

# AIR CONDITIONING TECHNOLOGY

## PART 3

### REFRIGERATION CYCLES

In last months article we covered basic thermodynamics, elementary formulae and studied the effects of pressure over water. Figure 1 provides a clear visual understanding of the behaviour of water at a pressure of 1.01325 bar when heat energy is added or removed.

#### FIGURE 1

It is important to remember the key values for water shown in Figure 1 as these can be used in many calculations for air conditioning and refrigeration design and commissioning work.

#### Steam Tables

Changes in the pressure above any liquid or vapour affect the temperatures at which a change of state occurs and the amount of heat energy involved. Steam Tables list these different values over a wide range of pressures. Table 1 lists the values for water at a few selected pressures.

TABLE 1

| Pressure<br>(bar) | Saturation<br>Temperature<br>(Deg C) | Specific<br>Volume<br>(m <sup>3</sup> /kg) | Heat Energy Content |                   |                  |
|-------------------|--------------------------------------|--|---------------------|-------------------|------------------|
|                   |                                      |  | Sens<br>(kJ/kg)     | Latent<br>(kJ/kg) | Total<br>(kJ/kg) |
| 0.006112          | 0.01                                 | 206.1                                      | 0.0                 | 2500.8            | 2500.8           |
| 0.006566          | 1.0                                  | 192.6                                      | 4.2                 | 2498.3            | 2502.5           |
| 0.01227           | 10.0                                 | 106.4                                      | 42.0                | 2477.2            | 2519.2           |
| 0.02337           | 20.0                                 | 57.84                                      | 83.9                | 2453.7            | 2537.6           |
| 0.04242           | 30.0                                 | 32.93                                      | 125.7               | 2430.0            | 2555.7           |
| 0.07375           | 40.0                                 | 19.55                                      | 167.5               | 2406.2            | 2573.7           |
| 0.1233            | 50.0                                 | 12.04                                      | 209.3               | 2382.1            | 2591.4           |
| 0.1992            | 60.0                                 | 7.678                                      | 251.1               | 2357.9            | 2609.0           |
| 0.3116            | 70.0                                 | 5.045                                      | 293.0               | 2333.3            | 2626.3           |
| 0.4736            | 80.0                                 | 3.408                                      | 334.9               | 2308.3            | 2643.2           |
| 0.7011            | 90.0                                 | 2.361                                      | 376.9               | 2282.8            | 2659.7           |
| <b>1.01325</b>    | <b>100.0</b>                         | <b>1.673</b>                               | <b>419.1</b>        | <b>2256.7</b>     | <b>2675.8</b>    |
| 5.0               | 151.8                                | 0.375                                      | 639.0               | 2562.0            | 3201.0           |
| 10.0              | 179.9                                | 0.194                                      | 762.0               | 2584.0            | 3346.0           |
| 20.0              | 212.4                                | 0.099                                      | 907.0               | 2600.0            | 3507.0           |
| 30.0              | 233.8                                | 0.066                                      | 1004.0              | 2603.0            | 3607.0           |

Note the substantial changes that occur in specific volume and the rate of change of pressure in relation to saturation temperature. Observe the substantial amount of latent heat energy transfer involved in the change of state from *Saturated Liquid* to *Saturated Vapour* (or from *Saturated vapour* to *Saturated Liquid*) and how this changes considerably with pressure. This is far greater than the small amount of sensible heat energy associated with a change in temperature alone. Clearly, a cooling system for air conditioning or refrigeration using a circulating fluid would be most effective if the latent heat energy transfer can be harnessed through a change of state.

The *Vapour Compression Cycle* and *Absorption Cycle* use this characteristic very effectively. The *Double Effect Absorption Cycle* actually uses water as the *Refrigerant*. The *Single Effect Absorption Cycle* uses ammonia as the *Refrigerant*. A *Refrigerant* can be defined as a reticulating fluid transferring heat energy from one part of the system to another.

The *Vapour Compression Cycle* uses a wide range of *Refrigerants* according to application requirements including operating temperatures, pressures, ambient temperatures and efficiency. Compare the characteristics of Refrigerant R22 (Chlorodifluoromethane) in Table 2 with those of water in Table 1.

