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ABSTRACT

In typical commercial dishwasher application, high temperature water (>82.2°C) is needed for rinse process and electrical booster heater is used to provide such hot water. In the same time, exhausted high humidity hot vapor must be vented out with specially installed hood. This paper presents the development of a high temperature water heat pump to reclaim the heat in the exhaust vapor and deliver high temperature hot water to save electrical energy used in booster heater. While in the same time, the dehumidified exhaust air can be vented directly indoor without a specially installed hood. Both R-134a and R-513A refrigerant are tested successfully in a prototype system on a typical conveyor commercial dishwasher. More than 80% dehumidification target achieved and more than 20 kW energy saving potential demonstrated with the prototype system.

1. INTRODUCTION

Commercial dishwasher has been widely used in food service industry and are responsible for around one third of water consumption in kitchens, and a large portion of energy consumption (David Styles et.al, 2013). In typical commercial dishwasher application, high temperature water (>82.2°C) is needed for rinse process per certification to NSF/ANSI 3-2019 (NSF, 2019) and electrical booster heaters are typically used to provide such high temperature water. In the same time, exhausted high humidity hot vapor must be vented out with specially installed type II hoods per 507.3 of 2015 International Mechanical Code (ICC, 2014). A research on an efficient modern conveyor-type machine suitable for hotel and restaurant kitchens reported that its total energy consumption is dominated by heating of the final rinse water (56%) (Meiko, 2011). Machines utilizing heat recovery and heat pump technology demonstrate significant lower water-heating energy consumption compared with standard machines and the most efficient machines consume two-thirds less energy for water heating than standard machines as reported in (Kromo, 2011). This paper presents the development of a high temperature water heat pump to reclaim the heat in the exhaust vapor and deliver high temperature hot water to save electrical energy used in booster heater. While in the same time, the dehumidified exhaust air can be vented directly indoor without a specially installed hood. The construction of prototype system is described in following first. The experimental running results with both R-134a and R-513A refrigerant are presented to demonstrate the energy saving achieved with this technology. Future investigation is proposed based on the results obtained.

2. PROTYPE VENTLESS DISHWASHER UNIT

2.1 Typical Conveyor-Type Dishwasher Unit

A typical conveyor-type dishwasher unit used for implementation of ventless dishwasher prototype has a plumbing schematic as shown in Figure 1.

