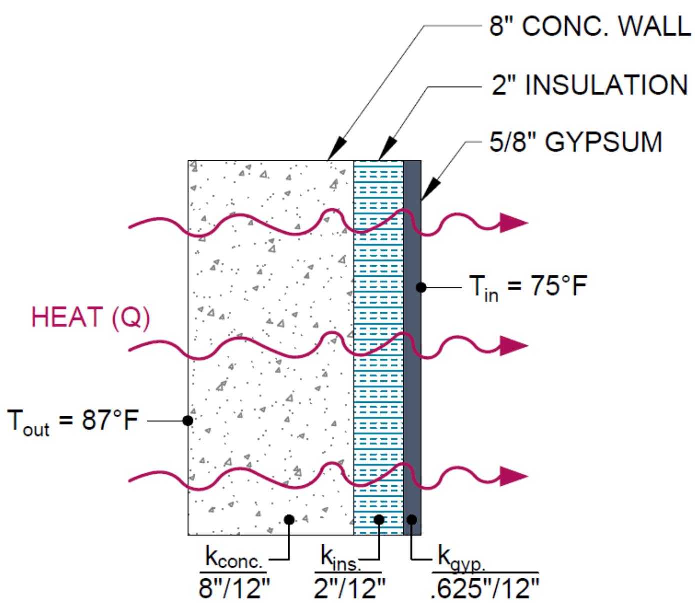


Figure 1: Conduction through a building wall

The amount of heat transferred is linearly dependent on the difference in temperature between the inside and outside surfaces of the wall. The conduction equation shows that as the temperature difference increases, the heat load also increases. The same is also true for the

The following two equations split the total heat gain into the sensible and latent heat loads.

Sensible Heat Gains are calculated by multiplying the CFM of the infiltrated air by the difference in the dry bulb temperatures of the indoor and outdoor air.

$$Q_{sensible} = 60\frac{min}{hr} * 0.075\frac{lb}{ft^3} * CFM * 0.24\left[\frac{\frac{Btu}{hr}}{lb * °F}\right] * (T_{leaving} - T_{entering})$$

$$Q_{sensible} = 1.1 * CFM * (T_{leaving} - T_{entering})$$

Latent Heat Gains are calculated by multiplying the CFM of infiltrated air by the difference in the humidity ratio of the indoor air and the outdoor air.

$$Q_{latent} = 4{,}840 * CFM * (W_{leaving} - W_{entering})$$

$$W = humidity\ ratio\ [lbm_{wet}/lbm_{dry}]$$

6.2 Water

The sensible heat equation (no phase change) shows power as a function of temperature and water flow rate. The constant at the beginning of the equation is typically 500 and this constant encompasses the multiplication of water density, heat capacity and the conversion from minutes to hours.

$$Q\ [Btuh] = Constant * GPM * \Delta T[°F]; Typically \rightarrow Q[Btuh] = 500 * GPM * \Delta T[°F]$$

6.3 Quick Equations

The cooling/heating equations for air and water are used to enhance your speed on the PE exam. These quick equations make some assumptions on standard air or water conditions. In order to help you to use these equations during all conditions, you can adjust the constants by understanding the origin of the constants.

Since the PE exam is now computer based testing, you will not be able to take into the exam these constants. But, you should have the most common constants memorized for the exam.

Power as a Function of Temperature for Water Equation

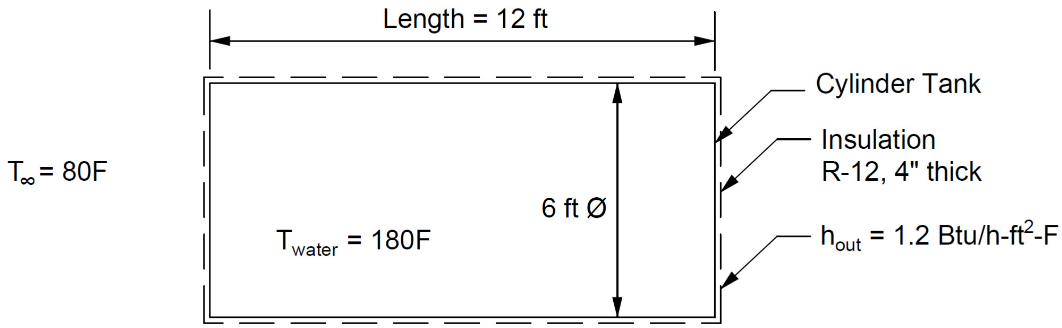
$$Q\ [Btuh] = Constant * GPM * \Delta T[°F]; Typically \rightarrow Q[Btuh] = 500 * GPM * \Delta T[°F]$$

Power as a Function of Humidity Ratio for Air Equation (version 1)

$$Q\ [Btuh] = Constant * CFM * \Delta W\left[\frac{lbm\ H_2O}{lbm\ dry\ air}\right];$$

9.5 Problem 5 - Conduction

A horizontal, cylindrical tank holds water at 180 °F. The tank is 12 ft long, has a 6 ft diameter, and is insulated by 4" thick, R-12 insulation. The tank is located in a room at 80 °F and is raised off of the ground. The tank ends are flat, assume that the heat transfer through the tank wall is negligible, and that the exterior surface coefficient is 1.2 Btu/hr-ft^2-°F. The tank is completely filled. What is the rate of heat transfer to the space? Assume no internal convective heat transfer.



(a) 2300 Btu/h

(b) 3600 Btu/h

(c) 3900 Btu/h

(d) 4200 Btu/h

9.6 Problem 6 - Convection

Which term is not applicable to calculating the convection coefficient of a forced convection fluid, regardless of the fluid viscosity and turbulence?

(a) Nusselt Number

(b) Reynolds Number

(c) Grashof Number

(d) Prandtl Number

9.7 PROBLEM 7 - PIPE RESISTANCES

A pipe has an outer diameter of 1.315 inches and an inner diameter of 1.049 inches. The thermal conductivity of the pipe material is 20 Btu/h-ft-°F. The inner convective heat transfer coefficient between the fluid within the pipe and the inner pipe walls is 150 Btu/h-ft^2-°F. The outer convective heat transfer coefficient between the outer pipe wall and ambient air is 50 Btu/h-ft^2-°F. What is the overall heat transfer coefficient per length of pipe?

(a) 12 Btu/hr-ft-°F

(b) 42 Btu/hr-ft-°F

(c) 85 Btu/hr-ft-°F

(d) 107 Btu/hr-ft-°F

9.8 PROBLEM 8 - PIPE RESISTANCES

A pipe has an outer diameter of 4.2 inches and an inner diameter of 4.0 inches. The thermal conductivity of the pipe material is 10 Btu/h-ft-°F. The inner convective heat transfer coefficient between the fluid within the pipe and the inner pipe walls is 35 Btu/h-ft^2-°F. The outer convective heat transfer coefficient between the outside insulation layer and ambient air is 5 Btu/h-ft^2-°F. The pipe has 2 inches of insulation. The insulation has a thermal conductivity of 0.05 Btu/h-ft-°F. If the temperature of the fluid within the pipe is 300 °F and the ambient air outside of the pipe is 75 °F, then what is the rate of heat transfer per foot of pipe?

