Analysis of a DDGS Air-Drying System with heat recovery

by

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Table of Contents

ABSTRACT

Dry Distiller Grains with Soluble (DDGS) are a co-product of the conversion from corn into Ethanol fuel. Several applications depend on the ability of a drying process to remove moisture from a product, such as DDGS, in an effective and economical manner. Common drying methods use air to facilitate product drying as it proficiently absorbs the unwanted moisture, creating a moist-air mixture that captures both the latent and sensible heat released from the product. The most economical approach to an Air Drying System integrates a heat recovery system that transfers the heat removed by the moist-air mixture during drying back into the drying system before rejecting the moist-air mixture out of the system. The ability to condense moisture out of the moist-air mixture represents the potential energy available for recovery in the heat recovery system.

The DDGS Drying System analyzed in this study includes four separate components, namely the DDGS Heater, the Intermediate Water Loop, the Air Drying Unit, and the Heat Recovery Unit. The DDGS Heater raises the product's temperature from ambient conditions to drying conditions, while the Air Drying Unit supplies air to the product after it exits the Product Heater to initiate the drying process. The Heat Recovery Unit takes the air exiting from the Air Drying Unit and removes the heat rejected from the drying process by condensing the moisture out of the air stream. The Intermediate Water Loop connects the Product Heater and the Heat Recovery Unit through a system of water piping and heat exchangers. The Intermediate Loop receives heat from the Heat Recovery Unit and then uses an External Heater to raise the loop water up to operating conditions. Once reaching operating conditions, the loop expels heat to the DDGS Heater and then returns to the Heat Recovery Unit to start the process over again.

Energy and mass balances around the major components listed above provide a model for the DDGS Drying System. The DDGS Flow Rate, DDGS Entering Moisture Content and Operation Temperature dictate the performance of the system. Either ambient/operation temperatures or approach temperature differences specify the states of each component in the drying system. Theses approach temperature differences represent the inefficiencies

in heat transfer that occur throughout the drying system. The model adjusts the Air Flow Rate and the Loop Water Flow Rate to maintain the state temperatures specified for each component of the drying system.

This project encompassed several objectives. The first object included the creation of a theoretical model that depicts the behavior and performance of an Air Drying System that utilizes a heat recovery process. The second objective involved utilizing this model to ascertain the theoretical behavior of the system as its inputs vary. The third objective incorporated the theoretical behavior of the model with the variation of the inputs to establish the theoretical performance of the modeled Air Drying System.

The fourth objective of this project included the use of experimental data to compare and contrast the similarities and differences between this data and the theoretical model. The fifth and last objective of this project included the use of the established behavioral metrics to provide operational guidelines for experimental use.

This analysis showed that the DDGS Flow Rate and DDGS Entering Moisture Content controlled the System Behavior, while the Operation Temperature dictated the System Performance. Analysis of the Experimental Data showed that the experimental data followed the trends established in the theoretical model. It also showed a 17.5 °F Theoretical Approach Temperature Difference accurately simulated the experimental system analyzed, with the main source of inefficiency being the interactions between the DDGS product and Intermediate Water Loop. Lastly, the analysis yielded to dimensionless ratios that provide Operation Guidelines to possible improve system performance. Specifically, the model formulated ratios for the Air to DDGS product and Intermediate to DDGS product flow rates that are a function of DDGS Entering Moisture Content.

CHAPTER 1: INTRODUCTION

Dry Distiller Grains with Soluble (DDGS) are a co-product of the conversion from corn into Ethanol fuel. Several applications depend on the ability of a drying process to remove moisture from a product, such as DDGS, in an effective and economical manner. Common drying methods use air to facilitate product drying as it proficiently absorbs the unwanted moisture, creating a moist-air mixture that captures both the latent and sensible heat released from the product. The most economical approach to an Air Drying System integrates a heat recovery system that transfers the heat removed by the moist-air mixture during drying back into the drying system before rejecting the moist-air mixture out of the system. The ability to condense moisture out of the moist-air mixture represents the potential energy available for recovery in the heat recovery system.

This project encompasses several objectives. The first object includes the creation of a theoretical model that depicts the behavior and performance of an Air Drying System that utilizes a heat recovery process. The second objective involves utilizing this model to ascertain the theoretical behavior of the system as its inputs vary. The third objective incorporates the theoretical behavior of the model with the variation of the inputs to establish the theoretical performance of the modeled Air Drying System.

The fourth objective of this project includes the use of experimental data to compare and contrast the similarities and differences between this data and the theoretical model. The fifth and last objective of this project includes the use of the established behavioral metrics to provide operational guidelines for experimental use. This report includes a description, analysis and discussion of the objectives expressed above.

CHAPTER 2: THEORETICAL SYSTEM MODEL DESCRIPTION

The drying system analyzed and evaluated in this study applies to solid products that require moisture removal. The system proposed herein recovers the heat consumed during the solid product drying by transferring the energy from the water vapor removed from the product along with the heat used to raise the product to drying temperatures to a heat recovery system. As shown in Figure 1 below, the system consists of four major components: namely, a Product Heater, a Heat Recovery Unit, an Air Drying Unit and an External Heater.

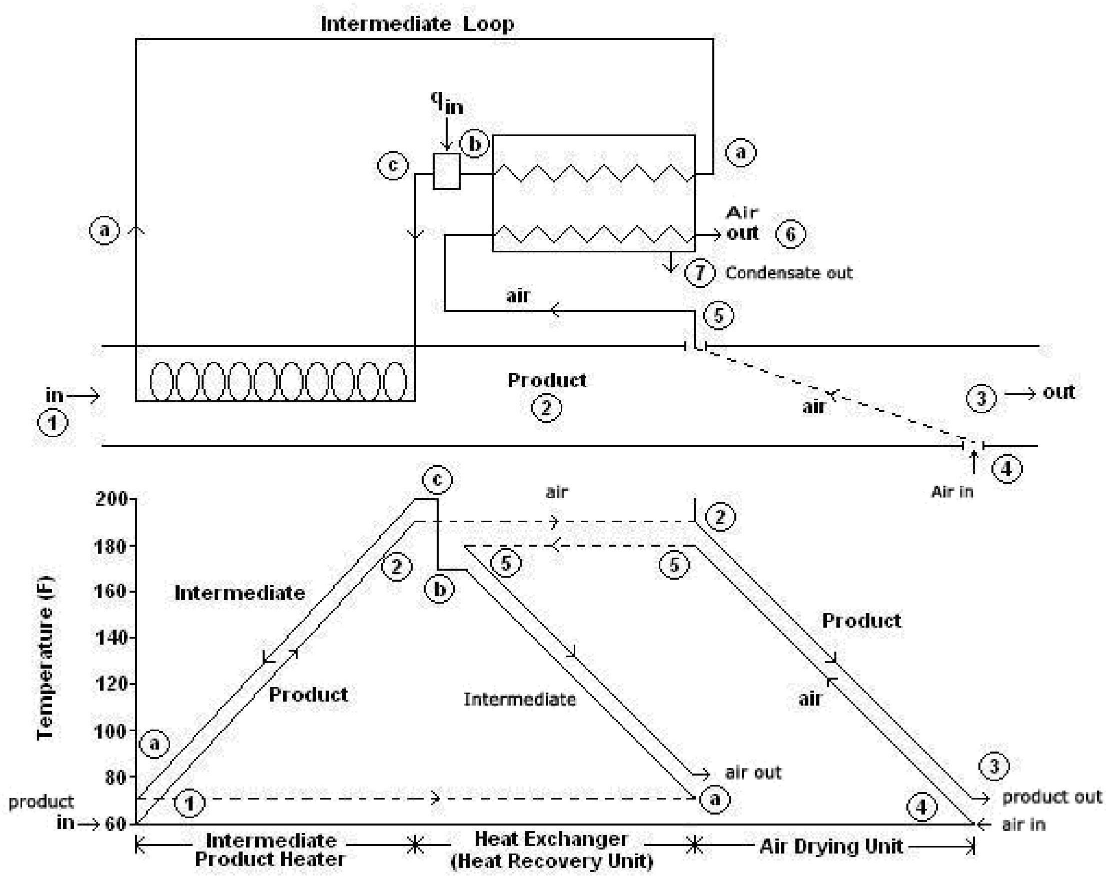

Figure 1: System Schematic and Temperature Plot

Product Heater

The product heater uses an intermediate water loop to supply heat to the product in order to evaporate moisture and hence dry the product. Figure 2 shows a schematic of the Product Heater.

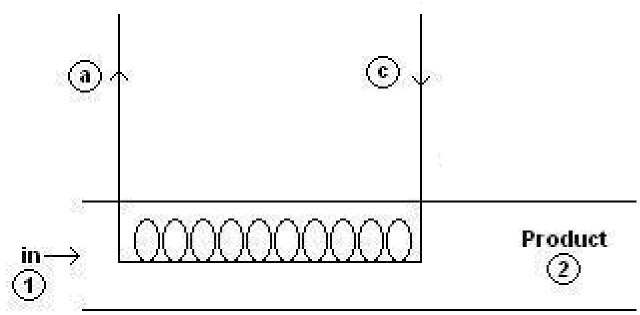

Figure 2: Product Heater Schematic

The product enters the product heater at ambient conditions at State 1 and heat transferred from the intermediate loop water raises the product's temperature to exit conditions at state 2. The intermediate water loop enters the Product Heater at the Operation Temperature at State c. Heat transfers from the intermediate loop to the DDGS product and the intermediate loop water temperature drops to its exit temperature at State a.

A mass balance around the Product Heater shows that the Dry Grain Flow Rate ($\dot{m}_g$) and Grain Moisture Flow Rate ($\dot{m}_w$) remain constant. The Intermediate Loop Water Flow Rate ($\dot{m}_{loop}$) remains constant in all of the drying system components including the Product Heater. The expressions below summarize the mass balances for this component.

$$\dot{m}_g = \text{constant} \qquad (1)$$

$$\dot{m}_w = \text{constant} \qquad (2)$$

$$\dot{m}_{loop} = \text{constant} \qquad (3)$$

Equation 4 below shows an energy balance around the Product Heater.

$$\dot{m}_g cp_g T_1 + \dot{m}_w h_{f,1} + \dot{m}_{loop} h_{f,c} = \dot{m}_g cp_g T_2 + \dot{m}_w h_{f,2} + \dot{m}_{loop} h_{f,a} \text{ .} \tag{4}$$

The Product Heater raises the temperature of the Dry Grain from T_1 to T_2 and the balance of the $\dot{m}_g cp_g T_1$ term and the $\dot{m}_g cp_g T_2$ term captures the latent heat required to facilitate this change. Additionally, the Product Heater raises the temperature of the Grain Moisture from T_1 to T_2. The balance of the $\dot{m}_w h_{f,1}$ term and the term $\dot{m}_w h_{f,2}$ denotes the latent heat required for this increase in temperature. Lastly, the Product Heater removes heat from the Intermediate Water Loop, which is accounted for by the balance of the $\dot{m}_{loop} h_{f,c}$ and the $\dot{m}_{loop} h_{f,a}$ terms. The loss in heat causes the temperature of the intermediate water to fall from T_c to T_a. The mass and energy balances derived above create the foundation for the numerical model of the Product Heater.

Air Drying Unit

The Air Drying Unit uses ambient air to remove moisture from the heated product and transfer it to the Heat Recovery Unit. This component extracts all of the moisture available for removal and the model assumes the system removes no moisture before or after this component. Figure 3 shows a schematic of the Air Drying Unit.

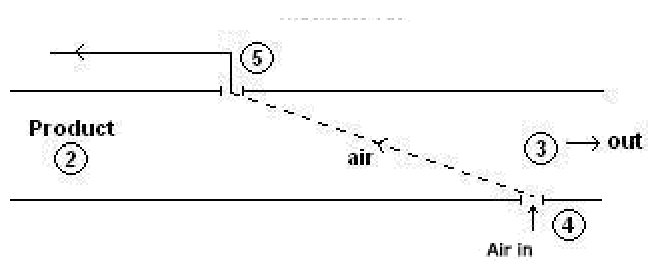

Figure 3: Air Drying Unit Schematic

The product enters the Air Drying Unit from the Product Heater at State 2. Ambient moist air entering at state 4 evaporates moisture from the product as well as removes sensible heat from the product and exits as a heated moist air at state 5. The cool dried DDGS product proceeds to exit the Air Drying Unit at state 3.

The DDGS Drying System models the moist air that travels through the Air Drying Unit using psychometric air principles with an entering humidity ratio (ω_4) and exiting humidity ratio (ω_5). A mass balance around the Air Drying Unit shows that the Air Flow Rate ($\dot{m}_{air}$) and Dry Grain Flow Rate ($\dot{m}_g$) remain constant. The balance between the entering Grain Moisture Flow Rate ($\dot{m}_w$) and the exiting Grain Moisture Flow Rate ($\dot{m}_{w,out}$) account for the changes in moisture mass between the DDGS product and moist air stream in the Air Drying Unit. The expressions below express the mass balances described above.

$$\dot{m}_{air} = \text{constant} \qquad (5)$$

$$\dot{m}_g = \text{constant} \qquad (6)$$

$$\dot{m}_w + \dot{m}_{air}\omega_4 = \dot{m}_{w,out} + \dot{m}_{air}\omega_5 \qquad (7)$$

$$\dot{m}_{dried} = \dot{m}_w - \dot{m}_{w,out} \qquad (8)$$

Equation 9 below shows an energy balance around the Air Drying Unit.

$$\dot{m}_g cp_g T_2 + \dot{m}_w h_{f,2} + \dot{m}_{air} h_{a,4} + \dot{m}_{air}\omega_4 h_{g,4} = \dot{m}_g cp_g T_3 + \dot{m}_{w,out} h_{f,3} + \dot{m}_{air} h_{a,5} + \dot{m}_{air}\omega_5 h_{g,5} \qquad (9)$$

The Air Drying Unit transfers sensible heat from the DDGS product to the incoming air stream. A balance of the $\dot{m}_g cp_g T_2$ term and the $\dot{m}_g cp_g T_3$ term accounts for the loss in sensible heat of the Dry Grain as it progresses from T_2 to T_3. Additionally, a balance of the $\dot{m}_w h_{f,2}$ term and the $\dot{m}_{w,out} h_{f,3}$ accounts for the loss in sensible heat of the Grain Moisture not removed from the product as it goes from T_2 to T_3 . Similarly, a balance of the $\dot{m}_{air} h_{a,4}$ term and the $\dot{m}_{air} h_{a,5}$ account for the sensible heat gain by the incoming moist air stream as it progresses from T_4 to T_5. Lastly, a balance of the $\dot{m}_{air}\omega_4 h_{g,4}$ term with the $\dot{m}_{air}\omega_5 h_{g,5}$ term account for the latent heat associated with the evaporation of the Grain Moisture. The energy and mass balances described above provide the basis for the numerical model of the Air Drying Unit.

Heat Recovery Unit

The Heat Recovery Unit transfers heat to the intermediate loop by condensing the moisture removed from the product while cooling the air stream down to near ambient conditions. Figure 4 below displays a schematic of the Heat Recovery Unit.

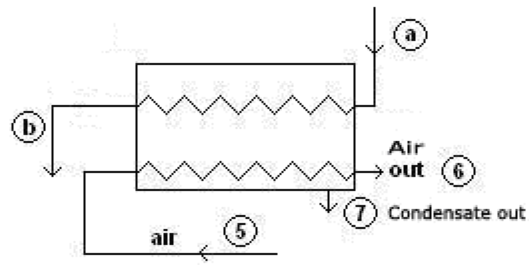

Figure 4: Heat Recovery Unit Schematic

The Intermediate Loop Water enters the Heat Recovery Unit from the Product Heater at State a. Meanwhile, the moist air mixture from the Air Drying Unit enters the Heat Recovery Unit at State 5. The air-moisture mixture transfers heat to the Intermediate Loop, which cause moisture to condense from the air-moisture stream. This condensate water exits the Heat Recovery Unit at state 7. The remaining moist air mixture exits the Heat Recovery Unit at state 6. The Intermediate Loop Water receives the heat transferred from the air-moisture mixture and exits the Heat Recovery Unit at state b.

Again, the DDGS Drying System models the moist air that travels through the Heat Recovery Unit using psychometric air principles with an entering humidity ratio (ω_5) and exiting humidity ratio (ω_6).A mass balance around the Air Drying Unit shows that the Air Flow Rate ($\dot{m}_{air}$) and Intermediate Loop Water Flow Rate ($\dot{m}_{loop}$) remain constant. The balance between the water vapor present in the moist air at the entrance ($\dot{m}_{air} w_5$) and the water vapor present in the moist air at the exit ($\dot{m}_{air} w_6$) account for the mass of moisture condensed from moist air stream ($\dot{m}_{w,cond}$) in the Heat Recovery Unit. The expressions below express the mass balances described above.

$$\dot{m}_{air} = \text{constant} \qquad (10)$$

$$\dot{m}_{loop} = \text{constant} \qquad (11)$$

$$\dot{m}_{air} w_5 = \dot{m}_{air} w_6 + \dot{m}_{w,cond} \qquad (12)$$

Equation 13 below expresses the energy balance around the Heat Recovery Unit

$$\dot{m}_{air} h_{a,5} + \dot{m}_{air} \omega_5 h_{g,5} + \dot{m}_{loop} h_{f,a} = \dot{m}_{air} h_{a,6} + \dot{m}_{air} \omega_6 h_{g,6} + \dot{m}_{loop} h_{f,b} + \dot{m}_{cond} \cdot h_{f,7} \qquad (13)$$

The Heat Recovery Unit transfers the latent heat from the water vapor condensed from the moist air stream along with the sensible heat lost due to the temperature drop in the Heat Recovery Unit to the Intermediate Loop Water. A balance of the $\dot{m}_{air} h_{a,5}$ term with the sum of the $\dot{m}_{air} h_{a,6}$ and $\dot{m}_{cond} \cdot h_{f,7}$ terms accounts from the sensible heat removed from the moist air as its temperature drops from T_5 to T_6.The model assumes the temperature of the condensation (T_7) equals the temperature of the moist air exiting the Heat Recovery Unit (T_6). A balance of the $\dot{m}_{air} \omega_5 h_{g,5}$ term with the $\dot{m}_{air} \omega_6 h_{g,6}$ term accounts for the latent heat energy transferred from the moist air to the Intermediate Loop Water. A balance of the $\dot{m}_{loop} h_{f,a}$ term with the $\dot{m}_{loop} h_{f,b}$ term accounts for the total energy received by the Intermediate Loop from the moist air exiting the Heat Recovery Unit. The relationships discussed above provide the basis for the numerical model of the Heat Recovery Unit.

External Heater

The Heat Recovery Unit cannot recover all of the energy utilized in the Product Heater; therefore, the system needs an External Heater to provide the additional heat required to raise the loop water temperature from the intermediate loop water temperature at the exit of the

Heat Recovery unit at State 5 to its Operation Temperature at State 6. Figure 5 below shows a schematic of the External Heater.

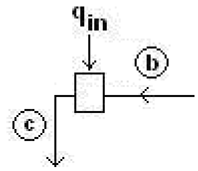

Figure 5: Schematic of the External Heater

In the External Heater, the Intermediate Loop Water Flow Rate ($\dot{m}_{loop}$) remains constant, while an energy balance between State 5 and State 6 determines the required amount of external heat ($\dot{Q}_{heater}$). The equations shown below illustrate the mass and energy balances discussed above.

$$\dot{m}_{loop} = \text{constant} \tag{14}$$

$$\dot{Q}_{heater} = \dot{m}_{loop}\left(h_{f,c} - h_{f,b}\right) \tag{15}$$

System Assumptions

The theoretical model analysis in this project uses several assumptions to analysis the provided DDGS Drying System. This section discusses these assumptions and provides insight on why these assumptions where chosen.

Moisture Content of Product

The moisture content of DDGS is usually specified on a wet mass basis, meaning the percent of total moist DDGS mass that is liquid water. In this study and analysis, the symbol Z is used to represent the percent moisture content in corn on a wet mass basis as follows

$$Z = \frac{lbw}{lbw + lbg} = \frac{m_w}{m_w + m_g} \tag{16}$$

where m_w = lbw = water mass (i.e., moisture) and m_c = lbg = dry DDGS mass. Even though DDGS moisture is specified on a wet mass basis, it is often desirable to base calculations on a dry mass basis, which is the ratio of water mass (i.e. moisture) to dry corn mass as follows

$$X = \frac{lbw}{lbg} = \frac{m_w}{m_g} \qquad (17)$$

Relationships can be derived that allows one to convert from a wet mass basis to a dry mass basis and vice versa. For example, to determine Z from X, the equations are derived as follows starting with

$$Z = \frac{m_w}{m_w + m_g} \qquad (18)$$

then

$$\frac{1}{Z} = \frac{m_w + m_g}{m_w} = 1 + \frac{m_g}{m_w} \qquad (19)$$

and since

$$X = \frac{m_w}{m_c} \qquad (20)$$

then

$$\frac{1}{Z} = 1 + \frac{1}{X} \qquad (21)$$

which upon rearranging becomes,

$$Z = \frac{X}{X + 1} \qquad (22)$$

In order to calculate X from Z, the 1/Z equation can be rearranged to solve for X,

$$\frac{1}{Z} - 1 = \frac{1}{X} \qquad (23)$$

so that

$$X = \frac{Z}{1 - Z} \qquad (24)$$

Dry Product Specific Heats

The model uses the specific heat determined for corn as a source of data for the specific heat of DDGS product. Therefore, it is desirable to determine the dry corn specific heat and hence the dry DDGS product specific heat because it is a key parameter in the formulated energy equations derived earlier in this study. Table 1 below shows specific heats for moist corn (i.e., water mass and dry corn mass combined) as a function of moisture content based on a wet mass basis (communication with Steve Shivvers). These wet mass percents, Z, have been converted to dry mass percents, X, and the resulting values are shown in the second column of the table.

Table 1: Calculated Values for Dry Corn Specific Heat

Moisture Content		Specific Heat	Dry Corn Specific Heat
Z = wet basis	X = dry basis	Btu/lb F	Btu/lb F
5.10%	5.37%	0.404	0.372
9.80%	10.86%	0.438	0.377
20%	25%	0.531	0.414
30%	42.86%	0.588	0.411

The procedure presented below shows the method for finding the specific heat of dry corn by mass weighting the water (w = water) and dry grain (c = corn) specific heats in order to determine the specific heat of the moist corn (t = total). For example, if the mass weighted equation for moist corn specific heat is:

$$m_t c_{pt} = m_w c_{pw} + m_c c_{pc} \qquad (25)$$

Upon rearrangement it becomes,

$$m_t c_{pt} - m_w c_{pw} = m_c c_{pc} \qquad (26)$$

then,

$$c_{pc} = \frac{m_t c_{pt} - m_w c_{pw}}{m_c}$$

$$c_{pc} = \frac{m_t}{m_c} c_{pt} - \frac{m_w}{m_c} c_{pw} \qquad (27)$$

$$c_{pc} = \frac{1}{1-Z} c_{pt} - X c_{pw}$$

where

$$1 - Z = \frac{m_t}{m_t} - \frac{m_w}{m_t} = \frac{m_c}{m_t} \qquad (28)$$

The values for dry corn specific heat shown in the previous table are found from the equations above, and they are shown to be within 10% of each other, which could represent the experimental error associated with measuring moist-corn specific heat. Since the moisture content of the moist DDGS in this study ranges from 20% to 40%; the 20%, and 30% moisture content data points were used to obtain an average dry-corn specific heat of 0.4 Btu/ lb °F. This average value is within 5% of all four data points shown in the table above.

Another source states that the specific heat for corn with a moisture content of 15% on a wet mass basis is 0.486 Btu/lb°F (communication with Steve Shivvers). Using the same procedure as before to determine the dry corn specific heat, results in

$$c_{pc} = \frac{1}{1-0.15}0.486 - 0.176 \times 1$$
$$c_{pc} = 0.396\frac{Btu}{lb^{0}F} \qquad (29)$$

This value of 0.396 Btu/lb°F is approximately 0.4 Btu/lb°F, which verifies the data and procedure for finding an approximate dry corn specific heat.

The discussion above proves the value of 0.4 Btu/lb°F for the dry corn specific heat is an acceptable value and it will be used as the dry DDGS specific heat for the DDGS Drying System analyzed in this project.

Approach Temperature Difference

In any heat transfer process that uses a medium to transfer heat between substances, there is a limit to the how close the temperature of the colder substance can come to the temperature of hotter substance due to losses in the medium itself. When analyzing a theoretical system, it is important to account for these losses in order to improve the accuracy of the simulation. The magnitudes of theses losses can vary greatly from process to process due to many factors include the configuration, materials of construction, etc, therefore it is convenient to model these losses as a limit on the extent that the colder substance temperature can reach the hotter substance temperature. The Approach Temperature Difference ($\Delta T_{Approach}$) describes the minimum difference between the hot substance temperature and cold substance temperature that must be maintained at that point in the heat transfer process. In this project, uniform Approach Temperature Differences between all heat exchangers were specified for the theoretical model. This uniform Approach Temperature Difference represents the minimum temperature difference between the substances traveling through a heat exchanger in the system.

System Pressures

For simplicity, this analysis assumes that the pressures of moist air and DDGS product remain at a constant atmospheric value of 14.7 psi regardless of their location in the DDGS drying system. The Intermediate Loop analysis assumes a pressure value of 50 psi in order to prevent phase change in the intermediate loop water from occurring during simulation. This step is necessary to maintain the validity of the energy equations for each system component derived earlier in this section.

