Refrigeration of Mine Air

- Refrigeration of mine air is necessary when its temp. becomes excessive so that no further increase in quantity of air would improve environmental conditions.

- Two processes or systems are utilized in mine air conditioning to produce chilled fluids for heat transfer underground. They are

  – Refrigeration and
  – Evaporative cooling.

Function of refrigerating system:

- Refrigeration is a process of cooling.

- A refrigeration machine uses mechanical work to absorb/remove heat from a substance at one temp. and to reject/discharge it to sink at a higher temp.

- Refrigeration or cooling plants are usually designed to produce tolerable environmental conditions throughout the year at working places in the mine.

- Normally the air is cooled and dehumidified so that it is saturated at 275 to 278 K.

- The cooled air is then conducted to the working faces as such or after mixing with a stream of uncooled air so as to obtain the desired face temperature.

- Hence a refrigeration plant should be designed to have a capacity, sufficient for cooling the farthest face under the worst surface-temperature conditions as my occur in the summer.

Refrigeration Process

- The mechanical process of absorption of heat from one location and its transfer to and rejection at other place is termed as *refrigeration*.

- Most commonly in refrigeration, the working medium or refrigerant alternates between the liquid and vapour phases. Hence such processes are called *change of state* or *vapour refrigeration*.

- Household refrigerators and most commercial units employ vapour cycle.

- Several refrigeration systems are used commercially, but **the commonest type of refrigeration plant suitable for both surface and underground mining operation is the vapour-compression type.**

- A **vapour-compression** refrigeration system consists of a cycle of four basic processes circulating a refrigerant, the heat-transfer medium.

- The purpose of refrigerant is to absorb heat from a **“source” (evaporator)** and discharge it through a **“sink” (condenser).**

- The liquid refrigerant is allowed to evaporate and extract the latent heat of evaporation from the mine air.

- To achieve this at temperatures as near the atmospheric as possible, the refrigerant is compressed.

- A vapour pump, in the form of a **compressor,** is located between the source and sink so that the energy absorbed by the refrigerant in the evaporator may be transferred to the condenser for discharge.

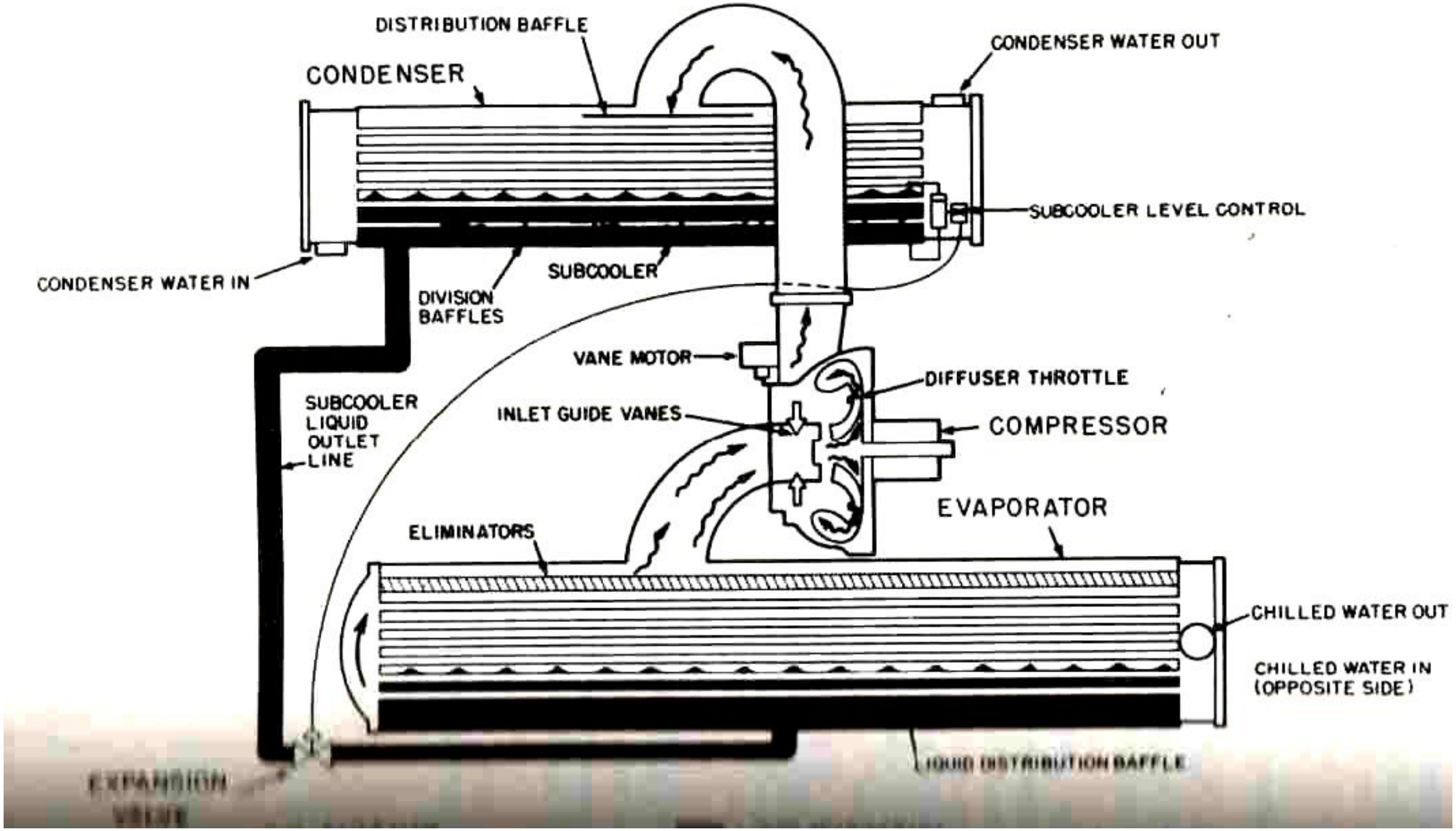
- For economy, the refrigerant is used in a cycle system where it is condensed after evaporation and reused.

- In addition, **a receiver** for storing the liquid refrigerant and **an expansion valve** for reducing the pressure for cooling of the refrigerant in its turn to the evaporator and controlling the flow-rate of the refrigerant are needed.

