AIR CONDITIONING TECHNOLOGY

PART 8

Air Cooled Condensers

IN the last three month’s articles we studied various compressor types. Following compression, the high-pressure refrigerant vapour is passed to the condenser where the latent heat of condensation is rejected thus returning the refrigerant to liquid form. As this step follows compression, a study of condensers now follows:

FIGURE 1

Air Cooled Condensers

These normally consist of a finned coil matrix with one or more fans to force ambient air over the coil. The heat rejection capacity of an air-cooled condenser is mainly determined by the temperature difference (TD) between the refrigerant condensing temperature and the ambient dry bulb temperature.

The main purpose of the air-cooled condenser is to reject to atmosphere heat energy from two sources:

1 Heat energy extracted by the evaporator(s) from the conditioned space (comprising the sensible and latent cooling loads)

2 Heat energy added to the system by the compressor (heat of compression)

The sum of these is termed the *Total Heat of Rejection (THR)*.

It should be remembered that many systems employ hermetic or semi-hermetic compressors where the compressor motor is contained within the compressor housing and that motor cooling is achieved by passing the cool refrigerant gas returning from the evaporator over the motor windings. As the motor is cooled, the heat energy is passed to the refrigerant vapour, which must be rejected at the condenser to atmosphere. Condensers are therefore slightly larger for hermetic / semi-hermetic systems than for open-drive systems where the motor is itself air-cooled.

Another interesting side effect occurs where hermetic / semi-hermetic compressors are concerned in that the heating of the refrigerant gas as it passes over the motor windings causes the specific volume of the gas to increase thereby resulting in a reduction of the mass of gas pumped by the compressor when compared to open-drive compressors.

The compressor must raise the pressure and corresponding saturation temperature for the refrigerant above the maximum ambient temperature to allow heat energy to flow from the refrigerant to the relatively cool ambient air via the condenser. The superheated refrigerant vapour leaving the compressor undergoes the following changes as it passes through the condenser:

1 The refrigerant vapour dissipates sensible heat energy to the cooler ambient air and drops in temperature until the saturation temperature is reached. Only a small part of the condenser is required for this part of the process.

2 Once the saturation temperature is reached, the refrigerant starts to change phase (state) as latent heat energy is released. The largest part of the condenser is dedicated to this process since the majority of heat energy is released during this stage.

3 Liquid refrigerant at the base of the condenser will be at or close to the saturation temperature, which is still above the ambient temperature. Further sensible heat energy is then passed to the ambient air and the refrigerant is sub-cooled by a small amount. This sub-cooling is beneficial and only a small part of the condenser is dedicated to this. Systems with liquid receivers allow most of the liquid refrigerant to drain from the condenser and sub-cooling then occurs in the liquid receiver instead.

Condenser Performance and Capacity

The refrigerant condensing temperature is the saturated temperature corresponding to the pressure of the refrigerant entering the condenser and is therefore adversely affected by the pressure drop within the discharge line leading from the compressor. If a condenser is designed to operate at a 10K TD, a pressure drop in the discharge line equivalent to 1K drop in refrigerant saturation temperature will reduce the capacity of the condenser by 10%. Correct sizing of refrigerant lines is therefore essential and will be covered later in the series.

Assuming that the condenser has been selected correctly for the total heat rejection (THR) requirement and that the refrigerant lines have been correctly sized, the following points need careful consideration to ensure proper operation.

FIGURE 2

a) Draining of the Refrigerant

One of the most common reasons preventing an air-cooled condenser from achieving its rated capacity is the failure of the condensed refrigerant liquid to drain freely. Refrigerant within the condenser is either a superheated or saturated vapour or a saturated liquid. Liquid refrigerant forms on the tube walls and passes through the coil and into the liquid drain line due to gravity.

Inevitably, some refrigerant will still be in the gaseous state as it leaves the condenser although it will be just on the point of condensing into liquid. This gas must be able to leave the condenser or it will obstruct the free passage of the liquid - known as 'gas locking'. Gas locking will cause the condensing pressure to rise and the liquid line pressure to fall. This causes liquid to back up within the condenser and some of the condenser surface area provided to condense the refrigerant will become flooded by liquid and will no longer be available for condensation (latent heat rejection). With less surface available, the flow of refrigerant from the condenser will reduce whilst the compressor will continue to pump vapour to the condenser. The condensing pressure and saturation temperature will therefore rise thus increasing the operating temperature difference in an attempt to compensate for the reduction in surface area. The increase in the compressor discharge pressure also causes the power absorbed to rise. This will not only increase the system running cost but also cause the plant to shut down on high-pressure trip if either the load or the ambient are close to the design maximum.

