Get your energy back

Recovering energy in malt distilleries using high-temperature heat pumps

In a typical malt whisky distillery a great deal of energy is lost in the still house. A well-designed high-temperature heat pump system will not only recover this energy but could also future-proof your expansion plans.

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Distillation is an energy-intensive process with 90% of the thermal energy in a malt whisky distillery being used in the still house. The malt whisky distillation process is performed in two steps using a wash and spirit pot still. Each still charge is heated to its boiling point and evaporated. The resultant distillate vapour exiting the still passes through a condenser where it meets cooling water and condenses. Heat for the stills is typically provided by steam generated in a boiler burning natural gas. Hot distillate in the condenser transfers its heat to the incoming cooling water. The cooling water is supplied to the condenser from a cooling tower or a natural cooling source such as a river or loch. Rejecting heat from the distillery using either of these water sources causes the energy to be lost to the atmosphere.

There is however an opportunity to capture and recover that energy for use in the distillery. As a distillery-owner with free access to a natural water source, you might ask why you would be interested in recovering the energy. There are two main reasons. First, saving energy from going to waste brings environmental benefits and will save you in the long term. Secondly, if your distillery plans to expand the additional demand on utilities may not be supported by the existing infrastructure. Well-designed heat recovery systems could allow you to expand production significantly without the infrastructure.

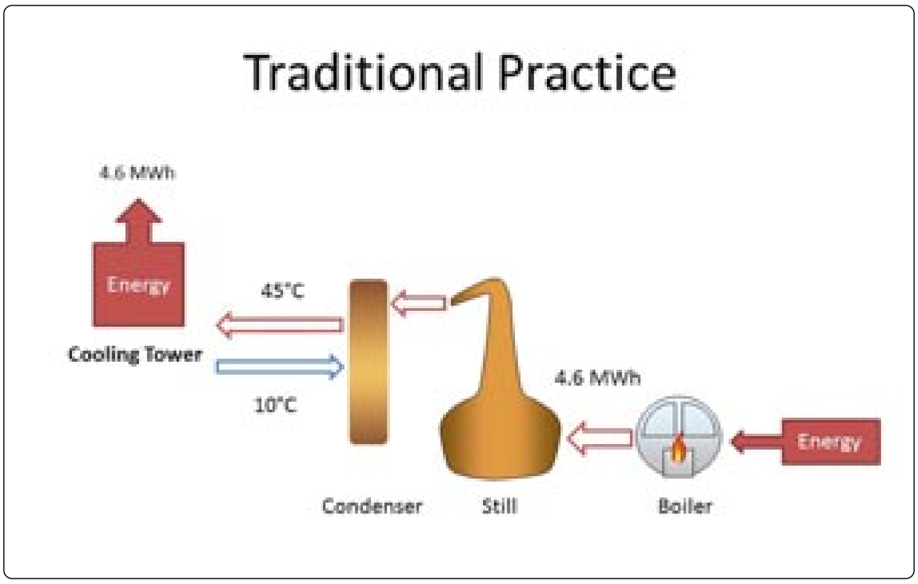

Figure 1 Current practice in a malt whisky distillery. Calculations based on a wash charge batch size of 20m3 with an 8% ABV. Energies for each process stream are calculated on an MWh basis.

This article reviews two types of high temperature heat pumps that can assist in achieving this goal.

Energy recovery at the still

Traditional practice

In 1985 the combined thermal and electrical energy used in Scottish malt distilleries was reported to range from 30 to 72 Mega Joules (MJ) per litre of pure alcohol (lpa) with the average requiring 43 MJ/lpa (*Dr A W Deakin, Brewing & Distilling International,*