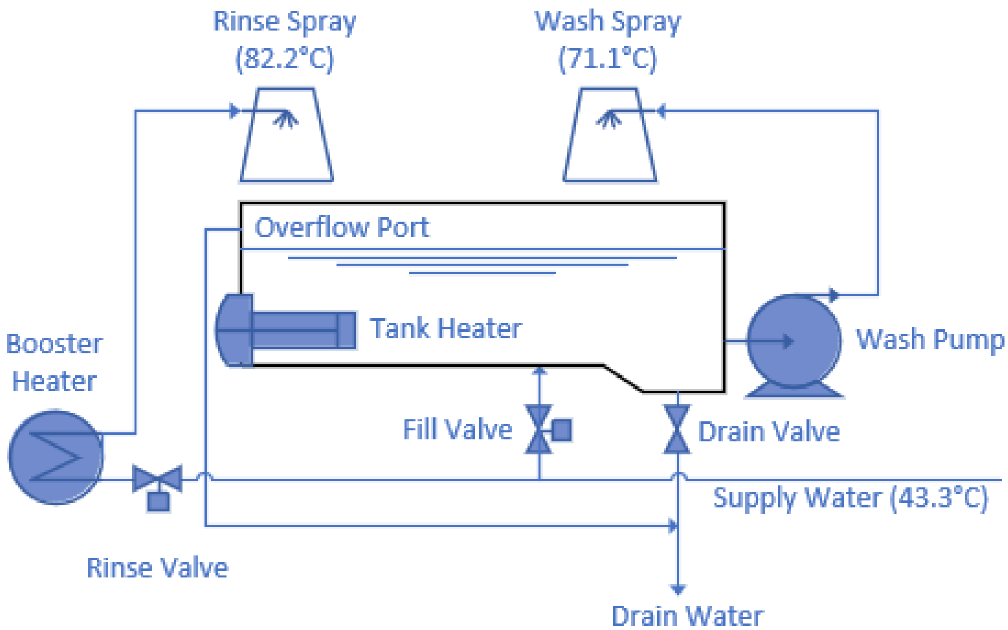

Figure 1: Plumbing Schematic of Typical Convery-Type Dishwasher

Hot water (around 43.3°C) is feed through fill valve to fill the water tank until full. The fill valve will be closed, and rinse valve will be opened to let the booster heat to heat up the water to 82.2°C and being sprayed through rinse spray. The electrical tank heater is used to heat up tank water to around 71.1°C and wash pump will pump the heated water through wash spray to wash the dishes entering the conveyor dishwasher. The conveyor belt will move the dish rack through washing section into rinsing section and be rinsed by high temperature rinse water. A vent hood installed on top of the dishwasher will remove the hot high humidity exhaust air out of the room per building code.

2.2 Prototype Ventless Conveyor-Type Dishwasher Unit

The prototype ventless conveyor-type dishwasher unit presented here employs an existing energy recovery coil, and adds heat pump technology to heat up water from city water temperature (around 15.6°C) by reclaim heat from condensing of hot moisture in the exhaust air such that it can be vented inside the room without an extra range hood. The plumbing schematic of this prototype unit is shown in Figure 2.

It should be noted that the schematic shows a separate implementation of heat recovery and heat pump water plumbing design without interfering the original dishwasher operation. The prototype unit is only used to demonstrate the energy saving potential of such technology. The assembly and instrumentation of completed prototype unit is shown in Figure 3. The exhaust from dish rack entrance side is mixed with the exhaust from dish rack exit side after it passes through the already installed energy recovery coil and heat up the city water. The mixed exhaust then being pulled through the evaporator coil by a blower and being blown out of a duct with air sampler installed to measure its DB/WB temperatures with an accuracy of ±0.1°C. Water temperatures at energy recovery coil inlet/outlet and water-cooled condenser inlet/outlet were measured with thermocouples with an accuracy of ±0.5°C. Water flow rate through the energy recovery coil and water-cooled condenser is measured with a float flow meter with an accuracy of ±2% of reading. Compressor and blower power each are measured with a power meter with an accuracy of ±1% of reading.

