Thermal & Fluid Systems

Mechanical PE

Exam Textbook

Winter 2021 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

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Thermal & Fluids Textbook

How to pass the PE exam

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Section 1.0 - Introduction

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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/):

I. Principles (28-44 questions)

A) Basic Engineering Practice *(5-8 questions)*

1 Engineering terms and symbols
2 Economic analysis
3 Units and conversions

B) Fluid Mechanics *(5-8 questions)*

1 Fluid properties (e.g., density, viscosity)
2 Compressible flow (e.g., Mach number, nozzles, diffusers)
3 Incompressible flow (e.g., friction factor, Reynolds number, lift, drag)

C) Heat Transfer Principles (e.g., convection, conduction, radiation) *(5-8 questions)*

D) Mass Balance Principles ((e.g., evaporation, dehumidification, mixing)) *(4-6 questions)*

E) Thermodynamics *(5-8 questions)*

1 Thermodynamic properties (e.g., enthalpy, entropy)
2 Thermodynamic cycles (e.g., Combined, Brayton, Rankine)
3 Energy Balances (e.g., 1st and 2nd laws)

4 Combustion (e.g., stoichiometric, efficiency)

F) Support Knowledge *(4-6 questions)*

1 Pipe system analysis (e.g., pipe stress, pipe supports, hoop stress)
2 Joints (e.g., welded, bolted, threaded)
3 Psychrometrics (e.g., dew point, relative humidity)
4 Codes and Standards

II. Hydraulic and Fluid Applications

A. Hydraulic and Fluid Equipment (*13-21 questions)*

1. Pumps and fans (e.g., cavitation, curves, power, series, parallel)
2. Compressors (e.g., dynamic head, power, efficiency)
3. Pressure vessels (e.g., design factors, materials, pressure relief)
4. Control valves (e.g., flow characteristics, sizing)
5. Actuators (e.g., hydraulic, pneumatic)
6. Connections (e.g., fittings, tubing)

B. Distribution Systems (e.g., pipe flow) *(8-12 questions)*

III. Energy/Power System Applications

A. Energy/Power Equipment *(7-11 questions)*

1. Turbines (e.g., steam, gas)
2. Boilers and steam generators (e.g., heat rate, efficiency)
3. Internal combustion engines (e.g., compression ratio, BMEP)
4. Heat exchangers (e.g., shell and tube, feedwater heaters)
5. Cooling towers (e.g., approach, drift, blow-down)
6. Condensers (e.g., surface area, materials)

B. Cooling/Heating (e.g., capacity, loads, cycles) *(5-8 questions)*

C. Energy Recovery (e.g., waste heat, storage) *(5-8 questions)*

D. 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 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.

1.3 Computer Based Test (CBT)

As of April 2020, the exam will be converted from the paper-pencil/scantron testing method to a computer based platform. This allows 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. 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 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
- 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.

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:

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 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.			
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**		

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

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.

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.

$$Q\ [Btuh] = Constant * CFM * \Delta T[°F]; Typically \rightarrow Q[Btuh] = 4.5 * CFM * \Delta H[Btu/lbm]$$

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

2 – Basic Engineering Practice

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

Section 2.0 - Basic Engineering Practice

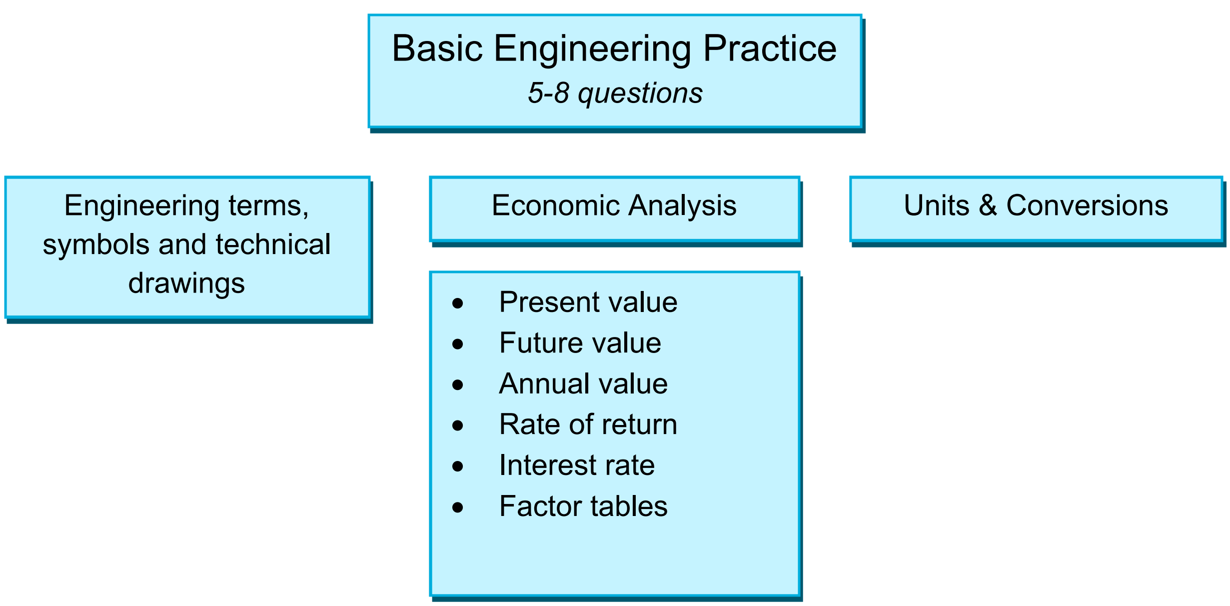
Table of Contents

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.



