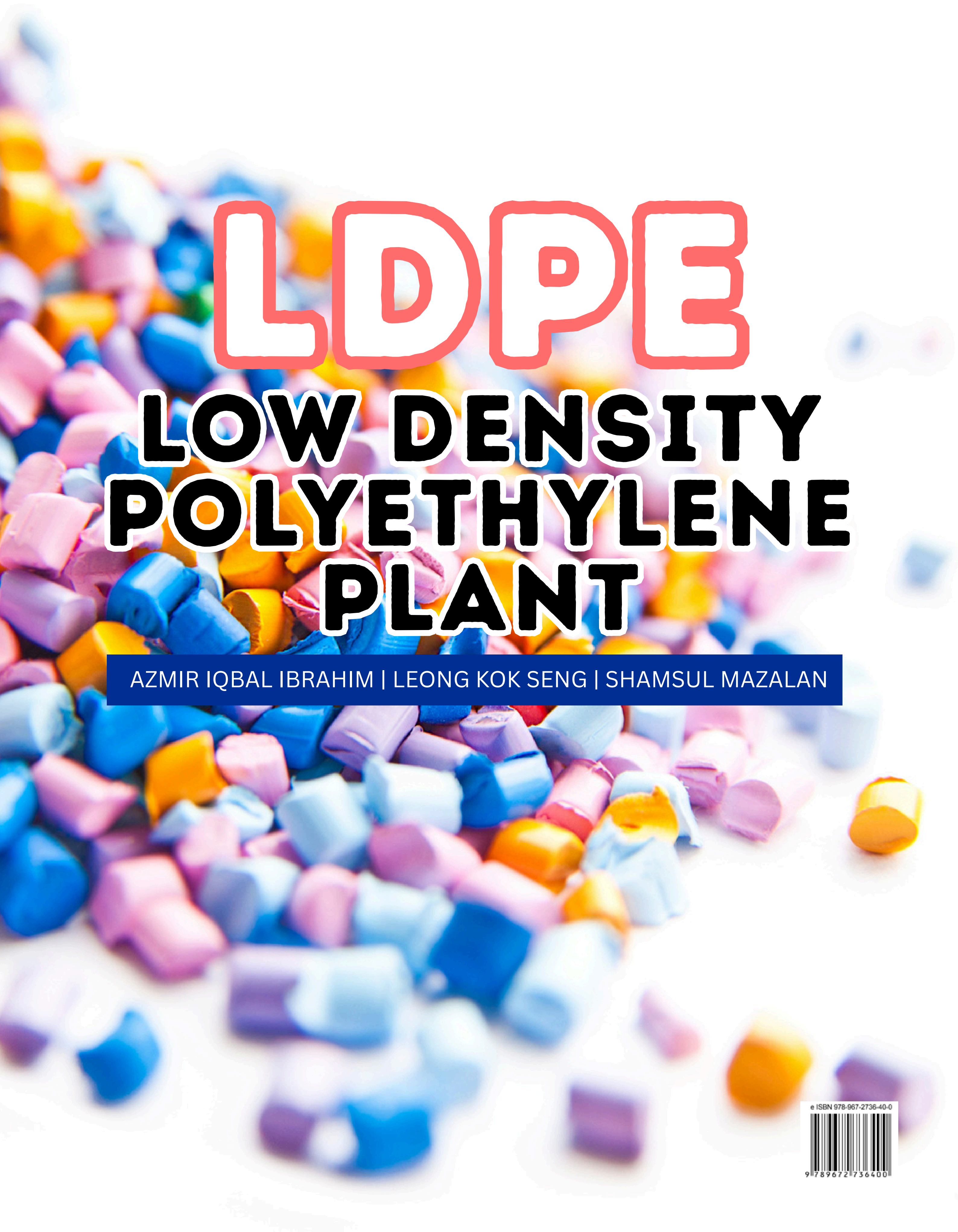

LDPE

LOW DENSITY POLYETHYLENE PLANT

AZMIR IQBAL IBRAHIM | LEONG KOK SENG | SHAMSUL MAZALAN

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PREFACE

In the name of Allah, the Almighty who give us the enlightenment, the truth, the knowledge and with regards to Prophet Muhammad S.A.W for guiding us to the straight path. We thank to Allah for giving us the strength to write this book. May Allah give us the ability to continue our good deeds to the community in this field.

This book consists of Introduction to Low Density Polyethylene (LDPE), Utilities and Auxiliary System and Fundamentals of Fluid Behaviour. Each chapter discusses the theory concept followed by test basic knowledge to ask basic concept. Suitable examples are given and arranged in ascending order of difficulties so that the students can understand each concept and method.

We are happy to receive any comments and suggestions to improve the quality of this book. We hope that this book can be beneficial to the educationist and students. InsyaAllah.

AZMIR IQBAL BIN IBRAHIM
LEONG KOK SENG
SHAMSUL BIN MAZALAN

April 2025

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KM 1 Jalan Panchor
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LOW DENSITY POLYETHYLENE (LDPE)