The fall in the liquid pressure may reduce the amount of liquid passing into the evaporator depending on the type of control employed which would reduce the cooling capacity of the system. As these two effects tend to be linked, the system capacity will fall while the power absorbed will rise.

Unfortunately things are never that simple and the reduction in liquid pressure and the rise in condensing pressure will vary as slugs of liquid manage to fight their way out of the condenser leading to system instability.

So what do we do to ensure that the condenser is adequately drained and gas locking does not occur? The secret lies in the sizing of the pipework leaving the condenser normally referred to as the "condensate" or "liquid drain" line. This line has to carry both the condensed liquid and any entrained gas. As gravity has a major influence in affecting refrigerant flow through this line, it must have a continuous downward slope over its entire length. In order to be able to handle both the condensed liquid and the entrained vapour the liquid drain line will need to be larger than the liquid line and should be sized for a maximum velocity of 0.5m/sec (assuming the refrigerant is all liquid). This will allow the liquid to spiral down the tube walls and leave sufficient space for the gas to vent back into the outlet header of the condenser. If a receiver is being fitted below the condenser, the liquid drain line should be kept as short as possible, sloped as steeply as possible and have the minimum number of long radius bends. Elbows or short radius bend should not be used.

In many systems a receiver is included can often be some distance from the condenser. In these circumstances the available pipe route is unlikely to be straightforward and it may not make economic sense either to run the large liquid drain line any further than necessary or to fit another receiver under the condenser. Arranging the liquid drain line to provide space for the liquid and gas to separate by incorporating a large diameter section piped to provide a liquid seal will be found to be adequate in most cases. A vertical separation vessel can be accommodated on condensers with horizontal coils within the height of the legs but the liquid drain outlet from units with vertical or 'vee' block coils will be close to the base of the unit dictating the use of a horizontal vessel. To be effective these must be of fairly large diameter.

Note: Every vessel must be designed such that it cannot fill completely with liquid and will be filled to maximum of 80% under the most adverse circumstances..

In some systems the condenser will incorporate a sub-cooling section either as part of the main coil or as an additional coil mounted in the air stream. The sub-cooling section will have been circuited to accept liquid and any gas present will cause liquid to back up into the condenser section. Sub-cooling sections must be piped via the liquid receiver or separation vessel in order to prevent this happening.

b) Siting

Air-cooled condensers are exactly what they say they are - air-cooled. If an air-cooled condenser is to operate successfully it is absolutely imperative that it receives the correct volume of air and at a temperature at or below the design ambient inlet temperature. The manufacturers' recommendations must be followed at all times if the system is to operate at design capacity, reasonable power input and for many years of trouble free operation. Compressor and motor life in particular will be extended if the correct guidelines are adhered to. Bear in mind that external air cooled condensers are designed to be installed in large open areas with no plant or walls close enough to affect or even restrict the air flow through the unit. Any item closer than approximately 2 metres and/or taller than the condenser is likely to have an adverse effect on performance.

Wind direction and the possibility of down draughts must be considered and units should not be sited in wells or be surrounded by two or more walls or equipment, which would create a similar situation. If an installation has to be screened, consideration must be given to the possibility of leaving the base of the screen open and the condensers should be mounted such that the fans are level with the top of the screen.

Localised air heating due to solar gain is very often experienced, particularly when condensers are installed on a roof with a highly reflective lightly coloured surface. Care in positioning and changing the roof surface treatment in the vicinity of the condensers will obviate the problem.

Recirculation (short cycling) of hot discharge air into the coil inlet face must be avoided at all costs. Low noise units tend to discharge air at around 15^o to 25^o above the horizontal making them particularly susceptible to recirculation. The aim is to have a large enough reservoir of air below the units to provide all the air required which can then be replaced without the velocity of the air entering the area having to exceed 1.0 m/s. Under these conditions, sufficient air will be available below the units and recirculation would be unlikely.

When several units are installed side by side, air blowing along the line of units can lead to hot discharge air leaving one unit being blown below the next downwind unit and so on. Where recirculation is a likelihood, consideration should be given to raising the units to provide say 2 metres between the plinth or roof slab and the coil inlet face. Where more than one unit is involved, mounting the units very close together will make recirculation more difficult. Multiple units mounted close together must be raised as discussed above.

