•••POWER
ENGINEERING

Fourth Class

Edition 3.5

Typical Industrial Plant Configurations

Part B

Unit B-12

Published by PanGlobal Training Systems Ltd.
Publishers of Power Engineering Learning Materials

The material in this series is aligned with the SOPEEC Fourth Class Syllabus, dated November 2017, and the IPECC Curriculum, November 2017.
For more info visit http://www.sopeec.org

Preface – Note to Readers

On 30 June 2025, PanGlobal Training Systems Ltd. (PG) ceased operations. Ownership of the Power Engineering Learning Materials previously published through PG, is now jointly held by the Northern Alberta Institute of Technology (NAIT), the Southern Alberta Institute of Technology (SAIT), and the British Columbia Institute of Technology (BCIT).

All three institutions intend to make these learning materials publicly, and freely available, guided by the principles established through Creative Commons. Specifically, the institutions intend that these learning materials circulate in accordance with the spirit of the following license:

> **Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International**[1]
> **(CC-BY-NC-SA)**

This means that:

- Users may distribute, remix, adapt, and build upon this material in any medium or format, for non-commercial purposes only.
- Non-commercial means: not primarily intended for or directed towards commercial advantage or monetary compensation.
- If others modify or adapt the material, they must license the modified material under the same terms of CC-BY-NC-SA.

Given that CC licenses are designed to recognize individual creators of content, not corporate owners, the institutions request the following acknowledgement accompany any non-commercial re-use of the materials:

> This material has been made available by the Northern Alberta Institute of Technology (NAIT), the Southern Alberta Institute of Technology (SAIT), and the British Columbia Institute of Technology (BCIT).

March 2026

A. Ojimelukwe
NAIT

Rysen Jordan
SAIT

Sanja Boskovic
BCIT

---

[1] See "About CC Licenses," at *Creative Commons,* as accessed 4 March 2026*;* *https://creativecommons.org/share-your-work/cclicenses/*. See also License Deed at https://creativecommons.org/licenses/by-nc-sa/4.0/

These learning materials are endorsed by the Institute of Power Engineers (IPE).

LEGAL NOTICE
The information, figures and procedures presented in this book are provided as general training and background information, and should not be taken as specific operating practice for any specific piece of equipment or in any individual plant implementation. Training for specific pieces of equipment, and their implementations should be provided by the employer and the equipment manufacturer.

The information and illustrations contained in this book are provided "As Is", without warranty of any kind, expressed or implied, including without limitation any warranty concerning the accuracy, adequacy, or completeness of such information. Neither the publisher, the authors, nor the copyright holders shall be held responsible for any claims attributable to error, omissions, or inaccuracies contained in this book. Nor shall they be liable for direct, indirect, special, incidental or consequential damages arising out of the use of such information or materials.

Printed in Canada
Fourth Class - Part B - Unit B-12 - Typical Industrial Plant Configurations
Edition 3.5, July 2020

ISBN13: 978-1-77251-265-6 (Part B Print Set)
ISBN13: 978-1-77251-266-3 (Part B Ebook Set)
ISBN13: 978-1-77251-313-4 (Unit B12 Print)
ISBN13: 978-1-77251-314-1 (Unit B12 Ebook)

For information on this and other products visit our website located at **panglobal.org**.
Any technical or editorial errors may also be reported on our website by using our on-line ticketing system.

#11, 1339 – 40th Ave. NE
Calgary, Alberta
T2E 8N6

Features of the Fourth Class Edition 3.5 Textbooks

Using the Margin Icons

The Fourth Class Edition 3.5 uses a number of icons, located in the margins of the text or in special text boxes. These icons are meant to add value to the learning flow of the topic. Some icons reference other resources that are available to you that will be useful in preparing for your certification examinations. Some provide additional context or another way to look at each topic. Here is a list of the icons and what they mean.

ACADEMIC SUPPLEMENT
A S
	When this icon appears, the formula, conversion factors, charts, or constants being used can be found in the PanGlobal Academic Supplement Edition 2.0 (available in PanGlobal's bookstore (panglobal.org). This Supplement is approved by SOPEEC for use in certification examinations, so take the time to learn how to use it. HINT: Do not write in the Academic Supplement if you plan to use it for examinations.
	Content includes:
	• SI and USCS units and multiples
	• Useful formulas in
	    • Mathematics
	    • Applied mechanics
	    • Thermodynamics
	    • Electricity
	• Periodic table
	• Common ion names
	• Interest tables
	• Steam tables in SI units
	• Properties of refrigerants in SI units
	• Psychrometric chart

ACADEMIC EXTRACT A E	When this icon appears, the textbook's code reference can be found in PanGlobal's ASME Academic Extract. The ASME Academic Extract presents ASME code for the use of Power Engineering students. Like the Academic Supplement, the Academic Extract is approved by SOPEEC for use in examinations: do not write in it. Volumes 1 and 2 of the ASME Academic Extract are available in PanGlobal's bookstore (panglobal.org).
ON TRACK ✓	The check mark icon appears when you need to stay focused and on track. Sometimes, the material may be a bit confusing, so On Track messages help provide clarity. When you see the check mark, make sure you understand the theory behind these important concepts. Use an On Track message as an opportunity for a quick self-assessment of your understanding of the concepts in the learning objective.
SIDE TRACK ↱	The Side Track icon directs you to other chapters or resources if you want more information about a topic.
MEDIA ▶	Media icons show that some form of supporting medium is available. These media may include videos, animations, 2D and 3D models, multi-views of cutaways, simulations, and more. Media elements are available to registered textbook purchasers online via MyPower Study.
SAFETY or CAUTION ⚠	The Safety or Caution icon alerts you to important safety issues or operational concepts. The safety issues may be personal safety (do not look at a welding arc) or operational safety (keep the water in the gauge glass to prevent a boiler pressure vessel failure). Pay strict attention to these icons.

4th Class Edition 3.5 • Part B

UNIT B-12

TYPICAL INDUSTRIAL PLANT CONFIGURATIONS

UNIT INTRODUCTION

Although many Power Engineers are employed in plants and processes dedicated solely to the production and use of steam, such as thermal power stations and direct heating/cooling plants, the majority of Power Engineers work in industries that use steam or heat as part of a production process. Examples of these plants include hot oil, wood, and biomass processing; liquid hydrocarbon processing; natural gas; food processing; and metallurgical processing plants.

Within these environments, Power Engineers often assume process operator duties on non-steam equipment. This unit looks at each of these plant types and identifies common processes and equipment that Power Engineers play a role in managing or operating.

UNIT RATIONALE

At the heart of every industrial or commercial complex whose processes or infrastructure depend on thermal energy, there is a central or dispersed utility system that supplies that energy. Power Engineers have the knowledge and skillset required to safely and efficiently operate and manage these thermal processes. It is wrongly assumed that Power Engineers are only involved in power generation. The Power Engineer is a valuable contributor to the safe and efficient operation of plants in all energy-intensive industrial and commercial sectors.

4th Class Edition 3.5 • Part B • Unit 12

CHAPTER 1

Common Plant Configurations in Hydrocarbon-centric Industries

LEARNING OUTCOME

When you complete this chapter you should be able to:

Identify steam-related processes employed in common types of plants.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

1. *Identify standard thermal system pathways and segments commonly used in plants.*
2. *Identify equipment and processes in heat transfer fluid (HTF) heating systems.*
3. *Identify the main thermal processes used in oil refining industries.*
4. *Describe the main processes used in steam assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS).*
5. *Identify thermal processes used in gas separation and compression plants.*

CHAPTER INTRODUCTION

Hydrocarbon processing is a complex segment of the economy. Thermal fluids are essential to the physical processes and chemical reactions that are part of hydrocarbon processing.

Heat is used to both separate and chemically alter the characteristics of the hydrocarbon feedstocks. Common thermal processing stages used throughout the industry include generation, distribution, end use, and recovery of thermal fluids.

Plants within different types of industries use common equipment configurations to complete these processing stages. Heating and cooling thermal processes create and separate saleable end products. Basic feedstocks can include a wide variety of fluids, such as sweet and sour (containing hydrogen sulfide – H_2S) natural gas, conventional crudes, heavy crudes, and oil sands. Effectively managing these thermal operations requires the unique skill set of the Power Engineer.

Objective 1

Identify standard thermal system pathways and segments commonly used in plants.

Steam is the principal energy transfer medium that industry depends on for process applications. Steam provides energy for process heating, pressure control, mechanical drives, electrical generation, and component separation. Process steam is also a source of water (condensate) for many industrial operations and chemical reactions.

The popularity of steam as an energy transfer medium originates from the many advantages it has over other options, including the following:

- Low toxicity
- Transportability
- High efficiency
- High heat capacity
- Low acquisition and production costs

Saturated steam has the ability to retain a significant amount of energy (between 2500 and 2800 kJ/kg), making it an ideal energy transport medium. This energy can be extracted from the steam in the form of mechanical work through a turbine or as heat for process heating.

Most of the heat contained in steam is in the form of **latent heat**. Large quantities of energy can be transferred efficiently at a constant temperature, which is useful for many process heating applications. In addition, process steam systems are used to control the pressures and temperatures of many chemical and physical processes.

A **heat transfer fluid (HTF) system** is an industrial system that uses a pump to circulate a special heat transfer liquid through a fired **heat exchanger**. The HTF operates in either the vapour or, more commonly, liquid phase. A vapour phase system employs an internal or external flash drum. A flash drum is not required for a liquid phase. An HTF operates in a closed loop circulation system under atmospheric pressure.

Although there are relatively few HTF systems compared to steam systems, the choice between the two is mostly governed by the thermal requirements of the process. If the required temperature of the system is above freezing but below approximately 175°C, the choice is most often steam. Above 175°C, an HTF system may be preferred.

The direct conversion of thermal energy from the combustion of fuel gas into mechanical energy using a gas turbine is an increasingly popular option, due to both economic and environmental considerations.

The configuration and operation of steam or HTF processing systems in energy conversion industries vary significantly; however, four processes are common to all plants:

1. Generation of heat and steam
2. Distribution of thermal energy
3. End use processes
4. Recovery and reuse of excess energy and fluid

Each process uses a variety of equipment. Depending on the system configuration and its operating conditions, qualified Power Engineers are often required to manage and operate steam and HTF systems.

GENERATION

In most industrial plants, energy is converted from one form to another to generate heat (e.g., combustion). This heat then transfers from the source into a heat transfer medium. The medium used is typically one of three options: steam, HTF, or compressed gas. The chosen medium will determine equipment configurations within the generation section of the plant.

Heat Conversion Mediums

Thermal energy, or heat, can be transferred through conduction, convection, or radiation. For heat to be transferred through conduction and convection, a medium is required. A *medium* is the solid or fluid that is used to transfer heat energy from one source to another due to thermal equilibrium. Objects reach thermal equilibrium when a warmer object transfers heat to a cooler object. The objects will approach the same temperature, and, in the absence of heat loss to other objects, they will then maintain a constant temperature.

Steam

A boiler (firetube, watertube, or electric) or a heat recovery steam generator generates steam by transferring the thermal energy released in a heat generating process (from combustion, mechanical, or electric sources) into liquid water. This raises the temperature of the water and converts it into vapour. The steam (or water, if in liquid form under pressure) carries the additional energy to an end use. Then, a thermal or mechanical action transfers the energy out of the steam (or water).

Heat Transfer Fluid

Combustion, mechanical, or electric sources are also used to add heat to a thermal fluid. The activity of these sources raises the temperature of the thermal fluid. A heat exchange process can then transfer this additional thermal energy to an end use. Examples of HTFs are glycol, oil, **diluent**, and condensate.

Compressed Gas

When combusted directly in a furnace, compressed hydrocarbons produce heated gases that can be used as a direct thermal energy transfer medium.

Additional Heat Transfer Equipment

In some boilers, a superheater will further increase the energy content of the steam. The result is a steam temperature that exceeds a saturation temperature at a specific pressure.

An economizer is an integral part of the generation section. An economizer recycles recovered thermal energy from the combustion gases exiting the boiler, or steam generator. The recovered heat from the combustion gases is directly transferred to the incoming feedwater through a heat exchanger located in the furnace outlet.

Combustion air preheaters (heat exchangers) apply the same principle as an economizer; however, they transfer the excess heat from the end use into the incoming combustion air to reduce energy requirements.

Ancillary equipment and controls ensure feedwater quality, efficiency, and process safety in the generating system equipment and controls.

DISTRIBUTION

The heat generated by a furnace, boiler, or steam generator will be transferred by the thermal transfer medium (steam, gas, or thermal liquid) through the distribution system and ultimately on to the end user. If the medium is steam or gas, a significant pressure differential drives the process. Because the pressure differential is not high in HTF systems, a pump provides the force required to move the fluid.

A distribution system regulates the delivery of thermal energy through its response to changing pressure and temperature requirements. A number of factors can affect the efficiency of this distribution, such as thermal insulation, piping, and component separation technologies.

Appropriate insulation surrounding the thermal distribution system increases the following:

a) Comfort levels in the plant by reducing the transfer of heat from the distribution system into areas of the plant inhabited by staff

b) Plant safety by lowering surface temperatures, which reduces the risk of burns

c) Amount of thermal energy available for end uses by reducing the amount of heat lost to the plant environment

The piping required to carry these fluids needs to be properly sized, supported, insulated, and configured with the flexibility to ensure efficient system operation. Many distribution systems have several take-off lines that operate at different pressures. Various types of isolation valves, pressure-regulating valves, pressure-relief valves, and traps separate these distribution lines.

In steam systems that generate wet steam, steam separators remove water droplets, usually by controlled centrifugal flow. A **steam accumulator** allows the additional energy in excess steam to discharge into a pressure vessel partially filled with water. If the system later requires this energy, dropping the pressure of the steam accumulator allows the energy to be removed from the steam the water releases.

The addition of an appropriate number and type of steam traps greatly improves steam distribution system efficiencies. During system start-up, steam traps allow air in the equipment and lines to escape. During system operation, steam traps enable condensate to pass into the condensate return system while trapping the steam in the system; this minimizes the need for make-up steam.

A distribution system that performs properly delivers sufficient quantities of high-quality steam or HTF at the right pressures and temperatures for the end uses. Effective performance of the system requires proper steam pressure balance, efficient condensate return systems, optimum insulation with regular repair and maintenance, and proper **pressure regulation**.

END USE

There are many end uses for the thermal fluid, steam, or combustion gases that exit from the distribution system. Ultimately, all of these will transfer their thermal energy into other forms of useful energy. Examples of end uses include process heating, mechanical drive, electrical generation, chemical reactions, and fractionation of hydrocarbon components.

The types of processes used can be categorized into two types:

1. Physical
2. Chemical

Physical Processes

Physical processes do not add sufficient energy to produce a chemical change in compounds; however, the processes do emit enough energy to cause physical changes in the make-up of the compounds. The following section describes several physical processes.

Adsorption

During an **adsorption** process, adsorbing agents called **molecular sieves** are used as a filtering medium to separate molecules based on their physical size. An example of this process is the separation of the C4 refinery product stream, which contains 1-butene, 2-butene, butane, and isobutene. The isobutene will separate cleanly, since it is too bulky to be adsorbed on the 3–10 angstrom pores of the molecular sieve.

Compression/Cooling

Industrial vapour-compression refrigeration processes maintain temperatures and also separate components by their condensation temperatures. Commercial refrigerators for the large-scale storage and shipping of chilled or frozen products use this process. Many types of industrial plants use vapour-compression refrigeration systems for both temperature maintenance and separation. These plants include oil refineries, petrochemical and chemical processing plants, and natural gas processing plants.

Crystallization

In a **crystallization** process, a crystalline substance separates from a non-crystalline substance. First the solution is cooled, and then the components are separated through a process such as filtration or centrifugation. This process is often used to remove crystalline waxes from petroleum or edible oils.

Dilution

Steam is often used to dilute a process gas. Diluting the gas reduces the buildup of solids on heat exchangers.

Distillation/Fractionation

During **distillation** (usually carried out in a distillation tower or fractionating column), compounds are separated into fractions by differential boiling points. Distillation is a common industrial process.

Drying/Evaporation

The process of **drying** or **evaporation** may be defined as the vaporization and removal of water or other liquids from a solution, suspension, or other solid-liquid mixture to form either a more-concentrated liquid or a dry solid.

Pressure Regulation

Steam, injected into a fixed-volume reaction vessel, can control the pressure of a reaction.

Process Quenching

In **process quenching**, which is separate from compression processes, steam is occasionally used to cool and thus stop high-temperature reaction processes.

Solvent Extraction

Solvent extraction separates substances by using differences in solubility between compounds in complex mixtures. An example of this process in a petroleum refinery is the use of diethylene glycol to extract benzene, toluene, and xylene (BTX) from the distillation mixture.

Stripping Towers

In **stripping towers**, steam pulls unwanted contaminants from a process fluid and directs them to waste or back into the process for further refinement.

Thermo-Mechanical Conversion

In the final stages of power generation, steam turbine generators convert thermal energy into mechanical energy.

Conversely, direct conversion of mechanical energy into thermal energy occurs in **thermo-mechanical** pulping (TMP), a process that uses mechanical action to separate wood chip fibres. In this process, the mechanical energy causes friction, which produces steam from the moisture contained in wood chips.

Transport

Steam is often injected directly into a process to facilitate product transport.

Chemical Processes

A **chemical conversion process** converts one compound into another by chemical reaction. The process involves chemical manipulation of either molecular size or chemical structure.

Molecular Size Reduction

The **molecular size reduction** process involves breaking the chemical bonds of a large molecule and creating smaller molecules. This is done to convert surplus, unsaleable product into a new product that is in demand. For example, if there is more paraffin wax than required to meet market demand, some of the wax can be run through a catalytic cracker to convert it into naphtha or gasoline.

Chemical Structure Adjustment

A **chemical structure adjustment** rearranges the chemical structure of a compound or mixture to create a different product or to improve performance in the original product. For example, heat is required to promote the electrochemical processes used in smelting or steel manufacture, which convert metallic ores into solid metals. In the gasoline manufacturing process, a product with a more branched chemical structure will have a higher octane number. An isomerization process may be used to convert straight-chain alkanes into branched-chain alkanes.

There is a wide range of end-use equipment used in these and other applications. The U.S. Department of Energy, in their **Steam Source Book**, has compiled a comprehensive list of the major steam end-use equipment used in energy intensive industries. Table 1 uses this compilation as the basis for an overview.

Table 1 – End Use Equipment in Energy Intensive Industries

Equipment	Typical process application	Example industry
Chillers	Process/facility cooling	Human comfort, food, chemicals, cold storage, recreation (e.g., arena ice)
Condenser	Steam turbine operation (gland sealing), distillation	Aluminum, chemicals, forest products, glass, metal casting, petroleum refining, steel
Deaerator	Direct contact process heating	Electricity generation, chemicals, biomass, petroleum, food, metals, manufacturing
Distillation tower	Distillation, fractionation	Chemical manufacturing, petroleum refining
Dryer/**evaporator**	Drying or evaporating to a solid or concentrated liquid	Chemical manufacture, forest products, food processing, medical, pharmaceutical
Fired heater	HTF systems (high temperature, low pressure), fractionating towers	Oil and gas, metals, high-temperature processing
Generator	Conversion of mechanical energy to electrical energy	Electricity generation, chemicals, biomass, petroleum, food, metals, manufacturing, and more
Gas turbine	Power generation, mechanical drive, heat recovery steam generator	Electricity generation, oil and gas, pipelines, distributed power, combined heat and power (CHP)
Heat exchanger	Process air and water heating, gas recovery/light ends distillation, storage tank heating	Aluminum, chemical manufacturing, food processing, forest products, glass manufacture, metal casting, petroleum refining, steel
Reboiler	Improved fractionation in distillation processes	Petroleum refining, chemical manufacturing
Reformer	Hydrogen generation normally through a reaction of steam with methane	Chemical manufacturing, petroleum refining
Separator	Component separation	Chemical manufacturing, forest products, petroleum refining
Steam ejector	Turbine condenser operation, vacuum distillation, gland sealing	Aluminum, chemical manufacturing, forest products, glass, metal casting, petroleum refining, steel, HVAC
Steam injector	Agitation/blending, heating	Chemical manufacturing, forest products, petroleum refining
Steam turbine	Power generation, compressor mechanical drive, pump mechanical drive, feed pump mechanical drive	Aluminum, chemical manufacturing, forest products, glass, metal casting, petroleum refining, steel
Steam jacketed kettle/ proofing boiler	Cooking	Food industry
Sterilizer/autoclave	Sterilization	Food industry, medical
Stripper	Distillation (crude and vacuum units), component removal, component separation, fractionation	Chemical manufacturing, petroleum refining
Thermocompressor	Drying, steam pressure amplification	Forest products, food industry

Adapted from US DOE Steam Source Book.
https://energy.gov/sites/prod/files/2014/05/f15/steamsourcebook.pdf

RECOVERY AND REUSE

If gas is the energy transfer medium, the recovery and reuse processes are simple when compared to steam or thermal fluid. Reuse involves the use of a heat exchanger to extract energy that exceeds the process needs. This energy can then preheat or warm up combustion air.

When steam condenses completely, it forms condensate in the same mass, at the same pressure and temperature. The system will continue to have a significant level of useable heat (sensible). An efficient steam system will maximize recovery and reuse of this condensate, once the end-use process has extracted the energy it requires.

Condensate is normally reused as feedwater in the boiler, after appropriate conditioning. The condensate return system sends the condensate back to the boiler. Any condensate not returned must be replaced by make-up water, which means additional costs of water, water treatment, and fuel to heat the water from a lower temperature.

The condensate returns through piping to a collection tank (condensate receiver). Sometimes the treated make-up water and chemicals are added here; at other times this is done in the deaerator. From the condensate receiver, the condensate is pumped to the deaerator, which strips oxygen and non-condensable gases. Boiler feed pumps increase the feedwater pressure above boiler pressure and inject feedwater into the boiler to complete the cycle.

Unlike steam systems, HTF systems do not usually have a condensate collection process, nor do they operate at high pressures. This simplifies the return of the fluids, which is usually through low-pressure piping. Reuse is commonly after only a simple filtering process.

OBJECTIVE 2

Identify equipment and processes in heat transfer fluid (HTF) heating systems.

HEAT TRANSFER FLUIDS: HOT OIL SYSTEMS

This objective will explain and describe a hot oil HTF system. A **hot oil system** uses oil as a thermal fluid, instead of steam or water, to transfer heat from a central source to other areas of a plant. This system consists of the following components:

- A heat source with internal coils (usually a fired heater)
- Piping to distribute the heated oil and return the cooled oil
- Heat exchangers to transfer the heat from the oil to other fluids
- A circulating pump to create and maintain the required circulation

An HTF system is very much like a hot water heating system. The fundamental differences are that oil has a much higher boiling point than water, and the system runs at a higher temperature. Because of the higher temperatures, HTFs exhibit much lower vapour pressure than steam. Under jurisdictional regulations, hot oil systems may be registered at a lower level than the equivalent operational steam system.

HTFs, especially hot oils, are widely used to carry thermal energy in oil and gas, process heating, metalworking, and machine-cooling applications. These fluids are mainly used in high-temperature process applications, where low pressures are preferred.

Hot oil systems were initially used due to higher energy efficiency and heat transfer rates, than water or glycol heating systems. However, the original oils used were unstable if the temperature regularly increased above the rated stable temperature for the oils. This led to the breakdown of the oils as they became partially oxidized and thermally unstable. Oils used today are more thermally stable under harsh conditions, they are nontoxic, and they can create and stably maintain higher temperatures at atmospheric pressure.

The following are reasons to consider selecting an oil-based heating system instead of a steam heating system:

- Low system pressures
- High operating temperatures
- No corrosion or freezing concerns
- Simple circuit requirements; no blowdowns, steam traps, or condensate return systems needed
- No retubing, minimal filtering
- No water treatment requirements
- A single fluid is used for a process that requires both heating and cooling

Hot oil systems operate at atmospheric or higher pressures. These systems can be either vapour-based (Figure 1) or liquid-based systems (Figure 2).

Vapour-Based System

The operating temperature of a vapour-based system is the HTF saturation temperature. The saturated gas works as the heat transfer medium. The process of gas phase heat transfer involves heating the HTF to generate HTF vapour in a manner similar to the generation of steam. The difference is that the HTF vapour generates at higher temperatures but exhibits lower pressures.

The additional thermal energy transfers to heat-consuming equipment, usually through a heat exchanger device. The HTF cools down after releasing its latent heat. A circulating pump flows the condensed HTF back to the heating furnace. The heating temperature of the vapour phase heat transfer system is even and constant. The temperature difference between the inlet and outlet of heat-consuming equipment can be controlled within a 1°C–2°C range.