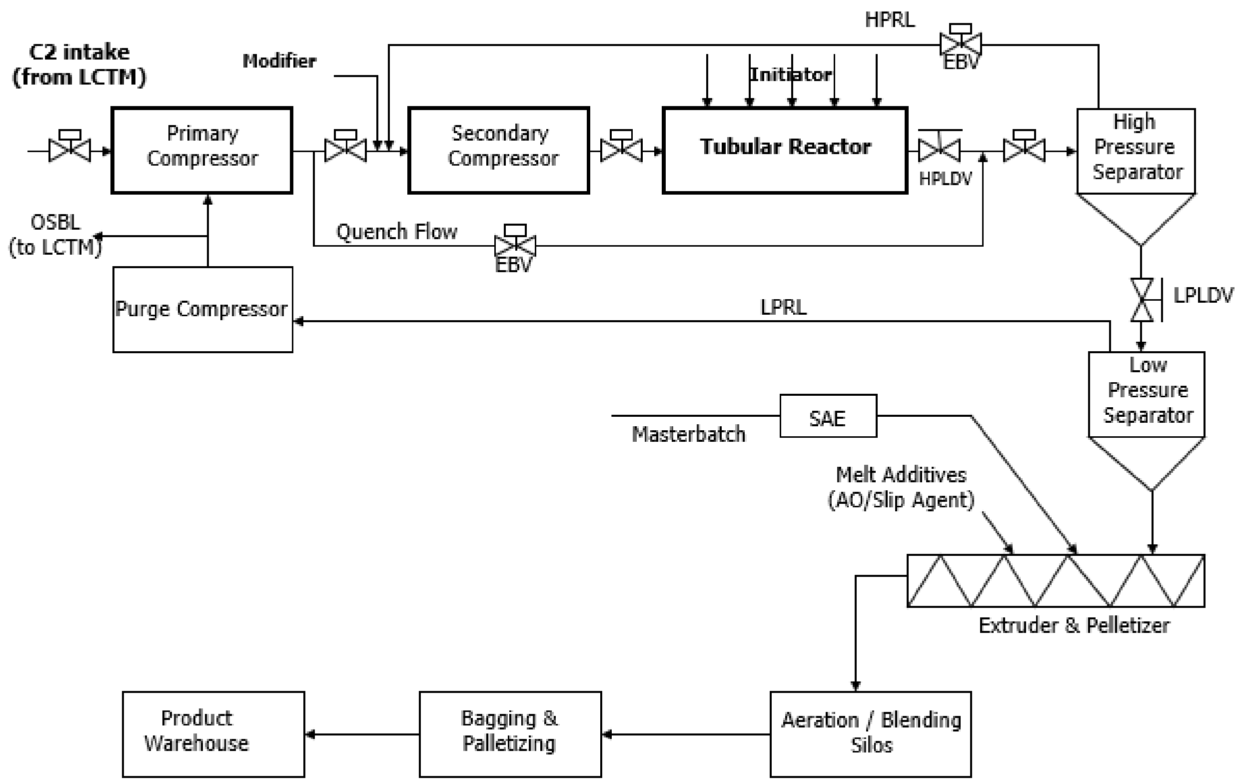

Figure 1

The Figure 1 above shows the block flow diagram of low density polyethylene (LDPE) Tubular process.

↓

The incoming high polymerization of ethylene are come from naphtha cracker are increased from low pressure to high pressure by the primary compressor. After cooling, the ethylene feed is divided into two stream where one of the stream will be feed in the secondary compressor, while the other are added to the polymer mixture downstream of high pressure reactor as “low pressure cold quench”.

↓

The gas from the high pressure recycle system is combined with the ethylene from primary compressor in the secondary compressor. The pressure increases in secondary compressor. Modifiers are added to the secondary compressor. The functions of the modifiers are to control the melt index of the polyethylene. Modifier are added to the reactor to control product properties.

Different application of LDPE such as film, injection grade and coating grade have different value of melt index. The discharge flow of the secondary compressor is feed into five different reactors. Peroxides in the organic solvent are injected into the five different reactor. The function of the peroxides initiator is to initiate the reaction and maintain the temperature of the process.

↓

The flow of the reactor is heated up. The reaction heat is removed by an increase of the temperature of the ethylene, by injection of the cold side stream ethylene and by the heat transfer through the reactor wall to a closed loop jacket water cooling system.

↓

After polymerization, the reaction fluid is decompressed through high pressure let-down valve and cooled with low pressure cold quench from the primary compressor and discharged, the mixture then enters the high pressure separator where it will remove unreacted ethylene.

↓

The off gas from the high pressure separator goes to the high pressure recycle system which consists of cooler and knock out drum returned back to the secondary compressor at a lower temperature. The molten polymer is again decomposed through the low pressure let down valve and fed into low pressure separator.

↓

The remaining entrained ethylene will separate from the LDPE and sent back to the purge gas compression system. At this point part of the gas is purged from the LDPE line to the ethylene recovery system, while majority (80-90%) is recycled via the primary compressor. The polymer melt is feed to the hot melt extruder from low pressure separator. Additives such as antioxidant, antiblock and slip are mixed in the hot melt extruders. The polymer is cut into pellet in the extruders. The pellets are cooled, dried and pneumatically transferred to the weigh bins and are conveyed to bulk loading or bagging facilities.

REACTION MECHANISM

The polymerization of ethylene at high pressure proceeds through a free radical mechanism. A free radical being a short lived reactive intermediate with an unpaired electron. The reaction starts when a free radical reacts with an ethylene molecule forming a new radical that propagates the reaction with ethylene molecules until the growth of long chain molecules ends. The overall polymerization reaction is:

$n\ (CH_2 = CH_2) \rightarrow (-CH_2\text{-}CH_2\text{-})_n$

The following four steps are:

Initiation

Free radical sites for polymerization are formed by reaction between primary initiator free radical fragments and vinyl monomer molecules.

$I \rightarrow R\bullet$

$R\bullet + M \rightarrow RM\bullet$

Propagation

Polymerization then proceeds through a series of additions of monomer molecules to the growing polymer chain with the free radical site jumping to the end of the growing chain after each addition.

$RM\bullet + M \rightarrow RMM\bullet$

Termination

Active free radicals are destroyed by two free radical sites coming together and reacting to form either one or two dead polymer chains.

$M_{n\bullet} + M_{m\bullet} \rightarrow M_{n+m}$

$M_n - CH_2 - CH_{2\bullet} + M_m - CH_2 - CH_{2\bullet} \rightarrow M_n - CH_2 - CH_3 + M_m - CH = CH_2$

Chain Transfer Reactions

Active free radical sites at the end of growing chains jump to another sites on the same polymer molecule, another polymer molecule or a solvent, monomer or modifier molecules. Chain transfer affects the size, structure on the polymers. This category include chain transfer to saturated (eg hexane) and unsaturated (e.g. propylene and butane-1) modifiers, but also chain transfer to ethylene, impurities and depolymerization.

Some examples of these kind of chain transfer reactions are:

- Chain Transfer to Ethylene
  Chain transfer can occur between a growing chain and an ethylene monomer molecule:

$M_n - CH_2 - CH_2\bullet + CH_2 = CH_2 \rightarrow M_n - CH{=}CH_2 + CH_3 - CH_2\bullet$

- Chain Transfer to Unsaturated Modifiers
  Unsaturated modifiers such as propylene, butane and hexane are often used in the production to control the melt index. Chain transfer to propylene, butane and hexane occurs through the following hydrogen abstraction mechanism
  $M_n\bullet + N \rightarrow M_n + N\bullet$

SAFETY INTERLOCK SYSTEM IN THE PROCESS

High Pressure Separator Gas Temperature Controller

- To keep the temperature in the High Pressure Separator constant by adjusting the LPQ flow.
- The LPQ flow is controlled by manipulating the TV valve in the suction of the secondary compressor M (the LPQ flow is increased by further closing of the TV valve.)