Condensers with vertical coils (horizontal airflow) are more prone to recirculation and must be mounted in an open area. Again the manufacturers recommendations must be followed but usually an adjacent wall or other item is permissible at the air on face provided it is approximately 1.5 times the coil height from the unit. Vertical coil units are more susceptible to the effects of wind direction. When wind blows against the air flow direction, the overall capacity of the unit will be reduced while wind in the other direction may cause over condensing resulting in considerable drop in high side system pressure and a lack of control at times of low cooling load and/or low ambient.

Figure 3 provides a general guide to the positioning of single and multiple air cooled condensers.

FIGURE 3

Windmilling Effect

When the condenser fan(s) are switched off, wind blowing in the opposite direction to the condenser air flow will cause the fans to windmill in the wrong direction which may lead to nuisance overload trips on fan motor start up. Low noise units are the most susceptible to this problem.

Some manufacturers incorporate an anti-windmilling device on every fan, which is similar to a low friction ratchet to prevent the fan running backwards. Externally mounted water chillers with integral condensers and multiple fans are often fitted with anti-windmilling devices to prevent one or more fans not in use running backward due to reverse airflow currents created by other fans which are still in operation.

Vertical coil units should be positioned such that the coil inlet face is not in direct sunlight. The surface temperature generated by solar radiation in the UK can easily exceed 50^{o}C on dark surfaces and this can severely reduce the capacity of the condenser.

c) Condensing Pressure Control

Condensing Pressure Control is also known as *Head Pressure Control* or *Low Ambient Control*. There are only two ways to provide Condensing Pressure Control on an air-cooled condenser:

1) By varying the volume of the air passing through the coil

2) By varying the amount of internal tube surface that the refrigerant gas can come into contact with.

It is possible, and sometimes necessary, to combine both of the above.

Due to the way in which an air-cooled condenser works, it is difficult to find a convenient point in the coil block where the gas will only ever be condensing rather than de-superheating or where liquid is sub-cooling. This makes it practically impossible to use the condensing temperature as a signal reference to control the operation of the fans. The pressure within the coil however is constant whether the refrigerant is de-superheating, condensing or sub-cooling and is therefore the best reference to use as the control signal. However, this is more expensive!

When considering varying the air volume as a means of condensing pressure control, it should be born in mind that the relatively hot coil will induce air flow even with all fans stopped. The capacity this will provide is dependent on the coil detail and the temperature difference between the coil and air temperatures but is not affected by the design air volume. It follows therefore that the capacity of a unit with a low design air volume will be proportionately greater with all fans stopped than for a unit using the same coil but with a high design air volume. As a guide, a high air volume, high noise level, unit might be capable of 10 to 15% of its design capacity with stationary fans while a low air volume, low noise level, unit using the same coil might be capable of in excess of 30% of its design capacity.

Variation of the amount of air passing over the coil can be achieved in the following ways:

1) Changing the number of fans running. (Fan Cycling)

   Individual fan wiring, starters and switching controlled by sensing the refrigerant pressure would be required. In the case of single-phase fan motors, starters may not be required if the motors are internally protected.

2) Varying the fan speed.

   Single-phase fan motors can often be speed controlled using a simple pressure sensing controller varying the voltage at the motor. More than one motor can be controlled by a single controller within its current carrying capacity. The motors would require internal protection since over-current on a single motor could not be satisfactory detected by a controller running several fan motors.

   The speed of three phase motors can be controlled either by a triac based controller or an Inverter system. While the triac controller is cheaper it is less kind to the motors, can induce motor noise and does not provide motor protection. An inverter, particularly one which can vary both the voltage and the frequency, will not stress the motor, will provide motor protection, will not create motor noise and will also reduce the energy taken by the fan motor as the speed falls.

3) Combining the above.

It is possible to combine fan speed control with a fan cycling arrangement and it is only necessary to ensure that the switching differential and fan speed controller operating band are compatible to achieve an acceptable working arrangement.

d) Damper Control

Usually used on condensers fitted with centrifugal fans, it is also used where insufficient fans makes fan cycling inappropriate and where fan speed control is either not available or not cost effective. The system is best employed on units mounted within buildings or where the damper system can be wholly contained within the condenser housing to avoid the dampers and/or linkages freezing in winter. Dampers can be motorised or controlled by actuators responding directly to the refrigerant pressure within the system.

