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BASELINE, EXHAUST-FIRED, AND COMBINED OPERATION OF DESICCANT DEHUMIDIFICATION UNIT

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ABSTRACT

The performance of a commercially available direct-fired desiccant dehumidification unit (DFDD) has been studied as part of a microturbine generator (MTG)-based Integrated Energy System (IES) at Oak Ridge National Laboratory (ORNL). The IES includes a second-generation air-to-water heat recovery unit (HRU) for the MTG. The focus of these tests was to study the performance of a DFDD in baseline (direct-fired with its natural gas burner) mode and to compare it with a DFDD performance in the exhaust-fired and combined modes as part of the ORNL IES, when waste heat received from the MTG was used for desiccant regeneration. The baseline tests were performed with regeneration air heated by a natural gas burner (direct-fired).

The testing of the waste-heat, or exhaust-fired DFDD as part of IES involved using the exhaust gas from the HRU for regeneration air in the DFDD after hot water production in the HRU. Hot water from the HRU was used to produce chilled water in an indirect-fired (water fired) absorption chiller. The combined DFDD was the combination of natural gas burner and exhaust-fired testing. The study investigated the impact of varying the process and regeneration conditions on the latent capacity (LC) and latent coefficient of performance (LCOP) of the DFDD, as well as overall IES efficiency.

The performance tests show that LC increases with increasing dew point (humidity ratio) of the process air or the increased amount of waste heat associated with increased MTG power output. In addition, baseline LC was found to be three times higher than the LC in the exhaust-fired mode of operation. LCOP in baseline operation is also almost three times higher than that obtained in the exhaust-fired mode (55.4% compared to 19%). But, at the same time, addition of the DFDD to the IES with the MTG at maximum power output increases the overall IES efficiency by 4-5%.

Results of the combined tests performed at a reduced MTG power output of 15 kW (51,182 Btu/h) and their comparison with the baseline and exhaust-fired tests show that activation of the DFDD gas burner during exhaust-fired tests increases the LC over the baseline value from 91,514.9 Btu/h (25.8 kW) to 101,835.8 Btu/h (29.8 kW). The LCOP during the combined mode is less than the “baseline” LCOP, because in addition to gas input, the low-grade MTG/HRU exhaust heat input to the DFDD are also being considered. The overall IES efficiency during the combined mode is approximately 8% higher than without the DFDD integrated into the IES.

INTRODUCTION

The problems caused by electric power deregulation in the United States and other developed countries have created an important opportunity for distributed energy technologies [1, 2]. In the 2001 report by the National Energy Policy Development Group, the concept of Combined Cooling, Heating and Power (CHP), currently known as Integrated Energy Systems (IES), is identified as a strategy for addressing the increasing energy demands and peak power issues [3]. Recent developments in distributed generation (DG) technologies have opened new opportunities for relatively small-scale IES that can be used in commercial buildings. DG in combination with thermally-activated technologies (TAT), which use waste heat directly for heating purposes or as input to thermally-driven desiccant dehumidification and absorption cooling, provide important opportunities for IES to be a viable technology for buildings [1, 4].

This research activity investigated the baseline, exhaust-fired, and combined performance of a commercially available direct-fired desiccant dehumidification unit (DFDD) over a wide range of conditions in a steady-state operating mode. The DFDD is part of a flexible "National User" IES laboratory (Fig. 1) that allows for the connection of basic IES-CHP components into various configurations. The IES Laboratory can study the characteristics of each component and the overall IES under various operating modes. The DFDD system, which is shown schematically in Fig. 2, consists of a honeycomb desiccant wheel coated with titanium silicate and process and regeneration air circuits. As the process air flows through the desiccant wheel, the moisture that would normally be entering the building is removed from the air stream. The desiccant material is restored to its sorbent (dry) state by exposure to the heated regeneration air stream as the desiccant wheel rotates. After passing through the wheel, the outlet regeneration air is then discharged to the atmosphere.

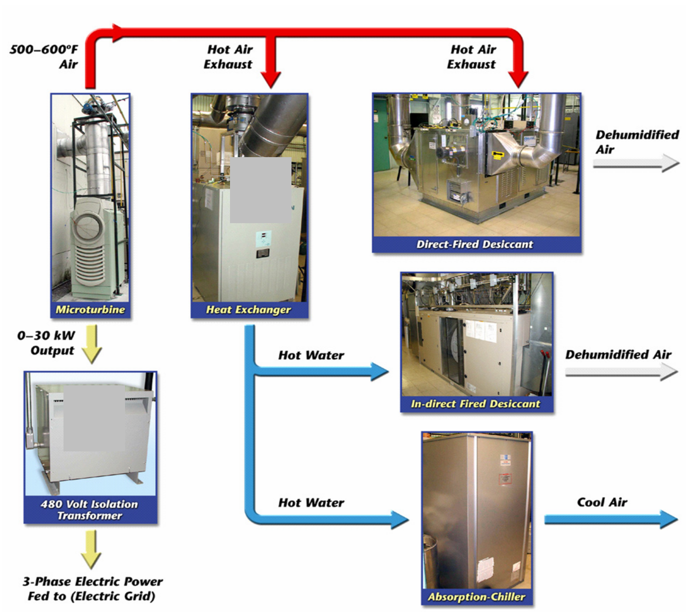

Figure 1. IES Testing Laboratory.