Analyzer suction secondary compressor

- Analyses the modifier and comonomer concentration in the suction of the secondary compressor prior to the modifier and comonomer injection. The same sample system is used to analyze oxygen concentration to check the adequacy of the purging operation prior to the reactor start up.

Secondary compressor auto suction valve

- To isolate the secondary compressor from the primary compressor, recycle system and comonomer injection pumps.

Modifier injection flow controller

- To control the amount of modifier injected in order to keep the melt index on target.
- The amount of modifier injected is controlled by the speed of pump

Comonomer injection flow controller

- To control the amount of comonomer injected in order to keep on target.
- The amount of comonomer injected is controlled by adjusting the speed of the pump.

Modifier/comonomer shuf off valves

- To shut off hydrocarbon supply to the modifier and comonomer pumps

Pressure difference indication on 1st and 2nd stage secondary compressor

- Measure the load on the 1st and 2nd stage of the secondary compressor
- The rod load measurement are constraints in the primary compressor discharge pressure controller and the reactor pressure controller.

Secondary compressor 2nd stage suction temperature controller
- To control the suction temperature of the secondary compressor
- Manipulates the valves in the chilled water outlet of the trim intercoolers.

Peak temperature controller reactor zones 1 up to 5
- To have a stable peak temperature
- The high signal selector from the peak picker of each reaction zone control the output of the initiator injection pump.

Initiator back pressure controllers
- To have a discharge pressure on the initiator injection which is 250 bar higher than the reactor pressure in the corresponding reaction zone

Initiator dump valves
- To dump the initiator to the initiator waste collection system.

Reactor pressure controller
- To have a stable level in HPS
- Manipulates the HPLDV (high pressure letdown valve)

Purge compressor suction pressure controller
- To have a stable purge compressor operation.
- Manipulates the purge compressor spillback valve.


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UTILITIES AND AUXILIARY SYSTEM

System	Function
Electrical power	Substation should deliver power to all electrical systems
DCS and interlock (ESD) system	Provide general control over all system in the unit
Safety system	Gas analyzers/detector, gas detection, system for ethylene in water, fire extinguishers
Flare system	Safety burning ethylene vented to the flare from pressure regulator valve (PSV) vent valves
Fire water	Provides deluge capacity in case of fire and emergencies
Plant air	Various applications, part of the plant air is dried for instrument air applications
Instrument air	Provides air power for control valve operation
Cooling Water	Provides sufficient cooling capacity to all coolers
Potable Water	Provides water to safety shower, silo wash system
Boiler feed Water	Provides make up water to the steam boilers, the recycle waste heat boilers, the reactor, recycle and extruder utility water system and the chilled water system
Plant Water	Only for general cleaning and silo washing.
Chilled Water Systems	Provides chilled water to the purge gas compressor trim cooler, the primary compressor 2nd stage trim after cooler
Utility water system	Provides temperature controlled water to the reactor jacket water system, the hot recycle cooler
Steam	For general heating of heaters
Hydraulic oil power packs	For operation of dump valves, HPLDV

Effect of Changes Temperature, Pressure, Flow Rate and The Level in The Process

1. Too high a pressure in HPS:

- Polymer from HPS comes into the recycle system and plugs the coolers.
- Pressure controller primary compressor works in an abnormal way. Check the computer control and if necessary transfer to automatic on lower set point.
- Too high a level in settling tanks.

- Recycle coolers are contaminated.
- With the least doubt, do hard probe test and check wax settling from D1503 on polymer.

2. Too high a temperature in HPS:

- Check LPQ and position TV1427B suction C1150.
- Check tail-end temperature (if necessary take 5th point out of service).
- Initiator from reactor comes in HPS.
- Check reactor profile.

3. Too high temperatures in the outlet pipe of the separate coolers.

- Cooler is contaminated.
- Loss of cooling medium.
- Blow through the settling tanks.
- If necessary vent top vents of coolers at water side.

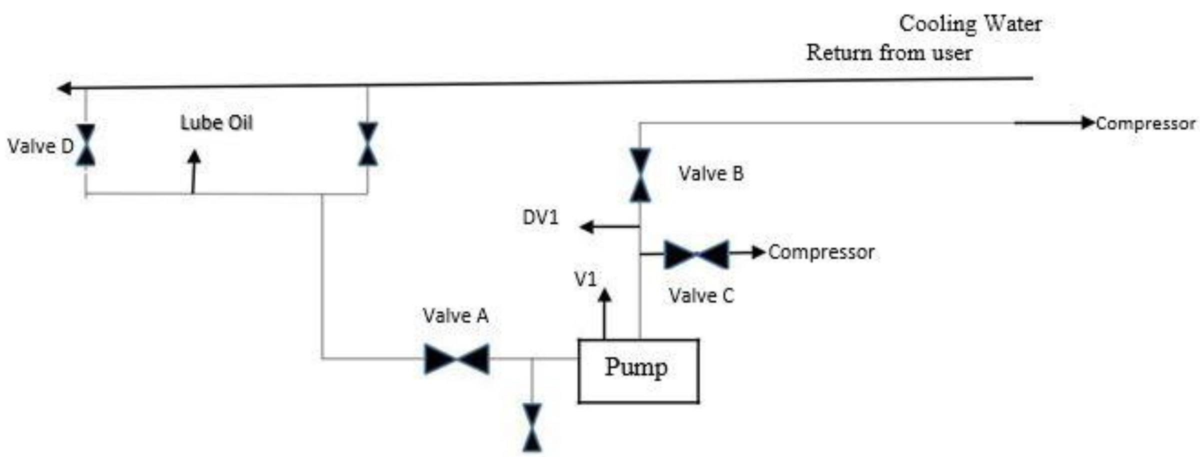
4. Sweeping along of wax in the suction pipe of the high-pressure compressor.

- Too high a level in settling tanks.

5. Overflow of polymer in recycle system:

- Too high a level in HPS.
- Too low a temperature in HPS.
- Bad separation gas/polymer by changing inlet nozzle position.
- Determine zero-point level HPS.