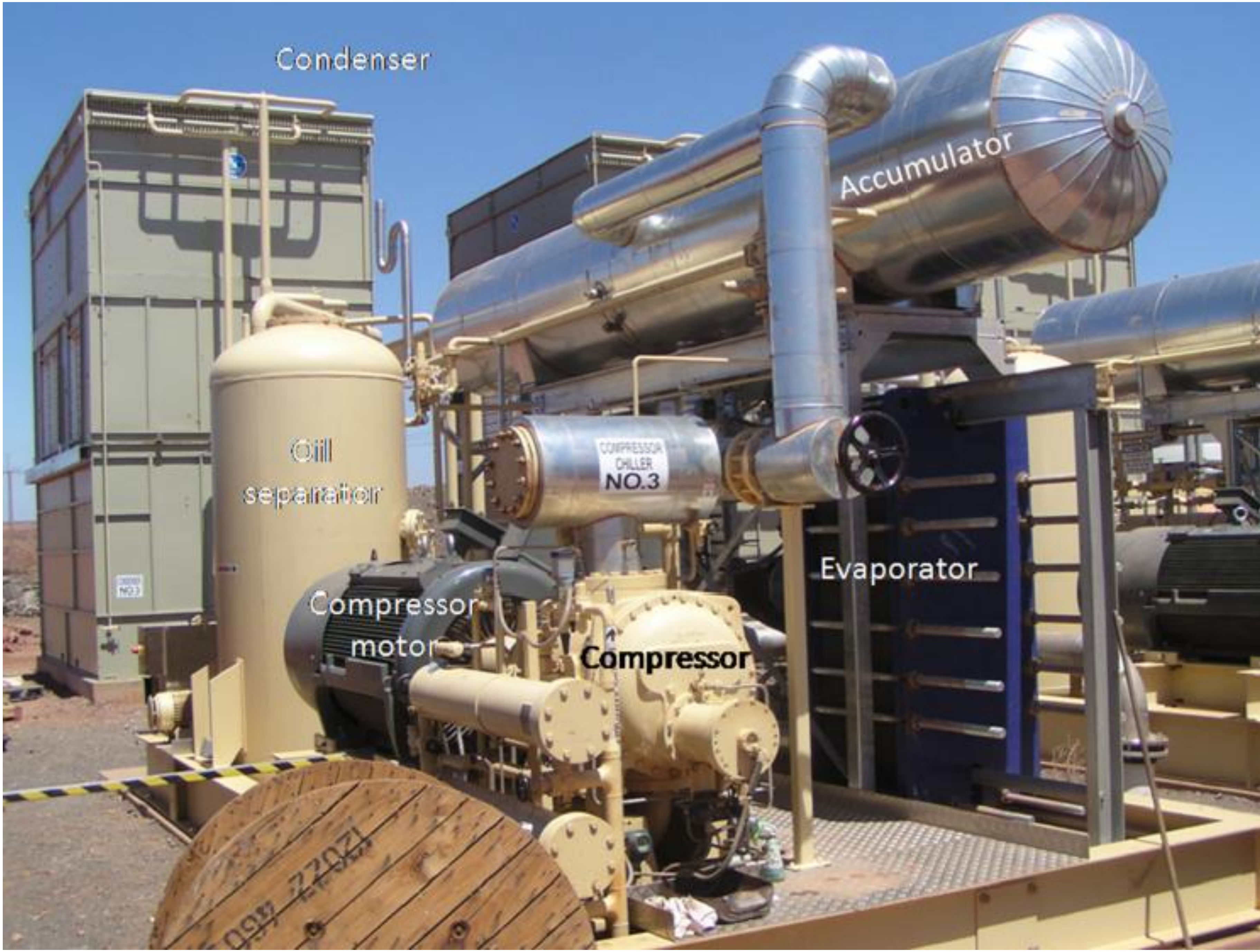
- **Thus vapour refrigeration system is essentially a compression system, involving heat exchange through a change of the state of refrigerant from liquid to gas and then back to liquid.**

Basic vapour-compression refrigeration system

A complete vapour-compression refrigeration system comprises of an **evaporator, a compressor, a condenser and an expansion valve.**



Diagrammatic sketch of a single-stage centrifugal refrigeration machine


Condenser
Accumulator
COMPRESSOR
CHILLER
NO.3
Oil
separator
Evaporator
Compressor
motor
Compressor

- **An evaporator**: where the liquid refrigerant “boils” (evaporates) by extracting the latent heat from the air it cools.
  - Hence, changing state from liquid to gas and absorbing heat from substance to be cooled, with no change in temperature.
- **A compressor**: for compressing the refrigerant vapour in order to raise its temperature of condensation.
  - In the vapour state, refrigerant flows to compressor, where work is done in compressing it.
- **A condenser**: to turn the vapour refrigerant into liquid again.
  - Vapour condensed to liquid again gives up heat without a temperature change.

Vapour refrigeration cycle

- It is schematically represented by the block diagram.