(a) 105 Btu/hr

(b) 671 Btu/hr

(c) 1,743 Btu/hr

(d) 2,990 Btu/hr

5 – Mass Balance Principles

Evaporation | Dehumidification | Mixing

TEXTBOOK
www.engproguides.com

Section 5.0 – Mass Balance

Table of Contents

1.0 INTRODUCTION

Mass Balance accounts for approximately 4-6 questions on the Thermal & Fluids Mechanical PE exam.

This section focuses on the mass balance equations that govern various thermodynamic processes. These processes include evaporation, condensation and mixing. The important concept to understand is that in each process, mass of the fluid is conserved, even if the fluid is changing from gas to liquid or liquid to gas.

Condensation, evaporation and dehumidification were heavily covered in the Support Knowledge section under Psychrometrics, so this section will be relatively short.

2.0 CONSERVATION OF MASS

Conservation of mass is a law in nature and states that mass cannot be created or destroyed. Therefore, when transfers of states or changes in phases occur in a system, a mass balance equation can be created to solve for the unknown properties in a system or cycle.

Essentially, the equations are derived from the law that

$$\sum \text{mass}_{\text{in}} = \sum \text{mass}_{\text{out}}$$

Similarly the flow of mass entering the system will be equal to the flow leaving the system, like in a condenser or a boiler.

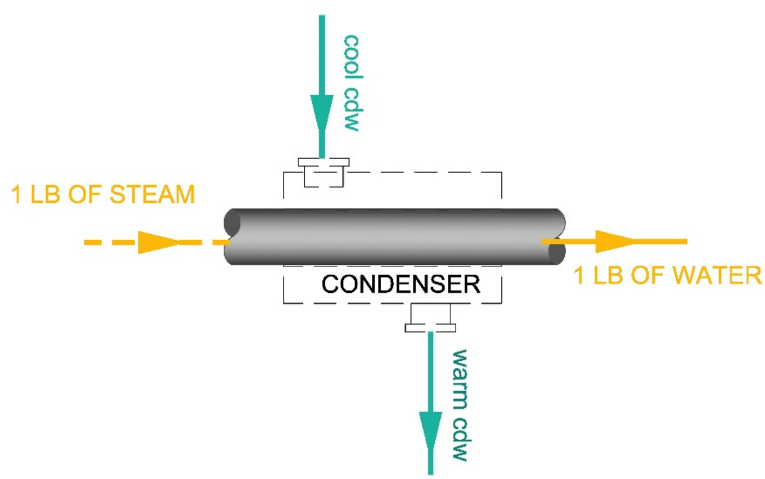


Figure 1: This figure shows one pound of steam entering a condenser and leaving as one pound of water.

8.0 Practice Problems

8.1 Problem 1 - Humidifier

Background: An evaporative humidifier works by blowing air over a wet medium, evaporating the water in the medium into the air, thereby increasing the humidity ratio of the air. This will reduce the dry bulb temperature of the air since the air lost heat to evaporate the water in the medium. For the purposes of this problem, this effect will not be taken into account.

1,000 CFM of air at 75°F DB/20% relative humidity passes through a humidifier with 8,000 Btu/h of latent heat, assume that the humidifier is 100% effective. What is the resulting state of air?

(a) 70°F DB/22.4% Relative Humidity

(b) 72°F DB/33.2% Relative Humidity

(c) 75°F DB/29.3% Relative Humidity

(d) 75°F DB/35.1% Relative Humidity

8.2 Problem 2 – Dehumidifier

Background: A desiccant dehumidifier most often has a silica gel medium, which absorbs moisture from air as it is passed over the medium. For the purposes of this problem, it is assumed that the dry bulb temperature is not affected and the dehumidifier only provides latent cooling (dehumidification).

1,000 CFM of air at 80°F DB/72°F WB passes through a de-humidifier. The dehumidifier removes 10,000 Btu/h of latent heat, assume that the de-humidifier is 100% effective. What is the resulting state of air?

(a) 80°F DB/.009 lbm H20/lbm dry air

(b) 80°F DB/.011 lbm H20/lbm dry air

(c) 80°F DB/.013 lbm H20/lbm dry air

(d) 80°F DB/.015 lbm H20/lbm dry air

6 – Thermodynamics

Thermodynamic properties (e.g., enthalpy, entropy) | Thermodynamic cycles (e.g., Combined, Brayton, Rankine) | Energy balances (e.g., 1st and 2nd laws) | Combustion (e.g., stoichiometric, efficiency)

TEXTBOOK
www.engproguides.com

Section 6.0 – Thermodynamics

Table of Contents

1.0 INTRODUCTION

Thermodynamics accounts for approximately 5-8 questions on the Thermal & Fluids Mechanical PE exam.

Thermodynamics includes the principles and transitions encountered in the gas turbine, Brayton and Rankine cycles. Also the concepts discussed in this section are used in the sections on Supportive Knowledge – Psychrometrics and Energy/Power Equipment.

You should be able to properly navigate the gas turbine cycles, Brayton (steam turbine) cycles and Rankine cycles and be able to answer questions on any part of the cycles. There are multiple variations of each cycle and you should know each variation. Each part of the cycle also corresponds to a piece of equipment, which you should also understand and learn about in this section and in the Energy/Power Equipment section. As you go through each step of each cycle, look for the energy balance equations that govern each step.

Next, most power cycles start with combustion as its heat source. So you must be familiar with a few types of questions on combustion. The heat from combustion is used to produce steam in a majority of the power cycles throughout the United States. Thus you should understand steam, its properties and be able to navigate its corresponding diagrams and tables.

Finally, the vapor compression cycle and the refrigeration cycle is a support cycle to the main power cycle that may be tested on the Thermal & Fluids exam.

2.0 THERMODYNAMICS PROPERTIES

On the exam, you should be able to find thermodynamic properties very easily through the use of your thermodynamic property tables for given fluids, located in your NCEES Mechanical PE Reference Handbook. These properties are the building blocks for solving the problems on the exam. You should also have a concept of what these properties mean in the real world. These concepts will help to reality check your answers, instead of blindly following the results of your equations. Hopefully, this helps you to catch any math errors and speeds up your elimination of incorrect multiple choice answers.

2.1 PRESSURE

Pressure is one of the two most likely properties that you will start off with in a real world situation, because pressure is a thermodynamic property that is easily measured.

The two major application areas of the open gas turbine cycle are for vehicles and electric power generation. In an open cycle the working fluid (air) only passes through the cycle once and is then exhausted to the atmosphere. In a closed cycle, the working fluid (air) is recycled through the cycle. One assumption that you should be aware of is that the mass flow rate through both the open and closed cycles are assumed to be constant. Although fuel does enter the cycle, it is assumed that the only mass flow rate to be considered in doing problems is the mass flow rate of the air. This is typically a safe assumption because the ratio of air to fuel is quite large, typically fuel can be around 2% of the total mass flow rate.