Start Up, Shutdown and Swing Over Cooling Water System (Simple Schematic Diagram)



Start Up step:

1. Check the lube oil
2. Confirm valve A (pump suction) and D (cooling water return) fully open.
3. Confirm valve B (pump discharge) and C (pump minimum circulation) are fully closed.
4. Air free pump by opening vent valve V1. Purge until water flow out and close V1.
5. Purge supply line by open DV1 to ensure water in the pipe. Close all drain valves after confirmed.
6. Inform charge man to energize the pump.
7. Select local switch to manual. Start pump from local.
8. Slowly open valve C to fully open.
9. Check for any abnormality (vibration, noise, temperature, packing leakage).

Shutdown Step:

1. Close valve B and valve C slowly until fully closed.
2. Inform charge man and stop the pump at local.

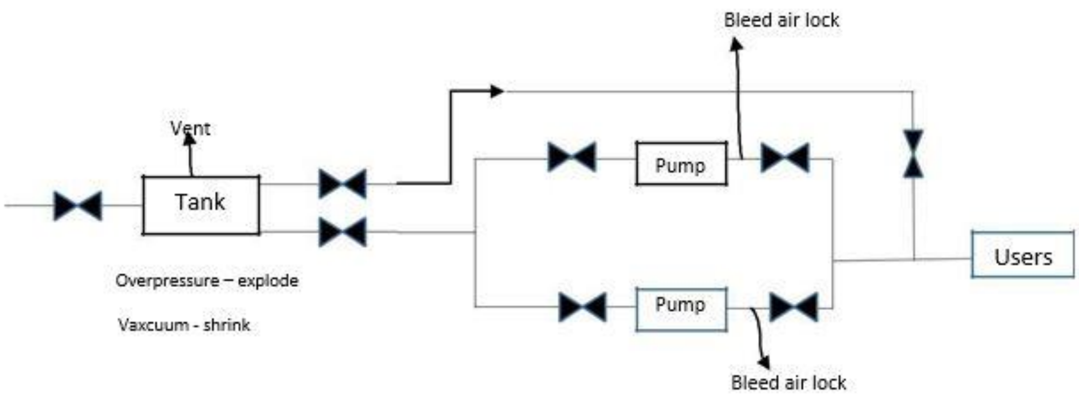
Swing Over Step:

1. Swing over cooling water circulation pump only allow during plant shutdown or during emergency case.

2. Pinch down intended pump to stop flow rate to 1000 m^3/hr by pump discharge valve.

3. Start standby pump as per start up step 1 to 9.

4. After confirm standby pump in normal condition, stop intended pump as per shutdown step.



<u>Centrifugal pump</u>

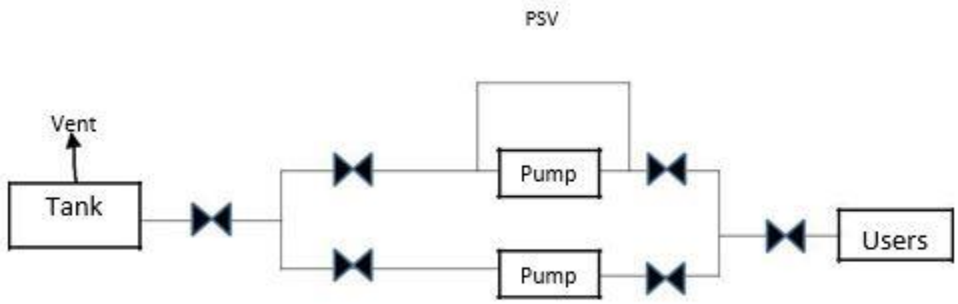
For centrifugal compressor, low displacement pressure with high flow rate.

To start,

1. Open suction, discharge close.
2. Bleed air lock from pump discharge/ pump suction 3.
3. Start pump/ open discharge valve 4. Observe pressure gauge (fluctuating)

To stop,

1. Close discharge valve
2. Stop pump



<u>Positive displacement pump</u>

Positive displacement (depend on the ball bearing).

Normally operate in high air pressure with low flow rate.

To start,

Open all valve then press start.

<u>Pressure sensors</u>

Pressure sensors are devices that detect the force exerted by one object on another.

Pressure is the amount of force applied to an area expressed as force per unit area.

Example diaphragm and differential pressure sensors:

Diaphragm- is a flexible membrane that is made of rubber for low pressure measurements. Diaphragm is mounted in a cylinder, creating a space on both of its sides. One space is open to the atmosphere and the other is connected to the pressure source to be measured. When the pressure is applied, the diaphragm expands into the open space, and the amount of movement is proportional to the pressure being applied. The intermediate segment uses the movement to drive the potentiometer, causing a change in resistance or to drive a mechanical switch, providing pressure limit.

Differential Pressure Sensor- A differential pressure sensor is a modified diaphragm sensor where pressure can be applied to both ends of the cylinder. When pressure is applied to both ends, the diaphragm moves towards the end with the lowest pressure. The movement of the diaphragm, which is the difference between the two pressure is detected and connected to the arm of a switch or potentiometer.

Flow Sensor

Flow sensors can be classified into two types:

Intrusive- sensor that disturb the flow of the fluid that they are measuring

Non- intrusive – sensor that do not disturb the flow of the fluid that they measuring.

Orifice plate

Orifice plate is a washer-shaped device that is installed in a piping system and the flow rate is determined from the measurements of pressure in front of and behind the plate.

Level sensors

Differential Pressure Level Sensors

In the case of open vessel, the level can be measured by insert a pressure sensor at the bottom of the vessel. When the vessels is totally sealed, the liquid level can be calculated by measuring the differential pressure between the top and bottom of the tank. The level transmitter can be calibrated to output 4mA when the tank is at 0% level and 20mA when the tank is at 100% level.

Actuators

The actuator is a translation of the converted control signal into action on the control element. Thus if a valve is to be operated, then the actuator is a device that converts the control signal into the physical action of opening or closing the valve.

Examples of actuators solenoid

A solenoid is a device that converts an electrical signal into mechanical motion. Solenoid consists of a coil and plunger. Solenoid are used when a large, sudden force must be applied to perform some job.

Calibration of Pressure Sensors

- Calibration of pressure sensors (including both absolute and differential pressure sensors) involves using a constant pressure source such as deadweight tester.
- With a deadweight tester, constant pressure is produced for the sensor while the sensor output is monitored and adjusted to make the electrical output proportional to the applied pressure.
- For example, a pressure sensor may be calibrated to produce an output in the range of 4-20mA for pressure inputs covering the whole span of the sensor (0 to 100%).
- For most pressure sensors, with no pressure applied, the transmitter output is adjusted to produce a 4 mA signal.
- Next a pressure that corresponds to 100% of the span is applied by the deadweight tester and the sensor output is adjusted to 20mA.