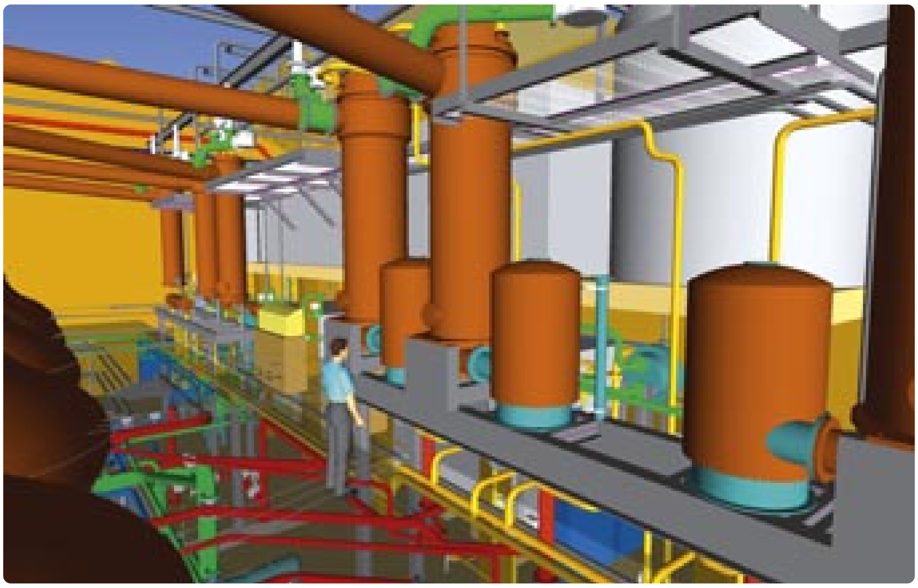

Figure 2 shows a 3D model of an existing still house with revised wash condensers and flash vessels.

Figure 3 TVR wash condensers and flash vessels.

“Reducing energy usage in whisky distilleries”). A traditional Scotch Malt Whisky should achieve a thermal energy use of approximately 26 MJ/lpa. Based on an energy balance that excludes heat losses and a process that uses pot ale and spent lees for wash, and low wines and feints charging, Figure 1 shows energy being wasted to the atmosphere via the cooling tower that could potentially be recovered.

Current practice

In addition to the heat recovery from the pot ale and spent lees, many distilleries now recover hot water from their condensers. This allows them to increase the wash, low wines and feints preheating temperatures and also to preheat water used for processes such as mashing and CIP. This approach can reduce the thermal energy use of the distillery to approximately 24 MJ/lpa. Whilst this is beneficial, the total amount of hot water that is produced from a still cannot be fully re-used, resulting in a large surplus. The surplus of hot water may be beneficial in a co-located maltings, pot ale evaporator, or aquaculture. Co-location presents a large opportunity and the implementation cost is usually attractive, increasing the efficiency of the process significantly. However, it should be noted that the actual MJ/lpa and total energy use of the process for spirit production is unchanged. Further reduction below 24 MJ / lpa requires the implementation of technologies to directly capture and re-use the energy in the still. To enable this, the still heating needs to be extensively modified.

Still heating

Conventionally, wash stills are heated with internal coils or pans to drive off the low wines. However, having an internal heating element within the still reduces the working volume and has a comparable lower heat transfer area when compared to an external heating system. To achieve the desired evaporation rate, steam at 2.0 bar(g) (135°C) or above is usually required to drive the still.

In vapour recompression systems the heat transfer is achieved using an external heat-exchanger, which allows the heat transfer area to be significantly increased. A major benefit to this is that steam pressures as low as 0.3 bar(g) (107°C) can be used, which maximises the efficiency of the heat recovery technology employed. Additional benefits include reduced fouling due to the lower temperature differential between the wash charge and steam. The wash is usually pumped at a high flow rate with recirculation rates exceeding 15× still contents per hour. The additional electrical load required for this pumping is not insignificant.

It is possible to offset this additional load by allowing the wash to thermoshyphon whereby the change in density of the wash from liquid to vapour in the heat-exchanger provides sufficient driving force to adequately recirculate the contents of the still. The main challenges to running the still using an externally heated recirculation system are the handling of wash at high recirculation rates without causing pump cavitation, whilst minimising foaming and ensuring an effective CIP of the high surface area heat-exchangers used. It should be noted that each of these aspects can be solved with good process engineering design.

