Absorption Chilling: Turning Biogas-Fueled Engine Waste Heat into Chilled Water

Part 3: Technical feasibility of dairy farm applications of absorption chillers

March 2020

Quantity and quality of heat required to generate chilled water

It takes approximately 430,000 BTU/hour of hot water to generate 25 refrigerated tons (RT) per hour of 45°F chilled water with a single-effect absorption chiller with a coefficient of performance (COP) of 0.7 (1 RT = 12,000 BTU). The quality of the heat is also important. A typical LiBr absorption chiller requires the hot water input temperature to be over 185°F to generate chilled water temperatures of 40 to 45°F, and an NH_3 absorption chiller requires input temperatures exceeding 212°F to achieve cooling temperatures below 38°F. [1]

For the application of milk cooling, we can assume that a milking cow produces 90 lbs of milk a day and harvesting occurs over a 21-hour period, resulting in an average milk production mass flow rate of 4.3 lb/cow-hour. To cool milk from 100°F to 36°F, the cooling energy required is 256 BTU/cow-hour at this average flow rate. A farm with 1,000 milking cows therefore requires 256,000 BTU/hour of cooling energy, equivalent to 21.3 RT/hour, to cool the harvested milk to the proper temperature. The heat input to a single-effect absorption chiller to obtain this amount of cooling energy is approximately 365 to 425 BTU/cow-hour (assuming the COP is between 0.6 and 0.7). If a well or municipal water pre-cooling system is used to bring the milk temperature down to 62°F initially, the heat input required to complete milk cooling is 150 to 175 BTU/cow-hour. Additional cooling energy is required to maintain the cooled milk temperature within a storage tank.

Quantity of heat available and potential cooling capacity

We took daily measurements for 12 continuous months on three northeastern US dairy farms of the total useful heat recovered from biogas-fueled CHP systems employing reciprocating internal combustion engines, the heat used by the anaerobic digester, and the vented (or unused) heat. One of the farms had 3,200 lactating cows and 1,500 heifers feeding the anaerobic digester; the daily average and standard deviation of the total heat recovered, heat used by the digester, and remaining vented (unused) heat is shown in Figure 1. Heat flow is in units of million BTU (MMBTU) per day on the left-hand y-axis and the average hourly chilled water generation potential from the vented heat flow available each month, on the right-hand secondary y-axis.

During the colder months of November through March, the digester used approximately 50% of the total heat recovered from the engine-generator. During the warmer months of June through September, the digester used approximately 35% of the total heat recovered leaving 65% available for other use. Thus, the average vented heat available in the warmest months was 42.5 million BTU/day or 1.77 million BTU/hour. A single-effect LiBr absorption chiller could use this waste heat and generate 100 RT/hour of 45°F chilled water to cool milk. In the colder months, 80 RT/hour of cooling capacity is practical.

From an energy balance standpoint, the cooling capacity generated from the vented heat is enough for milk cooling year-round (with or without the use of a pre-cooling system). However, chilled water from a NH_3 absorption chiller is necessary to cool milk to temperatures below 38°F, unless a LiBr absorption chiller is used for pre-cooling milk in conjunction with an electric compression cooling system.

> Lithium bromide (LiBr) absorption chiller technology is an appropriate application for farms with biogas-fueled CHP systems that do not pre-cool milk with a potable water-to-milk heat exchanger; if a water pre-cooler is used, the applicability is limited.

