DOCUMENT RESUME

ED 254 710 | CE 040 986

TITLE	Stationary Engineers Apprenticeship. Related Training Modules. 16.1-16.5 Combustion.
INSTITUTION	Lane Community Coll., Eugene, Oreg.
SPONS AGENCY	Oregon State Dept. of Education, Salem.
PUB DATE	[82]
NOTE	85p.; For related documents, see CE 040 971-990. Many of the modules are duplicated in CE 041 000.
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051)
EDRS PRICE	MF01/PC04 Plus Postage.
DESCRIPTORS	*Apprenticeships; Behavioral Objectives; Energy; Energy Occupations; Equipment Maintenance; Equipment Utilization; *Fuels; Job Skills; Job Training; Learning Modules; Postsecondary Education; *Power Technology; *Trade and Industrial Education
IDENTIFIERS	*Combustion; *Stationary Engineering

ABSTRACT

This learning module, one in a series of 20 related training modules for apprentice stationary engineers, deals with combustion. Addressed in the individual instructional packages included in the module are the following topics: the combustion process, types of fuel, air and flue gases, heat transfer during combustion, and wood combustion. Each instructional package in the module contains some or all of the following: a lesson goal, performance indicators, a study guide, a vocabulary list, an introduction, instructional text, an assignment, a job sheet, a self-assessment activity, a post-assessment instrument, answers to the post-assessment instrument, and a list of recommended supplementary references. (MN)

ED254710

APPRENTICESHIP

STATIONARY ENGINEERS

RELATED TRAINING MODULES

16.1-16.5 COMBUSTION

CE040986

STATEMENT OF ASSURANCE

IT IS THE POLICY OF THE OREGON DEPARTMENT OF EDUCATION THAT NO PERSON BE SUBJECTED TO DISCRIMINATION ON THE BASIS OF RACE, NATIONAL ORIGIN, SEX, AGE, HANDICAP OR MARITAL STATUS IN ANY PROGRAM, SERVICE OR ACTIVITY FOR WHICH THE OREGON DEPARTMENT OF EDUCATION IS RESPONSIBLE. THE DEPARTMENT WILL COMPLY WITH THE REQUIREMENTS OF STATE AND FEDERAL LAW CONCERNING NON-DISCRIMINATION AND WILL STRIVE BY ITS ACTIONS TO ENHANCE THE DIGNITY AND WORTH OF ALL PERSONS.

STATEMENT OF DEVELOPMENT

THIS PROJECT WAS DEVELOPED AND PRODUCED UNDER A SUB-CONTRACT FOR THE OREGON DEPARTMENT OF EDUCATION BY LANE COMMUNITY COLLEGE, APPRENTICESHIP DIVISION, EUGENE, OREGON, 1984.

LANE COMMUNITY COLLEGE IS AN AFFIRMATIVE ACTION/EQUAL OPPORTUNITY INSTITUTION.

APPRENTICESHIP

STATIONARY ENGINEERS
RELATED TRAINING MODULES

COMPUTERS

1.1 Digital Language
1.2 Digital Logic
1.3 Computer Overview
1.4 Computer Software

SAFETY

2.1 General Safety
2.2 Hand Tool Safety
2.3 Power Tool Safety
2.4 Fire Safety
2.5 Hygiene Safety
2.6 Safety and Electricity

DRAWING

3.1 Types of Drawings and Views
3.2 Blueprint Reading/Working Drawings
3.3 Scaling and Dimensioning
3.4 Machine and Welding Symbols

TOOLS

4.1 Measuring, Layout and Leveling Tools
4.2 Boring and Drilling Tools
4.3 Cutting Tools, Files and Abrasive
4.4 Holding and Fastening Tools
4.5 Fastening Devices

ELECTRICITY/ELECTRONICS

5.1 Basics of Energy
5.2 Atomic Theory
5.3 Electrical Conduction
5.4 Basics of Direct Current
5.5 Introduction to Circuits
5.6 Reading Scales
5.7 Using a V.O.M.
5.8 OHM'S Law
5.9 Power and Watt's Law
5.10 Kirchoff's Current Law
5.11 Kirchoff's Voltage Law
5.12 Series Resistive Circuits
5.13 Parallel Resistive Circuits
5.14 Series - Parallel Resistive Circuits

REFRIGERATION

MACHINE COMPONENTS

LUBRICATION

BOILERS

PUMPS

STEAM

TURBINES

STATIONARY ENGINEER
SUPPLEMENTARY REFERENCE DIRECTORY

Note: All reference packets are numbered on the upper right-hand corner of the respective cover page.

Supplementary Packet #	Description	Related Training Module
12.1	Correspondence Course, Lecture 1, Sec. 2, Steam Generators, Types of Boilers I, S.A.I.T., Calgary, Alberta, Canada	12.1 Boilers, Fire Tube Type
12.2	Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Types of Boilers II, S.A.I.T., Calgary, Alberta, Canada	12.2 Boilers, Water Tube Type
12.3	Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Boiler Construction & Erection, S.A.I.T., Calgary, Alberta, Canada	12.3 Boilers, Construction
12.4	Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fittings II, S.A.I.T., Calgary, Alberta, Canada	12.4 Boilers, Fittings
12.4	Corresondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fitting I, S.A.I.T., Calgary, Alberta, Canada	12.4 Boilers, Fittings
12.5	Correspondence Course, Lecture 10, Sec. 2, Steam Generation, Boiler Operation, Maintenance, Inspection, S.A.I.T., Calgary, Alberta, Canada	12.5 Boilers, Operation
12.7	Correspondence Course, Lecture 3, Sec. 2, Steam Generation, Boiler Details, S.A.I.T., Calgary, Alberta, Canada	12.7 Boilers Heat Recovery Systems
12.8	Refer to reference packet 14.3/12.8	
		PUMPS
13.1 13.2 13.4 13.6 13.7	Correspondence Course, Lecture 9, Sec. 2, Steam Generator, Power Plant Pumps, S.A.I.T., Calgary, Alberta, Canada	13.1 Types & Classification 13.2 Applications 13.4 Calculating Heat & Flow 13.6 Monitoring & Troubleshooting 13.7 Maintenance
13.3 13.5	Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Pumps, S.A.I.T., Calgary, Alberta, Canada	13.3 Construction 13.5 Operation

