



Ammonia Refrigeration Cycle Integration in Buildings Heating System

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This work investigates the possibility of ammonia low potential heat utilisation with use of Process Integration methodology. The two operation modes are considered. The first one is the use of ammonia gas super-heating and partly ammonia condensation. The low condensation temperature of ammonia is limiting the low potential heat usage. The second option is introduction of ammonia additional compression to increase the temperature of ammonia condensation. The low potential heat consumers are the hot water supply system, air pre-heating system and air heating for the fans.

1. Introduction

The energy consumption increase leads to rise of CO₂ emissions and have negative impact on environment and negatively influence economic indicators. It gives the push up effect for the development of energy efficiency methods and tools. This problem requires methods of energy saving in buildings, especially low potential heat utilisation (Klemeš et al., 2008). Most food supermarkets, which are situated in dwelling zones in Ukraine and Russia use ammonia refrigerating units to obtain low temperatures for production processes and product storage. Such type of cooling machine produces a big amount of low potential heat which is not used and mostly rejected into the ambient. The techniques of low potential heat utilisation are well known and well described in literature, e.g. by Reay and Macmichael (1988) and Gorshkov (2004). However without a detailed analysis of process equipment, process streams, its potential, recuperation potential and different levels temperature of heat exchange is difficult to obtain for an optimal solution. The methods of low potential heat utilisation for other process demands were described by Korfitsen and Kristensen (1998). The Process Integration method an advanced tool for achievement of optimal energy efficiency and low capital and operation cost. It has been overviewed by Smith (2005) and by Kemp (2007); and most recently by Klemeš et al. (2012). In Russian was published an overview by Smith et al., 2000. This methodology is widely used in food processing and storage as was shown in some publications of different authors (Klemeš et al., 2008). In paper by Kapustenko et al. (2008) the possibility of ammonia cooling cycle integration into the heat system of cheese production plant was observed. It is shown the significant potential for energy saving and pollution reduction.

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In the present work investigated the possibility of ammonia low potential heat utilisation.

2. Process modelling

The analysed refrigerator of the supermarket is the traditional ammonia cooling unit (Scherbin and Ginberg, 1976). On the basis of extracted technological data the process simulation was built using UniSim Design[®] software. The process model gives the opportunity to idealise the stream data. Figure 1 shows the model of the ammonia cooling cycle. Ammonia overheating and condensation heat are dropped to the ambient. This heat can be used for heating of process streams, so far heated by utilities. Process streams and their physical properties are presented in Table 1.

Table 1. Stream data of the existing process

No	Name of stream	Type	TS, °C	TT, °C	G, t/h	C, kJ/(kg·°C)	r, kJ/kg	CP, kW/°C	ΔH, kW
1	Ammonia cooling	Hot	155	30	3.194	3.250		2.883	360.43
	Ammonia condensation	Hot	30	30	3.194		1146		1016.76
	Cooling of liquid ammonia	Hot	30	20	3.194	4.750		4.214	42.14
2	Water heating	Cold	15	60	15.000	4.190		17.458	785.63
3	Air preheating	Cold	10	30	50.000	1.005		13.958	279.17
4	Air to fans	Cold	10	55	25.000	1.005		6.979	314.06

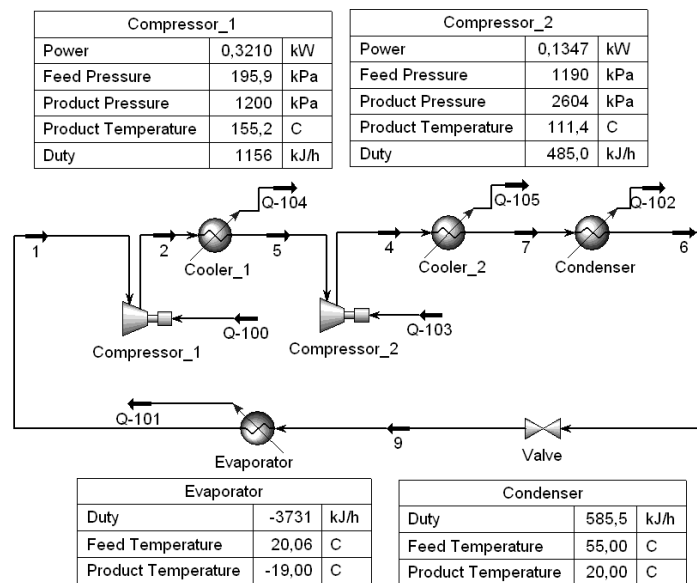


Figure 1. UniSim model of the Ammonia cooling cycle.