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.

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

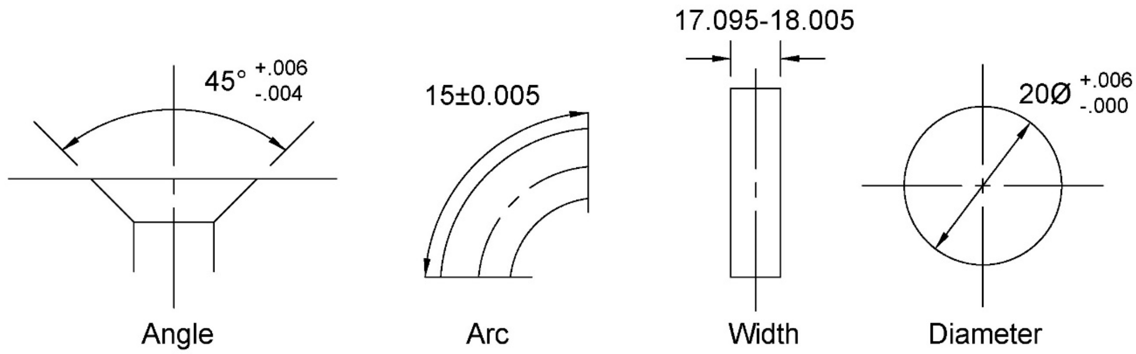


Figure 10: Dimensioning can occur on angles, arcs, lengths, diameters and more.

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.

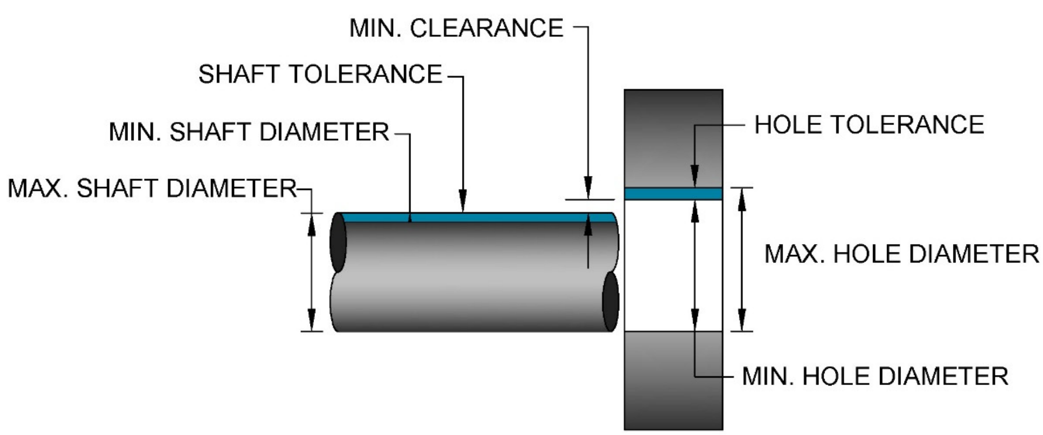


Figure 11: A clearance fit occurs when there is positive clearance between the hole and the shaft.

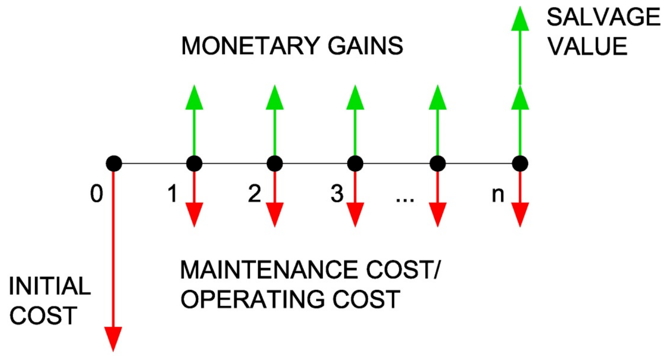


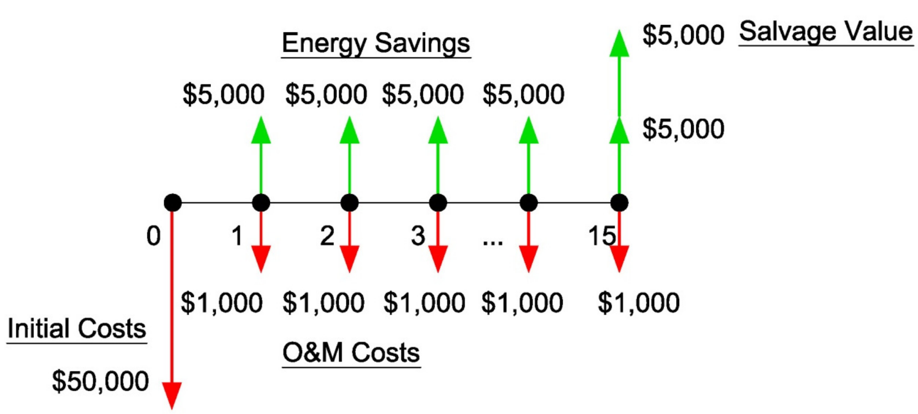
Figure 18: Economic analysis of gains and losses over time.

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 -).

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%.



