MASTERCLASS

Part 42

Liquid pressure amplification

This month Masterclass takes a look at a product that demands a fresh perspective on the basic direct expansion refrigeration cycle – the liquid pressure amplifier.

Mike Creamer of Business Edge revisits his Masterclass series of articles, updating and adding to the information which proved so useful to readers when the series was first published ten years ago. In this reincarnation, the series will cover both air conditioning and refrigeration and serve as an on-going source of technical reference for experienced personnel as well as providing a solid educational grounding for newcomers to our industry.

WITH the increase in the cost of electricity, many organisations are now looking to make improvements in refrigeration and air conditioning system efficiency. It is clear that a fundamental change in operating parameters is necessary to provide significant reductions in energy consumption and greenhouse gas emissions, this of course, being the British Government's ultimate aim in order to meet their responsibilities as agreed with other nations.

It is well documented that reduced compressor discharge pressures and the corresponding reduction of compression ratios in a refrigeration cycle are desirable in that reduced energy consumption and increased system life are the result. These provide reduced operating costs and increased equipment life cycle. However, a problem then arises in that as compressor discharge pressure is decreased, flash vapour (the partial re-evaporation of liquid refrigerant which has been condensed) in the system liquid line (and receiver if fitted) increases. Any occurrence of flash vapour in a refrigeration or air conditioning system will result in a direct loss of refrigeration capacity within the evaporator. The resulting increase in running time alone to meet the refrigeration load will lead to increased energy consumption and the refrigeration system therefore becomes less efficient.

There is, however, a solution which will allow compressor discharge pressures to be significantly lowered whilst preventing the occurrence of flash vapour. This solution thus allows the refrigeration system to run at higher efficiency and thus lower system absorbed power.

The application of liquid pressure amplification (LPA) to a refrigeration or air conditioning system provides the means by which a considerable reduction in compressor discharge pressure can be permitted. Liquid pressure amplification (LPA) is achieved by an hermetically sealed, magnetically-driven liquid refrigerant pump which is installed in the liquid line from the condenser (or receiver) and thus sits between the condensing and evaporative phases.

By overcoming the liquid line pressure drop, flash vapour can be completely eliminated. Moreover, lower compressor discharge pressures can then offset this elevation of the liquid line pressure. Improvements in refrigeration system efficiency of up to 50% are achievable according to operating conditions. Annual improvements of 20%-40% are more normal due to the limits on savings during the warmer months. Savings will also vary according to the usage pattern of the system.

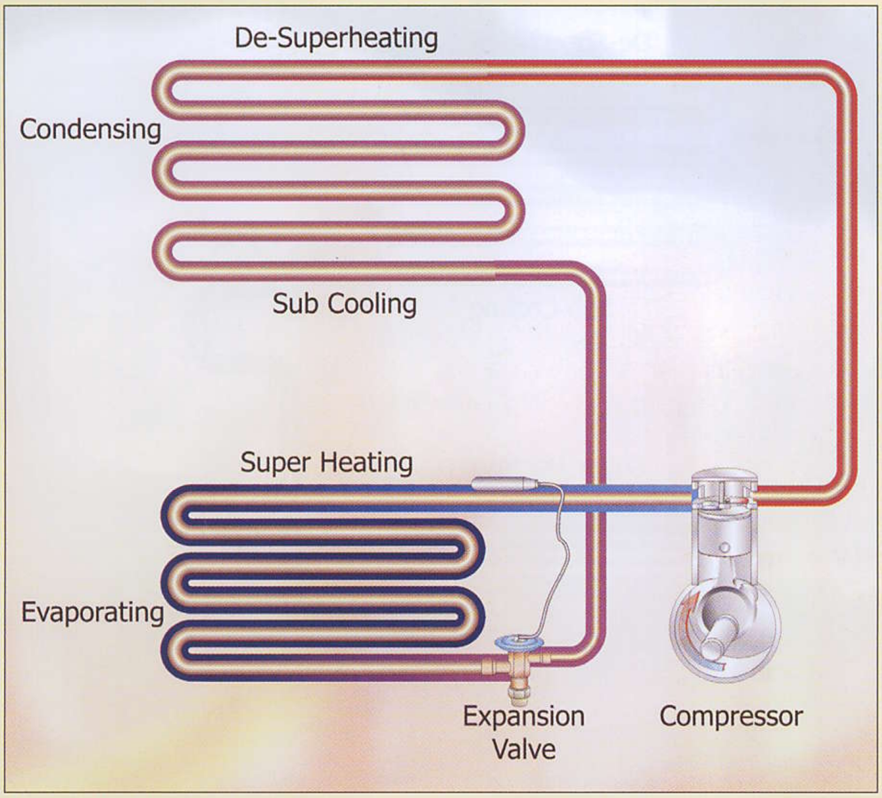
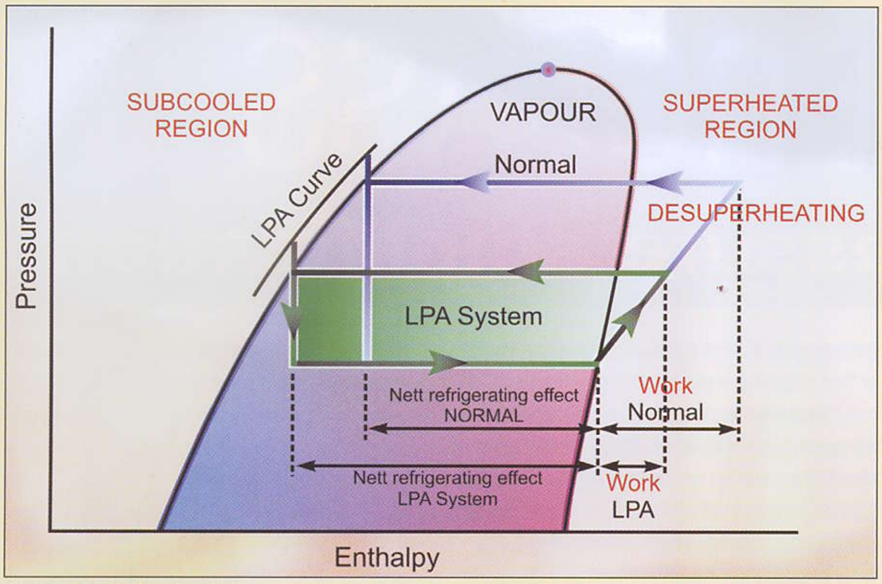