- These adjustments to the output are made by setting two potentiometers provided in the pressure sensor. These adjustment devices are referred to as the zero and span potentiometers.
- The next step in the calibration of a pressure transmitter is to apply known pressure transmitter is to apply known pressure between 0 and 100% of span to verify the linearity of the transmitter and to make any necessary adjustments to obtain accurate mA outputs for all inputs.

Calibration of Temperature Sensors

- Temperature sensors such as RTD and the thermocouple are calibrated using a constant temperature bath and a standard thermometer.
- This type of calibration bath used depends on the temperature range, the accuracy requirements and the application of the sensor.
- For example, for the calibration of primary and secondary temperature standards, melting or freezing point cells are used.
- These cells are made of such material as tin, zinc, silver and gold whose melting and freezing temperatures are set by nature and are accurately known.
- These cells are referred to as intrinsic standards. These fixed point cells are expensive, difficult to maintain, and normally are used only in standard laboratories.
- For the calibration of average temperature sensors, the fixed points cells are seldom used. The more likely choice for a reference cell is an ice bath, an oil bath or an electric furnace controlled bath.
- The sensor to be calibrated is installed in a temperature bath along with a standard reference sensor. The reference sensor is used to measure the bath temperature.

- A data table is then made of the bath temperature vs the output of the sensor being calibrated. The procedure is repeated for a number of widely spaced temperatures covering the temperature range of the sensor.

Calibration of Smart Instruments

- Smart instruments such as smart pressure sensors often can be calibrated remotely and without the need for manual zero or span adjustment at the sensor location.
- The zero is adjusted by adding or subtracting a bias signal at the output of the sensor as necessary to offset the zero shift.
- The span is adjusted by changing the gain of the sensor output as necessary to make up for changes in sensor span.
- The main advantages of the remote calibration of smart instruments is time conservation.
- For example, to calibrate a conventional pressure sensor, its cover must be removed to access the zero and span potentiometers. This can be a difficult and time consuming task when the pressure sensor is installed in a harsh industrial environment.

Piping

Piping is a network or system of pipes, valves, and auxiliary equipment that channels fluids (liquids, gases, or fluidized solids) between plant vessels and equipment.

In a process facility, piping directs the flow of fluids between the various vessels and equipment. To understand piping and its functions, you need to first understand fluids and the forces that act upon them.

A fluid is any substance that flows. This, essentially, includes all substances that are not large undivided solids. Liquids, gases, and finely divided fluidized solids are all fluids. For the purposes of this module, fluids are able to flow through an enclosed piping system.

A liquid is a fluid that flows freely but does not have a tendency to separate. Water is a good example. Internal forces hold a liquid together in a cohesive mass, while allowing it to flow and assume the shape of its container. A liquid does not appreciably change its volume when it is exposed to pressure variations.

A gas is an uncohesive fluid that expands to completely fill its container, and it has no independent shape or volume. Gases are compressible and can expand indefinitely. Gases have a proportional relationship between their quantity, volume, pressure, and temperature. If any one of these four variables change, a proportional change must occur in one or more of the other factors.

Fluidized solid is a finely divided solid can be made to behave as a fluid if the mass of particles is aerated. Aeration is intermixing air, steam, or other gases into a bed of small solid particles so that the particles become separated and "lubricated." While the aeration is maintained, the aerated mass can flow through piping, valves, and fittings as if it were a liquid. An example of a fluidized solid is the circulating catalyst in a fluid catalytic cracking unit.

In addition to size and schedule, pipe is sold according to the material used in its manufacture. Common materials for piping are:

- Carbon steel
- Alloy steel
- Plastics and resins
- Cast-iron

Each kind of piping material is best suited for a specific use. Carbon steel pipe is lowest in cost and has good general-use properties. However, it cannot be used for high temperature service, for hydrogen service, nor for handling certain corrosives. Properly designated alloy piping can serve in high temperatures, with most corrosives, and with hydrogen. Plastic and resin piping is the best material for strong acids and caustics. Cast-iron pipe and fittings were the traditional pipe for sewer systems but have largely been replaced with PVC (plastic) pipe. Cast-iron is rarely used for process piping, but it is still used for process plant sewers.

Piping performs three major functions in the handling of fluids.

<u>Functions</u>

The three major functions that piping performs are:

- Transporting fluids
- Containing fluid pressure
- Directing fluid flow and regulating flow rate

FUNDAMENTALS OF FLUID BEHAVIOUR

NATURE OF FLUIDS

1. Petroleum processing involves many types of fluids. Any substance that can flow is a *(fluid, solid).*

2. Fluids have no definite shape. The oil in a storage tanks assumes the *(shape, volume)* of the tank.

3. Oil *(is, is not)* a fluid.

4. Water and gasoline are also *(solid, fluid).*

5. Oil, water, and gasoline can be all be made to *(flow, movement).*

6. Substances exist as liquids, solids, gases or as mixture of liquids, solids, or gases. Crude oil is a *(liquid, gas).*

7. Gasoline is usually a (gas, liquid).

8. Air is also a fluid. The hydrogen, oxygen, and other substances in the air are usually *(gas, liquid).*

9. Natural gas is made up largely of methane. Methane is a substance that exists normally as a *(gas, liquid).*

10. Liquids flow and have no definite shape. Gases such as methane and air are also *(have, have not)* a definite shape.

11. Any substance that can flow is a fluid. Liquid and *(gases, solids)* are fluids.

12. Air *(is, is not)* a fluid.

13. Water and steam are also *(fluids, solids).*

14. A fluid is any substance that can *(flow, vibrate).*

15. Which of these following are usually handled as fluids?

    (water, steam, catalyst pellets, kerosene, crude oil, methane, lump coke, air, ice, sulphuric acid, dry ice, carbon dioxide gas, rust, ash).

16. Whenever you see a pipe, a steam line, a tank, a pump, a compressor, a tower, an instrument, or even a filled sample container, it almost certainly contains a *(fluids, solids).*

17. Whenever a problem occurs in any part of the process, it *(is, is not)* likely to be related to the laws and properties of fluids.