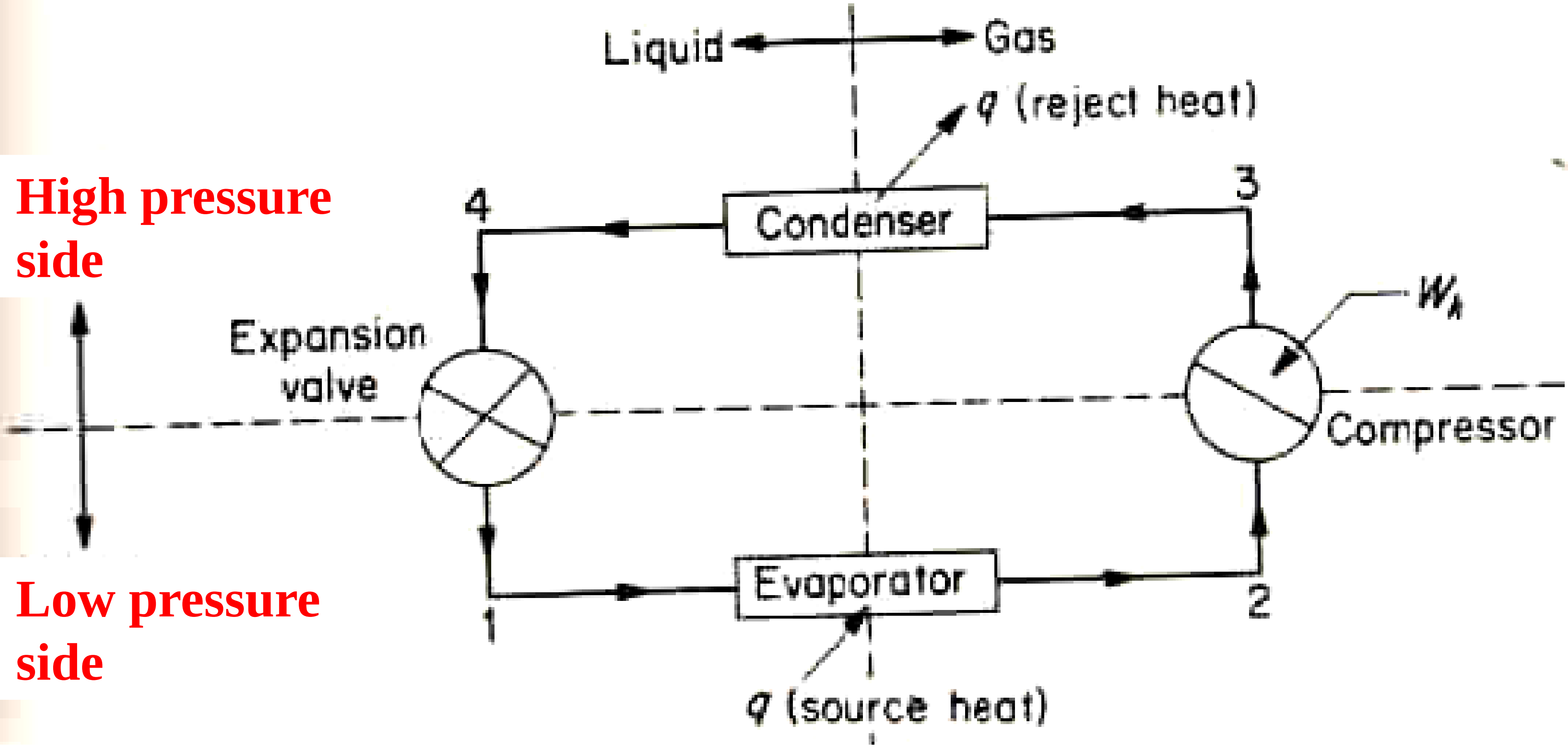
- The state of the refrigerant (liquid or gas) is indicated in the schematic, referenced to a vertical axis.

- The changes of state of the refrigerant are actually controlled by varying the pressure; this leads to the designations *low-pressure side* and *high-pressure side* of the system, as shown with reference to a horizontal axis.