A vapour-based system can be used if higher temperatures and heat transfer rates are required, but this system is generally more expensive and complex than a liquid-based system. Vapour systems have one of the following:

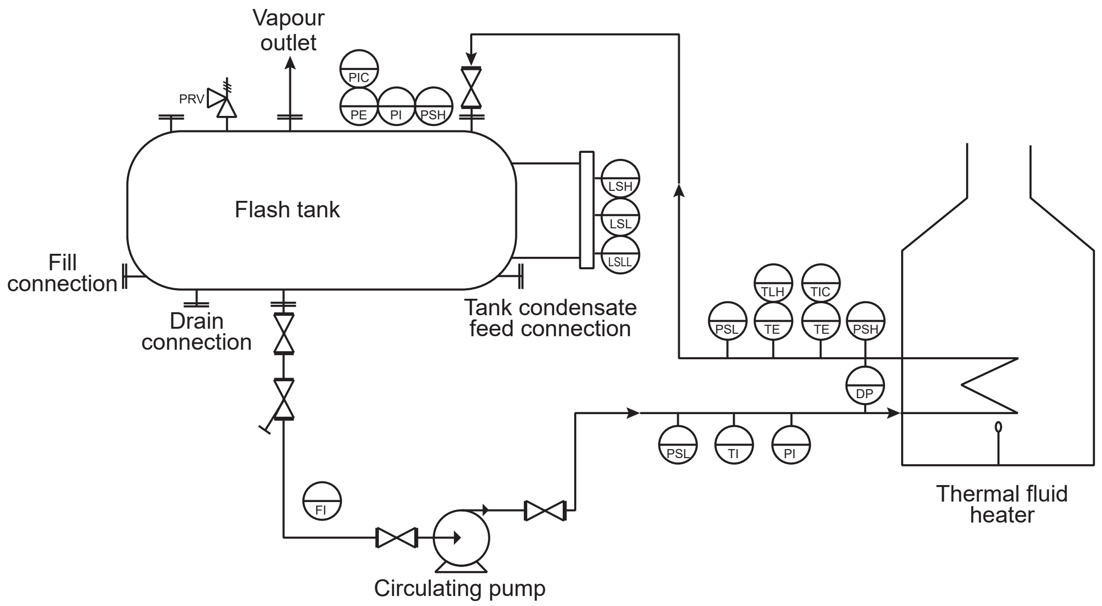
- A heater, in which vaporization of the fluid takes place

  or

- A flooded heater, in which the fluid is vaporized externally through a flash drum or flash tank

HTFs degrade over time in elevated temperatures and will oxidize if in contact with atmospheric air. Overheating and contamination will impede heat transfer. Contaminants also deposit and spoil the heating surfaces. Sedimentation from solids may block pipes and valves and burn the heater elements as well.

Figure 1 – Vapour-Based Heat Transfer Fluid System

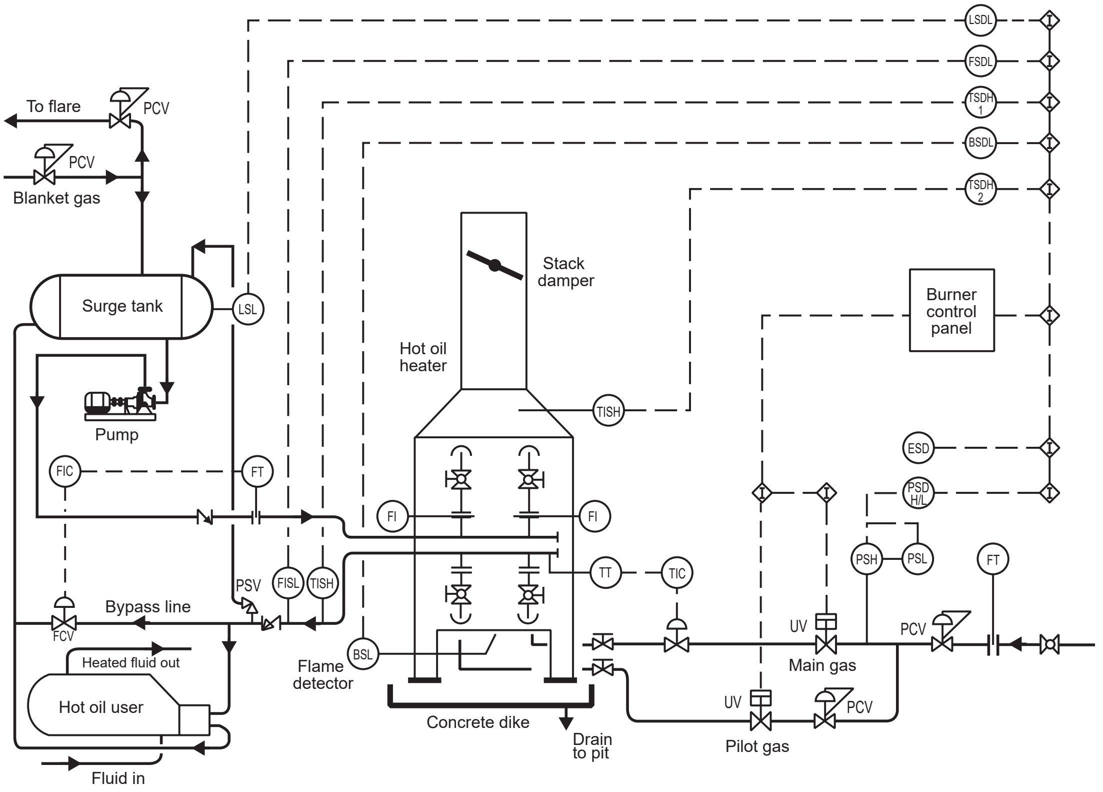


Liquid-Based System

A liquid-based thermal HTF system will usually have a centrifugal pump, but sometimes the system will use a gear pump instead. A centrifugal pump is preferable because it has higher flow rates that can enhance heat transfer. Due to the high temperature of the thermal fluid, the circulating pumps are often water cooled.

The expansion (or surge) tank is critical for the operation of the system. The main purpose of the tank is to allow the HTF to expand when heated or contract when cooled. The tank is also a built-in reservoir for the system. In the event of a leak, the expansion tank will feed the system to keep it full. If the level in the tank drops, it means that a leak may have developed; therefore, it is important to monitor the level of the expansion tank daily.

Figure 2 – Liquid-Based Heat Transfer Fluid System



Choosing an HTF

The choice of HTF depends upon the process requirements. For example, if a vapour system with a high process temperature is required, the fluid options are extremely limited (typically temperatures over 400°C will often use molten salts). However, if a liquid system that operates within a temperature range of 200°C–300°C is required, then a wide choice of fluids is available.

Many HTFs have relatively high coefficients of thermal expansion. Adequate allowance must be made for thermal expansion at the design stage when sizing expansion tanks or overflow and venting systems.

HTF Deterioration and Safety

HTFs are noncorrosive. Any corrosion problems in the system are usually caused by contaminants, such as cleaning fluids left in the system at start-up or process fluid leaking into the system. It is important to test the HTF annually to check for contaminants to protect the integrity of the system.

Over time, all HTFs have an increasing potential to deteriorate due to the continuing elevated temperatures. When replacing degraded HTF, it is essential to first clean the system and remove all traces of the old fluid. Then recharge the clean system with fresh fluid. Failure to do so will result in premature degradation of the new fluid.

Important: The range between efficient operation and the point at which the oil starts to degrade and tube wall life starts to decrease is very narrow. This range can be as little as a 20°C–30°C difference. Temperatures must be closely monitored in order for the HTF system to operate efficiently.

The potential hazards of hot oil HTF systems include the following:

a) Burn hazards: exposed piping systems are extremely hot and pose a burn hazard to personnel.

b) High flashpoint: the system almost always operates above the flashpoint, which can produce vapours that will form burnable mixtures with air.

c) Ignition source in the form of a fired heater or furnace in a hazardous area: if a leak occurs in an HTF system, this could produce a flammable mist exiting at high temperatures, which could create an explosion hazard.

CAUTION

Warning: The combination of a hydrocarbon fluid, and an ignition source, creates the potential for a serious accident to occur if the correct design, operation, and maintenance procedures are not carried out.

HTF EQUIPMENT MANAGED BY POWER ENGINEERS

HTF systems use three types of heaters: radiant, convection, and a combination of the two.

In **radiant heaters**, the combustion gases do not flow across the tube surfaces. Instead, heat transfers from the burning fuel to the tubes through radiation across the furnace space. Radiant heaters have a 40%–50% efficiency, which is quite low.

In **convection heaters**, the combustion gases flow across the tubes, which are usually of the extended type (i.e., have fins on their outer surface). Heat then transfers by conduction through the tube metal to the hot oil flowing in the tubes. Convection heaters generally have an efficiency of 75%–85%.

Combination radiant and convection heaters are most commonly used. This combination can have greater than 85% efficiency, particularly in larger units.

Typical Fired Heater Design

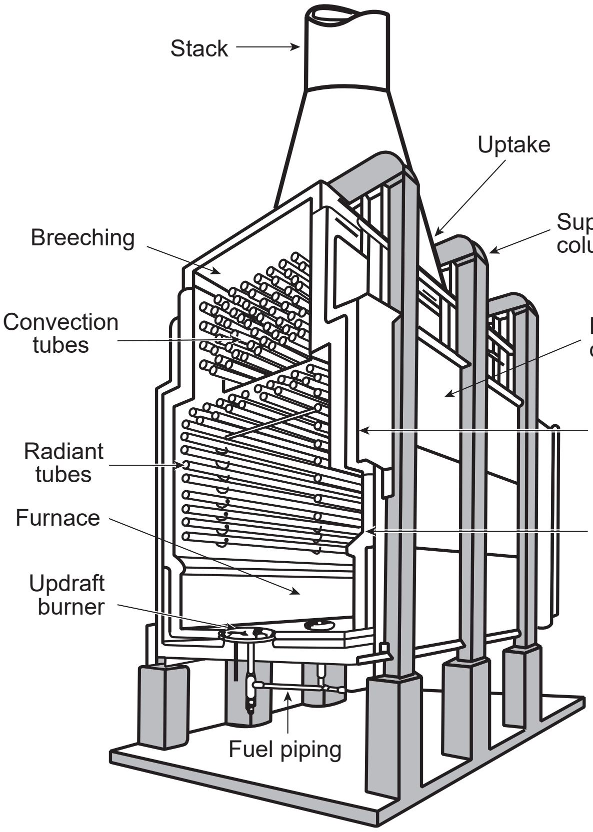
A typical fired heater design is the updraft model. It consists of both radiant and convection tube sections.

Figure 3 illustrates a horizontal rectangular heater in which the convection section is located in the breeching. This construction is very common in modern direct heaters.

Hot oil enters the heater tubes located in the convection section (usually arranged in two separate passes). The oil flows along each tube as it descends in series and enters the radiant section, where the tubes are located along each wall of the furnace. Hot oil exits from the lowest tube on each wall and is delivered to the process equipment in the plant.

The gas updraft burners are mounted on the floor of the furnace, and they extend along a centre line from the front to the back.

Figure 3 – Horizontal Rectangular Direct-Fired Heater



Refractory brick and other suitable insulating materials line the inner walls and floor of the furnace. This insulation contains the heat inside the furnace and prevents the metal skin that encloses the furnace from overheating. Structural support beams mounted on reinforced concrete piers strengthen and support the heater.

A concrete dike surrounds the foundation to prevent hot oil from spreading beyond the immediate confines of the heater in case of a tube rupture. A drain, which goes from the diked area to a pit about 50 metres from the heater, allows the hot oil to drain to a safe area.

Protective Devices

As with a boiler, the fired heater of a hot oil system requires careful operation. Properly functioning safety devices will reduce the risk of workplace injuries and major damage to property. The hot oil is in a liquid form and under moderate pressures, so it is unlikely to present an expansive explosion hazard like steam does; however, its elevated temperature and ability to burn rapidly is still of concern.

CAUTION

In the event of poor oil flow through the furnace, followed by an overheated tube that fails and splits open, hot oil will spray into the furnace and become ignited by the burners. The oil thus takes part in the general combustion within the furnace. Because of the volume of oil sprayed, the furnace will quickly overheat.

The flow of oil to the coils and fuel gas to the burners must immediately stop. Otherwise, the heater will burn up in a large fire. Generally, this will result in the complete loss of the heater. In the worst case, the size of the fire may threaten personnel, as well as other vessels and equipment in the vicinity.

Because of these explosion hazards, hot oil systems have several automatic shutdown devices, or **interlocks**. (An interlock makes two mechanisms dependent on each other.)

The following is a list of the protective devices typically included in a hot oil system:

a) An expansion tank low oil level indicator: prevents loss of suction to the pump

b) A burner flame failure device: shuts off fuel to the burner if it detects a flame-out situation. A heater with multiple burners usually does not require all pilot burners to be lit. If two or three adjacent burners are lit, the shutdown will not cause an interruption of fuel.

c) A low hot oil flow indicator: is always installed in the outlet line from the heater. Severe overheating and probably tube failure will occur if hot oil stops flowing through the heater.

d) A hot oil high-temperature shutdown device: is installed in the outlet line from the heater. Degradation and coking of hot oil is very likely if temperatures become excessively high.

e) A high stack temperature indicator: is installed at the stack outlet. This indicator shows the result of a tube failure, which permits oil to spray into the furnace space and combust, raising the temperature of the furnace. The device senses the high furnace temperature at the stack outlet and sends a signal to shut the furnace down.

f) An emergency shutdown switch: allows the operator to manually shut down the plant in case any part of the plant is in danger because of equipment malfunction, release of gas or liquid to the atmosphere, smoke, fire, or any other occurrence that leads the operator to conclude that a total plant shutdown is necessary.

g) A high or low fuel level/pressure shutdown device: prevents unstable burner operation in the event of high or low fuel gas pressure

h) A pressure/safety relief valve: located downstream of the heater, is installed in the discharge line of the pump. The discharge from the valve returns to the hot oil surge tank.

i) A flow transmitter (flow meter) and flow switch: located in the discharge line from the pump. These devices monitor the hot oil flowing through the pump to ensure there is enough flow to protect the heater tubes from overheating.

If any of these devices sense a malfunction, the automatic gas shut-off valves will close, cutting off the fuel supply to the main and pilot burners.

Expansion Tank

The expansion tank (also called a *surge tank*) is critical for the operation of the system. The main purpose is to allow heat transfer fluid to expand when heated or contract when cooled. It is also a built-in reservoir for the system. In case there is a leak, the expansion tank will "feed" the system to keep the system full. It is important to monitor the level of the expansion tank daily. If the level drops, a leak may have developed.

Hot Oil Pumps

Hot oil pumps are usually single-stage centrifugal pumps, with the maximum allowable pump temperature governed by the mechanical seal material. If the non-metallic parts of the mechanical seal are Teflon, a maximum temperature of 200°C is allowed. The hot oil system has two pumps installed: one operates while the other is on standby.

Always leave the suction valve of the standby pump open; this allows a small amount of hot oil to flow backwards through the pump via a small bypass line around the discharge check valve. This flow maintains the standby pump at operating temperature; otherwise, the standby pump would be difficult to start in cold weather because of the high viscosity of oil at low temperatures.

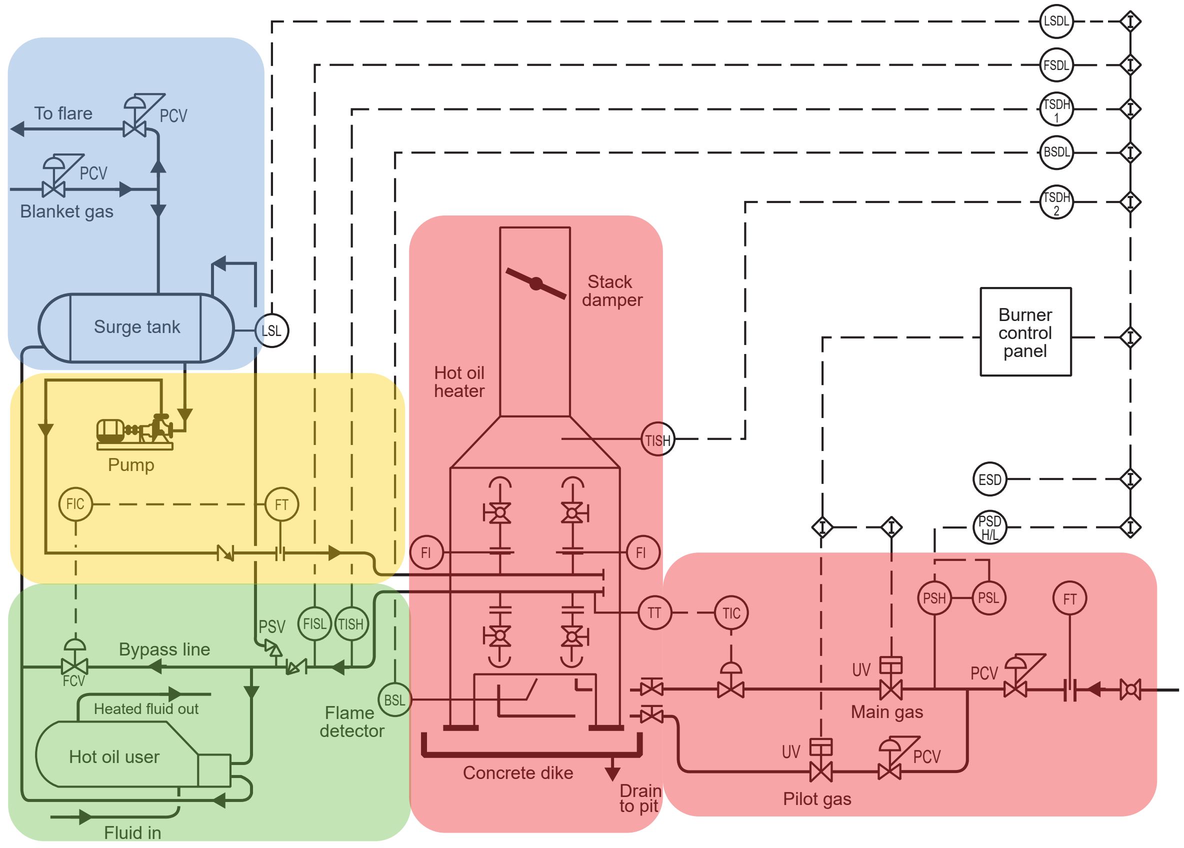
The pump should be located at a level sufficiently below the expansion tank. The pump location will provide the necessary static head to avoid possible cavitation in the pump suction.

Thermal Systems and Associated Equipment

As in all thermal operations, the equipment can be categorized into the four thermal systems discussed in Objective 1, and as shown in Figure 4.

1. Generation (red)
2. Distribution (yellow)
3. End-use/process (green)
4. Recovery and reuse (yellow)

Figure 4 – Liquid-Based Heat Transfer Fluid System – Thermal Systems



Some auxiliary equipment, such as piping, valves, and pumps, commonly occur in all four regions of the plant, as shown in Figure 4. Major equipment in each area includes all of the following:

- A heater, for thermal generation
- An expansion tank, which supplies the distribution system
- A motorized pump, which is central to the return system

OBJECTIVE 3

Identify the main thermal processes used in oil refining industries.

OIL REFINERIES

A petroleum refinery is a complex plant that contains several individual process plants. Each plant has a specific function, and each refinery is built to process a certain type or mixture of crude oil.

Crude oil refineries can produce petroleum products or feedstocks, depending on the crude oil supplied to the refinery and the equipment installed. Feedstocks will need to undergo further processing at another facility. Some examples of petroleum products and feedstock that are produced are:

a) Liquefied petroleum gases (LPGs):
   - Propane
   - Butane

b) Gasolines

c) **Kerosene**

d) Jet fuel

e) Diesel fuel

f) Heating fuels

g) Asphalt and tar

h) Petrochemicals and lubricating oil feedstock:
   - Plastics
   - Synthetic fibres
   - Paints and coatings
   - Adhesives
   - Ethylene
   - Propylene
   - Butadiene
   - Benzene

i) Coke

The overall goal of a refinery is to separate the hydrocarbon components in the crude oil and modify some of the components to maximize production of high-demand products, such as gasoline and petrochemical feedstocks. The following table gives a brief description of typical refinery products.

Table 2 – Common Products Manufactured from Crude Oil

Product manufactured	Description of product and its typical uses
Liquefied petroleum gases (LPG)	Light hydrocarbon gases at atmospheric pressure and room temperature; held in the liquid phase by pressure to facilitate storage, transport, and handling. These gases consist primarily of propane and butane. Used for home heating and as a petrochemical base stock.
Gasoline	A refined petroleum distillate that normally boils within the range of 30°C–300°C. It is most often used as a fuel in spark-ignited internal combustion engines. It may also be referred to as Number 1 oil.
Kerosene	A refined petroleum distillate, intermediate in volatility between gasoline and heavier gas oils used in some diesel engines and for home heating. It may also be referred to as Number 1 oil.
Distillate fuel oil	A general term meaning those distillable hydrocarbon liquid mixtures of lower volatility than kerosene. Used as a fuel in industrial and home heating applications. It may be referred to as Number 2 oil.
Residual fuel oil	The material remaining as unevaporated liquid from distillation or cracking processes. Used mainly as boiler fuel in power plants and ocean-going ships. Is commonly referenced as Number 6 oil, but may also be referred to as bunker C oil.
Aviation jet fuel	Specifically blended grades of petroleum distillate suitable for use in jet engines. These fuels have high stability, a low freezing point, and overall high volatility.
Petrochemical feedstocks	A broad term encompassing those refinery products that have typically low molecular mass and high purity, such as ethane, ethylene, propylene, acetylene, butane, butadiene, and benzene.
Other products	May include petroleum coke, petroleum solvents, lubricating oils, greases, or asphalt.

(Courtesy of "The Petroleum Refining Industry" – a US Congress publication)

Crude petroleum is a mixture of hydrocarbon molecules of many different sizes and shapes. For example, two carbon atoms in a chain with six hydrogen atoms attached is called *ethane*, three carbon atoms in a chain with eight hydrogen atoms attached is called *propane*, and so on. The boiling point of hydrocarbons increases with the number of carbon atoms.

The first processing stage in a refinery separates fractions by boiling point ranges. As the molecular weight of the crude oil increases, so does the boiling point. Therefore, by heating the oil to vaporize it and then cooling the vapour gradually, the crude can be separated into various fractions. As the vapour cools, the heavier molecules condense first, and they are removed. With further cooling, the lighter hydrocarbon fractions also condense, and they are also removed. This process does not chemically alter the compounds in the original oil; it only alters their concentration in the different fractions. This stage is typically performed in distillation towers.

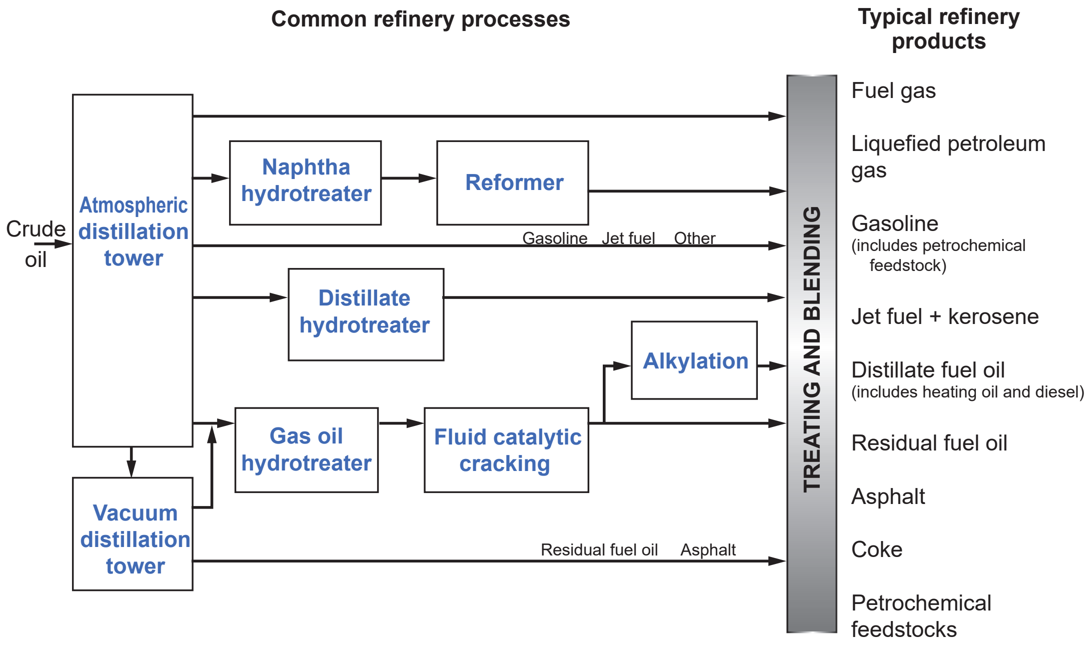
The next stage in the refining process converts the separated fractions into the various product streams, such as those described in Table 2. This stage involves the separation processes as in the first stage above. However, it also requires processes that alter the molecular structure of the compounds to produce product fractions. Typical examples of these types of processes include hydrotreating, cracking, forming, and alkylation.

Once the products are formed, they are further processed to remove undesirable contaminants such as sulfur and carbon dioxide. The raw products are then blended and additives are introduced to produce the desired products for sale.

Refinery Processes

Petroleum refineries produce saleable petroleum products from crude oil. Figure 5 provides a simple overview of a typical crude refinery process flow.

Figure 5 – Typical Conventional Oil Refinery Processes and Products



Before entering the separation and chemical reaction processes, the crude oil must first be heated to the required temperature in an efficient manner. In this case, efficiency means using the least amount of fuel, as well as considering that prolonged exposure to heat or high temperatures may result in chemical decomposition of the oil. At this stage, two types of heaters are used. The first is a heat exchanger, and the second is a furnace.

