

Heat Recovery Units on Dairy Farms

Introduction

This technical note covers work funded by the Milk Development Council, SWEB and PowerGen to provide independent, up-to-date information about the application and cost benefits of heat recovery units (HRU's). The application of refrigerant to water heat recovery units on dairy farms is a well-proven technique. However, long capital paybacks through energy savings have meant that the numbers of HRU's in commercial operation are relatively low.

The heat recovery process involves the transfer of 'waste' heat from the refrigerant of the milk cooling system into water. The water is pre-heated by the refrigerant before it enters the dairy water heater, where the temperature is 'topped up' using the existing immersion heater.

Types of HRU



Two generic types of HRU are available, a flow based HRU and a storage based HRU. Regardless of type, an HRU is installed in the refrigerant line between the compressor and condensing unit where the refrigerant is at its highest temperature, typically 70 – 80°C. The refrigerant is placed in thermal contact with the water and heat transfer takes place.

The type of HRU and milk cooling system used will determine how best to install and operate the HRU to give optimum performance. Two overriding factors need to be considered:

- The cheapest way to heat water electrically is to use cheap rate electricity. Operation of the HRU

should not be allowed to increase the use of day rate electricity;

- The water heater should always be full of water at the appropriate temperature, at the required time, e.g. 85°C by the end of the morning milking for circulation cleaning.

Flow Based HRU

As the name suggests, this type of HRU relies on a flow of water passing over the hot refrigerant pipes to recover heat. Although the construction of different products will vary, they essentially operate in the same way as a milk to water plate heat exchanger (PHE).

Once water has passed through an HRU, its temperature can be as high as 60°C and it must be stored in a well-insulated container to prevent heat loss prior to use.

The key to obtaining the best performance from this type of HRU is to ensure that water flow occurs whenever the compressor is operating. This has a significant effect on installation and operation. The system can therefore be controlled in a number of ways:

- Direct link to compressor operation;
- Fit a time-switch to match normal compressor operating times;
- Install a thermostat which operates on an increase in refrigerant temperature;
- Combination of the above.

Two types of flow based HRU's are available:

Single pass - the water is passed through the HRU once, at a very low flow rate and stored prior to use.

Circulation - the water is circulated at a higher flow rate from the storage tank through the HRU and back again whenever the compressor is operating.

On balance there is little performance difference between single pass and circulation operation.

Flow Based (single pass) - Ice Bank Milk Cooling System



As long as the water heater is at least partially empty for the majority of the compressor operating time, it can be used to store the warmed water leaving the HRU. If this is not practical, an additional insulated warm water tank can be installed which will obviously increase the installation cost.

The normal compressor operating times for an ice bank tank fitted with an 'E7 controller' can be split into three parts:

- 1 Operation during the cheap rate period, normally 00:30 to 07:30, prior to and during morning milking.
- 2 Operation immediately after morning milking in the on-peak period. This is to ensure sufficient ice reserves are available to rapidly cool the afternoon milk.
- 3 Operation shortly after the start of the afternoon milking, continuing until minimum ice levels have been reached.

Where heat recovery takes place towards the end of the Economy 7 period or during the day-rate period, it will be necessary to 'top-up' the water temperature by switching on the immersion heater using higher cost day-rate electricity. The economics of this are marginal when the comparative cost of heating an equivalent volume of cold water on cheap rate electricity is considered. The balance of costs usually means that it is best not to recover heat during this period.

The simplest way of controlling when water flows through the HRU is by using a time-switch, set to coincide with compressor operation. One advantage of this control regime is that, should the compressor operating time be much shorter than normal, water flow will still take place for the set time ensuring that the water heater will be full when required. The main disadvantage is that as milk production, and hence compressor operation varies, the time-switch and water flow rate need to be adjusted to recover as much heat as possible.

Calculating a required water flow rate is best shown using an example.

A 228 litre (50 gal) water heater combined with an ice bank tank compressor operating for 12 hours each day (720 minutes).

$$\text{Water flow rate} = 228/720 = 0.32 \text{ l/min}$$

If the compressor operating time increased to 15 hours (900 minutes).

$$\text{Water flow rate} = 228/900 = 0.25 \text{ l/min}$$

It is advisable to set the flow rate slightly higher than the optimum to make sure the water heater is always full.

Flow Based (Circulation) - Ice Bank Milk Cooling System

An alternative way of operating this HRU is to use a small pump to circulate the contents of the water tank through the HRU whenever the compressor is operating. This simplifies the control of the HRU because the pump operation can be linked to the compressor. The main disadvantage is that rather than cold water always entering the HRU, the water temperature gradually rises, thus reducing the rate of heat recovery. Offsetting this is the fact that the water flow rate can be made much higher, increasing the rate of heat recovery.

Flow Based (Single pass/Circulation) - DX Milk Cooling System

Integration with a DX based milk cooling system is more limited. The majority of compressor operation occurs during and shortly after each milking. To ensure the water is heated during the cheap rate period means that the water heater must be full and up to temperature just after the morning milking has started. The result is that unless additional intermediate warm water storage is available, heat cannot be recovered for a large proportion of the compressor operating time. Therefore when operating a flow based HRU with a DX based milk cooling system, an intermediate warm water storage tank is required.