<u>STATES OF MATTER</u>

18. All substances are made up of atoms, which combine to form molecules. A molecule of oxygen (O_2) is made up of two *(atoms, molecules)* of oxygen.

19. In water (H_2O), two atoms of hydrogen and one atom of oxygen combine to form one *(atoms, molecules)* of water.

20. A molecule is a combination of *(atoms, molecules).*

21. CH_4 is *(an atom, a molecule)* of methane.

22. H_2SO_4 is *(an atom, a molecule)* of sulphuric acid.

23. The chemical symbol for a substance indicates the kind and number of *(atoms, molecules)* in each molecule of a substance.

24. For instance, the chemical symbol for methane is CH_4. This means that one molecule of methane contains one *(atoms, molecules)* of carbon and *(four, five)* atoms of hydrogen.

25. A molecule of ethane contains *(two, three)* carbon atoms and *(five, six)* hydrogen atoms.

26. The chemical symbol for ethane is *(C_2H_6, C_3H_6).*

27. A hydrocarbon molecule contains only atoms of *(carbon, nitrogen)* and atoms of *(oxygen, hydrogen).*

28. Crude oil is a mixture of many different hydrocarbons. Different hydrocarbon molecules contain *(the same numbers, different numbers)* of hydrogen and carbon atoms.

29. There are more heavy carbon atoms in a molecule of *(propane, butane).*

30. A butane molecule is *(heavier, lighter)* than a propane molecule.

31. Molecules are always in motion. The molecules of all substances *(move, does not move)* constantly in all direction.

32. Molecules and their motion cannot be seen, but without molecular motion there would be no heat. Heat is the motion of *(molecules, air).*

33. Heating a substance is the same as *(increase, decrease)* the motion of molecules.

34. A metal bar expands when it is heated. Heating a substance tends to move its molecules *(close together, farther apart).*

35. Thermal expansion is the expansion of a substance caused by *(heat, cool).*

36. Because of the thermal expansion, oil drums are not fitted to the top. Some space is left in the drums for the thermal *(expansion, contraction)* of liquid.

37. Thermal expansion occurs because heat *(increases, decreases)* molecular motion and causes molecules to move *(closer together, farther apart).*

38. Gases are made up of separate molecules in random and chaotic motion. Attractive forces have almost no effect on the molecules of a dry *(gas, liquid).*

39. Substances like methane (CH_4) and hydrogen (H_2) are made up of small, light molecules. For a given amount of heat energy, these molecules move *(more, less)* than heavy molecules.

40. In the open air at ordinary temperature, substances with small, light molecules tend to be *(gases, solids).*

41. Substances with large, heavy molecules or strong molecular attractions tend to be *(gases, solids)* at room temperature and pressure.

FLUIDS AND FORCE

42. Heat is one form of energy. Heat energy is caused by the *(movement, vibration)* of molecules.

43. Mechanical force is also a form of energy. If you push an object to make it move, you are applying *(force, movement)* to the object.

44. Force is energy applied in a direction. A piston could be used to apply *(force, movement)* to a fluid.

45. The energy of moving piston *(is, is not)* applied in a direction.

COMPRESSIBILITY OF GASES

46. The cylinder contains gas. Applying force to the gas *(compress, expand)* it into a smaller space.

47. Cooling a substance is the same as removing heat or thermal energy. Cooling *(speeds up, slow down)* molecular motion.

48. A substance *(expands, contracts)* when it is cooled. This is because the loss of heat energy *(increases, decreases)* the distance between molecules.

49. Besides heat energy, molecules are affected by internal attractive forces. The *(molecules, force)* of a substance are attracted to each other.

50. These attractive forces tend to hold molecules *(together, apart).*

51. Molecular attractions act against the energy of heat. A heated substance expands *(in spite of, because of)* molecular attraction.

52. The molecules of *(solids, liquids)* are held together in a close, patterned arrangement.

53. Liquid molecules are attracted to each other, but they slide past each other. The molecules of a liquid move too *(freely, hard)* to be held in a fixed shape.

54. Because gas molecules are so far apart, a gas can be *(compress, expand)* into a smaller volume.

55. The arrangement of liquid molecules are already close together, a liquid *(can, cannot)* be compressed very much.

56. Below its boiling point, butane is a liquid. Liquid butane *(is, is not)* compressible.

57. Above its boiling point, butane is gas. Butane gas is *(compressible, practically incompressible).*

58. Compressibility is a characteristic of (*liquids, gases, all fluids).*

59. Gas are compressible because of the great amount of *(distance, heat)* between gas molecules.

60. Gas handling equipment can be built smaller because gases are *(compressible, expanded).*

61. The energy of compressed *(gas, solid)* can be used to do work.

62. A gas always expands to fill a larger space. A gas can be *(compress, expand)* into smaller space.

63. The space a substance occupies is its volume. Gases *(have, do not have)* a fixed volume.

64. The *(volume, shape)* of a gas changes to fit the available space.

65. A gas always assumes the volume of its container. But when a liquid poured into a larger container, it *(fills, does not fill)* the container.

66. A liquid *(can, cannot)* be compressed into smaller volume.

67. Both liquids and gases have indefinite shapes. However, *(gas, solid)* have indefinite volume.

68. Liquid have *(definite, indefinite)* volumes.

69. A fluid exerts pressure on everything it touches. The oil in the tank exerts *(pressure, volume)* on the bottom of the tank.

70. Pressure is force per unit of area. Ten pounds is not a pressure measurement because it doesn't specify *(force, area).*

71. Gas molecules move in all directions. As gas molecules move, they repeatedly *(strike, expand)* each other.

72. Cooling is a substance is the same as removing heat, or thermal energy. Cooling *(speeds up/ slow down)* molecular motion.

73. The molecules of a *(gas, liquid)* are farthest apart.

74. Liquid molecules are attracted to each other, but they slide past each other. These molecules of a liquid move too *(fast, moderate)* to be held in a fixed shape.

75. Gases are made up of separate molecules in random and chaotic motion. Attractive forces have almost no effect on the molecules of a dry *(gas, volume).*

76. Substances with large, heavy molecules or with strong molecular attractions tend to be *(solid, liquid)* at room temperature and pressure.