3. The Development of Heat Recovery System

The Pinch analysis has been now routinely used for design of the heat recovery system (Klemeš et al., 2010). Let's construct Composite Curves of process streams. The minimal temperature difference between the heat carriers is taken equal to 5 °C. This minimal temperature approach may be achieved for existing heat exchange equipment (shell-and-tube condensers and evaporators). It also enables fully use the streams' potential for heat recovery. The construction of Composite Curves shows the possibility of energy saving for the existing process, hot and cold utility targets and pinch point

localisation (Smith, 2000). The Composite Curves with the minimal temperature difference of 5°C are shown on Figure 2.

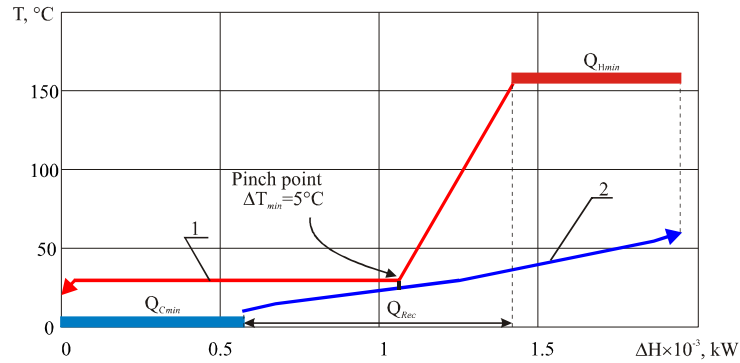


Figure 2. The Composite Curves for existing process for $\Delta T_{min}=5\text{ }^{\circ}\text{C}$; 1 – Hot Composite curve; 2 – cold composite curve; $Q_{Hmin} = 530\text{ kW}$ – hot utilities; $Q_{Cmin} = 570\text{ kW}$ – cold utility; $Q_{Rec} = 849\text{ kW}$ – heat recovery

The Composite Curves show that the heat recovery for the existing system of process streams has a minimum 849 kW for $\Delta T_{min}=5\text{ }^{\circ}\text{C}$. Based on the analysis of data, gathered from the constructed Composite Curves, the heat exchangers network was built. For heat exchangers network (HEN) development Grid diagram representation is used. The Grid diagram of HEN for the investigated process streams is shown in Figure 3.

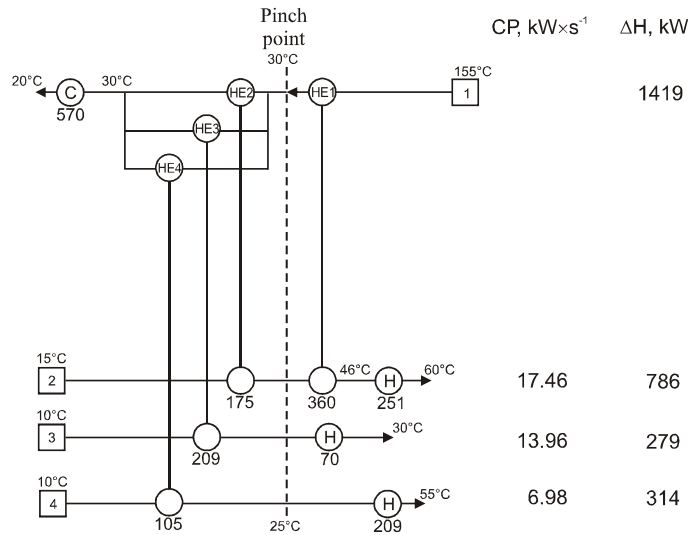


Figure 3. The Grid diagram of the investigated streams system for $\Delta T_{min}=5\text{ }^{\circ}\text{C}$; HE1-4 – recuperative heat exchangers; C – cooler; H – heater; CP – stream heat capacity; ΔH – stream enthalpy.