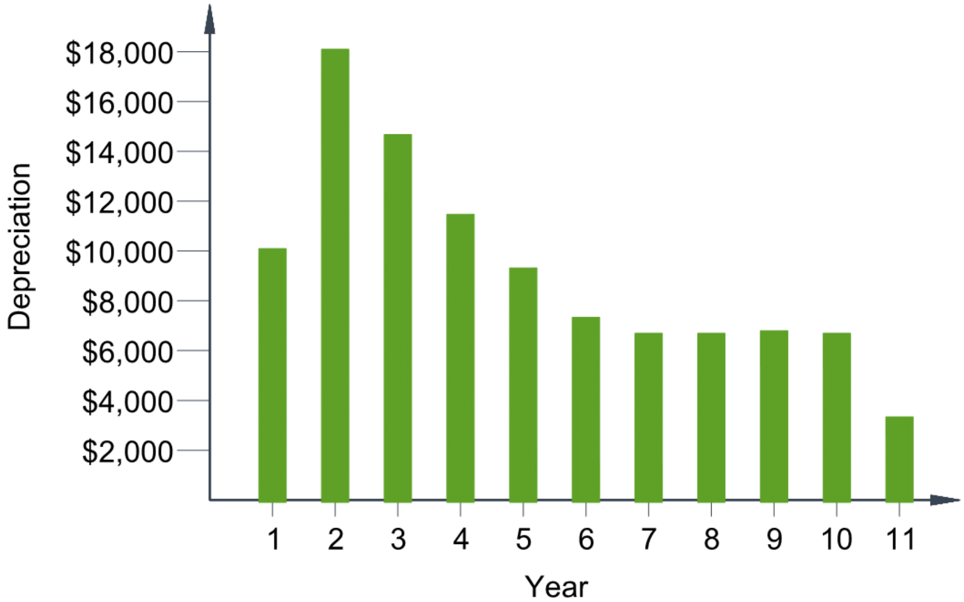


Figure 20: Example of MACRS Depreciation for an asset with ten years of usable life

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.

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

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

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.

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

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

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

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

8.9 SOLUTION 9 - ELECTRICAL

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) |

Section 3.0 – Fluid Mechanics

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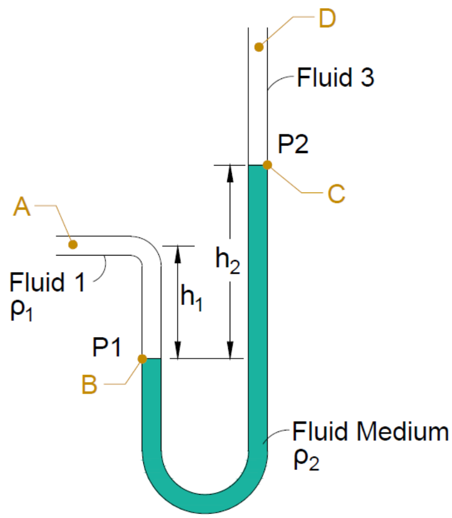
1.0 INTRODUCTION

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.

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.

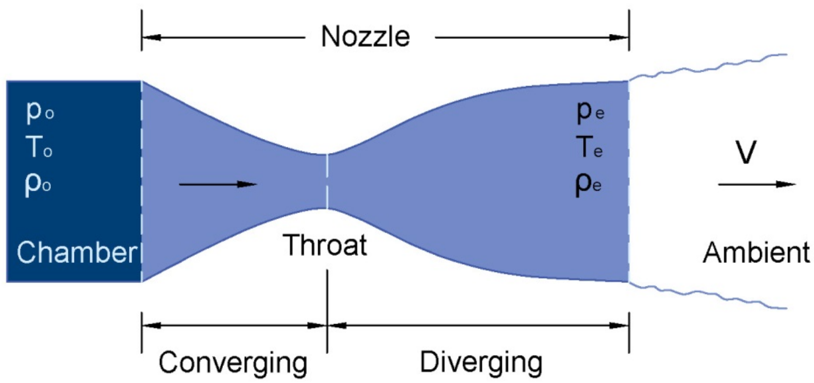


Figure 15: Converging diverging nozzle

5.4 DIFFUSERS

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

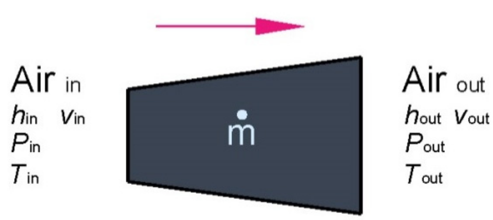


Figure 16: A diffuser decreases the pressure of the fluid, increases temperature and decreases the velocity of the fluid.

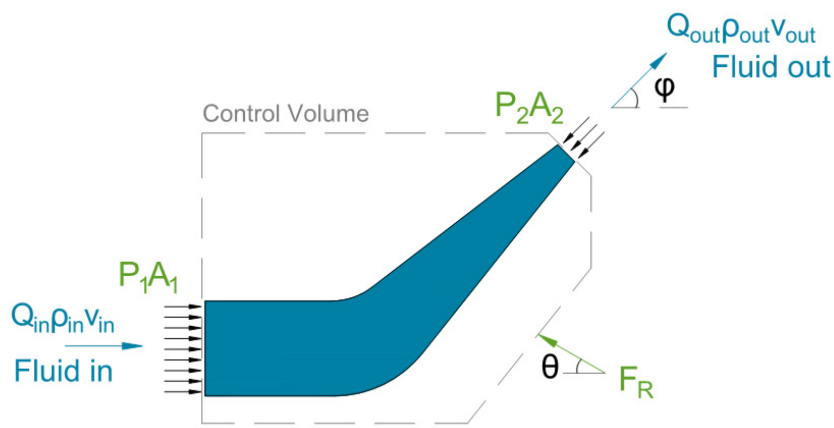
On the exam, use the same equations to solve diffuser problems as you would for nozzle problems.