Supplementary Packet #	Description	Related Training Module
14.3 12.8	Correspondence Course, Lecture 6, Section 3, Steam Generators, Steam Generator Controls, S.A.I.T., Calgary, Alberta, Canada	14.3 Steam, Transport 12.8 Boilers, Instruments & Controls
14.4	Correspondence Course, Lecture 11, Section 2, Steam Generators, Piping II, S.A.I.T., Calgary, Alberta, Canada	14.4 Steam, Purification
15.1	Correspondence Course, Lecture 1, Sec. 4, Prime Movers & Auxiliaries, Steam Turbines, S.A.I.T., Calgary, Alberta, Canada	15.1 Steam Turbines, Types
15.2	Correspondence Course, Lecture 4, Sec. 3, Prime Movers, Steam Turbines I, S.A.I.T., Calgary, Alberta, Canada	15.2 Steam Turbines, Components
15.3	Correspondence Course, Lecture 2, Sec. 4, Prime Movers & Auxiliaries, Steam Turbine Auxiliaries, S.A.I.T., Calgary, Alberta, Canada	15.3 Steam Turbines, Auxiliaries
15.4	Correspondence Course, Lecture 6, Sec. 3, Prime Movers, Steam Turbine Operation & Maintenance, S.A.I.T., Calgary, Alberta, Canada	15.4 Steam Turbines, Operation & Maintenance
15.5	Correspondence Course, Lecture 8, Sec. 3, Prime Movers, Gas Turbines, S.A.I.T., Calgary, Alberta, Canada	15.5 Gas Turbines
16.2	Boilers Fired with Wood and Bark Residues, D.D. Junge, F.R.L., O.S.U. 1975	16.2 Combustion Types of Fuel
16.2	Correspondence Course, Lecture 5, Sec. 2, Steam Generators, Fuel Combustion, S.A.I.T., Calgary, Alberta, Canada	16.2 Combustion Types of Fuel
16.3	Correspondence Course, Lecture 5, Sec. 2, Plant Services, Fuel & Combustion, S.A.I.T., Calgary, Alberta, Canada	16.3 Combustion, Air & Fuel Gases
17.1	Correspondence Course, Lecture 12, Sec. 3, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada	17.1 Feed Water, Types & Operation
17.2	Correspondence Course, Lecture 12, Sec. 2, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada	17.2 Feed Water, Water Treatments

Supplementary Packet #	Description	Related Training Module
17.3	Correspondence Course, Lecture 7, Sec. 2, Steam Generators, Boiler Feed Water Treatment, S.A.I.T., Calgary, Alberta, Canada	17.3 Feed Water, Testing
18.1	Correspondence Course, Lecture 2, Sec. 5, Electricity, Direct Current Machines, S.A.I.T., Calgary, Alberta, Canada	18.1 Generators, Types & Construction
18.1 18.2	Correspondence Course, Lecture 4, Sec. 5, Electricity, Alternating Current Generators, S.A.I.T., Calgary, Alberta, Canada	18.1 Generators, Types & Construction 18.2 Generators, Operation
19.1	Corrspondence Course, Lecture 5, Sec. 4, Prime Movers & Auxiliaries, Air Compressor I, S.A.I.T., Calgary, Alberta, Canada	19.1 Air Compressors, Types
19.1 19.2	Correspondence Course, Lecture 6, Sec. 4, Prime Movers & Auxiliaries, Air Compressors II, S.A.I.T., Calgary, Alberta, Canada	19.1 Air Compressors, Types 19.2 Air Compressors, Operation & Maintenance
20.1	Basic Electronics, Power Transformers, EL-BE-51	20.1 Transformers
21.1	Correspondence Course, Lecture 7, Sec. 5, Electricity, Switchgear & Circuit, Protective Equipment, S.A.I.T., Calgary, Alberta, Canada	21.1 Circuit Protection
22.1	Correspondence Course, Lecture 10, Sec. 3, Prime Movers, Power Plant Erection & Installation, S.A.I.T., Calgary, Alberta, Canada	22.1 Installation Foundations

RECOMMENDATIONS FOR USING TRAINING MODULES

The following pages list modules and their corresponding numbers for this particular apprenticeship trade. As related training classroom hours vary for different reasons throughout the state, we recommend that the individual apprenticeship committees divide the total packets to fit their individual class schedules.

There are over 130 modules available. Apprentices can complete the whole set by the end of their indentured apprenticeships. Some apprentices may already have knowledge and skills that are covered in particular modules. In those cases, perhaps credit could be granted for those subjects, allowing apprentcies to advance to the remaining modules.

We suggest the the apprenticeship instructors assign the modules in numerical order to make this learning tool most effective.

SUPPLEMENTARY INFORMATION

ON CASSETTE TAPES

Tape 1: Fire Tube Boilers - Water Tube Boilers and Boiler Manholes and Safety Precautions

Tape 2: Boiler Fittings, Valves, Injectors, Pumps and Steam Traps

Tape 3: Combustion, Boiler Care and Heat Transfer and Feed Water Types

Tape 4: Boiler Safety and Steam Turbines

NOTE: The above cassette tapes are intended as additional reference material for the respective modules, as indicated, and not designated as a required assignment.

INSTRUCTIONAL LEARNING SYSTEMS

16.1

COMBUSTION -- PROCESS

Goal:

The apprentice will be able to describe the basic process of combustion.

Performance Indicators:

1. Describe basic combustibles--carbon, gaseous hydrocarbons and carbon monoxide and hydrogen.
2. Describe perfect combustion.
3. Describe complete combustion.
4. Describe incomplete combustion.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Carbon
* Carbon dioxide
* Carbon monoxide
* Combustible
* Combustion
* Complete combustion
* Decomposition
* Gaseous hydrocarbons
* Incomplete combustion
* Perfect combustion
* Soot
* Sulfur dioxide

Introduction

Fuels are burned for the energy that they contain. The burning of fuels is referred to as combustion. As combustion takes place, the heat energy is collected and used for producing steam and other purposes.

The basic conbustion process involves combining combustibles with oxygen. Combustion cannot take place in the absence of air (oxygen). The control of air to the combustion chamber is critical for efficient capture of heat energy. Combustion is a chemical process that recombines carbon, hydrogen, oxygen and sulfur molecules.

A plant operator must understand the basic combustion process and how to recognize the characteristics of flames. They must be able to control the oxygen supply in a way that complete combustion can take place. If this is not done properly, the heat energy is lost up the smoke stack.

Information

The process of combustion must be understood by the operator. Different fuels react in different manners during the combustion process. The portions of a fuel that burns during combustion is called <u>combustibles</u>. The basic combustibles in a fuel are:

* Solid carbon
* Gaseous hydrocarbons
* Carbon monoxide and hydrogen

<u>Carbon</u>

Carbon fuels such as coke, coal and charcoal burns with a white, luminous flame. The carbon is represented by the symbol C. When carbon mixes with oxygen (O_2) from the air, the following products result:

$C + O_2$ -------------- CO_2 (<u>carbon dioxide</u>)
$C + O$ -------------- CO (<u>carbon monoxide</u>)

A dioxide means that two oxygen atoms are combined with each carbon atom. Monoxide means that only one oxygen atom combines with each carbon atom. A prefix of <u>di</u> means two. A prefix of <u>mono</u> means one in all chemical formulas. Carbon dioxide is a product of <u>complete combustion</u>. Carbon monoxide is a product of <u>incomplete combustion</u>. Complete combustion is dependent on the amount of oxygen or air that is available to the combustion process. The control of air to a furnace is critical to efficient combustion.

<u>Gaseous Hydrocarbons</u>

Gaseous hydrocarbons are the basic combustible of fuel oil, natural gas and the heavy tars found in bituminous coal. These hydrocarbons are vaporized before combustion takes place. Hydrocarbons must be mixed with large quantities of air if complete combustion is to take place. The oxygen combines with the carbon atoms to form lighter compounds which are combustible. Another method for combustion of hydrocarbons is to reduce them to soot through <u>decomposition</u>. Decomposition breaks the hydrocarbons into carbon (soot) and hydrogen molecules. The soot (C) is then combined with oxygen (O_2) and burned.