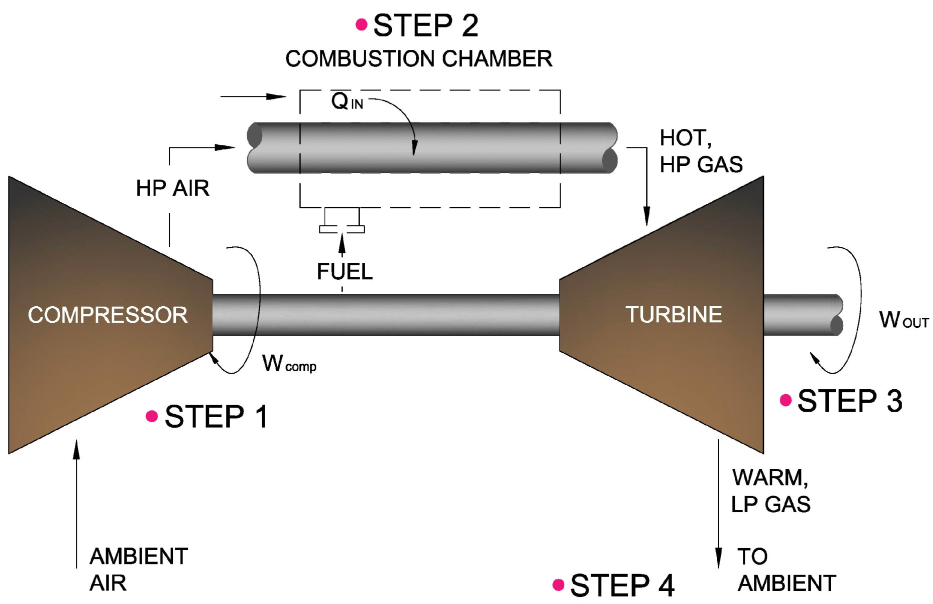


Figure 6: The above figure shows the components of an open Brayton cycle. Step 1 to 2 is the isentropic compressor. Step 2 to 3 is a constant pressure combustion chamber. Step 3 to 4 is the isentropic turbine.

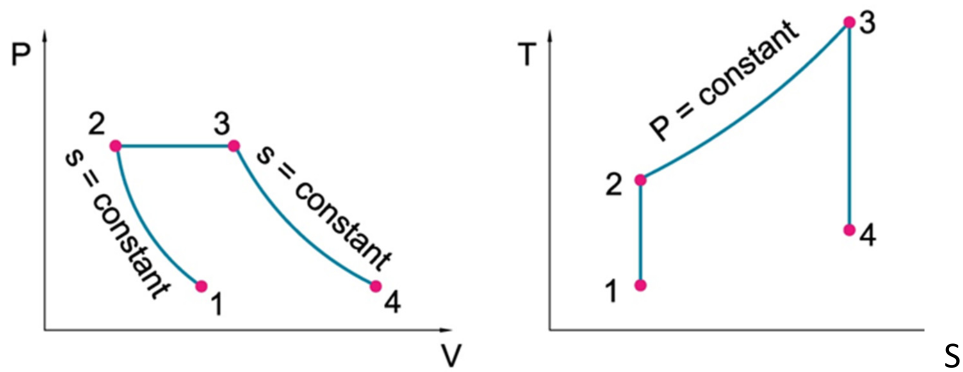
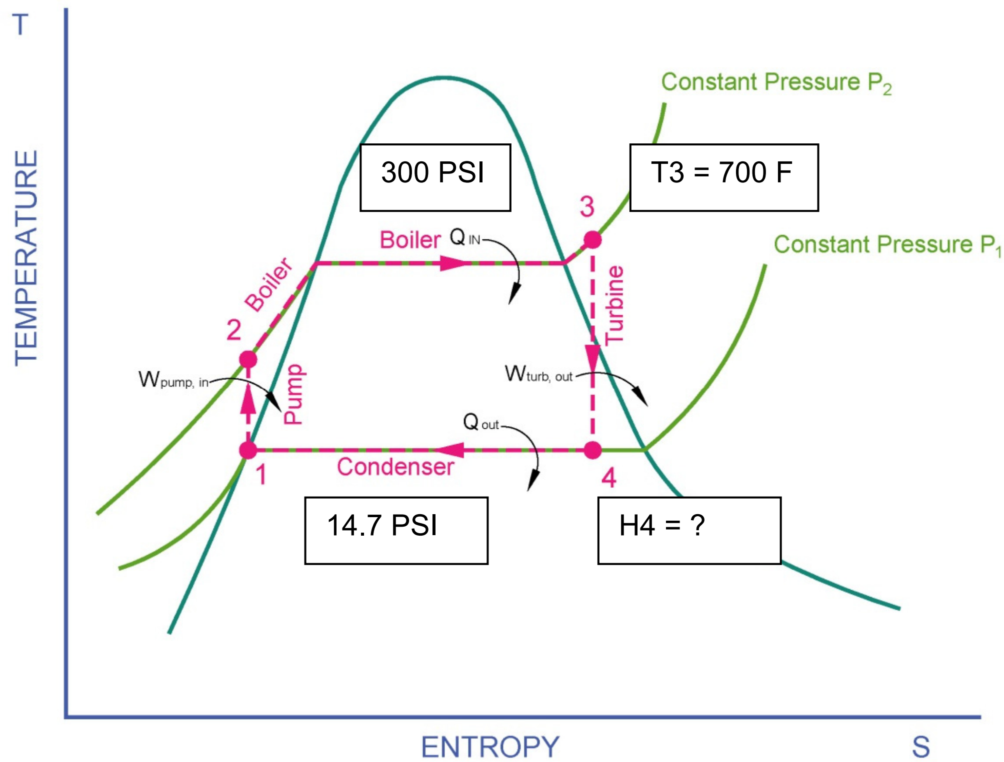


Figure 7: These figures show the constant entropy and constant pressure paths in the Brayton cycle. Use these figures with the previous figure to match each point to each piece of equipment.

9.0 SOLUTIONS

9.1 SOLUTION 1 – RANKINE CYCLE

Background: A steam power plant boiler operates at a pressure of 300 psi. Steam exits the turbine at 14.7 psi. If the boiler heats the steam to 700 °F, then what is the enthalpy of the steam leaving the turbine? Assume an isentropic turbine.



The first step is to find the entropy of h_3 with the steam tables. If we look at the standard steam tables in your NCEES Mechanical PE Reference Handbook, we find that at a pressure of 300 PSI, saturated steam is at a temperature of 417 °F. Therefore we must use the superheated steam tables, we find the following.

$$h_3 = 1368.6 \frac{Btu}{lbm}; s_3 = 1.6756$$

$$Since\ the\ turbine\ process\ is\ isentropic, s_4 = s_3 = 1.6756$$

$$We\ also\ know\ that\ the\ pressure\ at\ step\ 4\ is\ 14.7\ psi\ and\ according\ to\ the\ steam\ tables$$

$$s_f = 0.3122\ and\ s_g = 1.7566, but\ s_4 = 1.6756; so\ s_4 is\ governed\ by\ the\ following\ equation$$

$$s_4 = s_f + x * s_{fg}; where\ s_{fg} = entropy\ of\ evaporation\ at\ 1.4445\ amd\ x =\ steam\ quality$$

$$s_4 = 1.6756 = 0.3122 + x * 1.4445$$

Next, solve for quality (percent vapor).

$$1.6756 = 0.3122 + x * 1.4445$$

$$x = 0.944$$

Now that you have the quality (percent vapor), you can solve for enthalpy.

$$h_4 = h_f + x * h_{fg};$$

$$h_4 = 180.2 + .944 * 970.1$$

$$h_4 = 1{,}096$$

The answer is most nearly (c), 1,100 Btu/lbm.