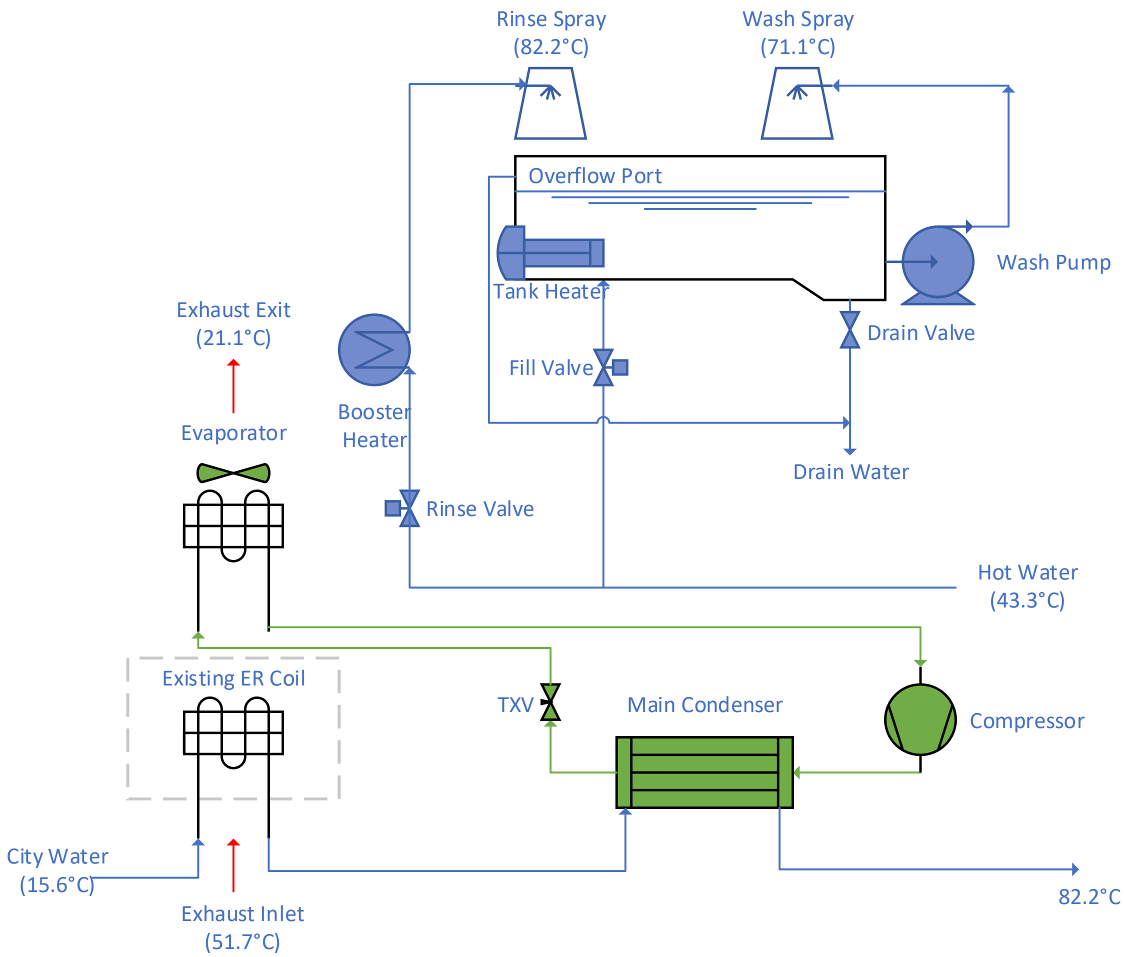

Figure 2: Plumbing Schematic of Prototype Ventless Convery-Type Dishwasher

Figure 3: Prototype Unit Compressor and Water-Cooled Condenser Assembly

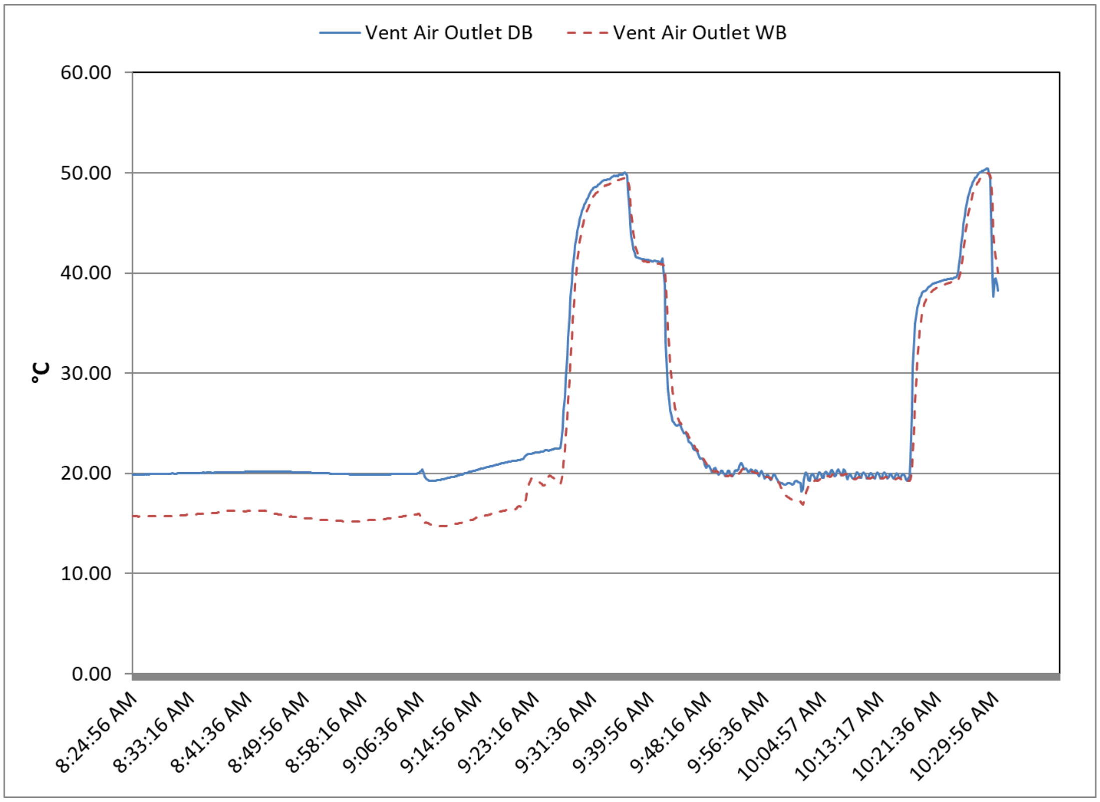

Figure 4: Exhaust DB/WB with/without Prototype Unit Running Comparison

3. TEST RESULTS AND DISCUSSION

3.1 Comparison Test With/Without Energy Recovery Coil/Heat Pump Running

The exhaust air DB/WB measured by the air sampler with/without prototype unit running is shown in Figure 4. Before energy recovery coil and heat pump unit being turned on, the exhaust air DB/WB reaches over 48.9°C with dishwasher in operation. With energy recovery coil being fed with city water, the exhaust air DB/WB drops below 40.6°C. With heat pump unit being turned on, the exhaust air DB/WB drops to below 19.4°C. Tuning off the heat pump, the exhaust air DB/WB rises over 38.9°C and if further shut off water flow into energy recovery coil, the exhaust air DB/WB rises over 48.9°C again. It clearly demonstrates the effectiveness of the energy recover coil and heat pump unit to reduce the exhaust air DB/WB to let it be safely vented indoor instead of using an extra range hood to vent them outside.

3.2 Parametric Study Results

The parametric study of room temperature and blower VFD drive frequency is listed in Table 1, Table 2 and Table 3. A power saving of more than 20kW can be achieved by reclaiming the heat from the exhaust air to heat up city water to be used as rinse water in the dishwasher.