High-temperature heat pumps (HTHP)

High-temperature heat pumps recover energy, usually in the form of steam from hot water returning from the still house condensers. In the process of recovering steam from the condenser loop the hot water is effectively cooled allowing it to be re-used without being passed to a cooling tower. There are two primary methods of applying

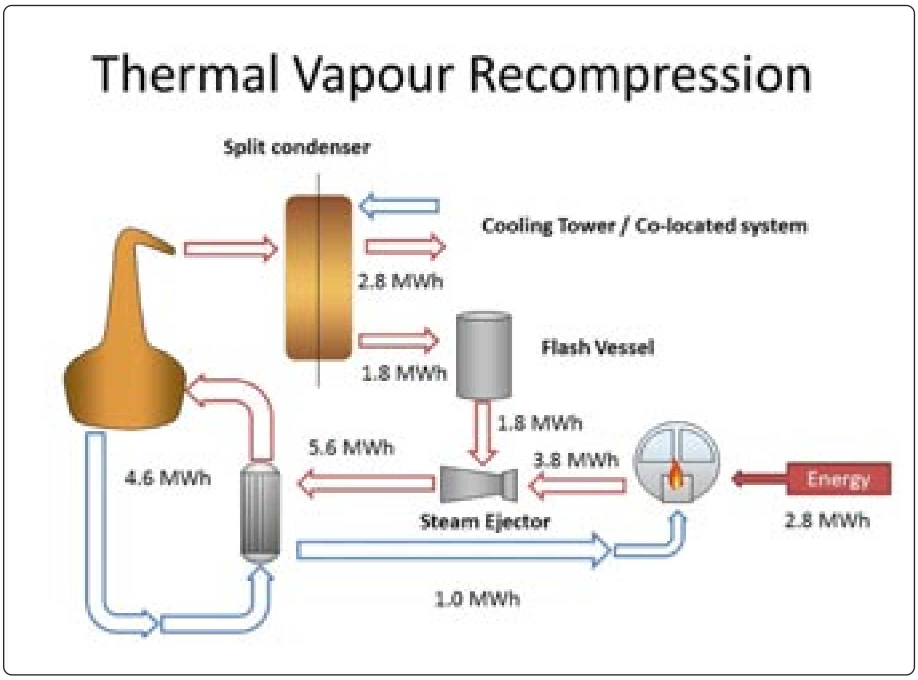

Figure 4 Example of a TVR system using recovered energy from the still condenser and boiler steam to heat the still.

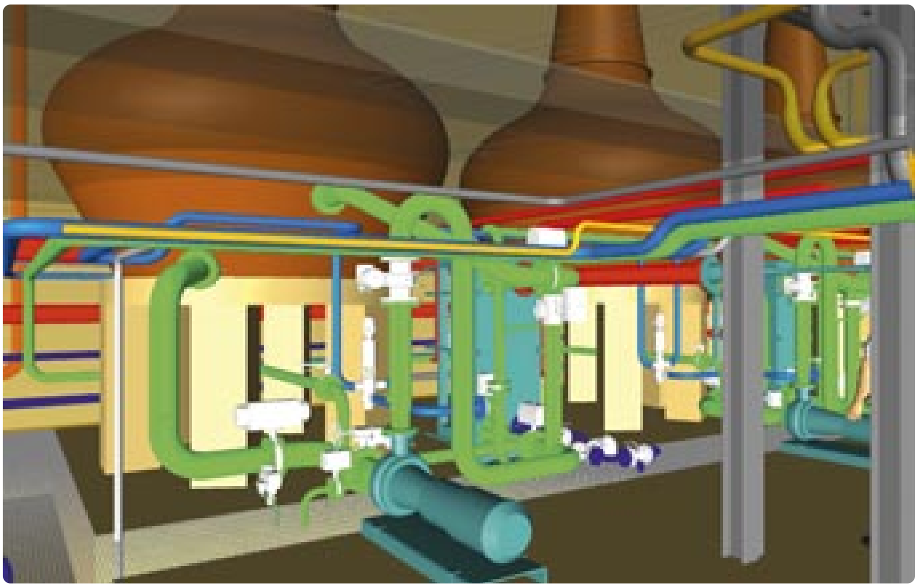

Figure 5 shows a 3D model of a TVR system implemented in an existing still house. 3D modelling allows optimal placement of pipework and equipment to allow existing still houses to be upgraded even where space is tight.