Basic Vapour-Compression Cycle

High pressure side

Low pressure side



Schematic and block diagram of vapour refrigeration system using vapour cycle

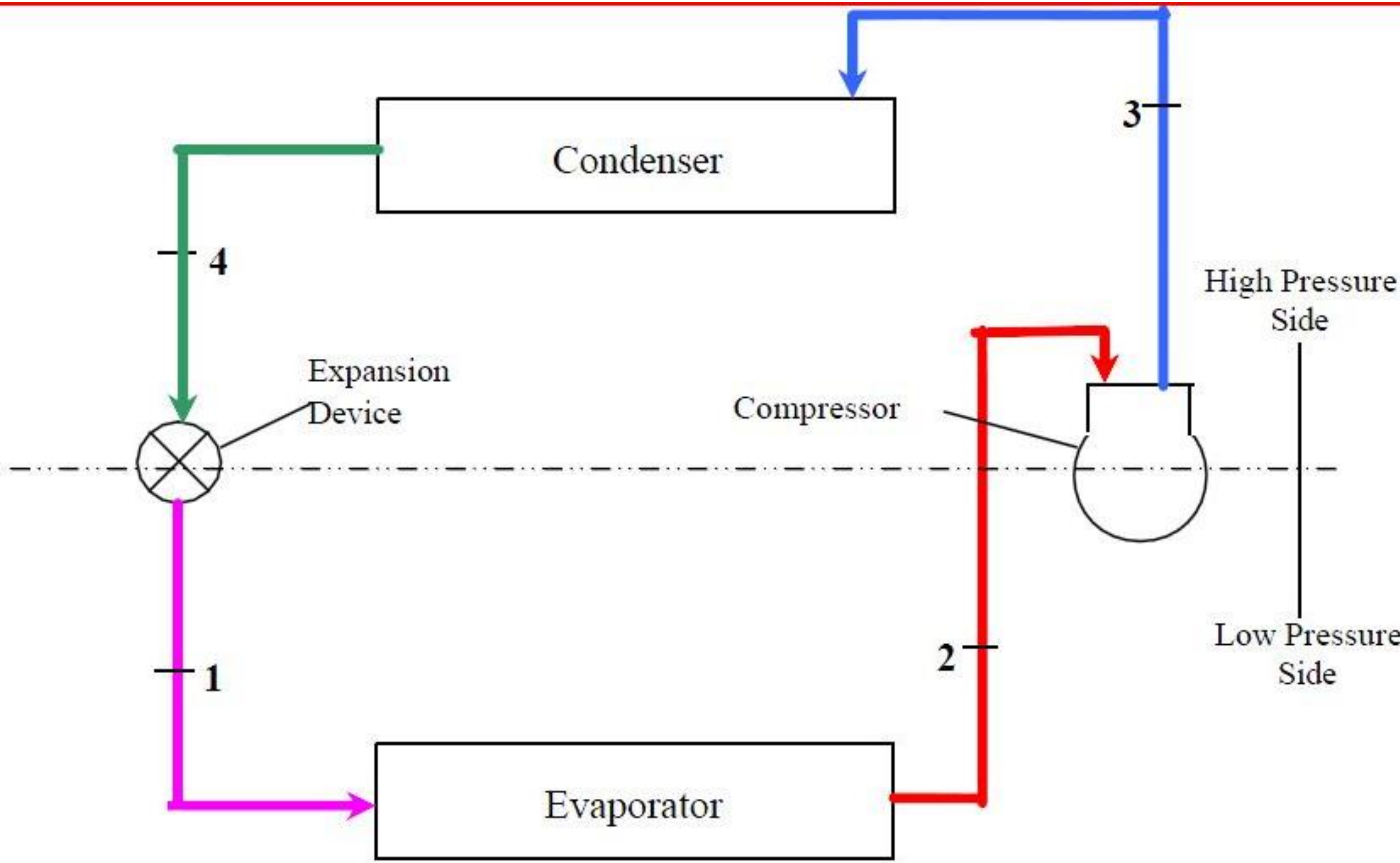
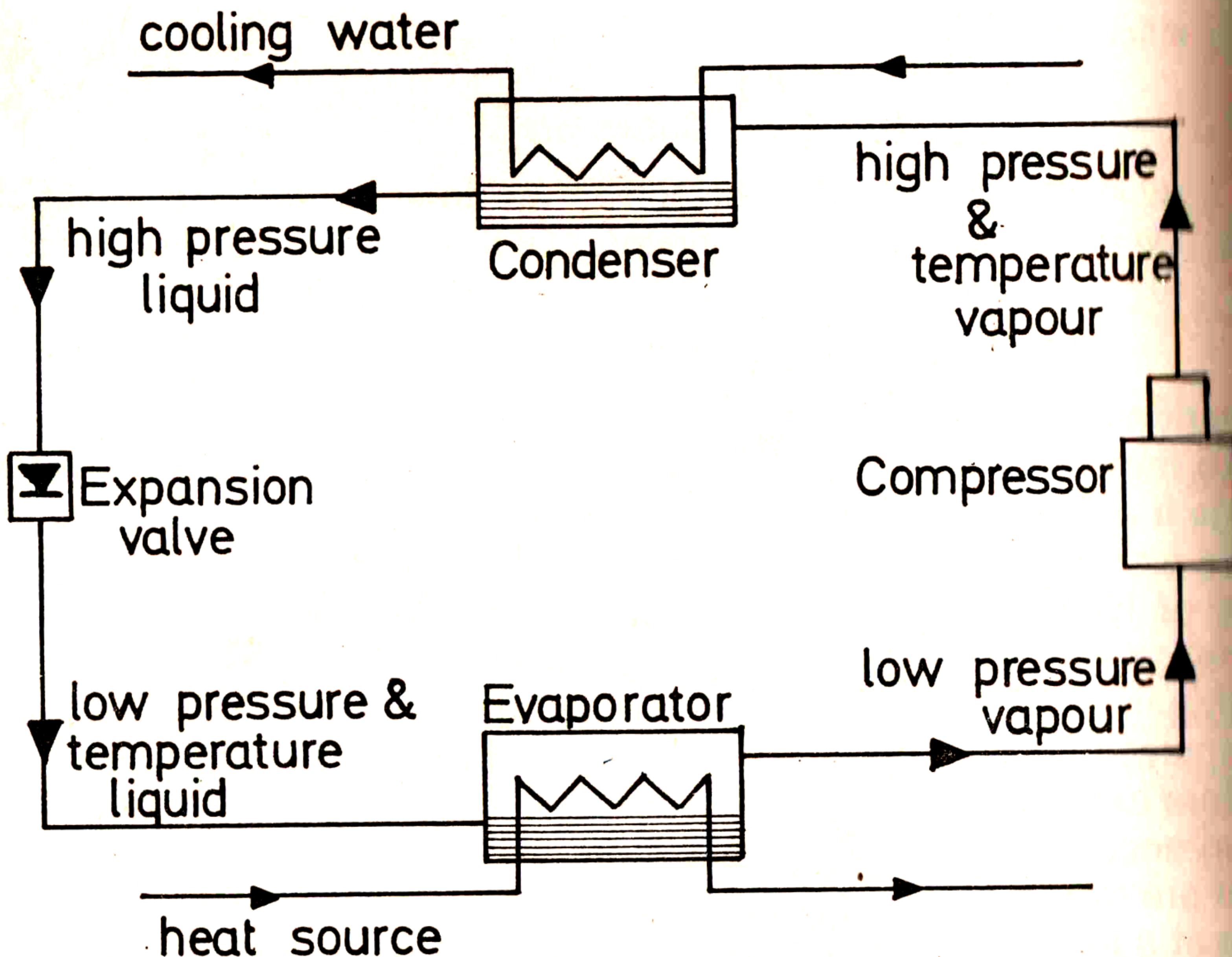
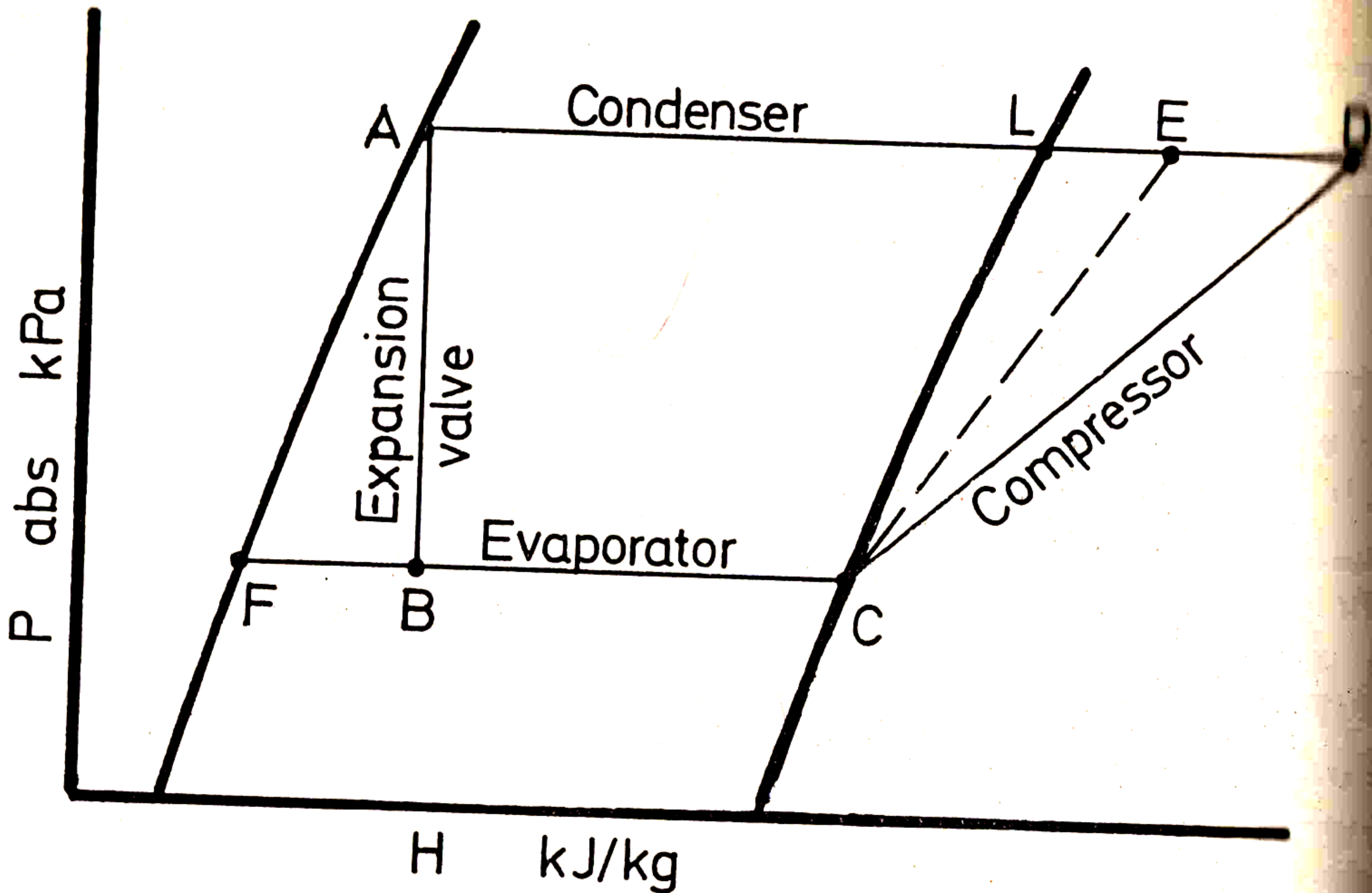