Figure 1: Normal system without LPA

As all acr engineers are aware, the vapour compression cycle consists of four major components and the following is a simplistic description of their functions:

- The evaporator – provides cooling to the space or cooling medium
- The compressor – increases the pressure and saturation temperature of the refrigerant vapour
- The condenser – rejects heat energy from the refrigeration system to ambient air or another sink medium
- The expansion device – regulates the flow of liquid refrigerant to the evaporator.

The controls associated with such a system are



Pressure enthalpy diagram

commonly used to help maintain relatively constant pressures within the compressor and within the evaporator downstream from the expansion device. This regulation of discharge pressure suppresses the formation of flash vapour.

In order to understand how improvements in refrigeration efficiency can be achieved, we must firstly analyse the components, shown in Fig 1 (overleaf), and understand where the inefficiencies exist.

The refrigerant in the evaporator is divided into two parts: the liquid refrigerant undergoing vaporisation and the superheated vapour. The element that performs the majority of the refrigeration work and provides us with the required cooling effect is the liquid refrigerant changing from liquid state to vapour state. The more liquid refrigerant we are able to maintain in the evaporator, the higher the evaporator efficiency. The percentage of liquid to vapour in the evaporator is a function of expansion device performance, the load and the expansion device setting, the percentage of flash vapour passing through the expansion device and the temperature of the liquid refrigerant. Following full evaporation within the evaporator, the temperature of the vapour will continue to rise while the pressure remains relatively constant.

This process will also continue in the suction line to the compressor. This increase in temperature while the pressure remains constant is referred to as superheat.

The ideal condition in most refrigeration systems is to have the refrigerant vapour enter the compressor at a saturated condition containing no liquid or superheat. This is not normally possible and would in fact pose some risk to the compressor according to its design.

The behaviour of the refrigerant within the condenser is divided into three separate stages. Prior to being converted back into a liquid, the refrigerant undergoes de-superheating, condensation from saturated vapour to saturated liquid, and finally, a degree of sub-cooling.

The discharge temperature of the refrigerant vapour leaving the compressor is very much related to the degree of superheat within the evaporator and the suction line coupled with the heat of compression through the compressor.

When the superheated vapour enters the condenser, the first thing to occur is the de-superheating of the refrigerant prior to the refrigerant vapour undergoing the condensing phase.

As seen in the pressure enthalpy diagram (above), the area of condenser used is directly related to the temperature of the superheated vapour. The higher the temperature of the superheated vapour, the greater the increase in pressure and volume. This therefore results in the vapour occupying more condenser space.

The rejection of heat from the de-superheated portion of the refrigerant vapour is much less effective than the latent phase, saturated vapour to saturated liquid.

In the condensing section of a condenser, the refrigerant vapours are cooled to the point of saturation. It is at this point that the vapour will start to condense into liquid state. As the refrigerant vapour changes state, the pressure within the condenser remains relatively constant. The refrigerant continues to condense during its passage through the condenser tubes, and it is this phase that rejects heat energy most efficiently.