(a) 180 Btu/lbm

(b) 970 Btu/lbm

(c) 1,100 Btu/lbm

(d) 1,200 Btu/lbm

9.2 SOLUTION 2 – RANKINE CYCLE

Background: A steam power plant boiler operates at a pressure of 300 psi. Steam exits the turbine at 14.7 psi. The boiler heats steam to 700 °F. If the steam mass flow rate is 100 lb/hr, then what is the work output of the turbine?

Use the enthalpies from the previous problem to find the work output.

$$W = \dot{m} * (h_4 - h_3)$$

$$W = 100\ lbm/hr * (1368.6\frac{Btu}{lbm} - 1{,}096\frac{Btu}{lbm})$$

$$W = 27{,}260\ Btuh$$

The answer is most nearly (a), 27,000 Btuh.

(a) 27,000 Btu/h

(b) 35,000 Btu/h

(c) 42,000 Btu/h

(d) 55,000 Btu/h

7 – Support Knowledge

Pipe system analysis (e.g., pipe stress, pipe supports, hoop stress) | Joints (e.g., welded, bolted, threaded) | Psychrometrics (e.g., dew point, relative humidity) | Codes and standards

TEXTBOOK
www.engproguides.com

Section 7.0 – Supportive Knowledge

Table of Contents

1.0 INTRODUCTION

This book is intended to be a focus on ONLY the application of the key concepts and skills of the Thermal & Fluids Systems Mechanical PE Exam, specifically the Support Knowledge topic of the Mechanical P.E. Exam. Support Knowledge accounts for approximately 4-6 questions on the Thermal & Fluids Mechanical PE exam.

The support knowledge section includes any principle that did not fit in the principle categories in the previous sections, but might be used in the application section. Pipe system analysis could be used in the Hydraulic and Fluid Applications – Distribution Systems section. This part covers the supports and stresses in a piping system. Similarly, different types of joints could also be included in this section. Psychrometrics are building blocks to air properties in cooling/heating air and also in air heat exchangers. Finally, codes and standards that govern the minimum safety and efficiency requirements for practicing engineers are mentioned here.

Support Knowledge
4-6 questions

Pipe System Analysis
- Pipe stress
- Pipe supports
- Hoop stress

Joints
- Welded
- Bolted
- Threaded

Psychrometrics
- Dry bulb
- Wet bulb
- Relative humidity
- Humidity ratio
- Enthalpy
- Specific volume
- Dew point
- Sensible heating/cooling
- Latent heating/cooling
- Sensible heat ratio
- Mixing air streams

Codes & Standards
- ASTM
- ASME
- UL
- NFPA
- ASHRAE

$$Q_{latent,@\ new\ elevation} = DF * (4840 * CFM * \Delta W_{LB})$$

$$where,\ \ DF\ (density\ factor) = \frac{\rho_{new\ elevation}}{\rho_{@STP}} = \frac{\rho_{new\ elevation}}{0.075\ lb/ft^3}$$

To calculate the atmospheric pressure at various elevations above sea level, the following equation can be used.

$$P_{@Altitude}\ (psia) = P_{standard} * \left[1 - 6.875 * 10^{-6} * Altitude\ (ft)\right]^{5.2559}$$

$$where,\ \ P_{standard} = 14.7 psia$$

The movement on the psychrometric charts provided for higher elevations will follow the same movements as the standard sea level chart.

5.0 CODES AND STANDARDS

The NCEES outline does not indicate that you will be provided with any Codes or Standards. The sample questions also do no reference looking up a code or standard information. Based on this information, it is most likely that excerpts of the code will be given in the exam or questions will be based on a general knowledge of the most common codes in the Thermal & Fluids field. This section will give you the general knowledge on the most common codes and standards, including (1) ASTM, (2) AWS, (3) ANSI, (4) UL and (5) ASME.

5.1 ASTM

ASTM (American Society of Testing and Materials) is a voluntary standards organization that has over 12,000 ASTM standards. For the purposes of the exam, it is not important to know all the standards or even to have access to these standards. However, it is important to know what standards are available and to have an overview of the standards that are specific to the Thermal & Fluids field.

Here is the index to the entire ASTM Standards:

https://www.astm.org/BOOKSTORE/BOS/index.html

The following is an outline of all the topics covered by ASTM.

- Section 1 – Iron and Steel Products:
    - Volume 01.01 Steel--Piping, Tubing, Fittings
    - Volume 01.02 Ferrous Castings; Ferroalloys
    - Volume 01.03 Steel--Plate, Sheet, Strip, Wire; Stainless Steel Bar
    - Volume 01.04 Steel--Structural, Reinforcing, Pressure Vessel, Railway
    - Volume 01.05 Steel--Bars, Forgings, Bearing, Chain, Tool

8 – Hydraulic & Fluid Equipment

Pumps and fans (e.g., cavitation, curves, power, series, parallel) | Compressors (e.g., dynamic head, power, efficiency) | Pressure vessels (e.g., design factors, materials, pressure relief) | Control valves (e.g., flow characteristics, sizing) | Actuators (e.g., hydraulic, pneumatic) | Connections (e.g., fittings, tubing)

TEXTBOOK
www.engproguides.com

Section 8.0 – Hydraulic & Fluid Equipment

Table of Contents

1.0 INTRODUCTION

"Hydraulic and Fluid Applications" accounts for approximately 21-33 questions on the Thermal & Fluids Mechanical PE exam.

Hydraulic and Fluid Applications is broken up into two parts

1. Hydraulic and Fluid *Equipment (13-21 questions)*
2. Hydraulic and Fluid *Distribution Systems (8-12 questions)*

Both topics, Equipment and Distribution Systems, point towards the topics of Hydraulics and Pneumatics.

Hydraulics includes the equipment necessary to do work with liquid. This includes pumps, pipes, pressure vessels, control valves, actuators and connections, as shown in the simply hydraulic system.

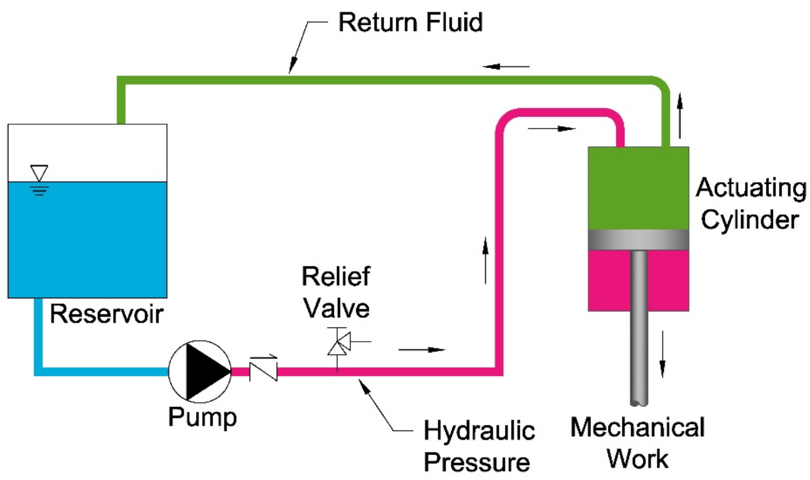


Figure 1: A simple hydraulic system consists of a reservoir that holds the hydraulic fluid, followed by a pump that pressurizes the fluid. The pressurized fluid in pink is then used to power an actuating cylinder to conduct mechanical work. In order to avoid over pressurization, there is a relief valve in the system. The green line shows the hydraulic fluid returning back to the reservoir when not needed

Pneumatics includes the equipment necessary to do work with air. This includes compressors, tubing, pressure vessels, control valves, actuators and connections, as shown in the simply pneumatic system.