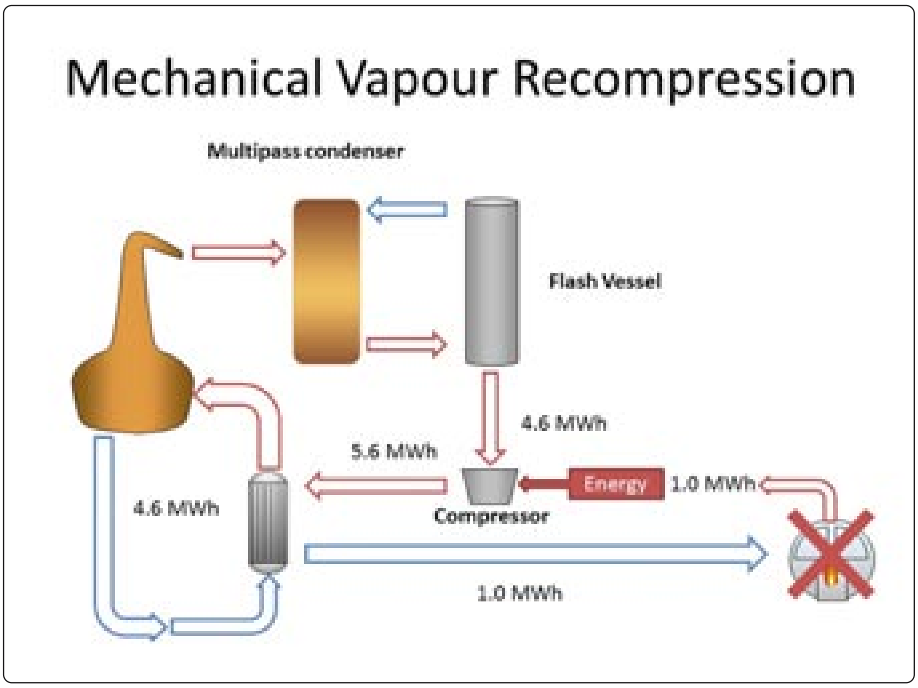

Figure 6 Example of a MVR system using recovered energy from the still condenser and electricity to heat the still.

Table 1 Energy Price and Carbon Dioxide (CO2) released per unit energy (kWh) for a range of fuel types used in a distillery

Fuel Type	p/kWh[a]	kgCO2/ kWh[b]
Electricity (Green)	11.0	0
Electricity (Grid)	9.3	0.43
Heavy Fuel Oil	4.9	0.26
Natural Gas	3.0	0.18
Coal	1.2	0.30

Source:
[a]Prices of fuels purchased by manufacturing industry, Department of Energy & Climate Change, updated 18 December 2014. Data average from 2014 Q3. (https://www.gov.uk/government/statistical-data-sets/prices-of-fuels-purchased-by-manufacturing-industry)
[b]Carbon Trust Conversion Fact Sheet

heat pumps to the stills as it stands today. These are thermal and mechanical vapour recompression.

Thermal vapour recompression (TVR)

Heat from the still vapour is recovered by a vertically split condenser. Stage one of the condenser operates as a conventional multi-pass hot water condenser with water typically entering at 50□ and leaving at 80□. The recovered hot water can be used for heating other processes within the distillery as discussed previously. Stage 2 operates as a falling film evaporator where boiler condensate from the hotwell is allowed to fall on to the tube side of the condenser. As the condensate falls down the tubes it picks up heat from the incoming low wine vapour and is vaporised forming steam. The steam is separated in a flash vessel and entrained via a low-pressure nozzle fed with boiler pressure motive steam (typically 8.0 bar(g)). TVR is most effective on wash stills but can be applied to the spirit stills with an expected energy reduction to 18 MJ/lpa (Table 2). The entrained steam typically makes up 40% of the total steam used for the still heating, creating a 40% reduction in the steam used for distillation. Briggs has recently achieved a greater than 50% reduction in steam usage in the implementation of a TVR system.

TVR is typically applied to individual stills and provides direct reduction of boiler steam and fuel input. The paybacks are predictable with an expected implementation cost to upgrade a conventional still with TVR is approximately £160k (including all equipment and engineering as shown in Figure 4, excluding the still and boiler). The nozzle itself is relatively cheap and reliable providing the recovery system is well installed. Additional noise in the still house is minimal. TVR systems have many reference sites in the industry and while the industry standard is a 40% steam saving at distillation, it is possible to extend these efficiencies significantly as the technology develops further.