State Characteristics

State 1 (Product): Product Heater Entrance

The product enters the DDGS Drying system at State 1. At this state, the theoretical model assumes the Dry DDGS Grain and DDGS Moisture, modeled as liquid water, enter at ambient temperature and pressure. These parameters provide a means to find Enthalpy values for liquid water at this state. The equations shown below present the parameters discussed above.

$$T_1 = T_{ambient} \qquad (30)$$

$$h_{f,1} = h\left(H_2O, T_1, P\right) \qquad (31)$$

State 2(Product): Product Heater Exit / Air Drying Unit Entrance

State 2 describes the transition of the DDGS product for the Product Heater exit to the Air Drying Unit entrance. The theoretical model assumes that State 2 maintains a temperature based on the heat exchange between the DDGS product and the Intermediate Loop, which becomes the Operation Temperature minus the Approach Temperature Difference. The temperature of State 2 (T_2) provides the information needed to calculate the saturation pressure at this state ($P_{sat,2}$). The State 2 temperature (T_2) and the System Pressure (P)

supply the needed information to find the Enthalpy of liquid water at this state ($h_{f,2}$). Meanwhile, The State 2 temperature (T_2) and the Saturation Pressure ($P_{sat,2}$) provide the needed information to find the Enthalpy of saturated vapor at this state ($h_{g,2}$). The equations provided below show the state characteristics discussed above.

$$T_2 = T_{operation} - \Delta T_{approach} \quad (32)$$

$$P_{sat,2} = P_{sat}\left(H_2O, T_2\right) \quad (33)$$

$$h_{f,2} = h\left(H_2O, T_2, P\right) \quad (34)$$

$$h_{g,2} = h\left(H_2O, T_2, P_{sat,2}\right) \quad (35)$$

<u>State 3(Product): Air Drying Unit Exit</u>

State 3 is where the DDGS product exits the Air Drying Unit. The theoretical model assumes that State 3 maintains a temperature based on the heat exchange between the DDGS product and incoming moist air, which becomes the Ambient Temperature plus the Approach Temperature Difference. The State 3 temperature (T_3) and the System Pressure (P) supply the needed information to find the Enthalpy of liquid water at this state. The equations shown below show the state characteristics discussed above.

$$T_3 = T_{ambient} + \Delta T_{approach} \quad (36)$$

$$h_{f,3} = h\left(H_2O, T_3, P\right) \quad (37)$$

<u>State 4(Air): Air Drying Unit Entrance</u>

The theoretical model assumes an ambient temperature and pressure for the moist air entering the Air Drying Unit at State 4. The model assumes a relative humidity (ϕ_4) for the moist air of 50%. The model calculates the enthalpy of air ($h_{a,4}$) based on the State 4 temperature (T_4) and the System Pressure (P). It calculates a humidity ratio based on the State 4 temperature (T_4) the System Pressure (P) and the State 4 relative humidity (ϕ_4).The temperature of State 4 (T_4) provides the information needed to calculate the saturation pressure at this state ($P_{sat,4}$). Meanwhile, The State 4 temperature (T_4) and the Saturation Pressure ($P_{sat,4}$) provide the needed information to find the Enthalpy of saturated vapor at this state ($h_{g,4}$). The equations provided below show the state characteristics discussed above.

$$T_4 = T_{ambient} \quad (38)$$

$$\phi_4 = 50\% \quad (39)$$

$$P_{sat,4} = P_{sat}\left(H_2O, T_4\right) \quad (40)$$

$$h_{g,4} = h\left(H_2O, T_4, P_{sat,4}\right) \quad (41)$$

$$h_{a,4} = h\left(Air_{ha}, T_4, P\right) \quad (42)$$

$$w_4 = w\left(AirH_2O, T_4, \phi_4, P\right) \quad (43)$$

<u>State 5(Air): Air Drying Unit Exit / Heat Recovery Unit Entrance</u>

At this state air exits the Air Drying Unit while carrying water vapor removed from the product during the heating stage. State 5 describes the transition of the moist air form the Air Drying Unit exit to the Heat Recovery Unit entrance. The theoretical model assumes that State 5 maintains a temperature based on the heat exchange between the moist air and the DDGS Product, which becomes the State 2 DDGS product temperature (T_2) minus the Approach Temperature Difference. The model calculates the enthalpy of air ($h_{a,5}$) based on the State 5 temperature (T_5) and the System Pressure (P). The temperature of State 5 (T_5) gives the information needed to calculate the saturation pressure at this state ($P_{sat,5}$).The State 2 temperature (T_2) and the Saturation Pressure ($P_{sat,2}$) provide the needed information to find the Enthalpy of saturated vapor at this state ($h_{g,5}$). The equations provided below show the state characteristics discussed above.

$$T_5 = T_2 - \Delta T_{approach} \quad (44)$$

$$P_{sat,5} = P_{sat}\left(H_2O, T_5\right) \quad (45)$$

$$h_{g,5} = h\left(H_2O, T_5, P_{sat,5}\right) \quad (46)$$

$$h_{a,5} = h\left(Air_{ha}, T_5, P\right) \quad (47)$$

State 6(Moist Air): Heat Recovery Unit Exit

State 6 describes the moist air exit of the Heat Recovery Unit. The theoretical model assumes an ambient temperature plus 2 times the Approach Temperature Difference for the State 6 temperature. It also assumes ambient pressure at this state. The model calculates the enthalpy of air ($h_{a,6}$) based on the State 6 temperature (T_6) and the System Pressure (P).The temperature of State 4 (T_6) provides the information needed to calculate the saturation pressure at this state ($P_{sat,6}$). Meanwhile, The State 6 temperature (T_6) and the Saturation Pressure ($P_{sat,6}$) provide the needed information to find the Enthalpy of saturated vapor at this state ($h_{g,6}$). The equations shown below show the state characteristics discussed above.

$$T_6 = T_{ambient} + 2 \cdot \Delta T_{approach} \quad (48)$$

$$P_{sat,6} = P_{sat}\left(H_2O, T_6\right) \quad (49)$$

$$h_{g,6} = h\left(H_2O, T_6, P_{sat,6}\right) \qquad (50)$$

$$h_{a,6} = h\left(Air_{ha}, T_6, P\right) \qquad (51)$$

<u>State 7(Condensed Liquid): Heat Recovery Unit Exit</u>

The liquid condensed out of the moist air passing through the Heat Recovery Unit exits at this state. State 7 assumes the same temperature as State 6 for simplicity. The State 7 temperature (T_6) and the System Pressure (P) provide enough information to calculate the enthalpy of liquid water at this state ($h_{f,7}$). The equations below show the State 7 characteristics previously discussed.

$$T_7 = T_6 \qquad (52)$$

$$h_{f,7} = h\left(H_2O, T_7, P\right) \qquad (53)$$

<u>State "a" (Loop Water): Product Heater Exit / Heat Recovery Unit Entrance</u>

State "a" represents the transition of the intermediate loop water from the exit of the Product Heater to the entrance of the Heat Recovery Unit. The temperature of state "a" is based on the incoming product temperature (T_1) and is calculated by adding the approach temperature difference ($\Delta T_{approach}$) to the incoming product temperature (T_1). The State "a" temperature (T_a) and the Intermediate Loop Pressure (P_{loop}) supply the necessary information to calculate the enthalpy of liquid water at this state ($h_{f,a}$).The equations provided below contain the state characteristics discussed above.

$$T_a = T_1 + \Delta T_{approach} \qquad (54)$$

$$h_{f,a} = h\left(H_2O, T_a, P_{loop}\right) \qquad (55)$$

State “b” (Loop Water): Heat Recovery Unit Exit / External Heater Entrance

State “b” corresponds to transition from the Heat Recovery Unit exit to the External Heater entrance. The temperature of the moist air entering Heat Recovery Unit (T_5) dictates the temperature at State “b”, which is found by subtracting the approach temperature difference from the State 5 temperature. The State “b” temperature (T_b) and the Intermediate Loop Pressure (P_{loop}) present the information needed to calculate the enthalpy of liquid water at State “b” ($h_{f,b}$). The equations below show the State “b” characteristics previously discussed.

$$T_b = T_5 - \Delta T_{approach} \tag{56}$$

$$h_{f,b} = h\left(H_2O, T_b, P\right) \tag{57}$$

State “c” (Loop Water): External Heater Exit / Product Heater Entrance

State “c” corresponds to the transition between the External Heater exit and the Product Heater entrance. Upon exiting the External Heater, the intermediate loop water reaches the Operation Temperature, which sets the temperature for State “c”. The enthalpy of liquid water at state 3($h_{f,c}$) is found by the State “c” temperature (T_c) and the Intermediate Loop Pressure (P_{loop}). The equations below contain the characteristic for State “c” discussed in this section.

$$T_c = T_{operation} \tag{58}$$

$$h_{f,c} = h\left(H_2O, T_c, P\right) \tag{59}$$

CHAPTER 3: THEORETICAL METRICS OF SYSTEM BEHAVIOR

The analysis of the DDGS Drying System considered the effect of three independent system inputs, namely the system Operation Temperature, DDGS Flow Rate and the DDGS Entering Moisture Content on the drying system's performance. This analysis was performed using Engineering Equation Solver (EES) where two of the inputs were held constant while the third input was varied. To capture the dynamics of this process, the Ambient Temperature was set to 60 °F and the Approach Temperature Difference remained constant at 10 °F. Additionally, the Operation Temperature was varied from 100 to 210 °F, the DDGS Flow Rate was varied from 0 to 5 bushels per hour (bph) and the DDGS Entering Moisture Content was varied from 20 to 40%. From these inputs, the theoretical model calculated several significant outputs, which provided information on the function and characteristics of the drying system. The following sections of this report explain, analyze and discuss these outputs in detail.

Dry Grain Flow Rate

The model analyzed in this study considers the entering DDGS as two streams. One stream consists of dry moisture-free grain, while the other stream is the grain moisture itself represented as a water stream at the entering grain temperature. The Dry Grain Flow Rate ($\dot{m}_g$) is defined as the amount of dry moisture-free DDGS that enters the drying system. According to DDGS data with a dry-basis moisture content of 14.7%, the density of DDGS is 483.3 kg/m^3 or 30.17 lb/ft^3. The total mass of a DDGS bushel (m_{bushel}) is then calculated by multiplying the density of the DDGS product (ρ_{DDGS}) by the volume of a DDGS bushel (V_{Bushel}), which is 1.244 ft^3/bushel. The equations and example calculations below show the calculation of the total mass of a DDGS bushel.

$$m_{bushel} = \rho_{DDGS} V_{Bushel} \qquad (60)$$

$$m_{bushel} = \left(30.17 \frac{lb}{ft^3}\right)\left(1.244 \frac{ft^3}{bushel}\right) \qquad (61)$$

$$m_{bushel} = 37.53 \ \frac{lb}{bushel} \qquad (62)$$

Next, the equation shown below converts the DDGS from a dry basis moisture content of 14.7% to a wet-basis moisture content.

$$Z = \frac{x}{1+x} = \frac{0.147}{1.147} = 0.1282 = 12.82\% \qquad (63)$$

A 14.7% dry basis moisture content yields a wet basis moisture content of 12.82%. Therefore, the mass of dry DDGS per bushel, m_{grain}, is the difference between the total mass per bushel and the mass of moisture per bushel as shown in the equation below.

$$m_{grain} = m_{bushel}\left(1 - Z\right) \qquad (64)$$

$$m_{grain} = 37.53 \ \frac{lb}{bushel}\left(1 - 0.1282\right) \qquad (65)$$

$$m_{grain} = 32.72 \ \frac{lb}{bushel} \qquad (66)$$

The value for mass of dry DDGS bushel of 32.72 lb/bushel is assumed constant for all values of entering moisture content therefore; the Dry Grain Flow Rate ($\dot{m}_g$) can be defined as the mass of dry DDGS (m_{grain}) multiplied by the flow rate of entering DDGS (bph) in bushels/hr as shown in the equation below.

$$\dot{m}_g = m_{grain}\left(bph\right) = 32.72 \frac{lb}{bushel}\left(bph\right) \qquad (67)$$

Figure 6 below plots the relationship between Dry Grain Flow Rate and DDGS Flow Rate.

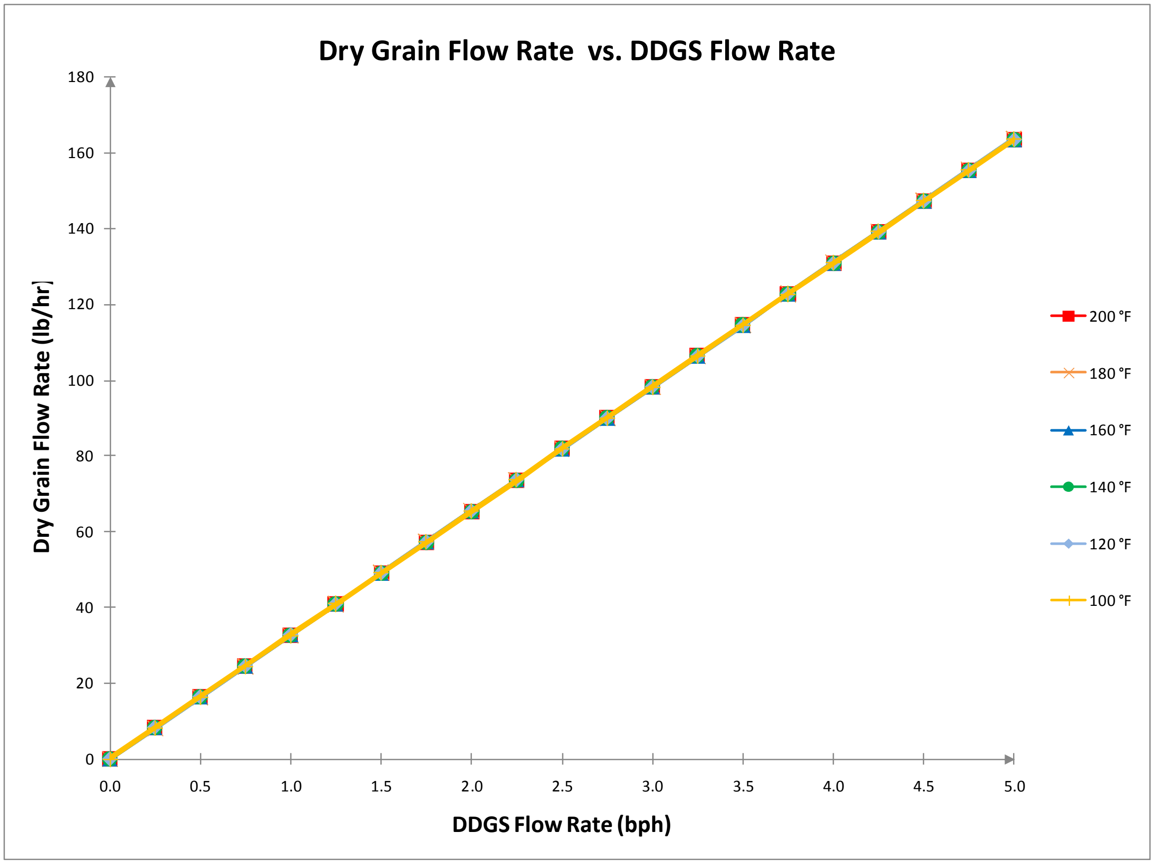

Figure 6: Dry Grain Flow Rate vs. DDGS Flow Rate

The Dry Grain Flow Rate expectedly increases with an increase in DDGS Flow Rate. Since the theoretical system models the incoming DDGS product as two separate streams, one dry grain stream and one liquid water stream, The Dry Grain Flow Rate remains unchanged with changes in the Operation Temperature and DDGS Entering Moisture Content. Table 2 below contains values for the Dry Grain Flow Rte as it varies with DDGS Flow Rate.

Table 2: Calculated Values for Dry Grain Flow Rate

Bph	$\dot{m}_g \ (lb/hr)$
0.00	0.00
0.50	16.36
1.00	32.72
1.50	49.08
2.00	65.45
2.50	81.81
3.00	98.17
3.50	114.50
4.00	130.90
4.50	147.30
5.00	163.60

Grain Moisture Flow Rate

The Grain Moisture Flow Rate ($\dot{m}_w$) is defined as the amount of moisture entrained in the entering DDGS that is modeled as an incoming stream of water. To calculate the Grain Moisture Flow Rate ($\dot{m}_w$), the moisture content of the entering DDGS stream is converted from a wet basis to a dry basis as described earlier in this study. The equation below repeats this conversion again for convenience.

$$x = \frac{Z}{1-Z} \qquad (68)$$

The dry basis moisture content is the ratio of water mass to dry grain mass, therefore, the dry basis percentage can be multiplied by the mass of dry grain per bushel (m_{grain}) to provide the mass of moisture per bushel (m_w) as seen below.

$$m_w = x\left(m_{grain}\right) \qquad (69)$$

The Grain Moisture Flow Rate ($\dot{m}_w$) is found by multiplying the mass of moisture per bushel (m_w) by the DDGS Flow Rate (bph) as shown below.

$$\dot{m}_w = bph\left(m_w\right) \qquad (70)$$

Like the Dry Grain Flow Rate, the Grain Moisture Flow Rate remains independent of the Operation Temperature. However, it is dependant on both DDGS Flow Rate and the DDGS Entering Moisture Content.

Figure 7 shows the relationship between Grain Moisture Flow Rate and DDGS Flow Rate on a 38% wet basis.

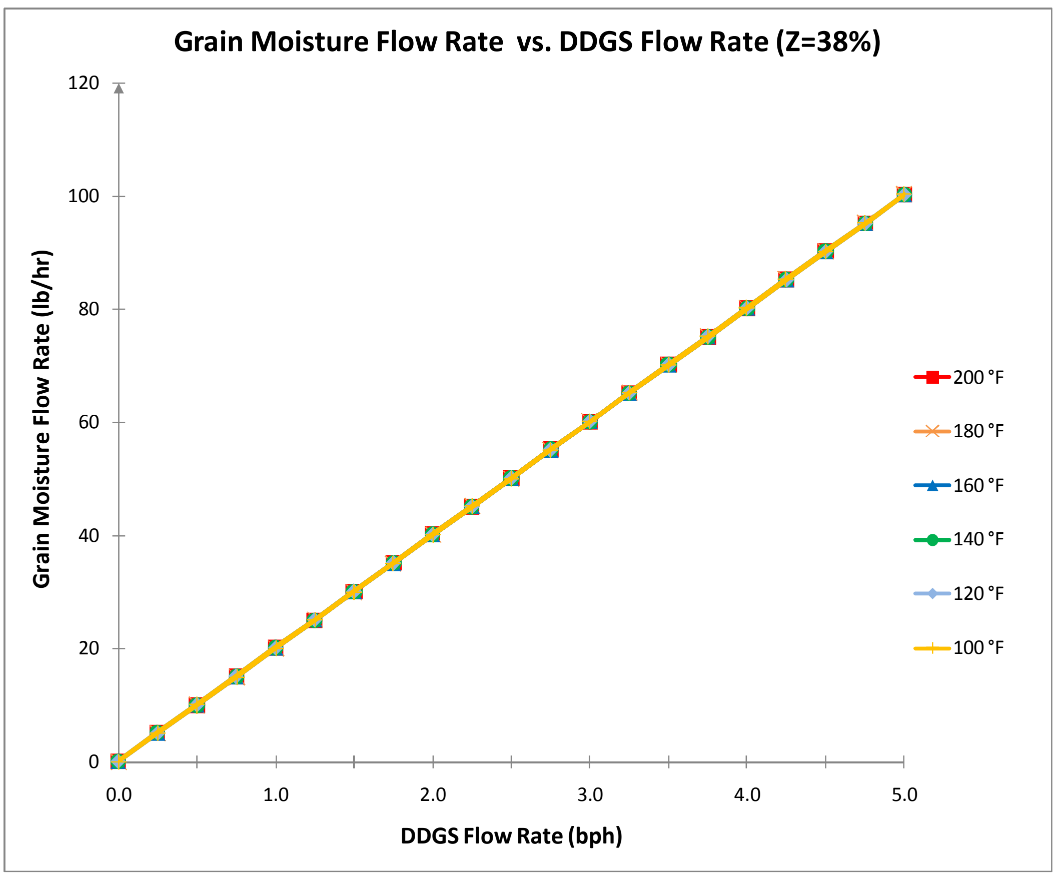

Figure 7: Grain Moisture Flow Rate vs. DDGS Flow Rate

The Grain Moisture Flow Rate increases with DDGS Flow Rate as expected. At 38% Entering Moisture Content, the Grain Moisture Flow Rate increases from 20.06 lb/hr at 1.0 bph to 100 lb/hr at 5.0 bph. This change is of special importance because it will provide insight into the other metrics of performance analyzed later in this section. It is also important to note that the Grain Moisture Flow Rate remains constant over all operating temperatures because it is assumed that no moisture is removed from the product during the heating phase of the process.

The correlation between Grain Moisture Flow Rate and DDGS Entering Moisture Content can be seen in Figure 8 below.

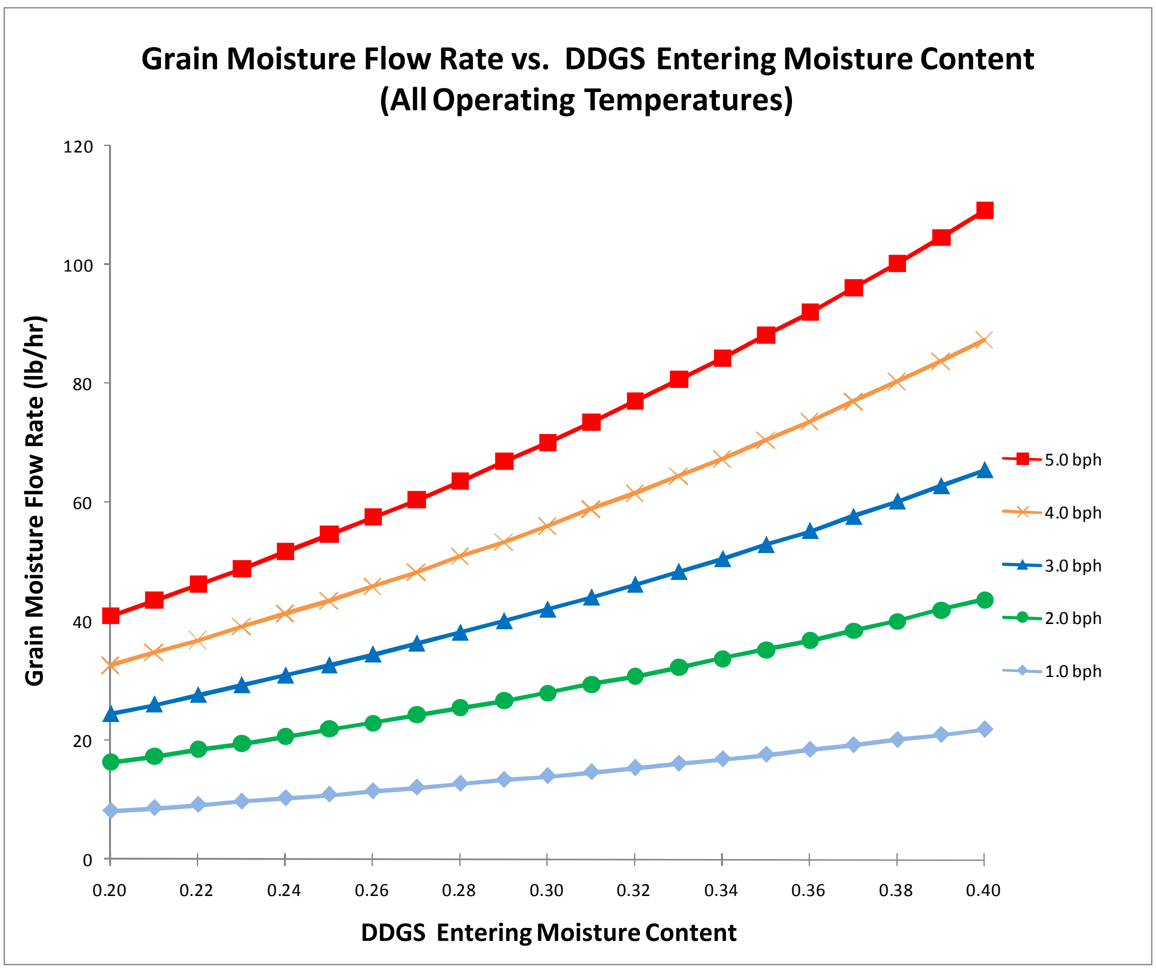

Figure 8: Grain Moisture Flow Rate vs. DDGS Entering Moisture Content

The Grain Moisture Flow Rate increases with an increase in DDGS Entering Moisture Content and each of the curves follow the exponential $Z/1-Z$ relationship as described in the method of calculating Grain Moisture Flow Rate. This effect appears more visible at larger DDGS flow rates as the Grain Moisture Flow Rate varies about 14 lb/hr from 20 to 40% Moisture Content at a DDGS Flow Rate of 1.0 bph, while it varies about 68 lb/hr from 20 to 40% Moisture Content at a DDGS Flow Rate of 5.0 bph. However, as seen in Table 3 below, the percent change between moisture contents of 20% and 40% show that it is the same percent increase at all DDGS flow rates.

Table 3: Calculate Values for Grain Moisture Flow Rate (lb_w/hr)

Z/bph	1.0	2.0	3.0	4.0	5.0
0.20	8.18	16.36	24.54	32.72	40.90
0.22	9.23	18.46	27.69	36.92	46.15
0.24	10.33	20.67	31.00	41.33	51.67
0.26	11.50	22.99	34.49	45.99	57.49
0.28	12.73	25.45	38.18	50.90	63.63
0.30	14.02	28.05	42.07	56.10	70.12
0.32	15.40	30.80	46.20	61.60	76.99
0.34	16.86	33.71	50.57	67.43	84.29
0.36	18.41	36.81	55.22	73.63	92.03
0.38	20.06	40.11	60.17	80.22	100.30
0.40	21.82	43.63	65.45	87.26	109.10
% Change	167%	167%	167%	167%	167%

Air Flow Rate

The Air Flow Rate ($\dot{m}_{air}$) is the rate at which air that travels through the Air Drying Unit. It is determined from the energy and mass balances discussed in the System Model section of this report. Specifically, since the temperature at the entering and exit states of the Air Drying Unit are fixed, the air flow rate is determined from these temperatures and the amount of heat and moisture removed from the product during this stage of the drying system.

Figure 9 below displays the relationship between DDGS flow rate to the Air Flow Rate.

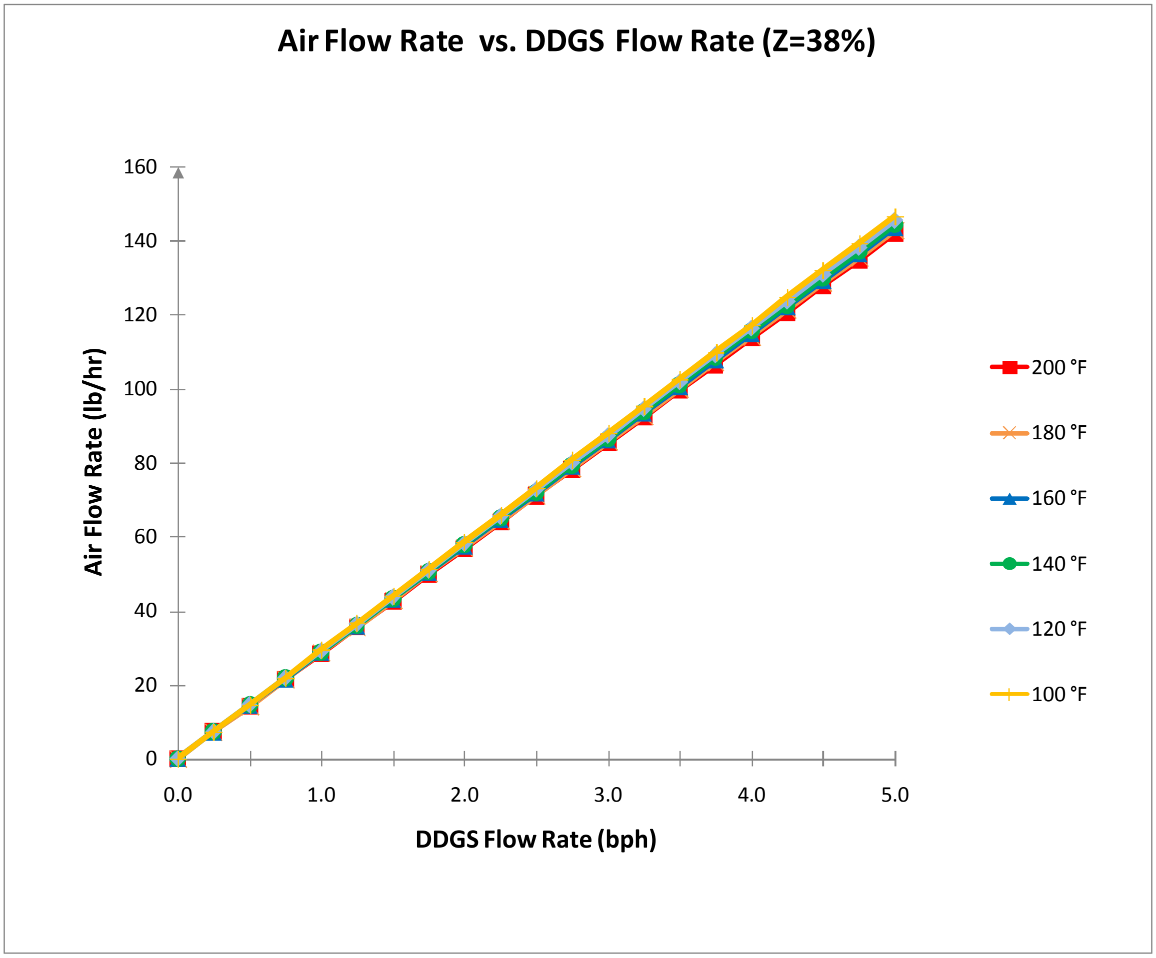

Figure 9: Air Flow Rate vs. DDGS Flow Rate

It appears from the plot above that the Air Flow Rate increases with DDGS Flow Rate from 0 to around 144 lb/hr at 5.0 bph. This is practical because as the speed of DDGS entering the drying system increases there will be an increased need for air to maintain the performance of the system. It also appears that there is a weak dependence on Operational Temperature and Figure 10 shows this effect more clearly below.