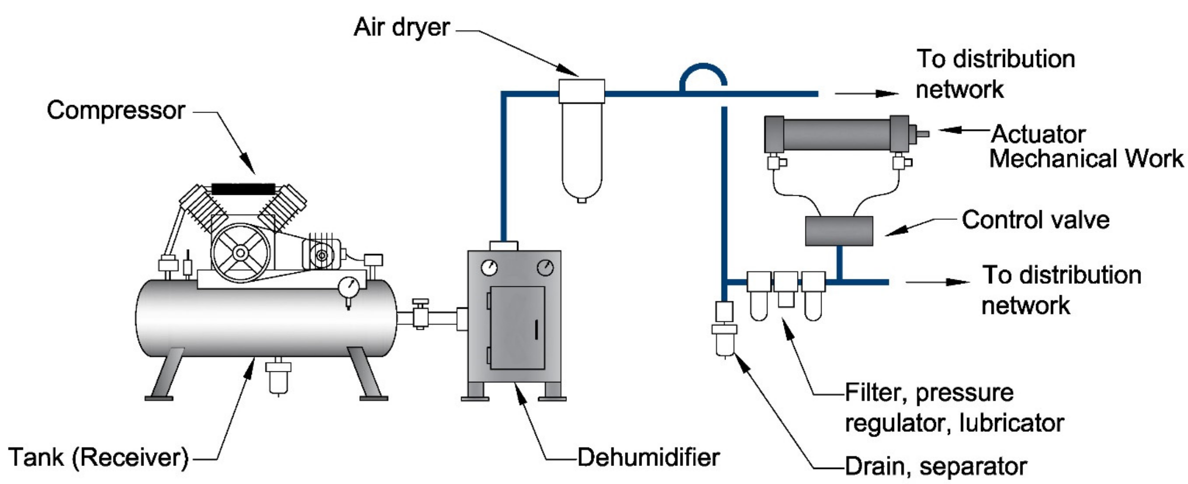


Figure 2: A simple pneumatic system consists of a receiver that holds the compressed gas, followed by a compressor that pressurizes the gas. The pressurized gas then goes through a dehumidifier, air dryer filters and drains, before it finally reaches the actuator. The actuator is used to conduct mechanical work.

R

S

T

U

V

Y

9 – Hydraulic and Fluid Distribution

Pipe flow

TEXTBOOK
www.engproguides.com

Section 9.0 – Hydraulic & Fluid Distribution

Table of Contents

1.0 INTRODUCTION

"Hydraulic and Fluid Applications" accounts for approximately 21-33 questions on the Thermal & Fluids Mechanical PE exam.

Hydraulic and Fluid Applications is broken up into two parts.

1. Hydraulic and Fluid *Equipment (13-21 questions)*
2. Hydraulic and Fluid *Distribution Systems (8-12 questions)*

Both topics, Equipment and Systems, point towards the topics of Hydraulics and Pneumatics.

Hydraulics includes the equipment necessary to do work with liquid. This includes pumps, pipes, pressure vessels, control valves, actuators and connections, as shown in the simply hydraulic system.

2.0 OUTLINE OF HYDRAULIC AND FLUID APPLICATIONS

The blue indicates the topics that are covered under Equipment and the green indicates the topics that are covered under Distribution Systems.

Hydraulic and Fluid Equipment
13-21 questions

Pumps & Fans	Compressors	Pressure Vessels	Control Valves	Actuators	Connections
• Cavitation • Curves • Power • Series • Parallel	• Dynamic head • Power • Efficiency	• Design • Material • Pressure relief	• Flow • Sizing	• Hydraulic • Pneumatic	• Fittings • Tubing
• Pipes • Ducts • Open /closed systems	• Pipes • Tubing	• N/A	• N/A	• Tubing	• Fittings • Tubing

Hydraulic and Fluid Distribution
9 questions

This section focuses on Hydraulic and Fluid Distribution.

3.0 LIQUID DISTRIBUTION (HYDRONIC)

In the Thermal & Fluids field, fluids are distributed throughout various types of systems, like chilled water, hot water, condenser water, condensate systems, fuel, compressed air and steam. These systems have three things in common, (1) piping, (2) pumps and (3) liquids.

(1) Piping is used as the means to transfer the liquid from one point to the next. It is important to be able to (a) determine the pressure drop through a piping system and (b) determine the velocity of liquid through a pipe. These skills will be discussed as part of this section.

(2) Pumps are used to provide the necessary mechanical energy to move a desired liquid flow rate at the desired pressure. The important pump skills consist of (a) selecting the appropriate pump, (b) determining the necessary volumetric flow rate, (c) determining the total dynamic head and (4) determining the net positive suction head available. All of these items are

8.0 PRACTICE PROBLEMS

8.1 PROBLEM 1 – VALVE LOSSES

A 2" valve in a compressed air line has a friction loss coefficient of 0.15. What is the minor friction loss through the valve at an air flow rate of 200 SCFM? Assume standard air conditions.

(a) 0.78 ft

(b) 4.7 ft

(c) 9.4 ft

(d) 54.4 ft

8.2 PROBLEM 2 – ORIFICE/VALVE

A hydraulic fluid with specific gravity 0.85 flows through a valve at 0.1 GPM. What is the pressure drop through this valve, if the manufacturer provides a valve coefficient of .05?

(a) 1.7 psi

(b) 3.5 psi

(c) 4.9 psi

(d) 9.1 psi

10 – Energy/Power Equipment

Turbines (e.g., steam, gas) | Boilers and steam generators (e.g., heat rate, efficiency) | Internal combustion engines (e.g., compression ratio, BMEP) | Heat exchangers (e.g., shell and tube, feedwater heaters) | Cooling towers (e.g., approach, drift, blowdown) | Condensers (e.g., surface area, materials)

TEXTBOOK
www.engproguides.com

Section 10.0 – Energy/Power Equipment

Table of Contents

1.0 INTRODUCTION

"Energy/Power System Applications" accounts for approximately 21-33 questions on the Thermal & Fluids Mechanical PE exam.

Energy/Power System Applications is broken up between four different parts:

1. Energy/Power Equipment *(turbines, boilers/steam generators, internal combustion engines, heat exchangers, cooling towers and condensers) 7-11 questions*
2. Cooling/Heating (*capacity, loads, cycles) 5-8 questions*
3. Energy/Recovery *(waste heat, storage) 5-8 questions*
4. Combined Cycles *(components, efficiency) 4-6 questions*

1.1 ENERGY/POWER CYCLES

The following diagram shows that all four of these parts are actually part of bigger Energy/Power cycles that are used in power plants throughout the country. For this reason, Thermal & Fluids engineers should know the overall power cycle and how all the individual parts work together.

These cycles are depicted on the following diagram. If you are able to grasp this diagram and understand how each part works within the diagram, then you will put yourself in a very good position to pass the exam by having a high probability of answering 24 out of 80 questions. At first glance, this diagram may appear daunting, but this guide will take you through each individual piece and build up the diagram, to help you understand this diagram.

From top to bottom, gas turbines burn fuel. The turbine compresses air and mixes it with fuel that is heated to a very high temperature. The hot air-fuel mixture turns the gas turbine and generates electricity through a generator.