The DG component of the IES includes a 30-kW* (102,433 Btu/h) natural gas-fired microturbine generator (MTG) and an air-to-water heat recovery unit (HRU). The IES also includes an indirect-fired absorption chiller (AC). Detailed descriptions of these units are given in earlier publications [5, 6].

* The microturbine full-load power output is 28 kW (95,604 Btu/h); 2 kW (6,829 Btu/h) is auxiliary power consumed by the microturbine

NOMENCLATURE

Abbreviations:

AC	= absorption chiller
DB	= dry-bulb temperature
DFDD	= direct-fired desiccant dehumidification unit
DG	= distributed generation or generator
DP	= dew-point temperature
HHV	= higher heating value (i.e, of natural gas)
HRU	= heat recovery unit
IES	= integrated energy system
LC	= latent capacity
LCOP	= latent coefficient of performance
MTG	= microturbine, or microturbo generator
WB	= wet-bulb temperature

Variables:

C_{Pair}	= heat capacity of air, Btu/lb.°F or kJ/kg.°C
G	= volumetric air flow rate, scfm or m^3/min
h	= enthalpy, Btu/lb or kJ/kg
Q	= heat input, thermal output, Btu/h or kW
t	= temperature, °C or °F
W	= electric power, Btu/h or kW
δ	= percent difference, %
η	= efficiency, %
ρ_{air}	= density of air, lb/ft^3 or kg/m^3

Subscripts

abs	= absolute
cl	= cabinet loss
in	= input
out	= output
p	= pressure
par	= electrical parasitics
pr	= process
reg	= regeneration

EXPERIMENTAL SETUP

Figure 2 shows the experimental setup used to collect the baseline performance data on the direct-fired desiccant dehumidification (DFDD) unit. The natural gas flow rate of the unit was monitored by a pulse count natural gas test meter equipped with a 0 to 15 in. wc (0 to 3.73 kPa) pressure gauge. The desiccant unit is fully instrumented to measure dry-bulb and dew-point temperatures, process and regeneration air flow rates at the outlets; and total electrical power used by the unit is also monitored. Sensors used for these measurements and associated accuracies are shown in Table 1. The required accuracy of the test instrumentation is in accordance with the ASHRAE Standard 139-1998 [7]. Measurements for the process and regeneration airstreams include inlet and outlet dry-bulb and dew-point temperatures. Three chilled mirrors and one humidity and temperature transmitter were used to

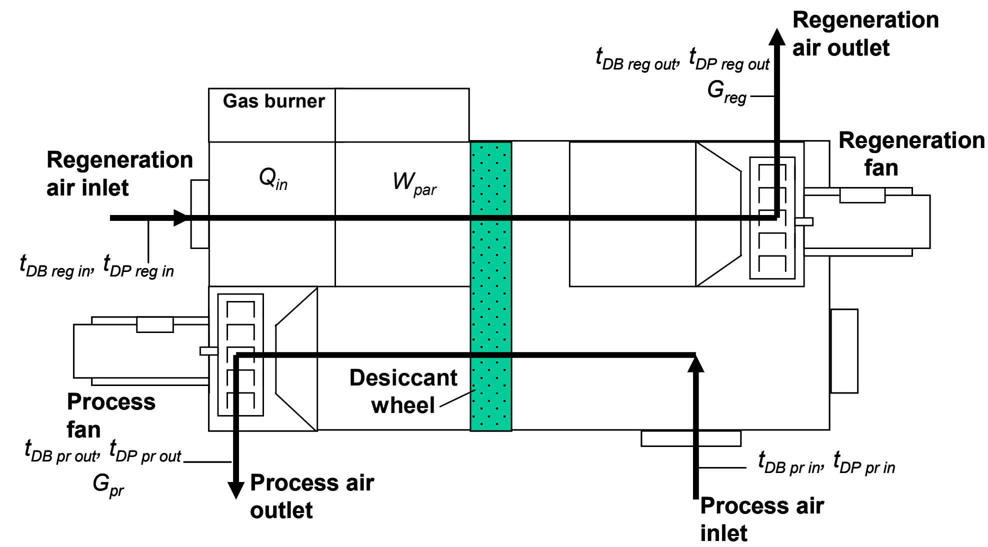

Figure 2. Schematic Diagram of the Direct-Fired Desiccant Dehumidification Unit (Q_{in} = heat input, W_{par} = electrical parasitics, t_{DB} = dry-bulb temperature, t_{DP} = dew-point, G_{pr} = process air flow rate, and G_{reg} = regeneration air flow rate)

Table 1. Instrumentation Used in Direct-Fired Desiccant Dehumidification Tests

Measurement	Sensor	Accuracy
Air flow	Fan evaluator*	±2% Range 500 to 5,000 scfm (14.2 to 141.6 m^3/min)
Dew-point temperature	Chilled mirror	±0.2^{o}F (±0.1^{o}C) Range -40 to 140^{o}F (-40 to 60^{o}C)
Dew-point temperature	Humidity/temperature transmitter	±0.4^{o}F (±0.2^{o}C) Range -40 to 140^{o}F (-40 to 212^{o}C)
Gas flow – DFDD	Pulse count test meter	±0.2% Range 0 to 200 cfh (0 to 5.7 m^3/h)
Gas flow - MTG	Pulse count test meter	±0.2% Range 0 to 415 cfh (0 to 11.8 m^3/h)
Gas pressure – DFDD	Pressure transducer	±0.5% of full scale Range 0 to 15 in wc (0 to 3.73 kPa)
Gas pressure – MTG	Pressure transducer	±0.5% of full scale Range 0 to 15 in wc (0 to 49.77 kPa)
Power	Watt transducer	±0.5% of full scale Range 0 to 40 kW (0 to 136,577 Btu/h)
Temperature	RTD	±0.2^{o}F (±0.1^{o}C) Range -328 to 1,562^{o}F (-200 to 850^{o}C)
Water flow	Flow meter	±1% Range 0 to 0.38 m^3/min (0 to 100 gpm)