<u>Carbon Monoxide and Hydrogen</u>

Carbon monoxide results from the combustion of hydrocarbon fuels. It is part of most gas fuels. Hydrogen is also liberated in the form of H during the burning of hydrocarbons. Both of these products can be burned at temperatures of 760°C

Information

to 1540 C with excess supply of oxygen. Carbon monoxide burns with a light blue flame. Hydrogen shows a colorless flame. The burning of carbon monoxide and hydrogen converts the combustible to carbon dioxide (CO_2) and water (H_2O). The chemical formula for the combustion of carbon monoxide is:

$CO + O_2$ ---------- CO_2 (carbondioxide) + O (excess oxygen)

Hydrogen burning is shown as:

$2H_2 + O_2$ --------- $2H_2O$(water)O (oxygen)

Sulfur Combustion

Most fuels contain sulfur. The sulfur (S) combines with oxygen (O) sulfur dioxide (SO_2).

$S + O_2$ ---------- SO_2

Sulfur is an impurity in the fuel and should be avoided as much as possible. It changes into acid forms that damage metal.

Perfect Combustion

If all combustibles were completely burned it would be perfect combustion. In perfect combustion, the products would be carbon dioxide, sulfur dioxide, water, nitrogen and ash. Perfect combustion is nearly impossible because of the problems in getting the combustible molecules linked up with oxygen molecules. Large quantities of diluting gases must be present to allow all combustible molecules to find oxygen partners.

Complete Combustion

Complete combustion occurs when an excess of air is provided beyond that provided for perfect combustion. In addition to CO_2, SO_2, H_2O, N_2 and ash, the flue gases will have O_2 because of the excess air used in the process.

Incomplete Combustion

In incomplete combustion some of the conbustibles pass out the stack without yielding up their heat. The products of incomplete combustion are CO_2, SO_2, H_2O, and N_2 as found in complete combustion. In addition, carbon monoxide (CO), hydrogen (H_2), soot (C) and methane (CH_4) will be passing out the stack. These

Information

products are lost to the heat production process by incomplete combustion. Usually, a lack of oxygen is the cause of incomplete combustion. Care must be used in supplying excess air to the combustion process. Too much air can move flue gases out before they give up their heat. On the other hand, too little air always results in heat losses due to incomplete combustion. The air must be well mixed with combustible gases to make the chemical changes needed for complete combustion. Sometimes the flow patterns of gases and air become stratified in layers which prevents mixing. A short bright fire is one that has plenty of or an excess of air. Gas flames with too much air may appear blue at the tips while oil fires emit sparklers. On oil fired boilers a blue haze from the stack indicates excessive air. New air pollution standards require that less excess air be used. This may result in less efficiency because of incomplete combustion.

The operator must learn to recognize the characteristics of flames and stack emissions. Visual inspections are the basis for monitoring the combustion process. Efficient harvesting of the heat is dependent on the completeness of combustion.

Assignment

* Complete the job sheet.
* Complete the self-assessment and check answers.
* Complete the post-assessment and have instgructor check the answers.

Job Sheet

COMPLETE VISUAL INSPECTION OF COMBUSTION PROCESS

* Inspect flame and note characteristics.

* Inspect stack emissions and note characteristics.

* Describe the combustion process as to its completeness or incompelteness based on visual inspection.

* If there is a problem with the combustion process, recommend action for its improvement.

* Check your observations and recommendations with the operator to determine if your inspection was a valid one.

Self Assessment

Match the following terms and phrases.

____ 1. Carbon monoxide

____ 2. Carbon dioxide

____ 3. Gaseous hydrocarbons

____ 4. Decomposition

____ 5. Complete combustion

____ 6. Incomplete combustion

____ 7. Carbon

____ 8. Mono

____ 9. Excess air indicator

____ 10. Di

A. One

B. Products are CO , SO , H O, N and ash.

C. Product of complete combustion.

D. Blue haze at the stack.

E. Basic combustibles of fuel oil and natural gas.

F. Product of incomplete combustion.

G. Two

H. Products are CO , SO , H O, N and CO, H , C, CH .

I. Reduction of hydrocarbons to soot.

J. Burns with a white, luminous flame.

Self Assessment Answers

F 1.

C 2.

E 3.

I 4.

B 5.

H 6.

J 7.

A 8.

D 9.

G 10.

Post Assessment

1. What is the most common product of incomplete combustion?

2. What is the most common product of complete combustion?

3. What one product is found in complete combustion that is not found in perfect combustion?

4. What harm is done when gases and air become stratified in layers in their flow patterns?

5. Do air pollution requirements always increase the efficiency of combustion?

6. In an oil fired boiler, what would sparklers at the flame tips indicate to the operator?

7. What is the process called in which hydrocarbons are reduced to soot so that combustion can take place?

8. What is the color of a carbon monoxide flame?

9. What two products result from combining carbon and oxygen in the combustion process?

10. What is the product of this chemical reaction? $S + O \longrightarrow SO$

Instructor Post Assessment Answers

1. Carbon monoxide

2. Carbon dioxide

3. 0

4. They fail to mix causing incomplete combustion.

5. No

6. Too much air.

7. Decomposition

8. Light blue

9. Carbon monoxide, carbon dioxide

10. Sulfur dioxide

Supplementary References

* Free choice reading of texts, pamphlets or manufacturer information on the combustion process.

INSTRUCTIONAL LEARNING SYSTEMS

16.2

COMBUSTION -- TYPES OF FUEL

Goal:

The apprentice can describe types of fuels.

Performance Indicators:

1. Describe coal fuels.
2. Describe oil fuels.
3. Describe natural gas fuels.
4. Describe wood fuel.
5. Describe proximate and ultimate analyses.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Anthracite
* Bituminous
* Crude petroleum
* Fixed carbon
* Heavy oil (Residual oil)
* Hogged fuel
* Light fuel oil
* Proximate analyses
* Pulverized coal
* Semi-anthracite
* Sub-bituminous
* Ultimate analyses
* Volatile matter

Introduction

Fuels contain carbon and hydrogen which can be easily combined with oxygen in the combustion process. A fuel can be either a solid such as coal or wood; a liquid such as fuel oil; or a gas such as nautral gas.

An operator should understand the fuels and their characteristics, advantages and disadvantages. Each fuel has unique qualities that should be fully understood if efficient heat yields are to be obtained from the combustion of the fuel.

Information

Fuels are substances that will produce combustion when mixed with oxygen. Many types of fuel are used to operate power plants. The common fuels are:

1. Coal
2. Fuel oil
3. Natural gas
4. Wood

Coal

Coal is made up of fixed carbon and volatile matter. The volatile matter portion of coal is made up of hydrocarbons that convert to gas form when heated. The portion of coal that is left after the volatile matter is passed off is called fixed carbon. Coals are divided into classes according to their content of fixed carbon and volatile matter.