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

$$\sum F_{external} = P_1A_1 - P_2A_2 - F_R$$

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

$$P_1A_1 - P_2A_2 - F_R = Q_{out}\rho_{out}v_{out} - Q_{in}\rho_{in}v_{in}$$

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

X-Component:

$$P_1A_1 - P_2A_2\cos\varphi - F_{R,x} = Q_{out}\rho_{out}(v_{out}\cos\varphi) - Q_{in}\rho_{in}v_{in}$$

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?

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

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

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

$$Re = 266{,}667$$

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?

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

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

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

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

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

R

S

T

U

V

W

4 – Heat Transfer Principles

Conduction | Convection | Radiation

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Section 4.0 – Heat Transfer Principles

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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:

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

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

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

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

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

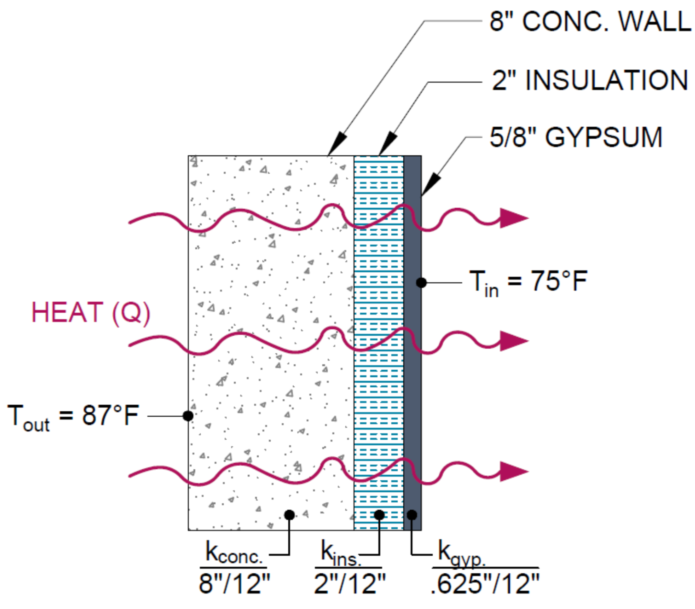


Figure 1: Conduction through a building wall

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

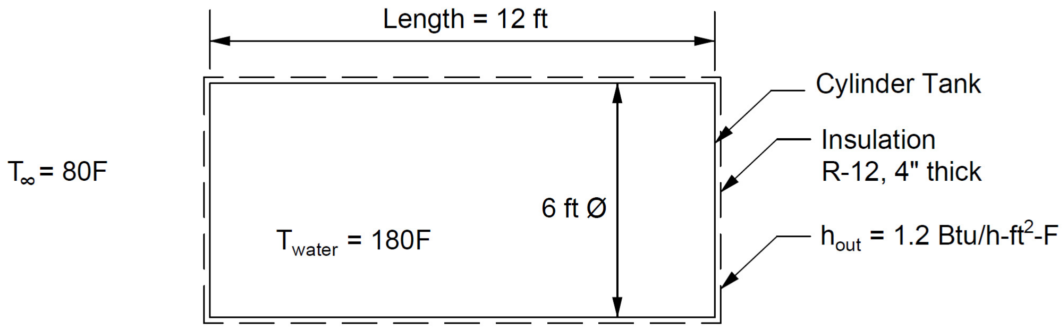
$$Q\ [Btuh] = Constant * GPM * \Delta T[°F]; Typically \rightarrow Q[Btuh] = 500 * GPM * \Delta T[°F]$$

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

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Section 5.0 – Mass Balance

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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.

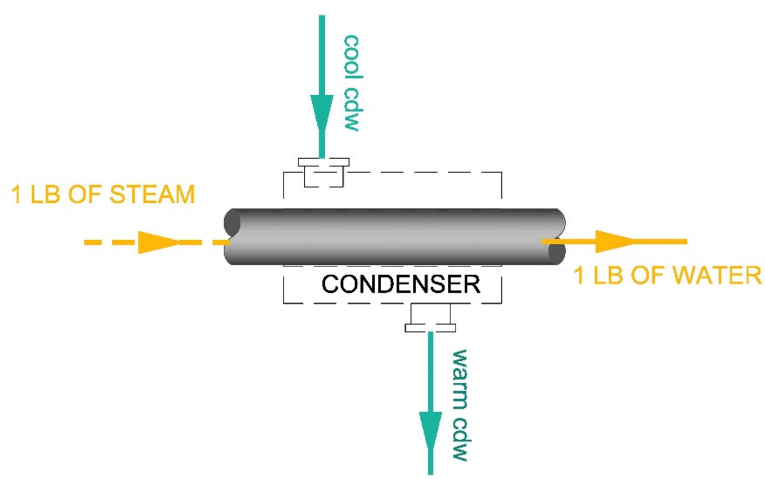


Figure 1: This figure shows one pound of steam entering a condenser and leaving as one pound of water.

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)

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.