* A multi-point, self-averaging Pitot traverse station with integral air straightener-equalizer honeycomb cell which is capable of continuously measuring fan discharges or ducted airflow.

measure the dew-point temperatures of the air streams. The wet-bulb temperatures, enthalpies, humidity ratios, latent capacity (LC), and latent coefficient of performance (LCOP) were calculated from these measurements.

IES tests involved testing with the following equipment: the 30-kW MTG, the HRU, the AC, and the DFDD.

TEST PROCEDURES

The baseline DFDD tests were performed with regeneration air heated by direct burning of natural gas. The exhaust-fired used waste heat recovered from the MTG exhaust. The exhaust gas from the MTG was used as input to the HRU to heat water and the HRU outlet exhaust was used as the regeneration air in the DFDD. The hot water from the HRU was used to produce chilled water in the AC. The combined DFDD tests were the combination of baseline and exhaust-fired tests in that the DFDD natural gas burner on the regeneration side was used to supplement the waste heat recovered from the MTG exhaust.

The LC is calculated using the following equation [8]:

$$Q_{latent} = Q_{total} - Q_{sensible} \tag{1}$$

where total cooling capacity Q_{total} and sensible cooling capacity $Q_{sensible}$ are as follows:

$$Q_{total} = \rho_{air} \cdot G_{pr} \cdot \left(h_{pr\ out} - h_{pr\ in}\right) \tag{2}$$

$$Q_{sensible} = C_{Pair} \cdot \rho_{air} \cdot G_{pr} \cdot \left(t_{pr\ out} - t_{pr\ in}\right) \tag{3}$$

where ρ_{air} is the density of air at standard condition, G_{pr} is the volumetric flow rate of process air, $h_{pr\ in}$ and $h_{pr\ out}$ are the process inlet and outlet enthalpies, C_{Pair} is the specific heat capacity of air, and $t_{pr\ in}$ and $t_{pr\ out}$ are the process inlet and outlet dry-bulb temperatures.

The LCOP, a measure of the desiccant dehumidification unit's efficiency, is calculated by the ratio of the LC to the total energy input (thermal + electrical). The energy input, includes the gas input (based on the higher heating value or HHV of the natural gas) and electrical parasitics (desiccant wheel motor, fans, electronics *etc.*). It should be noted that hereinafter the electrical power, measured in kilowatts, was converted to thermal energy using a conversion factor (3,412 Btu/kWh). The DFDD test runs were performed at two inlet conditions of process and regeneration air. Due to certain limitations on the initial space conditions where the unit is located, it was not possible to run the tests at high dry-bulb and low wet-bulb temperatures; therefore, the conditions studied were:

- 85°F (29.4°C) dry-bulb, 75.8°F (24.3°C) wet-bulb
- 85°F (29.4°C) dry-bulb, 78.1°F (25.6°C) wet-bulb.

The DFDD air flow rate was within 3,330-3,570 scfm or 94.3-101.1 m^3/min (face velocity 1,063.9-1,140.6 ft/min or 324.3-347.7 m/min) for the process side and 840-960 scfm or 23.8-27.2 m^3/min (face velocity 260.4-306.7 ft/min or 79.4-93.5 m/min) for the regeneration side. The desiccant wheel face area and speed were 3.13 ft^2 (0.29 m^2) and 8 rph respectively. The process area was 3/4 of the total desiccant wheel area. The process air-side pressure drop across the wheel was 2.9 in. wc (0.007 atm), and the regeneration air-side pressure drop was 2.5 in. wc (0.006 atm). It should be noted that purge was not used on the desiccant wheel. During the tests the modulating function of the desiccant dehumidification unit that controls the gas input as a function of the regeneration outlet temperature was turned off, so the gas input was kept almost constant (145,200 Btu/h or 42.5 kW). The electrical parasitics were measured to be between 5.8 and 6.1 kW (19,803.7 and 20,828.0 Btu/h).

The exhaust-fired and combined tests were performed at constant hot, chilled, and cooling water flow rates. The ambient temperatures and relative humidities varied slightly over the range of 74-77°F or 23.3-25.0°C and 94-100% respectively. The near constant ambient temperatures and humidities allowed for the comparison of the test results with no correction for ambient conditions. The exhaust-fired testing was performed at three different steady-state MTG power levels: 15 kW (51,182 Btu/h), 20 kW (68,288 Btu/h) and 22.8-23.5 kW (77,797-80,185 Btu/h). The last level was the maximum achievable MTG power output at the given ambient temperature. The combined DFDD testing was conducted only at 15 kW MTG power output because higher power output and exhaust temperatures resulted in the regeneration temperature exceeding the maximum permissible wheel temperature of 320°F (160°C). This in turn resulted in the deactivation of the DFDD gas burner. This was caused by the lack of the modulation capability in this burner.