1. Anthracite -- a shiny, hard coal with e high percentage of fixed carbon (92%) and a low percentage of volatile matter (8%).

2. Semianthracite -- a dark grey colored coal with 86 to 92% fixed carbon and 8 - 14% volatile matter.

3. Bituminous -- a black to dark brown coal that are best suited for power plant fuel. The supply is plentiful and coat is reasonable. The volatile matter content ranges from 14 % to more than 31 %.

4. Sub-bituminous -- High moisture content coal which reduces their shipping for power plant fuel.

5. Lignite -- Brown colored coal with high moisture and ash content and low heating value. It is not economical to ship lignite long distances.

6. Pulverized Coal -- Coal that has been finely ground and can be fed into the furnace with a stream of air. Pulverized coal is utilized by large plants that are located near the coal deposit.

Fuel Oil

Fuel oil is made from petroleum. It may be of three types.

1. Crude petroleum -- as it comes out of the well without processing.

Information

2. Heavy Oil or Residual Oil -- The residue of crude petroleum after partial refining. Gasoline and other volatile materials have been removed to make it a safer fuel.

3. Light fuel oil -- Residue of petroleum after complete refining.

Fuel oils are designated by grades that range from No. 1, the lightest grade, to No. 6, the heaviest grade. No. 6 fuel oil is the most common to steam generation plants. Fuel oil has many advantages over coal as a fuel. The combustion efficiency is higher; less storage is required; and it requires less labor and equipment.

Natural Gas

Natural gas is largely methane which is a hydrocarbon with the formula of CH_4. This means that each molecule of methane is composed of one carbon and four hydrogen atoms that are hooked together like this:

```
     H
     |
H -- C -- H
     |
     H
```

Methane makes up about 77% of natural gas. There is some 6% ethane which is bonded together like this:

```
     H    H
     |    |
H -- C -- C -- H
     |    |
     H    H
```

The chemical formula for ethane is C_2H_6 or two carbon atoms and six hydrogen atoms to each molecule.

In addition to methane and ethane, natural gas contains 4% of other hydrocarbons, 7% hydrogen sulfide and 5% carbon dioxide. The sulfur is usually removed from natural gas before it is burned.

Natural gas is the ideal boiler fuel. It does not leave an ash or residue, can be easily mixed with air; and is easy to control. It is more expensive than

Information

solid fuels and may require long lines to bring it to the plant site.

Wood

Wood and bark residues can be utilized to fuel boilers. Hogged fuel is wood that has been reduced to small pieces in a machine called a "hog". A typical unit of hogged fuel (200 cubic feet) would contain the following:

* Total weight -- 3650 pounds
* Dry weight -- 2190 pounds
* Water by weight -- 40 percent
* Heating value per dry pound -- 9840 BTU
* Heating value per unit -- 21, 200, 220 BTU
* Ash content — 1.88 percent

Hogged fuel is classified by species of wood, size, moisture content, ultimate analysis proximate analysis and heating value. The fuel has a high oxygen content which reduces the demands on outside air supply. The sulfur content of hogged fuel is so low that the problems of air pollution are not a risk. The volatile matter content of wood and bark is high (70-90%) and varies between species. Woods with high resin content produce much more heat than low resin woods.

Ultimate Analyses

Ultimate analyses are used to determine the chemical content of fuels. The amounts (percentages) of hydrogen, carbon, nitrogen and ash in the wood are determined by ultimate analysis. The ultimate analyses for Douglas Fir and Western Hemlock hogged fuel is shown in the following table.

Table 2. Typical Ultimate Analyses Data for Moisture-Free Samples of Hogged Fuel Bark.

Component	Douglas fir (14)	Western Hemlock (14)	Avg of 22 samples[1]
	%	%	%
Hydrogen	6.2	5.8	6.1
Carbon	53.0	51.2	51.6
Oxygen	39.3	39.2	41.6
Nitrogen	0.0	0.1	0.1
Ash (inorganics)	1.5	3.7	0.6

[1]These samples were collected and analyzed by Weyerhaeuser Company. They were random samples of hogged fuel taken from various mill sites.

Information

Proximate Analyses

Proximate analyses are used to determine the percentages of volatile matter, fixed carbon and ash in a fuel. A proximate analyses of several types of bark and sawdust fuels are shown in the following table.

Table 3. Typical Proximate Analyses of Moisture-Free Wood Fuels (8).

Species	Volatile matter	Charcoal	Ash
	%	%	%
BARK			
Hemlock	74.3	24.0	1.7
Douglas fir, old growth	70.6	27.2	2.2
Douglas fir, young growth	73.0	25.8	1.2
Grand fir	74.9	22.6	2.5
White fir	73.4	24.0	2.6
Ponderosa pine	73.4	25.9	0.7
Alder	74.3	23.3	2.4
Redwood	71.3	27.9	0.8
Cedar bark	86.7	13.1	0.2
SAWDUST			
Hemlock	84.8	15.0	0.2
Douglas fir	86.2	13.7	0.1
White fir	84.4	15.1	0.5
Ponderosa pine	87.0	12.8	0.2
Redwood	83.5	16.1	0.4
Cedar	77.0	21.0	2.0

Assignment

* Complete self-assessment and check answers with the answer sheet.
* Complete post-assessment and have instructor check your answers.

Self Assessment

Match the words and phrases.

____ 1.	Volatile matter	A.	Shiny, hard coal with high level of fixed carbon.
____ 2.	Fixed carbon	B.	Oil as it comes out of the ground.
____ 3.	Anthracite	C.	Oil that has had complete distillation.
____ 4.	Pulverized coal	D.	Makes up 77% of natural gas.
____ 5.	Bituminous	E.	Fed into furnace by air stream.
____ 6.	Crude petroleum	F.	Low in sulfur content.
____ 7.	Heavy oil	G.	Portion of fuel left after volatile matter is passed off.
____ 8.	Light fuel oil	H.	Type of coal that is best suited as power plant fuel.
____ 9.	Methane	I.	Oil that has had partial distillation.
____ 10.	Wood fuel	J.	Converts to gas when heated.

Self Assessment Answers

J 1.

G 2.

A 3.

E 4.

H 5.

B 6.

I 7.

C 8.

D 9.

F 10.

Post Assessment

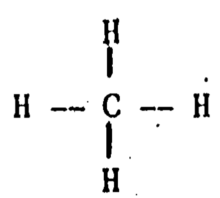
1. Coal is made up of fixed carbon and ______________________.

2. Anthracite has 92% fixed carbon and 8% ______________________.

3. List three types of fuel oil that can be used as furnace fuel.

4. The grades of fuel oil range from No. 1 to No. __________.

5. What does the following chemical formula represent?



6. Natural gas is made up of 77% ______________, 6% ______________, 4% of other hydrocarbons, 7% hydrogen sulfide and 5% carbon dioxide.