77. Heat is one form of energy. Heat energy is caused by the *(movement, contraction)* of molecules.

78. Mechanical force is also a form of energy. If you push an object to make it move, you are expending *(energy, volume).*

79. Force is energy applied in a direction. A piston could be used to apply *(force, volume)* to a fluid.

80. The energy of a moving piston *(is, is not)* applied in a direction.

81. A cylinder contains gas. Applying force to the gas *(compress, expand)* it into a smaller space.

82. Because gas molecules are so far apart, a gas can be *(compress, expand)* into a smaller volume.

83. When a gas is compressed, it's *(molecules, force)* are forced closer together.

84. Gases are compressible fluids. Liquids are *(compressible, practically incompressible)* fluids.

85. Below its boiling point, butane is a liquid. Liquid butane *(is, is not)* compressible.

86. Above its boiling point, butane is a gas. Butane gas is *(compressible, practically incompressible).*

87. Compressibility is a characteristic of *(liquids, gases, all fluids).*

88. Gases are compressible because of the great amount of (distance, force) between gas molecules.

89. Gas pressure is caused by the *(motion, movement)* of gas molecules.

90. Compressing a gas *(increases, decreases)* its pressure.

91. Compressing a gas *(increases, decreases)* its volume and *(increases, deceases)* its pressure.

92. The force applied by the piston is transmitted through the liquid. The liquid exerts *(more, less)* pressure on everything it touches.

93. When a liquid is trapped, force applied to a liquid is transmitted equally through the liquid. This added force increases the *(pressure, volume)* of the liquid.

94. A piston cannot *(compress, expand)* liquid into a smaller volume.

95. Methane has a *(higher, lower)* melting point than butane.

96. Methane molecules are *(heavier, lighter)* than butane molecules.

97. Petroleum and its products are *(mixture, pure substances).*

98. Hydrocarbon products are tested for pour points and cloud points. The pour point of a liquid is the temperature at which it will cease to *(flow, expand).*

99. If a liquid is below its pour point, it *(will, will not*) pour.

100. Liquids flow at temperature *(above, below)* their pour points.

101. When solid particles such as paraffin begin to settle out in a liquid, the liquid is *(clear, cloudy).*

102. The cloud point of a liquid is the temperature at which it becomes *(clear, cloudy).*

103. When a liquid drops below its cloud point, particles of *(solid, gas)* are forming in the liquid.

104. A liquid appears clean or clear as long as it is above its (cloud, boiling) point.

105. Melting or freezing points, pour points and cloud points are properties of liquids. These properties are known and calculated for most liquids and are helpful in analyzing the composition of *(element, mixture).*

106. Another term word for gas is *(vapor, air).*

107. Some molecules are always escaping from the surface of a liquid. When molecules escape the liquid surface, they are in *(vapor, solid)* phase.

108. Molecules that strike the liquid surface are absorbed back into the liquid. Thus molecules are always passing between the vapor and *(liquid, gas)* phase.

109. Equilibrium is reached when *(equal, not equal)* numbers of molecules are exchanged between the liquid and vapor phase.

110. In equilibrium, the number of molecules escaping from the liquid *(equal, not equal)* the number of molecules absorbed back into the liquid.

111. When the system reaches equilibrium, the level of liquid in the container *(rises, fall, remain the same).*

112. Evaporation occurs when more molecules are leaving the liquid phase. Condensation occurs when more molecules are leaving the *(liquid, vapor)* phase.

113. The vapor pressure of a liquid is measured by heating liquid in a closed container and allowing the liquid and its vapor to reach equilibrium. Then the measured pressure of the vapors is the *(vapor pressure, temperature vapor)* of the liquid at that temperature.

114. Vapor pressure is the pressure exerted by a liquid's vapors when the liquid and its vapors are in the state of *(static, equilibrium).*

115. The vapor pressure represents the energy available for molecules to escape into the *(vapor, liquid)* phase.

116. As temperature increases, the molecules exert more pressure as they reach a state of equilibrium. Heating a liquid *(increases, decreases)* its vapor pressure.

117. All liquids have higher vapor pressure at higher *(temperature, pressure).*

118. Propane molecules are *(heavier, lighter)* than butane molecules.

119. For the same amount of heat, *(propane, butane)* molecules move more rapidly.

120. At the same temperature, propane has a *(higher, lower)* vapor pressure than butane.

121. Liquid with low boiling points have *(low, high)* vapor pressure. Propane has a *(higher, lower)* vapor pressure than water.

122. Heat also increases liquid *(pressure, volume)* by increasing the speed of liquid molecules.

123. The total pressure of fluid in a closed system may be greater or less than the vapor pressure of the liquid. If mechanical force is applied to the system, the pressure of the fluid is *(greater, smaller)* than the liquid's vapor pressure.

124. If a pump or other mean is used to draw off liquid or vapor, a partial vacuum may form in a closed system. Then the total pressure of the fluid may be less than the *(vapor pressure, temperature)* of the liquids at the existing temperature.

125. As the pressure increases, the molecules require *(more, less)* energy to escape the liquid phase in piston.

126. Increasing the pressure on a liquid-vapor system tends to cause *(evaporation, condensation).*

127. The heaviness of petroleum liquids is usually measured in units of API gravity. ◦API is used to measure the heaviness of hydrocarbon *(liquid, solid).*

128. API gravity *(is, is not)* used in measuring gas.

129. The stem of the hydrometer is scaled in units of *(◦API, BMI).*

130. The hydrometer is placed in the liquid being measured. A heavy liquid will tend to support or “buoy up” the *(thermometer, hydrometer).*

131. If the hydrometer is placed in a light, low density liquid it will tend to *(sink, expand).*

132. The hydrometer settles deeper in liquids with *(high, low)* densities.

133. If a liquid is dense or heavy, its API gravity reading is *(high, low).*

134. A high API gravity reading indicates a liquid that is *(light, heavy).*

135. Water has a higher density than 40◦ API crude oil. But the oil has a *(higher, lesser)* API gravity than the water.

136. As the heaviness of a liquid increases, its API gravity *(increases, decreases).*

137. As API gravity increases, density and specific gravity *(increases, decreases).*

138. 20◦API crude oil is *(heavier, lighter)* than 30◦API crude oil.

139. Suppose methane gas is vented to the atmosphere. The methane will tend to *(rise, settle near the ground).*

140. Gases that are lighter than air tend to *(rise, settle near the ground)* in the atmosphere.

141. *(Butane, Methane)* is heavier than air.