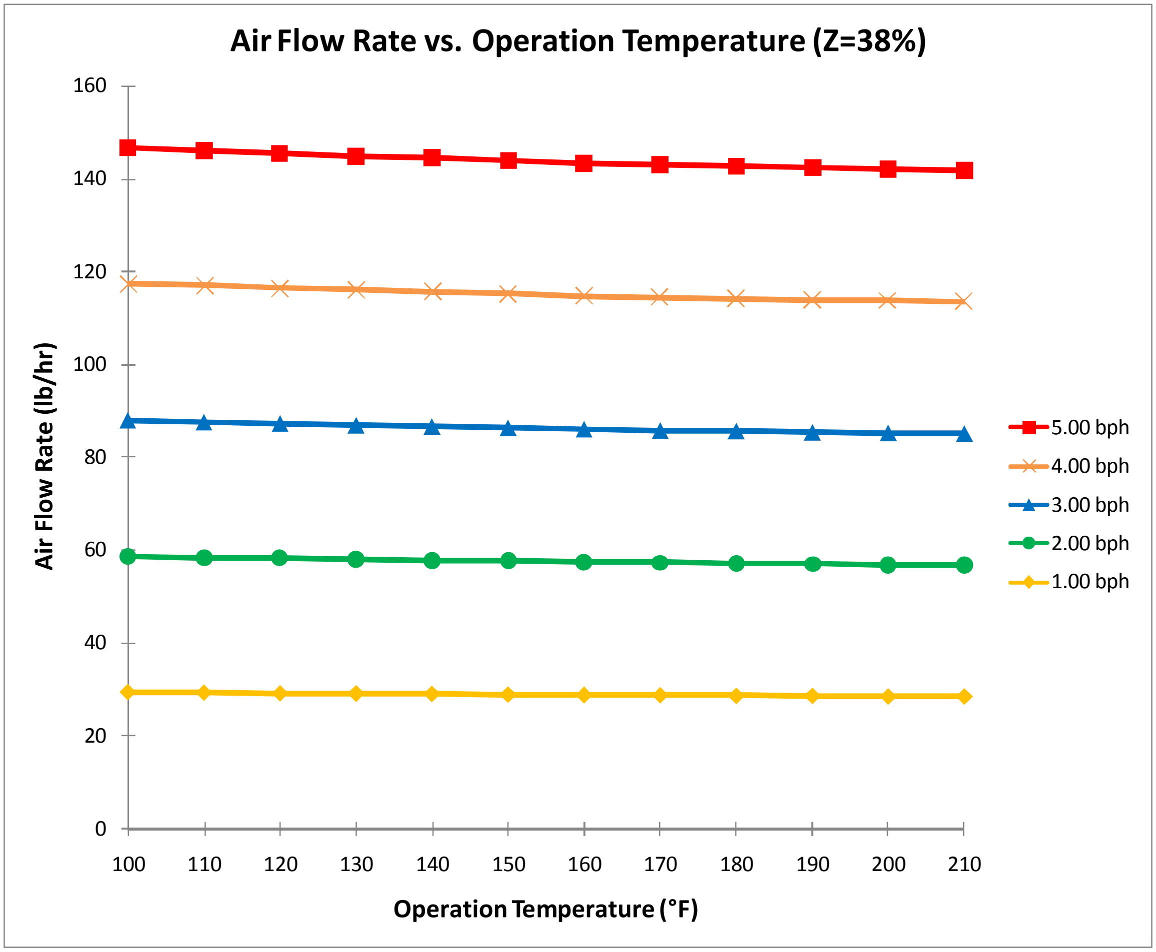

Figure 10: Air Flow Rate vs. Operation Temperature

The plot above shows that as the Operation Temperature increases the Air Flow Rate decreases. This result is due to the fact that as the air becomes warmer, it's ability to hold water vapor increases and hence the Air Flow Rate decrease. This effect appears more visible at higher DDGS flow rates as at 1.0 bph the Air Flow Rate falls from 29.33 Btu/hr at 100 °F to 28.37 Btu/hr at 500 °F, while at 5.0 bph the Air Flow Rate decreases from 146.7 Btu/hr at 100 °F to 141.9 Btu/hr at 500 °F. However, as seen in the Grain Moisture Flow Rate, the percent change is nearly the same for all flow rates. Table 4 shows values at a Moisture Content of 38% for Air Flow Rate as the DDGS Flow Rate and Operation Temperature vary.

Table 4: Calculated Value for Air Flow Rate (lba/hr), Z=38%

Bph/T_{op}	100	120	140	160	180	200	% Change
1.00	29.33	29.11	28.89	28.70	28.54	28.42	-3.10%
2.00	58.66	58.22	57.78	57.40	57.08	56.84	-3.10%
3.00	88.00	87.33	86.68	86.09	85.62	85.26	-3.11%
4.00	117.30	116.40	115.60	114.80	114.20	113.70	-3.07%
5.00	146.70	145.60	144.50	143.50	142.70	142.10	-3.14%
% Change	5.33%	5.34%	5.33%	5.33%	5.34%	5.34%	N/A

Figure 11 below shows the interaction between Air Flow Rate and Moisture Content.

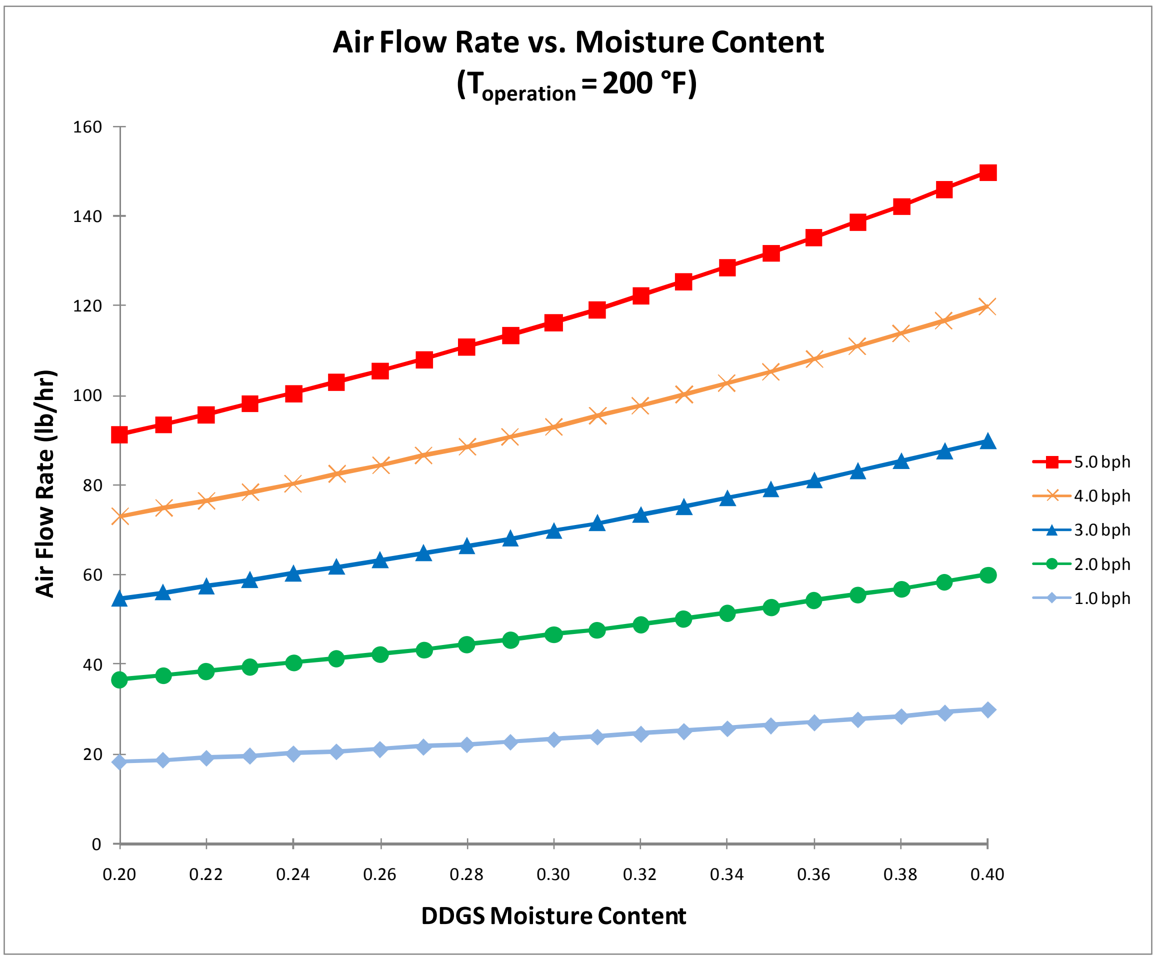

Figure 11: Air Flow Rate vs. Moisture Content

The Air Flow Rate increases as the DDGS Moisture Content increases. This attribute is in line with expectations, as it is logical to expect the need for an increased Air Flow Rate as the

Moisture Content increases because of the presence an additional amount of moisture available for evaporation. Table 5 shows values for Air Flow Rate at an Operation Temperature of 200 °F as it varies with Moisture Content and DDGS Flow Rate. Table # contains values for Air Flow Rate as it varies with Moisture Content and Operation Temperature.

Table 5: Air Flow Rate vs. DDGS Flow Rate and DDGS Entering Moisture Content (lb_a/hr)

Z/bph	1.0	2.0	3.0	4.0	5.0
0.20	18.24	36.47	54.71	72.95	91.18
0.22	19.14	38.27	57.41	76.54	95.68
0.24	20.08	40.17	60.25	80.33	100.40
0.26	21.08	42.16	63.24	84.32	105.40
0.28	22.13	44.27	66.40	88.53	110.70
0.30	23.25	46.49	69.74	92.99	116.20
0.32	24.43	48.85	73.28	97.70	122.10
0.34	25.68	51.35	77.03	102.70	128.40
0.36	27.00	54.01	81.01	108.00	135.00
0.38	28.42	56.84	85.26	113.70	142.10
0.40	29.93	59.85	89.78	119.70	149.60
% Change	64%	64%	64%	64%	64%

Table 6: Ai Flow Rate vs. Operation Temperature and DDGS Entering Moisture Content (lb_a/hr)

Z/T_{op}	100	120	140	160	180	200
0.20	18.83	18.68	18.55	18.42	18.32	18.24
0.22	19.75	19.61	19.46	19.33	19.22	19.14
0.24	20.73	20.57	20.42	20.28	20.17	20.08
0.26	21.76	21.60	21.43	21.29	21.17	21.08
0.28	22.85	22.67	22.50	22.35	22.23	22.13
0.30	24.00	23.81	23.64	23.48	23.35	23.25
0.32	25.21	25.02	24.83	24.67	24.53	24.43
0.34	26.50	26.30	26.10	25.93	25.79	25.68
0.36	27.87	27.66	27.45	27.27	27.12	27.00
0.38	29.33	29.11	28.89	28.70	28.54	28.42
0.40	30.89	30.65	30.42	30.22	30.05	29.93
% Change	64%	64%	64%	64%	64%	64%

The percent change in Air Flow Rate as the Moisture Content varies from 20 to 40% remains constant at 64% for all DDGS Flow Rates and all Operation Temperatures. This shows that the Air Flow Rate is dependent on all three inputs, namely DDGS Flow Rate, Operation Temperature, and DDGS Entering Moisture Content, but these three inputs are independent of each other.

Intermediate Loop Flow Rate

The Intermediate Loop uses water to capture the heat recovered in the Heat Recovery Unit. It also receives heat from the External Heater. It then transfers the combined energy gained from both the Heat Recovery Unit and the External Heater to the DDGS flowing through drying system in order to raise the DDGS temperature making it suitable for drying. The Intermediate Loop Flow Rate ($\dot{m}_{loop}$) represents the flow rate of water required in the Intermediate Loop to sustain the drying system operating conditions. It is determined from the equations described in the System Model portion of this report. The Intermediate Loop Flow Rate depends on the DDGS Flow Rate and the DDGS Entering Moisture Content and it is independent of Operation Temperature. Figure 12 below shows the relationship between Intermediate Loop Flow Rate and DDGS Flow Rate.

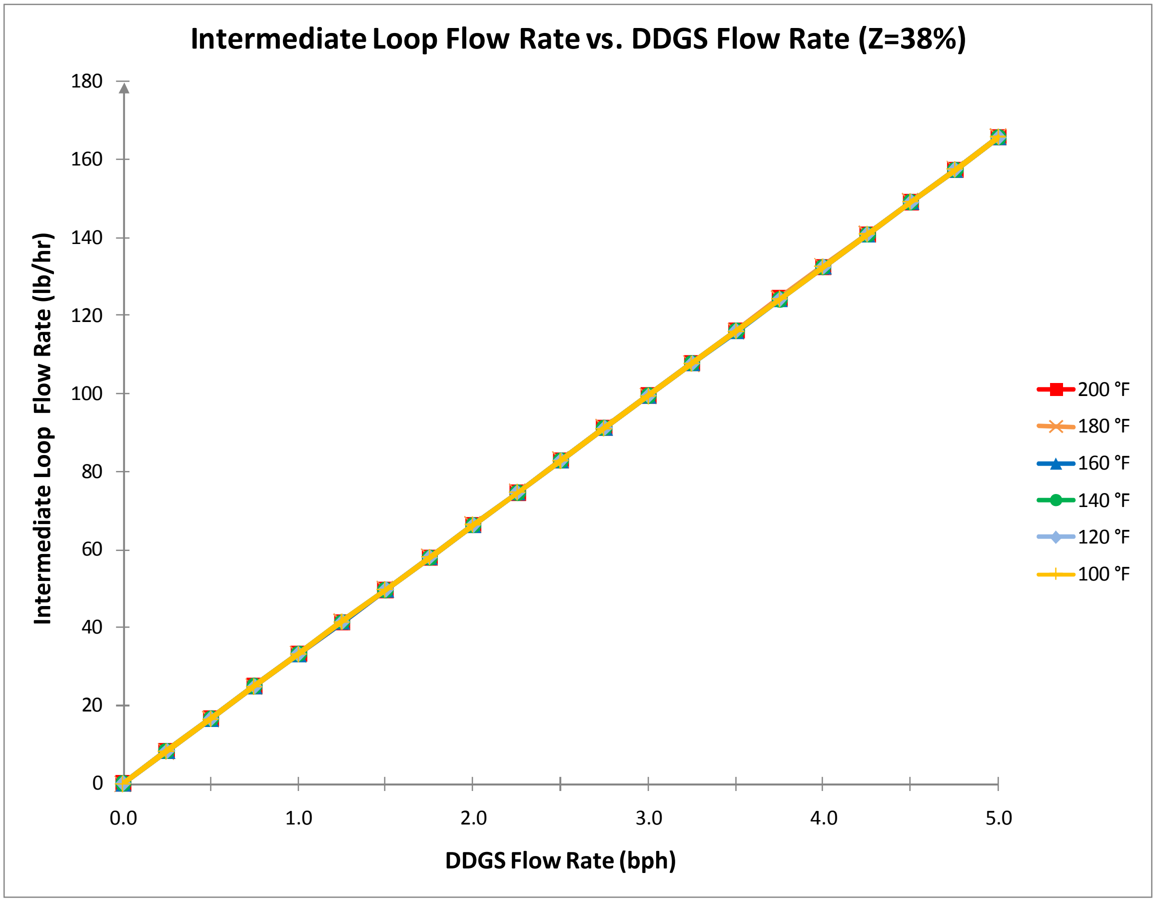

Figure 12: Intermediate Loop Flow Rate vs. DDGS Flow Rate

The DDGS Flow Rate drives the Intermediate Loop Flow Rate as it increases directly proportional to the DDGS Flow Rate. As mentioned earlier, the operation temperature of the system has no influence on the Intermediate Loop Flow Rate because this system was modeled to increase or decrease these flow rates to maintain operating conditions. At a moisture content of 38%, the percent change between 1.0 bph and 5.0 bph remains constant at 400% for all Operation Temperatures. Table 7 below contains values for the Intermediate Loop Flow Rate as it varies with DDGS Flow Rate.

Table 7: Intermediate Loop Flow Rate vs. DDGS Flow Rate and Operation Temperature (lb_w/hr)

Bph/T_{op}	100	120	140	160	180	200
1.00	33.16	33.16	33.16	33.16	33.15	33.14
2.00	66.31	66.32	66.32	66.31	66.30	66.27
3.00	99.47	99.48	99.48	99.47	99.44	99.41
4.00	132.60	132.60	132.60	132.60	132.60	132.50
5.00	165.80	165.80	165.80	165.80	165.70	165.70
% Change	400%	400%	400%	400%	400%	400%

Figure 13 below shows the connection between DDGS Entering Moisture Content and Intermediate Loop Flow Rate.

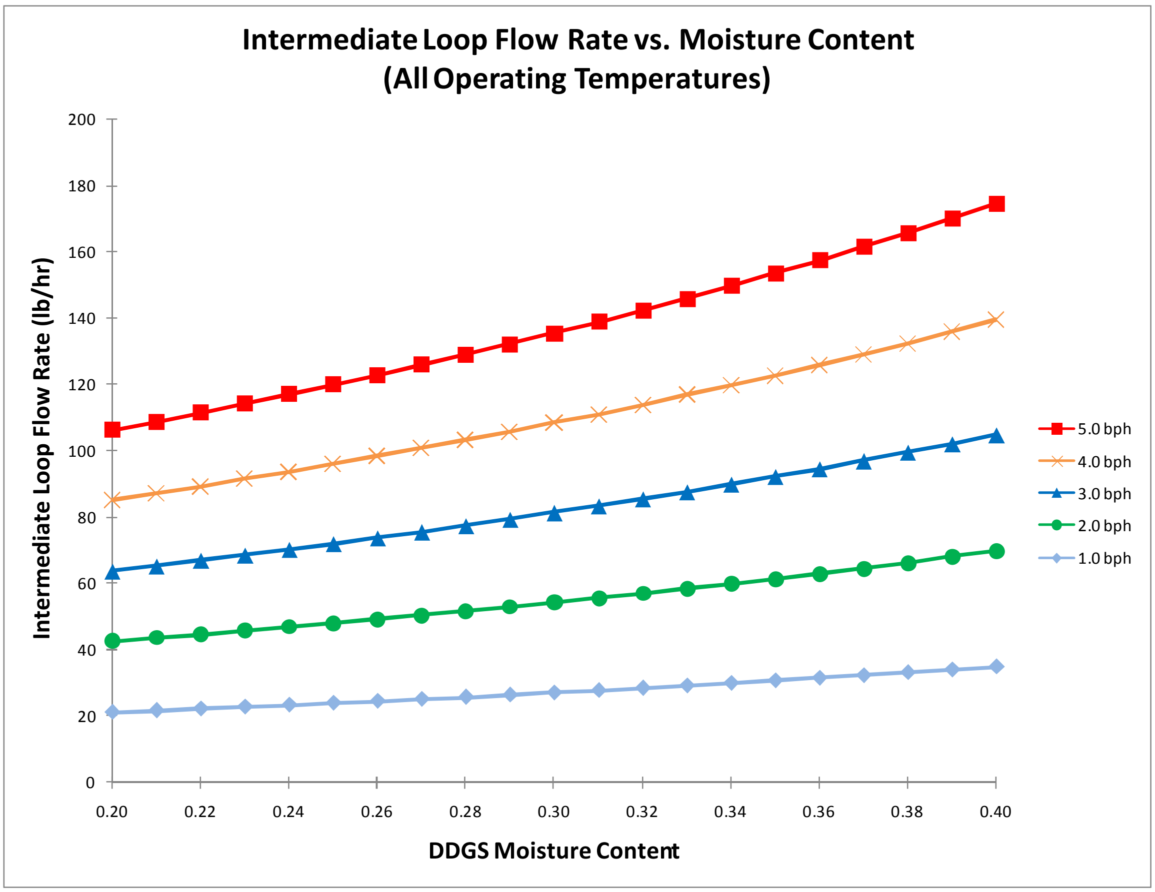

Figure 13: Intermediate Loop Flow Rate vs. Moisture Content

The Intermediate Loop Flow Rate increases as the Moisture Content increases, this increase is necessary to provide additional heat to the DDGS Flow to accommodate the increase in moisture present. The Intermediate Flow Rate appears to be more sensitive to changes in DDGS Entering Moisture Content at higher DDGS flow rates. However, the percent change is consistent at each DDGS flow rate; therefore, the perceived sensitivity of the Intermediate Loop Flow Rate to change in DDGS Entering Moisture Content is due to the fact that there is more Grain Moisture at higher DDGS Flow rates. Table 8 below shows how the variation of DDGS Flow Rate and DDGS Entering Moisture Content affect the Intermediate Loop Flow Rate.

Table 8: Intermediate Loop Flow Rate vs. DDGS Entering Moisture Content and DDGS Flow Rate (lb_w/hr)

Z/bph	1.0	2.0	3.0	4.0	5.0
0.20	21.27	42.53	63.80	85.06	106.30
0.22	22.31	44.63	66.94	89.25	111.60
0.24	23.42	46.83	70.25	93.67	117.10
0.26	24.58	49.16	73.74	98.32	122.90
0.28	25.81	51.62	77.42	103.20	129.00
0.30	27.11	54.21	81.32	108.40	135.50
0.32	28.48	56.96	85.44	113.90	142.40
0.34	29.94	59.88	89.81	119.80	149.70
0.36	31.49	62.97	94.46	125.90	157.40
0.38	33.14	66.27	99.41	132.50	165.70
0.40	34.89	69.79	104.70	139.60	174.50
% Change	64%	64%	64%	64%	64%

Moisture Removal Flow Rate

The Moisture Removal Flow Rate ($\dot{m}_{dried}$) describes the flow rate of moisture that evaporates from the DDGS flowing through the drying system. A mass balance between the moisture entering the Air Drying Unit and the moisture remaining after drying determines this flow rate, as describe in the system model section of this report. Figure 14 below relates the Moisture Removal Flow Rate to the DDGS Flow Rate.

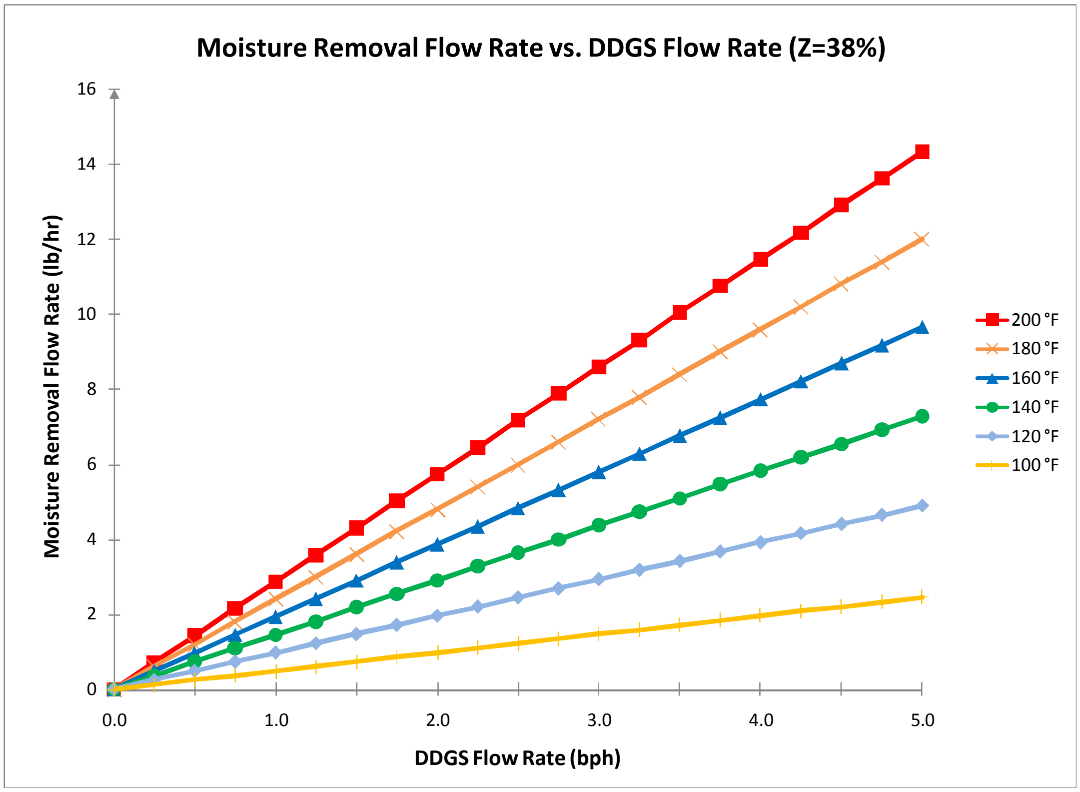

Figure 14: Moisture Removal Flow Rate vs. DDGS Flow Rate

The Moisture Removal Flow Rate is linearly proportional to the DDGS Flow Rate, as the DDGS Flow Rate increases, the Moisture Removal Flow Rate increases. This is due to the fact that as more DDGS enters the drying system, there is more moisture available for drying, therefore more moisture is removed from the system. Table 9 below contains values for Moisture Removal Flow Rate as it varies from 1.0 bph to 5.0 bph at different Operation Temperatures.

Table 9: Moisture Removal Flow Rate vs. DDGS Flow Rate (lb_w/hr)

Bph/T_{op}	100	120	140	160	180	200
1.00	0.49	0.98	1.46	1.93	2.40	2.86
2.00	0.98	1.96	2.91	3.86	4.80	5.72
3.00	1.48	2.93	4.37	5.79	7.20	8.59
4.00	1.97	3.91	5.83	7.72	9.60	11.45
5.00	2.46	4.89	7.29	9.66	12.00	14.31
% Change	400%	400%	400%	400%	400%	400%

The percent change in Moisture Removal Flow Rate between 1.0 bph and 4.0 bph remains constant at 400% for all Operation Temperatures.

Figure 15 below illustrates the interaction between Moisture Removal Flow Rate and Operation Temperature.

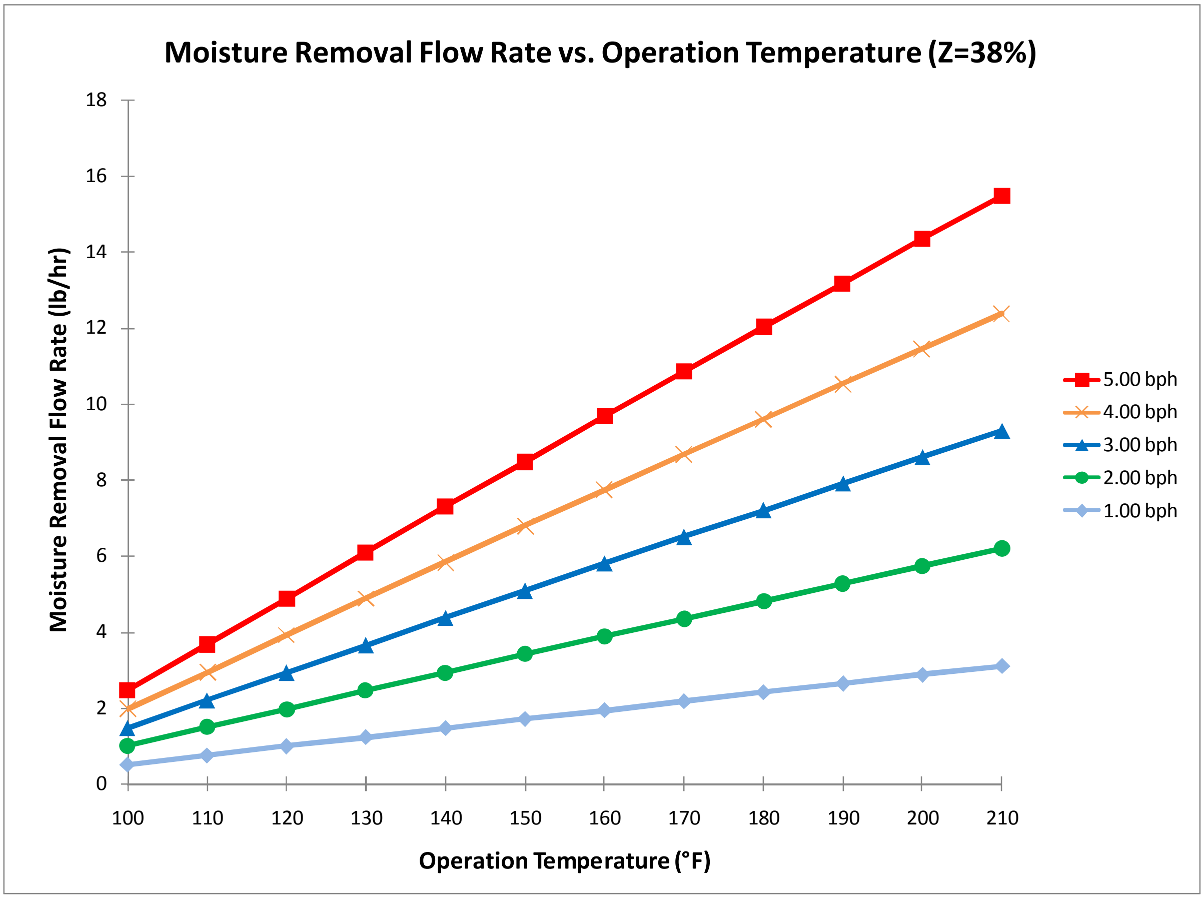

Figure 15: Moisture Removal Flow Rate vs. Operation Temperature

The Moisture Removal Flow Rate is also linearly proportional to Operation Temperature. It increase as the Operation Temperature increase. With a constant DDGS flow, an increase in Operation Temperature provides more heat to the same amount of DDGS, this causes the DDGS to exit the Product Heater at a higher temperature, which facilities an increased amount of moisture removal as it passes through the Air Drying Unit. Table 10 below shows values for Moisture Removal Flow Rate as it varies with Operation Temperature at different DDGS Flow Rates.