The pressure, which exists in the condenser, is a function of the total condenser area together with other factors. The total condensing area is equal to the total condenser area minus the de-superheating and sub-cooling areas. Therefore, the less superheat within the condenser, the more area available for condensing the vapour to a liquid, thus leading to increased condenser efficiency.

When the saturation temperature of the refrigerant liquid falls below that of the surrounding temperature, the refrigerant vapour starts to evaporate (flash vapour). The purpose of LPA is to allow the temperature and pressure within the condenser to float up and down with ambient temperatures, thus allowing discharge pressures to be dramatically reduced during low ambient conditions, especially during the night.

Many systems employ low ambient control, which deliberately prevents this. The primary

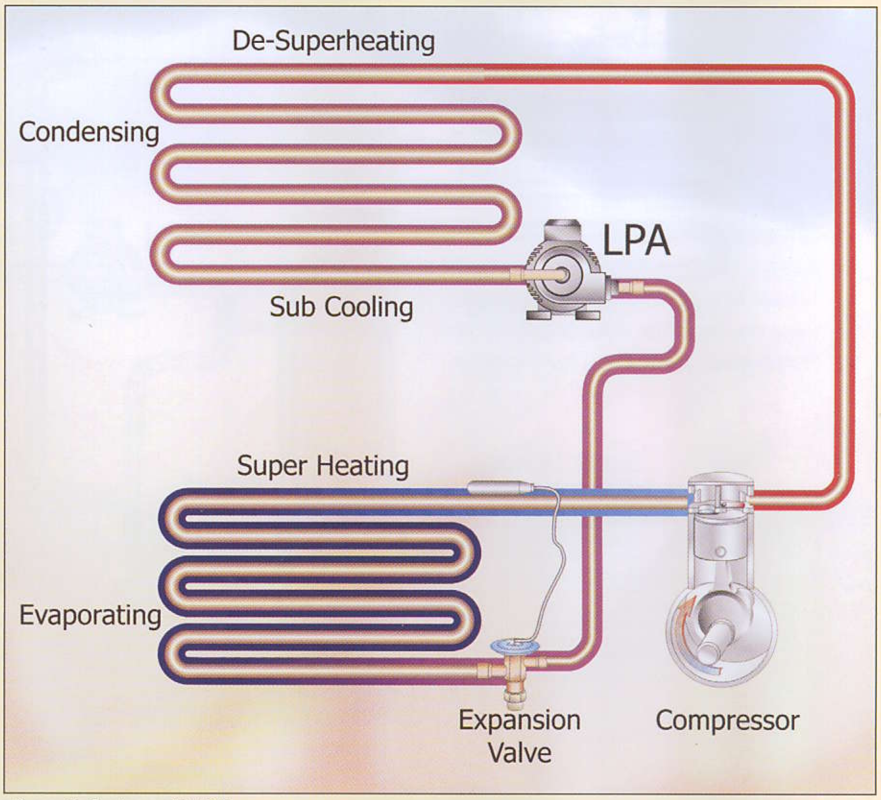


Figure 2: System with LPA

purpose of low ambient control is the maintenance of high compressor discharge temperature in order to prevent flash vapour and to allow, for example, long liquid refrigerant line length, which would otherwise cause flash vapour due to the drop in liquid line pressure and thus, refrigerant saturation temperature.

Crucially, since LPA will prevent the liquid refrigerant flashing back to refrigerant vapour after the condensing process, these new operating parameters can now allow a reduction in compressor absorbed power and an increase in overall refrigeration capacity. System reliability also benefits with fewer failures due to the lower operating pressures and temperatures.

Fig 2 shows a system utilising LPA.

LPA and the expansion device

In order for an evaporator to operate efficiently, it must operate with as high a percentage of liquid-to-vapour ratio as possible. To accomplish this, the expansion device must be able to regulate the flow of liquid refrigerant into the evaporator at the same rate at which it evaporates.

As seen in most systems, the overfeeding and underfeeding of the expansion device drastically affects the efficiency of the evaporator. With the LPA system installed and running, the flow rate is consistently higher with a more evenly modulating expansion device.

The increase in refrigerant flow and improved control of the expansion device provides better utilisation of the evaporator, creating an increase in pressure and a reduction in superheat temperature entering the compressor.

Higher pressure vapour entering the compressor is possible with LPA leading to an increase in compressor capacity, thus providing further efficiency gains.

It is thought that the potential reduction of superheated refrigerant vapour temperatures via LPA reduces the expansion of reciprocating compressor cylinder walls and therefore improves reliability.