The Grid diagram shows heat recovery system which consists of 4 recuperative heat exchangers with total heat load 849 kW. In this case the hot and cold utilities are 530 and 570 kW. The total additional heat transfer area will be 225 m². Considering that the cost of installation of one heat exchanger is 5000 USD, the cost of 1 m² of heat transfer area is 500 USD, and the cost of hot utilities is 350 USD

per 1 kW/y, the cost of cold utilities is 35 USD per 1 kW/y (the price level of 2011), the approximate pay-back period makes up to 5 months.

4. The Application of the Additional Ammonia Compression

The form of the Composite Curves demonstrated on Figure 2 shows that the condensation temperature increasing will change the location of Pinch Point and will raise the heat recovery potential. Using UniSim Design software the model of the cooling unit with additional compression was built. It allowed obtaining stream data for the further analysis purposing to improve the Heat Integration of supermarket's ammonia cooling cycle into the building heating system. Table 2 shows the data of the process streams, which can be taken for the heat integration.

Table 2. Data of process streams for the system with additional compression

№	Name of stream	Type	TS, °C	TT, °C	G, t/h	C, kJ/(kg·°C)	r, kJ/kg	CP, kW/°C	ΔH, kW
1	Ammonia cooling 1 st stage	Hot	125	30	3.194	3.250		2.883	273.93
2	Ammonia cooling 2 nd stage	Hot	111	60	3.194	4.275		3.793	193.44
	Ammonia condensation	Hot	60	60	3.194		986.2		874.98
	Cooling of liquid ammonia	Hot	60	20	3.194	4.935		4.378	175.14
3	Water heating	Cold	15	60	15.000	4.190		17.458	785.63
4	Air heating	Cold	10	30	50.000	1.005		13.958	279.17
5	Air for air curtains	Cold	10	55	25.000	1.005		6.979	314.06

For definition of the minimal temperature difference for the HEN the cost relations of heat transfer area, utilities and total reduced costs from ΔT_{min} were plotted (Figure 4). The curve of total reduced costs has minimum at $\Delta T_{min} = 23$ °C. But on the curve's range from $\Delta T_{min}=17$ °C to $\Delta T_{min}=27$ °C the value changes are insignificant. At the same time the cost for heat transfer area is less at $\Delta T_{min}=17$ °C. The minimum on the utilities cost curve (curve 1 of Figure 4) can be explained by the threshold problem of Composite Curves (Klemeš, 2010). As a rule, for the threshold problems ΔT_{min} is selected equal to ΔT_{min} of the threshold. In our case this value is equal to 17 °C. Accordingly, if $\Delta T_{min}=17$ °C is selected for the heat network design, then the total cost of the project will be minimal and the value of ΔT_{min} will conform to the threshold value.

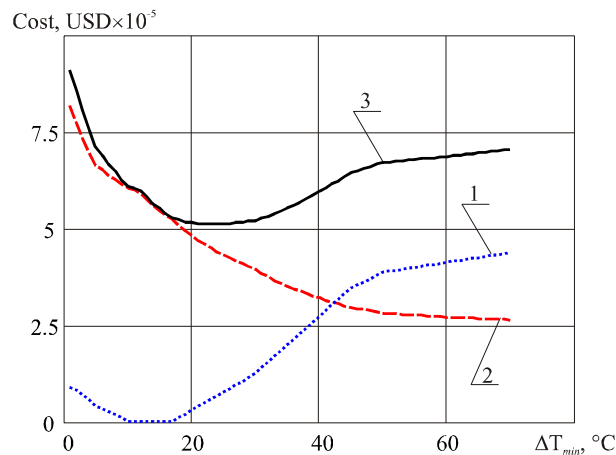


Figure 4. The costs curves: 1 – reduced utilities costs; 2 – the reduced capital costs; 3 - total reduced costs.

The Composite Curves for process streams with the additional compression constructed for $\Delta T_{min}=17\text{ }^{\circ}\text{C}$ are shown in Figure 5. It is obvious, that the heat recovery increases up to 1,379 kW, cold reduces on 139 kW and it is no need in hot utility.