After being preheated in the heat exchangers and furnace upstream, the crude oil enters the atmospheric distillation towers. Here the crude separates into liquid and vapour phases. The liquid falls and the vapours rise up through the column. The distillation column contains a series of stacked plates or trays. As the vapours rise through the column, mechanical contact with the trays and falling liquids decreases the boiling point of components in the rising vapour, causing entrained liquids to drop out of the gas. Each level of stacked plates or trays is called a stage. When vapour changes state from a gas to a liquid, the liquid falls down to the previous stage in the column, and the gas continues to rise to the next stage. The liquid-free vapour eventually exits out the top of the atmospheric distillation tower and proceeds downstream for further processing.

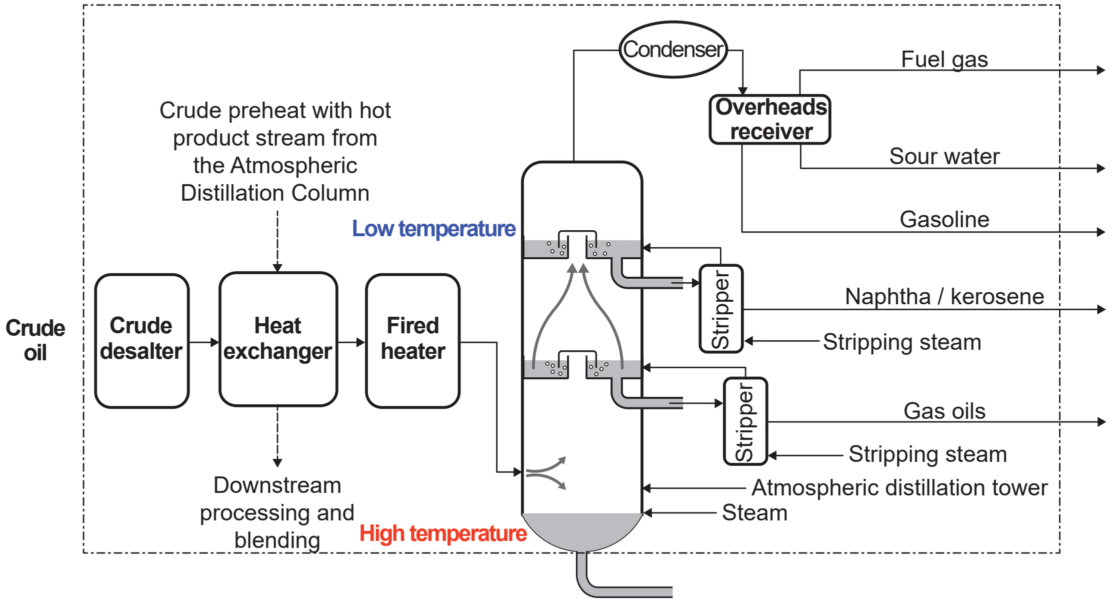
The liquids from the atmospheric tower collect in the trays and flow into a secondary distillation tower, called a vacuum distillation tower or stripper. In the secondary column, steam is injected into the fraction liquids to further extract any crude vapours. The vapours will be transported back to the main column with the **stripping steam** for further fractionation. This process of recovering liquids in the secondary columns is cyclical.

Lighter hydrocarbons, such as butane and other LPGs, gasoline-blending components, and naphtha, are recovered at the lowest temperatures. Mid-temperature range products include jet fuel, kerosene, and distillates (such as home heating oil and diesel fuel). The heaviest products, such as residual fuel oil, are recovered at high temperatures, sometimes over 530°C.

For those fractions requiring more processing, additional stages can include **hydrotreating**, cracking, **reforming**, and **alkylation**, among others.

Figure 5 provides an overview of how these processes are connected. Figure 6 shows where the different hydrocarbon products are created.

Figure 6 – Initial Refinery Heating and Separation Processes



Petrochemical Feedstocks

Many refineries produce base petrochemical feedstock in addition to fuels. These petrochemicals are divided into three groups, depending on their chemical structure:

1. **Olefins** (double-bonded carbons), including ethylene, propylene, and butadiene, are produced in the cracking process assisted by steam using the following sequence:

   Hydrocarbons (HC condensate [liquid natural gas], naphtha, ethane, propane, and butane) → Steam cracking → Olefins

2. **Aromatics,** including benzene, toluene, and xylenes, are produced in the reforming process.

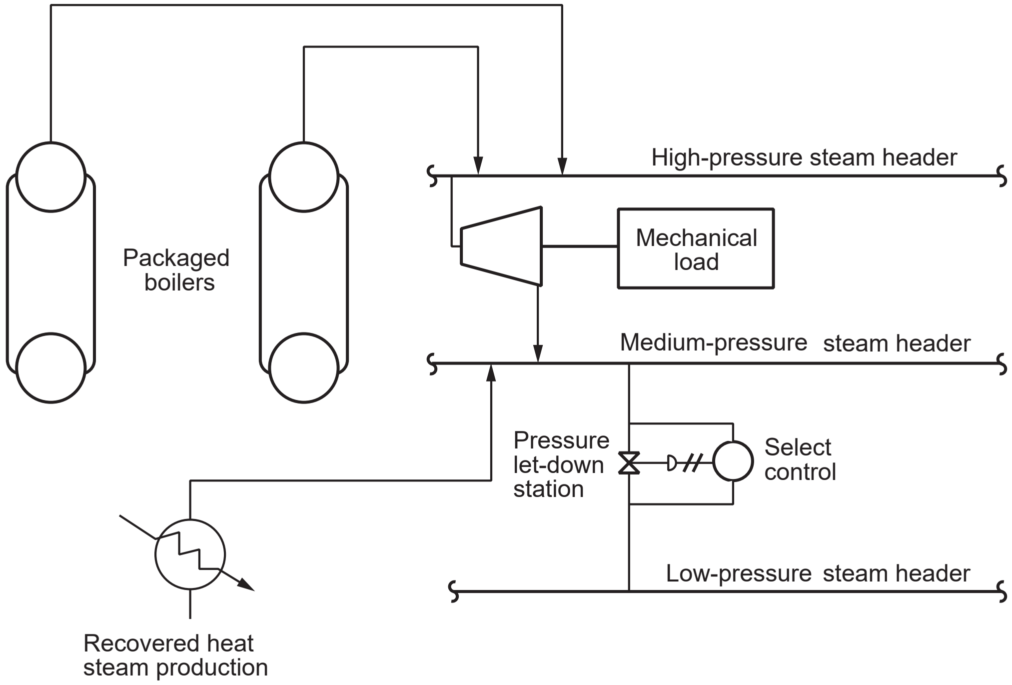
3. **Synthesis gas (syngas)** is a mixture of carbon monoxide (CO) and hydrogen (H_2) and is produced either through lean combustion (reduced oxygen) or steam reforming (direct reaction of steam with methane).

REFINERY STEAM SYSTEMS

Steam processes are some of the most important utilities required to operate an oil refinery or petrochemical plant. Steam generation powers much of the refinery, so it is generally the first system to start up and the last to shut down. Most plants operate at least three distinct steam systems: high pressure, medium pressure, and low pressure, as shown in Figure 7. The systems are interconnected through let-down, or pressure-reducing stations that exhaust the high-pressure system to the medium-pressure system and the medium-pressure system to the low-pressure system. The systems can also be interconnected by equipment, such as a steam turbine, utilizing the steam at a higher pressure and exhausting the steam at a lower pressure. Condensate is collected and returned to the boilers or steam generating equipment. Depending on the design and size of a plant, the high-pressure steam system could be anywhere from 4130 kPa (600 psi) to 10 340 kPa (1500 psi) pressure. Low-pressure systems range from 103 kPa (15 psi) to 415 kPa (60 psi).

The utility systems for each plant are designed for their specific jobs. Steam pressure and volume and the configuration of equipment will differ in each plant; however, the basic design is common to all operations.

Figure 7 – Refinery Steam Generation



Some refinery units produce steam as a by-product. The steam produced by cooling hot products or by a waste heat boiler is added into the steam system. The steam produced becomes an integral factor in the plant's steam balance.

High-pressure steam is used to drive turbines or larger, more critical pieces of equipment, including the following:

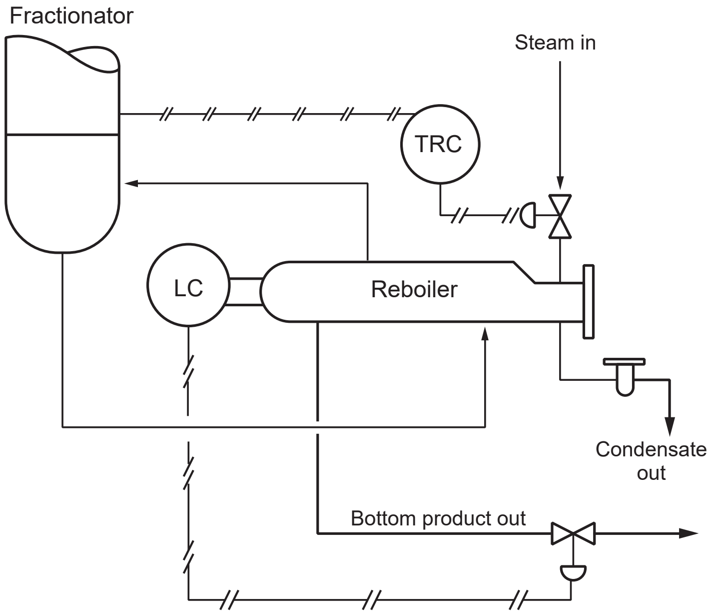
- Emergency power generators
- The fluid catalytic cracking (FCC) unit's main air blower
- Unit feed and bottom product pumps
- Some unit compressors

Typically, in the refinery, the steam produced in the plant is a more reliable utility than purchased power. Steam can be used to support many processes in the refinery.

Reboiler Heat

Steam is used in tower reboilers to provide heat for the fractionation process (Figure 8).

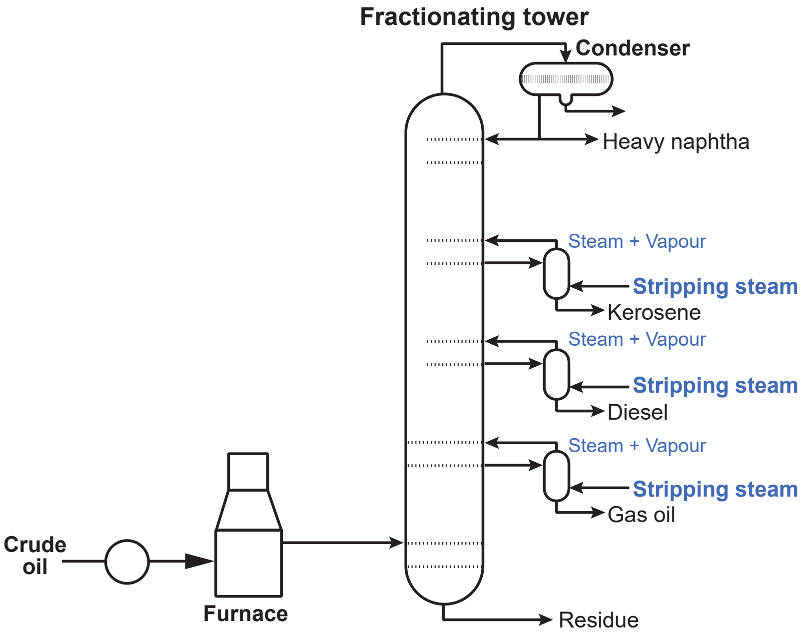
Figure 8 – Tower Reboiler Using Steam Heat Supply



Stripping Steam

Steam is injected into side stream stripping columns to facilitate the movement of light products up the stripper column (Figure 9). The injected steam carries the lighter hydrocarbons out of the column and back into the main fractionating tower.

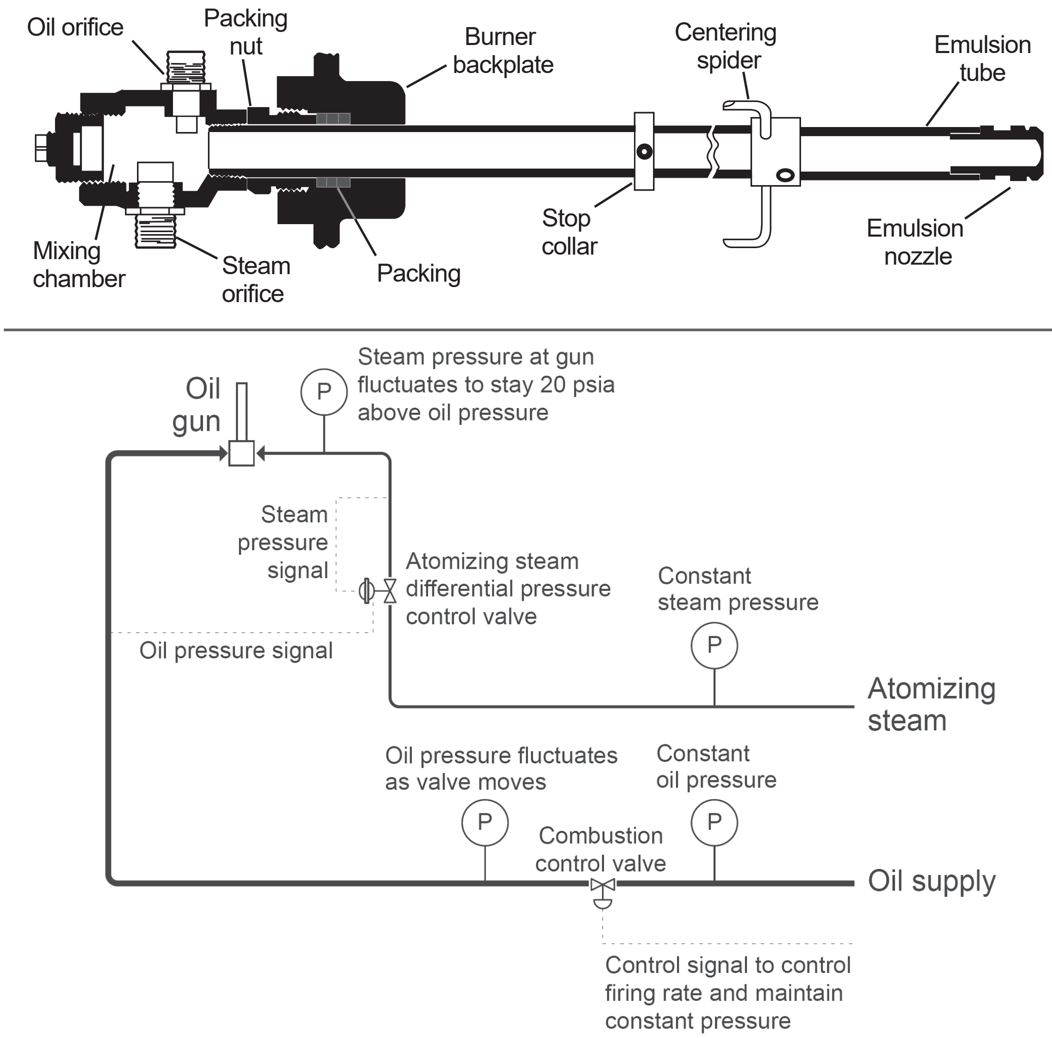
Figure 9 – Steam Stripping



Atomizing Steam

Most plants burn a portion of their heavy fuel oil in unit furnaces and heaters. Steam is injected with the fuel oil at each burner through a pressure-reducing valve station and a mixing chamber in the oil burner gun. This atomizing steam enhances combustion by heating the fuel oil and breaking it into very fine droplets to maximize the heat value of the fuel oil, resulting in a clean burn (Figure 10).

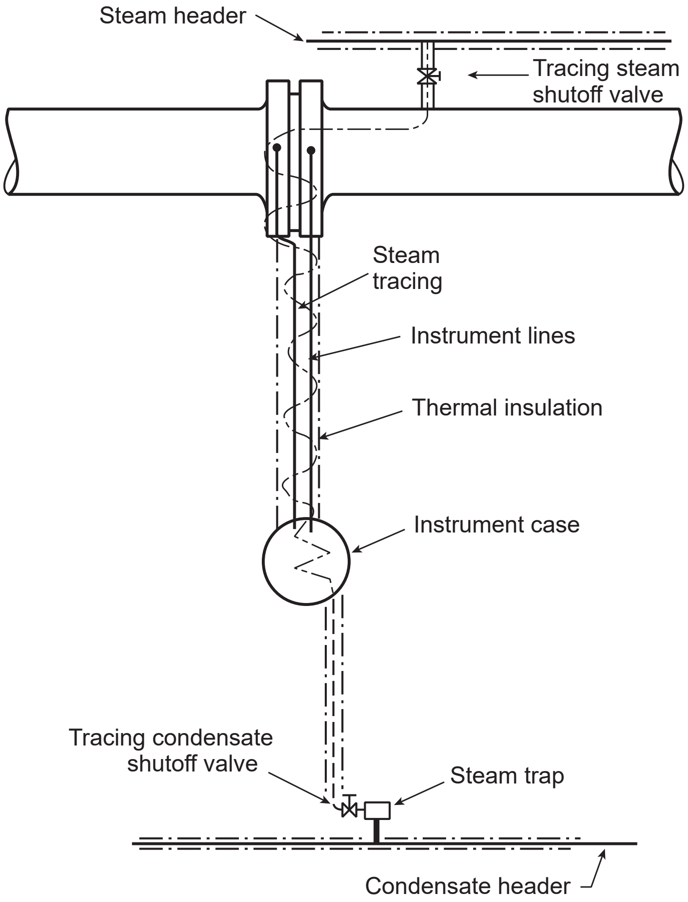
Figure 10 – Fuel Oil/Steam Burner System and Gun



Heat Tracing

The most common method of **heat tracing** flow lines, valves, meters, and recorders is to use steam. Most plants have intricate steam tracing systems. Without steam heat tracing, plants could not operate in cold weather (Figure 11).

Figure 11 – Steam Tracing System in a Typical Operation



Regeneration

Steam is used to remove impurities or regenerate certain chemicals and catalysts.

Heating Buildings

Most plants take advantage of their own utility systems to heat buildings, process areas, and heavy oil tanks.

Cold Weather Operation

Even a plant with a properly functioning steam tracing system is vulnerable to cold weather. Frozen gauges, sample points, transmitters, valves, and pumps are common where winters are severe. All refinery units are equipped with steam stations where technicians can hook up a steam hose to thaw frozen equipment and lines.

Equipment Purging

Purging equipment with steam is an effective method of preparing a refinery hydrocarbon unit for turnaround. Steam purging will clean towers and associated equipment in preparation for vessel entry. Steam is also introduced prior to start-up to heat up and remove oxygen from refinery towers and associated equipment.

Flare Control

Steam mixed with the gas flow at the tip of a flare stack will control smoke and lessen the environmental impact of the flare.

HEAVY OIL UPGRADER OPERATIONS

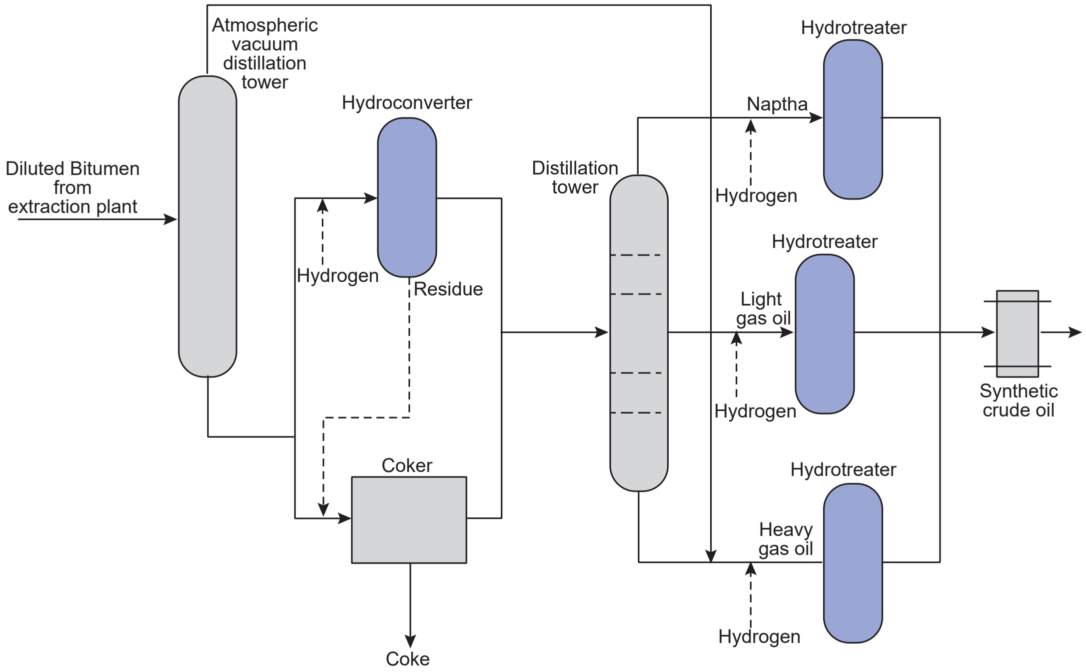
Refineries are increasingly being presented with heavier crudes to process. Canada's oil sands produce a heavy oil typically referred to as **bitumen**. The upgrading process for this oil converts bitumen into a high quality, light, low sulfur crude oil.

Locally processed bitumen has no diluent but has undergone separation from water and particulate matter in the extraction plant (pretreatment) before entering the primary upgraders.

If the bitumen is piped or trucked to the refinery, it arrives diluted with a naphtha cut as a mixture called diluted bitumen (**dilbit)**. From this point, the upgrading process is as follows:

- The first step in the upgrading process is to remove the naturally occurring light gas oil component of dilbit and to recover the diluent naphtha. This is done in the diluent recovery units (DRU), which operate much like an atmospheric distillation unit in a conventional refinery (Figure 5).
- When the bitumen from the extraction plant enters the upgrading facility (shown in Figure 12), it is sent to an atmospheric vacuum distillation tower. Here, the product is separated into light gas oil and heavy gas oil products.
- The light gas oil stream is sent to the hydrotreaters.
- From the atmospheric vacuum distillation unit, the heavy gas oil products are sent to the cokers for further refining. The lighter gas oils from this step are directed to the hydroconverter before being sent to the next distillation tower.
- After distillation, each of the naphtha, light gas oil, and heavy gas oil streams is sent to its own separate **hydrotreater** to remove sulfur and nitrogen by adding hydrogen. The resulting products from each of the separate hydrotreaters are then combined to produce synthetic crude oil.
- The bottom products, or residue, from the cokers are upgraded, and the final by-product of this stream is coke.

Figure 12 – Schematic of Bitumen Upgrading



The cokers are thermal conversion units that crack long chain bitumen molecules into more valuable short chain molecules — heavy gas oil, light gas oil, and naphtha. A portion of the coke produced in this process is transferred to a burner to provide heat for the thermal cracking process.

There are numerous other units in upgrading that support the operation. These include hydrogen units that supply hydrogen to the hydrotreaters, environmental units that treat water and gas streams, and sulfur recovery units. There is also a flue gas desulfurization unit that processes the burner flue gas from the cokers to remove sulfur and reduce emissions.

OBJECTIVE 4

Describe the main processes used in steam assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS).

The extraction of heavy oil from oil sands using **in situ oil recovery** techniques has depended on steam injection since the 1950s. Bitumen is an important hydrocarbon that is processed into a variety of valuable and useful fuel and petrochemical products. Bitumen is very heavy and viscous and will not flow without first being heated. Bitumen is found in geological formations mixed with sand, commonly called *oil sands*. For the oil sands to be of any use, the bitumen and sand must be separated from each other. **Steam assisted gravity drainage (SAGD)** and **cyclic steam stimulation (CSS)** are common methods of extracting and de-sanding heavy crude bitumen in a fully underground (in situ) process.

Traditionally, bitumen has been surface-mined, using large earthmoving machinery to strip away the overburden. However, not all bituminous sand is located near the earth's surface. SAGD and CSS processes are used when the bitumen is found too deep for economical surface mining. This is usually found to be at depths greater than 70 m.

SAGD and CSS work by reducing the **viscosity** of the bitumen so that it can flow to the surface. Because these processes use high-pressure steam, plant operators are nearly exclusively Power Engineers of a variety of classes. These Power Engineers operate the steam boilers, the water treatment facilities, and the **wellhead** steam distribution. Power Engineers also operate the oil processing facilities.