Mechanical vapour recompression (MVR)

Heat from the still vapour is recovered by either a multi-pass hot water condenser or a falling film condenser (as used in TVR). Water enters the condenser at 80□ and exits at 90□. One benefit from the MVR system and the falling film condenser is that it is capable of recovering 100 % of the still vapour condensation energy.

The vapour is recovered from a flash vessel and recompressed using a screw or roots type compressor/blower. Including the energy required for still preheating, 90% of the energy used at the still can be recovered and re-used. The energy input to the compressor is typically electrical ranging between 120-150kW/tonne of steam recompressed, depending on the technology used and its efficiency.

MVR can be applied to both wash and

spirit stills. The actual setup is dependent on the scale of the distillery. As an example, a still house with three pairs of stills would be set up with a single compressor per still. This allows the compressor to minimise its electrical usage and in matching the required compression as the charge progresses. In larger distillation systems, for example greater than four pairs of stills, a larger centralised compressor can be used to reduce the number of compressors required. However, the compression ratio is much higher to accommo-

Table 2 Potential energy recovery options using MVR and TVR technologies

Note	Description	MJ/lpa	kWh / lpa	Energy saving compared to benchmark (%)
Traditional Practice	Heat recovery from pot ale and spent lees used in pre-heating the wash charge. Benchmark case.	26	7.2	-
Current Practice	Heat recovery from pot ale and spent lees for wash preheating with additional hot water used for preheating for processes such as mashing and CIP waters	24	6.7	5
TVR – Wash Stills	Wash Stills only	20	5.5	21
TVR – Wash Stills + Spirit Stills	Current Practice Hot Water Recovery system + TVR on Wash and Spirit Stills	18	5.0	30
MVR – Wash Stills	Current Practice Hot Water Recovery system + MVR on the Wash Stills only	17	4.7	35
MVR – Wash + Spirit Still	Current Practice Hot Water Recovery system + MVR on the Wash and Spirit Stills	12	3.3	52

TVR has a surplus of condensate from the flash vessel that can be fed into a maltings or pot ale evaporator. An MVR system typically applied to a still house on wash and spirit stills would not have a surplus of water to export, unless specifically designed to recovery energy to deliberately keep a surplus available for other uses.

Estimated annual financial paybacks and carbon footprint savings for TVR and MVR systems applied to a wash still:

$$\frac{\text{Implementation Cost £}}{\left(\frac{\text{Boiler Fuel Cost}\left(\frac{£}{\text{kWh}}\right)}{\left(\frac{\text{Boiler Efficiency (\%)}}{100}\right)}\right) - \left(\frac{\text{Vapour Recompression system fuel}\left(\frac{£}{\text{kWh}}\right)}{\text{COP}}\right) \times \text{Total (Steam) Energy}\left(\frac{\text{kWh}}{\text{annum}}\right)}$$