Waste heat from the above sequence is used to heat water to a high pressure steam. The high pressure steam turns turbines and generates electricity. Steam leaves the turbine at a lower pressure.

A portion of the low pressure steam is condensed back to low pressure water and then heated through a heat exchanger or feedwater heater. At this heat exchanger, steam is used to heat water. The hot water is then pressurized and fed to a boiler, where it is turned into steam and then used to drive a turbine.

The condenser is used to condense the low pressure steam to water, through the use of condenser water fluid. Cool water travels to the condenser, removes the heat from the low pressure steam, which condenses the steam. The initially cool water then leaves as warm water, since it has picked up heat from the steam. Then the warm condenser water is cooled back down through the use of a cooling tower.

11 – Heating and Cooling

TEXTBOOK
www.engproguides.com

Section 11.0 – Heating and Cooling

Table of Contents

1.0 Introduction

"Energy/Power System Applications" accounts for approximately 21-33 questions on the Thermal & Fluids Mechanical PE exam.

Energy/Power System Applications is broken up between four different parts:

1. Energy/Power Equipment *(turbines, boilers/steam generators, internal combustion engines, heat exchangers, cooling towers and condensers) 7-11 questions*
2. Cooling/Heating (*capacity, loads, cycles) 5-8 questions*
3. Energy/Recovery *(waste heat, storage) 5-8 questions*
4. Combined Cycles *(components, efficiency) 4-6 questions*

1.1 Energy/Power Cycles

The following diagram shows that all four of these parts are actually part of bigger Energy/Power cycles that are used in power plants throughout the country. For this reason, Thermal & Fluids engineers should know the overall power cycle and how all the individual parts work together.

These cycles are depicted on the following diagram. If you are able to grasp this diagram and understand how each part works within the diagram, then you will put yourself in a very good position to pass the exam by having a high probability of answering 24 out of 80 questions. At first glance, this diagram may appear daunting, but this guide will take you through each individual piece and build up the diagram, to help you understand this diagram.

From top to bottom, gas turbines burn fuel. The turbine compresses air and mixes it with fuel that is heated to a very high temperature. The hot air-fuel mixture turns the gas turbine and generates electricity through a generator.

Waste heat from the above sequence is used to heat water to a high pressure steam. The high pressure steam turns turbines and generates electricity. Steam leaves the turbine at a lower pressure.

A portion of the low pressure steam is condensed back to low pressure water and then heated through a heat exchanger or feedwater heater. At this heat exchanger, steam is used to heat water. The hot water is then pressurized and fed to a boiler, where it is turned into steam and then used to drive a turbine.

The condenser is used to condense the low pressure steam to water, through the use of condenser water fluid. Cool water travels to the condenser, removes the heat from the low pressure steam, which condenses the steam. The initially cool water then leaves as warm water, since it has picked up heat from the steam. Then the warm condenser water is cooled back down through the use of a cooling tower.

12 – Energy Recovery

TEXTBOOK
www.engproguides.com

Section 12.0 – Energy Recovery

Table of Contents

3.0 POWER CYCLES WITH ENERGY RECOVERY

The previous sub-section discussed air to air energy recovery devices. This section focuses on the energy recovery devices that can be used within the power cycles (Brayton and Rankine) to increase the efficiency of the cycles. The addition of these energy recovery devices will be described as variations to the power cycles. The Brayton cycle (gas turbine) variations will be discussed first, followed by the Rankine cycle (steam turbine) variations.

3.1 BRAYTON CYCLE WITH REGENERATION

As a starting point, you should be familiar with the Brayton cycle without regeneration. Although this is covered in the Thermodynamics section, the Brayton cycle is also provided here for ease.

The basic Brayton cycle can be either *open* or *closed.* The figure below shows an open cycle. In an open cycle the low pressure warm air and combustion products are exhausted to the atmosphere. Fuel enters the combustor and travels with the air. In a closed cycle, the air is kept within a closed system and only heat is transferred from the combustor to the air. The combustion products are kept separate from the air.

The basic Brayton cycle starts with low pressure cool air entering a compressor. Work is provided to the compressor, which produces high pressure warm air. Then this air enters the combustor, where it gains heat and increases in temperature. Finally, the high pressure, hot air, enters a turbine where it produces work. Some of this work is used to drive the compressor and the remaining is provided as useful work. The low pressure warm air is then exhausted to the atmosphere.

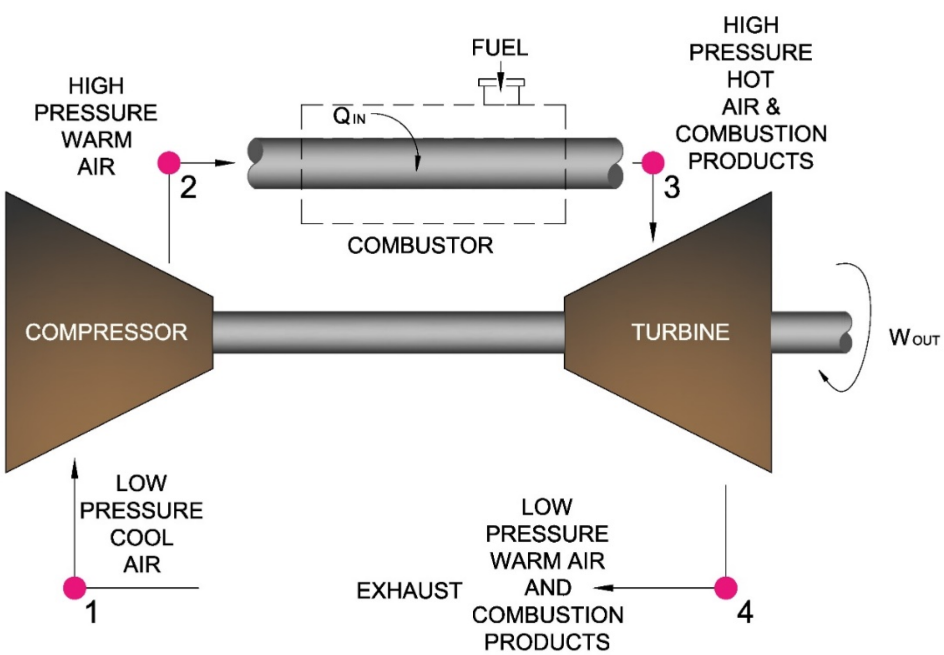


Figure 10: The above figure is an Ideal Brayton open cycle. The numbers correspond to the points on the graphs in the following figure.

Each step of the basic Brayton cycle is governed by a thermodynamic transition. In the ideal Brayton cycle, the compressor and turbine are isentropic. The combustor is assumed to occur at a constant pressure or isobaric. The following figure describes each of these transitions graphically.