Since the volume of exhaust air from the MTG during the exhaust-fired and combined tests was not enough to run the regeneration side of the DFDD, it was mixed with outside air that had almost the same inlet conditions as the process stream. This resulted in significantly lower regeneration temperature.

In this study, the IES efficiency is defined by the following equation:

$$\eta = \frac{W_{el} + \sum Q}{Q_{in} + \sum W_{par}} \cdot 100\text{, \%} \qquad (4)$$

where W_{el} is the net electric power output, ΣQ is the sum of useful thermal/cooling/latent capacity, Q_{in} is the gas input (based on the HHV of the gas), and ΣW_{par} is the sum of electrical parasitics of HRU, AC, DFDD *etc.*

Due to small inlet-outlet enthalpy differences of process and regeneration air streams found in this study, the validation of test results was determined on the basis of absolute heat input to/output from the DFDD. Equations for absolute heat input/output ($Q_{abs\ in}$, $Q_{abs\ out}$) and percent difference (δ) were defined as:

$$Q_{abs\ in} = \rho_{air} \cdot (G_{pr} \cdot h_{pr\ in} + G_{reg} \cdot h_{reg\ in}) + W_{par} \qquad (5)$$

$$Q_{abs\ out} = \rho_{air} \cdot (G_{pr} \cdot h_{pr\ out} + G_{reg} \cdot h_{reg\ out}) + Q_{cl} \qquad (6)$$

$$\delta = \frac{(Q_{abs\ in} - Q_{abs\ out})}{Q_{abs\ in}} \cdot 100\text{, \%} \qquad (7)$$

where ρ_{air} is the density of air at standard condition, G_{pr} is the volumetric flow rate of process air, G_{reg} is the volumetric flow rate of regeneration air, $h_{pr\ in}$ and $h_{reg\ in}$ are the process and regeneration inlet enthalpies, $h_{pr\ out}$ and $h_{reg\ out}$ are the process and regeneration outlet enthalpies, W_{par} is the electrical power consumed by the DFDD, and Q_{cl} is the DFDD cabinet loss calculated according to ASHRAE Standard 139-1998 [9].

Experimental results with differences δ not exceeding 2-3% were accepted as valid. The heat balance on the AC side generally was within allowable tolerances as defined by ARI Standard 560-2000 [10].

EXPERIMENTAL RESULTS

Baseline Test Results

The baseline tests were performed at 85/75.8°F (29.4/24.3°C) and 85/78.1°F (29.4/25.6°C) inlet dry/wet- bulb temperatures. The basic trends are the same as those observed previously [11]: the LC and LCOP increase with increasing dew point (humidity ratio) of the process air (Table 2, Fig. 3). The resulting LC for the 85/75.8°F (29.4/24.3°C) tests was

Table 2. Baseline, Exhaust-Fired, and Combined DFDD Test Results

Mode of operation	Process inlet conditions °F (°C)		Regeneration inlet plenum* conditions °F (°C)		Latent capacity Btu/h (kW)	Latent COP %
	DB[1]	WB[2]	DB[1]	WB[2]		
Baseline	85.2 (29.6)	75.7 (24.3)	85.3 (29.6)	75.8 (24.3)	91,514.7 (26.8)	55.4
IES 15 kW	85.5 (29.7)	75.7 (24.3)	125.3 (51.8)	90.7 (32.6)	13,958.6 (4.1)	31.3
Combined 15 kW	84.3 (29.1)	75.6 (24.2)	136.5 (58.1)	93.0 (33.9)	101,835.8 (29.8)	54.4
IES 20 kW	84.9 (29.4)	75.8 (24.3)	142.1 (61.2)	94.2 (34.6)	25,469.4 (7.5)	44.5
IES 30 kW*	84.8 (29.3)	75.5 (24.2)	153.8 (67.7)	97.7 (36.5)	28,248.8 (8.3)	43.8
Baseline	84.9 (29.4)	78.1 (25.6)	84.9 (29.4)	78.1 (25.6)	95,623.6 (28.0)	57.1
IES 20 kW	84.7 (29.3)	78.1 (25.6)	141.9 (61.1)	94.5 (34.7)	29,371.1 (8.6)	50.8
IES 30 kW**	84.8 (29.3)	77.7 (25.4)	157.5 (69.7)	98.4 (36.9)	34,340.0 (10.1)	51.2

*Actual MTG output is 22.8 kW (77797 Btu/h); **Actual MTG output is 23.5 kW (80185 Btu/h). [1]DB is the dry-bulb temperature; [2]WB is the wet-bulb temperature.