**TABLE 2**

| Pressure | Saturation Temperature | Liquid Volume      | Vapour Volume      | Heat Energy Content |         |         |
|----------|------------------------|--------------------|--------------------|---------------------|---------|---------|
|          |                        |                    |                    | Liquid              | Latent  | Vapour  |
| (bar)    | (Deg C)                | m <sup>3</sup> /Mg | m <sup>3</sup> /kg | (kJ/kg)             | (kJ/kg) | (kJ/kg) |
| 1.05161  | -40.0                  | 0.70924            | 0.20587            | 55.98               | 232.61  | 288.59  |
| 1.63466  | -30.0                  | 0.72420            | 0.136244           | 66.62               | 226.67  | 293.30  |
| 2.44438  | -20.0                  | 0.75046            | 0.093268           | 77.50               | 220.30  | 297.80  |
| 3.53431  | -10.0                  | 0.75822            | 0.065692           | 88.62               | 213.43  | 302.05  |
| 4.96256  | 0.0                    | 0.77778            | 0.047389           | 100.00              | 205.99  | 305.99  |
| 5.82289  | 5.0                    | 0.78834            | 0.040561           | 105.79              | 202.02  | 307.82  |
| 6.79153  | 10.0                   | 0.79949            | 0.034873           | 111.66              | 197.88  | 309.55  |
| 7.87684  | 15.0                   | 0.81131            | 0.030105           | 117.61              | 193.55  | 311.17  |
| 9.08749  | 20.0                   | 0.82387            | 0.026084           | 123.65              | 189.01  | 312.67  |

## Pressure - Enthalpy Diagram

The figures in Table 2 have been taken from Tables of Refrigerant Properties, which fully define all the thermodynamic characteristics of refrigerant R22. The detailed operating characteristics of a working vapour compression system can be plotted on this diagram.

### FIGURE 2

## The Vapour Compression Cycle

The primary purpose of an air conditioning or refrigeration system is to remove heat energy at a low temperature from a conditioned space or body and transfer (reject) this heat energy into another medium at a higher temperature. Heat energy may be rejected into air, water or soil.

This process is very often continuous since heat energy will always continue to flow from higher temperature surroundings into the conditioned space being maintained at lower temperature. Insulation plays a major part in minimising this heat energy flow in low temperature applications.

## Air Conditioning & Refrigeration Heat Load

Heat energy flow from higher temperature surroundings through the fabric of the conditioned space are termed *Transmission* or *Conducted* gains. There are many other sources of heat gain to the conditioned space and these include heat energy from:

- \* Solar radiation energy striking the surfaces of the building or cold store (*Sensible*)
- \* Warm, moist air entering the conditioned space through infiltration or ventilation (*Sensible & Latent*)
- \* Products or processes (*Sensible and Latent*)
- \* Lighting, motors, machinery and computers (*Sensible*)
- \* Occupants (*Sensible and Latent*)

These are carefully calculated and the total is popularly known as the *Heat Load* or *Cooling Load*. The *Heat Load* normally comprises *Sensible Heat* and *Latent Heat* and the air conditioning or refrigeration system must be capable of removing these continuously. The sum of *Sensible* and *Latent Heat* energy is known as *Total Heat* or *Total Enthalpy*. Air conditioning and refrigeration loads will be discussed later in the series.

## The Evaporator

Since the capacity of a refrigerant to absorb heat energy is greatest when changing state from liquid to vapour, the heat exchanger (*Evaporator*) within the conditioned space is continuously supplied with liquid refrigerant, which vaporises in order to absorb heat energy from the conditioned space. Air is used to transport sensible and latent heat energy from products, lights, machinery and occupants to the *Evaporator*. In order for this to be effective and efficient, an *Evaporator Fan* is used to pass return air over the *Evaporator Coil* and to distribute conditioned air throughout the space. See Figure 3.

If liquid refrigerant R22 is allowed to vapourise at a pressure of 1.01325 bar, the *Saturation Temperature* (or *Evaporating Temperature*) will be -40.8 Deg C. As the refrigerant vaporises, heat energy is absorbed and is termed *Latent Heat of Vaporisation*. The *Latent Heat of Vaporisation* (approximately 140 kJ/kg) required to vaporise the liquid is taken from the conditioned space thus providing cooling. The heat energy from the space is transferred to the vapour.

### FIGURE 3

However, in order to maintain the conditioned space at a suitable temperature for comfort air conditioning (22 Deg C), it is not necessary for the refrigerant to change state at such a low temperature (*Evaporating Temperature*). The design of the evaporator and the amount of airflow will determine what *Evaporating Temperature* is required for a given leaving air temperature from the evaporator coil. If an *Evaporating Temperature* of 5 Deg C were required, it will be necessary to raise the *Evaporating Pressure* to 5 bar. See Figure 4.