7. Describe the ash problem with natural gas fuel.

8. A ________________ analysis determines the chemical composition of a fuel.

9. A ________________ analysis determines the percentage of volatile matter, fixed carbon and ash in a fuel.

10. Is sulphur a big problem in wood fuels?

Instructor Post Assessment Answers

1. Volatile matter
2. Volatile matter
3. Crude petroleum, heavy oil, light fuel oil
4. No. 6
5. Methane
6. Methane, Ethane
7. There is no ash problem.
8. Ultimate analysis
9. Proximate analysis
10. No

Supplementary References

* Research Bulletin 17. Biolers fired with Wood and Bark Residues. David C. Junge. Forest Research Laboratory. Oregon State University. 1975.

* Correspondence Course. Fuels and Combustion. Second Class, Lecture 5, Section 2. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

INSTRUCTIONAL LEARNING SYSTEMS

16.3

COMBUSTION -- AIR AND FLUE GASES

Goal:

The apprentice will be able to describe air and flue gas relationships in combustion.

Performance Indicators:

1. Describe air requirements for combustion.
2. Describe flue gases.
3. Describe flue gas analysis

1

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.

* Read the vocabulary list to find new words that will be used in package.

* Read the introduction and information sheets.

* Complete the job sheet.

* Complete self-assessment.

* Complete post-assessment.

Vocabulary

* Analyzing cells
* Automatic gas analyzer
* Carbon dioxide (CO_2)
* Carbon monoxide (CO)
* Combustible analyzing cell
* Compensating filaments
* Excess air
* Measuring filaments
* Oxygen analyzing cell
* Sulfur dioxide (SO_2)
* Theoretical air

Introduction

The combustion process must be carefully monitored if efficiency in combustion is desired. Flue gases hold the clues that tell us whether the combustion was complete or incomplete.

Since flue gases cannot be physically measured, they must be anlyzed by chemical procedures. This can be accomplished by a laboratory approach or through the use of automatic analyzers.

Once the analyses have been completed, the operator must make adjustments to improve the combustion process. If too much CO is found in the flue gas, combustion is incomplete and more air should be supplied.

Information

Complete combustion requires air for oxygen. Air contains 21% oxygen and 79% nitrogen. The amount of air required for complete combustion is called theoretical air. In practice, more air must be added beyond the theoretical air to assure that all fuel comes in contact with oxygen molecules. Excess air is that amount of air added beyond the theoretical air requirement. Excess air is shown as a percentage of theoretical air.

Combustion in the presence of excess air produces substances that will appear in the flue gas. These are called the products of combustion. Complete combustion gives products of carbon dioxide, sulfur dioxide, water and excess O_2. Carbon monoxide in the flue gas is a product of incomplete combustion. The efficiency of combustion can be determined by analyzing the flue gas.

Flue Gas Analysis

A flue gas analysis determines the volume percentages of carbon dioxide (CO_2), carbon monoxide (CO) and oxygen (O_2). Water and sulfur content are not normally measured in a flue gas analysis.

The maximum content for CO_2 of various fuels is as follows:

* Coal 19%
* Oil 15.5%
* Nautral Gas 12%

These maximums are based on absence of excess air. If excess air is supplied, the percentages of CO_2 will be reduced.

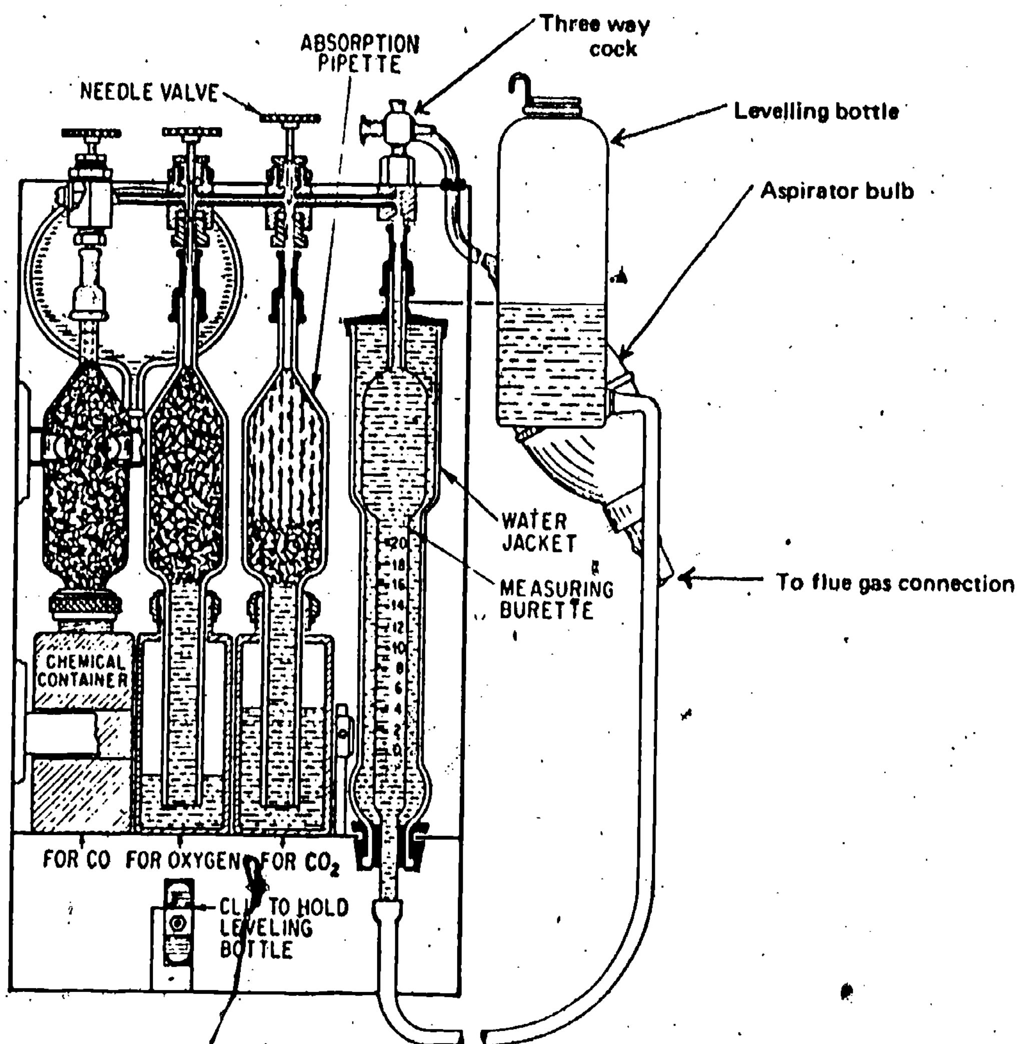
The analysis procedure can be completed by use of:

* Orsat Apparatus — a device composed of burrettes, bottles, bulbs and valves.

* Automatic gas analyzer which collects the sample, tests and records results.

The steps in analyzing for CO_2 with the Orsat apparatus are laboratory procedures that require detailed and painstaking effort. This process will not be detailed in this package. The apprentice that wishes to master the process should consult a manual. The same apparatus is used to analyze for O_2 and CO content.