Liquid injection

Liquid injection allows additional improvements in the refrigeration cycle. At high ambient temperatures, superheated vapour can occupy a large percentage of the condenser internal volume compromising capacity due to the reduced surface area for condensing.

Liquid injection (see Fig 3) provides superheat suppression, by injecting sub-cooled liquid refrigerant into the hot discharge line of the compressor, the reduction of superheated vapours greatly increases condenser efficiency and overall plant performance without adding work to the compressor. Increases in efficiency of 20% have been reported at ambient temperatures of 45°C; 8%-12% could realistically be expected at peak UK temperatures. The cooler operation of water-cooled condensers also prevents further scaling reducing the need for chemical treatment and maintaining good heat transfer.

Retro-fitting LPA

Retrofit applications for LPA generally fall into two categories: -

a) Systems which, due to technical shortfalls, do not provide the required refrigeration capacity in accordance with the original design.

This is often due to modifications, which have been made to the system, or the process is refrigerated or cooled. It is not uncommon to find compressors/condensers located 50m to 150m from the evaporators and several metres below (or above) evaporators.

Overcoming the liquid line (and suction line) pressure drop in a system like this will add significantly to the work that has to be done by the compressor, this work element being non-productive and therefore causing inefficiency. Any lack of quality liquid refrigerant at the evaporator directly results in a loss of capacity. Setting controls for a reduction in suction temperature further increasing compressor work and inefficiency sometimes compensates this for.

b) Projects which are initiated for environmental/energy conservation purposes: The potential annual improvements in efficiency can be quantified for both air conditioning and refrigeration applications. This is done using capacity details provided by the manufacturer and ambient temperature/frequency data. A simple spreadsheet analysis can then compare the efficiency of systems operating at fixed compressor discharge temperature (low ambient control) with those of the same system with floating discharge pressure capability and LPA. The energy analysis takes into account increased electrical consumption due to increased running of condenser fans and the LPA motor to give a comparison of energy consumption before and after the retrofit, enabling a persuasive case to be made for the necessary capital expenditure.

LPA limits

Whilst this article may give the impression that LPA is the panacea to some fundamental refrigeration problems, there are some limitations to its application. The major gains in efficiency come as a result of lower operating compressor discharge pressures. If condensers are undersized, the potential to achieve these lower discharge pressures will be limited. It may also be difficult to make a financial case for small air conditioning systems, which may only operate at higher ambient temperatures during daylight hours.

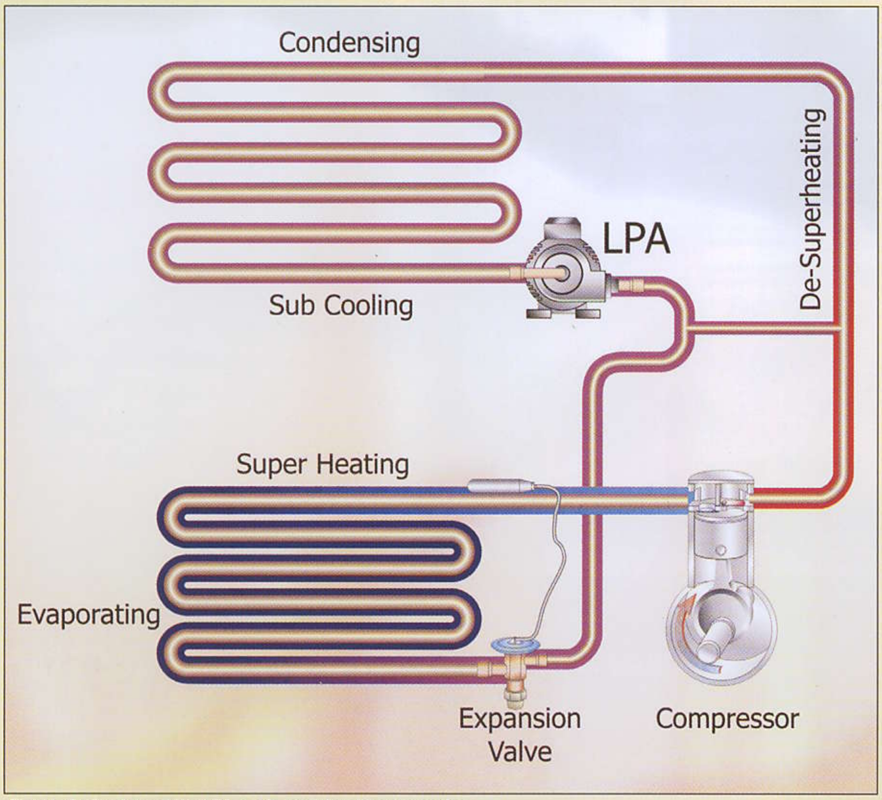


Figure 3: System with LPA and superheat suppression