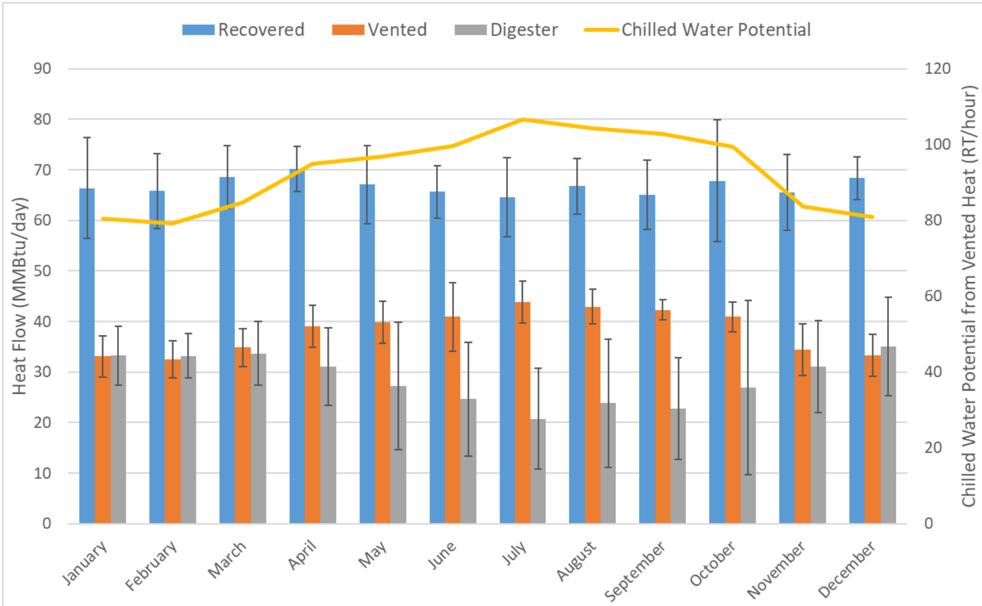

Figure 1. Average daily measured total CHP heat recovered, vented, and used for the anaerobic digester on a 3,200 cow dairy and predicted chilled water generation by a LiBr absorption chiller using vented heat.

Availability of technology and service personnel

As with most equipment, the long-term use of absorption chillers is impacted by the technology and service personnel availability. Selecting a unit that is not widely, or even narrowly, used within the US poses the risk of there being a lack of parts and support personnel available at a reasonable cost. Reliable field data on performance in the application being considered or a similar application is also important. Of the absorption chiller installations in the US, LiBr units for building air conditioning predominate. NH_3 absorption chillers have had limited US application and products are not easily found with a web search.

Major manufacturers

Among the smaller scale LiBr absorption chillers that are most applicable to farm milk cooling loads, Yazaki Energy Systems manufactures single-effect units in 5, 10, 20, 30, 50, and 100 RT cooling capacity increments. Thermax manufactures two different single-effect units ranging from 10 to 1,380 RT that can utilize hot water (minimum 167°F) as the heat input. (Note that higher temperatures of hot water are needed to achieve the specified minimum chilled water temperatures.) In 2008, Trane, Inc. (part of Ingersoll Rand) made an exclusive agreement with Thermax to manufacture its absorption chillers for the US and Canada markets. Other prominent LiBr chiller manufacturers include Johnson Controls (York chillers) and Broad USA. AGO AG Energie+Anlagen, headquartered in Kulmbach, Germany, manufactures NH_3 absorption chillers and has a 500 kW biogas-fueled trigeneration system case study on a German farm used to cool potatoes and carrots. [2]

FACT SHEET SERIES: Absorption Chilling: Turning Biogas-Fueled Engine Waste Heat into Chilled Water

Part 1: Absorption chilling process, types, and comparison to compression chilling
Part 2: Applications and practical considerations of absorption chilling for dairy farms
Part 3: Technical feasibility of dairy farm applications of absorption chillers
Part 4: Economic feasibility of milk cooling with lithium bromide absorption chiller

AUTHORS
Lauren Ray, C.E.M. email: ler25@cornell.edu
Curt Gooch, P.E. email: cag26@cornell.edu

[1] Ebrahimi M and Keshavarz A., 2015, *Combined Cooling, Heating and Power,* Elsevier, Chap. 2.
[2] AGO "ago congelo: when hot turns to cold", https://www.vamtec.co.uk/wp-content/uploads/2018/01/ago_congelo.pdf.