Information



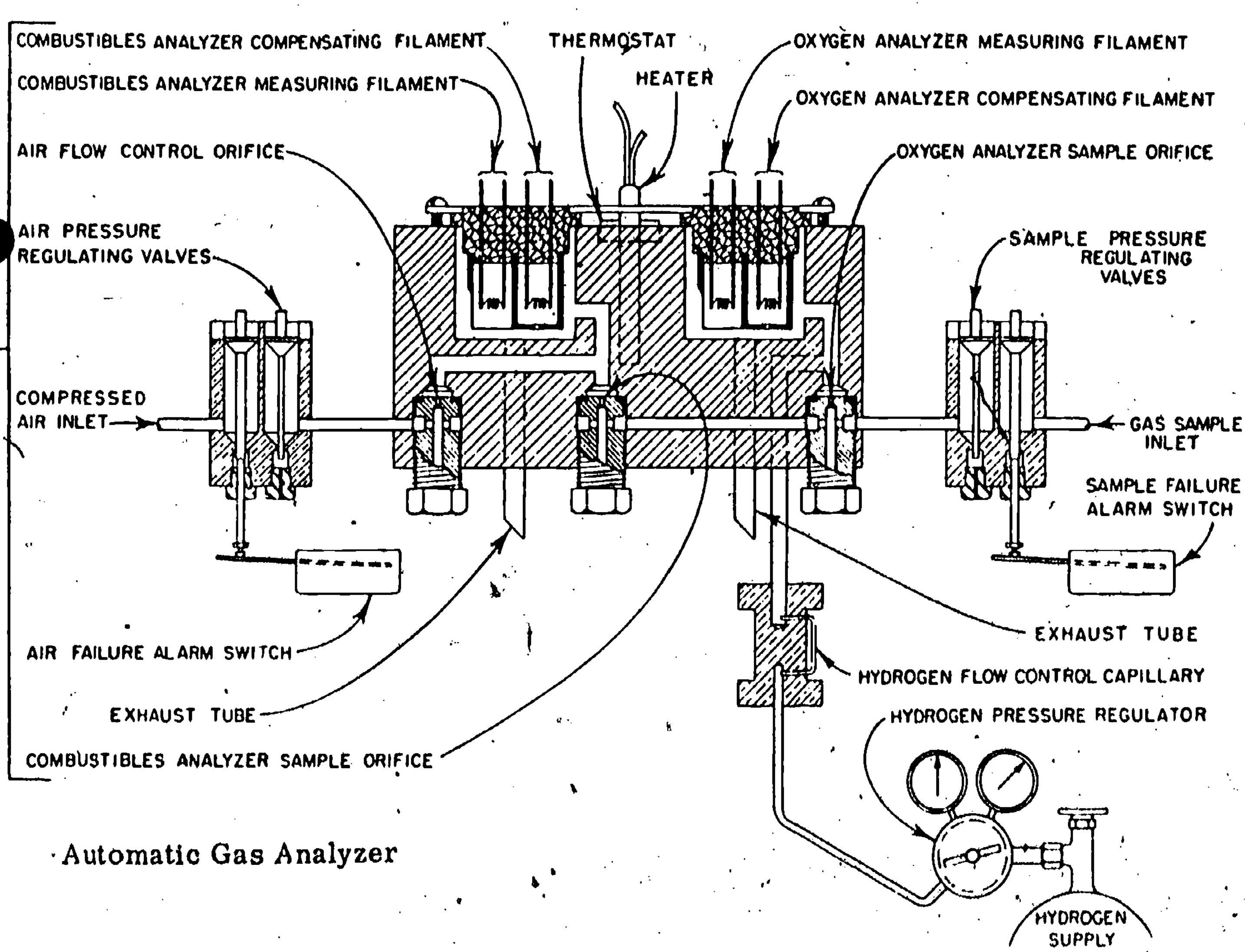
Orsat Apparatus

Automatic Gas Analyzers.

Modern power plants have instruments that automatically measure the levels of CO_2, O_2 and CO in the flue gases. Automatic analyzers use measuring filaments and compensating filaments of platimum. Hydrogen is suppplied to the filaments from a tank. When the sample gas meets the hydrogen at the filament, combustion occurs. The two filaments will heat up to different levels which changes the electrical resistance of the filaments. This electrical resistance is measured and recorded automatically. The measuring devices are called analyzing cells.

Information

Each analyzing cell contains the two platimum filaments. There is an oxygen analyzing cell and a Combustible analyzing cell in an analyzer. A diagram of an automatic gas analyzer is shown below.



Automatic Gas Analyzer

BEST COPY AVAILABLE

Assignment

* Read pages 13 - 20 in the supplementary reference.
* Complete job sheet.
* Complete self-assessment and check answers.
* Complete post-assessment and ask instructor to check answers.

Job Sheet

ASSIST JOURNEYMAN IN ANALYZING FLUE GAS

* Ask experienced operator to assist in making flue gas analysis.

* Observe their techniques in:

  - Pulling the gas sample
  - Testing for CO_2
  - Testing for O_2
  - Testing for CO

* Observe the computations of percentages.

* Ask operator to explain findings.

* Ask operator to explain actions to be taken as a result of the test.

* If automatic gas analyzers are used, ask operator to explain the recorded analysis.

Self Assessment

1. The exact amount of air needed to achieve complete combustion is called ______________ air.

2. Additional air beyond that needed for complete combustion is aded so that all fuel will be exposed to oxygen. The additional air is called ____________________ air.

3. The products of complete combustion are ____________ ____________, sulfur dioxide, H_2O and O_2.

4. A product of incomplete combustion is ____________ ____________.

5. What three substances are analyzed in a flue gas analysis.

6. Are sulfur and water content of flue gases analyzed?

7. The maximum CO_2 level is lowest for ____________ ____________ fuel.

8. The ____________ ____________ apparatus is used for analyzing flue gases.

9. What are the measuring devices in an automatic gas analyzer?

10. Automatic analyzers use compensating filaments and ______________ filaments in the analyzing cells.

Self Assessment Answers

1. Theoretical air
2. Excess air
3. Carbon dioxide
4. Carbon monoxide
5. CO_2, O_2, CO
6. No
7. Natural gas
8. Orsat
9. Analyzing cells
10. Compensating

Post Assessment

1. Flue gas can be analyzed by two methods. List those methods.

2. List two types of filaments in the analyzing cells of an automatic gas analyzer.

3. List two types of analyzing cells in an automatic gas analyzer.

4. Air contains ______% nitrogen and ______% oxygen.

5. List the products of complete combustion.

6. What is the major product of incomplete combustion?

7. How is the sulfur content of flue gas measured?

8. What is an Orstat apparatus used for?

9. Is the percentage levels of CO_2 increased or decreased with the addition of excess air?

10. What substances are analyzed in a flue gas analysis?

Instructor Post Assessment Answers

1. Orsat apparatus, automatic gas analyzer

2. Measuring and compensating

3. Oxygen analyzing cells and combustible analyzing cells

4. 79% nitrogen and 21% oxygen

5. Carbon dioxide (CO_2), sulfur dioxide (SO_2), water, oxygen (O_2)

6. Carbon monoxide (CO)

7. Sulfur is not measured

8. Analyze flue gases

9. Decreased

10. CO , O , CO

Supplementary References

* Correspondence Course, Lecture 5, Section 2, Third Class. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

INSTRUCTIONAL LEARNING SYSTEMS

16.4

COMBUSTION -- HEAT TRANSFER

Goal:

The apprentice will be able to describe heat transfer methods.