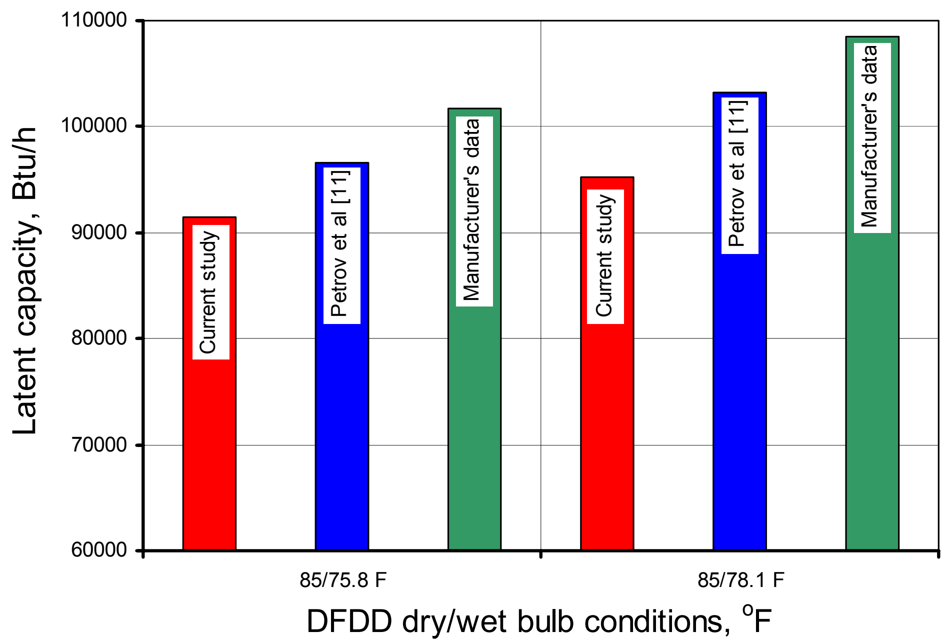

Figure 3. Comparison of the Current Baseline DFDD Results with Previous Tests [11] and Manufacturer's Data.

found to be 91,514.7 Btu/h (26.8 kW). It is 5.4% less than the corresponding value at the same conditions from the previous study (96,646.6 Btu/h or 28.3 kW) and 10.0% lower than manufacturer's data (101,660.0 Btu/h or 29.8 kW). It should be noted that in the previous study the gas input was (154,000-160,000 Btu/h or 45-47 kW, as compared to 145,200 Btu/h or 42.5 kW in this work. Furthermore, the LCOP which accounts for electric power consumed by the DFDD is 55.4 %. This is comparable with LCOP from the previous study (54%). If the parasitic losses are neglected, then the LCOP would be 63.1%.

The same trend applies to the current test results at 85/78.1°F (29.4/25.6°C) conditions: the LC in this case is 95,263.1 Btu/h (27.9 kW), which is less than that found in the previous study [11] (103,246.3 Btu/h or 30.2 kW) or reported by the manufacturer (108,460.0 Btu/h or 31.8 kW). However, the LCOP is almost the same (57.1% as compared to 58.0% in the previous tests). Without the DFDD parasitic losses, the LCOP under these conditions would be 64.9%.

Exhaust-Fired Test Results

The test results of the exhaust-fired operation of DFDD are presented in Table 2 and Fig. 4. The basic trends are the same as those observed previously [11]: the LC increases with increasing MTG power output or dew point (humidity ratio) of the process air. The LCOP in the exhaust-fired mode of operation was roughly estimated as the ratio of latent capacity to the sum of DFDD electrical parasitics and heat input at the regeneration side; the latter, in turn, was determined from the following equation:

$$Q_{in-DFDD} = C_{Pair} \cdot \rho_{air} \cdot G_{reg} \cdot \left(t_{reg\ in} - t_{reg\ out}\right) \qquad (8)$$

where ρ_{air} is the density of air, G_{reg} is the volumetric flow rate of regeneration air, C_{Pair} is the specific heat capacity of air, and $t_{reg\ in}$ and $t_{reg\ out}$ are the regeneration inlet and outlet dry-bulb temperatures.

The values of LC found in this study are much lower (~39%) than those from the previous study [11]: for example, 25,469.4 Btu/h (7.5 kW) as compared to 41,862.9 Btu/h (12.3 kW) a reduction of 16,393.5 Btu/h or 4.8 kW for the same conditions of 20 kW (68,288 Btu/h) MTG power output and DFDD inlet dry- and wet-bulb conditions of 85/75.8^{o}F (29.4/24.3^{o}C). The cause of this drastic reduction in LC is the significantly higher heat exchanger effectiveness of the 2nd generation HRU. The recovered heat of the 1st generation HRU was found to be 115,176.1 Btu/h (33.7 kW) as compared to 137,610.0 Btu/h (40.3 kW) for the 2nd generation HRU. This is a gain of 22,433.9 Btu/h (6.6 kW) or 19.5%. The higher HRU efficiency in turn means lower exhaust temperatures leaving the HRU (260^{o}F or 126.7^{o}C for 1st generation HRU versus 209^{o}F or 98.3^{o}C for 2nd generation HRU). Thus, there were lower HRU exhaust temperatures available for desiccant regeneration.

Comparison of different IES efficiency combinations shows that the maximum efficiency is achieved when the MTG is used with the HRU and DFDD (Figs. 5 and 6) in series. In this case it can reach 59.1 – 60.4%: the higher efficiency value corresponds to a higher MTG power output and inlet humidity ratio testing conditions. It should be noted that in the previous tests the maximum MTG+HRU+DFDD efficiency for an MTG output of 20 kW (68,288 Btu/h) and temperatures of 85/75.8^{o}F (29.4/24.3^{o}C) was around 58% compared to approximately 59% determined in this study. The loss in LC is compensated by the gain in the Q_{HRU}, assuming energy values being the same. The addition of the indirect-fired single-effect AC to the system reduces the IES efficiency to 46.0-47.7%. This is due to the single-effect AC's COP of approximately 0.7.