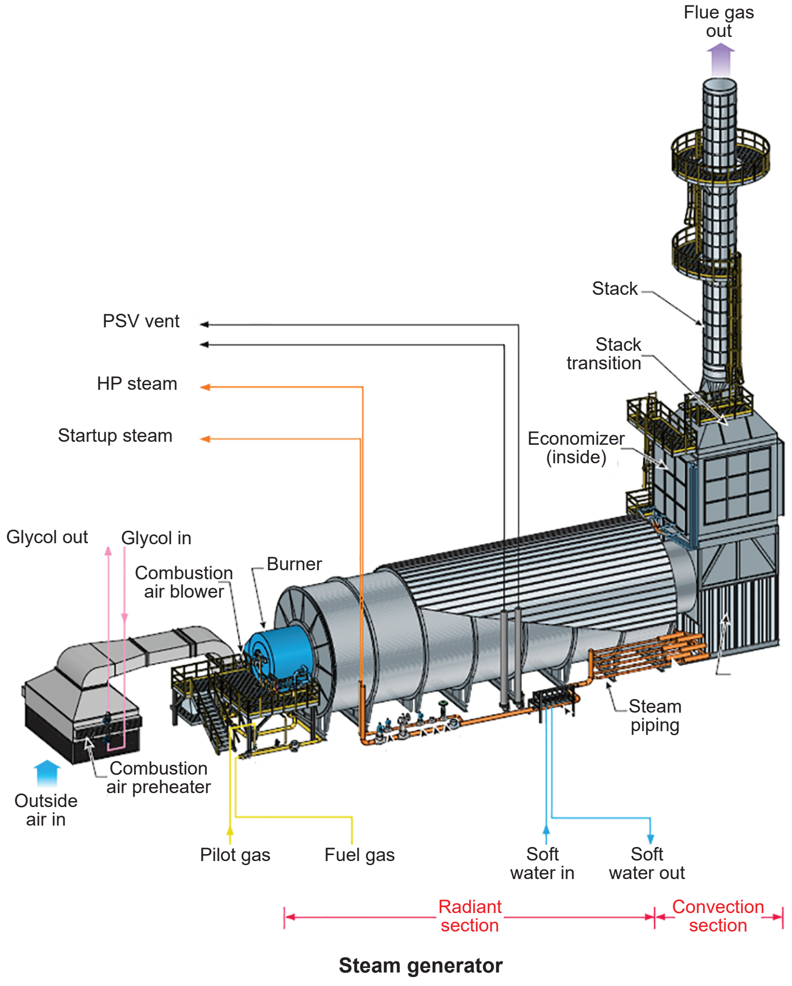
STEAM ASSISTED GRAVITY DRAINAGE (SAGD)

The following is an example of a typical SAGD process commonly found in industry. It is not meant to be representative of all SAGD plants.

Bitumen Extraction

Gas fired boilers generate wet steam at around 10 MPa. At this pressure, the steam is around 310°C. Instead of drum-type boilers, once-through steam generators (OTSGs) are frequently used. This is because OTSGs are relatively easy to clean using mechanical methods, which is an important consideration because boiler feedwater quality at SAGD plants may be of poor quality. A visual representation of the type of OTSG used in SAGD is presented in Figure 13.

Figure 13 – OTSG Used in SAGD



(Courtesy of Cenovus)

A great deal of natural gas is consumed to generate the required amounts of steam for an OTSG. Some of the gas may be sourced from the underground geological formation. Most of the gas is purchased and supplied to the plant under very high pressure from a third-party natural gas pipeline. An image of a typical configuration is shown in Figure 14. Note the stacks of the five OTSG units.

Figure 14 – SAGD Steam Plant

Because these OTSGs generate wet steam, separators are installed in the steam lines directly downstream of the boilers to dry the steam to near 100% dry and saturated. The saturated steam is piped to a number of wellheads to the injection wells. This vertical section of underground piping may be around 500 metres in length.

Once in the oil sands formation, the **injection well** travels horizontally for another 700–1000 metres. This horizontal section of piping is slotted along its length to distribute the steam evenly. Manual shut-off valves at the wellhead allow operators to isolate the wells. Pneumatic control valves allow the operations staff to remotely adjust the steam flow to various parts of the injection well. Figure 15 shows a row of wellheads at a SAGD facility.

Figure 15 – Row of SAGD Wellheads

When the injected steam condenses, it gives off its latent heat to the surrounding bitumen. The high-temperature steam reduces the bitumen's viscosity, allowing it to flow. The condensed steam mixes with the bitumen to form an **emulsion** (a mixture of oil, water, and gas). This emulsion is extracted through wells drilled 5 m below: the injection wells. The bottom well is called the **producer well**. It collects the emulsion and transports it back up to the surface. A surface view of an operating wellhead is shown in Figure 16.

Figure 16 – Typical SAGD Wellhead

Geological pressure, sometimes combined with steam pressure, forces the emulsion to the wellhead through the producer well. Plant equipment at the surface separates the bitumen, natural gas, and water. Sometimes the emulsion is pumped to the surface using subsurface wells.

CYCLIC STEAM STIMULATION (CSS)

Bitumen Extraction

CSS and SAGD both use OTSGs to supply high-temperature, high-pressure steam for injection into oil sands formations. Both processes heat the bitumen to allow it to flow to the surface. However, SAGD is a continuous recovery process, whereas CSS takes place in stages or cycles.

1. In the first stage of CSS, high-pressure, high-temperature wet steam, at around 320°C, is injected into vertical wellbores. This is called the injection stage.
2. Next, the steam is allowed to soak through the oil sands, melting the bitumen. This is the soaking stage.
3. Finally, the steam is shut off and the resulting bitumen and water emulsion is brought to the surface through the same wellbore. This is the production stage.

The CSS cycle is repeated many times (upwards of 15 cycles) on each well, until the bitumen reservoir is depleted. Each cycle of this process can take from four months to two years.

CSS is not used for shallow reservoirs. This is because shallow reservoirs do not have the thick shale cap that must be present to contain the injected high-pressure steam. Where oil sands reservoirs are deeper, CSS is superior to SAGD at extracting bitumen.

COMMON PROCESSES

In both SAGD and CSS, the emulsion returning from the producer wellhead contains water, bitumen, and some sand. At the plant site, the water, bitumen, and sand must be separated to recover water for boiler feed and to produce sales-quality bitumen.

Oil Dewatering

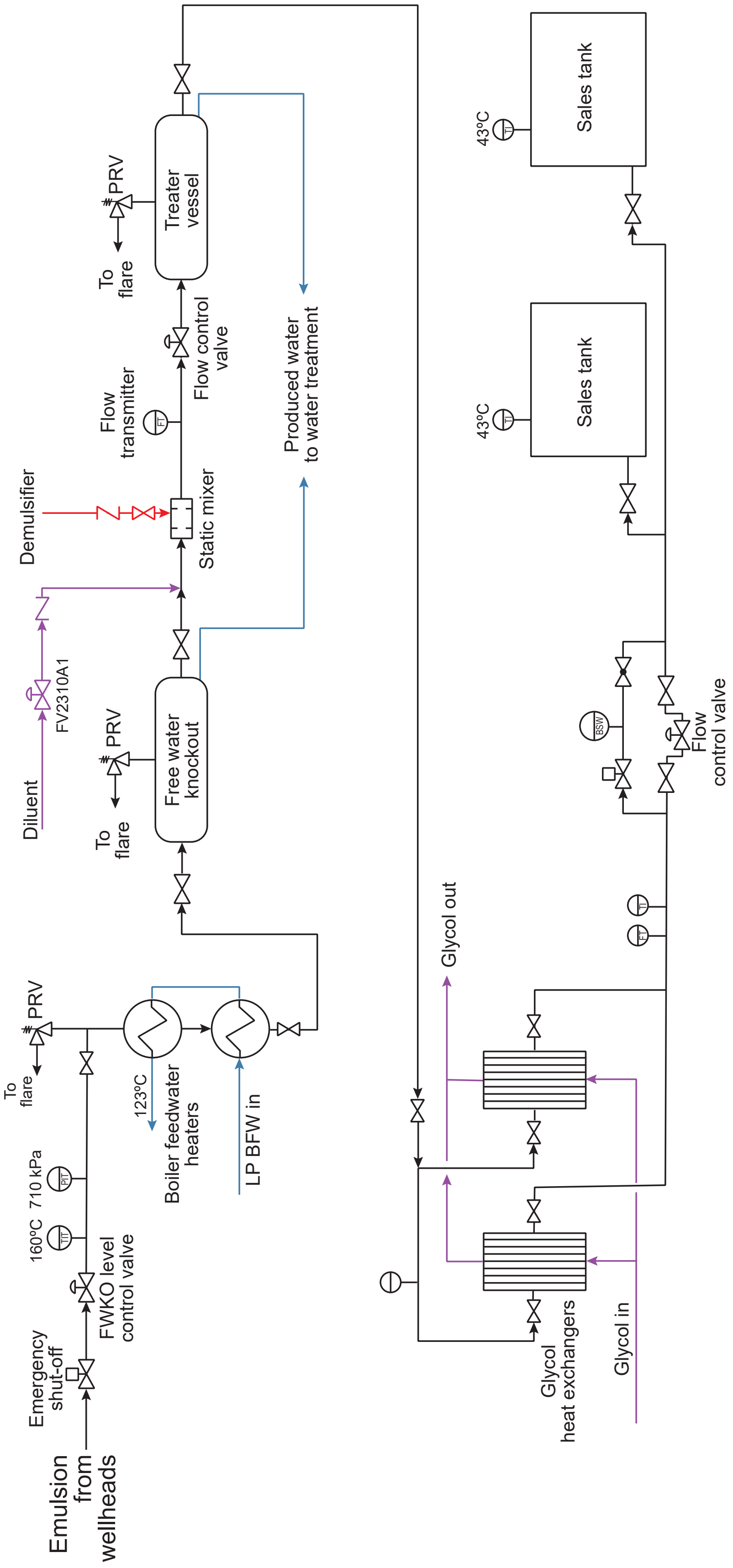
Figure 17 provides a schematic overview of a typical oil dewatering system. The emulsion returning from the wellhead may be 160°C–170°C. Some of the heat from the emulsion is used to preheat boiler feedwater using shell and tube heat exchangers. The emulsion, now cooled to approximately 115°C, enters a **knockout vessel**, which is the first step in emulsion separation. The knockout vessel separates free water (water not combined in an emulsion with oil) from the remaining bitumen and emulsion. Special **demulsifier** chemicals are added to assist in the separation process.

Two liquids flow from the knockout vessel: bitumen and water. The bitumen leaving the knockout vessel contains up to 2% water, and the water contains up to 1000 ppm (0.1%) oil. The bitumen will go through further dewatering, and the water will go through further de-oiling.

The bitumen that leaves the knockout vessel is then diluted and made less viscous by adding diluent. This permits the bitumen to be pumped through pipelines. The viscosity reduction also helps separate the bitumen from the **produced water** in the treater vessel. Diluent is a variety of gasoline-like hydrocarbon fluids that mix easily with bitumen. After **dilution**, the bitumen is called *dilbit*.

The dilbit flows to a **treater vessel**, where electrostatic grids and mechanical weirs help remove water. The final sales dilbit has less than 0.5% water content and a relative density of near 0.95. The dilbit is then stored in large tanks located at the plant. Pumps transport the sales dilbit to an upgrader facility through a pipeline. Dilbit must adhere to strict pipeline specifications when transported to downstream upgrader facilities, or producers can face fines and the product may be sent back.

Figure 17 – Oil Dewatering



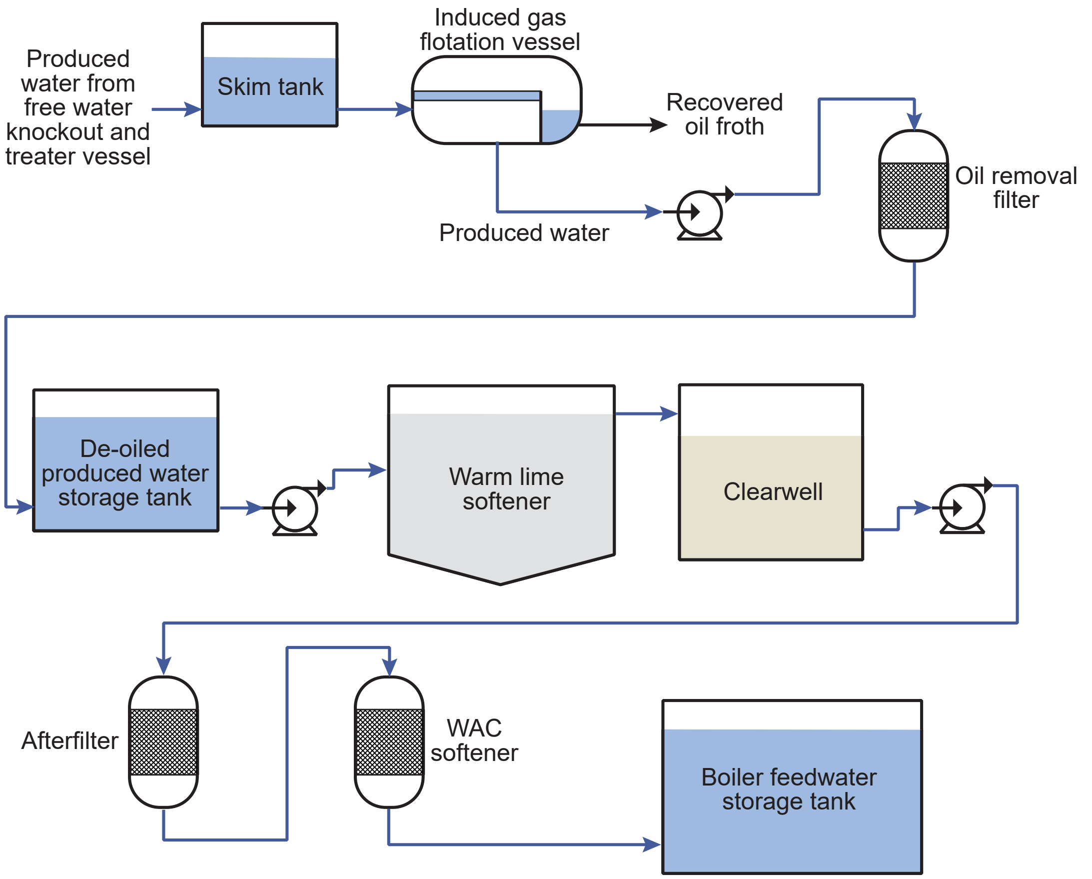
Water De-Oiling

In the process plant, water that leaves the free water knockout vessel combines with the water from the treater vessel. This water is now referred to as *produced water*. The combined stream flows to large settling tanks (skim tanks), where much of the oil floats to the surface and is recaptured. From the skim tanks, the produced water flows to an **induced gas flotation (IGF)** vessel. In the IGF vessel, natural gas is blown through the produced water, forming an oil froth, further removing oil from the water.

The last step in water de-oiling involves the use of **oil removal filters (ORFs)**. These filter vessels are filled with black walnut shells, which naturally attract oil. The water leaving the ORFs may contain less than 25 ppm oil.

The oil froth is skimmed from the IGF and is recovered. The de-oiling process is represented in Figure 18.

Figure 18 – Water De-oiling and Water Treatment



Water Treatment

The **de-oiled produced water** contains dissolved scale-forming compounds such as bicarbonates and silica. These impurities rapidly accumulate on boiler passes, decreasing heat transfer efficiency and increasing boiler metal temperature. Ultimately, this buildup of scale leads to failure of the boiler metal. Therefore, in the interest of safety and efficiency, these impurities must be removed.

The de-oiled produced water is softened using a hot lime or warm lime precipitation softener. The de-oiled water and the make-up water streams are heated using steam from the boilers. Lime is added to the softener to precipitate and remove temporary hardness. If permanent hardness is present in the influent, soda ash will also be added.

Magnesium is necessary to remove silica from the make-up and de-oiled water. Different water sources contain different amounts of dissolved magnesium. If the make-up or produced water streams contain little dissolved magnesium, magnesium oxide will be added to the softener. Magnesium oxide adsorbs silica when it hydrolyzes in the softener, thus reducing the dissolved silica content. The resulting softener effluent is about 10 ppm hard and has 50 ppm or less dissolved silica.

The softener effluent is filtered and then further softened by ion exchangers. Typically, weak-acid cation exchangers (WAC units) are used as opposed to strong acid cation exchangers (SAC units). WAC exchangers are more efficient ion exchangers than SAC units, so they cost less to regenerate. Both WAC and SAC units convert hardness to highly soluble sodium compounds, which will not precipitate as scale in the boilers. The resulting boiler feedwater has 0 ppm hardness, and less than 50 ppm dissolved silica.

The softened boiler feedwater is stored in a large reserve tank and pumped into the boilers using multi-stage boiler feed pumps.

Operating Parameters

SAGD and CSS facilities try to produce as much sales bitumen as possible, while requiring the least amount of input cost. The most expensive input is natural gas. How effectively the plant uses its steam, and therefore how effectively it uses natural gas, is expressed by the plant's **steam to oil ratio (SOR)**, which is the barrels of steam consumed per barrel of oil produced. Each plant tries to extract as much bitumen as it can using the least amount of steam. Target SORs range from 1.5–3. If the SOR becomes too high, then the plant becomes uneconomical and will be discontinued.

SAGD and CSS facilities also use a tremendous amount of water, despite recovering and reusing 85% or more of the steam injected downhole. Make-up water may be fresh or brackish (very high in dissolved minerals). Current environmental regulations restrict the use of fresh make-up water, so using brackish water is increasingly common. Due to its high mineral content, brackish water is not potable and is unsuitable for agricultural purposes. One of the primary functions of the lime softener is to make this poor-quality water suitable for boiler feed.

Environmental emissions are closely monitored by government regulatory bodies. These include effluent streams from the boiler stack, from the boiler waterside, from the water treatment facility, and from the bitumen processing facilities. Plants have continuous emissions monitoring systems and report their emissions to regulatory bodies. These same bodies define the acceptable emission levels in the facility's operating license agreement. Failure to comply with environmental restrictions is dealt with harshly, so it is in the interest of SAGD facilities to operate in an environmentally responsible manner.

OBJECTIVE 5

Identify thermal processes used in gas separation and compression plants.

NATURAL GAS PLANTS

Natural gas tapped from a gas well carries varying amounts of contaminants with it and must be purified before it can be used as an industrial or domestic fuel or as the raw material supply for a petrochemical plant.

Natural gas is defined as a mixture of hydrocarbons from which no liquid will condense under ordinary atmospheric conditions. Methane is the predominant constituent, often up to 95% by volume. Other hydrocarbon constituents include ethane, propane, butane, pentane, and hexane in respectively decreasing percentages. Contaminants in the gas stream include water vapour, carbon dioxide, nitrogen, hydrogen sulfide, and helium. Liquid natural gasoline (or **condensate**) is also often present.

The main functions of natural gas plants are to efficiently:

- Receive the natural gas withdrawn from underground geological reservoirs and remove impurities
- Separate and remove any entrained liquid hydrocarbons
- Separate and remove saleable by-products such as ethane, propane, butane, condensate, and sulfur.
- Re-pressurize the gas for transmission purposes

The required processes and the type of facilities needed to complete these functions depends on the nature of the gas well and the composition of the gas (sour or sweet). The processes may vary in complexity from the simplest (for simple water vapour removal) to the most complicated (for removal of sulfurous compounds, noncombustible gases, and many of the heavier hydrocarbons).

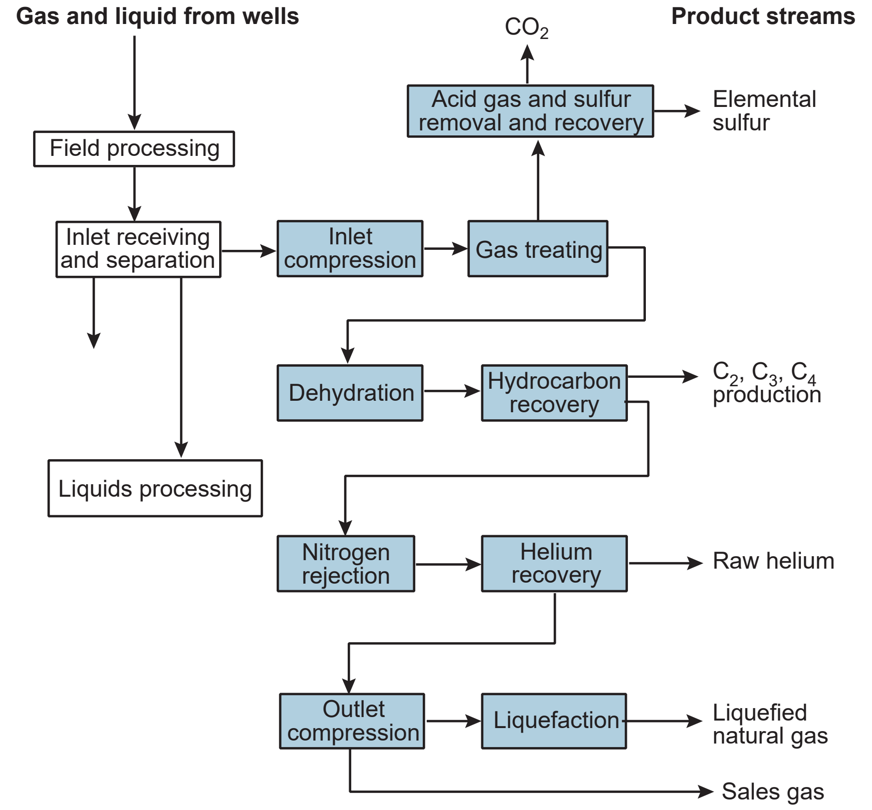
In the most common process, the production gas from wells passes through compression, separation, absorption, dehydration, stabilization, and recompression stages.

1. Separation involves a mechanical process to take out any liquid hydrocarbon content that is done in the inlet separator.
2. Absorption is the process where the hydrogen sulfide and carbon dioxide (acid gases) are absorbed by a solution of amine, often monoethanolamine (MEA).
3. Dehydration is an additional absorption process that removes water through contact with a glycol mixture.
4. Stabilization involves the flashing off of gases removed in the separation process at low pressure from the liquid hydrocarbons. These gases are treated with an amine solution to absorb impurities. The hydrogen sulfide removed from the natural gas in the absorption process and in fuel gas treatment after stabilization is sent to the sulfur plant for sulfur recovery.
5. Recompression is needed to increase the pressure of the gases from the stabilization process to a pressure suitable for sales gas or for the plant boiler fuel gas. Liquefaction is an extension of this process.

The main gas is then metered and passed out to sales.

A typical layout of a natural gas production facility is shown in Figure 19.

Figure 19 – Natural Gas Plant Block Diagram



Although there is a wide range of sizes and layouts, most natural gas production facilities have the same general equipment and processing systems shown in Figure 19. A description of the typical equipment used in the internal processes identified in blue helps clarify this common process.

Inlet Compression

A typical compression stage that includes the following process flow.

Inlet Gas

The inlet gas is initially cooled in a heat exchanger (often shell and tube).

The inlet gas then passes through a scrubber for liquid removal. This process typically uses a glycol mixture that removes the moisture through absorption. The liquid entrained in the glycol is removed by heating in a reboiler that boils out the liquids at a temperature range of 130°C–180°C.

In the compressor stage, compressor efficiency is maximized by using a cool, dry gas. Different compressors are typically used, depending on the characteristics of feed gas. Reciprocating compressors are used for low-pressure compression (also typically used for reservoir pressure maintenance gas injection). Screw compressors are often used for natural gas gathering systems and LNG applications. Centrifugal compressors are used most often in larger oil and gas operations. The lowest pressure used for gas to pipeline is atmospheric. Sometimes 3–5 MPa gas pressure is used for sending gas to the pipeline. Reservoir reinjection will typically require the gas to be compressed to 20 MPa (200 bar) and upwards, since there is no liquid in the tubing and the full reservoir pressure must be overcome. Therefore, compression is divided into several stages to improve maintenance and availability. Compressors are driven by gas turbines or electrical motors. Lower power requirements may allow the use of internal combustion engines. If sufficient thermal energy is available, steam turbines are also used.

Acid Gas and Sulfur Removal and Recovery

Gases like carbon dioxide (CO_2) and H_2S are removed to prevent corrosive damage to equipment and pipelines as well as meeting regulatory requirements. Three subprocesses and the major methods used in this stage are:

1. Absorption
2. Cryogenic removal
3. Claus process

Absorption

Absorption of H_2S and CO_2 is accomplished using amine solutions, mostly MEA. Equipment typical of this process includes fractionators, reboilers, pumps, and condensers.

Cryogenic Removal

The cryogenic removal process uses an expansion turbine (**turboexpander**). In this process, the gas stream flows through an expansion valve that lowers its pressure. This lowered pressure causes the gas to expand, which then cools to below the dew point for the gas to be removed. Cryogenic removal is most often used when CO_2 concentrations are high (approaching 50%). Mechanical energy from the gas expansion is converted to electrical energy in an attached generator.

Claus Process

Sulfur removal using the Claus process requires an H_2S rich gas stream. The Claus process initially burns one third of the H_2S in a furnace to produce sulfur dioxide (SO_2). The SO_2 is then reacted with the remaining H_2S in a catalytic process to produce water and elemental sulfur. The chemical reaction looks like this:

$$2H_2S + SO_2 \rightarrow 3S + 2H_2O$$

The Claus process can recover 95%–97% of the sulfur in the feed gases.

Gas Treating

Dehydration

Dehydration most often uses glycol-based absorption units similar to the scrubbers in the compression stage.

Hydrocarbon Recovery

Hydrocarbon recovery is undertaken by steam in most modern plants by using a cryogenic turboexpander followed by a fractionating process. This process leads the cooled liquids though separate distillation columns — called the **de-ethanizer**, **de-propanizer**, and **debutanizer** — to extract ethane, propane, and butane respectively, and leave a residual stream of pentane and higher hydrocarbons.

Nitrogen

Nitrogen (N_2) in the gas stream is removed by cryogenic distillation in a manner similar to hydrocarbons. Higher concentrations of N_2 are removed by an absorption process similar to scrubbers.

Helium

Helium is removed/produced mainly from helium-bearing natural gas in a process similar to nitrogen removal. In cases where sufficient concentrations of helium are available, a single cryogenic distillation column may remove and separate helium, nitrogen, and hydrogen.