Table 1: Room Temperature Effects on Prototype Unit Performance

Room DB (°C)	Initial DB/WB (°C)	Final DB/WB (°C)	Water Flow (liter/min)	Water In/Out (°C)	HR Reduction (%)
26.7	52.5/52.4	21.1/20.7	7.19	22.1/82.2	84.6
32.2	52.9/52.8	23.9/22.5	7.19	22.1/85.9	83.6

Table 2: Blower VFD Frequency Effects on Prototype Unit Performance

VFD Freq (Hz)	Initial DB/WB (°C)	Final DB/WB (°C)	Water Flow (liter/min)	Water In/Out (°C)	HR Reduction (%)
43.0	52.1/51.9	21.1/20.5	7.19	21.3/79.8	84.6
50.0	49.0/48.7	22.7/21.4	7.19	22.1/83.9	80.6

Table 3: Blower VFD Frequency Effects on Prototype Unit Energy Saving

VFD Freq (Hz)	ERC Load (kW)	Cond Load (kW)	Comp Power (kW)	Blower Power (kW)	Energy Saving (kW)
43.0	10.008	18.968	6.401	0.148	22.454
50.0	9.975	20.558	7.028	0.18	23.353

3.3 Alternative Refrigerant Test Results

As R-134a is a refrigerant that might be phased out in near future, an alternative refrigerant R-513A is employed to investigate its performance in such a unit. The performance comparison of two refrigerants in the prototype unit is shown in Table 4 and Table 5. R-513A has a little lower performance in humidity ratio reduction and energy saving compared with that of R-134a. However, it can still meet the target of the prototype unit for ventless dishwasher application. It also should be noted that in this comparison test, R-513A is used as a drop-in replacement for R-134a.