Basically, with an MTG power output of 20-23 kW (68,288.0-78,531.8 Btu/h), the addition of DFDD increases the overall IES (MTG + HRU + AC) efficiency by 4-5%. For an MTG power output of 15 kW (51,182 Btu/h) the increase is only 2%.

To achieve better overall IES efficiency, the thermal ducting losses should be minimized. These losses between MTG/HRU and HRU/DFDD were estimated to be approximately 6% and 0.3% respectively. It should be noted that these losses could be minimized in a packaged system with minimal ducting.

In addition, a better match between the exhaust volume of the MTG and the regeneration air flow rate of the DFDD would also improve the overall IES efficiency. This improvement was estimated to be approximately 8% (IES efficiency increase from 59% to 67%) with LC of approximately 60,441 Btu/h.

Combined Test Results

Results of the tests performed at 15 kW (51,182 Btu/h) MTG power output and with the DFDD 85/75.8^{o}F (29.4/24.3^{o}C) dry/wet-bulb temperature are presented in Figs 7-9. Activation of the DFDD gas burner inevitably increases the LC from about 13,958.6 Btu/h (4.1 kW) up to 101,835.8 Btu/h (29.8 kW). It takes about 40 minutes for the DFDD to get to its steady-state condition when the unit is switched from exhaust-fired to combined mode of operation (Fig. 7). From Fig. 8, there is a good LC balance: the difference between "baseline" + "exhaust-fired" LC and "combined" LC is 3.4%. The LCOP during the combined mode of operation turns out to be almost the same as the "baseline" LCOP (Fig. 9).

CONCLUSIONS

Performance of the commercially available direct-fired desiccant dehumidification unit, which is one of the main components of the ORNL IES Laboratory, was conducted for various process and regeneration conditions. The maximum baseline LC and LCOP were found to be 95,263.1 Btu/h (27.9 kW) and 57.1%, respectively, at the higher dew-point condition.

Addition of the DFDD with combined operation increased overall IES (MTG + HRU + AC) efficiency up to 48.4% which is almost 8% higher than achieved without the DFDD (40.6%). But this mode of operation should be implemented with caution since conventional filters installed at the regeneration inlet before the combustion chamber are not resistant to high temperatures and can be easily damaged by the exhaust flow from the HRU. In addition, desiccant material temperature restrictions made it impossible to operate this system at steady-state condition at the higher MTG power output. This restriction resulted in lower efficiencies for the other IES components.

In the exhaust-fired tests, the use of the MTG exhaust gas (what remains after passing through the air-to-water HRU) to drive the DFDD at maximum MTG power output results in an almost 3-fold decrease in the LC as compared with the baseline data. This is due to mismatch between the exhaust gas

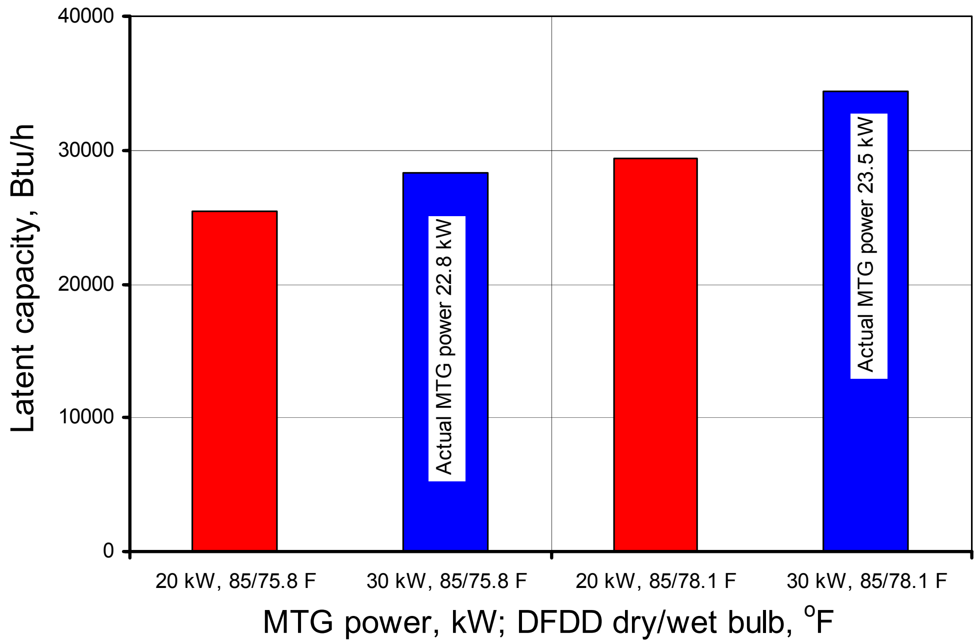

Figure 4. Effect of MTG Power Output and DFDD Inlet Conditions on DFDD Latent Capacity.