		MVR		TVR	
A	Estimated implementation cost incl. the equipment and engineering per still	£250k		£160k	
B	Boiler fuel cost	£0.03			Refer to Table 1
C	Boiler efficiency	80%			
		Electricity		Natural Gas	
		Grid	Renewable Source		
D	Vapour recompression system fuel cost	£0.09	£0.11	£0.03	Refer to Table 1
E	Coefficient of Performance (COP) of Vapour recompression system	5 Expect 5 – 7 depending on compressor type (roots and screw, respectively)		1.6	
F	Total Steam kWh per still per annum (20 m3, 8 hour TAT, 8% ABV, run 24 / 7, 46 weeks / annum)	3 batches per day (8 h TAT) x 7 days x 46 weeks = 966 batches per annum 966 batches x 7 Te / steam per batch 6762 Te / steam per annum 812 kW / Te steam = 5,490,000 kWh (5.4 GWh)			5,490,000 kWh
G	Boiler Fuel cost £/kWh	0.0375			(B/(Cx100) x F)
H	Vapour recompression system fuel cost £/kWh	0.0186	0.022	0.0188	(D/E)
I	Fuel cost saving £/kWh	0.0189	0.0155	0.0187	(G-H)
J	Fuel cost per annum using a natural gas powered boiler	£205,875			(G x F)
K	**Fuel cost per annum for the Vapour recompression system**	**£102,114**	**£127,780**	**£128,671**	(H x F)
L	**Energy cost saving per annum by implementing a Vapour recompression system**	**£103,761**	**£78,095**	**£77,204**	(I x F)
M	**Payback in years**	**2.4**	**3.2**	**2.0**	(A / L)
N	Te/CO2 from a boiler using Natural Gas	1,010			(0.184 kgCO2 / kWh /1000 x F)
O	Vapour recompression system kgCO2 / kWh	0.43	0	0.18	Refer to Table 1
P	Effective kg CO2 / kWh	0.086	0	0.113	(based on COP) (O / E)
Q	Te/CO2 per annum from the Vapour recompression system	472	1010	617	(P x F)
R	**Te/CO2 saving per still per annum**	**538**	**1010**	**392**	(N – Q)

date both the peak loading and start-up and shutdown of the stills at either end of their batches. In either case, the estimated implementation cost is expected to be equivalent to approximately £250k per still at today's prices. A typical MVR system will produce approximately five to seven times the amount of useful thermal energy per unit of electrical energy input, however the electricity is usually three times more expensive (see Table 1)

The coefficient of performance (COP) is used to compare the efficacy of different heat pumps. The COP is the ratio of the heating/cooling duty compared to the electrical input. A technology with a higher COP therefore uses less energy to heat or cool the product and therefore benefits from lower operating costs.

Coefficient of Performance = Qh/W

If the boiler fuel price fluctuates significantly compared to the electricity price (as it is today) it can become as expensive to run an MVR compressor on electricity as it needs to raise the steam in a conventional way. Applying MVR to the stills offers great benefits with respect to maximising energy recovery and reductions in the carbon footprint (electricity from a renewable source). Despite this however, only demonstration systems have been installed in the industry. Briggs was involved with the MVR system at Auchroisk distillery in 1985, which ran successfully but was eventually decommissioned due to the reasons stated above (notably a crash in oil price). MVR's greatest benefit as a technology is that it allows a route to decarbonise the malt distillery. If the electricity used by the compressor is obtained from a renewable source (solar panels/wind turbine) a significant carbon footprint reduction could be realised. A summary of the reductions in MJ/lpa for the MVR and TVR systems are shown in the Table 2.

Conclusions

Energy recovery in a malt whisky distillery is an important consideration to reduce current and future energy costs. Recovering energy can be achieved using schemes such as heat recovery from spent lees and pot ale. Co-location has a major benefit as a sink for the surplus hot water currently produced from the still condensers. However, not all distilleries will be able to benefit from co-location. In these instances and when the current infrastructure cannot support the malt whisky distillery expansion, alternative methods to reduce on-site energy production such as heat pumps are available.

Reducing the amount of energy sent to the atmosphere through cooling towers can be achieved using these heat recovery systems. These are typically higher implementation cost projects with payback periods typically realised over several years. The rate of payback is highly dependent on boiler fuel cost and the vapour recompression technology energy type. The implementation of both TVR and MVR systems are favourable when the current boiler fuel is very expensive such as heavy fuel oil.

TVR is cheaper to implement than MVR and allows energy and cost reduction irrespective of electricity cost fluctuations relative to boiler fuel costs. MVR offers greater annual cost savings at current electricity prices. The actual energy savings per annum for an MVR system are greater (£103,761) than TVR (£77,204). MVR offers excellent energy recovery capabilities and has the potential to de-carbonise the still house with electricity from renewable sources, even within the constraints of current compressor technologies. This may be increasingly important from a consumer and taxation perspective to minimise the carbon footprint of the products. It is expected that the implementation of an MVR system applied to both the wash and spirit stills can reduce the current energy required in a malt distillery from 24 MJ/lpa to 12 MJ/lpa (**Error! Reference source not found.**). In conclusion both technologies will allow you to save energy although the specific technology chosen will ultimately be dependent on your circumstances and location. ■