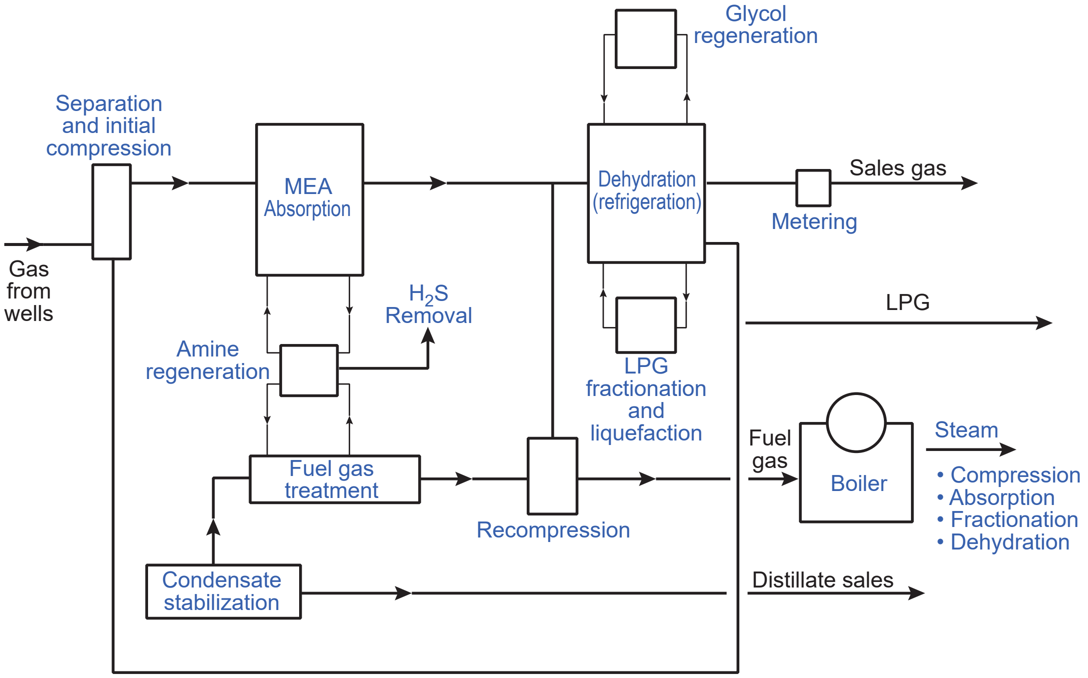
Liquefaction

Liquefaction of the natural gas feed produces an LNG that is typically > 90% methane. The cryogenic process most often uses a mixed refrigerant, multi-stage model to maximize the efficiency and stability of the cooling process. In a system with three cooling stages, the following descriptions of the stages are often used:

1. Pre-cooling cools the gas to a temperature of about −30°C to −50°C in the precooling exchange vessel. The cooling element is generally propane or a mixture of propane and ethane and small quantities of other gases.
2. Liquefaction cools the gas down to about −100°C to −125°C. This stage typically involves a mixture of methane, ethane, and other gases.
3. Subcooling takes the gas to the final LNG state at a temperature around −162°C. The refrigerant is usually methane, nitrogen, or both.

Figure 20 shows the process flows for a typical natural gas processing plant. It integrates both liquid and gas flows.

Figure 20 – Natural Gas Plant Process Flows



CHAPTER SUMMARY

Hydrocarbon processing is a critical segment of the economy. The physical processes and chemical reactions that must occur to create products require the use of significant steam and thermal fluid resources. The Power Engineer has the basic skill set required to operate and manage these processes.

This chapter discussed hydrocarbon industries by describing common thermal pathways seen in the generation, distribution, end use, and recovery of steam and other thermal fluids. HTF heating systems are broken down into common equipment and processes. Direct thermal processing of liquid hydrocarbons both in situ (SAGD and CSS) and at a refinery are discussed. The unit finishes with a description of the thermal processes, both heating and cooling, used in gas separation and compression plants.

Qualified operators manage the creation and use of thermal fluids within regulated and unregulated hydrocarbon processing plants. In these plants, thermal processes, both heating and chilling, are used to create and separate saleable end products.

4th Class Edition 3.5 • Part B • Unit 12

CHAPTER 2

Common Plant Configurations in Energy-Intensive Industries

LEARNING OUTCOME

When you complete this chapter you should be able to:

Identify steam related processes employed in common types of plants.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

1. *Identify the main steam/boiler processes used in wood and biomass processing plants.*
2. *Identify the important thermal processes used in food production and preservation.*
3. *Identify the common processes and equipment used in metallurgical processing plants.*

CHAPTER INTRODUCTION

Power Engineers work with steam in a variety of industries. Some are employed in plants and processes dedicated solely to the production and use of steam, such as thermal power stations and direct heating/cooling plants. Others work in industries that use steam or heat as part of a production process. Examples of these types of plants within the energy intensive industry sectors include wood and **biomass** processing, food processing, and metallurgical processing plants.

Within these environments, Power Engineers often assume process operator duties on non-steam equipment, as well as steam equipment. This unit looks at each of these plant types, identifying common processes and equipment that Power Engineers manage or operate.

OBJECTIVE 1

Identify the main steam/boiler processes used in wood and biomass processing plants.

PHYSICAL PROCESSES

Steam is used in wood and biomass processing plants to physically alter products. Examples of physical processes include the following:

- Drying
- Finishing
- Pelletizing
- Making veneers and plywood
- Manufacturing particleboard, oriented strand board (OSB), and medium-density fibreboard (MDF)

Drying

Sawn timber that is not sold when newly cut (green) must be air or kiln dried to prevent the wood from deforming through uneven natural drying. Drying and lowering the moisture content increases the wood's value because its dimensions stabilize, its strength increases, and its mass lowers (thus reducing transportation costs).

Air drying involves stacking sawn timber in piles so that they are exposed to a good flow of air until they reach the required moisture content. A full season of air drying is common.

Kiln drying accelerates the drying process and permits greater temperature and humidity control. The two most common kilns are the batch and progressive types.

Compartment kilns are a batch type of kiln that hold a large volume of timber in individual chambers that proceed through a batch-drying process. The kiln is completely loaded with lumber and the lumber remains stationary during the entire drying cycle. After the drying cycle, the batch of lumber is removed and a new batch of wet lumber is loaded in the kiln.

Progressive kilns dry the timber as it moves through the kiln on railed vehicles called *trucks*. Kiln drying can generally be completed within one week to one month, depending on the moisture level desired in the wood.

Kiln drying of sawn timber accounts for some 70%–90% of the total energy consumed in the sawmilling process. Standard practice in the sawmilling industry is to use its waste products as a fuel source to heat these kilns.

There are two types of kiln configurations used to deliver the heat.

1. **Indirect heated kilns** are the most common. In this type of kiln, steam or another fluid (e.g., hot oil) is transported from the boiler to one or more kilns through a collection of large insulated pipes, often called the *main feedline*. At the kiln, steam enters one or more distribution header pipes, each of which feeds a bank of heating pipes. The heating pipes transfer the heat from the steam to the air around the pipes, which circulates around the lumber to dry it. After giving up the heat to the air, the steam condenses in the piping and turns into condensate which is collected at the end of the piping in a condensate header. The condensate header returns the condensed steam as water to the boiler to be reused and reheated again.

2. In **direct heated kilns**, the hot gases produced by burning gas, oil, or wood waste in a fired heater are discharged directly into the kiln. These hot gases frequently pass through a mixing or blending chamber that controls the temperature and volume of air entering the kiln. Humidification levels in the kiln adjusts the lumber to the moisture conditions it will be subjected to after drying.

Finishing

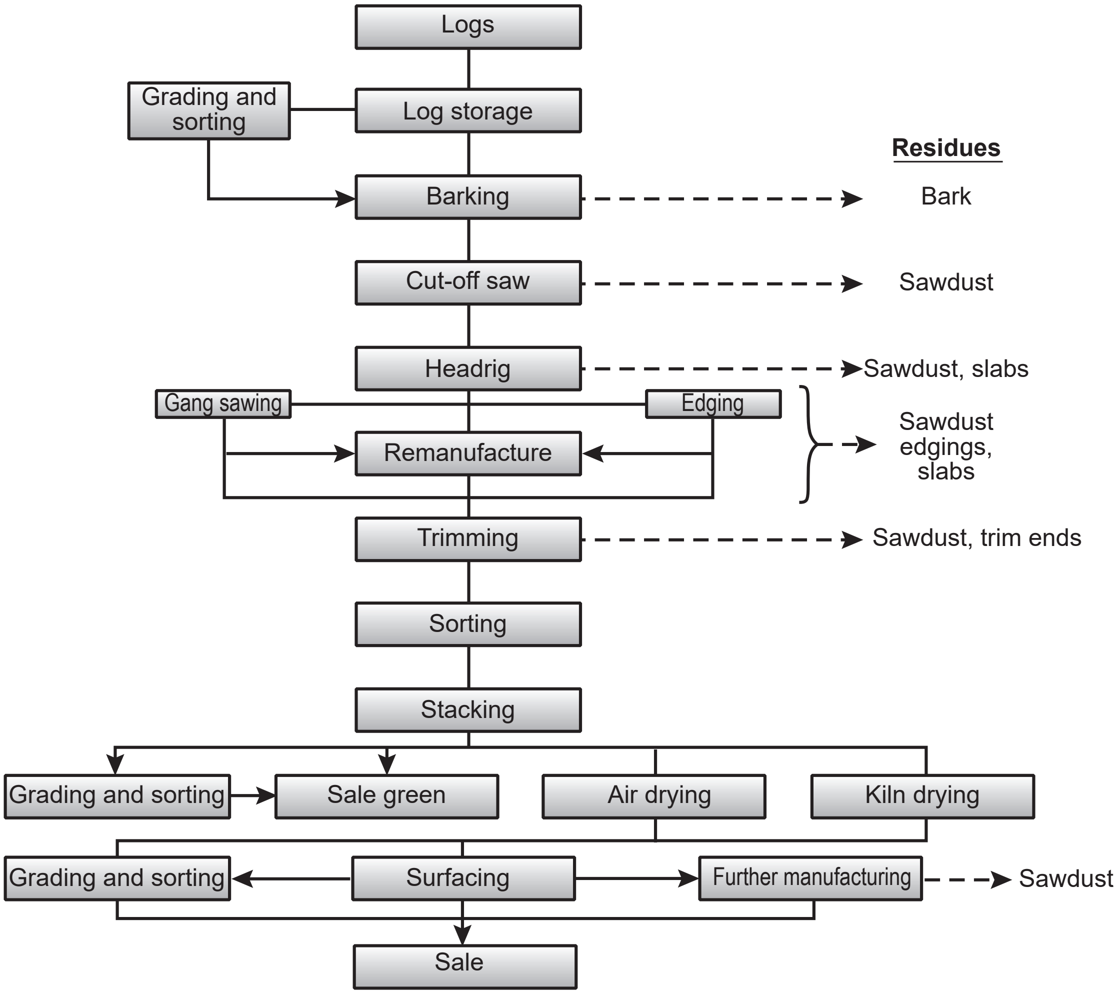
Dried rough lumber is further processed in a planing mill, where sharp knives revolving at high speed shave the lumber and give it a smooth surface.

Before stacking the sawn timber for storage, it is inspected for any defects that may have resulted during the drying process, such as split ends or loose knots, which are removed by additional trimming.

Further upgrading may occur by surface planing using rotary knife planers or abrasive belts, according to the needs of the market. Additional bonding processes create plywood, veneer, and other wood products.

Figure 1 provides an example of the typical process flow in a wood processing plant.

Figure 1 – Typical Process Flow in a Wood Processing Plant



Pelletizing

The pelletizing process compresses biomass, most often sawdust, into a small, rounded pellet that can then be used as a solid fuel. The general sequence of the pelletizing process involves the following steps:

Raw wood → Drying → Pulverizing → Pelletizing (forming pellets) → Cooling

Factors affecting the success of the pelletizing process include pressure, temperature, compression time, particle size of raw materials, moisture content, and chemical composition of wood.

The pelletizing process is heated by a wood- or biomass-fired boiler.

Making Veneers and Plywood

Certain logs are also selected for other thermal processes, including making veneers and plywoods. These logs undergo special cutting processes, such as peeling or slicing to shape the wood. The veneer is then moisturized, flattened, and bonded to a substrate. Additional surface treatment and finishing processes complete the individual veneer sheets. Commercial applications most often involve furniture or flooring.

Plywood is a flat panel built up of sheets of veneer fused together using a bonding agent under heat and pressure.

The operating heat and pressure are supplied by dryers and hot presses at 110°C–160°C and 750–1400 kPa.

Manufacturing Particleboard, OSB, and MDF

Particleboard is a general name for a panel manufactured from woody materials, usually in the form of particles, combined with a resin or other binder. The particles are bonded together with the resin while applying heat and pressure in a hot press.

Steam, hot oil, and hot water are all common options for providing the heat necessary to maintain the hot presses at their operating temperatures.

OSB is manufactured by combining rectangular-shaped wood strands in cross-oriented layers with a waterproof adhesive. The materials are then pressed into sheets. OSB shares many of the strength and performance characteristics of plywood but is much lighter to handle.

MDF has replaced particleboard as the preferred choice in many applications for a number of reasons:

- Improved machining characteristics for uses such as mouldings
- Improved mechanical characteristics such as moisture tolerance and strength
- A smoother appearance, allowing a wider variety of surface treatments

MDF is also finished in a press, as sheets, but it is initially broken down to much smaller components, usually fibres, than the particles used in particleboard.

WOOD PULP PROCESSING (PULP MILL)

A **pulp** mill is normally used to separate the fibres found in wood chips into a form that is suitable for the production of paper, tissue, cardboard, and other consumer products.

Pulp is defined as a cellulosic material, meaning that it is produced from **cellulose**. It is prepared from raw fibrous material such as wood, sugar cane, and straw. Wood is the most common raw material in use today. Most species of cellulose fibres are suitable for paper production, although some species are best suited for particular grades of paper.

Wood is composed of approximately 50% cellulose, 30% lignin, and 20% a combination of sugars and other organic compounds. The separation of cellulose fibres from the wood chip is accomplished using a mechanical or a **chemical process**.

Mechanical Process

In the mechanical process, wood is shredded by a grinder made from sandstone or a stone made of blocks of silicon carbide. The pulp produced by this means is called *ground wood*. Its most common use is in the manufacture of newsprint, which is made of 80%–90% ground wood. Ground wood is also used in many other grades of paper, such as magazine paper, flyer paper, and some book papers.

Mechanical pulping is the cheapest method of making pulp. Very little of the raw material is lost in the process (only about 5%–7%), and much less equipment is needed than for chemical processing. Mechanical pulping results in a pulp consisting of the whole wood.

Chemical Process

Chemical processes free the cellulose fibres contained in wood chips by treating them with reagents that dissolve the **lignin** and other non-cellulosic materials. Lignin is a binder between the cellulosic fibres, acting as the glue that holds the fibres together. After dissolving the lignin, the residual cellulose pulp is washed and bleached.

Chemical processes are generally more expensive than mechanical processes because of the equipment required and the high loss of raw material (about 50 percent by weight when dry). However, the resulting product has greater strength than ground wood products. The two main methods of chemical pulping are the acid or **sulfite process**, and the alkaline or **sulfate process**. The most common sulfate process is called the **kraft process**. The final product of the kraft process is called kraft pulp, which is the primary ingredient in things like paper towel, facial tissue, toilet paper, surgical masks, and diapers.

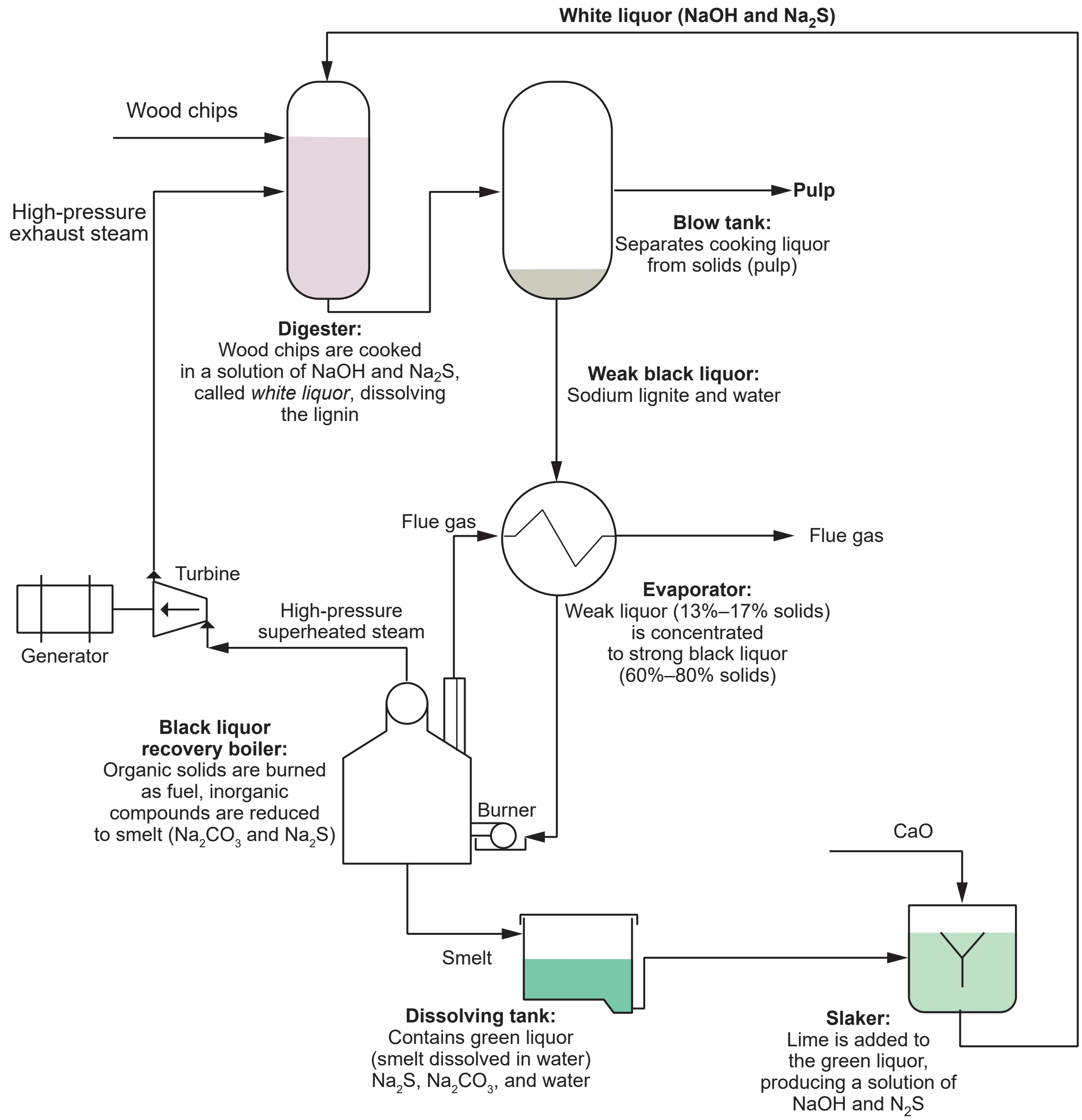
Both sulfite and sulfate processes use similar equipment. The wood is debarked, chipped, and then cooked to produce the pulp. The differences in the chemical processes appear in the digesting operations and the methods of chemical recovery used:

- The sulfite process uses aqueous sulfur dioxide (SO_2) and a base
- The sulfate process uses sodium sulfide (Na_2S) and sodium hydroxide ($NaOH$)

The sulfite process produces a pulp that can be bleached to a bright white colour and is mainly used for top-quality papers. The sulfate process uses an alkaline cooking liquor in place of the acid in the sulfite method. There are a number of wood species that cannot be successfully pulped by the sulfite process, including the pines, Douglas fir, and tamarack. The sulfate process can successfully pulp any kind of wood.

The flow diagram in Figure 2 shows a simplified arrangement of a typical pulp mill operating on the kraft process.

Figure 2 – Typical Kraft Process Pulp Mill



As Figure 2 shows, there are many pieces of equipment involved in wood pulp processing. These components serve three main purposes: fibre processing, chemical recovery, and steam and power generation.

Fibre Processing

The kraft process uses chemical agents, heat, and pressure change to separate wood into individual fibres. This separation begins in the digester and is completed in the blow tank.

Digester

The digester is filled with wood chips and **white liquor**, which is an alkaline solution made up of sodium sulfide and sodium hydroxide. The contents are heated with steam to about 175°C and cooked for up to six hours. The pressure in the digester is then reduced and the contents blown out into the blow tank. In a batch digestion process, several digesters are filled and cooked at staggered time intervals to simulate a continuous process. More recent advancements in pulp and paper technology have led to the development of the continuous digestion process, which cooks the wood chips as they flow through the digester.

Blow Tank

The rapid decrease in pressure from the digester to the blow tank causes the wood to separate into individual fibres. The lignin-containing white liquor, diluted with moisture from the wood chips, is called weak **black liquor**. The hot vapours are vented from the blow tank and used to heat water for the subsequent pulp washing. The washed pulp (or brown stock) is then taken to the bleaching plant on the way to the paper mill, for drying.

Chemical Recovery

The economic viability of a kraft pulp mill is highly dependent on the ability to recover the spent pulping chemicals for re-use. Weak black liquor contains organic material from the digestion process that needs to be removed. The chemical recovery process uses the organic material as fuel in a black liquor recovery boiler to significantly offset steam and energy costs. The recovery process includes the following unit processes:

Evaporators

Before the weak black liquor can be used as fuel in the recovery boiler, it must be concentrated using an evaporation process. Water is evaporated from the weak black liquor until the concentration increases to about 50 percent solids.

Multi-stage evaporators are used because of their economical operation. Medium pressure steam is supplied to the first effect, which is also the final evaporation stage for the black liquor. As the water-containing black liquor reaches its boiling point in the first effect, the water vapour discharges from the first effect and becomes the heat source for the second effect. This process is repeated through each effect. The liquid black liquor becomes more concentrated as the water content is boiled off.

The black liquor is then further concentrated using a steam-heated *concentrator* or *crystallizer*. The concentrator works similarly to the evaporators but is specifically designed to handle the high-viscosity black liquor. Following the final stage(s) of evaporation, the liquor contains 70% solids, or higher, and is called strong black liquor. Strong black liquor is then used as fuel in the recovery boiler furnace.

Black Liquor Recovery Boiler

Incineration of the strong black liquor is carried out in a **black liquor recovery boiler**. The organic solids in the black liquor act as the fuel. The heat of the recovery boiler reduces the sodium sulfate to sodium sulfide.

The quantity of black liquor available for firing is about 2600 kilograms per ton of kraft pulp produced. However, this depends primarily on the wood species and the density to which the black liquor was concentrated. In the recovery boiler, strong black liquor is atomized and sprayed on an inclined trajectory. The liquor droplets dry and begin to combust while in suspension. The black liquor accumulation on the furnace floor is known as the *char bed*. Combustion continues in the char bed and the remaining inorganic matter, known as **smelt**, collects at the bottom of the char bed.

Furnace temperature conditions must be carefully controlled because of the highly corrosive nature of the smelt and low ash fusion temperatures, which tend to cause slagging, or **slag** deposits, in the boiler passes.

Black liquor recovery boilers require special attention to ensure safe operation because of the special hazards inherent in the fuel. There have been many explosions in black liquor recovery boilers, causing fatalities and significant equipment damage. Most of these explosions fall into two categories, both of which are preventable:

1. Combustible gas explosions: Combustible gas explosions result from an accumulation of an explosive air-fuel mixture that is exposed to a source of ignition. Burner management systems and interlocks have largely prevented this type of explosion.
2. Smelt-water explosions: When water is exposed to the high-temperature smelt, the rapid expansion to steam can result in a boiler explosion. Common causes include leaking furnace tubes and the firing of low-concentration black liquor. Close monitoring and boiler interlocks have largely prevented the ability to fire low-concentration black liquor. In the event of a tube leak, the operator must recognize the emergency situation and initiate an emergency shutdown procedure (ESP) which involves the rapid draining of the boiler's waterside.

The inorganic chemicals present in the black liquor collect as a molten smelt at the bottom of the furnace. The smelt is broken down into small particles by steam jets and enters the dissolving tank. In this tank, the smelt dissolves in water to form a solution known as **green liquor**. The green colour is a result of iron impurities.

Slaker

The green liquor is pumped to the **slaker** mixing tank. The green liquor solution contains primarily sodium sulfide and sodium carbonate (Na_2CO_3).To convert the sodium carbonate back to its original sodium hydroxide form, re-burned lime (CaO) is added to the slaker.

As the re-burned lime is added, water in the green liquor converts the calcium oxide to calcium hydroxide, or **slaked lime** [$Ca(OH)_2$]. This process is known as slaking.

$$CaO + H_2O \rightarrow Ca(OH)_2 + \text{heat}$$

The calcium hydroxide then reacts with sodium carbonate, forming sodium hydroxide and calcium carbonate ($CaCO_3$). This process is known as causticizing.

$$Ca(OH)_2 + Na_2CO_3 \rightarrow 2NaOH + CaCO_3\ \text{(solid)}$$

A mixture of insoluble calcium carbonate and white liquor leaves the slaker. This is called unclarified white liquor. The insoluble calcium carbonate, or lime mud, is separated from the white liquor by filtration in pressure filters or by settling in clarifiers. The clarified white liquor can then be re-used in the digestion process.