Performance Indicators:

1. Describe heat transfer by conduction.
2. Describe heat transfer by convection.
3. Describe heat transfer by radiation.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Conduction
* Convection
* Convection currents
* Forced convection
* Heat transfer
* Insulation
* Joules
* Natural convection
* Radiation
* Thermal conductivity

Introduction

Heat is generated in a furnace and must be transferred to other locations. Water, steam and air must receive heat from the boiler furnace.

Much of the heat can be efficiently utilized if the methods of heat transfer are understood and followed. The operator must understand the basic methods of heat transfer in order to understand the procedures in boiler operation.

This package explains the three methods of heat transfer.

Information

Heat flows from one body to another. The flow is always from the body of high temperature to the one of lower temperature. The rate of flow is dependent on the temperature differences and type of material that the heat is flowing through. The movements of heat from one place to another is called <u>heat transfer</u>.

Heat transfer can be accomplished by three methods.

1. <u>Conduction</u>
2. <u>Convection</u>
3. <u>Radiation</u>

Conduction

In conduction, heat moves through a body from one molecule to the next molecule. If a high temperature is applied to one molecule, the heat will move to surrounding molecules of lower temperature. An example of conduction occurs when a metal object is heated on one end. The heat will travel from molecule to molecule until the opposite end will eventually become hot. Some materials conduct heat very well. The ability to conduct heat is called <u>thermal conductivity</u> which is expressed in <u>joules</u> of heat transferred. Copper has a high thermal conductivity. Air, wool, cork and asbestos have low thermal conductivity and are used as <u>insulation</u> to reduce the transfer of heat.

Convection

Heat transfer by convection involves liquids or gases. As a liquid or gas is heated, it expands and rises toward the top. When it moves upward, it is replaced by cool liquid that will be heated. The water in a boiler drum is heated by <u>convection currents</u>. Flue gases move up the smokestack by convection currents. This is known as <u>natural convection</u> because it rises on its own as the temperature increases. In cases where hot water is moved through a system by a pump, it is called <u>forced convection</u>. Many residental water systems in Alaska use forced convection to transfer heat. On -50 nights, one can hear the gurgle of forced convection as it moves hot water throughout the house.

Radiation

Radiation refers to the emission of electro-magnetic waves of light rays. In the case of heat transfer, the waves are emitted from a high temperature bodies. The receiving body will either absorb the thermal waves; allow them to pass on through; or reflect them away. Some materials absorb heat and others reflect it. Smooth surfaces tend to reflect it. Smooth surfaces tend to reflect heat while

Information

rough surfaces absorb it. Air tends to pass the energy through absorbing only a small part of the heat. In boiler operation, heat is transferred from the furnace to the tubes by radiation.

Assignment

* Read pages 8 - 9 in reference.
* Complete job sheet.
* Complete self-assessment and check answers.
* Complete post-assessment and have instructor check answers.

Job Sheet

CONDUCT EXPERIMENTS IN HEAT TRANSFER

1. Take a piece of copper wire. Hold on to one end and stick the other end in the fire. Continue holding until heat reaches your hand. (CONDUCTION)

2. Hold your hand over a fireplace fire or campfire at some distance above the flames. Feel the warm currents from hot air and gases. (CONVECTION)

3. Find a spot that will allow the sun to beam directly on to your body. Feel the warming by the thermal waves of the sun. (RADIATION)

Self Assessment

1. The movement of heat from one body to another is called ____________ ________________.

2. The movement of heat from molecule to molecule is called ______________________________.

3. Thermal waves move from one body to another by ________________________.

4. Fluids and gases move heat by rising upward as the temperature rises. This method of heat movement is called ____________________________.

5. The ability to conduct heat is called ________________ __________________.

Self Assessment Answers

1. Heat transfer
2. Conduction
3. Radiation
4. Convection
5. Thermal conductivity

Post Assessment

1. List three methods of heat transfer.

2. Which method of heat transfer is used to move heat from the furnace to boiler tube walls?

3. Which method of heat transfer is involved in moving flue gases up the smokestack?

4. The thermal conductivity of materials is expressed in ________________.

5. List two types of convection.

Instructor Post Assessment Answers

1. Conduction, convection and radiation.

2. Radiation

3. Convection

4. Joules

5. Natural and forced

Supplementary References

* Basic Training Manual for Steam Power Plant Operators. Pacific Gas and Electric Company. 1964.

INSTRUCTIONAL LEARNING SYSTEMS

16.5

COMBUSTION -- WOOD

Goal:

The apprentice will be able to describe factors affecting combustion of wood fuel.

Performance Indicators:

1. Describe fuel related factors affecting combustion.
2. Describe air related factors affecting combustion.
3. Describe other factors affecting combustion.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Evaporation
* Gaseous-phase reaction
* Moisture content
* Proximate analysis
* Size of particle
* Turbulence
* Ultimate analysis

Introduction

Waste wood products are becoming more important as a fuel for steam generation equipment. As forest products firms seek better utilization of their by-products, the generation of power offers a practical use for hogged fuels.

The Oregon landscape was recently dotted with wigwam burners and waste sawdust piles. Those scenes have vanished. Hogged fuels, sawdust and barkdust have become valuable by-products of a forest economy. Power generation is one option in full utilization of Oregon trees. Wood is the prime boiler fuel in Oregon and Washington.

The combustion of wood differs from other fuels. This package discusses some of the factors to be considered in the combustion of wood fuel.

Information

In Oregon, hogged fuel is used to generate steam in many plants because of its availability. The combustion process in wood differs from that of other fuels. Basically, it is a gaseous-phase reaction. About 75-85% of wood fuel is volatile matter and must burn in the gaseous state. Several factors affect the burning of wood fuels and their heat yield.

Size of Wood Particles

Since most of the wood must be converted into a gaseous state for burning, evaporation becomes important. The size of the wood particles determine how fast the evaporation takes place. The smaller pieces, the faster the wood will vaporize and burn. A surface area to volume ratio is used to designate the effect on combustion rates by different size wood particles.

Moisture Content

Moisture content directly affects the evaporation rate of wood fuel. Evaporation takes place immediately with dry wood fuel. In woods with high moisture content, much of the heat is needed to evaporate the moisture. The following table shows the moisture content and relative ratio of surface to volume and its effect on the rate of combustion for several types of wood fuel.

Wood and Bark Residues	Moisture Content (%)	Ratio Surface to Volume	Effect On Rate of Combustion
Bark	45	1	2
Planer Shavings (Kiln dry)	16	5	30
Planer Shavings (Green)	40	5	12
Sawdust	35	6	17

Note the effect of particle size by comparing bark and sawdust. The sawdust has a value of 17 as compared to 2 for bark. The rate of combustion is much faster for sawdust. Likewise, compare kiln dry and green planer shavings. Moisture content affects the rate of combustion considerably.