Table 10: Moisture Removal Flow Rate vs. Operation Temperature (lb_w/hr)

Bph/T_{op}	100	120	140	160	180	200	% Change
1.00	0.49	0.98	1.46	1.93	2.40	2.86	482%
2.00	0.98	1.96	2.91	3.86	4.80	5.72	482%
3.00	1.48	2.93	4.37	5.79	7.20	8.59	482%
4.00	1.97	3.91	5.83	7.72	9.60	11.45	482%
5.00	2.46	4.89	7.29	9.66	12.00	14.31	482%

The percent increase in Moisture Removal Flow Rate as Operation Temperature increases from 100 °F to 200 °F remains constant at 482% for all DDGS Flow Rates.

The constant percent changes of 400% and 482% as DDGS Flow Rate and Operation Temperature vary respective indicate that these variables are independent of each other. In other words, the trend for one input discussed above is uninfluenced by the other input and vice versa. Figure 16 below explores the dependence of the Moisture Removal Flow Rate on the DDGS Entering Moisture Content, while Operation Temperature varies.

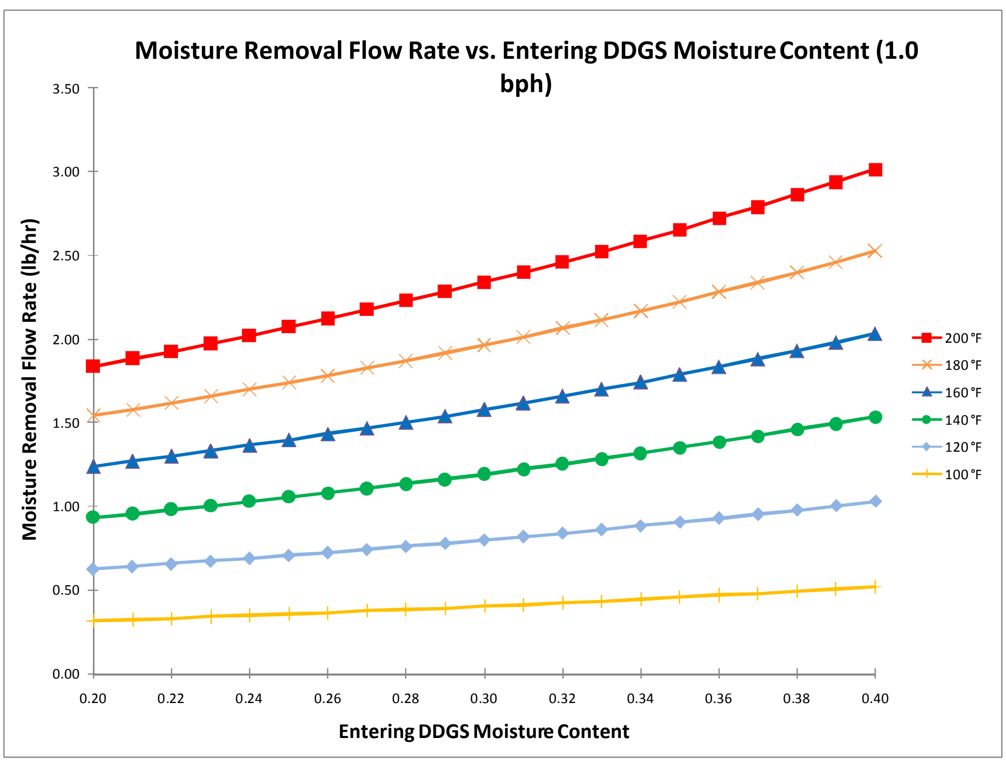

Figure 16: Moisture Removal Flow Rate vs. DDGS Entering Moisture Content (Temperature Aspect)

The Moisture Removal Flow Rate increases as the Moisture Content increase. Like Grain Moisture Flow Rate, an increase in entering moisture content increases the total moisture entering the drying system, which, in turn, increases the amount of moisture that evaporates to maintain the system operating conditions.

Table 11 shows values for Moisture Removal Flow Rate for a constant DDGS Flow Rate of 1.0 bph. This table varies the Moisture content from 20% to 40% and shows data for different Operation Temperatures.

Table 11: Moisture Removal Flow Rate vs. DDGS Entering Moisture Content and Operation Temperature (lb_w/hr)

Z/T_{op}	100	120	140	160	180	200	% Change
0.20	0.32	0.63	0.94	1.24	1.54	1.84	482%
0.22	0.33	0.66	0.98	1.30	1.62	1.93	482%
0.24	0.35	0.69	1.03	1.37	1.70	2.02	482%
0.26	0.36	0.73	1.08	1.43	1.78	2.12	482%
0.28	0.38	0.76	1.14	1.50	1.87	2.23	482%
0.30	0.40	0.80	1.19	1.58	1.96	2.34	482%
0.32	0.42	0.84	1.25	1.66	2.06	2.46	482%
0.34	0.44	0.88	1.32	1.75	2.17	2.59	482%
0.36	0.47	0.93	1.39	1.84	2.28	2.72	482%
0.38	0.49	0.98	1.46	1.93	2.40	2.86	482%
0.40	0.52	1.03	1.53	2.03	2.53	3.01	482%
% Change	64%	64%	64%	64%	64%	64%	N/A

As seen in the table above, at a constant Operation Temperature, the Moisture Removal Flow Rate, at DDGS Flow Rate of 1.0 bph, raises 64% when the DDGS Entering Moisture Content increase from 20 to 40% DDGS. Additionally, at a constant Moisture Content, the Moisture Removal Flow Rate increases 482% when the Operation Temperature raises from 100 to 200 °F. These constant percent increases indicate that the Operation Temperature and DDGS Entering Moisture Content do not affect each other in regards to Moisture Removal Flow Rate. In other words, the trends established for the relationship between Moisture Removal Flow Rate and one input, either Operation Temperature or DDGS Entering Moisture Content, are not affected by a variation of the other input. Figure # below investigates the dependence of Moisture Removal Flow Rate on DDGS Entering Moisture Content as DDGS Flow Rate varies.

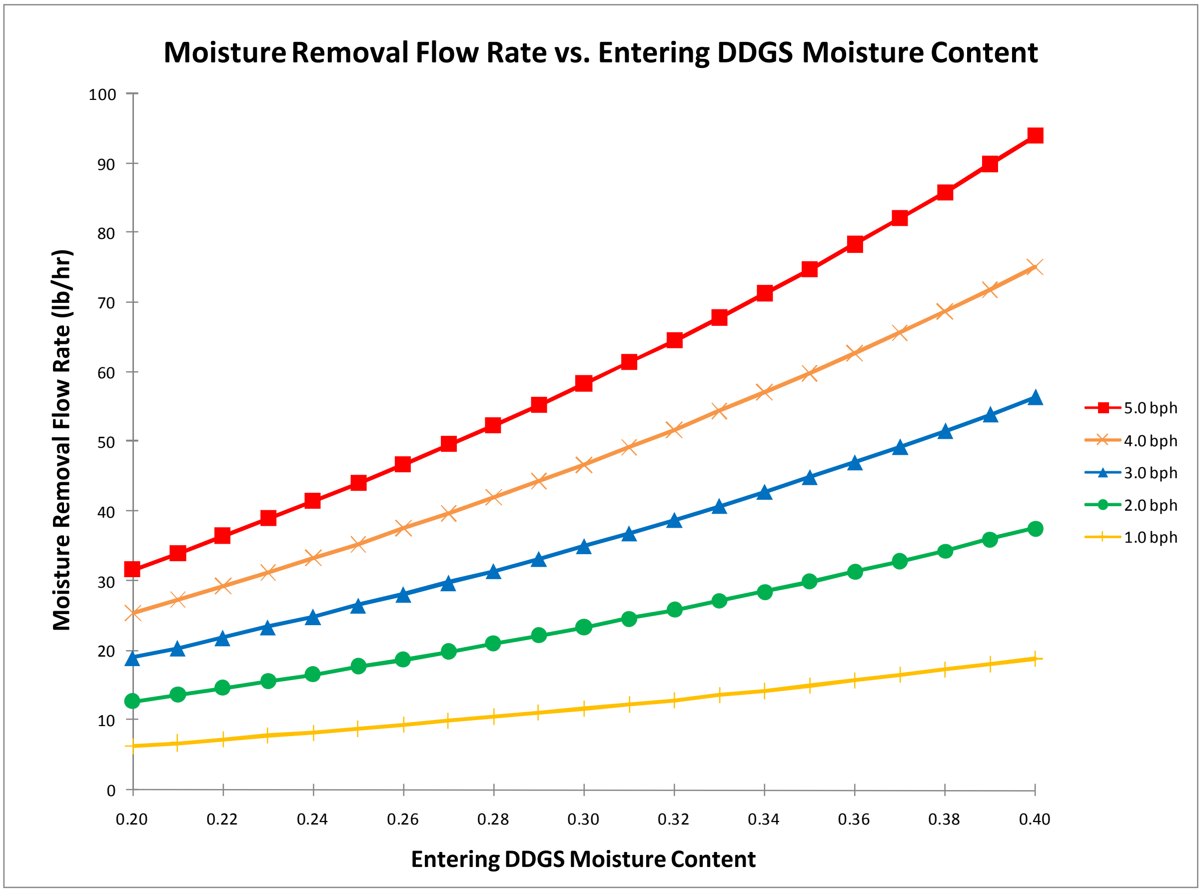

Figure 17: Moisture Removal Flow Rate vs. DDGS Entering Moisture Content (DDGS Flow Aspect)

The Moisture Removal Flow Rate increases with an increase in DDGS Entering Moisture Content as established previously. Table 12 contains values for Moisture Removal Flow Rate as it varies with DDGS Entering Moisture Content and DDGS Flow Rate at a constant Operation Temperature of 200 °F.

Table 12: Moisture Removal Flow Rate vs. DDGS Entering Moisture Content and DDGS Flow Rate (lb_w/hr)

Z/bph	1.0	2.0	3.0	4.0	5.0	% Change
0.20	1.84	3.67	5.51	7.35	9.18	400%
0.22	1.93	3.86	5.78	7.71	9.64	400%
0.24	2.02	4.05	6.07	8.09	10.11	400%
0.26	2.12	4.25	6.37	8.49	10.62	400%
0.28	2.23	4.46	6.69	8.92	11.15	400%
0.30	2.34	4.68	7.02	9.37	11.71	400%
0.32	2.46	4.92	7.38	9.84	12.30	400%
0.34	2.59	5.17	7.76	10.34	12.93	400%
0.36	2.72	5.44	8.16	10.88	13.60	400%
0.38	2.86	5.72	8.59	11.45	14.31	400%
0.40	3.01	6.03	9.04	12.06	15.07	400%
% Change	64%	64%	64%	64%	64%	N/A

The Moisture Removal Flow Rate again increases by 64% when moisture content rises from 20 to 40%. Additionally, at a constant moisture content, the Moisture Removal Flow Rate increase 400% when the DDGS Flow Rate increase from 1.0 to 5.0 bph. These trends confirm that the trends noticed between Moisture Removal Flow Rate and each other the input variables (i.e. DDGS Flow Rate, Operation Temperature, DDGS Entering Moisture Content) remain unaffected by a variation in any of the other input variables.

Remaining Moisture Flow Rate

The Remaining Moisture Flow Rate ($\dot{m}_{w,out}$) represents the moisture that remains entrained in the DDGS after the Air Drying process. Mass and energy balances around the Air Drying Unit, as described in the system model section of this report, determine this flow rate. Figure 18 below shows the interaction between DDGS Flow Rate and Remaining Moisture Flow Rate.

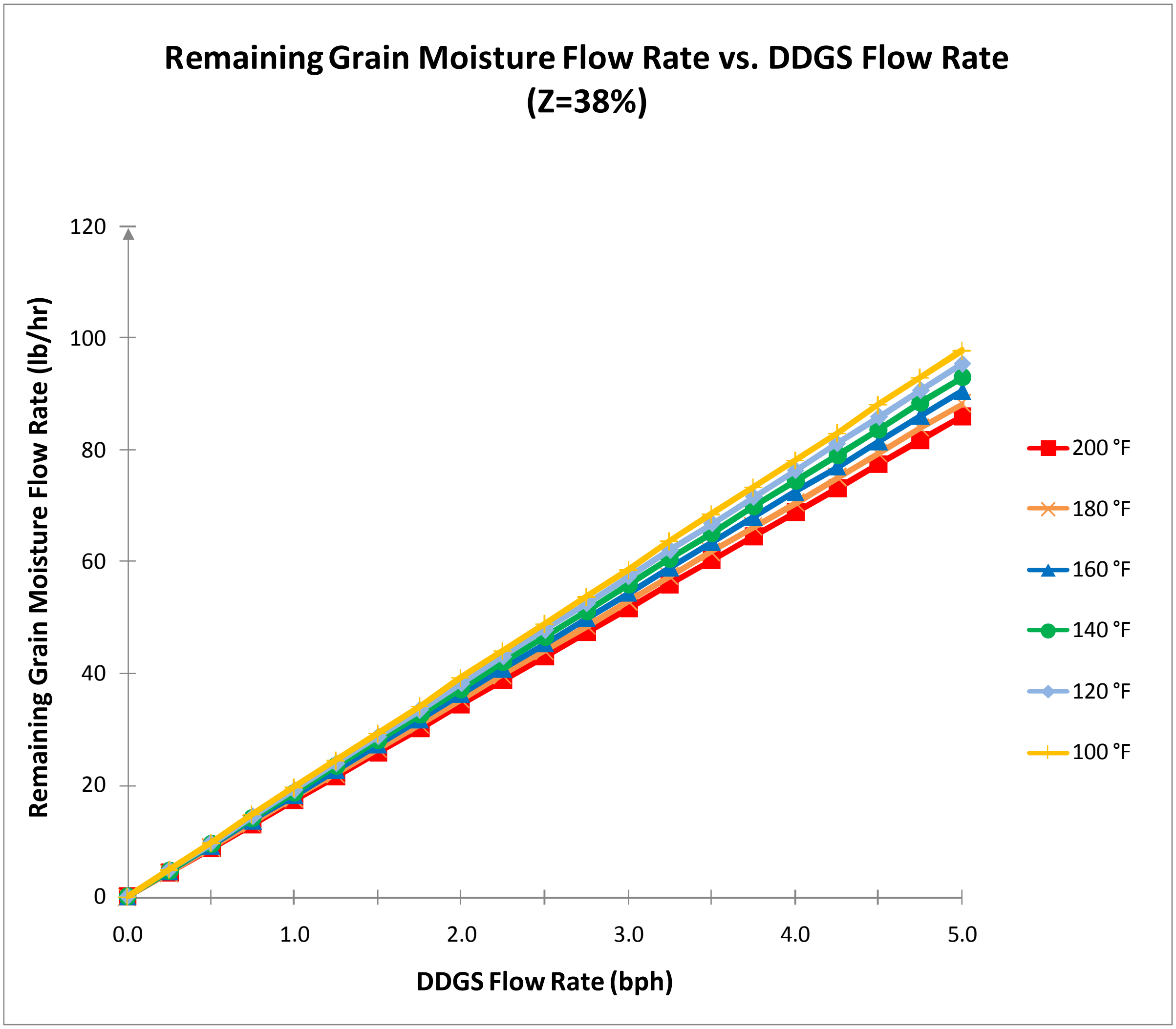

Figure 18: Remaining Moisture Flow Rate vs. DDGS Flow Rate

The figure above shows that as DDGS Flow Rate increases, the Remaining Grain Moisture Flow Rate also increases. This figure also shows a small dependence between Remaining Moisture Flow Rate and Operation Temperature. This outcome is expected because as more DDGS is introduced to the system there is an increase in total moisture available and hence an increase in the moisture that remains. Table 13 below displays values for Remaining Moisture Flow Rate in lb/hr as they vary from 1.0 bph to 5.0 bph at different Operational Temperatures with average flow rates of 18.37, 36.74, 55.11, 91.85 lb/hr for 1.0, 2.0, 3.0, 4.0, 5.0 bph, respectively. This results in an average change in Remaining Moisture Flow Rate between 1.0 and 5.0 bph of 73.48 lb/hr, which results in a 400% increase over this range.

Table 13: Remaining Moisture Flow Rate vs. DDGS Flow Rate (lb_w/hr)

Bph/T_{op}	100	120	140	160	180	200	Average
1.00	19.56	19.08	18.60	18.12	17.66	17.19	18.37
2.00	39.13	38.16	37.20	36.25	35.31	34.39	36.74
3.00	58.69	57.24	55.80	54.37	52.97	51.58	55.11
4.00	78.26	76.31	74.39	72.50	70.63	68.77	73.48
5.00	97.82	95.39	92.99	90.62	88.28	85.97	91.85
Change	78.26	76.31	74.39	72.50	70.62	68.78	73.48
% Change	400%	400%	400%	400%	400%	400%	400%

Figure 19 below examines the interdependence between Operation Temperature and Remaining Moisture Flow Rate more closely.

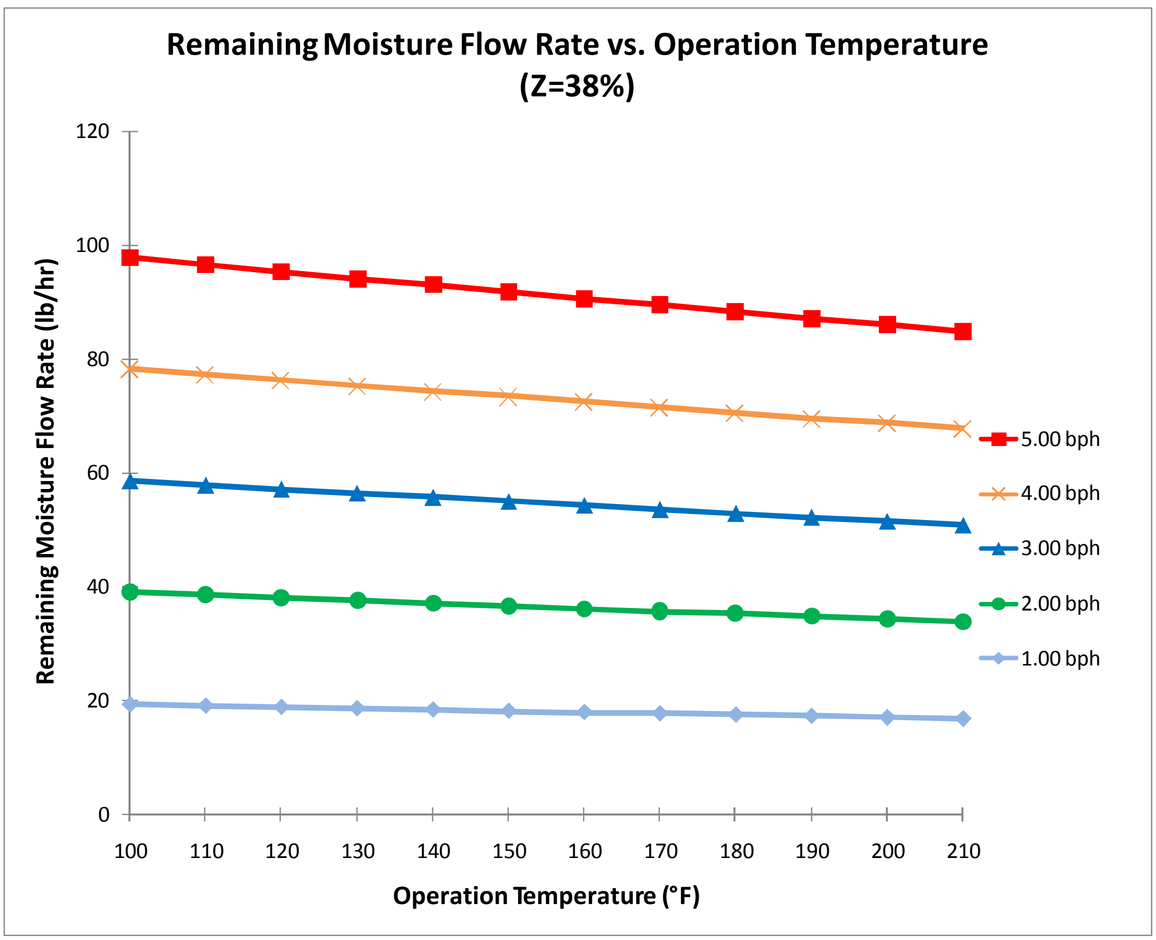

Figure 19: Remaining Moisture Flow Rate vs. Operation Temperature

The figure above illustrates that Remaining Moisture Flow Rate decreases as Operation Temperature increases. This result shows that higher Operation Temperatures more effectively utilize the heat available to dry the DDGS product than the lower Operation Temperatures and therefore less moisture remains at the system exit. The percent change between the highest and lowest Operation Temperatures for all flow rates remains constant at -12.1% for a constant Entering Moisture Content of 38%. Table 14 below contains values for Remaining Moisture Flow Rate as it varies with DDGS Flow Rate and Operation Temperature.

Table 14: Remaining Moisture Flow Rate vs. DDGS Flow Rate and Operation Temperature (lb_w/hr)

Bph/T_{op}	100	120	140	160	180	200	% Change
1.00	19.56	19.08	18.60	18.12	17.66	17.19	-12.1%
2.00	39.13	38.16	37.20	36.25	35.31	34.39	-12.1%
3.00	58.69	57.24	55.80	54.37	52.97	51.58	-12.1%
4.00	78.26	76.31	74.39	72.50	70.63	68.77	-12.1%
5.00	97.82	95.39	92.99	90.62	88.28	85.97	-12.1%

Figure 20 below investigates the relationship between Remaining Moisture Flow Rate and DDGS Entering Moisture Content at a constant temperature of 200 °F.

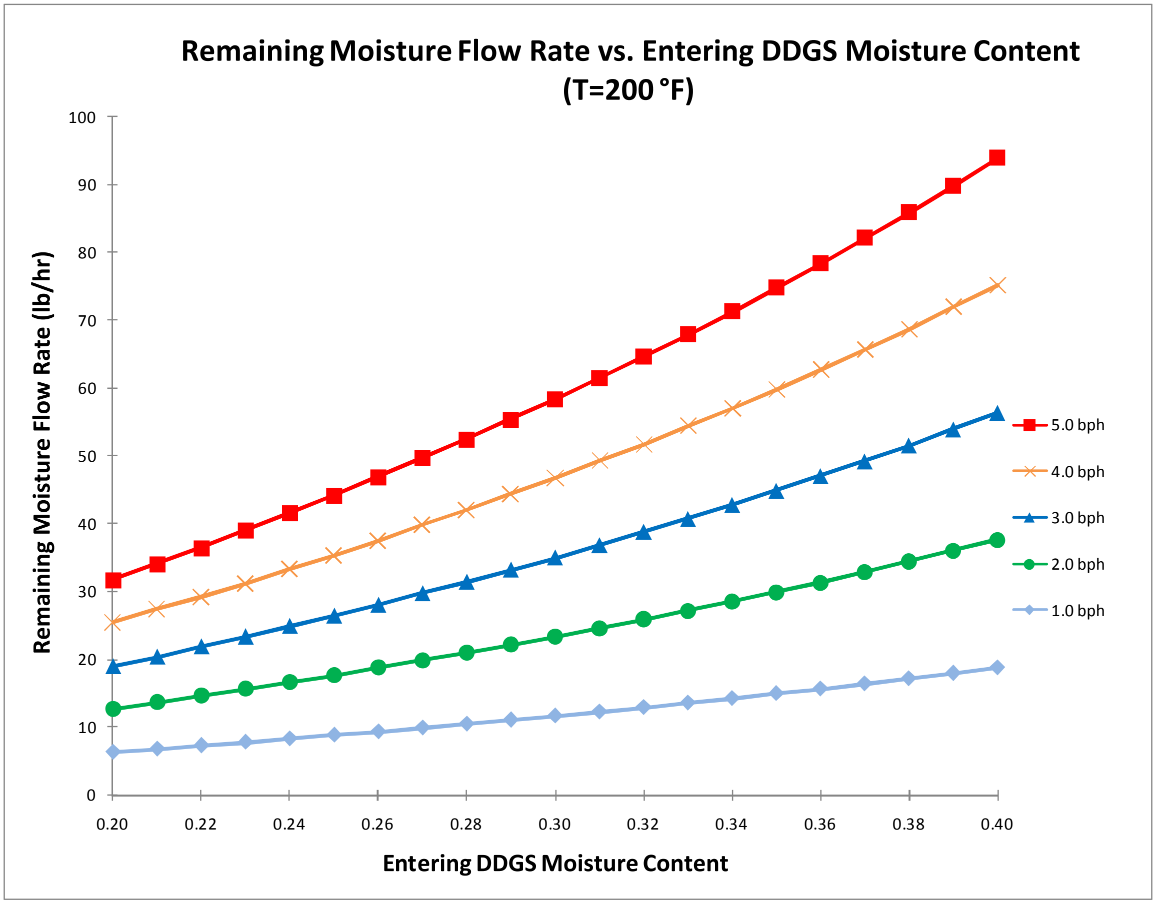

Figure 20: Remaining Moisture Flow Rate vs. DDGS Entering Moisture Content (DDGS Flow Aspect)

The DDGS Entering Moisture Content increases as the Remaining Moisture Flow Rate increases. Table 15 below shows the percent change for each DDGS Flow Rate at 200 °F over the range of all moisture contents analyzed in this study. A seen in this table, the percent change in Remaining Moisture Content remains constant at a 196% increase for all DDGS Flow Rates. This percent change due to the variation of DDGS Entering Moisture Content at 196% is about one-half the percent change due to the variation of DDGS Flow Rate at 400%. This demonstrates that the Remaining Moisture Flow Rate depends more on the DDGS Flow Rate than the DDGS Entering Moisture Content.