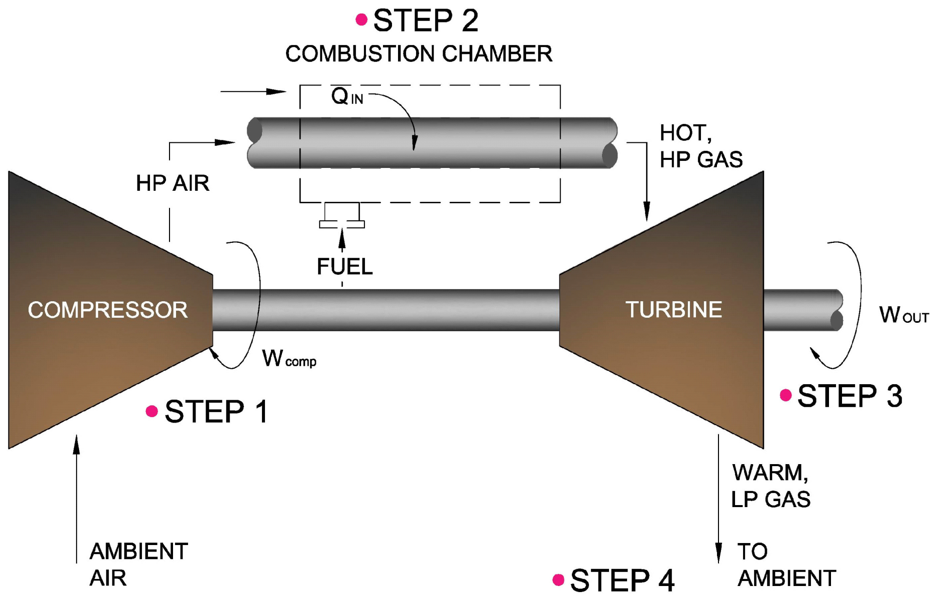


Figure 6: The above figure shows the components of an open Brayton cycle. Step 1 to 2 is the isentropic compressor. Step 2 to 3 is a constant pressure combustion chamber. Step 3 to 4 is the isentropic turbine.

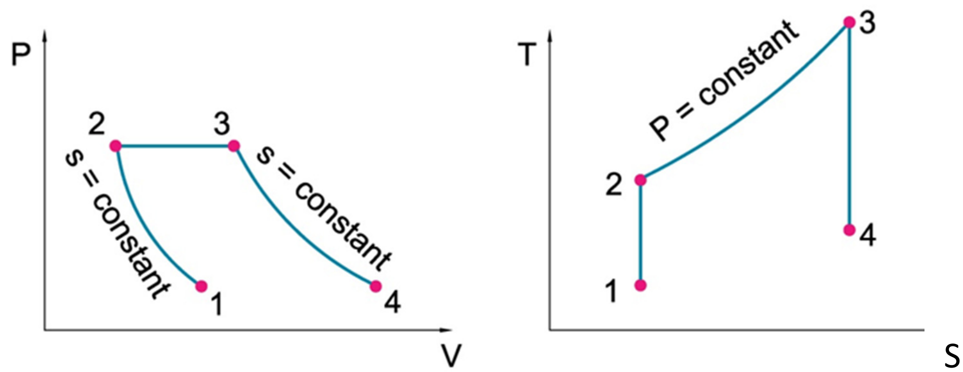
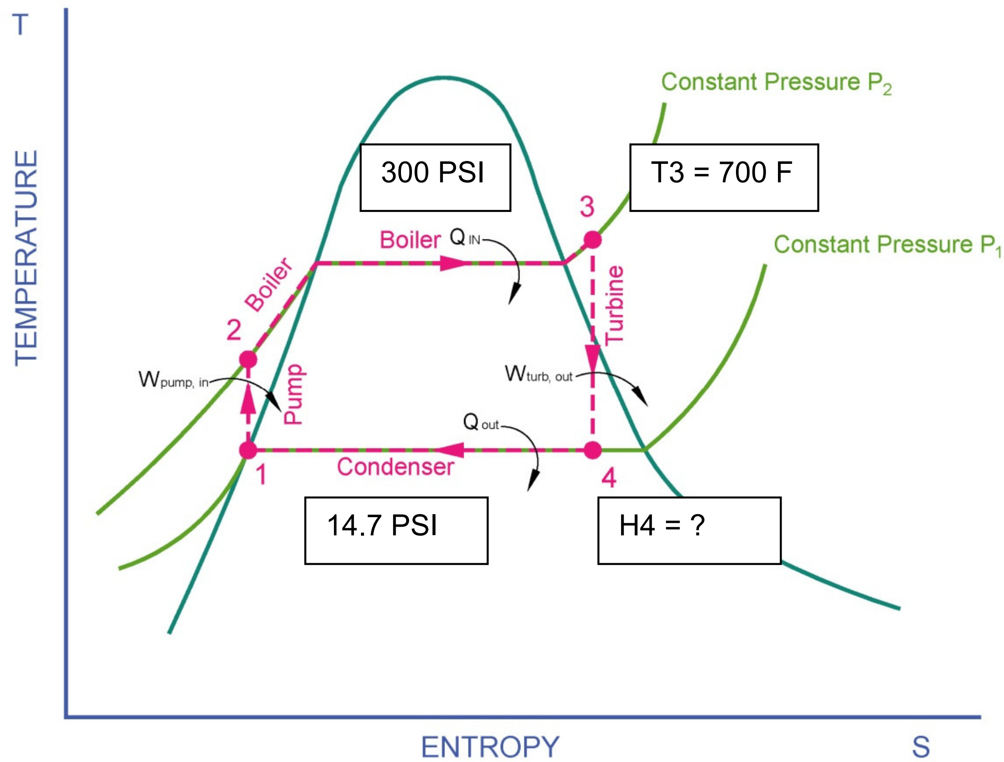


Figure 7: These figures show the constant entropy and constant pressure paths in the Brayton cycle. Use these figures with the previous figure to match each point to each piece of equipment.