Figure 3. Schematic representation of the vapour compression refrigeration cycle



The basic vapour compression refrigeration system



Diagrammatic representation of the basic vapour compression cycle on a pressure-enthalpy diagram

SYSTEM COMPONENTS

Compressors

- For most large capacity mine refrigeration plants, reciprocating compressors or centrifugal compressors are generally used.

- Rotary compressors are limited to small sizes only.

- Reciprocating compressors used in refrigeration plants are usually of the single-acting multi-cylinder type and may be driven by internal combustion engines, steam engines or electric motors.

- Generally high speed (up to 370 rad s^{-1} or 3500 r.p.m.) electrically driven compressors are exclusively used underground, and are usually air or water cooled.

- Centrifugal compressors have higher speed than reciprocating compressors and therefore, more compact, more versatile and capable of handling large volumes of gas.

- In mines they are electrically driven, operate at efficiencies of 70 to 80%, and are capable of duties of 100 to 3000 tons refrigeration per unit.

- Centrifugal compressors of single to eight stages have been used.

- Multistage compressors are employed when large pressure and temperature differences must be maintained.

Condensers and Evaporators

- They are nearly identical in appearance and have a **shell-and-tube construction**. In both cases, the refrigerant flows over the outside of the tubes.

Condensers

- The function of the condenser (may be air- or water-cooled) is to remove
  - the heat of compression from the refrigerant gas and
  - the heat extracted by the refrigerant in the evaporator.

▪ The refrigerant gas is condensed back into liquid in the condenser.

- Horizontal, water-cooled, shell-and-tube condensers are commonly used in mining applications.

- In this type, the cooling water passes through the tubes and the hot refrigerant gas flows over the outside of the tubes, onto which it condenses.

Evaporators

- Evaporator removes heat from the substance being cooled and in so doing causes the refrigerant to vaporize.

- Shell-and-tube evaporators, similar in construction to shell-and-tube condensers, are normally used in mine refrigeration plants.

- In the evaporator, water or brine (acting as a secondary refrigerant or intermediate heat transfer medium) flows in the tubes.

- The design of evaporator be such as to allow the boiling of the refrigerant with minimum drop of pressure as well as ensure efficient removal of heat from the medium being cooled.

- In condenser, water or another coolant used to reject heat to the atmosphere in cooling towers or spray ponds occupies the tubes.

Expansion valves

- It is the controlling device for the evaporator.

- When the warm liquid passes through the valve, the pressure of the liquid reduces from the condensing to the evaporating pressure, and the process is adiabatic.

- A drop in pressure results in a drop in the temperature of the liquid, accompanied by boiling or evaporation.

- The heat required for evaporation is taken from the liquid itself during the expansion process.

- Thus after passing through the valve, some of the refrigerant exists as vapour and the remaining as liquid, both now at a lower temp. corresponding to the prevailing pressure conditions in the evaporator.

- Only that part of the refrigerant that remains as a liquid is now available for heat removal by evaporation in the evaporator.

Additional equipment

- Numerous equipment are included in the refrigerant circuit, but do not affect the basic cycle and sequence of operations.

- The additional equipment includes:
  - Strainers
  - Controls
  - Oil traps
  - Liquid receivers
  - Purging and charging apparatus
  - Thermometers and
  - Pressure gauges

Refrigerant

- A variety of fluids, both liquids and gases, with good heat-transfer properties are used as refrigerants.

Factors to be considered for the selection of a refrigerant.

- A good refrigerant **should have a high latent heat of evaporation** so that
  - flow rates can be kept as low as possible and
  - should evaporate and condense as near atmospheric temperature and pressure as possible.

- Refrigerants **should be cheap and should not affect the lubricant used** in the compressor.

- **Should be non-corrosive, non-toxic, non-inflammable, non-explosive and must also be easily detectable** so that leakages from the refrigerating machine can be located.

- Besides safety and cost, other considerations in selecting a refrigerant are
  - volumetric requirements,
  - operating pressures,
  - power requirements,
  - stability, and
  - corrosive properties.

Refrigerants

Refrigerant	Boiling point Atm. Press. (101.3 kPa)	Critical temperature (ºC)
Trichloro-trifluoro-ethane (Refrigerant 113)	47.6	214.1
Trichloro-monofluoro-methane CCl_3F (Refrigerant 11) known as Freon 11	23.7	197.8
Methyl chloride	13.1	182.8
Dichloro-tetrafluoro-ethane (Refrigerant 114)	3.6	145.7
SO2	-10.0	157.2
Dichloro-difluoro-methane, CCL_2F_2 (Refrigerant 12) known as Freon 12	-29.8	112.2
Carrene 500	-33.3	105.1
Ammonia	-33.3	133.0
Monochloro-difluoro-methane (Refrigerant 22)	-40.8	96.1
CO2	-78.0	31.3

- Critical temperature is that temp. above which the gas cannot be made to liquefy no matter how great is the pressure.

- It forms a limit to the usefulness in mines of such refrigerants as CO2.

- Methyl chloride, SO2 and CO2 are seldom used in modern industrial or commercial plants.

- Ammonia and fluorinated hydrocarbons like Freon 11 (trichloro-monofluoro-methane, CCl_3F) and Freon 12 (dichloro-difluoro-methane, CCL_2F_2) etc. are suitable refrigerants for underground mines.

- Although CO_2 can reduce compressor size because of its low specific volume, it is not suitable for use at mines because of its low critical temperature (304.5 K) and toxicity.

- Ammonia has the largest latent heat of evaporation and cheap, but is toxic and corrosive for brass and copper.