**Table 15: Remaining Moisture Content vs.
DDGS Flow Rate and DDGS Entering Moisture Content (lb_w/hr)**

Z/bph	1.0	2.0	3.0	4.0	5.0
0.20	6.34	12.69	19.03	25.37	31.72
0.22	7.30	14.60	21.91	29.21	36.51
0.24	8.31	16.62	24.93	33.24	41.55
0.26	9.37	18.75	28.12	37.50	46.87
0.28	10.50	20.99	31.49	41.98	52.48
0.30	11.68	23.37	35.05	46.73	58.41
0.32	12.94	25.88	38.82	51.75	64.69
0.34	14.27	28.54	42.81	57.08	71.36
0.36	15.69	31.37	47.06	62.75	78.43
0.38	17.19	34.39	51.58	68.77	85.97
0.40	18.80	37.60	56.40	75.20	94.00
% Change	196%	196%	196%	196%	196%

Figure 21 below shows the interaction between DDGS Entering Moisture Content and Remaining Moisture Flow Rate at a constant DDGS Flow Rate.

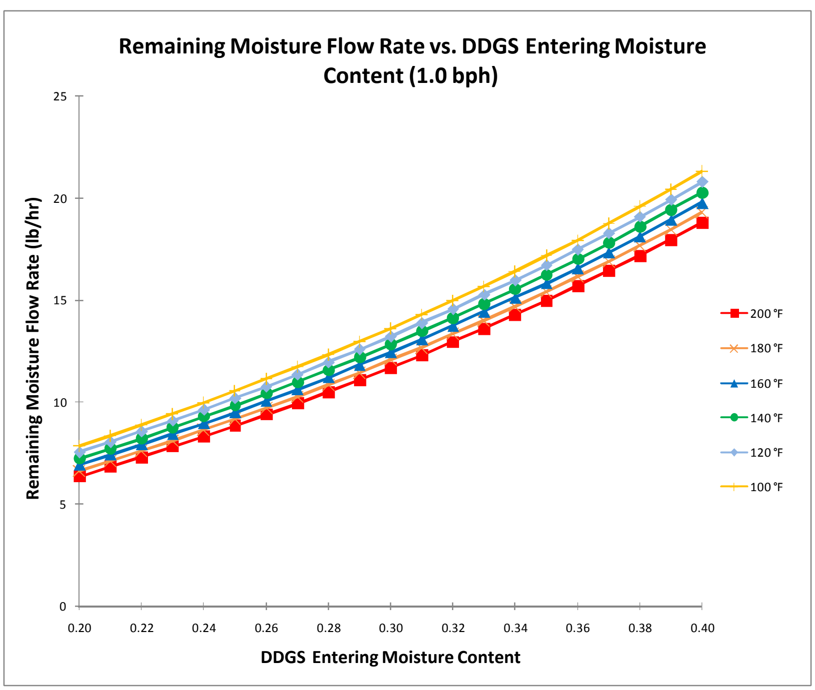

Figure 21: Remaining Moisture Flow Rate vs. DDGS Entering Moisture Content (Temperature Aspect)

The Remaining Moisture Flow Rate increases with DDGS Entering Moisture Content as noted previously. Similarly, the Remaining Moisture Flow Rate varies with Operation Temperature as seen in Figure 18 as discussed when comparing the Remaining Moisture Flow Rate to the DDGS Flow Rate. The key difference in Remaining Moisture Flow Rate trends appears while holding the DDGS Flow Rate constant. As seen in Table 16 below, the percent change in Remaining Moisture Flow Rate as it relates to variations in the Operation Temperature differs from the percent change calculated as the DDGS Entering Moisture Content varies. Specifically, as the Operation Temperature changes from 100 to 200 °F, the percent change in Remaining Moisture Flow Rate varies from 171% to 196% percent. Meanwhile, the percent change in Remaining Moisture Flow Rate varies from -19.34% to -11.74% when the DDGS Entering Moisture Content changes from 20 to 40% moisture content.

These percent changes due to variation in Entering Moisture Content confirm the trend that Remaining Moisture Flow Rate increases with an increase in Entering Moisture Content. Additionally, these percent changes reveal that this trend prevails more at higher Operating Temperatures than lower Operating Temperatures. This fact reinforces the trend that higher operation temperatures result in an increased rate of moisture removal from the DDGS product. Meanwhile, the percent changes due to the variation in Operation Temperature show that the increased Remaining Moisture Flow Rate due to higher Operation Temperatures is greater at lower moisture contents than higher moisture contents. This result illustrates that an attempt to increase drying effectiveness with an increase in Operation Temperature has more of an effect at higher moisture contents than lower moisture contents.

Table 16: Remaining Moisture Flow Rate vs. DDGS Entering Moisture Content and Operation Temperature (lb_w/hr)

Z/T_{op}	100	120	140	160	180	200	% Change
0.20	7.87	7.55	7.25	6.94	6.64	6.34	-19.34%
0.22	8.90	8.57	8.25	7.93	7.61	7.30	-17.94%
0.24	9.99	9.64	9.30	8.97	8.64	8.31	-16.77%
0.26	11.13	10.77	10.42	10.06	9.72	9.37	-15.78%
0.28	12.34	11.96	11.59	11.22	10.86	10.50	-14.91%
0.30	13.62	13.22	12.83	12.44	12.06	11.68	-14.24%
0.32	14.98	14.56	14.15	13.74	13.34	12.94	-13.62%
0.34	16.41	15.97	15.54	15.11	14.69	14.27	-13.04%
0.36	17.94	17.48	17.02	16.57	16.13	15.69	-12.54%
0.38	19.56	19.08	18.60	18.12	17.66	17.19	-12.12%
0.40	21.30	20.79	20.28	19.78	19.29	18.80	-11.74%
% Change	171%	175%	180%	185%	190%	196%	N/A

Moisture Condensed Flow Rate

The Moisture Condensed Flow Rate ($\dot{m}_{cond}$) expresses the amount of Moisture in the Recovery Air stream that condenses into a liquid and hence, transfers its heat to the Intermediate Loop in the Heat Recovery Unit. The model calculates this value by taking the difference in specific humidity ratio of the air entering the Heat Recovery Unit and the air exiting the Heat Recovery unit and multiplying this value by the Air Flow Rate, as shown in the equation below.

$$\dot{m}_{cond} = \dot{m}_{air}\left(\omega_5 - \omega_6\right) \qquad (71)$$

Figure 22 below shows the relationship between the DDGS Flow Rate and the Moisture Condensed Flow Rate.

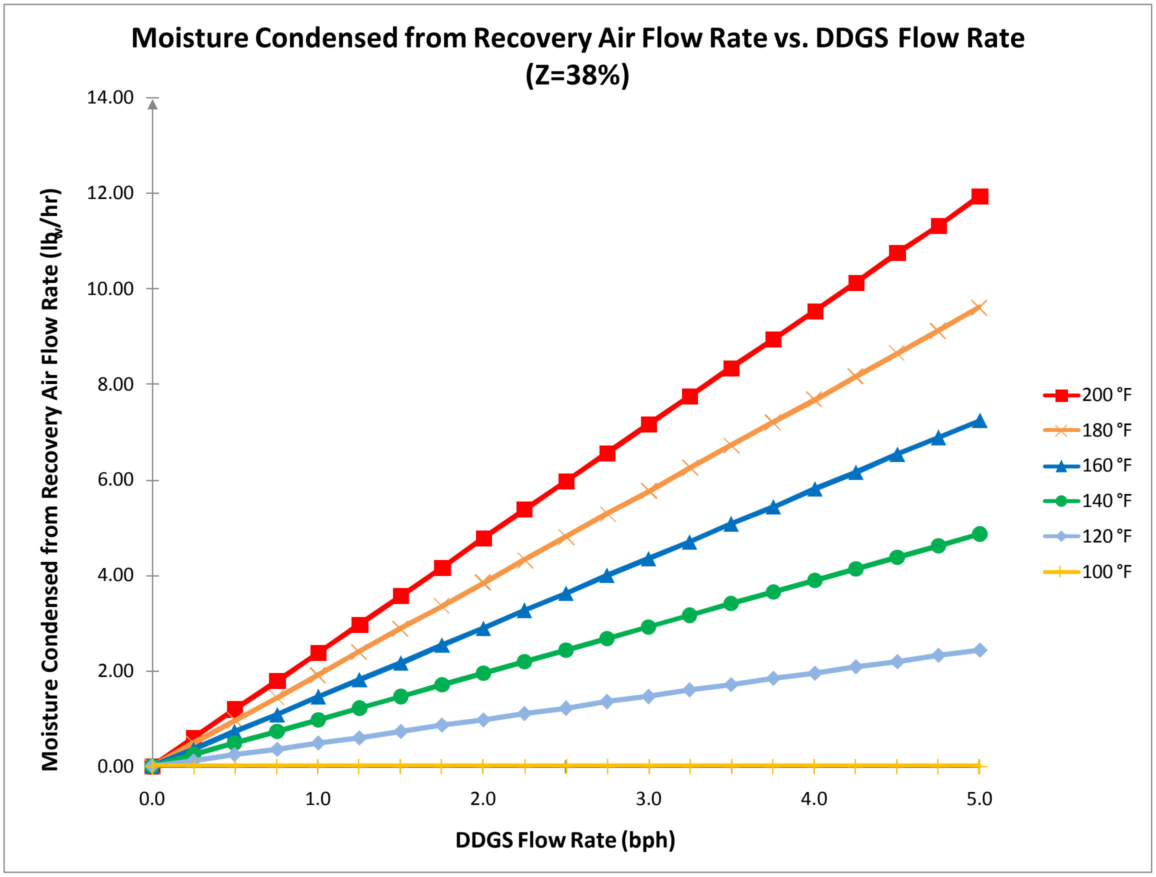

Figure 22: Moisture Condensed Flow Rate vs. DDGS Flow Rate

The Moisture Condensed Flow Rate increases with an increase in DDGS Flow Rate. The increase in system moisture due to the increase in total DDGS flow creates this trend. In other words, the greater the amount of total moisture available in the system the greater the amount of moisture condensed. Note, at 100 °F the temperature of the air entering the Air Recovery Unit equals the temperature of the air exiting the Air Recovery Unit. This results in negligible heat recovery from the Heat Recovery Unit. Figure 23below relates the Moisture Condensed Flow Rate to Operation Temperature.

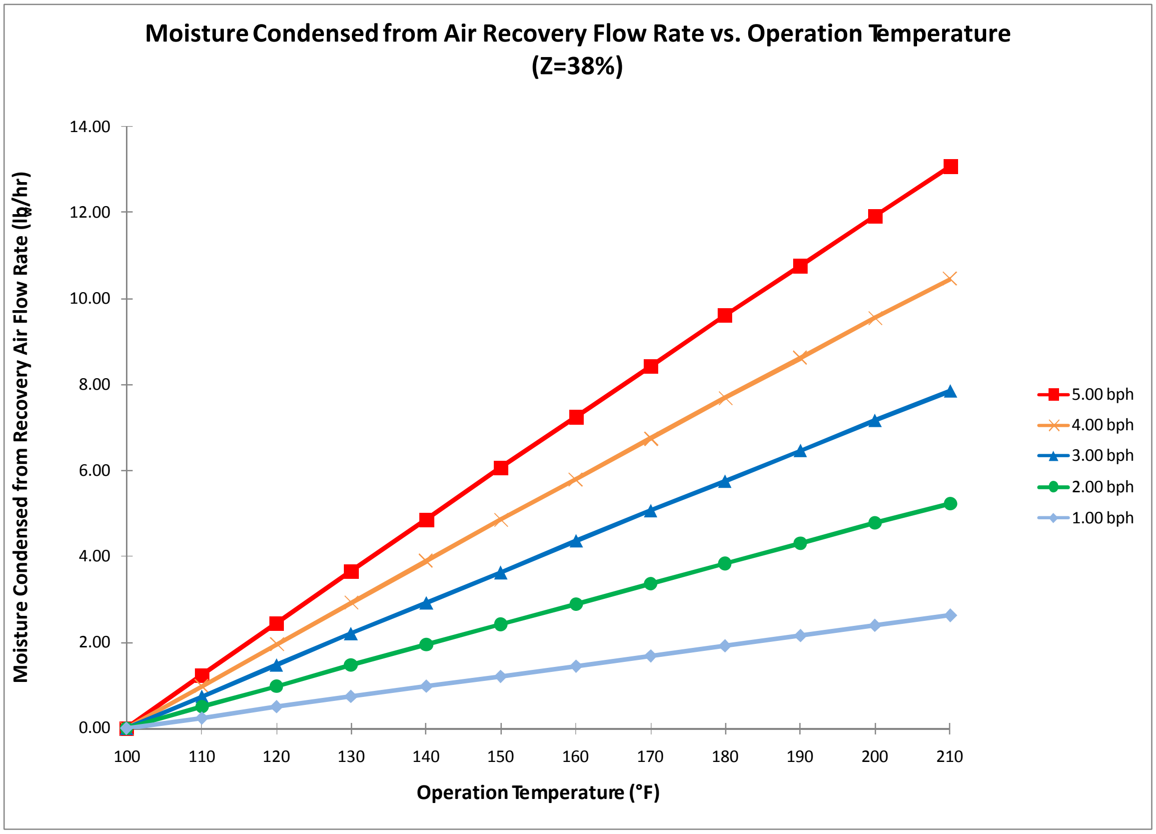

Figure 23: Moisture Condensed Flow Rate vs. Operation Temperature

The Moisture Condensed Flow Rate increases with an increase in Operation Temperature. This result occurs due to the fact that as Operation Temperature increases the amount of Moisture Removed from the DDGS increases. Meanwhile, the temperature at the air exit of the Heat Recovery unit remains constant and therefore, the increase in the moisture content of recovery air due to the increase in Operation Temperature allows for an additional amount of moisture condensation and hence an increased amount of heat recovery. Figures Figure 24 and Figure 25 below convey the interaction between DDGS Entering Moisture Content and Moisture Condensed Flow Rate.

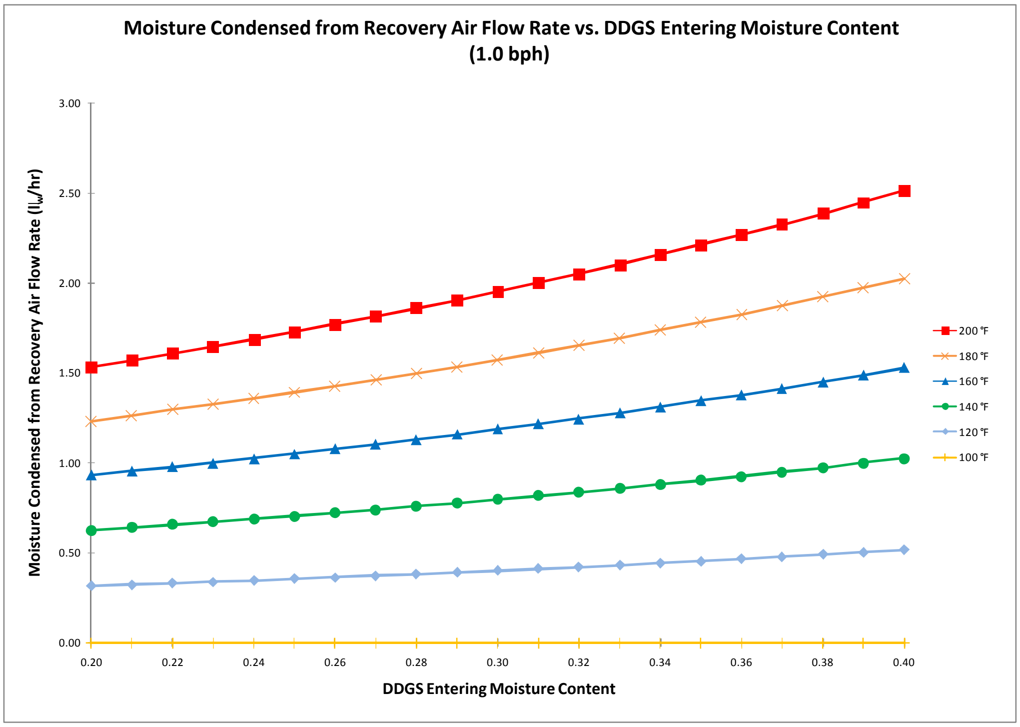

Figure 24: Moisture Condensed Flow Rate vs. DDGS Entering Moisture Content (Temperature Aspect)

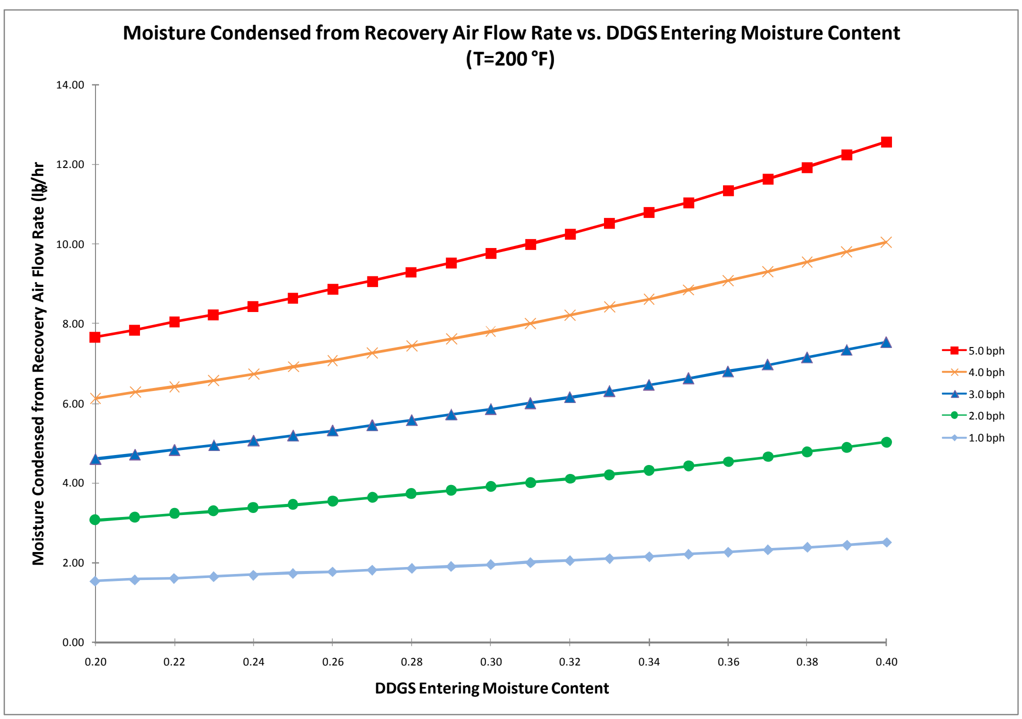

Figure 25: Moisture Condensed Flow Rate vs. DDGS Entering Moisture Content (DDGS Flow Aspect)

As seen in the figures above, the Moisture Condensed Flow Rate increase with an increase in DDGS Entering Moisture Content. When the DDGS Entering Moisture Content increases, the amount of total moisture in the system increases, which in turn, increases the amount of moisture removed and hence increasing the amount of moisture available for condensation (i.e. heat recovery). Tables # and # below contain values for the Moisture Condensed Flow Rate as DDGS Entering Moisture Content varies from 20 to 40%.

Table 17: Moisture Condensed Flow Rate vs. DDGS Entering Moisture Content and Operation Temperature (lb_w/hr)

Z/T_{op}	100	120	140	160	180	200
0.20	0.00	0.31	0.62	0.93	1.23	1.53
0.22	0.00	0.33	0.66	0.98	1.29	1.61
0.24	0.00	0.35	0.69	1.03	1.36	1.69
0.26	0.00	0.36	0.72	1.08	1.43	1.77
0.28	0.00	0.38	0.76	1.13	1.50	1.86
0.30	0.00	0.40	0.80	1.19	1.57	1.95
0.32	0.00	0.42	0.84	1.25	1.65	2.05
0.34	0.00	0.44	0.88	1.31	1.74	2.16
0.36	0.00	0.47	0.92	1.38	1.83	2.27
0.38	0.00	0.49	0.97	1.45	1.92	2.39
0.40	0.00	0.52	1.02	1.53	2.02	2.51
% Change	N/A	64%	64%	64%	64%	64%

Table 18: Moisture Condensed Flow Rate vs. DDGS Entering Moisture Content and DDGS Flow Rate (lb_w/hr)

Z/bph	1.0	2.0	3.0	4.0	5.0
0.20	1.53	3.06	4.59	6.13	7.66
0.22	1.61	3.21	4.82	6.43	8.03
0.24	1.69	3.37	5.06	6.75	8.43
0.26	1.77	3.54	5.31	7.08	8.85
0.28	1.86	3.72	5.58	7.43	9.29
0.30	1.95	3.90	5.86	7.81	9.76
0.32	2.05	4.10	6.15	8.20	10.25
0.34	2.16	4.31	6.47	8.62	10.78
0.36	2.27	4.53	6.80	9.07	11.34
0.38	2.39	4.77	7.16	9.54	11.93
0.40	2.51	5.03	7.54	10.05	12.56
%Change	64%	64%	64%	64%	64%

The tables above show that as DDGS Entering Moisture Content varies from 20 to 40% the percent change in Moisture Condensed Flow Rate remains constant at 64%. This result shows that the percent change in Moisture Condensed Flow Rate as the DDGS Moisture Content varies is independent of DDGS Flow Rate and Operation Temperature, which demonstrates that a change in one input variable does not depend on the other input variables and that the trends seen above remain true for all cases.

Recovery Air Humidity Ratio

The Recovery Air Humidity Ratio (ω_5) describes the ratio of the mass of water vapor to the mass of dry air for the composition of moist air at the Air Drying Unit Exit / Heat Recovery Unit Entrance. A mass and energy balance around the Air Drying Unit determines the amount of moisture transferred from the heated DDGS product stream to the incoming moist air stream, which, in turn, allows for the calculation of the Humidity Ratio for the moist air exiting the Air Drying Unit. This metric of performance reveals how much moisture that enters the Heat Recovery Unit, since the model assumes that no moisture condenses from the moist air as it travels from the Air Drying Unit to the Heat Recovery Unit. The moisture entrained in the moist airflow contains a large portion of the energy available for recovery. Figure 26 demonstrates the connection between DDGS Flow Rate and the Humidity Ratio of the air moving into the Heat Recovery Unit.

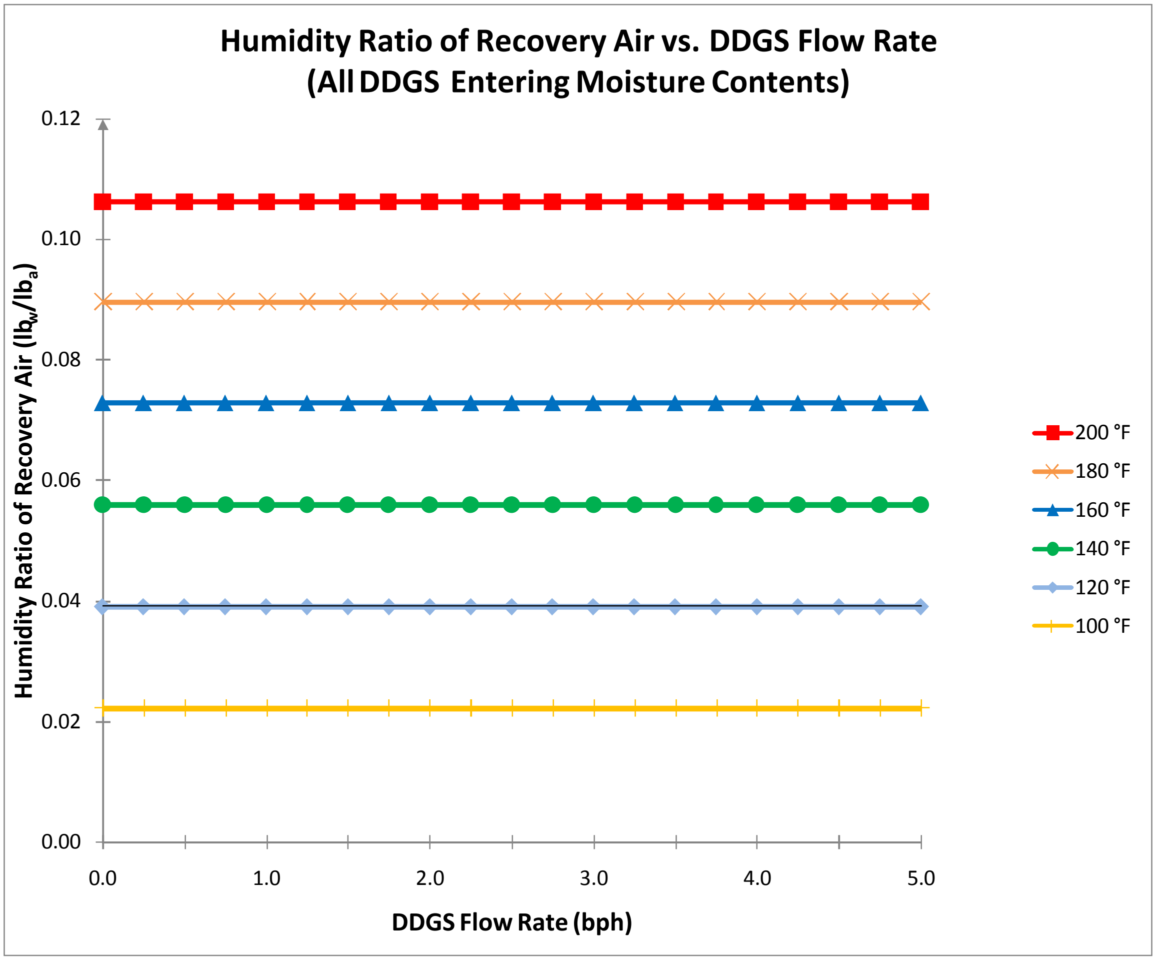

Figure 26: Recovery Air Humidity Ratio vs. DDGS Flow Rate

The horizontal lines on the plot above suggest that the Humidity Ratio of Recovery Air remains independent of DDGS Flow Rate. This fact reinforces the models solution techniques as it proves that the Air Flow Rate adjusts to maintain the constant system temperatures that define the system, and hence provide a constant humidity ratio. Figure 27 below shows the relationship between DDGS Entering Moisture Content and the Humidity Ratio of Recovery Air.

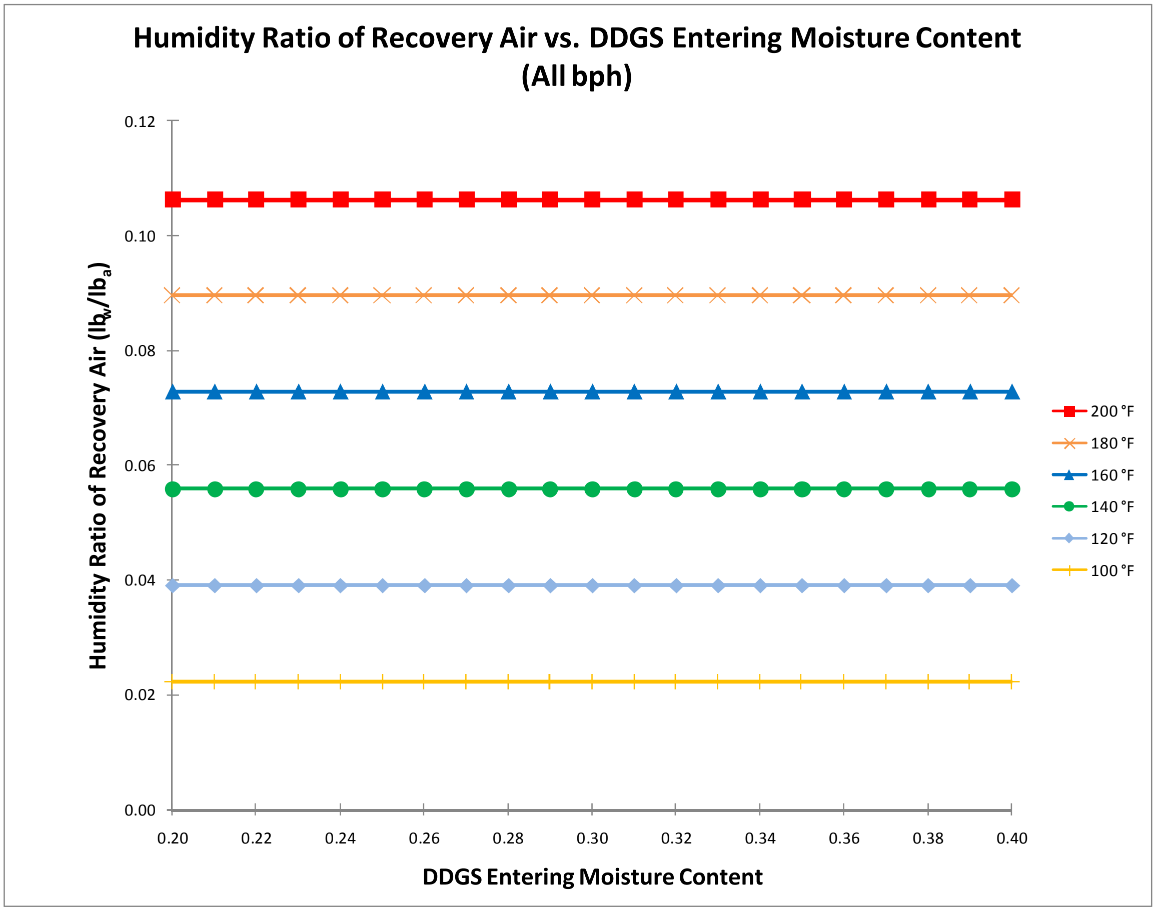

Figure 27: Recovery Air Humidity Ratio vs. DDGS Entering Moisture Content

The Humidity Ratio of Recovery Air stays constant as DDGS Entering Moisture Content varies. This fact also highlights the model's solution as it also verifies that the Air Flow Rate changes to maintain the systems parameters at each state, and hence provides a constant Humidity Ratio. The affect of a change in Operation Temperature on the Recovery Air Humidity Ratio is shown below in Figure 28.