Information

Ultimate Analysis

The ultimate analysis shows that 617 pounds of air is required to burn 100 pounds of hogged fuel. The excess air can be determined directly form measuring CO_2 and O_2 and comparing it with this ultimate analysis of wood fuel.

Proximate Analysis

The proximate analysis provides percentages of volatile materials, fixed carbon and ash in a fuel. From 75-85% of wood is volatile matter. A 2% ash content is of concern to an operator. Ash does not burn but it can cause problems by plugging up airways and grates. Mechanical collection equipment must be designed to withstand this high ash content.

Method of Feeding Fuel

The method for feeding fuel is dependent on the furnace design. In a Dutch oven furnace, the fuel is poured onto the top of a pile and allowed to tumble down the pile to the furnace grates. Combustion is slow in taking place. A spreader-stoker furnace is fed by spreading the fuel across the grate and fall through the flames. Combustion takes place immediately. The method of feeding will have an effect on the efficiency of combustion.

Distribution of Fuel in Furnace

Fuel must be spread evenly over the furnace floor. Even distribution of fuel should be practiced in all types of furnaces.

Variations in Fuel Feed Rates

Increases in fuel feed rates to meet load demands may affect combustion. Loading high moisture fuel into a furnace may cause an upset in the combustion process. The feed rate should be increased gradually--not all at once. Gradual increases help maintain stability of the combustion process.

Depth of Fuel Pile in Furnace

Deep piles of fuel cause a decrease in airflow under the fire. Most wood furnaces are not equipped to vary the air pressure. In Dutch oven furnaces, changes in fuel pile depth causes changes in the transfer of radiation heat. Care should be given to maintaining a fuel pile depth that is constant.

Information

Separate Firing Practices

Sometimes, several types of hogged fuel are used at the same time. Some operators mix the fuels together and others feed them into the furnace separately. Quite often sanderdust and bark are fed separately. Problems in combustion can arise when different fuels are fed into the furnace. Sanderdust is highly combustible while bark is less combustible. The uneven combustion rates may lead to problems in stabilizing the combustion process.

Auxiliary Fuel Usage

Other fuels are often used to support combustion of high moisture wood. Coal and oil contain sulfur which creates air pollution. This may not be desirable when air pollution standards are to be met. Natural gas is a good choice of auxiliary fuels because it is relatively free of ash.

Percentage of Excess Air

Some excess air is necessary for the combustion process. Too much excess air creates problems. Manufacturers recommend 20-50 percent range as being optimum for excess air in hogged fuel boilers.

Air Temperature

When air enters the combustion zone, it should be preheated. Preheated air is important to drying of the fuel and speeding up the combustion rate.

Ratio of Overfire to Underfire Air

The ratio will vary with the design of the furnace. A theoretical ratio shows that 75% of the air should be supplied above the fuel pile and 25% below it. Fuel moisture content and furnace design influence the ratio. With some high moisture woods, the underfire air should make up 75% of the total air.

Turbulence of Air

Complete combustion requires that oxygen molecules must come into contact with each fuel molecule. In order to make this contact, the air and fuel must be tossed around by a gas flow in the furnace. The more turbulence of air, the better the combustion process. Well mixed fuel and air is safer because fuel vapors are not allowed to collect in pockets. Explosions can be the result of such vapor pockets.

Information

Flow Relations Between Forced-Draft And Induced-Draft Systems

Some hogged fuel furnaces do not have balanced, automated draft systems. Such installations do not have good control of the combustion process. Incomplete combustion in the form of emissions of smoke cinders and other pollutants can be observed coming out of the stack.

Other Factors

Soot and ash deposits must be regularly removed if good combustion conditions are to be maintained.

Boiler cleaning and maintenance is important to good combustion.

The water level in the steam drum should be maintained for optimum combustion.

Assignment

* Read pages 19-29 in supplementary reference.
* Complete the job sheet.
* Complete the self-assessment and check answers.
* Complete the post-assessment and ask instructor to check answers.

Job Sheet

VISIT WOOD BURNING BOILER SITE

* Locate a nearby plant that uses wood as a fuel.

* Ask permission to visit and observe wood fueled equipment.

* Determine

  - What type of hogged fuel is used?
  - How is the fuel processed before entering furnace?
  - What kind of furnace is used?
  - What type of draft control is used?
  - Does the plant use an auxiliary fuel? What kind?
  - Does the plant use separate firing practices for more than one kind of hogged fuels?
  - What types of equipment are used to monitor fuel, air, exhaust gases?
  - What special equipment is used to control the combustion process?
  - How is air pollution monitored?

Self Assessment

1. What percentage of hogged fuel is volatile matter?

2. The rate of evaporation is largely determine by ________________ of the wood particles.

3. Which has the higher moisture content--sawdust or bark?

4. Which will burn faster--sawdust or bark?

5. What is shown in a proximate analysis?

6. What is shown in an ultimate analysis?

7. Should wood fuel be fed as a pile of fuel or spread evenly over the furnace?

8. What is caused by making the fuel pile too deep?

9. What is the major disadvantage of coal and oil as auxiliary fuels?

10. Why is air turbulence important to combustion?

Self Assessment Answers

1. 75 - 85 %

2. Size

3. Bark

4. Sawdust

5. Percentages of volatile matter, fixed carbon and ash in fuel

6. Percentages of carbon, hydrogen, oxygen, nitrogen and ash in fuel

7. Spread evenly over floor

8. Decreases in airflow under the fuel pile

9. Adds air pollution problem

10. Aid combustion and prevent gas vapor pockets

Post Assessment

1. In systems without good draft equipment, what are some observable signs of incomplete combustion?

2. Which furnace would offer the fastest rate of combustion due to its method of feeding--the Dutch oven or a spreader-stoker type?

3. When there is a sudden demand for steam load, should the operator increase the feed rate gradually or all at once?

4. Why do small wood particles give better combustion rates than large particles?

5. The effect of particle size on combustion rates is described as a surface area to ______________ ratio.

6. The percentages of oxygen, hydrogen, carbon, nitrogen and ash in a fuel is determined by ________________________ analysis.

7. The percentages of volatile matter, fixed carbon and ash is determined by a ________________________ analysis of wood fuels.

8. The theoretical ratio of air needed for combustion is _________ % supplied as overair and ________ % as underair. Due to design differences this ratio does not apply in many furnaces.

9. List two reasons why air turbulence is important to combustion?

10. Does the airflow increase or decrease under the fire when fuel is piled too deep?

Instructor Post Assessment Answers

1. Smoke cinders and pollutants passing out the stack

2. Spreader--stoker

3. Gradually

4. Allows evaporation to take place faster

5. Volume

6. Ultimate analysis

7. Proximate analysis

8. 75 % overair and 25% underair

9. Mixes fuel and air molecules and prevents fuel vapor pockets which may cause explosions.

10. Decrease

Supplementary References

* Boilers Fired With Wood and Bark Residues. David C. Junge. Research Bulletin 17. Forest Research Laboratory. Oregon State University. 1975.