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

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)

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.

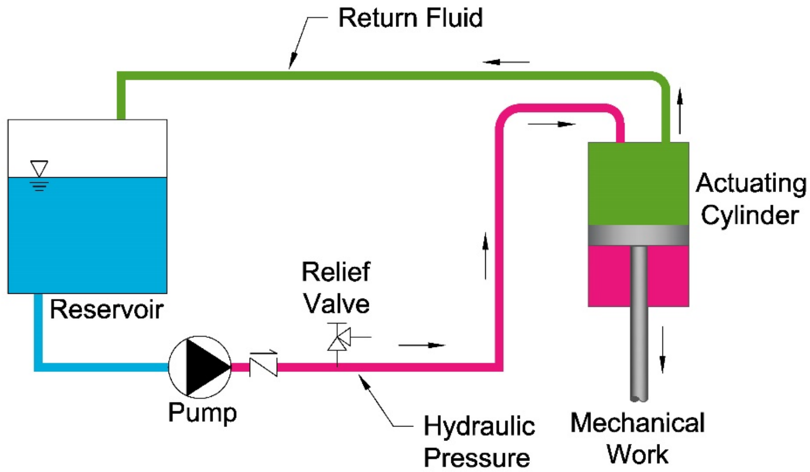


Figure 1: A simple hydraulic system consists of a reservoir that holds the hydraulic fluid, followed by a pump that pressurizes the fluid. The pressurized fluid in pink is then used to power an actuating cylinder to conduct mechanical work. In order to avoid over pressurization, there is a relief valve 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.

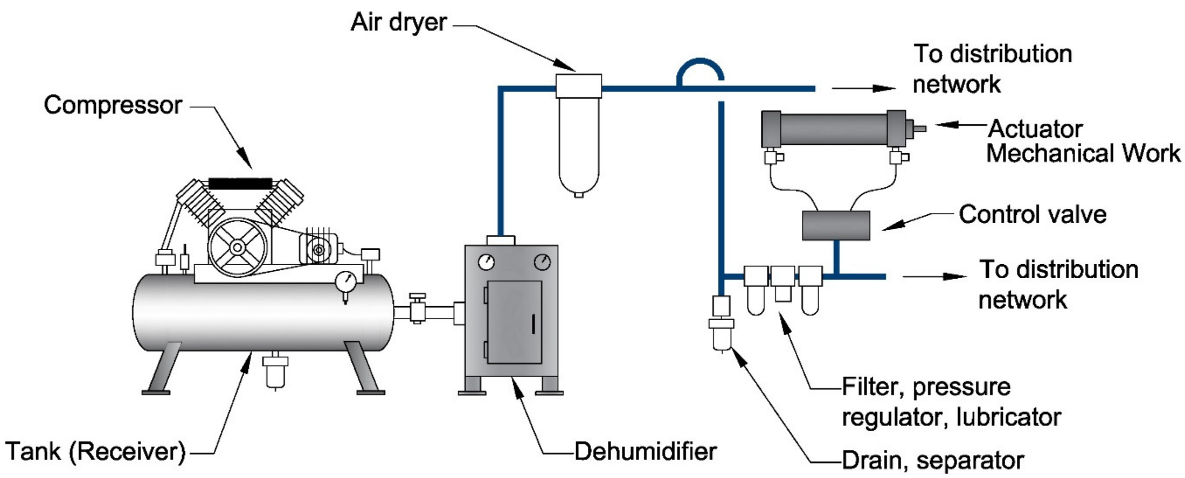


Figure 2: A simple pneumatic system consists of a receiver that holds the compressed gas, followed by a compressor that pressurizes the gas. The pressurized gas then goes through a dehumidifier, air dryer filters and drains, before it finally reaches the actuator. The actuator is used to conduct mechanical work.

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V

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9 – Hydraulic and Fluid Distribution

Pipe flow

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Section 9.0 – Hydraulic & Fluid Distribution

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1.0 INTRODUCTION

"Hydraulic and Fluid Applications" accounts for approximately 21-33 questions on the Thermal & Fluids Mechanical PE exam.

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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)

Section 10.0 – Energy/Power Equipment

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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

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Section 11.0 – Heating and Cooling

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1.0 INTRODUCTION

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4. Combined Cycles *(components, efficiency) 4-6 questions*

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12 – Energy Recovery

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Section 12.0 – Energy Recovery

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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.