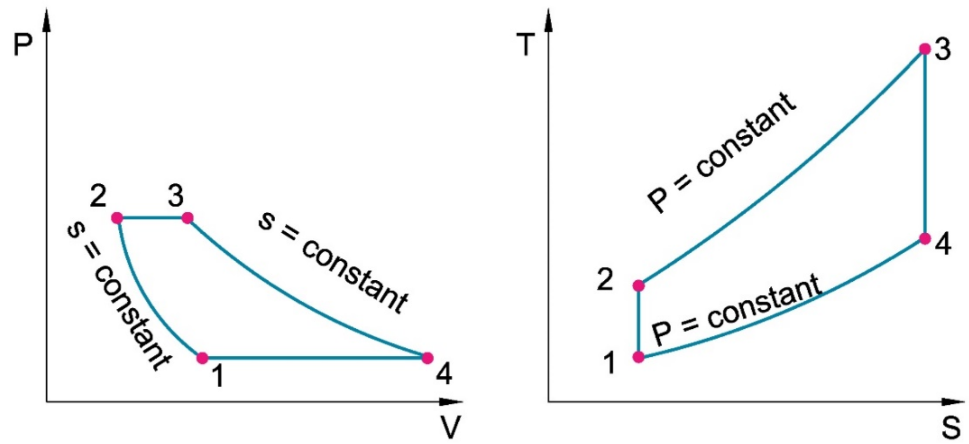


Figure 11: An ideal Brayton cycle on Pressure-Volume graphs and Temperature-Entropy graphs.

3.1.1 Step 1 to 2 - Compressor

The compression process is isentropic, meaning that there is no change in entropy.

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

3.1.2 Step 2 to 3 - Combustion chamber and heat exchanger

Heat is transferred from combustion to the air at constant pressure.

$$q_{in} = \dot{m} * (h_3 - h_2) = \dot{m} * c_p * (T_3 - T_2)$$

3.1.3 Step 3 to 4 -Turbine

This hot pressurized air then enters the turbine and as the gas expands (loses pressure and energy). The energy is converted to work to turn the turbine. Following the turbine, an electric generator is turned to produce electricity. Some of the work is used to power the compressor.

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{k-1}{k}}$$

3.1.4 Step 4 to 1 - Exhaust

The warm, low pressure air is then exhausted to the atmosphere. The Brayton cycle with regeneration uses the waste heat from the warm, low pressure air to pre-heat the air before it

13 – Combined Cycles

TEXTBOOK
www.engproguides.com

Section 13.0 – Combined Cycles

Table of Contents

1.0 Introduction

"Energy/Power System Applications" accounts for approximately 21-33 questions on the Thermal & Fluids Mechanical PE exam.

Energy/Power System Applications is broken up between four different parts:

1. Energy/Power Equipment *(turbines, boilers/steam generators, internal combustion engines, heat exchangers, cooling towers and condensers)* *7-11 questions*
2. Cooling/Heating (*capacity, loads, cycles)* *5-8 questions*
3. Energy/Recovery *(waste heat, storage)* *5-8 questions*
4. Combined Cycles *(components, efficiency)* *4-6 questions*

1.1 Energy/Power Cycles

The following diagram shows that all four of these parts are actually part of bigger Energy/Power cycles that are used in power plants throughout the country. For this reason, Thermal & Fluids engineers should know the overall power cycle and how all the individual parts work together.

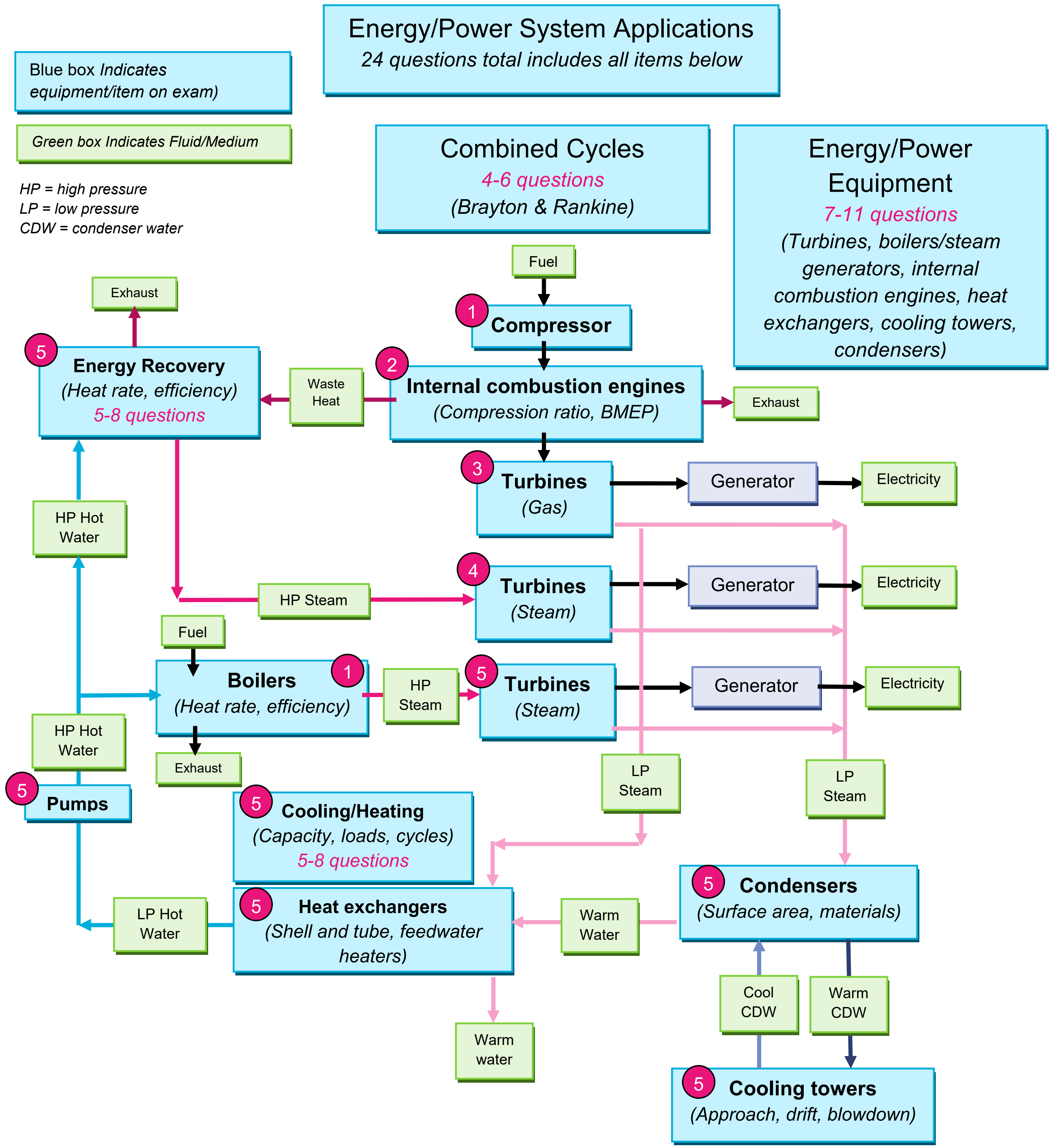
These cycles are depicted on the following diagram. If you are able to grasp this diagram and understand how each part works within the diagram, then you will put yourself in a very good position to pass the exam by having a high probability of answering 24 out of 80 questions. At first glance, this diagram may appear daunting, but this guide will take you through each individual piece and build up the diagram, to help you understand this diagram.

From top to bottom, gas turbines burn fuel. The turbine compresses air and mixes it with fuel that is heated to a very high temperature. The hot air-fuel mixture turns the gas turbine and generates electricity through a generator.

Waste heat from the above sequence is used to heat water to a high pressure steam. The high pressure steam turns turbines and generates electricity. Steam leaves the turbine at a lower pressure.

A portion of the low pressure steam is condensed back to low pressure water and then heated through a heat exchanger or feedwater heater. At this heat exchanger, steam is used to heat water. The hot water is then pressurized and fed to a boiler, where it is turned into steam and then used to drive a turbine.