- However, leakage of ammonia can be easily detected by smell and corrosion can be avoided by selecting suitable material for construction of the refrigerator.

- Although ammonia is one of the best refrigerants and low in cost, because of its pungent smell and toxic effects preclude its use underground and it can be employed only in surface refrigeration plants where leaks are not hazardous.

- **Due to non-toxic in nature, the Freon refrigerants (carbon-chlorine-fluorine compounds) are most commonly used in underground air-cooling plants even though they are costlier than ammonia.**

The Cooling Load or Rating of the Refrigerator

The cooling load or rating of the refrigerator (q) is the rate of heat removal in the evaporator in kW.

$$\mathbf{q = M_w .C. (T_1 - T_2)}$$

Where

q = rate of heat transfer in the evaporator or the cooling load, kW

M_w = the mass flow-rate of cooling medium (water), kg/s

C = specific heat of water, 4.187 kJ kg^{-1} K^{-1}

T_1 = temperature of water at the evaporator inlet, K

T_2 = temperature of water at the evaporator outlet, K

The Coefficient of Performance (COP)

- It is defined as the ratio of the cooling duty to the input power.

COP of the refrigeration plant = heat absorbed in evaporator / net work supplied

- While calculating COP, the compressor power is taken into account.
- It is a dimensionless number.

COOLING TOWERS

- Cooling tower is a heat-exchange device that cools liquid, usually water, by a combination of heat and mass transfer.

- In the cooling plant the heat rejected from the refrigerant to the water in the condenser, in underground situation, is generally rejected to the upcast (return) air at a cooling tower or spray chamber. In some cases the hot water of the condenser is pumped direct to the surface and cooled in spray ponds, rivers and lakes.

- Cooling towers are used to cool the heated condenser water for reuse in a cyclic system.

- Although they are principally used to dissipate heat from refrigerator condenser water, their unique application in mine air conditioning is to produce chilled water on the surface for use in cooling air directly underground heat exchangers.

Classification of cooling towers

- Cooling towers are classified as
  - Natural draught towers or
  - Mechanical draught towers.

Natural draught towers:

- They are used at surface plants and by definition not exist underground.
- They are dependent on the natural wind direction and natural ventilation pressure for the amount of air flowing through the tower.

Mechanical draught towers

- Mechanical draught, counter-flow cooling towers are commonly used underground.

- Airflow through the tower is produced by a fan and the condenser water is sprayed into the air stream.

- **The principal means of heat transfer involved in cooling towers is evaporative cooling.**

- Evaporation of a small portion of the water being sprayed in the air of the tower removes sensible heat from the remaining water.

- Increasing in heat content of the air is of no consequence, since the air is exhausted to the atmosphere on the surface or to the upcast shaft underground.

- Depending on the relative temperatures of air and water, sensible cooling of the water and latent heating plus sensible heating or cooling of the air occurs.

- In underground, cooling towers have to be properly located and designed depending on
  - the amount of heat to be extracted, and
  - temperature, humidity and flow rate of air available for cooling.

- Cooling towers are usually designed to cool condenser water by 7 to 9 ^{o}C.

- Air velocities in cooling towers may between 2.5 to 7.5 m/s, the higher velocities giving greater retention time for the droplets of the water, but

- velocities greater than 9 m/s are undesirable, as they tend to carry away a large amount of water droplets.

Spray chambers or spray towers

- **They are sometimes** are used instead of cooling towers on some underground cooling plants.

- They work on the same principle of cooling towers.

- Most spray towers are located in parts of shafts or winzes where the condenser water is sprayed at the top and works its way down through sets of screens, with the cooling air flowing upwards under the ventilating pressure of the mine.