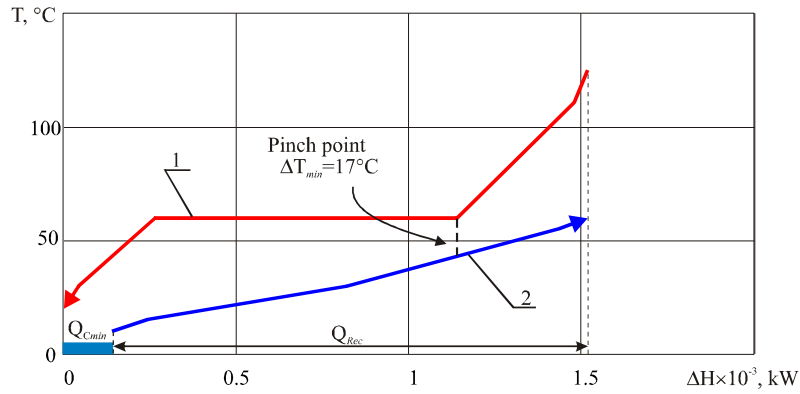


Figure 5. Composite Curves of the process with the additional ammonia compression for $\Delta T_{min}=17\text{ }^{\circ}\text{C}$: 1 – Hot Composite Curve; 2 – Cold Composite Curve; $Q_{Cmin}=139\text{ kW}$ – cold utility; $Q_{Rec}=1379\text{ kW}$ – heat recovery.

Thereby, the application of additional ammonia compression will satisfy the requirements of all cold streams heating by the hot streams without using of utilities. The Composite Curves show the Pinch point localization and Pinch Point temperatures. The next step is to estimate the economic efficiency of additional compression application. The Grid diagram of heat exchangers network is built (as shown in Figure 6).

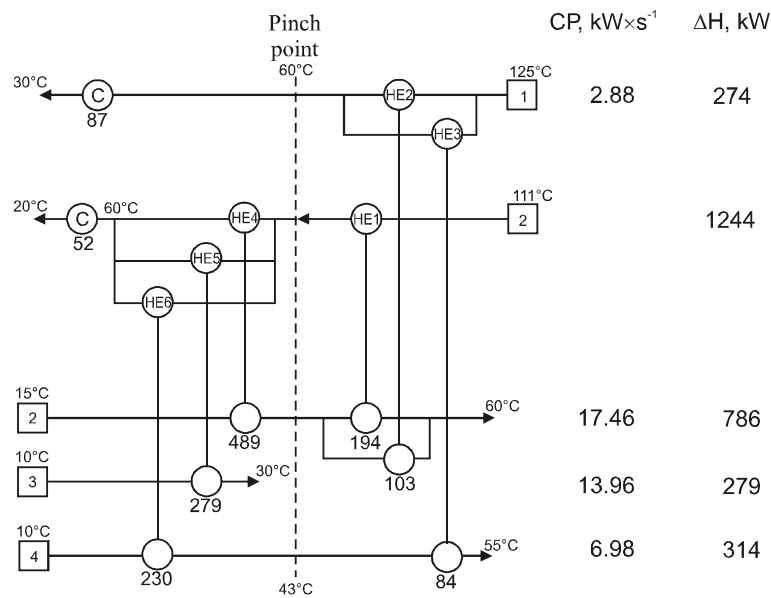


Figure 6. Grid diagram of streams system with the additional ammonia compression for $\Delta T_{min}=17\text{ }^{\circ}\text{C}$: HE1-6 – recuperative heat exchangers; C – cooler; H – heater; CP – stream heat capacity; ΔH – stream enthalpy.

The grid diagram includes 6 recuperative heat exchangers and two utility coolers. The total heat transfer area of the additional equipment will be 337 m². For the operation of flowsheet with the additional ammonia compression the compressor unit is also needed, and its demand in electricity is 135 kW. The compressor cost is 50,000 USD. The cost of heat exchange equipment and the utility costs is the same as for the flowsheet without additional ammonia compression. The pay-back period of the retrofit project with application of additional compression of ammonia stream will be up to 7 months.

5. Conclusion

The analysis of operation of supermarket's ammonia cooling cycle has shown the possibilities to use the overheating and condensation heat of ammonia stream. This heat can be used for air and water heating, and it will significantly reduce the utility costs. The application of the additional ammonia compression will improve the heat integration, but it also needs big capital investments. However, economic estimation of this project shows its reasonability.

The result of the presented work can be used for reconstruction and design of supermarkets' ammonia cooling cycles. For implementation such projects, it is required to carry out the additional analysis of energy consumption systems, because each of them has the specific streams and particular equipment, and also its own technological constraints.

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