### FIGURE 4

## Superheat

Note that some of the heat energy from the room is also raising the temperature of the refrigerant above the *Saturation Temperature* within the *Evaporator*. This *Superheating* of the refrigerant is essential to protect the compressor from taking in liquid refrigerant, which would otherwise result in mechanical damage and failure. However, as *superheating* the vapour does not absorb much heat energy from the conditioned space and also makes poor use of the evaporator, it should be maintained at a minimum level of 5.0 - 7.0 K.

The process taking place within the *Evaporator* is shown on the P-E Diagram in Figure 5. The amount of energy absorbed by the refrigerant during vaporisation is 167 kJ/kg (*Latent Heat of Vaporisation*) and a further 3 kJ/kg has been absorbed during *Superheating* of the vapour. The total of these (170 kJ/kg) is equal to the amount of cooling performed in the *Evaporator* (and the space) and is termed the *Net Refrigerating Effect*.

## FIGURE 5

### The Compressor

The *Superheated* refrigerant vapour leaving the *Evaporator* must be recycled and returned to liquid form for use at the *Evaporator*. In order for the refrigerant to be returned to a liquid state it is necessary to remove heat energy by bringing the refrigerant into contact with a medium (sink) at a lower temperature. If the system is to reject this heat energy to outdoor air during peak summer conditions where the air temperature may be as high as 30 Deg C, the *Saturation Temperature* of the refrigerant must be raised from 5 Deg C to a higher temperature than 30 Deg C, say 40 Deg C. This is achieved by raising the pressure of the *Saturated Vapour* leaving the *Evaporator* by passing the vapour through a *Compressor*. This higher *Saturation Temperature* is known as the *Condensing Temperature*. See Figure 6.

## FIGURE 6

The process taking place within the *Compressor* is shown on the P-E Diagram in Figure 7. Note that the compression process follows the lines of *Constant Entropy*. The refrigerant has taken up 23 kJ/kg of energy during this process and this is termed the *Heat of Compression*. The resulting leaving temperature is now much higher than the entering temperature (70 Deg C) and the *Condensing Pressure* has been raised to 15 bar.

## FIGURE 7

### The Condenser

The *Condenser* must remove heat energy from the refrigerant and reject this to a lower temperature medium (sink), usually outdoor (*Ambient*) air. Assuming an *Ambient Temperature* of 30 Deg C and a *Condensing Temperature* of 40 Deg C, a temperature difference of 10 K exists. This is often known as the *Approach Temperature*. See Figure 8.

## FIGURE 8

### Total Heat of Rejection

The energy that must be rejected by the *Condenser* comprises the heat energy removed by each kilogram of refrigerant passing through the *Evaporator* (170 kJ/kg) and the heat energy added to each kilogram of refrigerant passing through the *Compressor* (23 kJ/kg). The total heat that must be rejected therefore equals 193 kJ/kg and is termed the *Total Heat of*

*Rejection (THR).* The *Condenser* coil is therefore normally larger than the *Evaporator* coil.

The gas leaving the *Compressor* and entering the *Condenser* is considerably superheated. The *Condenser* must therefore *Desuperheat* the refrigerant first by 30 K until the *Saturation Temperature* of 40 Deg C is reached. (70 - 40 = 30 K).

When the refrigerant has reached the *Saturation Temperature*, the *Condenser* will then remove substantial latent heat energy as the refrigerant changes state from *Saturated Vapour* to *Saturated Liquid*. This energy is known as the *Latent Heat of Condensation*. (417 - 250 = 167 kJ/kg).

The *Condenser* normally holds a small amount of liquid refrigerant at the base of the coil. If the system is fitted with a *Liquid Receiver*, the *Condenser* coil holds very little liquid refrigerant, as this is stored in the *Liquid Receiver*. This liquid, at a starting temperature of 40 Deg C, loses further heat energy to the air passing over the coil at 30 Deg C (and whilst residing in a *Liquid Receiver*). This causes the liquid refrigerant to be *Sub-Cooled* to a temperature below the *Saturation Temperature*.

Figure 9 shows a loss of 10 kJ/kg due to *Sub-Cooling* in the *Condenser Coil* and the *Liquid Receiver*. (250 - 240 kJ/kg)

The process through the *Condenser* and *Liquid Receiver* on the P-E Diagram is illustrated in Figure 9.

## **FIGURE 9**

### **NEXT MONTH:**

More on the Vapour Compression Cycle and an introduction to the Absorption Cycle.