Lime Kiln

The lime mud is then washed, filtered, and fed into a lime kiln. The lime kiln is used to convert the calcium carbonate back to its original form, calcium oxide, for re-use in the slaker. As the calcium carbonate enters the lime kiln, it is first heated and dried. A further increase in temperature, as it approaches the combustion zone, evolves carbon dioxide (CO_2) and produces calcium oxide in a calcination reaction.

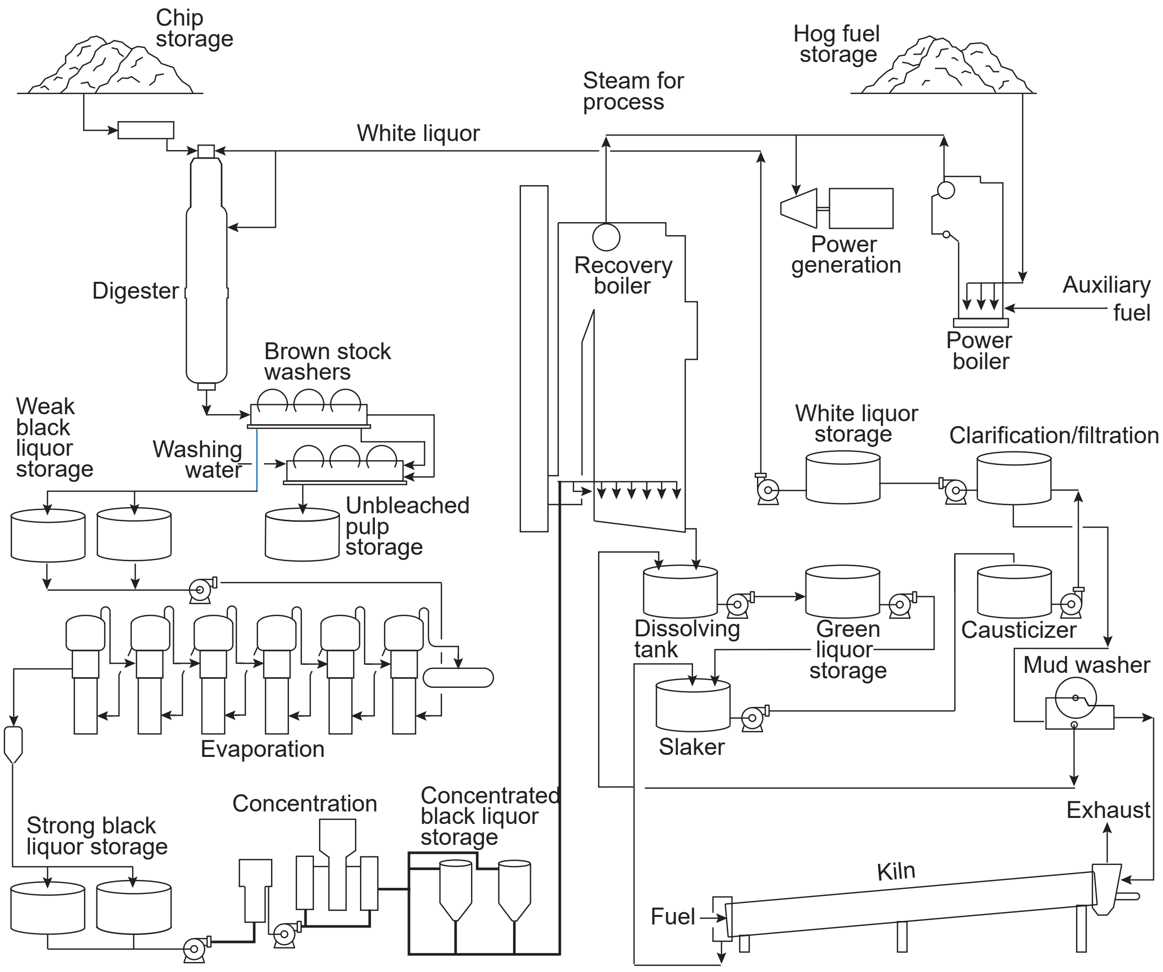
$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

Steam and Power

Although the primary role of the black liquor recovery boiler is to recover the pulping chemicals by incinerating the organic solids, a substantial amount of thermal energy is released during this process. The thermal energy is captured by the recovery boiler and used to generate high-pressure superheated steam, which can be used for power generation, process heat, and to drive fans and pumps.

A typical kraft pulp mill process flow, including steam and power generation, is shown in Figure 3.

Figure 3 – Thermal Water/Steam Cycle in a Pulp Mill



Steam is distributed throughout the mill at high, medium, and low pressures through separate distribution piping systems (headers), including the following:

- High-pressure steam: used primarily for driving steam turbine generators.
- Medium-pressure steam: used in the digestion process, black liquor evaporation and for pulp dryers.
- Low-pressure steam: used for building heat and process applications.

In kraft mills, the balance of the steam demand can generally be produced using wood waste, such as bark that has been removed from the timber and fines from the sawmills. This wood waste is referred to as hog fuel and it is burned in a hog fuel power boiler. The power boiler is typically equipped with auxiliary burners that are capable of burning natural gas, fuel oil, or both. Most of the high-pressure steam that is generated is expanded through steam turbine generators to produces electrical energy. Steam is extracted from the turbines to fulfil the medium-pressure steam requirements. Low pressure steam is extracted from a lower-pressure zone in the steam turbine or from the exhaust of a backpressure steam turbine.

Typical equipment managed by Power Engineers within the four areas of the thermal steam/water cycle include the following:

- Generation: steam turbine generators, hog fuel power boilers, and black liquor recovery boilers
- Distribution: steam header management through condensing turbines, backpressure turbines. and pressure-reducing stations
- End use: pulp dryers, digesters, and evaporators
- Recovery and reuse: condensers

WOOD WASTE AND OTHER BIOMASS PROCESSING

Biomass is organic material that comes from plants and animals. It is a renewable source of energy. When biomass is burned, its chemical energy is released as heat. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels. Examples of biomasses and their uses for energy include the following:

- Wood and wood processing wastes: burned to heat buildings, to produce process heat in industry, and to generate electricity
- Agricultural crops and waste materials: burned as a fuel or converted to liquid biofuels
- Food, yard, and wood waste in garbage: burned to generate electricity in power plants or converted to biogas in landfills
- Animal manure and human sewage: converted to biogas, which can be burned as a fuel

Wood Waste as an Alternate Solid Fuel

Mills producing lumber generate substantial quantities of waste suitable for fuel, including slabs, edgings, bark, sawdust, sander dust, planer shavings, and debris from log unloading and handling. Lumber mills produce more waste material than they need to satisfy their own energy requirements, so their waste is often used in other processes.

The addition of a cogeneration unit to a sawmill will increase the overall efficiency of the operation. Cogeneration facilities use waste heat from the process and convert it into electricity that can be used on site or sold to outside markets for a profit.

The largest volume of noncoal, solid fuel is wood or wood waste and bark from the paper or lumber industry. A hogger device chops the wood waste to a somewhat uniform size, so it can be easily handled and burned.

Hog fuel, the term used to describe the mixture of wood and bark burned to produce steam, normally contains 45%–55% moisture.

Wood waste is burned in a variety of furnace configurations, including Dutch ovens, cyclone furnaces, conventional packaged boilers using underfeed stokers, and fluidized bed combustors.

Wood is a valuable, renewable source of energy, but it must be burned cleanly and efficiently, not just incinerated. Therefore, a successful combustion system, plant load profiles, clean air laws, capital and operational costs, and energy conversion efficiency are all important design considerations for sawmills.

Additional Biomass Processes

There are many possible advantages of using biomass instead of fossil fuels for power generation, fuel production, and chemical manufacturing. These can include lower greenhouse gas emissions, energy cost savings, improved security of supply, waste management/reduction opportunities, and local economic development opportunities.

In order to analyze the use of biomass, it is important to consider three critical components of the process:

1. Biomass feedstocks: These come in a variety of forms and have different properties that impact their use for power generation.
2. Biomass conversion: This is the process by which biomass feedstocks are transformed into the energy form that will be used to generate heat or electricity, or into a feedstock for other processes.
3. Power generation technologies: A wide range of commercially proven power generation technologies can use biomass as a fuel input.

The source and sustainability of the biomass feedstock is critical to a biomass project's economics and success. Biomass feedstocks can be categorized as either urban or rural. Table 1 identifies a number of sustainable rural and urban biomass sources for commercial applications.

Table 1 – Biomass Fuel Feedstocks

Rural Sources	Urban Sources
• Forest residues and wood waste • Agricultural food crop residues (corn, wheat stalks, etc.) • Energy crops (grasses or trees) • Biogas from livestock effluent	• Municipal waste (packing crates, pallets, etc.) • Wastewater and sewage biogas • Landfill gas • Municipal solid waste • Food processing residues

A critical issue for the biomass feedstock is its homogeneity and its energy, ash, and moisture content. The values of these characteristics will impact the choice of conversion technology, as well as transportation, pretreatment, and storage costs. Ultimately, the characteristics affect the cost of the biomass feedstock per unit of energy generated.

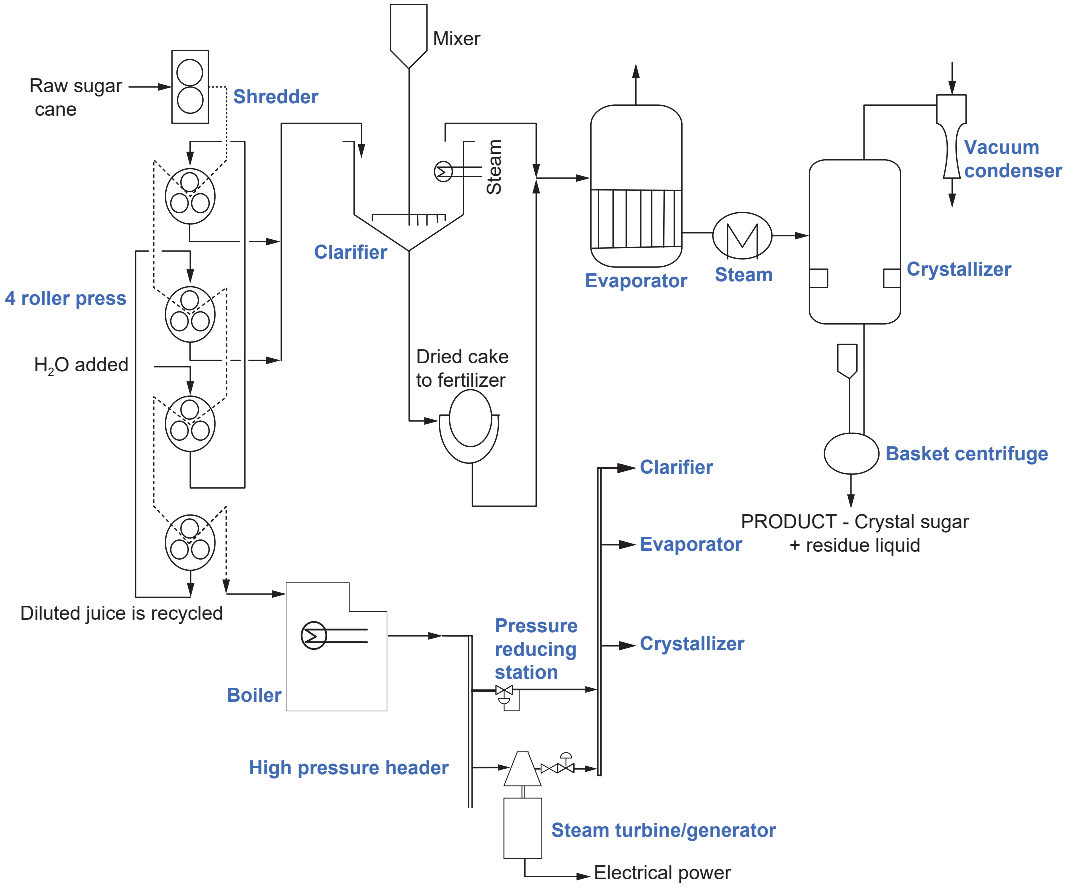
Bioenergy can be converted into power and other products through thermal-chemical processes (e.g., combustion, gasification, and pyrolysis) or biochemical processes such as anaerobic digestion. Table 2 provides an overview of a number of these processes.

Table 2 – Biomass Conversion Processes

Direct Thermal and Thermo-Chemical Processes	
Combustion and co-firing	Direct combustion of biomass for power generation is the most common form of biomass power generation. Feedstock availability and costs have a strong influence on project size and economics. Large-scale plants require more feedstock, which means greater transportation costs. Transportation costs can start to outweigh production revenue, which reduces economics of the process. Combustion typically involves burning the biomass in a high-pressure boiler to generate steam, which is then used in a variety of processes. Boilers and their support systems used for biomass combustion are similar to those used with other solid fuels and can include fixed, moving, or fluidized bed options. Mixed fuel boilers, often co-firing with coal, are commercially available.
Gasification	Gasification is achieved by the partial combustion of the biomass in a low oxygen environment, leading to the release of a gas. This gas is commonly called *producer gas* or syngas and has CO as a major constituent. The **gasifier** is most often a fixed or fluidized bed boiler. Along with CO, the producer gas includes water, carbon dioxide (CO_2), char, tar, and hydrogen. It can be used in combustion engines, microturbines, fuel cells, or gas turbines. When used in turbines and fuel cells, higher electrical efficiencies can be achieved than those achieved using steam in a steam turbine. Pyrolysis is a subset of gasification. Pyrolysis is combustion carried out at temperatures between 450°C–600°C, in the absence of oxygen, which results in the creation of a liquid bio-oil, as well as gaseous and solid products. The pyrolysis oil can then be used as a fuel to generate electricity.
Biodiesel	Biodiesel production modifies the molecular structure of oil and fats to reduce the flashpoint to a temperature similar to that of diesel fuel (approximately 160°C).
Biochemical Processes	
Anaerobic digestion	Anaerobic digestion, also referred to as **biomethanization**, takes place in almost any biological material that is decomposing in warm, wet, airless conditions. The resulting gas consists mainly of methane (CH_4) and CO_2 and is referred to as **biogas**. Biogas is often a product of underground landfill systems. Biogas can be used, after cleanup, in internal combustion engines, microturbines, gas turbines, fuel cells, and Stirling engines. It can also be separated and the CH_4 concentrated in a compressor station for distribution.
Precatalyzed fermentation	This conversion uses biocatalysts, such as enzymes, in addition to heat and other chemicals, to convert the carbohydrate portion of the biomass into an intermediate sugar stream. These sugars can then be fermented or chemically catalyzed into biofuels and chemicals. The most common industrial products produced using fermentation processes include ethanol, acetone-butanol, hydrogen, and lactic acid. Typical thermal equipment used includes fermenters, distillers, and low-pressure boilers.

Figure 4 provides a simple overview of the uses of steam that is derived from the production of sugar. Major equipment includes a boiler, evaporator, clarifier, crystallizer, and steam turbine/generator. Similar processes can be used with waste from peach pits, walnut shells, and more.

Figure 4 – Steam Processes in Sugar Production



In the sugar production process, raw sugar cane is first shredded to remove the leaves and nodes, and then pressed to extract the sugar-containing juices. The remaining fibrous residue, known as bagasse, is used as fuel in the high-pressure boiler, shown in Figure 4. Steam is used for electrical power generation, as well as in unit processes, such as the crystallizer, evaporator and clarifier.

Co-firing is the process of adding a percentage of biomass to the fossil fuel mix in a solid-fuel-fired plant. This process is typically used to reduce the potential environmental impacts associated with the combustion of fossil fuels. Co-firing typically works best with large coal-fueled utilities that have materials handling capabilities on site.

There are three possible technology set-ups for co-firing:

1. Direct co-firing: Biomass and coal are fed into a boiler with shared or separate burners.
2. Indirect co-firing: Solid biomass is converted into a fuel gas that is burned with the coal.
3. Parallel co-firing: Biomass is burned in a separate boiler and steam is supplied to the coal-fired power plant.

The co-firing of biomass with coal in large coal-fired power plants is becoming increasingly common. Thermal power generation is co-fired with biomass with as little as 3% to as much as 95% biomass fuel content. The advantage of biomass co-firing is that, on average, electric efficiency in co-firing plants is higher than in dedicated biomass combustion plants.

OBJECTIVE 2

Identify the important thermal processes used in food production and preservation.

FOOD INDUSTRIES

The food industry sector covers the sourcing, raw material transportation, reception, processing, conversion, preparation, preservation, and packaging of foodstuffs. The raw materials used are generally of vegetable or animal origin and are produced by agriculture, farming, breeding, and fishing.

In food processing plants, different types of processing can take place in each of three temperature ranges:

1. Ambient temperature food processing prepares freshly harvested or slaughtered food for further processing, altering the food's size, mixing foods as ingredients, or separating the components of food. These are essential operations in nearly all food processes.
2. Elevated temperature food processing converts raw materials (plant or animal based) into edible and inedible components using steam or hot water. Processing with heat can improve eating quality and increase shelf life.
3. Reduced temperature food processing (preservation) prolongs the safe storage time frame through the addition of chemical additives, or by freezing, drying, or blanketing with inert gas.

Table 3 provides an overview of a number of food processing plant types, material examples, and the thermal processing segments involved.

Table 3 – Food Processing Industry Examples and Their Processing Characteristics

Industry	Typical materials processed	Ambient temperature processing	Elevated temperature processing	Reduced temperature processing	
				Initial storage	Preserving after processing
Meat and fish processing	Beef, lamb, pork, poultry	Slaughtering, portioning	Cooking	Cold storage	Sterilization, refrigeration, deep-freezing
Fruit and vegetable processing	Fresh fruit and vegetables	Chemical stabilization (most often with SO_2), peeling, grinding, mixing, portioning	Blanching, cooking, vacuum evaporation	Processed immediately	Sterilization, pasteurization, drying, dehydration, freeze-drying
Milling	Grains	Grinding, crushing, maceration	Drying, cooking		
Baking and biscuit making	Milling products, dairy, finishing ingredients	Crushing, mixing, reforming	Baking		
Pasta manufacture	Milling products, finishing ingredients	Mixing, forming	Drying		
Sugar processing	Sugar beet, sugar cane	Crushing, maceration, centrifuging	Vacuum evaporation, crystallization, drying		
Chocolate processing	Cocoa bean, finishing ingredients	Roasting, grinding, mixing, conching, moulding		Immediate processing and cold storage	
Milk and milk products processing	Milk, finishing ingredients	Skimming, churning, coagulation, ripening	Pasteurization, sterilization, desiccation	Immediate processing and cold storage	Cold storage
Brewing and beverage processing	Grains, fruit	Milling, mixing, filtering, fermentation	Pasteurization, distillation	Immediate processing and cold storage	
Oils and fats processing	Grains, fruits, nuts, animal fats	Milling, crushing, filtering and pressing	Solvent extraction, steam extraction, pasteurization	Cold storage	Cold storage

Ambient Temperature Food Processing

Ambient temperature food processing methods mostly rely on mechanically extracting, sizing, and separating specific food products from the base materials. The beverage and milk products industries also focus on biological reactions such as fermentation and cheese ripening.

The initial stage of ambient temperature processing is a surface treatment. This can involve a variety of cleaning, sorting, grading, and peeling processes. These processes can be dry or wet but most often do not involve the use of any thermal processes. Among several notable exceptions is peeling via high-pressure steam or fire.

After this initial preparation, ambient temperature processing focuses on resizing the food into the appropriate form. This can involve both direct maceration (slicing and dicing), or grinding, crushing, and homogenization processes. Mixing and moulding of ingredients often occurs.

Once foodstuffs are in the correct form, more disruptive processing will often take place. At ambient temperatures, this can involve the application of fermentation and enzyme technologies. These promote the digestion of different components of the food to produce products such as fermented beverages and cheeses.

Many separation processes occur at ambient temperatures. Centrifuges separate liquids from solids and immiscible liquids, like water and oil, from each other. Filtration processes separate components by size. Larger particles are separated using either vacuum or pressurized filters. Micro-, ultra-, and nanofilters can separate food components such as yeast, plant pigments, gelatin, fats and oils, and sugars. They are also used to separate bacteria and viruses that can contaminate foodstuffs. Examples of these kinds of filtration methods include the following:

- Concentration of pastes such as sucrose or tomato
- Removal of proteins from honey and syrups
- Treatment of distillation effluents

Solvent extraction of liquids or solids involves dissolving the desired component in a specific solvent. This is accomplished by mixing the food and solvent together, either in a single- or multi-stage process, holding the mix for a period of time, and then separating the solvent, often through a distillation process. Foods that commonly undergo solvent extraction include seeds, beans, nut oils, instant tea and coffee, decaffeinated coffee, and olive oil.

Elevated Temperature Food Processing

Elevated temperature food processing involves operations that are often seen in other thermal processing industries, such as evaporation, extrusion, and dehydration. For food products, other important heating processes include sterilization and pasteurization.

Thermal processing of food uses steam as the main heat source. The thermal transfer of energy is either through direct contact of the food with the steam or indirect contact via a heat transfer surface. Steam used for direct injection into products is most often called **culinary steam**. Culinary steam must meet all appropriate codes and regulations of the local jurisdiction. The Canadian Food Inspection Agency, for example, provides guidance in creating culinary steam in its **Safe Food for Canadians Regulations**:

a) General requirements in a food processing facility:
    - Boiler feedwater must be potable or equivalent.
    - Boiler feedwater treatment and control shall be under supervision of trained personnel or a firm specializing in industrial water conditioning.
    - Pretreatment practices should favour ion exchange rather than the addition of conditioning chemicals.
    - Boilers and steam generation equipment shall be operated in such a manner as to prevent foaming, priming, carryover, and excessive entrainment of boiler water into the steam.

b) Additional culinary steam requirements:
    - Approved piping systems must be used for delivery of culinary steam from the steam main to the processing equipment. These piping systems must generally include the following characteristics:
        i) Between a steam main and approved filtering device the piping will contain:
            - An entrainment separator
            - A condensate trap
            - A differential pressure measuring device

ii) Between the approved filtering device and the process application the piping shall:
   - Be made from an appropriate stainless steel grade
   - Have a sampling device
   - Have a spring-loaded sanitary check valve
   - Be sanitary piping

Steam Equipment

A number of different types of equipment are used to transfer the heat energy in the steam to the food being processed. A number of examples include the following:

Shell-and-tube heat exchangers are commonly used to heat a flowing liquid by heat exchange from the circulating heating medium (steam or other fluid) through the tube walls into the liquid product being heated. Because of the thermal sensitivity of foods, hot water is often used as the circulating medium. It is heated by the plant's steam in a separate heat exchanger.

Steam injection heaters directly contact pumpable food with culinary steam.

Steam infusion heaters use a chamber, similar to a deaerator, where the product is cascaded through a steam environment.

Steam spargers bubble culinary steam into the liquid food from nozzles near the bottom of the heating tank.

Steam jacketed kettles have a dual skin design. The inner skin is in contact with the food, the outer skin is in contact with the atmosphere, and a steam chamber in between allows thermal contact over the entire surface of the kettle.

Drum dryers have an internally heated metallic drum on which a thin layer of wet material is applied. Steam is the usual source of heat.

Sterilizers use culinary steam to achieve the high temperatures and moisture levels required to sterilize enclosed surfaces (such as closed tanks, pipes, and valves) in food processing equipment as well as destroying microbial and enzyme activity in foodstuffs.

Distillation columns are common in hydrocarbon and chemical processing but are also used for the production of alcoholic spirits and the separation of volatile flavour and aroma compounds (e.g., production of essential oils by steam distillation).

Indirect heating ovens use tubes that are either heated directly by burning fuel or supplied with steam from a remote boiler. The steam tubes heat the air in the baking chamber. Heated air in the oven is commonly recirculated through the baking chamber and through a separate heat exchanger.

Reduced Temperature Food Processing and Preservation

Reducing the temperature of food slows the biochemical and microbiological changes that would otherwise take place during storage. This preserves both the freshness of foods as they await any thermal preparations as well as their sensory and nutritional characteristics as products. There are two general outcomes in reduced temperature processing and preservation of food: chilling and freezing.

1. Chilling: Reducing the rate of biochemical and microbiological changes is a positive effect of moderately reducing the temperature of fresh and partially processed foods. With their internal temperature between 8°C and −1°C, most foods have both an increased shelf life and an increased perception of freshness.

   Precise temperature control is essential at all stages to avoid the risk of food spoilage or food poisoning. For example, fresh and precooked meats, pizzas, and unbaked dough must be prepared, packaged, and stored under strict conditions of hygiene and temperature control. The ability to reduce the temperature of the food to the chill zone (< 10°C) is important because higher temperatures, particularly between 4°C and 60°C, significantly promote the growth of microorganisms.

2. Freezing: When the temperature of a food is reduced below its freezing point and a proportion of the water undergoes a change in state to form ice crystals, the process is identified as *freezing*. Commercial freezing processes occur with a variety of foods, including fruits, vegetables, fish, meats, baked goods, and prepared foods.

   As food is frozen, ice crystals form within its matrix. At lower temperatures, the unfrozen material becomes more concentrated and forms a dense, unstructured fluid called **glass**. The glass encompasses the ice crystals, preventing their growth. Where the temperature of storage is below this temperature range, the formation of this glassy state protects the texture of the food and gives good storage stability.