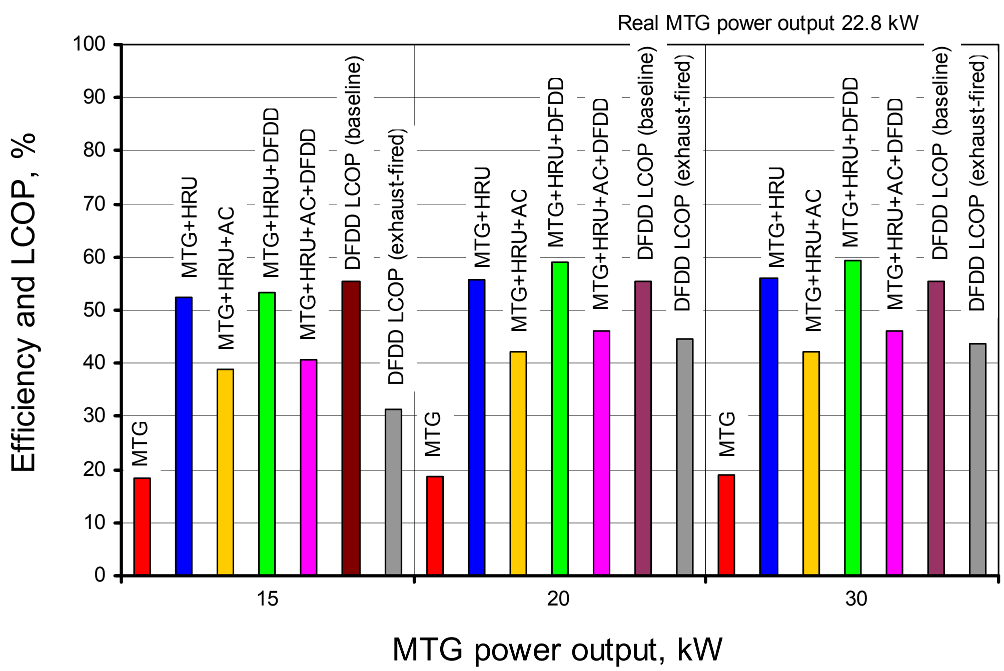

Figure 5. Effect of MTG Power Output on the DFDD's LCOP and Efficiencies of Different IES Arrangements (DFDD air inlet dry/wet bulb parameters 85/75.8°F or 29.4/24.3°C)

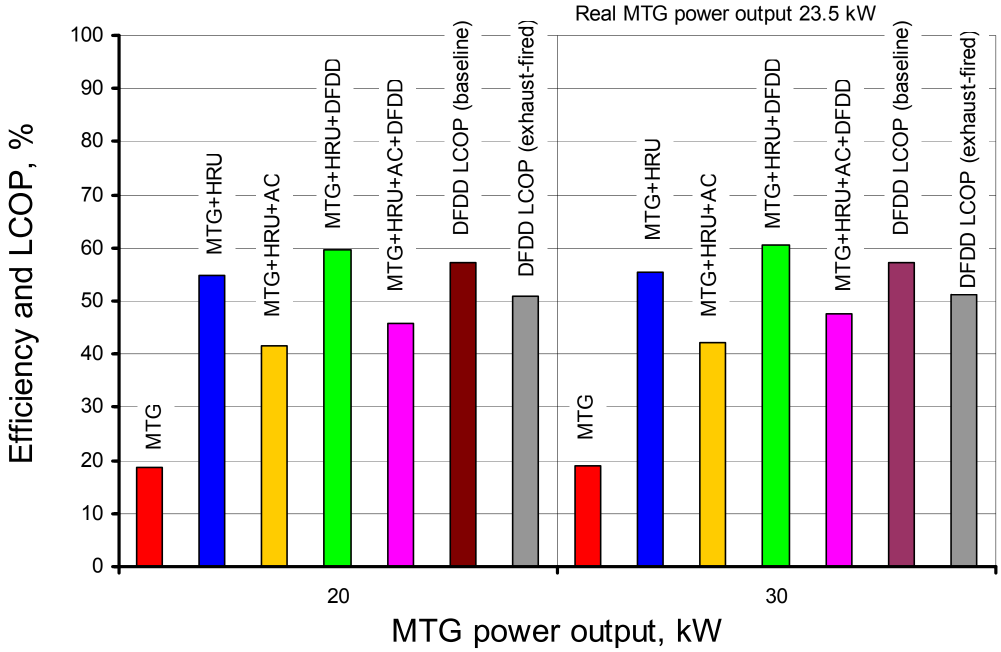

Figure 6. Effect of MTG Power Output on the DFDD's LCOP and Efficiencies of Different IES Arrangements (DFDD air inlet dry/wet bulb parameters 85/78.1°F or 29.4/25.6°C)