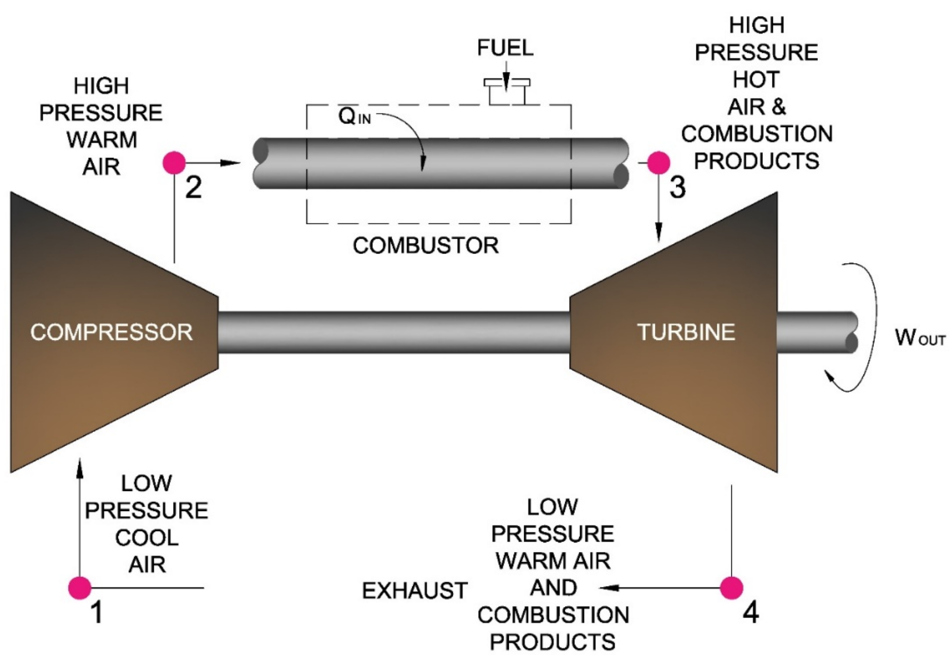

Figure 10: The above figure is an Ideal Brayton open cycle. The numbers correspond to the points on the graphs in the following figure.

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.

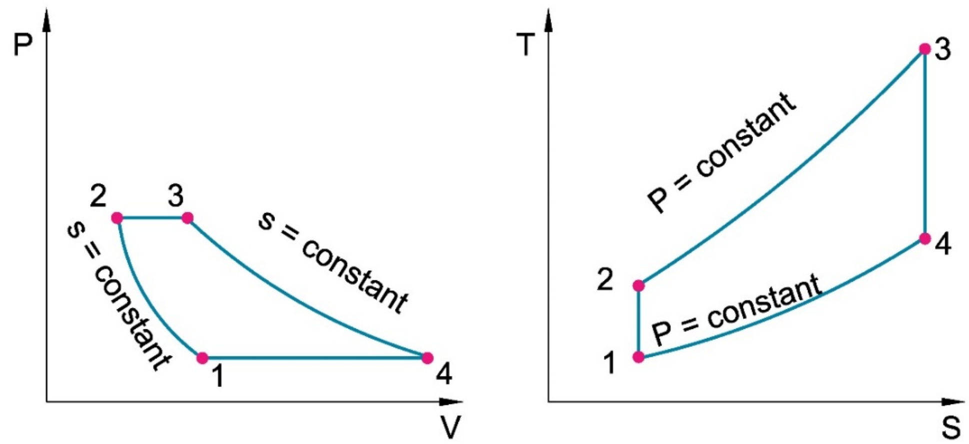

Figure 11: An ideal Brayton cycle on Pressure-Volume graphs and Temperature-Entropy graphs.

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

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Section 13.0 – Combined Cycles