Equipment Used for Chilling and Freezing

The equipment used for chilling and freezing can be divided into three categories:

1. Mechanical refrigerators
2. Heat exchangers
3. Cryogenic chillers and freezers

Mechanical refrigerators have components very similar to other industrial chilling systems and include an evaporator, compressor, condenser, and expansion valves. Ammonia (NH_3) is the most commonly used refrigerant in chillers. Other refrigerants include carbon dioxide, propane, and, increasingly rarely due to their being phased out as required by the Montreal Protocol, halogenated hydrocarbons.

Heat exchangers can chill water directly or indirectly and are used to reduce the temperature of a variety of foods.

Cryogenic chillers and freezers use solid carbon dioxide, liquid carbon dioxide, or liquid nitrogen as a chilling medium in the chilling chamber. The medium withdraws heat from the air surrounding it as it evaporates, and fans circulate the chilled air.

Whether a cryogenic system is used for chilling or freezing often depends on the contact time and immediacy of the thermal transfer. Chilling systems tend to be removed from direct contact, while freezing systems have a more universal or immediate exposure.

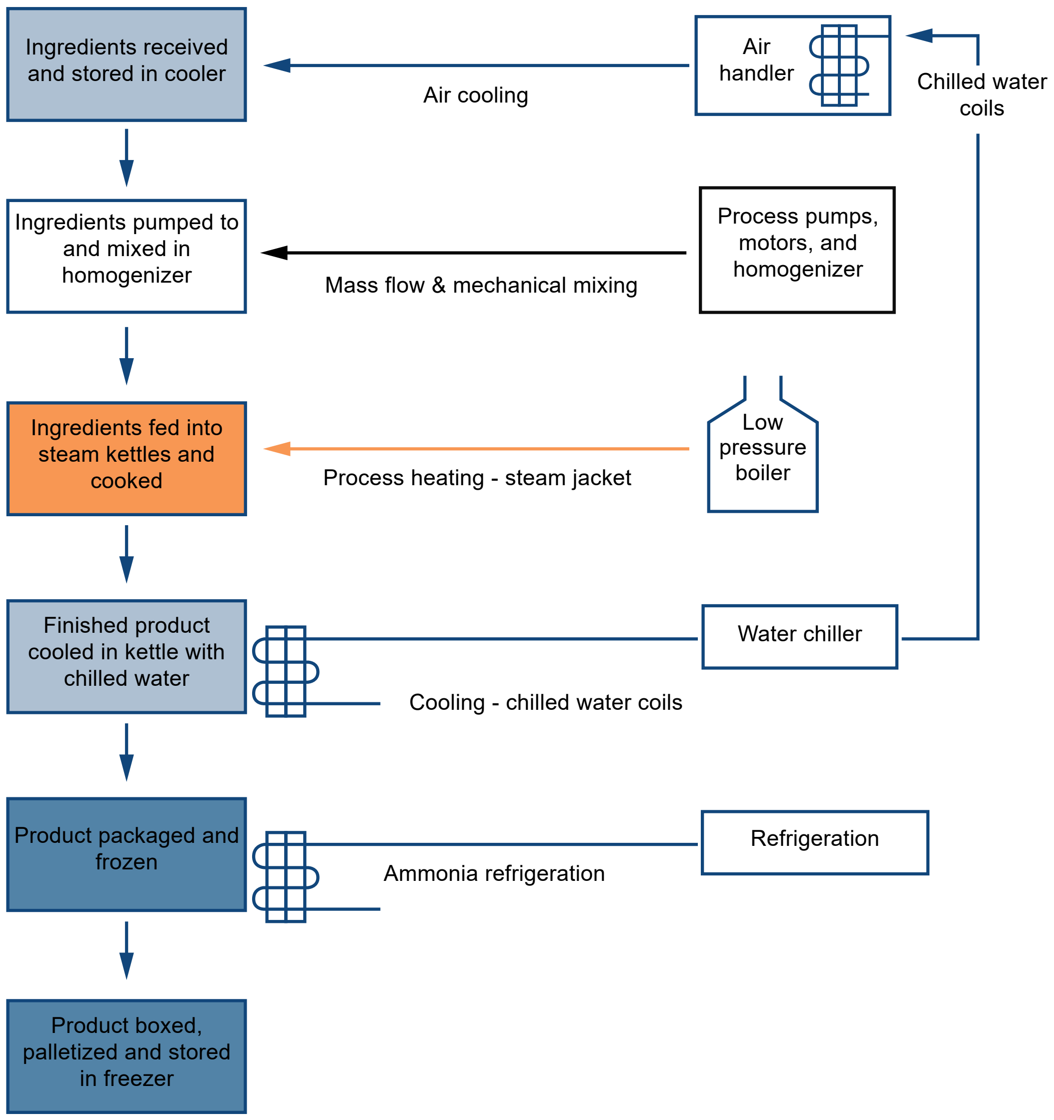
A reduction in the concentration of oxygen, an increase in carbon dioxide concentration of the storage atmosphere surrounding a food, or both, reduces the rate of respiration of fresh fruits and vegetables and also inhibits microbial and insect growth. When combined with chilling, this modified atmosphere is an important method of maintaining high-quality processed foods with an extended shelf life.

Integration of Food Processing Stages

Food processing systems may involve any combination of ambient, elevated or reduced temperature processing. Figure 5 provides a simple example of a food processing system that uses all three types of processing:

- Ambient temperature processing: Ingredients are moved into the homogenizer by piping and pumps and then are mixed or otherwise processed through mechanical means.
- Elevated temperature processing: The homogenized ingredients are heated in a steam kettle with steam supplied by a low-pressure boiler.
- Reduced temperature processing: A chilled water refrigerator provides the cooling medium both for initial storage as well as for reducing the temperature of the process product in the kettle. In addition, an ammonia-based refrigeration system freezes the product for durable long-term storage.

Figure 5 – Basic Food Processing Diagram



OBJECTIVE 3

Identify the common processes and equipment used in metallurgical processing plants.

MINERAL PREPARATION AND CONCENTRATION

Metals, like silver and copper, in their natural state, when combined with rock and other non-metallic components of the earth, are known as **minerals**. Although metals may exist naturally in the pure form, usually they must be extracted for use. The non-metallic elements of minerals are known as **gangue**. If minerals exist in a form and quantity that can be economically converted into metal, they are called **ores**. The majority of metallic ores exist in the following combinations:

1. Native ores: contain metals in the free form. These are generally non-reactive metals such as silver and gold that do not chemically combine easily with other elements.
2. Sulfide and arsenide ores: contain metals in combination with sulfur or arsenic. Examples include lead (II) sulfide (PbS), zinc sulfide (ZnS), chalcopyrite ($CuFeS_2$), and nickel arsenide ($NiAs$).
3. Oxide ores: contain metals in combination with oxygen or oxygen-based salts such as carbonates or nitrates. Examples include iron dioxide (Fe_2O_3), aluminum oxide (Al_2O_3), and magnesium oxide (MnO_2).
4. Carbonate ores: contain metals in contact with the carbonate ion (CO_3^{2-}). Examples include calcium carbonate ($CaCO_3$)and magnesium carbonate ($MgCO_3$)

The first step in all metallurgical processing is mining the ore. The second step is preparing the raw materials for metals extraction, usually by concentrating or enriching the ore to remove non-metallic elements. This step includes a number of physical processes:

Crushing reduces the rock to smaller pieces.

Grinding, using equipment such as a ball mill, reduces the smaller pieces into a fine powder.

Hydraulic washing is a form of classifier that separates the components of the mineral ore based on their different densities. By washing a slurry of the ore along a platform with wedges, the heavier, metallic components sink and are trapped in the wedges, while the lighter gangue is washed along by the water.

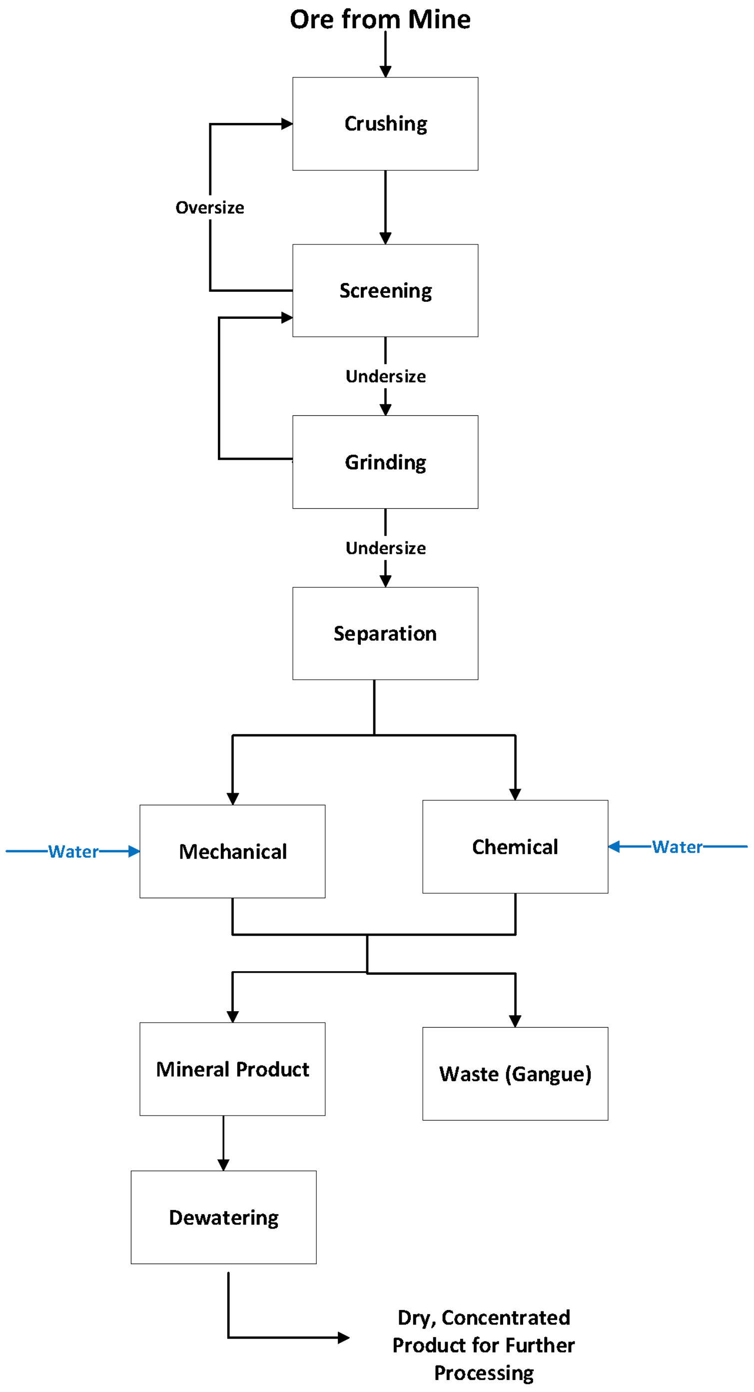
Froth flotation is especially common in the concentration of metallic sulfides. It is a process that separates according to differences in surface properties. A slurry of water, pine oil, detergent, and powder ore is placed in a tank. Compressed air is jetted into the tank, agitating the slurry. In a process often called "like attracts like," the hydrophobic (water-hating) sulfide particles are wetted by the oil and air bubbles and float to the surface in a froth. The hydrophilic (water-loving) gangue sinks.

Magnetic separation separates magnetic ores like MnO_2 from the non-magnetic gangue by bringing the ore in contact with an electromagnet.

Ore leaching is a chemical reaction that washes the ore with leachate (solvent) solution, which dissolves the metal. The resulting solution is separated from the remaining gangue and treated to isolate the metal, often through precipitation.

Figure 6 provides an overview of these stages in a typical minerals processing plant. During this processing, there is usually limited use of steam or hot water.

Figure 6 – Minerals Processing



CONVERSION OF MINERAL CONCENTRATES INTO OXIDES

Metal ores are most abundant in their oxide, sulfide, and carbonate forms. After the mineral ores are concentrated, the sulfide and carbonate ores of some metals are often converted into metal oxides. In these compounds, the metals exist as cations. For example, in copper sulfide (CuS) the copper exists as a Cu^{1+} ion. Copper metal (Cu) has no charge. Therefore, in order to convert these compounds into their fully metallic form (neutral) they will need to be reduced from their ionic form (i.e., $Cu^{1+} \rightarrow Cu$). The energy required to perform this reduction depends on the ionic nature of the metal–anion bond.

The metal–oxygen bond is more ionic than the metal–sulfur or metal–carbon bonds and requires less energy to break. Oxides are therefore preferred forms as a feedstock for metal reduction processes. The most common reducing agent is carbon in the form of **coke**, which first oxidizes to form carbon monoxide and then further oxidizes to form carbon dioxide There are two common methods for converting concentrated ores into their oxide forms:

1. **Calcination:** This process heats the concentrated ore in an oxygen-depleted atmosphere at a temperature below the melting point of the ore. This method is generally used for carbonates and hydrates. The water content and the volatile impurities also get expelled. Two examples include the following:

Zinc carbonate ($ZnCO_3$) is calcinated to obtain zinc oxide (ZnO):

$$ZnCO_3 + \text{Heat} \rightarrow ZnO + CO_2$$

Aluminum hydrate [$Al(OH)_3$] is calcinated to produce aluminum oxide (Al_2O_3):

$$2Al(OH)_3 + \text{Heat} \rightarrow Al_2O3 + 3H_2O$$

2. **Roasting:** This process heats the concentrated ore in the presence of excess oxygen and occasionally other materials. This method is generally used for sulfide ores. Sulfur dioxide is a co-product that may occasionally be used as a feedstock for sulfuric acid production. Volatile contaminants are also removed.

Zinc sulfide (ZnS) is roasted to obtain zinc oxide (ZnO):

$$2ZnS + \text{Heat} + 3O_2 \rightarrow 2ZnO + 2SO_2$$

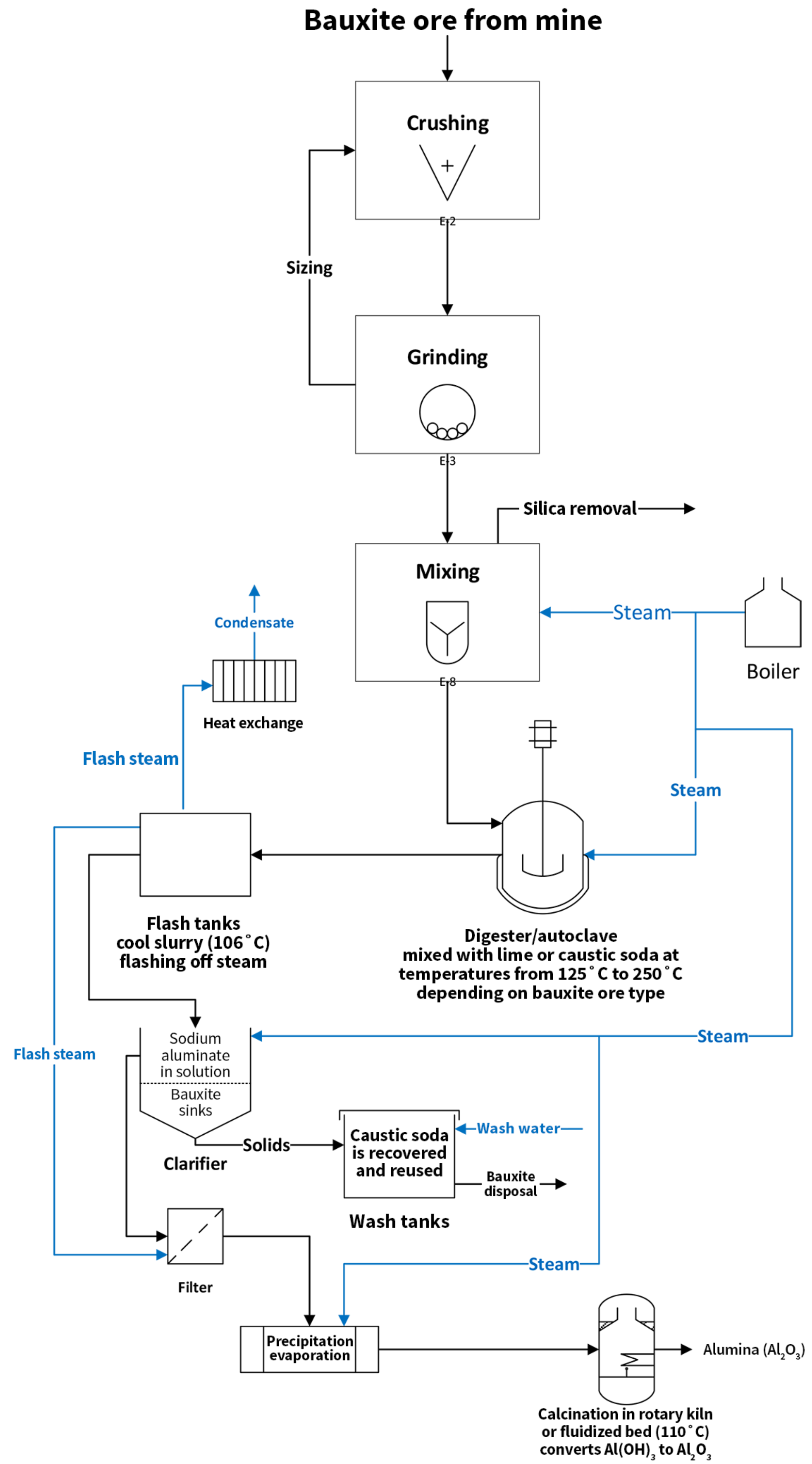
Copper sulfide (Cu_2S) is roasted to obtain copper oxide (Cu_2O):

$$2Cu_2S + \text{Heat} + 3O_2 \rightarrow 2Cu_2O + 2SO_2$$

Figure 7 provides an overview of a typical process for the production of aluminum oxide. At the very end of the process, the aluminum hydrate [$Al(OH)_2$] is calcinated to create pure aluminum oxide (Al_2O_3) while releasing water. Readily identified steam and other thermal equipment includes the following:

- Boiler
- Heat exchanger
- Clarifier
- Digester/autoclave
- Rotary kiln/fluidized bed furnace

Figure 7 – Processing Aluminum Ore into Aluminum Oxide



METALLURGICAL REDUCTION PROCESSES

Metal processing plants and smelters are facilities that extract various metals from concentrated ores to create more-refined metal products. Common metals include the following:

- Copper
- Nickel
- Lead
- Zinc
- Silver
- Cobalt
- Gold
- Aluminum
- Iron

Smelting involves heating the ore with a reducing agent, such as coke, charcoal, or other purifying agents. Smelting processes are used for mine ore and recovered scrap.

The reduction of metal oxides into the base metal commonly involves one of five basic processes:

1. Heating: Direct heating of metal oxides that are less reactive, such as silver and mercury, may release the oxygen in the ore, allowing only the metal to remain. For example:

   $$2Ag_2O + \text{Heat} \rightarrow 4Ag + O_2$$

2. **Carbon reduction:** Metals such as lead, copper, zinc, and iron may be obtained by removing their oxides by adding carbon, so that the carbon pairs with the oxides, as in the following reaction:

   $$Fe_2O_3 + 3C + \text{Heat} \rightarrow 2Fe + 3CO$$

3. **Carbon monoxide reduction:** Some oxides may be reduced at high temperatures by reacting them with CO. Examples include the following:

   $$FeO + CO + \text{Heat} \rightarrow Fe + CO_2$$

   $$PbO + CO + \text{Heat} \rightarrow Pb + CO_2$$

4. **Aluminum reduction:** Some oxides require a stronger reducing agent, such as aluminum powder. An example of these types of reactions is the reduction of chromium oxide (Cr_2O_3):

   $$Cr_2O_3 + 2Al + \text{Heat} \rightarrow Al_2O_3 + 2Cr$$

5. **Electrolysis:** Metals such as sodium, magnesium, calcium, and aluminum are too reactive for their oxides to be reduced by the above agents. They are recovered by passing an electric current through the purified molten ore. The cations, like sodium (Na^{2+}) and calcium (Ca^{2+}) will be attracted to the negative electrode or cathode. The anions, like oxygen ($O_2{}^{2-}$), will be attracted to the positive electrode or anode. When the current is passed through the molten oxide or chloride, the pure metal is deposited on the cathode.

IRON AND STEELMAKING

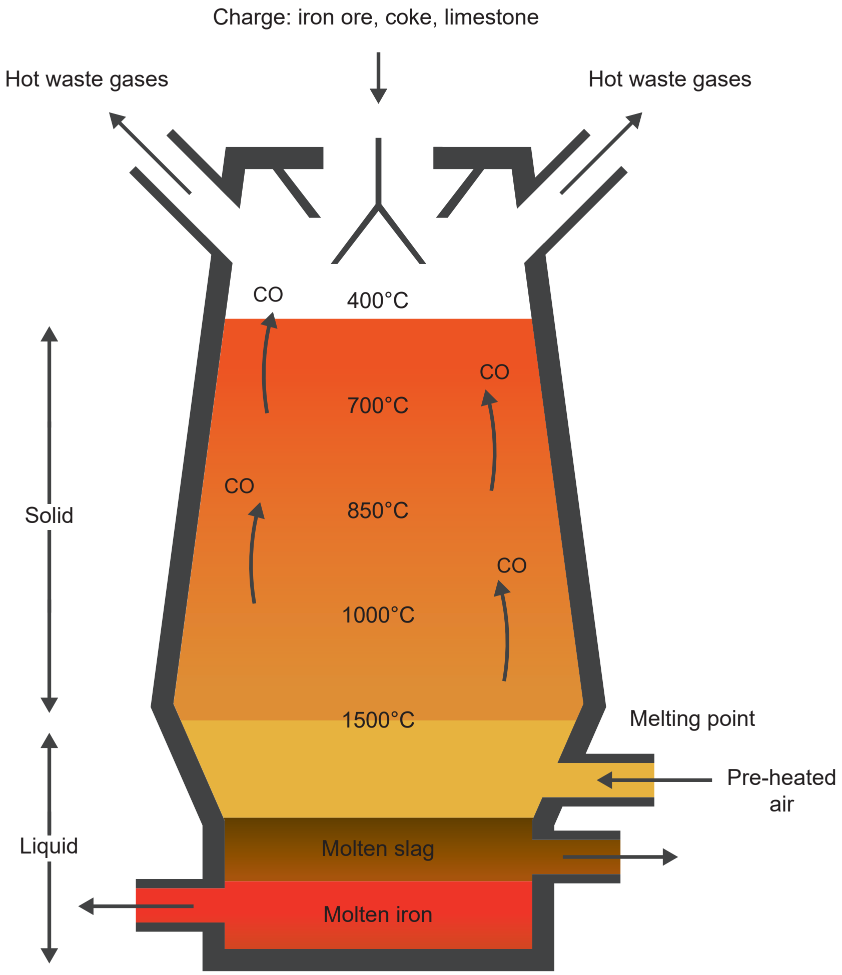
The conversion of iron oxide to iron is an important step in metal processing. Iron exists in nature mostly as hematite (Fe_2O_3), and its reduction to iron metal accounts for a large majority of all metals produced by the metallurgical processing industries.

Iron and steel production most commonly begin with the reaction of concentrated iron ore (mostly Fe_2O_3) with carbon in the form of coke, which reduces the iron to its metal form. Limestone is also added to assist the reaction and in the creation of slag. Coke is either purchased from a third party or generated on site from the heating of coal in an oxygen-free oven.

Blast Furnace

The prepared ore, coke, and limestone are loaded, or charged, into the top of a **blast furnace** in the correct ratio, at the same time a blast of hot air is injected at the bottom of the furnace. The heated air burns the coke to carbon monoxide, which rises through the downward-moving ore to reduce the iron oxides to metallic iron. When the iron reaches the bottom of the furnace, the temperature is sufficient (> 1500°C) to melt the iron, producing a liquid, low-grade iron called *pig iron*. Figure 8 provides a simple illustration of the process in an iron blast furnace.

Figure 8 – Iron Blast Furnace



Pig iron has a number of impurities—mainly carbon, silicon (Si), magnesium, phosphorus, and sulfur—that must be removed if it is to be used for steel. Typical differences in composition between pig iron and steel are shown in Table 4.