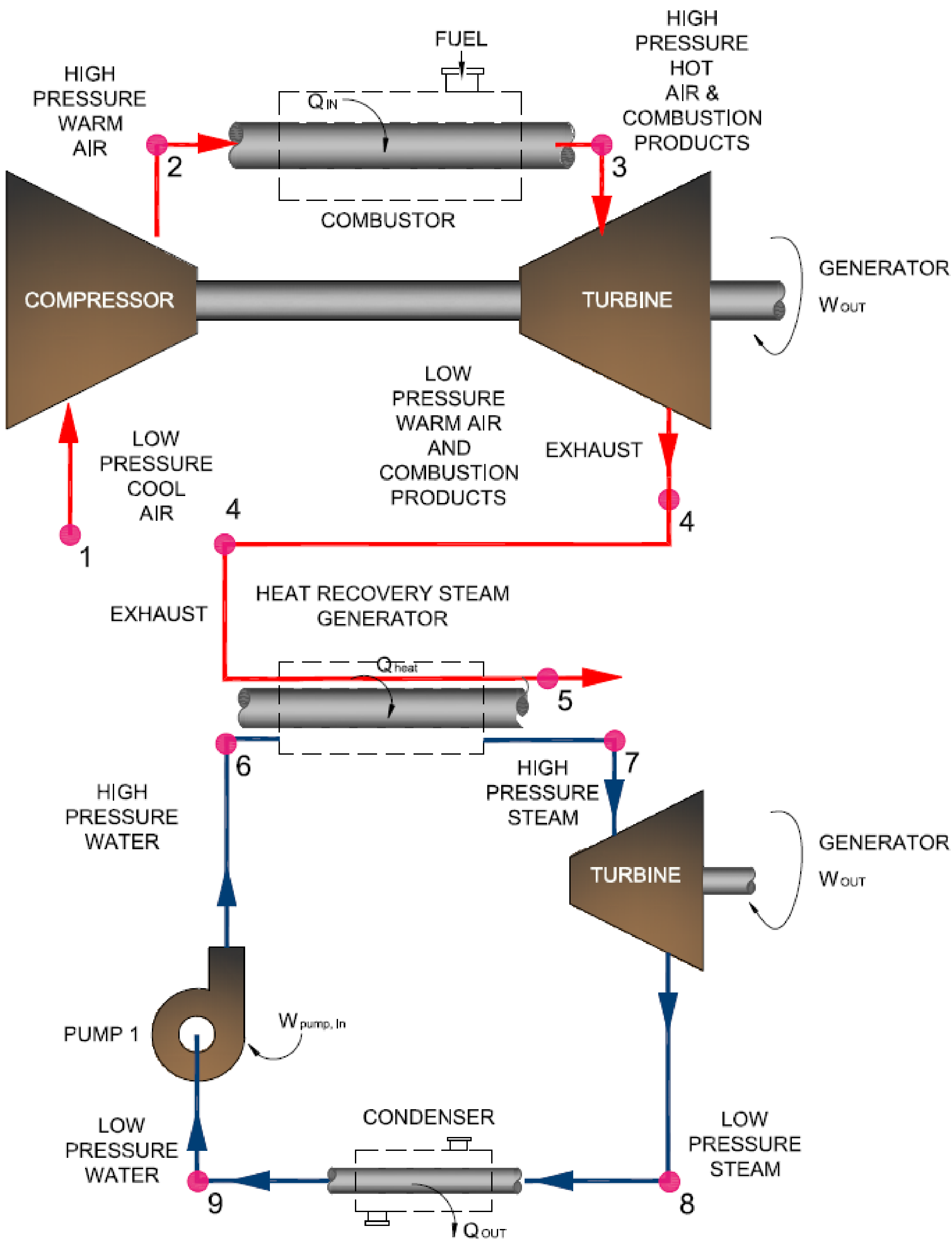
The condenser is used to condense the low pressure steam to water, through the use of condenser water fluid. Cool water travels to the condenser, removes the heat from the low pressure steam, which condenses the steam. The initially cool water then leaves as warm water, since it has picked up heat from the steam. Then the warm condenser water is cooled back down through the use of a cooling tower.



Energy/Power System Applications
24 questions total includes all items below
Blue box Indicates equipment/item on exam)
Green box Indicates Fluid/Medium
HP = high pressure
LP = low pressure
CDW = condenser water
Combined Cycles
4-6 questions
(Brayton & Rankine)
Energy/Power Equipment
7-11 questions
(Turbines, boilers/steam generators, internal combustion engines, heat exchangers, cooling towers, condensers)
Fuel
1 Compressor
Exhaust
5 Energy Recovery
(Heat rate, efficiency)
5-8 questions
Waste Heat
2 Internal combustion engines
(Compression ratio, BMEP)
Exhaust
3 Turbines
(Gas)
Generator
Electricity
HP Hot Water
HP Steam
4 Turbines
(Steam)
Generator
Electricity
Fuel
Boilers 1
(Heat rate, efficiency)
HP Steam
5 Turbines
(Steam)
Generator
Electricity
HP Hot Water
Exhaust
LP Steam
LP Steam
5 Pumps
5 Cooling/Heating
(Capacity, loads, cycles)
5-8 questions
5 Heat exchangers
(Shell and tube, feedwater heaters)
LP Hot Water
Warm Water
5 Condensers
(Surface area, materials)
Cool CDW
Warm CDW
Warm water
5 Cooling towers
(Approach, drift, blowdown)

2.0 COMBINED CYCLES (COMBINED POWER CYCLE)

In the Thermodynamics sections, the following cycles were introduced, (1) Open gas turbine cycle, (2) Closed gas turbine cycle, (3) Ideal Brayton cycle, (4) Actual Brayton cycle and (5) Rankine cycle. In this section, combined cycles discusses the combination of the gas turbine (Brayton cycle) and the steam power cycle (Rankine Cycle).



14 – Conclusion

TEXTBOOK
www.engproguides.com

14.1 Conclusion

If you have any questions on this book or any other Engineering Pro Guides product, then please contact me at my email below. Also if you are looking for more Thermal & Fluids PE products, then please visit the website and purchase the complete set of Thermal & Fluids PE products. The website also has a bunch of free information that you can use to facilitate your studying. Finally, each webpage also has a section for you to ask questions on the product and to leave comments, in addition the errata for each product is located on their respective webpages.

Thermal & Fluids PE Textbook:
https://www.engproguides.com/thermalguide.html

Thermal & Fluids PE Full Exam (80 unique questions):
https://www.engproguides.com/thermalexam.html

Thermal & Fluids PE References Exam (experience based problems):
https://www.engproguides.com/thermalreferenceexam.html

If you have any questions, please email me Justin Kauwale at contact@engproguides.com

Hi. My name is Justin Kauwale, the creator of Engineering Pro Guides. I will be happy to answer any questions you may have about the PE exam. Good luck on your studying! I hope you pass the exam and I wish you the best in your career. Thank you for your purchase!

Justin Kauwale at contact@engproguides.com

Company Facebook: https://www.facebook.com/engineeringproguides/

Company LinkedIn: https://www.linkedin.com/company/engineering-pro-guides/

Person LinkedIn: https://www.linkedin.com/in/justin-kauwale/

11 – Index

TEXTBOOK
www.engproguides.com

R