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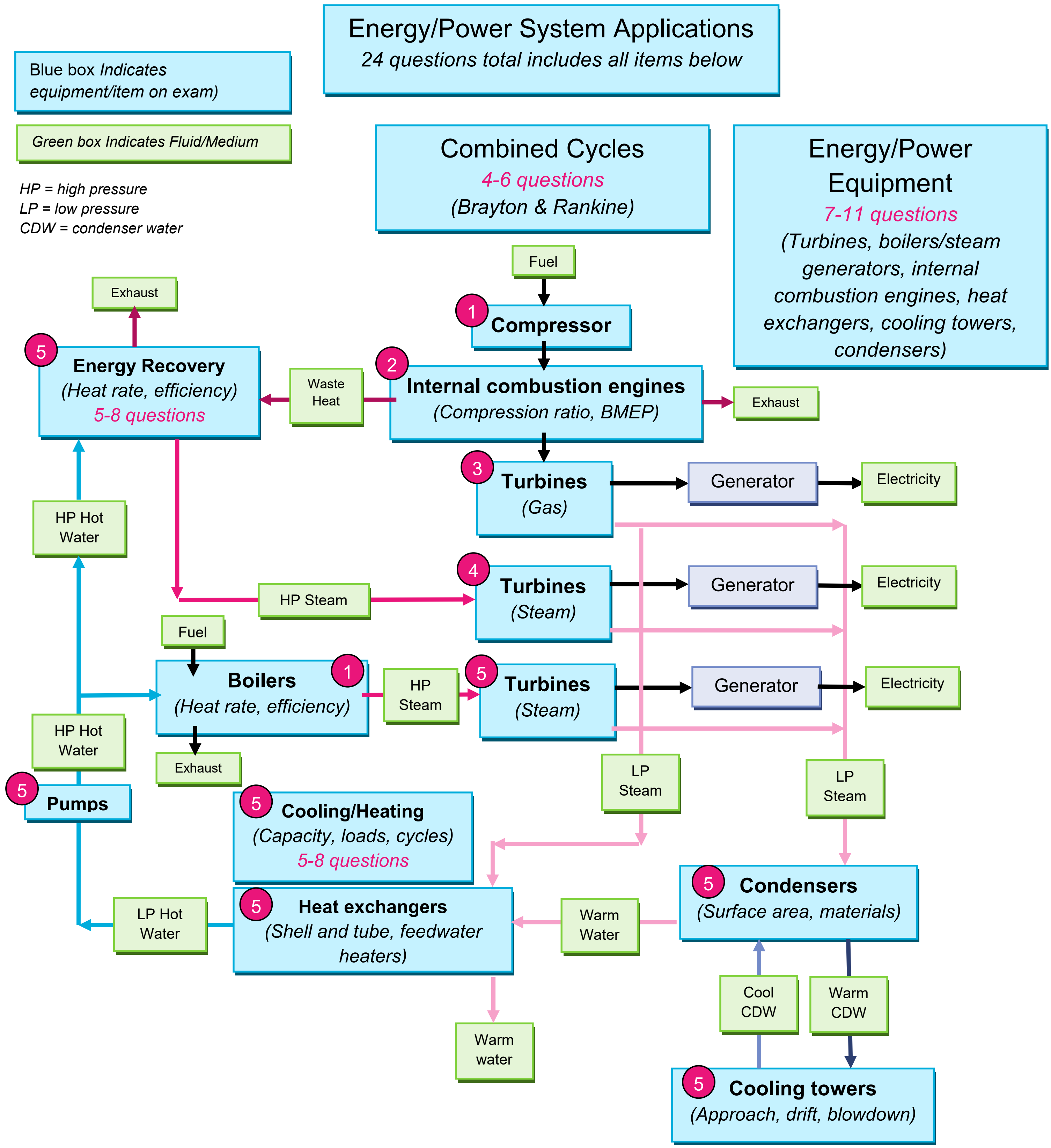
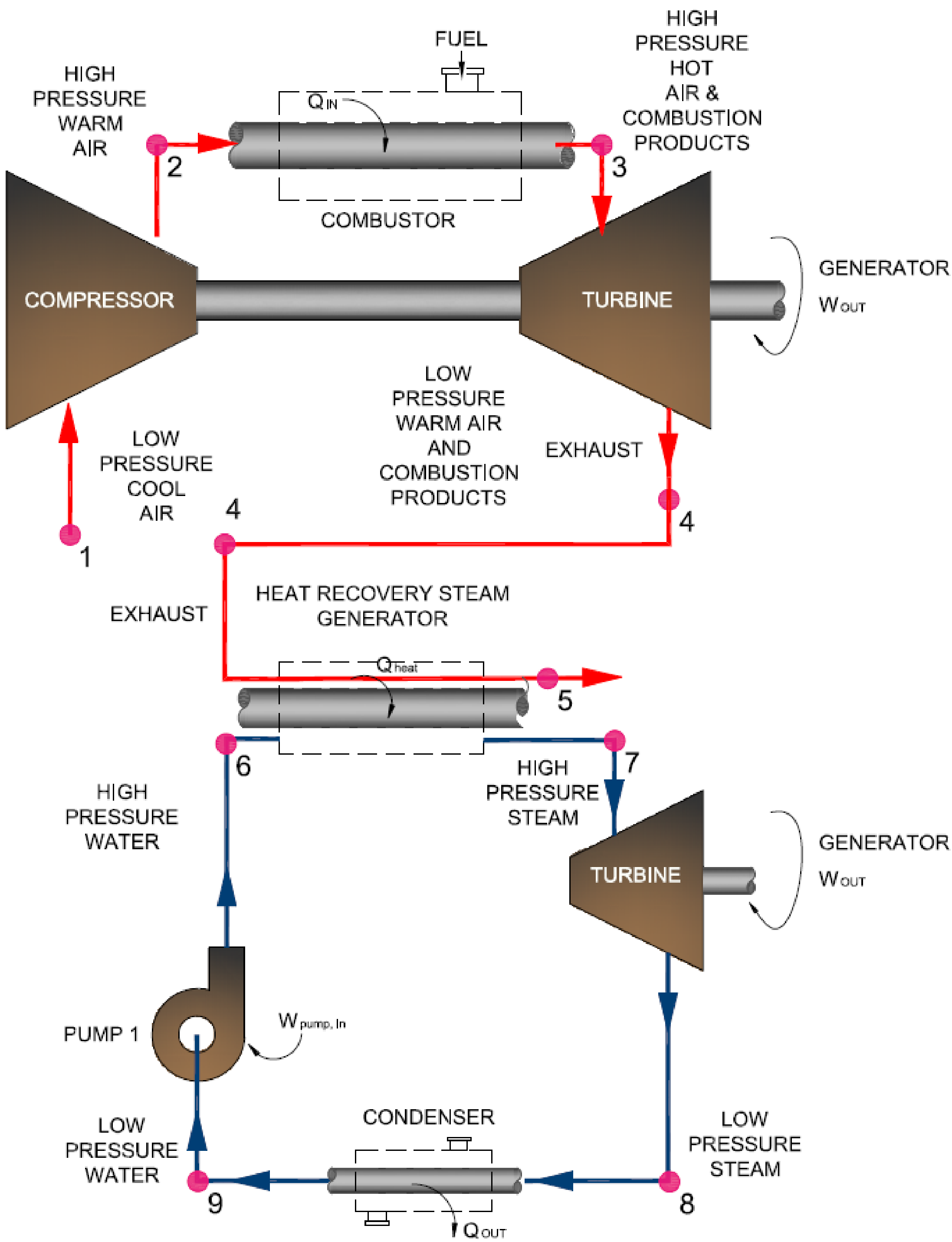

Energy/Power System Applications
24 questions total includes all items below
Blue box Indicates equipment/item on exam)
Green box Indicates Fluid/Medium
HP = high pressure
LP = low pressure
CDW = condenser water
Combined Cycles
4-6 questions
(Brayton & Rankine)
Energy/Power Equipment
7-11 questions
(Turbines, 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
5
Pumps
5
Cooling/Heating
(Capacity, loads, cycles)
5-8 questions
LP Steam
LP Steam
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

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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.

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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!

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