Assuming the intermediate storage is available, the HRU can be operated in single pass or circulation mode as described earlier.

Storage based HRU

A storage based HRU is essentially an insulated water tank with a heat exchanger built in. There are a number of ways to do this but two methods are the most common:



- 1 A coil of copper pipe within the tank.
- 2 A plate attached to the outer surface of the tank leaving a gap between the two. The refrigerant is passed between the gap.

The benefit of this type of HRU is that heat recovery will always take place whenever the compressor operates. In addition, the HRU is effectively a header tank connected to the water heater and the water supply to it is always on, i.e. not controlled by a time-switch and solenoid valve. The result is that the water heater will always completely fill with water independently of HRU and compressor operation. This is also the case when using an additional warm water storage tank with the flow based HRU.

As a guide, the water holding capacity of this type of HRU should be slightly greater than that of the water heater.

A control system for this type of HRU is not necessary. The hot water flowing from the HRU enters the water heater through the normal mains water inlet. The existing inlet controls on the water heater should not need altering. However it is important to check that any valves, etc., are suitable for use with hot water otherwise they may fail prematurely.

Common Installation Considerations

An HRU interacts very closely with the refrigeration system and it is advisable to take steps to ensure that both operate satisfactorily:

- Anti-vibration fittings should be fitted to reduce the transmission of noise and vibration to the HRU preventing loss of the refrigerant due to the failure of refrigerant pipes and fittings;
- It is possible to over-cool the refrigerant, known as over-condensing, this reduces the cooling capacity of the bulk tank. This is less likely with newer refrigerants such as R22, but it needs to be taken into consideration;
- It is possible sometimes for liquid refrigerant to flow back from the HRU into the compressor outlet, a non-return valve should be fitted to prevent this;

- The pulsing refrigerant flow from reciprocating compressors can cause excessive vibration in some HRU's depending on type and compressor size. A muffler can be fitted to reduce this effect.

In many cases none of these are a problem but it emphasises the need to use an experienced refrigeration engineer who can advise you accordingly.

Water connections between the HRU and water heater should be insulated, as temperatures of up to 70°C can be achieved. In any situation current water bylaws should be adhered to.

HRU Performance

Depending on the actual farm installation, five different HRU configurations may be encountered. These include:

- Flow based HRU with an ice bank tank, using the water heater as the warm water storage with the water passing through the HRU once only;
- Flow based HRU with a DX tank, with additional intermediate warm water storage and the water being circulated;
- Storage based HRU with an ice bank tank;
- Storage based HRU with a DX tank;
- Flow based HRU with an ice bank tank, with additional intermediate warm water storage and the water being circulated.

The first four are most commonly used.

The actual performance of each configuration will vary depending on the amount of milk being cooled and whether or not a plate heat exchanger is used, as this determines the compressor size and operating hours. The water heater capacity also affects the water flow rate and hence HRU performance.

Trial Results

The results, shown in Table 1, are the average on-farm figures, adjusted to a 100 cow herd size, and recorded over a 12 month period on 40 farms.

The kWh savings represent around 30% of the total



electricity consumption of the water heater. The majority of farms that took part in these projects had a plate heat exchanger, this roughly halves the milk cooling requirement. Where a plate heat exchanger is not used the savings in the table could be increased by about 50%.

The flow based HRU (circulation)* with a DX tank installation was only connected to one compressor and there are normally two compressors on a DX tank. If two had been installed the amount of heat recovered was expected to be 60% higher making it comparable with the storage based system. The other combinations used all the installed compressor capacity.

General Considerations

- Assuming that the water heater size stays the same an increased compressor running time (higher milk yield) of say 50% will only result in an increase of heat recovered by about 30%. This is as a result of the diminishing efficiency of the system as the flow water (or storage water) temperature becomes higher;

- The average water heater size was 200 litres (44 gal), a bigger water heater will marginally increase the amount of heat recovered. Similarly a smaller water heater will reduce it;
- It is unlikely that the heat recovered by an HRU will replace more than 75% of the energy required to heat the water.

From an investment/running cost view the water heating should be carried out with a well-insulated water heater using cheap night-rate electricity before an HRU is considered. A milk to water plate heat exchanger will pay for itself within two to five years which is much better payback than an HRU. Therefore the installation of a PHE should normally take priority over that of an HRU even though it reduces the potential savings from an HRU.

Finally, the decision as to which type of HRU to use and its configuration depends primarily on:

- Ease of installation;
- Ease of integration with existing equipment;
- Ease of operation;
- Total installed cost.

Table 1

Based on 2.6 p/kWh cheap rate, 7.6 p/kWh day rate

	Electricity Saving kWh per annum	Cost Saving based on displacing 'cheap rate' electricity £ per annum	Cost Saving based on displacing 'day rate' electricity £ per annum
Flow based HRU, single pass, IB tank	2330	£61	£177
Flow based HRU, circulation, DX tank*	1464	£38	£111
Storage based HRU, IB tank	3041	£79	£231
Storage based HRU, DX tank	2329	£61	£177