Table 4 – Typical Impurities in Iron and Steel

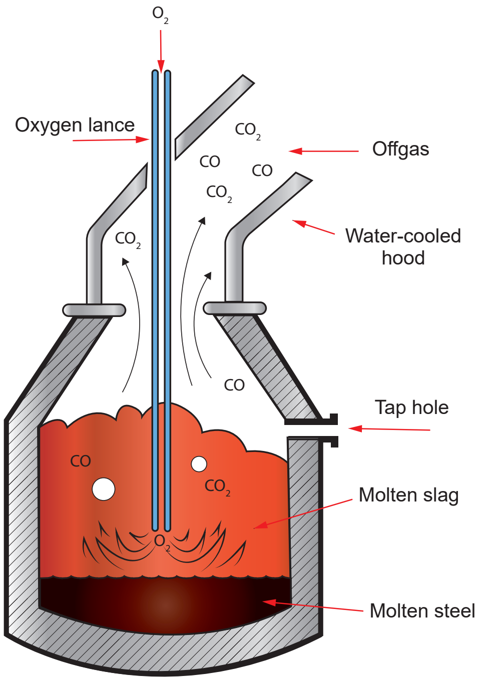
Metal	Iron composition	Impurities composition
Pig iron	90%–96%	C – 3.0%–4.3% Si – 0.5%–3.0% Mn – 0.5%–3.0% P – 0.05%–2.0% S – 0.1%
Steel	97.0%–99.8%	C – 0.04%–1.70% Si – trace Mn – 0.3%–0.9% P – < 0.04% S – 0.02%–0.04%

Basic Oxygen Furnace

Most steel today is made using a basic oxygen furnace (BOF). The BOF uses a lance to blast pure oxygen into a mixture of molten steel, scrap steel, and pig iron in order to reduce the carbon content of the mixture. The oxygen reacts with the carbon in the molten mixture, creating extremely high temperatures. During the time the oxygen lance is in service, the BOF produces CO and CO_2 gas (called off-gas) at temperatures between 1650°C and 1900°C. The off-gas is drawn into a water-cooled hood, where combustion air is introduced. The water-cooled hood is a type of waste heat recovery boiler. The hood is surrounded by watertubes, which pick up heat from the furnace to create steam in the steam drum. The addition of combustion air (oxygen) allows for the further combustion of the off gas from the oxygen blow. Increased combustion allows for additional heat and improved efficiency in the waste heat boiler.

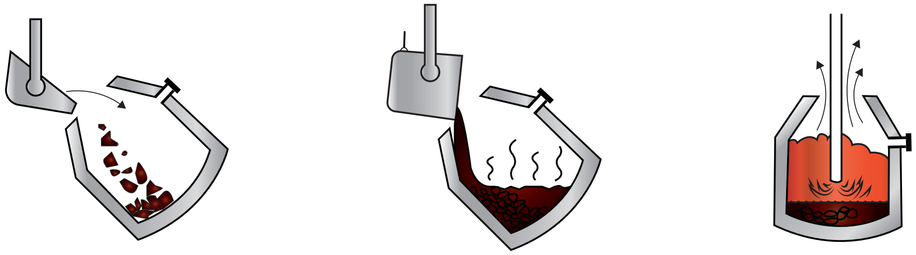
Figure 9 shows the elements of a BOF.

Figure 9 – Basic Oxygen Furnace



The basic sequence of operations in a BOF is illustrated in Figure 10. The figure shows the addition of molten steel, scrap steel and pig iron. Filling the furnace with these ingredients is called charging. In the next step, pure oxygen is used to reduce the carbon content of the steel. After the contents reach a set consistency, the BOF is tilted towards the slagging side of the furnace, and the molten steel is poured through a tap hole into a refractory laden containment. The materials that are left in the furnace after it is tapped is referred to as slag. The slag is poured into another containment and disposed of or reused.

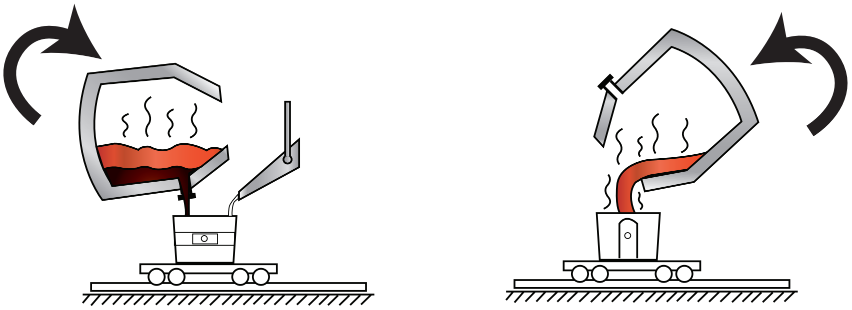
Figure 10 – Basic Oxygen Furnace Sequence of Operations



1. Charging with scrap steel and pig iron.

2. Adding molten steel and pig iron

3. Blowing with oxygen lance



4. Tapping the molten steel

5. Pouring off the slag

WASTE HEAT STEAM

The waste heat recovery boiler only generates steam during the BOF oxygen blow, which lasts about 45 minutes. After this time, the steel is ready, and the BOF pours its steel into a ladle. The waste heat boiler, then, must wait for the next oxygen blow to generate steam.

The steam is used in the plant for mill heating, steam tracing, and other process applications throughout the plant. Some plants use this waste heat steam for power generation.

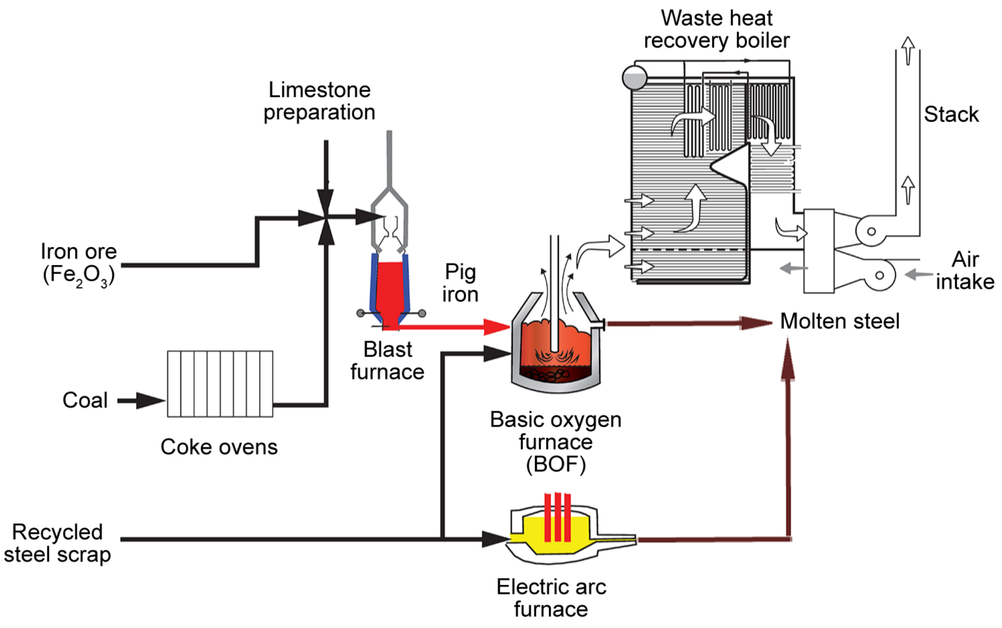
Because steam generation from waste heat only happens during the oxygen blow, the plant must use other means to ensure a steady steam supply. Sometimes large steam accumulators are installed to provide steam when the BOF is pouring. It is more common, though, to use regular fuel-fired boilers to provide steam for power generation and use the waste heat steam to augment the steam production of the boilers. In this way, the steam supply is steady.

Electric Arc Furnace

Steel scrap and cast-iron scrap may also be melted in an **electric arc furnace (EAF)**. In an EAF, an electric arc from graphite electrodes supplies the heat to melt the scrap steel and iron. The arc is situated above the molten slag. The slag acts as a heat distributor and a refining agent for the molten metal.

Figure 11 illustrates a simple view of a general steel mill configuration with an electric arc furnace.

Figure 11 – Integrated Steel Mill Configuration with Electric Arc Furnace



Power Engineers are employed to operate the boilers, turbines, and water treatment equipment found in the steel industry.

CHAPTER SUMMARY

Power Engineers typically describe their skill set as being able run the steam plant in an industrial or commercial facility. This simple statement should be looked at in its broadest context, because industries as diverse as food and metallurgical processing use the same processes to generate, distribute, use, and recycle steam and other thermal fluids. Not only are the processes the same, but also the equipment is the same. The differences between industries are really only about the specific needs of the product itself.

The Power Engineer has the skills and knowledge to effectively monitor and manage all the diverse thermal processes seen in every industry sector.

UNIT SUMMARY

This unit identifies and provides descriptions of typical plant configurations in many energy-intensive industries such as these:

- Hot oil plants
- Fuel and petrochemical refineries
- In situ oil sand recovery systems
- Natural gas processing
- Wood and biomass processing
- Food-centric plants
- Metallurgical processing and steelmaking

This unit discussed common thermal systems that exist in all thermally dependent industries, including heat generation, distribution, end-use, and recovery. An understanding of these processes progressed to a discussion of the common equipment used in these processes.

This unit provided a high-level overview of typical process flow for each industry and identified the use of thermal equipment in its operation. The Power Engineer's skillset is depended upon, in all industry sectors, to operate each plant's thermal processes. Although diverse in processes, industries are very similar in how they manage thermal operations and the equipment involved. The understanding of these commonalities allows Power Engineers to successfully operate and manage diverse plant systems, only requiring plant-specific operational procedures and knowledge updating.

A self-assessment tool is available on MyPower LMS. Login using the unique user ID and password found on the inside front cover of Unit 1.

Notes

Notes

Notes

Notes

Notes

Notes

Notes

4th Class Edition 3.5 • Part B

UNIT B-12

KNOWLEDGE EXERCISES AND UNIT GLOSSARY

KNOWLEDGE EXERCISES – CHAPTER 1

Name: ______________________________ Date: ______________________________

Instructor: ___________________________ Course: ____________________________

Objective 1

1. Identify the four types of steam processes in industrial plants.

2. Differentiate between steam separators and steam accumulators.

Objective 2

3. What are the critical components of an HTF system? Describe their use.

4. Why are centrifugal pumps preferred in HTF systems?

5. What range of temperatures has many HTF options?

Chapter 1 (Cont.)

6. Identify five interlock devices typically seen in an HTF System.

Objective 3

7. What is the use of a stripper column in a refinery?

8. What is dilbit?

Objective 4

9. What does the term *in situ* mean with respect to oil sands? Provide examples of two types of in situ recovery.

10. Why is a OTSG used in SAGD?

11. Describe the injection – production cycle in a SAGD well.

Chapter 1 (Cont.)

12. In a CSS operation, what is the IGF vessel use for?

13. If an in situ oil sands operation has an SOR of 5, what is the concern?

Objective 5

14. Describe the use of a typical expander in the hydrocarbon recovery stage of natural gas processing.

15. Identify the typical temperature ranges expected in a three-stage natural gas liquefaction process.

KNOWLEDGE EXERCISES – CHAPTER 2

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. Why is kiln drying a preferred log drying method as compared to air drying?

2. Define the term *pulp*.

3. All boilers require the constant attention of a qualified operator; however, extra care is required in operating a black liquor recovery boiler. Why is this so?

4. What is hog fuel?

5. Identify 10 pieces of equipment used in wood processing that may require steam or other thermal fluids to supply its energy.

Chapter 2 (Cont.)

6. Describe three configurations of co-firing with biomass fuels.

Objective 2

7. Identify three segments within all food processing industries.

8. Identify 10 pieces of equipment used in food processing that may require steam or other thermal fluids to supply its energy.

9. Identify two uses for chillers in food processing.

Objective 3

10. What is gangue?

Chapter 2 (Cont.)

11. Describe, with an example, the roasting process of ores.

12. Identify 10 pieces of equipment used in metallurgical processing that may require steam or other thermal fluids to supply its energy.

UNIT B-12 GLOSSARY

Term	Definition
Adsorption	Separation of compounds by their molecular size using molecular sieves.
Alkylation	In petroleum refining, a chemical process in which light, gaseous hydrocarbons are combined to produce high-octane components of gasoline.
Aluminum reduction	A process that reduces metals by reacting them with aluminum.
Aromatics	Hydrocarbons that have ring structures containing six carbons. In the ring, there are three alternating single and double bonds.
Aviation jet fuel	Highly volatile grades of petroleum distillate suitable for use in jet engines.
Biogas	A gaseous fuel primarily composed of methane that is created through anaerobic biological fermentation (also called biomethanization) of organic waste matter.
Biomass	A fuel made of organic material, usually plant based.
Biomethanization	A form of anaerobic digestion.
Bitumen	The heavy oil component of oil sand and oil shale composites.
Black liquor	The liquid leaving the digester in a pulp and paper operation after cooking wood chips in a caustic solution. It is a mixture of water, lignin from the wood chips, sodium sulfide (Na_2S), and sodium hydroxide (NaOH).
Black liquor recovery boiler	A steam-generating boiler that uses black liquor from the wood pulping process as fuel. A secondary product is various inorganic residues, called *smelt*, which are recovered and recycled.
Blast furnace	A furnace used to reduce metallic oxides into their metal form by reacting them with carbon. They are most commonly used in iron processing.
Calcination	An ore-processing stage that heats the ore in an oxygen-depleted atmosphere. It is generally used to convert carbonates and hydrates into oxides.
Carbon monoxide reduction	A process that reduces metals by reacting them with carbon monoxide (CO).
Carbon reduction	A process that reduces metals by reacting them with carbon, normally in the form of coke.
Cellulose	An insoluble organic substance that is the main constituent of plant cell walls. Cellulose is used in the production of pulp.
Chemical conversion process	A process that converts one compound into another by chemical reaction.
Chemical process	The process that uses chemicals to produce pulp from wood.
Chemical structure adjustment	To rearrange the chemical structure of a compound and to alter its reactivity.
Co-firing	The process of using two fuels in the same heating process at the same time.
Coke	A high-quality coal used as a fuel and source of carbon in the refining of metal.
Condensate, gas	Liquid natural gasoline. In gas plants, C5 plus is also called *condensate*.
Condensate, steam	Fluid formed when steam is cooled to below its saturation temperature.

Term	Definition
Convection heater	A device that transfers energy between fluids across heat exchange surfaces, primarily using forced or natural convection.
Crystallization	The separation of a crystalline substance from a noncrystalline substance by cooling and separating via a filtration process.
CSS	See *cyclic steam stimulation* (CSS).
Culinary steam	Steam used in direct food processing. This type of steam must meet jurisdictional codes and regulations in how it is sourced and treated to ensure it is safe if it comes in direct contact with the final food product.
Cyclic steam stimulation (CSS)	The removal of bitumen from oil-bearing formations by the pumping of steam underground and using this steam to increase formation pressure. This steam is allowed to soak into the formation. The steam is recovered as condensate, along with the emulsified bitumen and contaminants and pumped back up to the surface of the well.
Debutanizer	A separate distillation column used exclusively to extract butane and lighter components.
De-ethanizer	A separate distillation column used exclusively to extract ethane.
Demulsifier	A class of specialty chemicals used to separate emulsions, such as water in oil.
De-oiled produced water	Water returning from a heavy oil extraction process that, when further processed, may be reused as boiler feedwater.
De-propanizer	A separate distillation column used exclusively to extract propane and lighter components.
Dilbit	Bitumen diluted with naphtha to reduce its viscosity.
Diluent	A thinning agent. In the oil and gas industry, a diluent is added to bitumen to make it easier to transport.
Dilution	The process of reducing the concentration of a compound in a solution by adding additional solvent.
Direct heated kiln	A wood drying kiln that circulates combustion gases from the fired heater throughout the drying chamber.
Distillate fuel oil	Intermediate fractionation cuts in a refinery that have a lower volatility than kerosene but are still able to be distilled from an atmospheric or vacuum distillation unit.
Distillation (fractionation)	The separation of the components of a mixture by successive boiling and condensing; a type of fractionation.
Distillation column	A vessel used in food processing to separate alcoholic spirits on the basis of their different boiling points.
Distillation tower	A vessel into which a mixture of fluids is placed that separates them according to their different boiling points.
Drum dryer	Dryer in the food industries that has an internally heated (normally steam) metallic drum on which a thin layer of wet material is applied.
Dryer	A device used to remove moisture from a vapour.
Drying (evaporation)	The vaporization and removal of water or other liquids from a solution, suspension, or other mixture.
EAF	See *electric arc furnace* (EAF).
Electric arc furnace (EAF)	A metals processing furnace in which an electric arc from graphite electrodes supplies the heat to melt metal scraps.
Electrolysis	The production of a chemical reaction by passing an electric current through an electrolyte.

Term	Definition
Emulsion	Where one liquid is trapped in another liquid, such as water and oil.
Evaporation	Term applied to the changing of a liquid to a gas. Heat is absorbed in this process.
Evaporator	A vessel or piece of equipment designed to boil liquids.
FCC	See *fluid catalytic cracking* (FCC).
Fired heater	A heating device that circulates a process fluid stream through the convection and radiant areas of the combustion gases produced by a burner. The fluid is heated by direct thermal transfer.
Fluid catalytic cracking (FCC)	FCC treats a heavy petroleum distillate with additional heat with the use of a catalyst to break the long chain molecules in the fluid into shorter chain molecules that are collected as vapour.
Fractionation	See *distillation*.
Froth flotation	A form of classifier that separates the components of an ore based on their different surface properties.
Gangue	The non-metallic elements of rock and the residue after metals extraction from mineral ores.
Gasifier	An operating unit that partially combusts a fuel in an oxygen-reduced environment and releases combustible gases as a product
Gasoline	A refinery distillation cut having a boiling point between 30°C and 300°C.
Glass	A stage in the freezing process at which concentrated liquids form a dense, unstructured fluid that prevents ice crystals from continuing to form. At temperatures below which the glass is formed, food is able to maintain its structure for longer storage periods.
Green liquor	The smelt/water solution from the recovery boiler. The green colour comes from the combination of iron, sodium sulfide (Na_2S), sodium carbonate (Na_2CO_3), and carbon.
Grinding	A mineral-size reduction process that takes crushed ore and turns it into a fine powder.
Heat exchanger	Anything that transfers heat from one substance to another without allowing the substances to mix.
Heat tracing	A heating element run in physical contact along the length of a pipe.
Heat transfer fluid (HTF) system	An industrial system where a special non-aqueous heat transfer liquid is circulated by a pump through a fired heat exchanger.
Hog fuel	A fuel made of coarse wood chips and tree bark.
Hot oil system	See *heat transfer fluid (HTF) system.*
HTF	See *heat transfer fluid (HTF) system*.
Hydraulic washing	A form of classifier that separates the components of an ore based on their different densities.
Hydrotreater	This is the equipment used to complete the hydrotreating process. See also *hydrotreating*.
Hydrotreating	A catalyzed refinery process that mixes hydrogen-rich make-up gas with a reactor fluid to remove sulfur and nitrogen from the fluid by creating H_2S and ammonia (NH_3).
IGF	See *induced gas flotation* (IGF).
In situ oil recovery	In situ recovery methods are used to extract bitumen directly from oil sands that lie too deep beneath the surface for mining technologies.

Term	Definition
Indirect heated kiln	A log drying kiln that circulates air heated by contact with high temperature coils containing a heat transfer fluid.
Indirect heating ovens	An oven that is heated by the transfer of heat from a circulating hot fluid, normally steam.
Induced gas flotation (IGF)	In the process of IGF, natural gas is blown through produced water, forming an oil froth that, when skimmed off, further cleans the water.
Injection well	A well that injects steam into underground formations.
Interlock	An automatic safety switch incorporated into the boiler burner management system. It shuts down the combustion process if an unsafe boiler condition exists.
Kerosene	A refined petroleum distillate, intermediate in volatility between gasoline and heavier gas oil.
Kiln drying	Placing wood in a heated chamber to reduce drying time.
Knockout vessel	A drum/vessel used to separate condensate from a gas stream.
Kraft process (alkaline process; sulfate process)	A wood pulp process that uses sodium sulfide (Na_2S) and sodium hydroxide ($NaOH$) to separate lignin and other extracts from cellulose.
Latent heat	Heat, that when applied or removed, causes matter to undergo a phase change (such as solid to liquid or liquid to gas). Latent heat cannot be observed with sensing instruments such as thermometers.
Lignin	The compound that binds cellulose fibres in wood.
Liquefaction	A process to liquefy natural gas using a multi-stage refrigeration process that ultimately reaches –162°C.
Magnetic separation	A form of classifier that separates the components of an ore based on whether they are magnetic or not.
Minerals	Metals, in their natural state, when combined with rock and other non-metallic components of the earth.
Molecular sieves	A material with a specific, uniform pore size that is used to separate compounds by their molecular size.
Molecular size reduction	Reducing the size of compounds by breaking their molecular bonds, normally a C–C bond.
Oil removal filter (ORF)	Equipment used to reduce concentrations of oil in produced water streams.
Olefins	Hydrocarbon compounds that have at least one double C–C bond.
Ore	A raw form of metal found in nature.
Ore leaching	A chemical process that washes the ore with a solvent that dissolves the metal.
ORF	See *oil removal filter* (ORF).
Petrochemical feedstocks	A broad term encompassing refinery products that typically have low molecular weight and high purity (e.g., ethane, ethylene, propylene, acetylene, butane, butadiene, benzene).
Physical process	To change the physical nature of compounds or mixtures but not alter their chemical characteristics.
Pressure regulation	Controlling or regulating the pressure of a system, vessel, or both.
Process quenching	Cooling a process by adding an inert fluid and thus slowing or stopping the reaction.

Term	Definition
Produced water	A combination of water from the free water knockout vessel and water from the treater vessel.
Producer well	A well from which bituminous emulsions are recovered.
Pulp	A cellulosic material used for commercial purposes, such as the manufacture of paper and board. It is prepared from raw material, such as wood, rags, and straw.
Radiant heater	A heater that transfers thermal energy by means of radiation across the furnace space.
Reboiler	Auxiliary of a fractionating tower designed to supply additional heat to the lower portion. Liquid is usually withdrawn (or pumped) from the side or bottom of the tower; it is reheated by means of heat exchange, and the vapours and residual liquid, separately or together, are reintroduced to the tower.
Reformer	A vessel that thermally or catalytically converts petroleum fractions into more volatile products of higher-octane number.
Reforming	A chemical process used to convert petroleum refinery naphthas distilled from crude oil (typically having low octane ratings) into high-octane liquid products called *reformate*.
Residual fuel oil	In a refinery, this is the residue remaining as unevaporated liquid after distillation or cracking processes.
Roasting	An ore-processing stage that heats the ore in an oxygen-enriched atmosphere; it is generally used to convert sulfides into oxides.
SAGD	See *steam assisted gravity drainage* (SAGD).
Slag	The non-metallic waste materials generated in the smelting of ores.
Slaked lime	Calcium hydroxide ($CaOH_2$).
Slaker	In the kraft process, a stirred reactor into which green liquor is fed and where sodium hydroxide (NaOH) is formed the green liquor reacts with calcium oxide (CaO).
Smelt	The waste residue from a black liquor recovery boiler.
Smelting	In metallurgical processing, this involves heating the ore with a reducing agent such as coke, charcoal, or other purifying agents.
Solvent extraction	A process that separates substances by using differences in solubility between compounds in complex mixtures.
Steam accumulators	Pressure vessels that store thermal energy in both gaseous and liquid phases. When energy demand increases, energy is released back into the steam system by a reduction in vessel pressure.
Steam assisted gravity drainage (SAGD)	The removal of bitumen from oil-bearing formations by the admission of steam into horizontal wells in the formation. The steam reduces the viscosity of the bitumen, condenses, and forms an emulsion from which bitumen is separated.
Steam ejector	A fluid acceleration vacuum pump or compressor using the high velocity of a steam jet for entrainment.
Steam infusion heater	A heater that cascades a food product through a steam chamber.
Steam injection heater	A heater that injects culinary steam directly into a food paste.
Steam injector	A device that uses a jet of steam to agitate a mixture.

Term	Definition
Steam jacketed kettle	An industrial kettle that heats food by thermal transfer of heat through a metal wall separating an outer steam chamber from an inner food processing chamber.
Steam sparger	Bubbles culinary steam through a food product using steam nozzles near the bottom of the heating tank.
Steam to oil ratio (SOR)	A measure of the water and energy consumption related to oil production in cyclic steam stimulation and steam assisted gravity drainage oil production. SOR is the ratio of a unit of steam required to produce a unit of oil.
Sterilizer	Equipment that uses culinary steam to achieve the high temperatures and moisture levels required to sterilize enclosed surfaces.
Stripping steam	Steam injected into side stream stripping columns to facilitate the movement of light products up the column. The injected steam carries the lighter hydrocarbons out of the stripper column and back into the main fractionating tower.
Stripping towers	A special form of fractionating tower that uses steam to remove unwanted components from a process stream.
Sulfate process (alkaline process, kraft process)	A wood pulp process using sodium sulfide (Na_2S) and sodium hydroxide (NaOH) as the basic digestion reaction used to release the cellulose from other components of the wood.
Sulfite process	A wood pulp process using aqueous sulfur dioxide (SO_2) and a base as the basic digestion reaction used to release the cellulose from other components of the wood.
Sulfur removal	In moderate to high concentrations, sulfur is removed from a gas stream by burning one third of the H_2S and then reacting the SO_2 with the remaining H_2S, resulting in sulfur and water.
Syngas	See synthesis gas (syngas).
Synthesis gas (syngas)	A mixture of CO and H_2 produced using either lean combustion (reduced oxygen) or steam reforming (direct reaction of steam with methane).
Thermocompressor	Ejector for recompressing spent steam and process fluids.
Thermo-mechanical	The direct conversion of thermal energy into mechanical action.
Treater vessel	A vessel containing electrostatic grids to help remove water.
Turboexpander	An expansion turbine in which a compressed gas flows through an expansion valve that lowers its pressure, causing the gas to expand and lower the temperature below the dew point for the gas to be removed.
Viscosity	The measure of the internal friction or the resistance to flow of a liquid (its thickness).
Wellhead	The valve tree at the surface of an injection or production oil well.
White liquor	A chemical compound of sodium sulfide (Na_2S) and sodium hydroxide (NaOH); used for breaking down the lignin in wood.