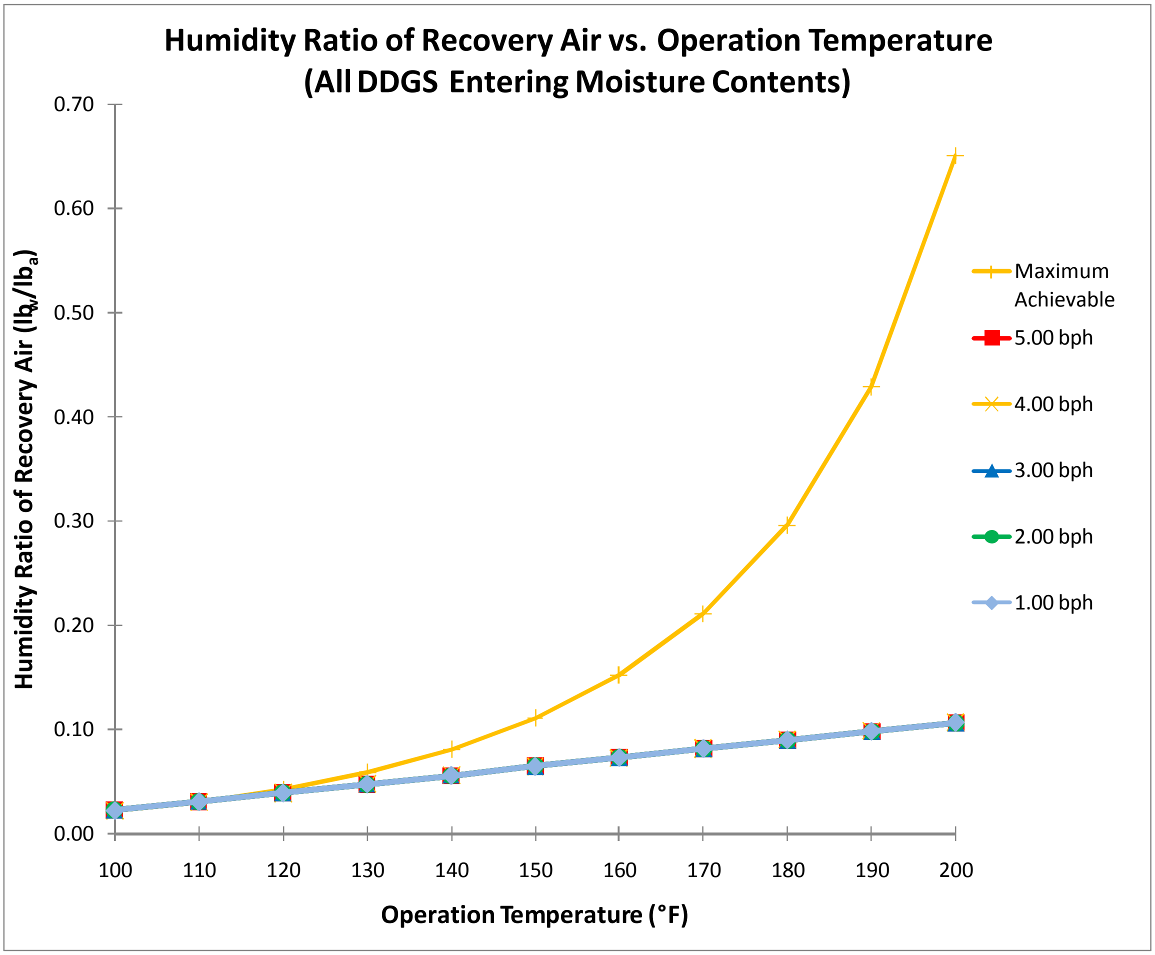

Figure 28: Recovery Air Humidity Ratio vs. Operation Temperature

The Humidity Ratio of Recovery Air linearly increases as Operation Temperature increases. As shown in previous sections, the Air Flow Rate has a small dependence on Operation Temperature as it varies very little over the range of all Operation Temperatures considered. Meanwhile, the Moisture Removal Flow Rate increases substantially as the Operation Temperature increases. Therefore, it follows that the Humidity Ratio of Recovery Air increases with an increase in Operation Temperature. The plot above also contains data for the maximum achievable humidity ratio. This value represents the maximum obtainable ratio between the mass of water vapor and the mass of dry air for the moist air entering the Heat Recovery Unit. Table 19 below shows values for the Humidity Ratio of Recovery Air at different Operation Temperatures.

Table 19: Recovery Air Humidity Ratio vs. Operation Temperature (lb_w/lb_a)

ω/T_{op}	100	120	140	160	180	200	% Change
Actual	0.0222	0.0390	0.0559	0.0728	0.0895	0.1062	378%
Max	0.0222	0.0430	0.0810	0.1523	0.2963	0.6502	N/A

The table above shows that the separation between the actual humidity ratio and maximum achievable humidity ratio expands as the Operation Temperature rises. Note at lower Operation Temperatures, the actual humidity ratio nearly equals the maximum achievable humidity ratio at those conditions. This factor may limit the amount of moisture allowed to transfer into the Heat Recovery Unit. Conversely, at higher Operation Temperatures the actual humidity ratio remains considerably less than the maximum achievable humidity ratio. This characteristic demonstrates capability for the incoming air stream to remove more moisture than it actually does. It also proves that the incoming air is not a limiting factor in the removal of moisture from the DDGS.

External Heater Power

The External Heater Power ($\dot{Q}_{heater}$) describes the additional power required to heat the intermediate loop water in order to raise the water's temperature from the heat recovery exiting temperature to the Operation Temperature. Figure 29 below displays the interaction between the External Heater Power and DDGS Flow Rate.

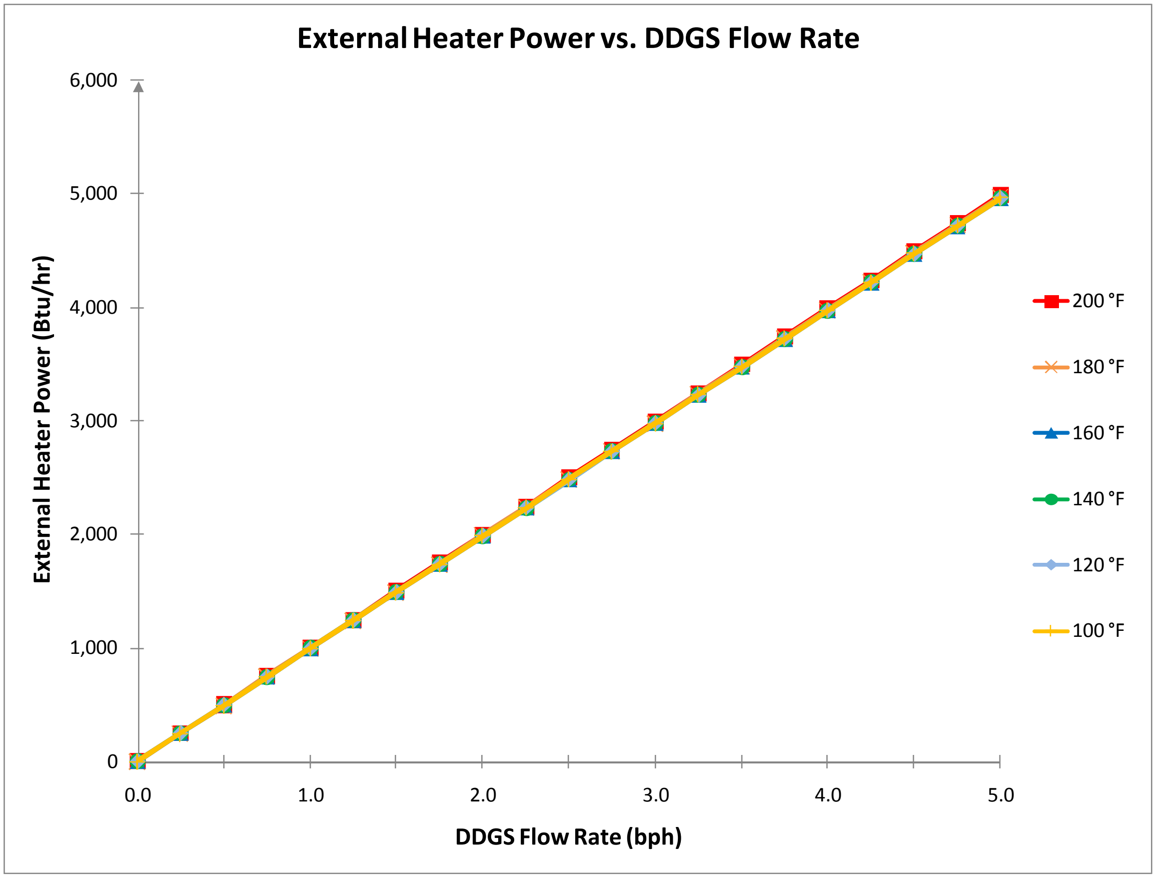

Figure 29: External Heater Power vs. DDGS Flow Rate

The power required from the External Heater increases as DDGS Flow Rate increases. This event occurs because an additional amount of DDGS in the system requires and additional amount of heat to maintain operation conditions and hence an additional draw of power from the External Heater. Figure 30 below plots the relationship between External Heater Power

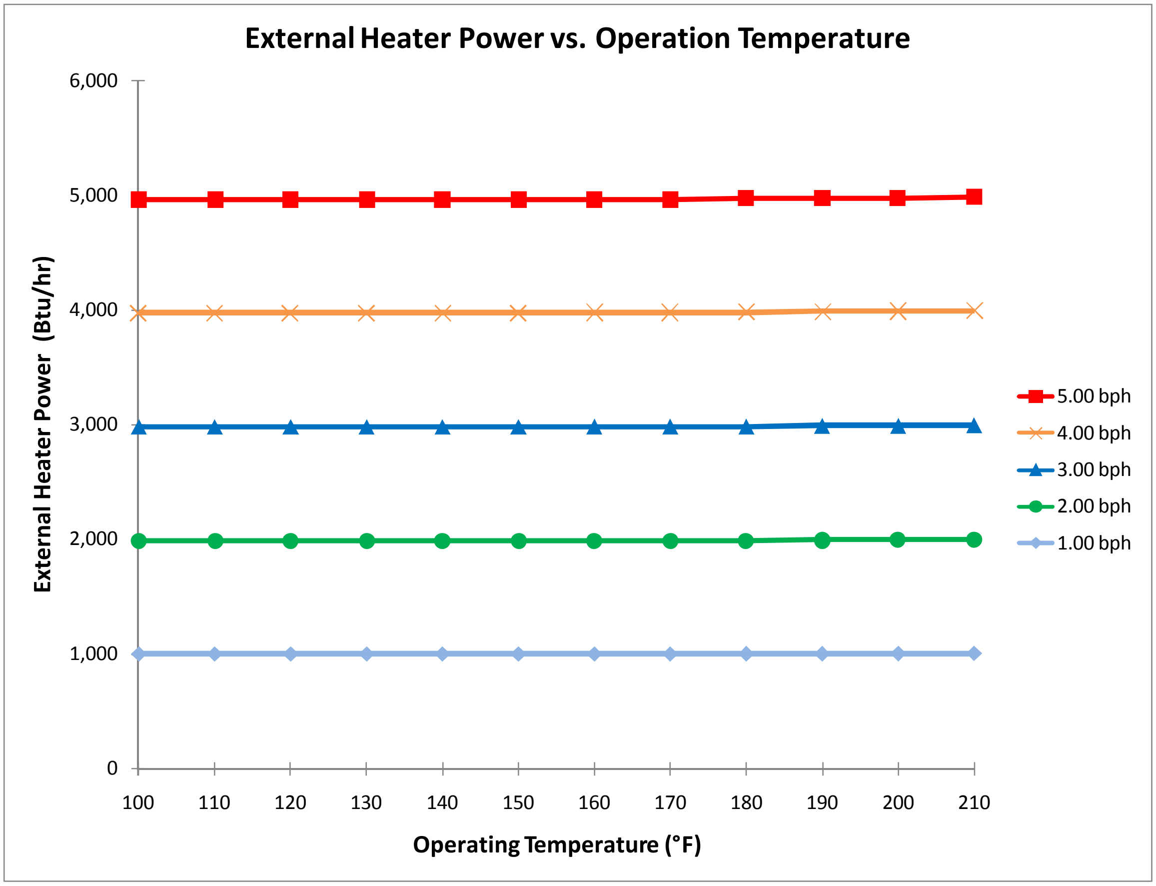

Figure 30: External Heater Power vs. Operation Temperature

The Operation Temperature does not affect the required External Heater Power as shown by the horizontal lines on the plot above. This results agrees with expectations as the system model maintains the temperatures at each state in the system, therefore, the same temperature difference exists between the entrance and exit of the External Heater, regardless of the Operation Temperature. Figure 31 shows the interaction between the required External Heater Power and the DDGS Entering Moisture Content.

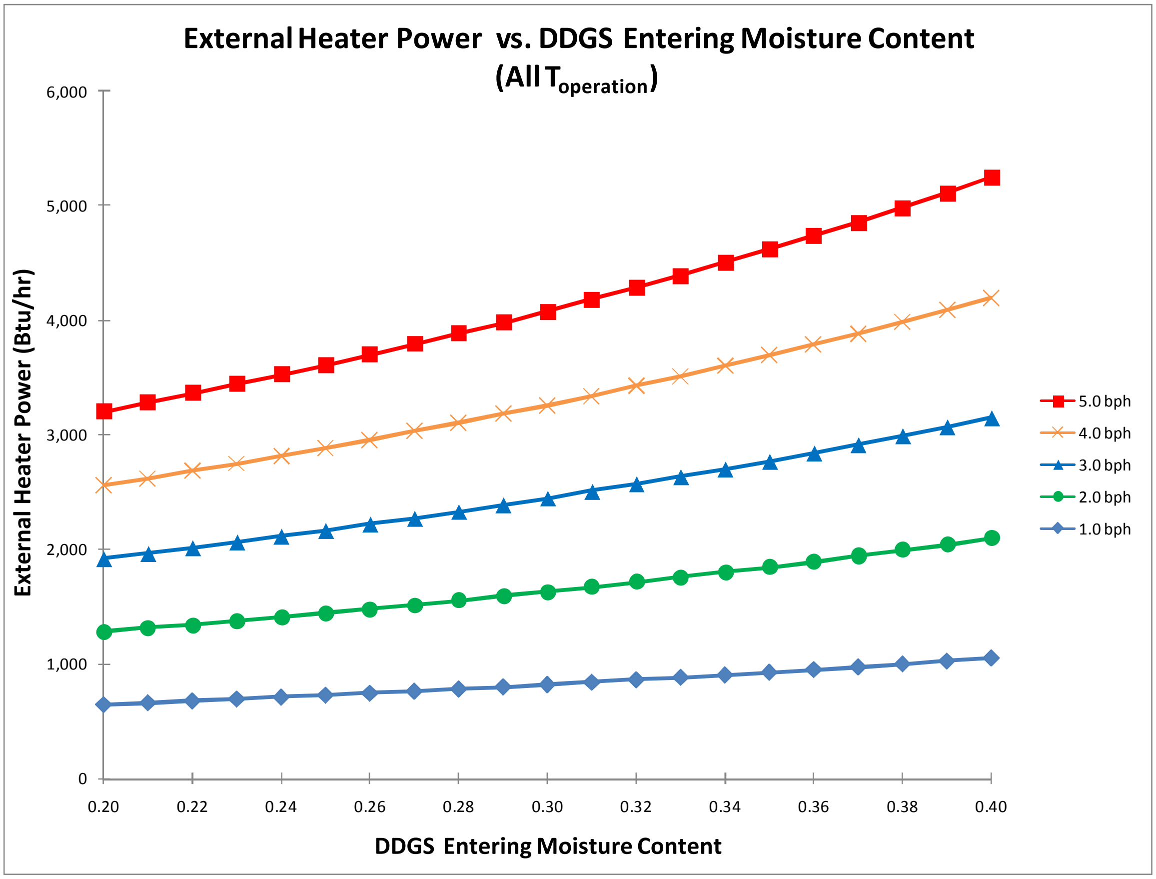

Figure 31: External Heater Power vs. DDGS Entering Moisture Content

The required External Heater Power increases with an increase in DDGS Entering Moisture Content. This event occurs because as the Moisture Content increases, the Intermediate Loop Flow Rate increases and the amount of total heat provided increases, and hence the External Heater Power increase. Note that the contribution of heat from the External Heater relative to the contribution of heat from the Heat Recovery Unit remains constant at all Moisture Contents, which again confirms that the efficiency is independent of Operation Temperature for this model. The tables below provide numerical results for the External Heater Power (Btu/hr, Table 20 and KW, Table 21) as it interacts with DDGS Flow Rate and DDGS Entering Moisture Content.

**Table 20: External Heater Power vs.
DDGS Entering Moisture Content and DDGS Flow Rate (Btu/hr)**

Z/bph	1.0	2.0	3.0	4.0	5.0	% Change
0.20	640	1,280	1,920	2,559	3,199	400%
0.22	671	1,343	2,014	2,686	3,357	400%
0.24	705	1,409	2,114	2,818	3,523	400%
0.26	740	1,479	2,219	2,958	3,698	400%
0.28	777	1,553	2,330	3,106	3,883	400%
0.30	816	1,631	2,447	3,262	4,078	400%
0.32	857	1,714	2,571	3,428	4,285	400%
0.34	901	1,802	2,702	3,603	4,504	400%
0.36	947	1,895	2,842	3,790	4,737	400%
0.38	997	1,994	2,991	3,988	4,985	400%
0.40	1,050	2,100	3,150	4,200	5,250	400%
% Change	64%	64%	64%	64%	64%	N/A

**Table 21: External Heater Power vs.
DDGS Entering Moisture Content and DDGS Flow Rate (kW)**

Z/bph	1.0	2.0	3.0	4.0	5.0	% Change
0.20	0.19	0.38	0.56	0.75	0.94	400%
0.22	0.20	0.39	0.59	0.79	0.98	400%
0.24	0.21	0.41	0.62	0.83	1.03	400%
0.26	0.22	0.43	0.65	0.87	1.08	400%
0.28	0.23	0.46	0.68	0.91	1.14	400%
0.30	0.24	0.48	0.72	0.96	1.20	400%
0.32	0.25	0.50	0.75	1.01	1.26	400%
0.34	0.26	0.53	0.79	1.06	1.32	400%
0.36	0.28	0.56	0.83	1.11	1.39	400%
0.38	0.29	0.58	0.88	1.17	1.46	400%
0.40	0.31	0.62	0.92	1.23	1.54	400%
% Change	64%	64%	64%	64%	64%	N/A

The tables above show that a change in DDGS Flow Rate has a greater affect on External Heater Power than a change in Moisture Content as a change over the range of DDGS Flow Rates at 400% is over 4 times larger than a change over the range of DDGS Entering Moisture Contents at 64%.

CHAPTER 4: THEORETICAL METRICS OF SYSTEM PERFORMANCE

Specific External Heater Energy

The Specific External Heater Energy (q_{Heater}) expresses the ratio of External Heater energy provided to the system per mass of moisture removed by the drying process.

This characteristic is calculated by dividing the External Heater Power by the Moisture Removal Flow Rate as shown in the equation below.

$$q_{Heater} = \frac{\dot{Q}_{Heater}}{\dot{m}_{dried}} \qquad (72)$$

Figure 32 illustrates the interaction between Specific External Heater Energy and DDGS Flow Rate.

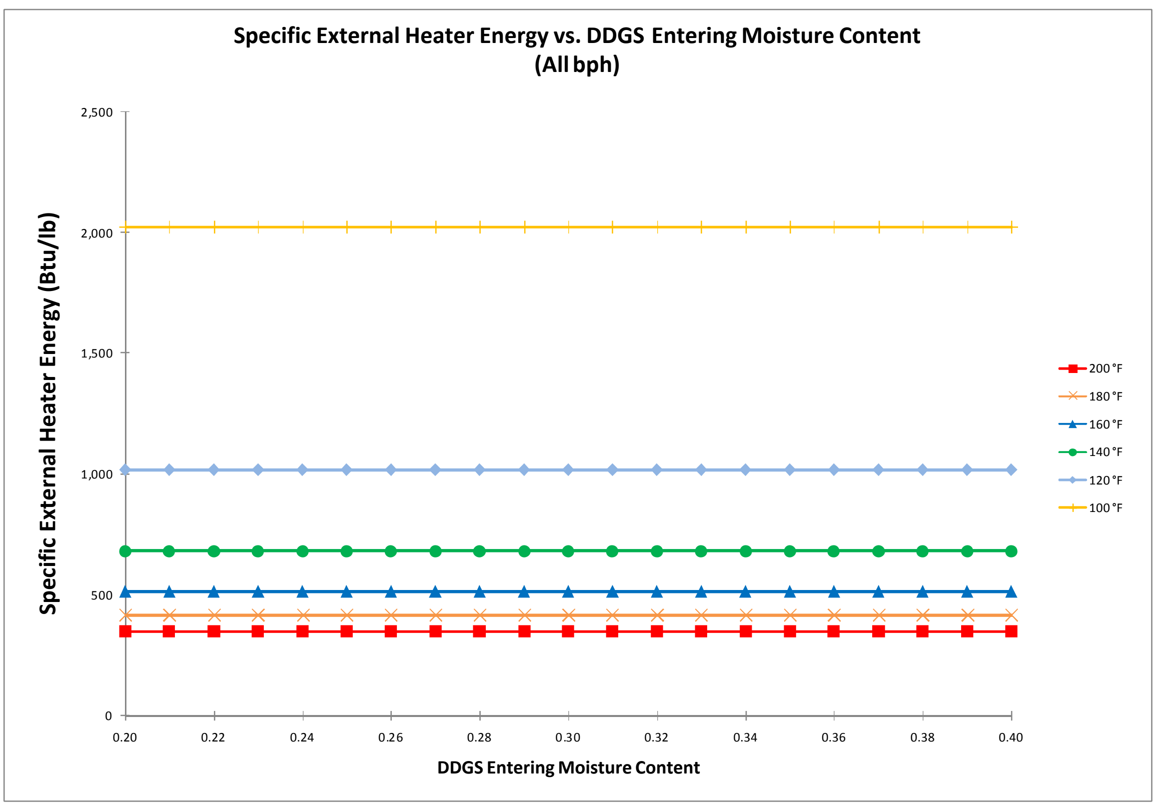

Figure 32: Specific External Heater Energy vs. DDGS Entering Moisture Content

The Specific External Heater Energy remains independent of DDGS Entering Moisture Content, as noted by the horizontal lines on the plot above. This result emerges because when the DDGS Entering Moisture Content changes, the Intermediate Loop Flow Rate changes to maintain the defined system temperatures. This produces an adjustment in the heat transferred to the DDGS and keeps the ratio of External Heater Power to Moisture Removal Flow Rate constant. Figure 33 shows the relationship between Specific External Heater Energy and Operation Temperature.

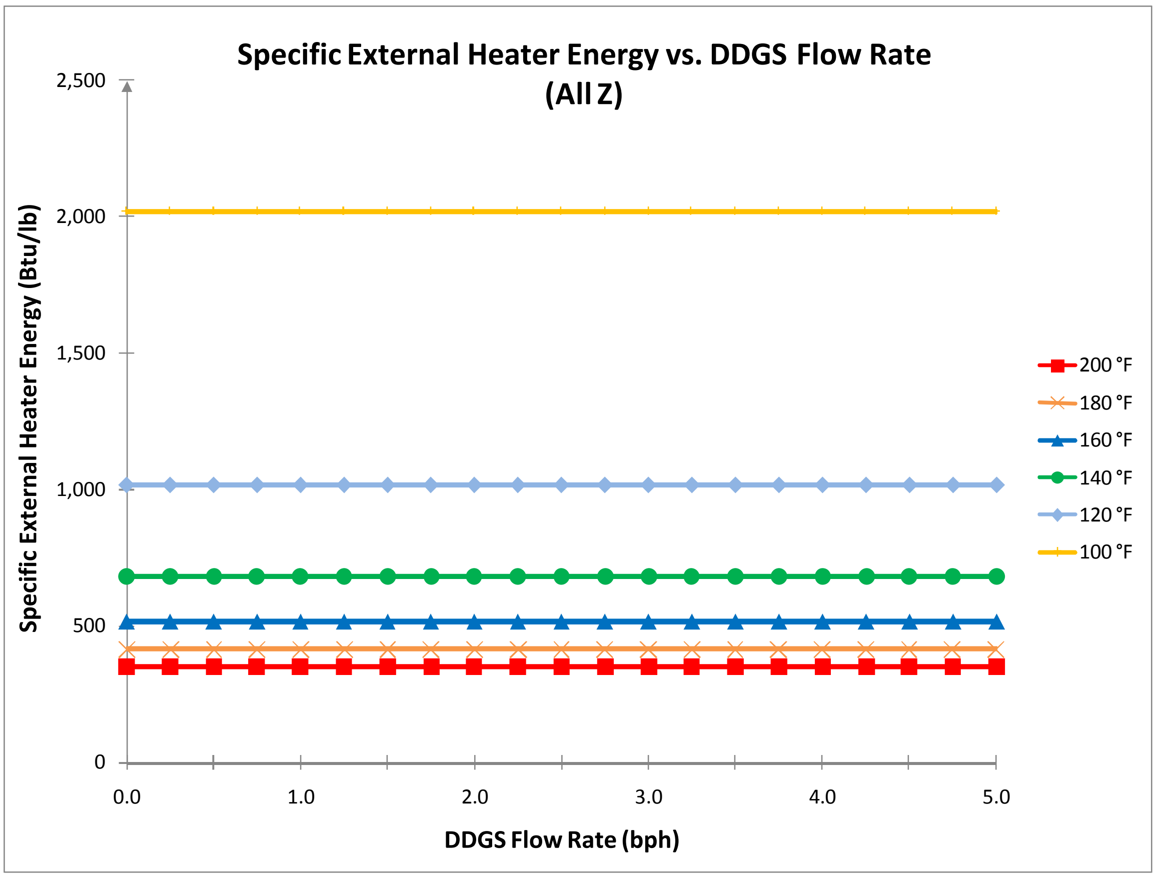

Figure 33: Specific External Heater Energy vs. DDGS Flow Rate

The Specific External Heater Energy also appears independent of DDGS Flow Rate. This trend remains consistent with previous results and expectations as once again the

Intermediate Loop and Air Flow Rates change to accommodate a variation in DDGS Flow Rate. Figure 34 below investigates the dependence of Specific External Heater Energy.