Variation of the amount of internal surface can again be achieved in several ways:

1) Liquid Flooding

Also known as liquid back up, this reduces the rate at which the liquid refrigerant can leave the condenser causing it to back up and cover a portion of the internal tube surface. A valve designed to maintain its upstream pressure (the back up or hold back valve) is installed in the liquid drain line to control the flow of liquid, while a pressure reducing valve is installed in a line connecting the discharge line and liquid receiver, which prevents the receiver pressure falling below a predetermined level. In small installations the valves are often combined into one unit. The system is self-adjusting but requires the inclusion of a liquid receiver capable of holding sufficient refrigerant to fill the condenser in addition to the normal receiver operating charge.

As this liquid will also contain oil, the additional refrigerant and oil charges required must be allowed for. A flooded condenser will provide a high degree of liquid sub-cooling which should be taken into account when considering the performance of the plant at low ambient.

2) Multi-sectioning.

Arranging the condenser in more than one section is often used to overcome the over-condensing/over-capacity situation experienced on low air volume units discussed above. Similarly, it is useful in plants incorporating refrigerant defrost which, by their nature, reduce the condenser load during defrost. The system merely requires the addition of a solenoid valve to allow the effective size of the condenser to be reduced by shutting off the appropriate section. Refrigerant, and therefore oil, will migrate into the idle section and this should be considered in the refrigeration system design. Under no circumstances should solenoid valves be installed on both the inlet and the outlet and the controlled section must be free draining at all times.

3) Combined systems.

While air volume control and liquid flooding can be combined, the drawbacks of liquid flooding will still occur. Air volume control with multi-sectioning provides a better solution from both an operational and a cost in use point of view.

d) Materials

Whist both the tube and fin material have to be compatible with the atmosphere in which the unit is to be installed, the tube materials must also be compatible with the refrigerant to be used. Of the commonly used refrigerants only Ammonia (NH3) cannot be used with copper tubes. Stainless or galvanised mild steel tubes are used with ammonia, usually of the small diameter, thin wall type expanded into aluminium or steel fins, although units with large diameter, thick wall tubes galvanised after manufacture are still available.

The most cost effective fin material is aluminium. Copper will give marginally better performance but at significantly greater cost. Stainless steel fin has a higher cost again and, due to relatively poor thermal conductivity, performance can reduce to as little as 50% of a similar unit constructed from copper tubes in aluminium fins.

The condenser manufacturer will offer guidance on the choice of materials for specific environments.

e) Multi-sectioning

Quite apart from its use as part of a condenser pressure control system, arranging the coil in more than one section can allow the unit to serve more than one air conditioning or refrigeration plant. These can have different operating conditions and utilise different refrigerants, provided they are all compatible with the same coil materials. This option is particularly attractive where space is at a premium but some thought will be needed to provide independent condensing pressure control for each section. Most manufacturers have units with two rows of fans in their range and therefore a two-section coil can be incorporated to provide independent control of two separate refrigeration systems. If condensing pressure control by liquid back up is acceptable, then the number of independent systems that can be served by one condenser is only limited by the capacity of the equipment available.

f) Energy Conservation

The energy consumed by any refrigeration plant is dependent on the operating conditions. Lower condensing pressures will reduce the energy absorbed by the compressors reducing the amount of heat that has to be rejected by the condensers, which in turn will reduce the size of the condenser required. However the performance of a multi-fan condenser at low ambient is determined by the number of fans fitted and the design operating temperature difference.

On units designed to operate on a small TD the airflow capacity of each fan is lower than for the same unit designed to operate on a larger TD and the capacity reduction available when cycling fans is therefore smaller. Designing to operate with a small TD will increase the size of the condenser required.

Typically a refrigerated storage facility having a cooling capacity of 100 kW, which absorbs 60kW at the compressors when condensing at 45oC, will only absorb approximately 40kW if the condensing temperature is allowed to fall to 20^{o}C, a saving of 20kW. The fans on a condenser capable of rejecting 160kW THR at 15K temperature difference will absorb less than 5kW in total with all fans running. While it is important to maintain the condensing pressure on simple systems to ensure adequate control of the low side performance, such systems do not maximise the energy savings possible. Leaving all the condenser fans running so as to allow the condensing pressure to fall with a falling ambient temperature will allow significant energy savings to be made by unloading, or even turning off, compressors. While this may require a rather more sophisticated system, the large running cost savings possible will provide a very attractive pay back time.

g) Noise Level

This is an important consideration in many installations. The manufacturers technical data will normally quote the noise level generated by each product. It must be remembered that where two or more air cooled condensers are sited in close proximity that the cumulative sound levels will be greater than that of a single unit. We hope to cover sound theory and practice to a limited degree later in the series.

NEXT MONTH: Part 9 - Water Cooled Condensers