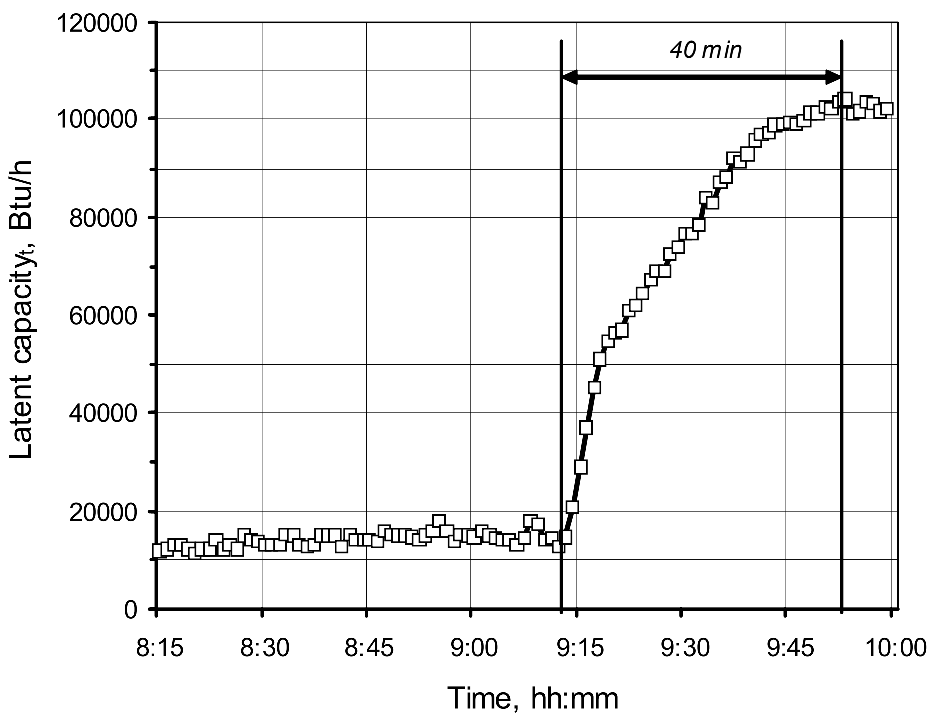

Figure 7. Dynamic Transition from Indirect-Fired to Combined Mode of DFDD Operation (MTG power output 15 kW or 51182 Btu/h, DFDD air inlet dry/wet bulb parameters 85/75.8°F or 29.4/24.3°C)

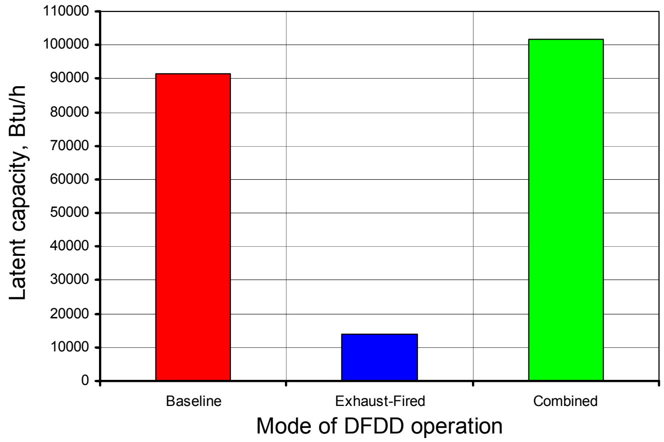

Figure 8. Latent Capacity of DFDD with Different Modes of Operation (MTG power output 15 kW or 51182 Btu/h, DFDD air inlet dry/wet bulb parameters 85/75.8^{o}F or 29.4/24.3^{o}C)

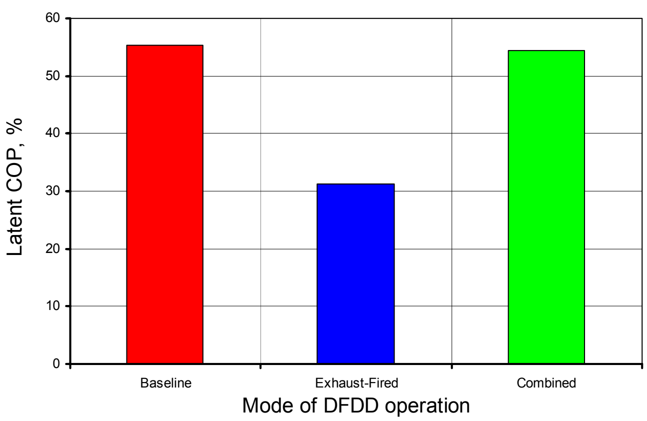

Figure 9. Latent COP of DFDD with Different Modes of Operation (MTG power output 15 kW or 51182 Btu/h, DFDD air inlet dry/wet bulb parameters 85/75.8^{o}F or 29.4/24.3^{o}C)

flow rate of the MTG and the regeneration gas flow rate of the DFDD. The volume of exhaust gas from the MTG is not enough to run the regeneration side of the DFDD. Thus, the exhaust gas was mixed with outside air that had almost the same inlet conditions as the process stream. This resulted in a lower regeneration temperature which in turn caused a decrease in the LC. It should be noted that a better match between the exhaust volume of the MTG and the regeneration air flow rate of the DFDD would have resulted in an increase in the overall IES efficiency. This improvement was estimated to be approximately 8% (IES efficiency increase from 59% to 67%).

The maximum efficiency (around 60%) is achieved with an IES consisting of an MTG, HRU, and DFDD. Integration of the DFDD into an IES that consists of the MTG, HRU, and an absorption chiller (AC), increases the overall IES efficiency by 4-5%. This results in an overall IES efficiency of 46.0-47.7%, based on the HHV of the natural gas. The lower overall efficiency is mainly due to the COP of the single-effect AC which is approximately 0.7. However, this would provide the end-user with another useful product – cooling.

The combination of an exhaust-fired mode and direct burning of natural gas for DFDD operation resulted in the maximum LC (101,835.8 Btu/h or 29.8 kW). It is almost 7 times higher than the LC produced during exhaust-fired operation and exceeds the baseline value for the same air inlet conditions. Also, integration of the DFDD into an IES that consists of an MTG, HRU, and AC, increases the overall IES efficiency by 8%. But this mode of operation should be implemented with caution, because conventional filters installed at the regeneration inlet before the gas chamber are not resistant to high temperatures and can be easily damaged by the exhaust flow after the HRU.

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