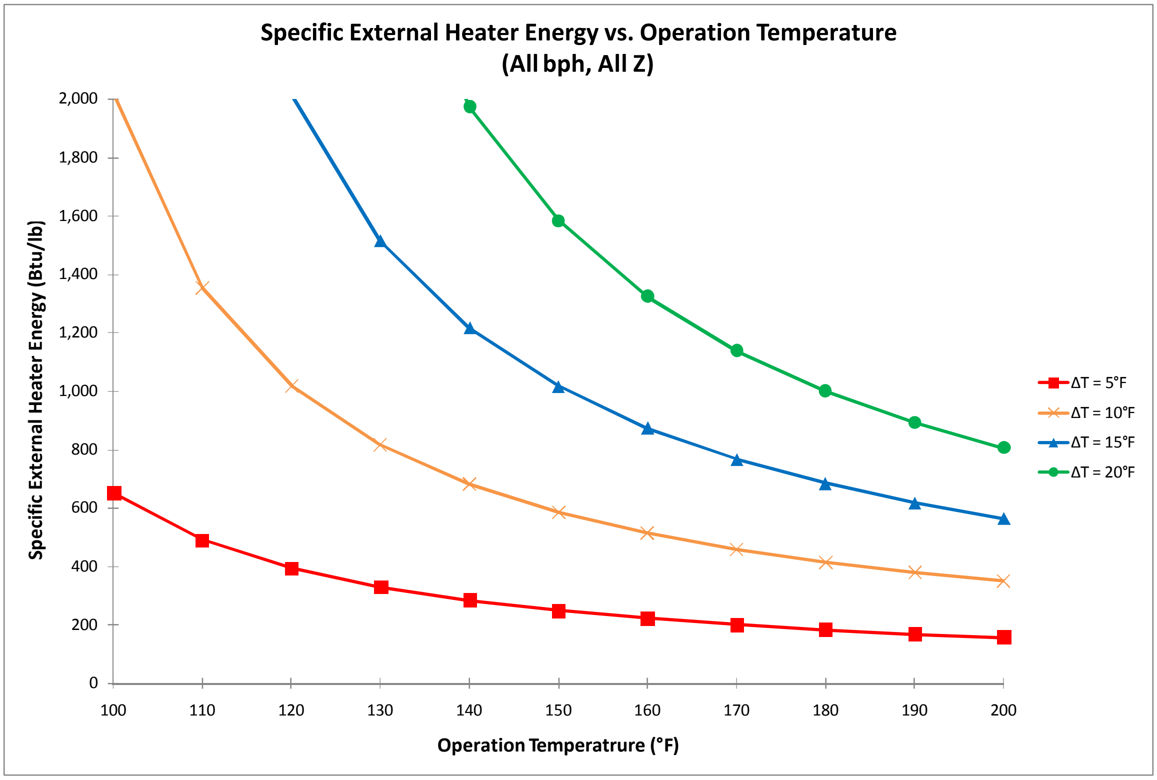

Figure 34: Specific External Heater Energy vs. Operation Temperature

The Specific External Heater Energy decreases as the Operation Temperature increases. As discussed previously, the Intermediate Loop Flow Rate and Air Flow Rate vary slightly with a change in Operation Temperature and it remains largely dependent on DDGS Flow Rate and on DDGS Entering Moisture Content. These observations imply that as the Operation Temperature increases the system increases the amount of energy recovered by the Heat Recovery Unit, since, at a given Operation Temperature, the Intermediate Loop Flow Rate and Air Flow Rates remain constant. This increase in heat recovered decreases the amount of heat required from the External Heater, which provides the decreasing trend in the figure above. The Specific Heater Energy also increases with an increase in Approach Temperature Difference. In essence, the Approach Temperature Difference depicts the inefficiency of the system to transfer all of the heat available from one process to another. In this instance, an increase in Approach Temperature Difference decreases the effectiveness of the Heat Recovery Unit and therefore, increases the amount of External Heater Energy required to maintain operating conditions. Table 22 below contains values for the Specific External Heater Energy as a function of Operation Temperature at different Approach Temperature Differences.

Table 22: Specific External Heater Energy vs. Operation Temperature and Approach Temperature Difference (Btu/lbw)

T_{op} (°F)	ΔT = 5°F	ΔT = 10°F	ΔT = 15°F	ΔT = 20°F	% Change
100	651	2,021	6,002	-	N/A
110	490	1,352	3,010	7,819	94%
120	393	1,017	2,013	3,922	90%
130	329	816	1,514	2,623	87%
140	283	682	1,215	1,973	86%
150	248	586	1,016	1,584	84%
160	221	515	873	1,324	83%
170	200	459	767	1,138	82%
180	183	415	684	999	82%
190	168	379	618	891	81%
200	156	348	564	805	81%
% Change	-76%	-83%	-91%	N/A	N/A

Table 22 includes values for the percent change in Specific External Heater Energy from an Operation Temperature of 100 °F to 200 °F. It also includes values for the percent change in Specific External Heater Energy between an Approach Temperature Difference of 5 °F and 20 °F. The percent change in Specific External Heater Energy as the Operation Temperature changes increases as the Approach Temperature Difference increases. This result reveals that the dependence of Specific External Heater Energy on Operation Temperature increases as the Approach Temperature Difference increases. Particularly, a change in Operation Temperature more has more of an affect on the Specific External Heater Energy at a higher Approach Temperature Difference than at a lower Approach Temperature Difference, which indicates a decrease in Heat Recovery Unit performance as Approach Temperature increases. The percent change in Specific External Heater Energy as it varies with Approach Temperature Difference decreases as Operation Temperature Increases. This suggests that the affects that inefficiencies in the system have on system performance decrease at higher Operation Temperatures.

DDGS Exiting Moisture Content

The DDGS Exiting Moisture Content (Z_{out}) expresses the ratio of water mass (i.e. Moisture) to DDGS mass exiting the drying system. This output describes a wet basis condition as discussed earlier in this report. The model calculates the DDGS Exiting Moisture Content by first determining the DDGS Exiting Moisture Content on a dry basis by dividing the Remaining Moisture Flow Rate by the Dry Grain Flow Rate as follows:

$$x_{out} = \dot{m}_{w,out} / \dot{m}_g \qquad (73)$$

Then, the model converts the dry basis to a wet basis as discussed earlier in this report. The equation below shows the conversion from a dry basis to a wet basis.

$$Z_{out} = \frac{x_{out}}{1 + x_{out}} \qquad (74)$$

Figure 35 below relates the DDGS Flow Rate to the DDGS Exiting Moisture Content.

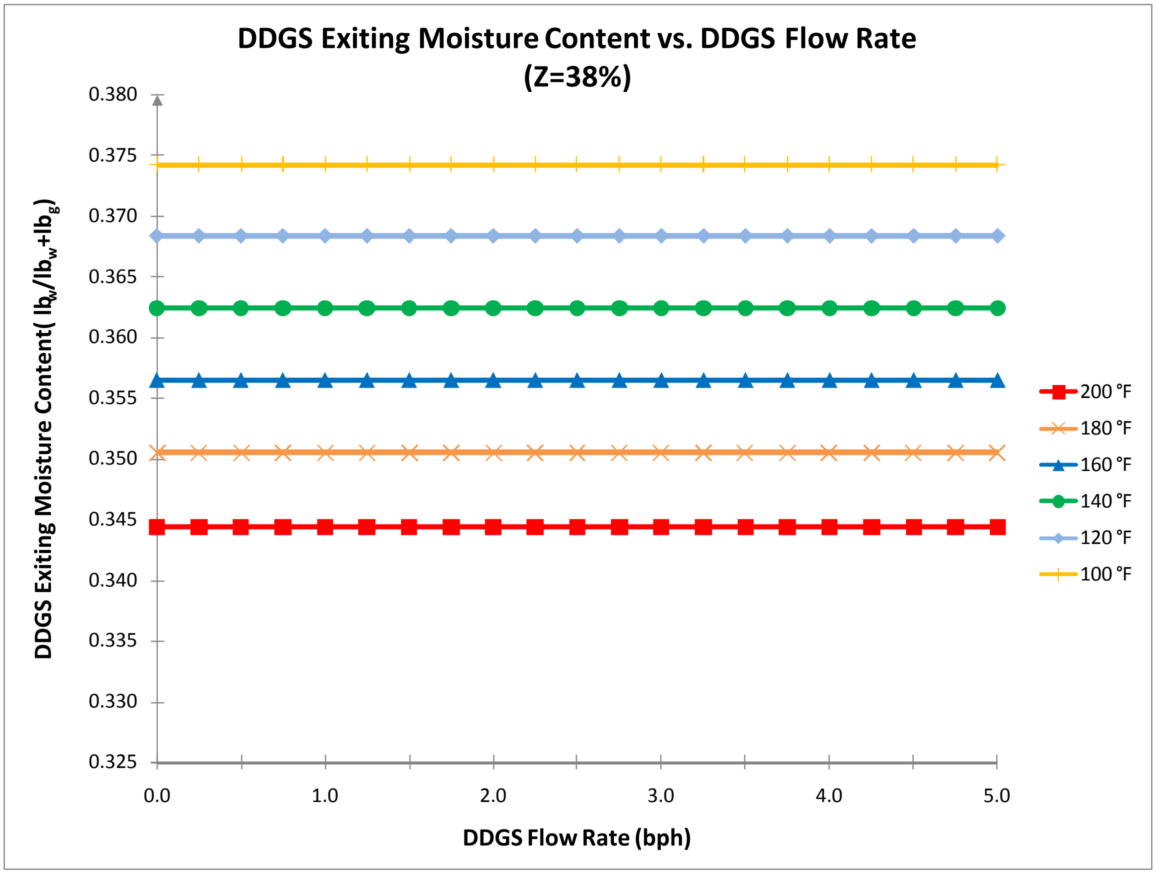

Figure 35: DDGS Exiting Moisture Content vs. DDGS Flow Rate

As seen in the plot above, the DDGS Exiting Moisture Content is independent of the DDGS Flow Rate. Interestingly, both of the inputs of DDGS Exiting Moisture Content, specifically the Dry Grain Flow Rate and the Remaining Moisture Flow Rate, are dependent on DDGS Flow Rate. As discussed earlier, both of these inputs increase as DDGS Flow Rate increases, therefore, the rate of increase of both of these inputs must be the same to allow for a constant DDGS Exiting Moisture Content value. Figure 36 below shows the relationship between DDGS Exiting Moisture Content and Operation Temperature.

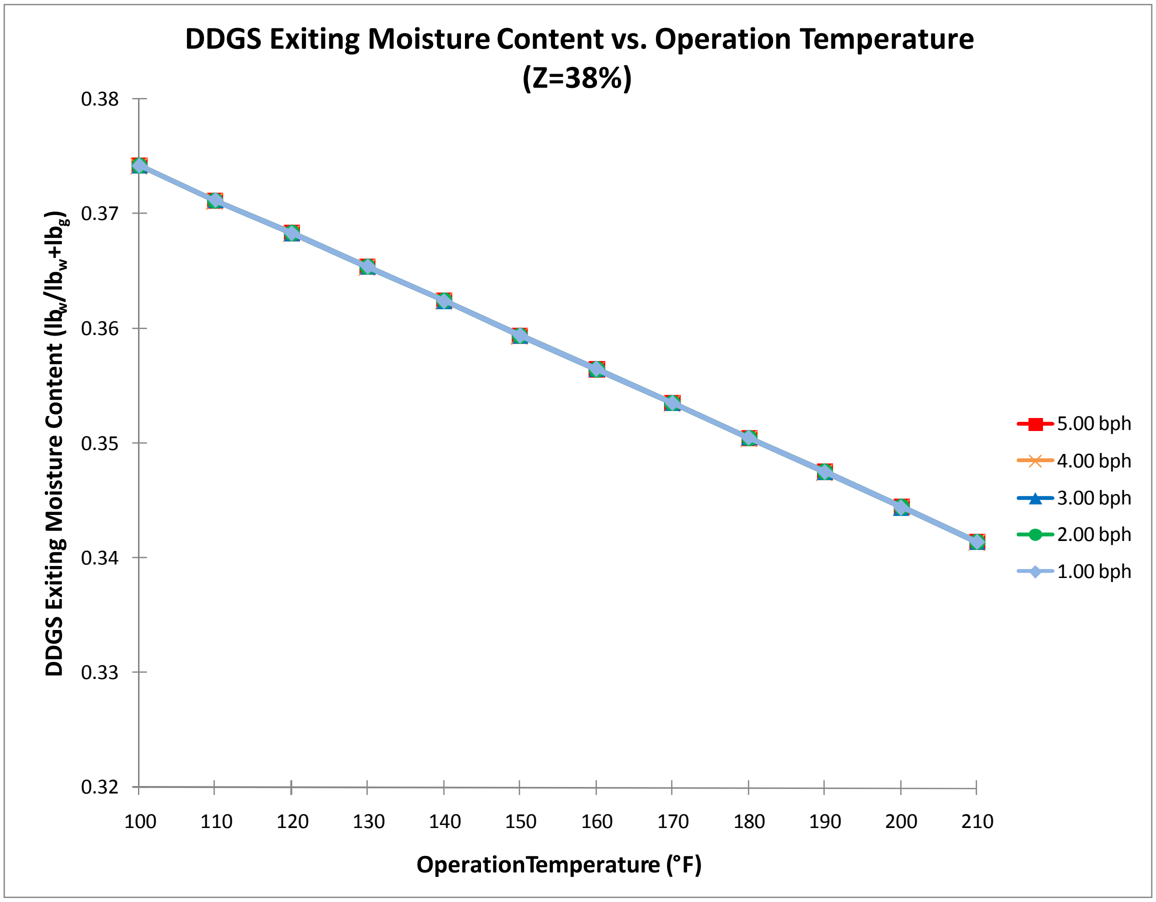

Figure 36: DDGS Exiting Moisture Content vs. Operation Temperature

The figure above shows that the DDGS Exiting Moisture Content is linearly proportionate to the Operation Temperature. This result remains consistent with expectations. The Dry Grain Flow Rate is constant with an increase in Operation Temperature and the Remaining Moisture Flow Rate increases with Operation Temperature, therefore the ratio of these variables results in a decrease in DDGS Exiting Moisture Content at higher Operation Temperatures. Figure 37 below represents the interaction between DDGS Exiting Moisture Content and DDGS Entering Moisture Content.

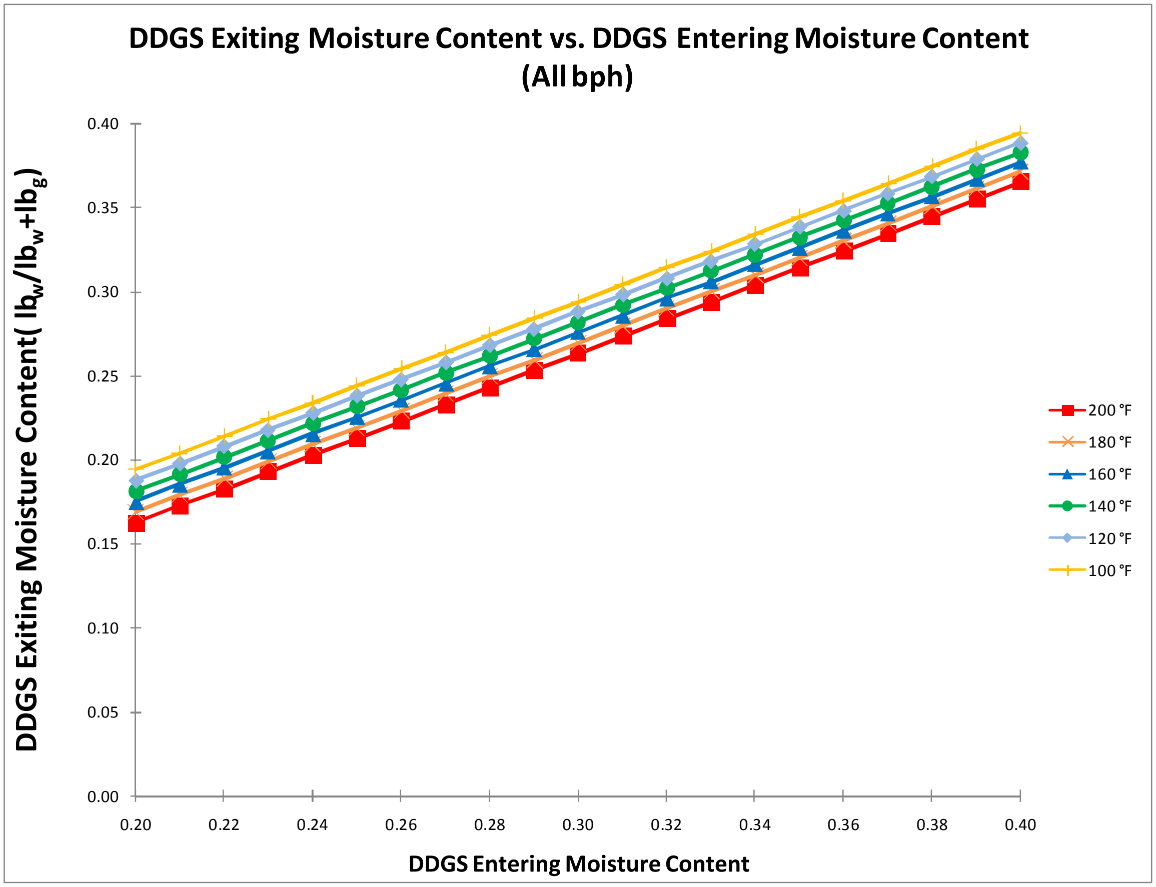

Figure 37: DDGS Exiting Moisture Content vs. DDGS Entering Moisture Content

The DDGS Exiting Moisture Content increases as the DDGS Entering Moisture Content increases. This result alone seems intuitive, as when a higher amount of moisture enters the system, a higher amount of moisture leaves the system.

Table 23 below contains values for DDGS Exiting Moisture Content as it relates to Operation Temperature and DDGS Entering Moisture Content.

Table 23: DDGS Exiting Moisture Content vs.
Operation Temperature and DDGS Entering Moisture Content ($lb_w/(lb_w+lb_g)$)

Z/T_{op}	100	120	140	160	180	200	Diff
0.20	0.19	0.19	0.18	0.18	0.17	0.16	-3.1%
0.22	0.21	0.21	0.20	0.20	0.19	0.18	-3.1%
0.24	0.23	0.23	0.22	0.22	0.21	0.20	-3.1%
0.26	0.25	0.25	0.24	0.24	0.23	0.22	-3.1%
0.28	0.27	0.27	0.26	0.26	0.25	0.24	-3.1%
0.30	0.29	0.29	0.28	0.28	0.27	0.26	-3.1%
0.32	0.31	0.31	0.30	0.30	0.29	0.28	-3.1%
0.34	0.33	0.33	0.32	0.32	0.31	0.30	-3.0%
0.36	0.35	0.35	0.34	0.34	0.33	0.32	-3.0%
0.38	0.37	0.37	0.36	0.36	0.35	0.34	-3.0%
0.40	0.39	0.39	0.38	0.38	0.37	0.36	-2.9%
Diff	20%	20%	20%	20%	20%	20%	N/A

Table 23 possesses values for the difference in DDGS Exiting Moisture Content as the DDGS Entering Moisture Content varies from 20% to 40%. This difference is consistent with the Difference due to changes in Operation Temperature as when the difference in DDGS Entering Moisture Content is 20% the difference in DDGS Exiting Moisture Content is 20%. In addition, a 20 °F increase in Operation Temperature decreases the DDGS Exiting Moisture Content by about 0.63%.

Table 23 includes the difference in DDGS Exiting Moisture Content as the Operation Temperature changes from 100 °F to 200 °F at each DDGS Entering Moisture Content. At each value of DDGS Entering Moisture Content there exists about a 3% drop in DDGS Exiting Moisture Content. Figure 38 below investigates the drop in DDGS Moisture Content from the DDGS Entrance to the DDGS Exit as it varies with Operation Temperature at different reference Approach Temperature Differences.

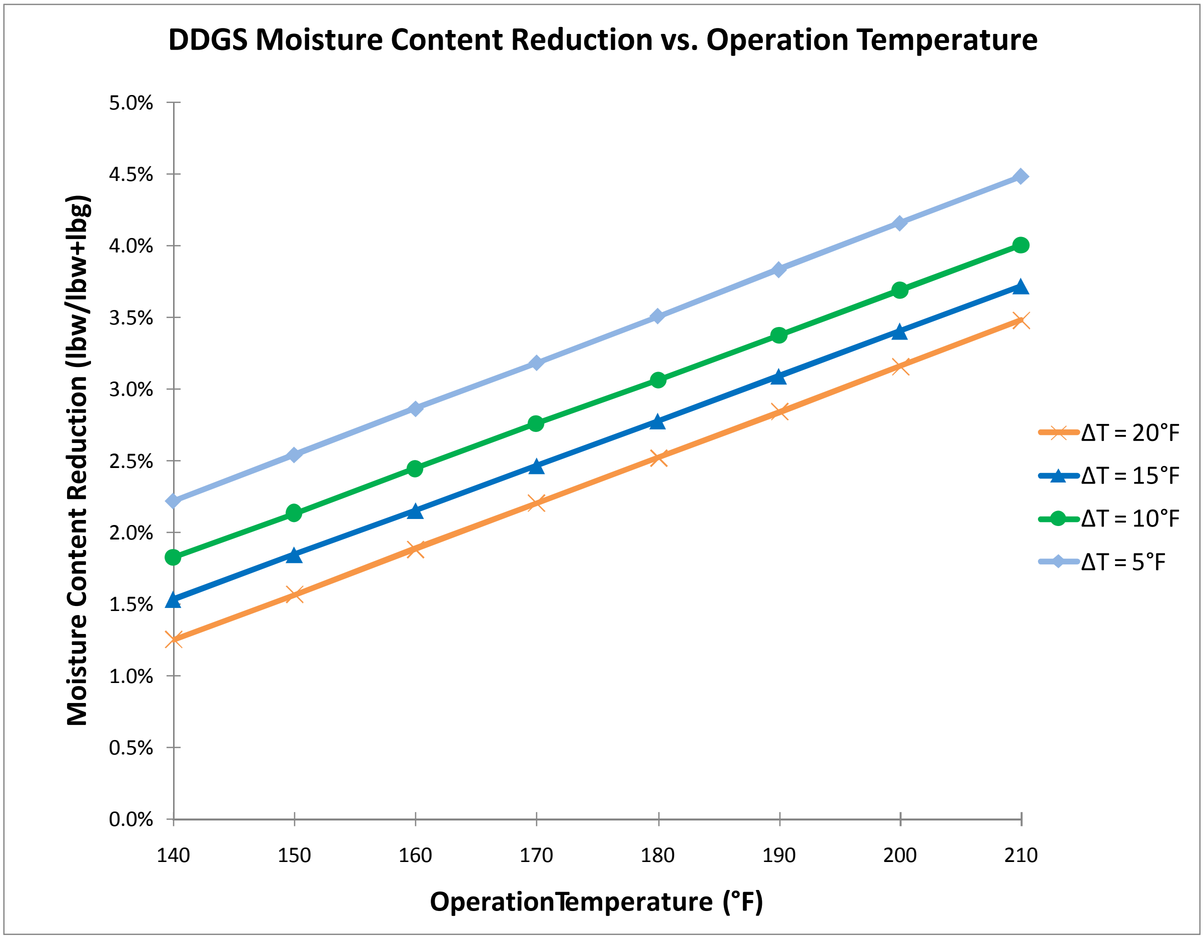

Figure 38: Moisture Content Drop vs. Operation Temperature

The drop in DDGS Moisture Content increases as the Operation Temperature increases. This result provides additional proof that as the Operation Temperature increases, the amount of grain moisture removed by the DDGS Drying System increases. Additionally, as the reference Approach Temperature decreases the drop in DDGS Moisture Content increases indicating that higher Operation Temperatures result in higher amounts of grain moisture removal. This figure points out that even at an Approach Temperature Difference of 5 °F with an operation of 210 °F only reduces the DDGS Moisture Content by 4.5%, which suggests that several stages of heating stages may be required.

Moisture Removed-Air Ratio

The Moisture Removed-Air Ratio ($R_{M/A}$) signifies the mass or mass flow ratio of the moisture removed from the DDGS in the system to the air flowing through the system. The equation below shows the calculation of this ratio.

$$R_{M/A} = \frac{\dot{m}_{dried}}{\dot{m}_{air}} \qquad (75)$$

Figure 39 reveals the relationship between Moisture Removed-Air Ratio and DDGS Flow Rate.

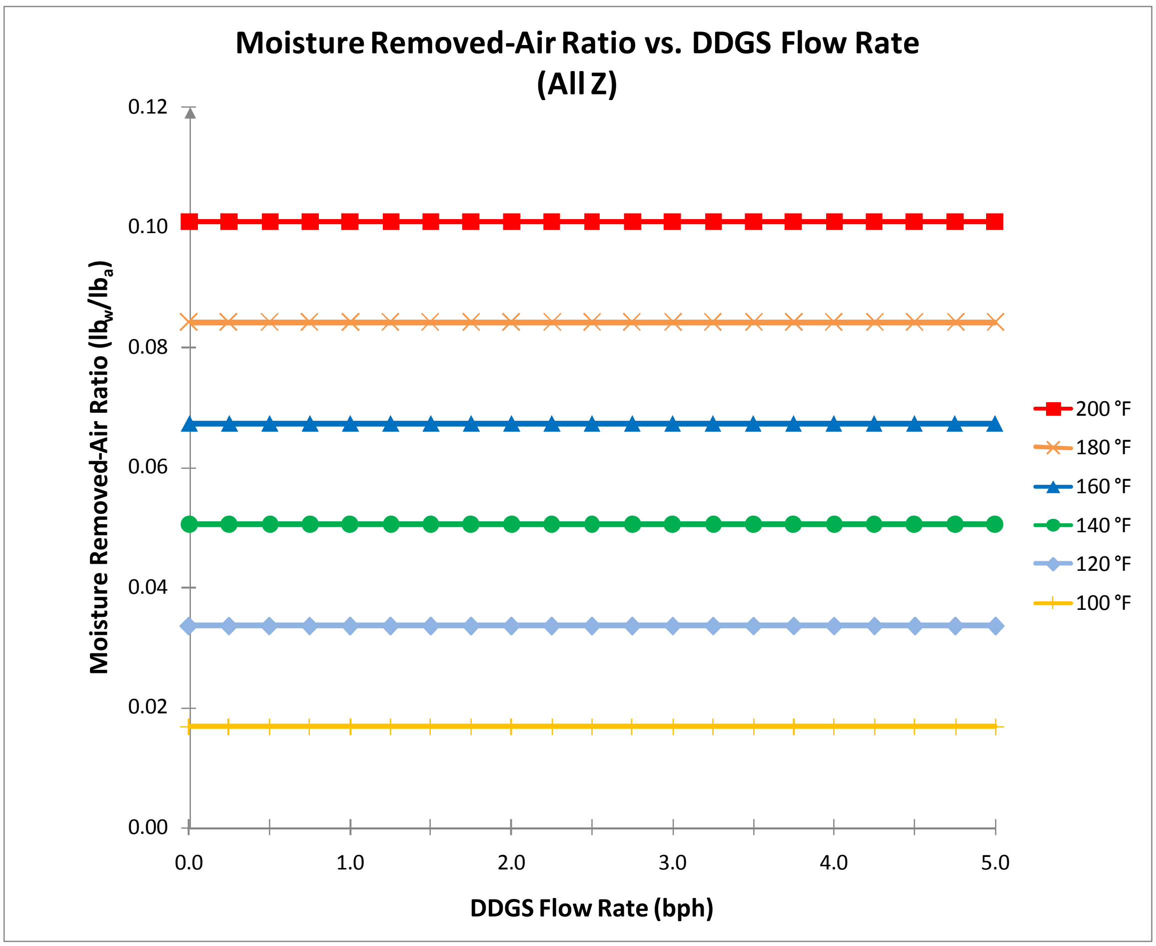

Figure 39: Moisture Removed-Air Ratio vs. DDGS Flow Rate

The Moisture Removed-Air Ratio remains constant with a change in DDGS Flow Rate. This result occurs because the Air Flow Rate changes with the DDGS Flow Rate and therefore, the amount of moisture removed remains the same. Figure 40 below conveys the connection between Moisture Removed-Air Ratio and DDGS Entering Moisture Content.