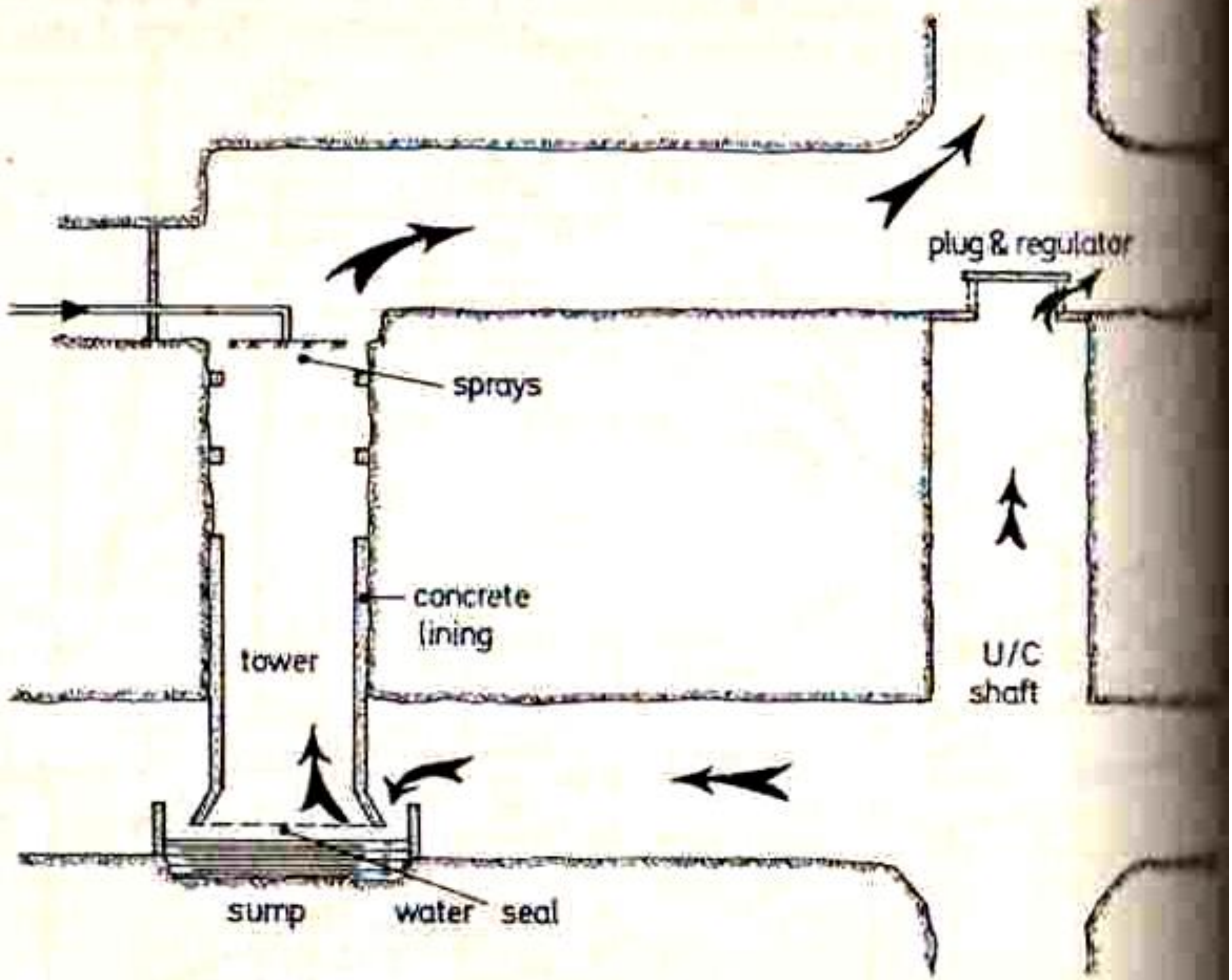


Fig: Layout of a typical underground cooling tower layout

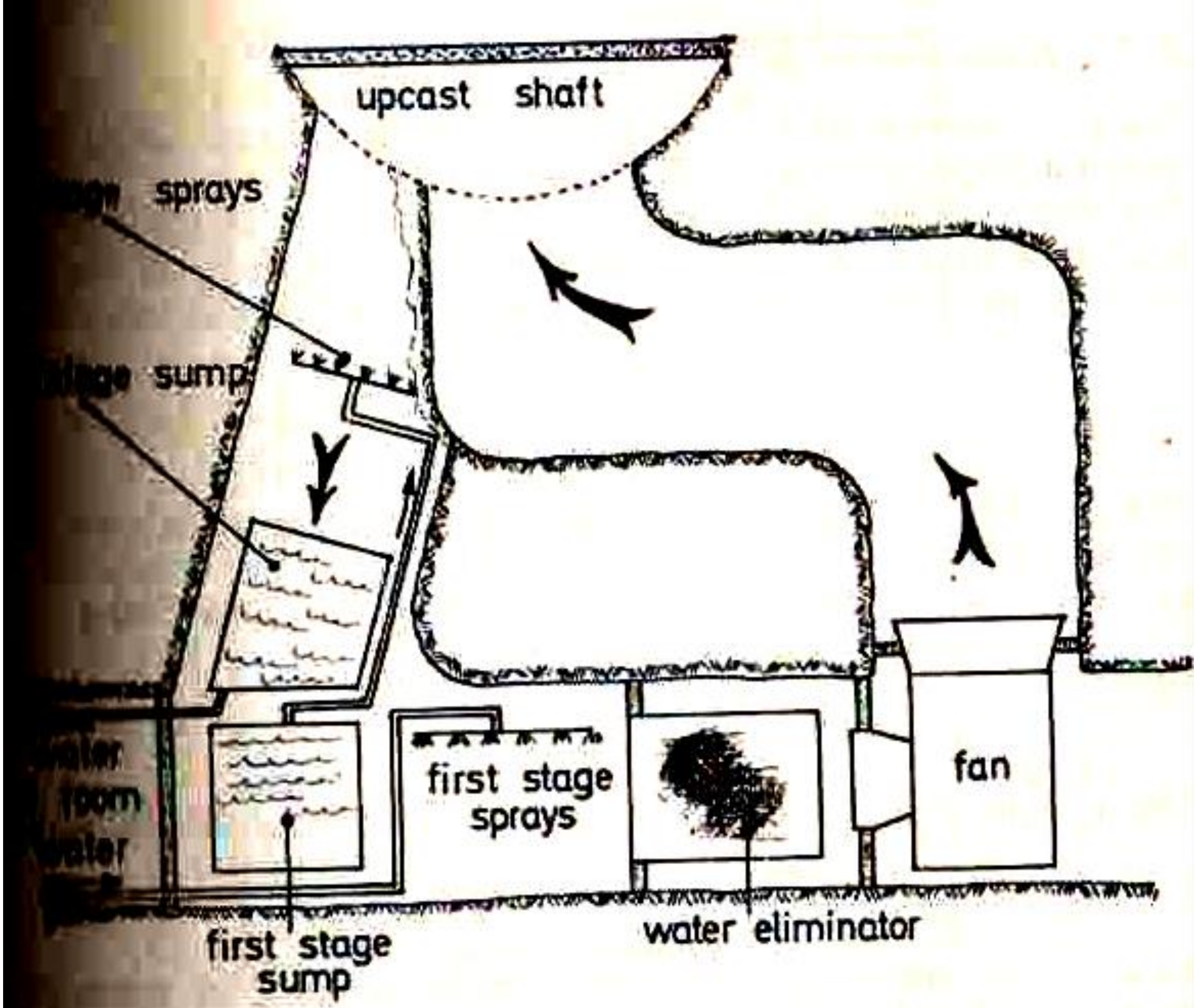


Fig: Diagram of a horizontal spray chamber

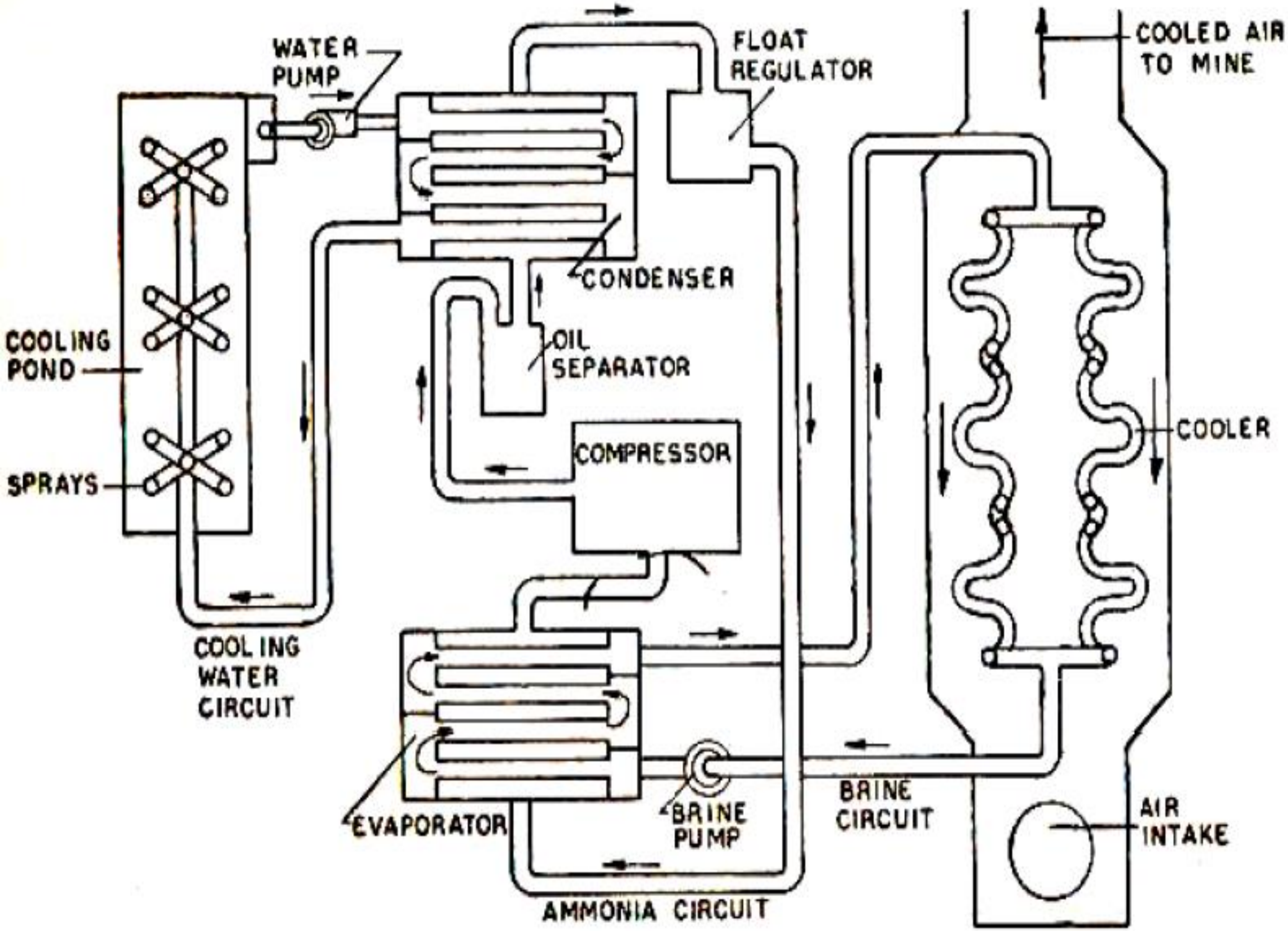