Table 4: Comparison of R-134a and R-513A on Prototype Unit Performance

Refrigerant	Initial DB/WB (°C)	Final DB/WB (°C)	Water Flow (liter/min)	Water In/Out (°C)	HR Reduction (%)
R-134a	52.1/51.9	21.1/20.5	7.19	21.3/79.8	84.6
R-513A	51.8/51.7	22.2/21.0	7.19	21.2/79.0	84.0

Table 5: Comparison of R-134a and R-513A on Prototype Unit Energy Saving

Refrigerant	ERC Load (kW)	Cond Load (kW)	Comp Power (kW)	Blower Power (kW)	Energy Saving (kW)
R-134a	10.008	18.968	6.401	0.148	22.454
R-513A	11.239	17.230	6.515	0.147	21.832

3.4 Energy Savings Benchmark

For commercial dishwasher, Energy Star® requirement by US environmental protection agency is effective as of February 1, 2013 (EPA, 2012). The benchmark that can be used to estimate the energy consumption for single tank conveyor dishwasher is water consumption requirement of $\leq$ 2.65 LPR. For a typical conveyor commercial dishwasher, it can handle more than 200 racks per hour. Thus, the water consumption should be $\leq$ 8.83 liter/min. Assuming 7.0 liter/min water needs for rinse, the power to heat rinse water from 43.3°C to 82.2°C can be calculated as 15.8 kW and a typical booster heater installed in such commercial conveyor dishwashers has a power rating of 18 kW. The commercial conveyor dishwasher typically requires an inlet water temperature > 43.3°C to ensure the booster heater can heat rinse water temperature to 82.2°C per NSF requirement. The heat pump prototype test results show that by reclaiming heat from exhaust vapor, only about 7 kW power needed to drive the compressor and blower and 7.19 liter/min water can be heated from 22.1°C to 82.2°C which equals 30 kW heating power. A power saving of 23 kW is achieved. For a typical commercial conveyor dishwasher, it has both 15-kW tank heater and 18-kW booster heater. Installing a 7-kW heat pump unit to replace 18-kW booster heater means a 33.3% energy saving.

4. FUTURE STUDY

The test results presented above demonstrate the feasibility of utilizing an existing energy recovery coil together with heat pump technology to reach the target of more than 80% humidity ratio reduction and more than 20 kW energy saving. However, to make the prototype unit into production, more research is needed. Beyond that, how to reduce minimal water flow rate requirement as well as control integration implementation and reliability study of whole unit under operation conditions need to be addressed before the unit can be incorporated into a production commercial dishwasher. The technology demonstrated in this paper can also be used to develop an independent heat pump to replace an electrical booster heater to supply high temperature hot water (>82.2°C) for sanitizing application by reclaiming latent heat from hot exhaust vapor to save energy.

5. CONCLUSIONS

This paper presented a novel prototype unit that incorporates existing energy recovery coil and heat pump technology to achieve more than 80% humidity ratio reduction and more than 20kW power saving for a conveyor-type commercial dishwasher. Test results for different room temperature and blower speed as well as different refrigerant are discussed. Future research to make a production unit is also proposed. Ventless dishwasher not only could save energy by reclaim heat from hot moisture in exhaust air, it also can vent the exhaust air directly indoor, so an extra range hood is not needed anymore.

NOMENCLATURE

DB	dry bulb temperature	(°C)
HR	humidity ratio	(kg water/kg dry air)
LPR	liter water per rack	(liter/rack)
WB	wet bulb temperature	(°C)

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