142. If butane is vented, it will tend to settle near the *(ground, atmosphere).*

143. Gases settle near the ground if their specific gravity is *(more or greater, less or greater)* than 1.

144. Gases rise quickly if their specific gravities are *(less, more)* than 1.

145. Propane, butane and pentane are often handled as LPG. These gases are *(heavier, lesser)* than air.

146. Gasoline is *(heavier, lighter)* than water.

147. If a liquid is lighter than water, its specific gravity *(more, less)* than 1.

148. The specific gravity of most oils is *(more, less)* than 1.

149. Liquids have *(higher, lower)* densities than gas.

150. Gas density is higher when the gas *(is, is not)* compressed.

151. Instead of liquid mercury, industrial thermometers may use metal strips that bend as they are heated. Metal strips *(expand, do not expand)* when they are heated.

152. The degree of expansion of the mercury or metal in the thermometer reflects the *(temperature, pressure)* of the substance being measured.

153. Industrial thermometers work on a principle of thermal *(expansion, contraction).*

154. The thermometer is filled with *(mercury, iron).*

155. When heat is applied to a liquid, molecular activity increases. A liquid *(expands, contracts)* when it is heated.

156. Absolute pressure is the total pressure including both the pressure within the system, or *(gauge, absolute)* pressure and the pressure of the *(gauge, atmosphere).*

157. Pressure is the amount of *(force, pressure)* per unit area.

158. As the altitude increases, atmospheric pressure *(increases, decreases).*

159. The closer the altitude is to sea level, the *(higher, lower)* atmospheric pressure is likely to be.

160. Many substances can be fluids. A substance is a fluid that can made from *(fluid, gas).*

161. Sometimes liquids evaporate at the suction of a pump. The low pressure at a pump's suction can cause liquid to *(evaporate, expand).*

162. A common process in petroleum processing is fractionation or distillation. In fractionating tower, crude oil is heated until it begins to *(boil, cool).*

163. The light fractions vaporize *(before, after)* the heavier fractions in the crude oil.

164. As the different fractions vaporize, the vapors can be collected separately and condensed. Fractionation is a way of separating the different *(pressure, fractions)* out of crude oil.

165. Fractionation does not involve a change in molecular structure. Fractionation involves changes in the *(structure, phase)* of hydrocarbons.

166. Some hydrocarbon processing involves changes in molecular structure. In cracking operation, large hydrocarbon molecules are broken down into *(smaller, bigger)* molecules.

167. In reforming operations, different hydrocarbon molecules are formed. Cracking and reforming *(change, do not change)* molecular structure.

168. Cracking and reforming operation require chemical reactions. A chemical reaction changes the (structure, volume) of molecules.

169. A phase changes the *(distance, volume)* between molecules.

170. Excessive heat can cause coke formation in fractionating towers. Coke is formed from a chemical *(reactions, structure)* between hydrocarbon molecules.

171. Chemical reactions can be caused by excessive *(air, heat).*

172. Suppose you reduce the pressure in a fractionating tower. The hydrocarbons require *(more, less)* heat to vaporise.

173. You can fractionate oil at lower temperature by reducing the *(volume, pressure)* on the oil.

174. Vacuum towers are often necessary for fractionation. In a vacuum tower, the pressure on the oil is *(more, less)* than atmospheric pressure.

175. Fractionation can be carried on at lower temperature in a *(vacuum, pressurized)* tower.

176. So vacuum tower operations tend to reduce the amount of coke formation during fractionation. Undesirable chemical reactions can be prevented by a combination of reduced pressure and reduce *(temperature, pressure).*

177. Vacuum tower operations depend on the principle that liquid vaporize at lower temperature when they are at *(lower, higher)* pressure.

178. Sometime liquids evaporate at the suction of a pump. The low pressure at a pump's suction can cause liquid to *(evaporate, expand).*

179. Liquid evaporate when suction pressure is *(greater, less)* than the vapor pressure of the liquid at pumping temperature.

180. You can prevent evaporation of liquid by cooling the liquid. Cooling *(increases, decreases)* the liquid's vapor pressure.

181. Gas at higher temperature can be condensed or liquefied by increasing the *(pressure, volume)* on the gas.

182. Petroleum gases are often liquefied for ease in storage and handling. Liquefied Petroleum Gas, LPG is gas that has been forced into the *(liquid, gas)* phase by a combination of cooling and high pressure.

183. At atmospheric pressure and temperature, the hydrocarbon in LPG would be *(liquids, gases).*

184. These gases are forced into the liquid phase primarily by increasing the *(pressure, volume)* on the fluid.

185. When gas is compressed into the liquid phase, the pressure on the gas must *be (as great as, less than)* the vapor pressure of the fraction in its liquid phase.

186. Suppose a pressurized cylinder of LPG is heated. The vapor pressure of the LPG *(increases, decreases).*

187. As the vapor pressure of the liquid increases, the LPG begins to *(boil, evaporate).*

188. Total pressure in the cylinder increases, and the cylinder could rupture. To prevent over pressuring, storage cylinder of methane, propane, butane and other LPG are often *(remove, store)* in the summer.

189. Heat from the sun can be great enough to *(boil, vaporize)* these liquids and cause a cylinder to overpressure.

190. Temperature does not measure the amount of heat in a substance. Temperature measures only the *(amount, intensity)* of heat.

191. Since the heat of phase change does not change a thermometer reading, it is called latent heat. Latent heat is absorbed or given off when a substance changes from one *(structure, phase)* to another.

192. Boiling and freezing points indicate the temperature at which substances are affected by *(latent, vapour)* heat.

193. Thermometers show changes in *(sensible, latent)* heat.

194. A substance absorbs latent heat when it is melting or boiling. A fluid gives off latent heat when it is condensing or *(boiling, freezing).*

195. The steam is generated at a central location and then piped to reboilers at the base of fractionating towers, where it is allowed to condense. Heat flows from the hot condensing *(steam, volume)* to the process liquid.

196. Steam is not the only fluid used in heat exchangers. But the high latent heat of steam makes it a *(good, poor)* fluid for heating.

197. Even low pressure exhaust steam from steam pumps and turbines can be used to *(cold, heat)* process liquid.

198. A liquid absorbs more heat when it is *(is, is not)* evaporating.

199. Pressure and temperature are two variables. Pressure and temperature *(change, does not change)* as a fluid is transported and handled.

200. The temperature effect on the volume of liquids is small. But volume is an important variable in handling *(liquid, gases).*