Fig. 3.22 Schematic diagram of the surface air-conditioning plant at Champion Reef mine, K.G.F.

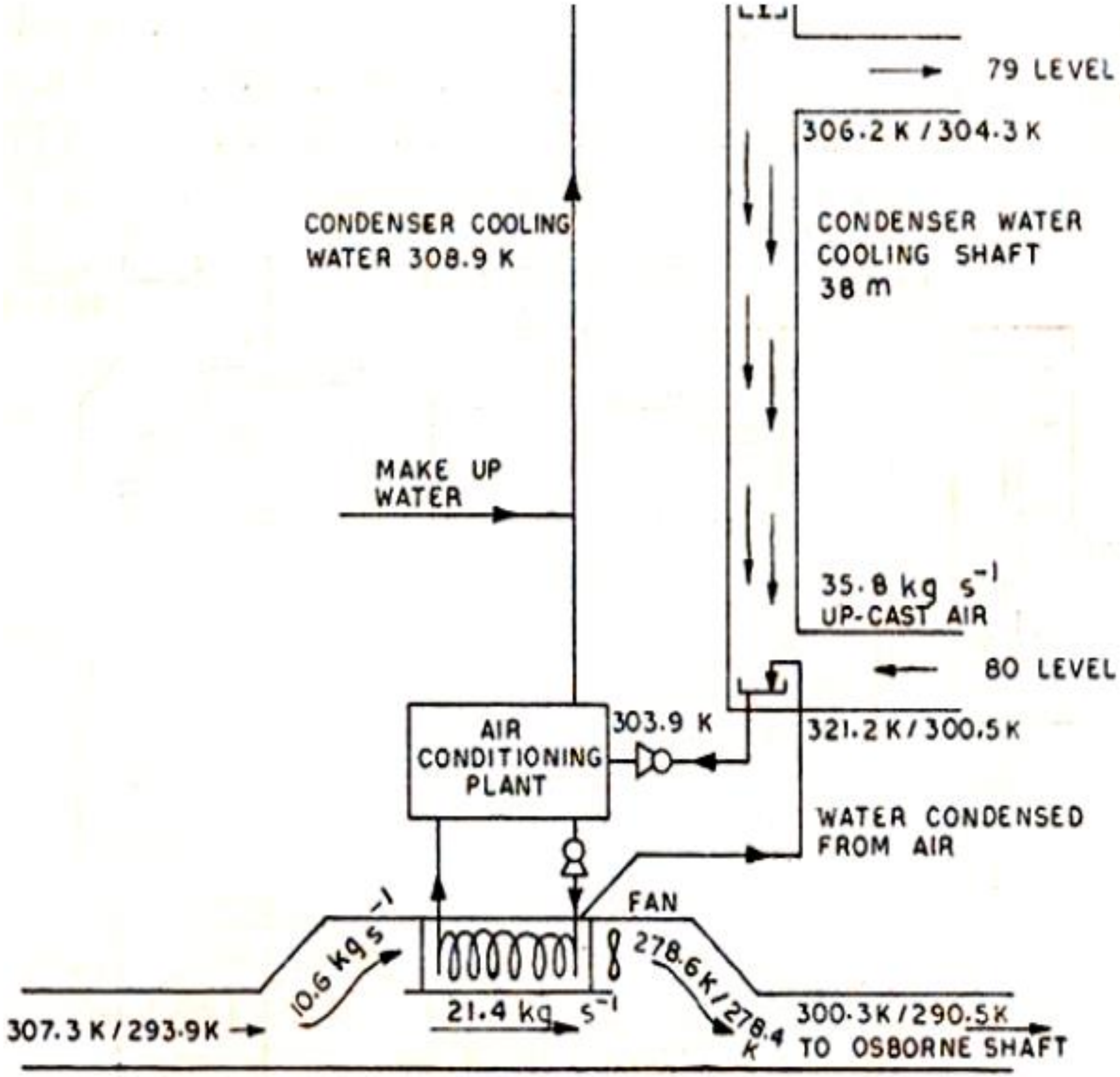


Fig. 3.23. Schematic diagram of the underground air-cooling plant at Champion Reef mine, K.G.F.