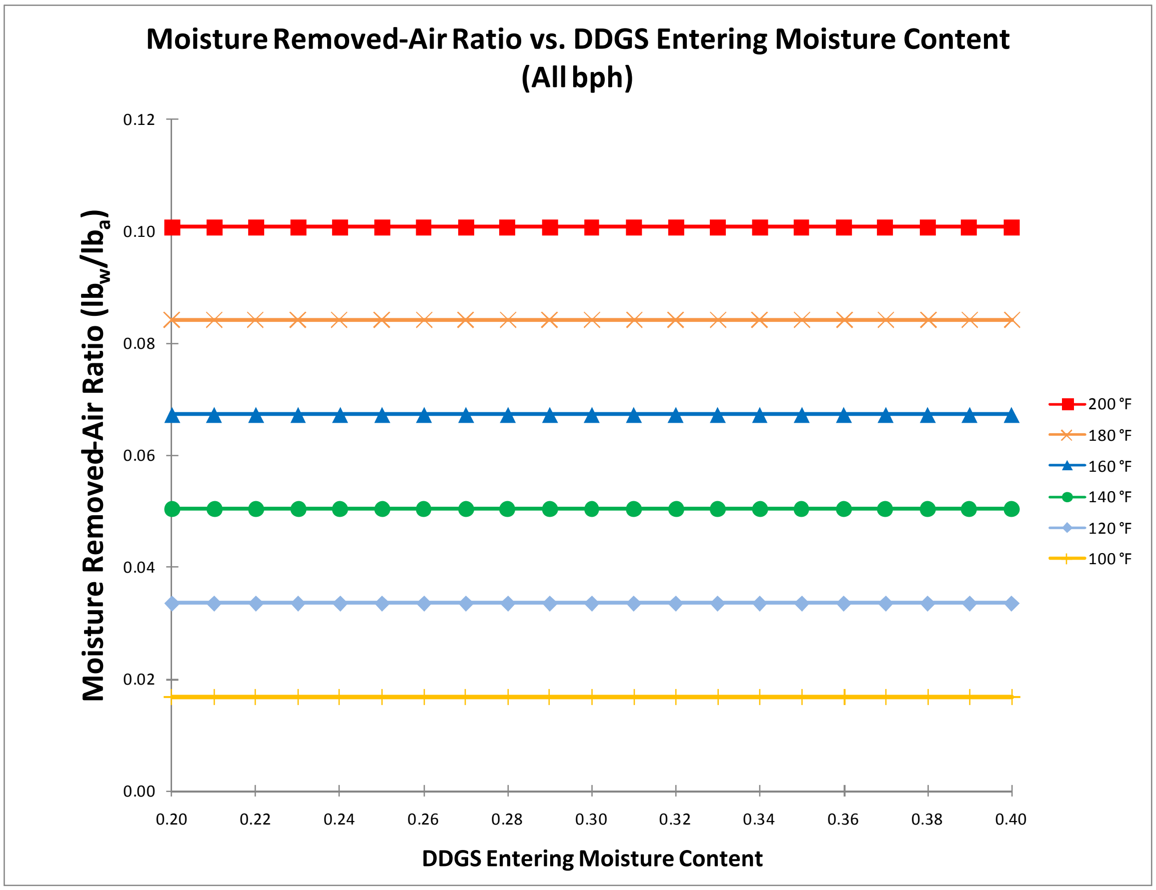

Figure 40: Moisture Removed-Air Ratio vs. DDGS Entering Moisture Content

The Moisture Removed-Air Ratio does not change with a change in DDGS Entering Moisture Content. As discussed earlier in this report, the Air Flow Rate varies with a change in DDGS Entering Moisture Content. Also, the Moisture Removal Flow Rate depends on the DDGS Entering Moisture Content. Therefore, the calculation of the Air Flow Rate and Moisture Removal Flow Rate already accounts for the variation in DDGS Entering Moisture Content and the ratio of these two output remains constant. Figure 41 illustrates the interaction between Moisture Removed-Air Ratio and Operation Temperature.

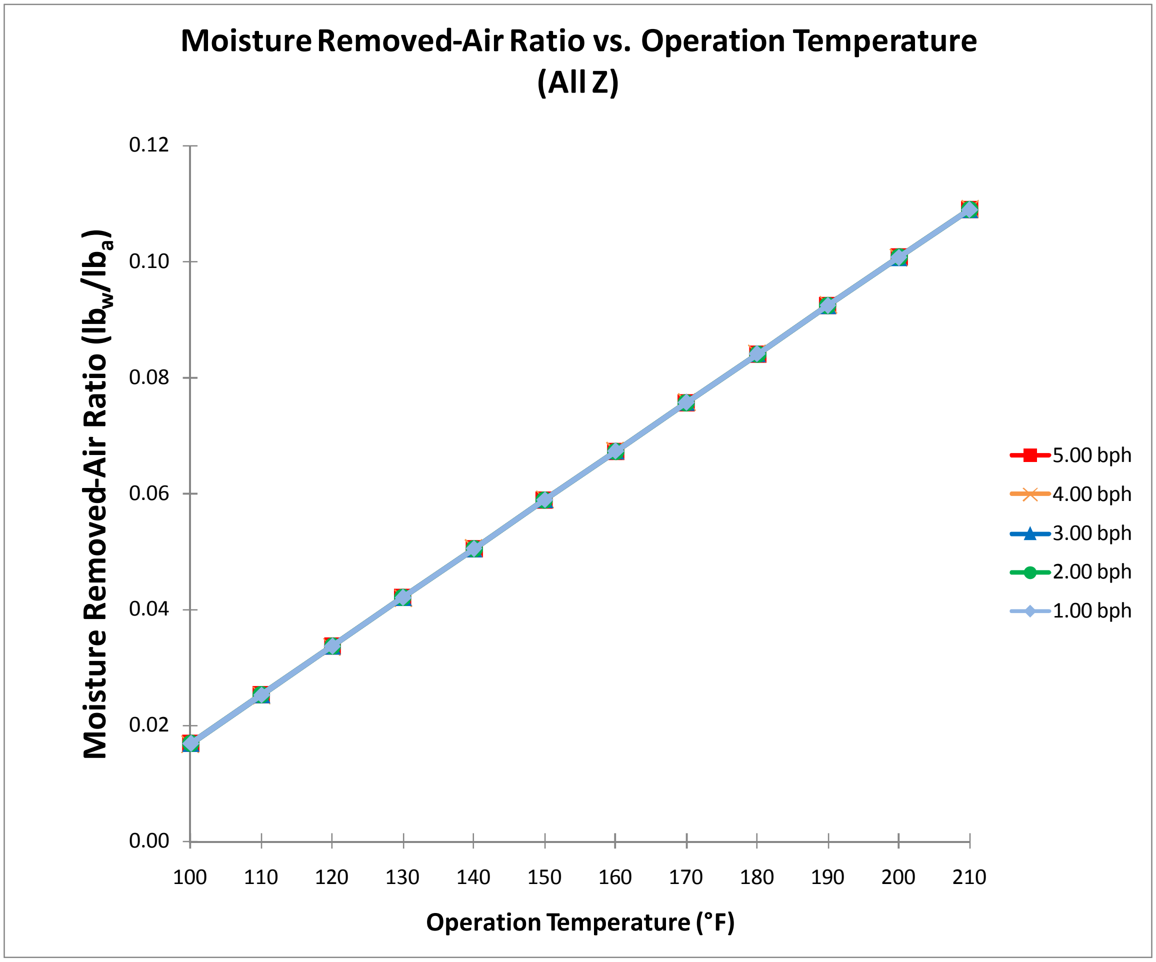

Figure 41: Moisture Removed-Air Ratio vs. DDGS Operation Temperature

The Moisture Removed-Air Ratio increases as Operation Temperature increases. This trend reveals that higher operation temperatures increase the effectiveness of the drying system. This increase in effectiveness results in an increase in water vapor delivered to the Heat Recovery Unit. This results in an increased heat recovery, which results in a higher system efficiency. Table 24 contains values for Moisture Removed-Air Ratio as it varies with Operation Temperature.

Table 24: Moisture Removed-Air Ratio vs. Operation Temperature

$T_{operation}$ (°F)	Moisture Removed-Air Ratio (lb_w/lb_a)
100	0.017
110	0.025
120	0.034
130	0.042
140	0.050
150	0.059
160	0.067
170	0.076
180	0.084
190	0.092
200	0.101
% Change	83.4%

Table 24 shows that the Moisture Removed-Air Ratio increases by 83.4% when the Operation Temperature increases from 100 °F to 200 °F, which demonstrates that an increase in Operation Temperature greatly increases the effectiveness of the Drying System.

Thermal Efficiency

The Thermal efficiency ($\eta_{Thermal}$) is defined as the ratio of the amount of energy used to evaporate the DDGS moisture removed during the drying process to the amount of energy available from the intermediate product heater. It provides a means of determining what fraction of the total energy provided for drying the system uses for DDGS moisture evaporation. The equation below shows the expression for Thermal Efficiency.

$$\eta_{Thermal} = \frac{\dot{m}_{w,dried} h_{fg}}{\dot{m}_{loop} \left(h_{f,c} - h_{f,a} \right)} \qquad (76)$$

Using this definition, values for the Thermal Efficiency of the system were found as a function of Operation Temperature, DDGS Flow Rate, and DDGS Entering Moisture Content.

Figure 42 below shows the relationship between Thermal Efficiency and DDGS Flow Rate.

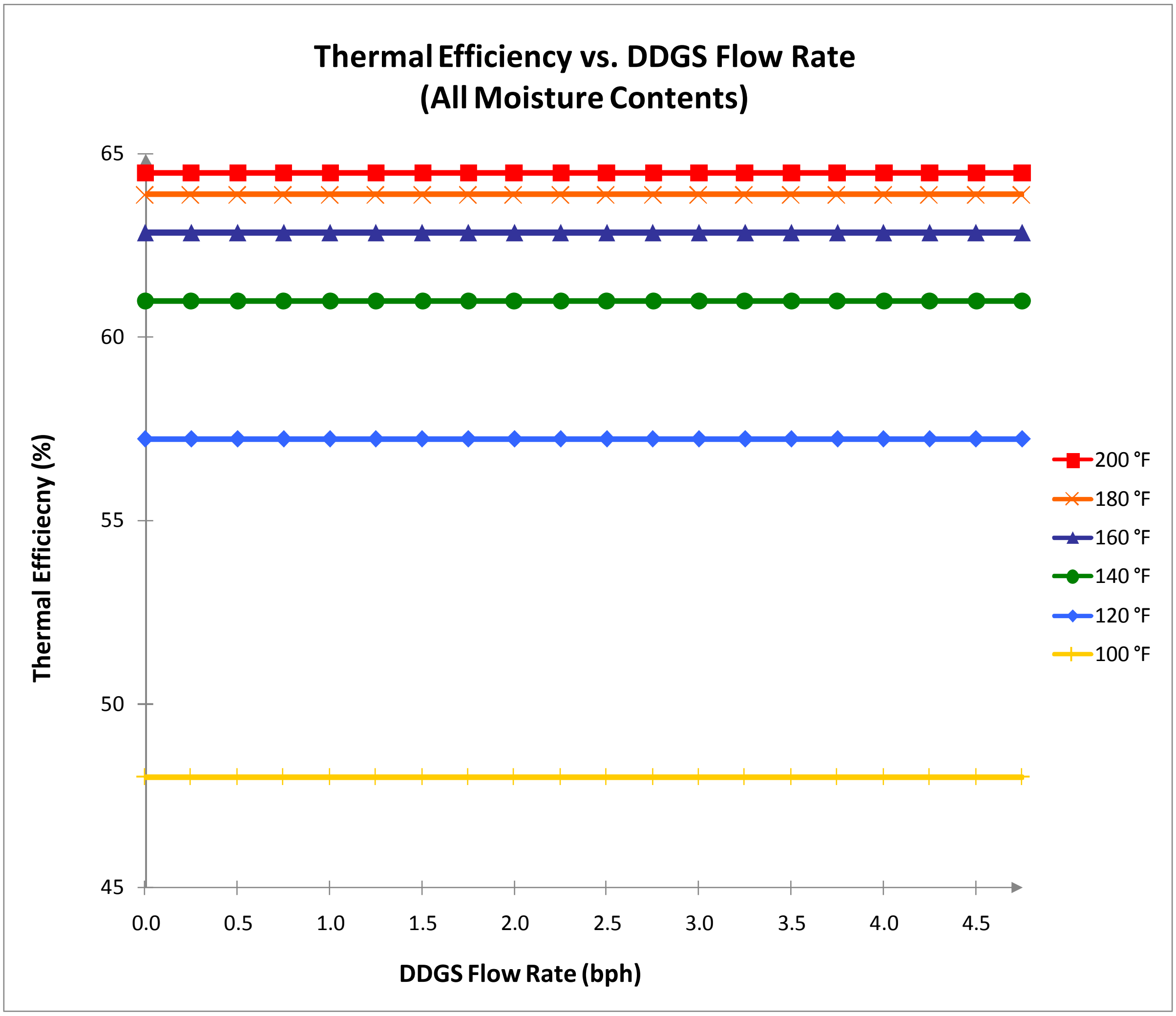

Figure 42: Thermal Efficiency vs. DDGS Flow Rate

As seen in the graph, the horizontal lines at each operation temperature indicate that the Thermal Efficiency is constant over all DDGS flow rates. This suggests that the Thermal Efficiency of the system is independent of DDGS Flow Rate. This is consistent with the method used to model the drying system in that the model adjusts the air and intermediate loop flow rates as the DDGS Flow Rate adjusts, therefore the heat provided by the drying system and the heat utilized by the product should remain independent of rate of DDGS flow, hence a constant Thermal Efficiency

Figure 43 below relates the Thermal Efficiency to moisture content of the entering DDGS as seen below.

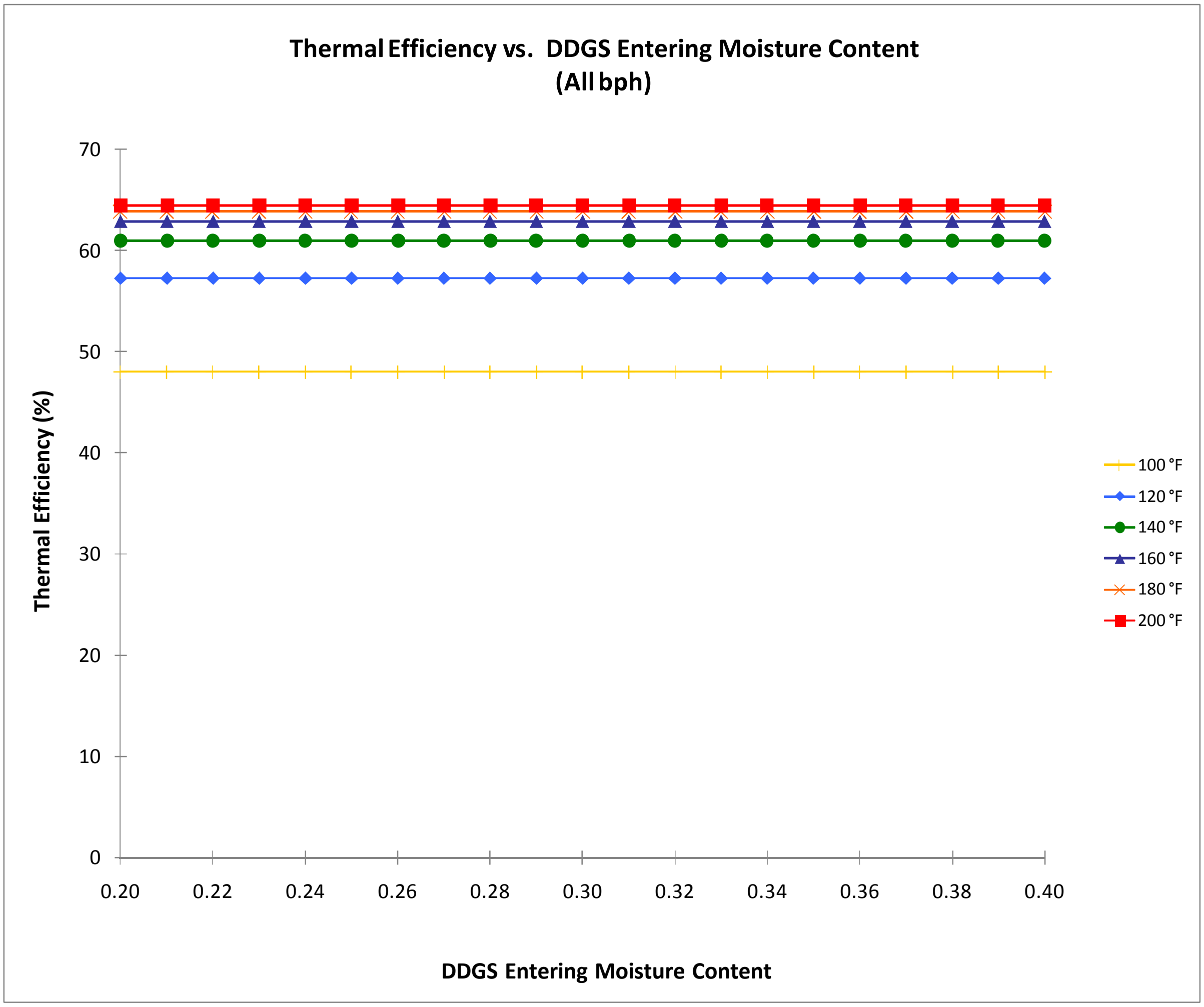

Figure 43: Thermal Efficiency vs. DDGS Entering Moisture Content

Again, the Thermal Efficiency forms horizontal lines on the graph above. This indicates that the Thermal Efficiency is independent of the DDGS Entering Moisture Content as the values are constant for each operation temperature shown. As mentioned before, the model adjusts the air and intermediate loop to account for a change in the DDGS Flow Rate, therefore the Thermal Efficiency is not a function of DDGS Entering Moisture Content as defined by the system model.

Figure 44 below shows the Thermal Efficiency as a function of Operation Temperature.

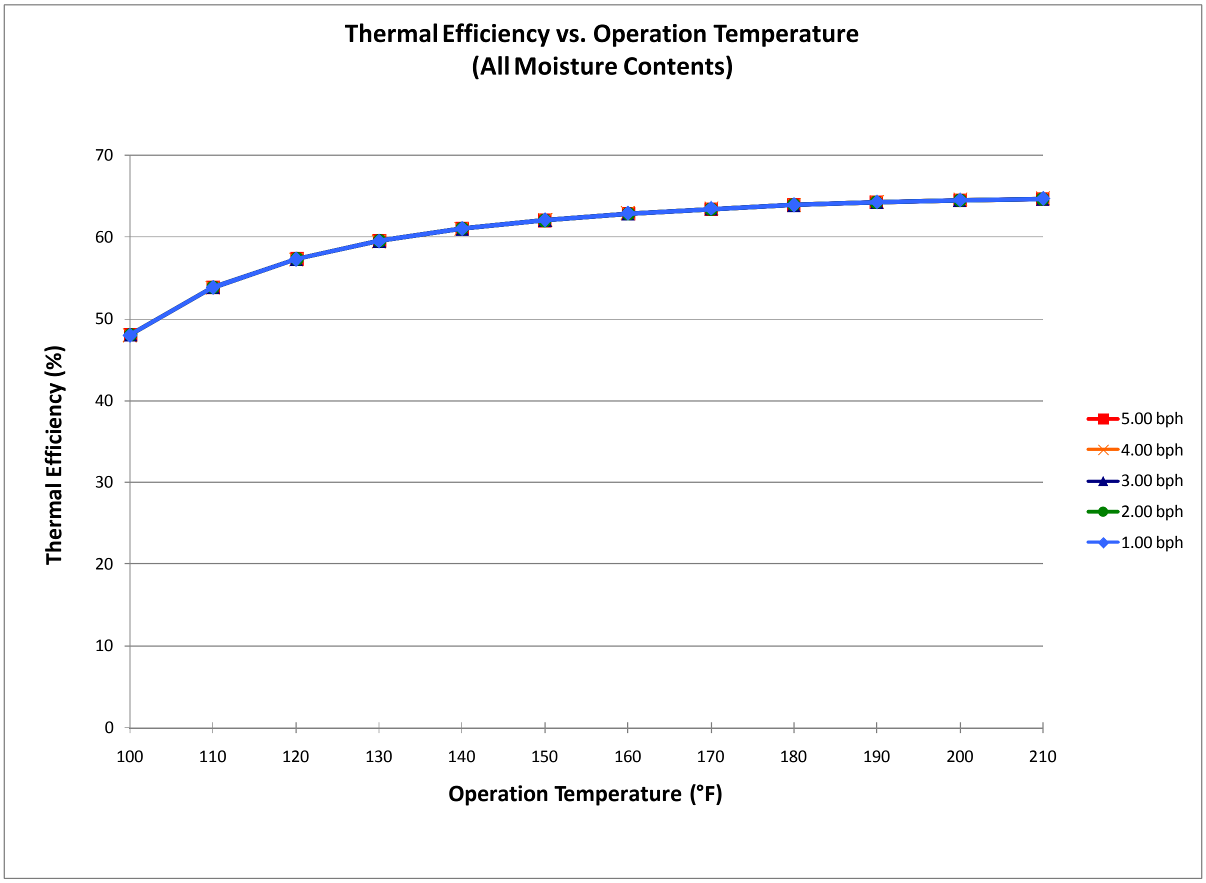

Figure 44: Thermal Efficiency vs. Operation Temperature

As seen in Figure 44 above and Table 25 to the below, the Thermal Efficiency is dependant of the system Operation Temperature. The value of Thermal Efficiency is 48% at 100 °F and asymptotes toward 65% as the Operation Temperature increases to 200 °F. This trend shows that higher Operation Temperatures yield higher efficiencies. The table below also displays the percent change in Thermal efficiency as the Operation Temperature increases. The percent increase in Thermal Efficiency decreases as the Operation Temperature increases. This result indicates that increasing the Operation Temperature does not uniformly increase the Thermal Efficiency, which is useful when choosing an Operation Temperature as the cost of supplying the additional external energy required to raise the Operation Temperature may be more than the potential energy savings that result from an increase in Thermal Efficiency.

Table 25: Thermal Efficiency vs. Operation Temperature

$T_{Operation}$	$\eta_{Exergetic}$	$\%_{Change}$
100 °F	48.00%	N/A
110 °F	53.83%	12.15%
120 °F	57.24%	6.33%
130 °F	59.45%	3.86%
140 °F	60.97%	2.56%
150 °F	62.05%	1.77%
160 °F	62.84%	1.27%
170 °F	63.44%	0.95%
180 °F	63.88%	0.69%
190 °F	64.21%	0.52%
200 °F	64.46%	0.39%
210 °F	64.64%	0.28%

Recovery Efficiency

The Recovery Efficiency (η_{Recovery}) defines the ratio of energy recovered by the Intermediate Loop to the energy expended by the Intermediate Loop into the Product Heater. This efficiency characterizes the effectiveness of the Heat Recovery Unit. The expression below shows the calculation of Recovery Efficiency.

$$\eta_{\text{Recovery}} = \frac{\dot{m}_{loop}\left(h_{f,b} - h_{f,a}\right)}{\dot{m}_{loop}\left(h_{f,c} - h_{f,a}\right)} \qquad (77)$$

Figure 45 shows the relationship between Recovery Efficiency and DDGS Flow Rate.

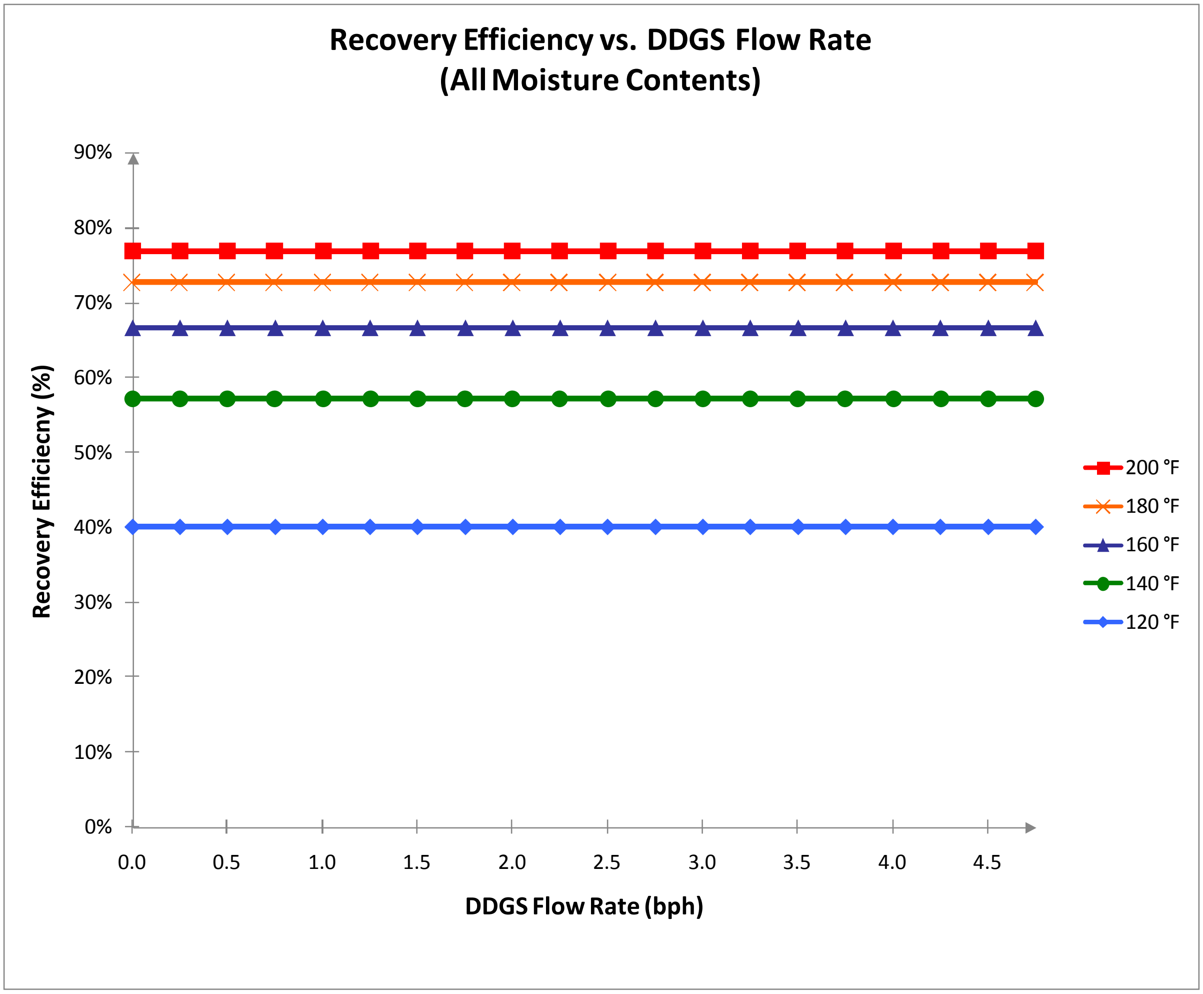

Figure 45: Recovery Efficiency vs. DDGS Flow Rate

The Recovery Efficiency does not vary with DDGS Flow Rate. Once again, the steady-state flow rates of air and intermediate loop water adjust with the DDGS flow, and hence the Recovery Efficiency of the system remains unchanged. Figure 46 displays the interaction between the Recovery Efficiency and DDGS Entering Moisture Content.

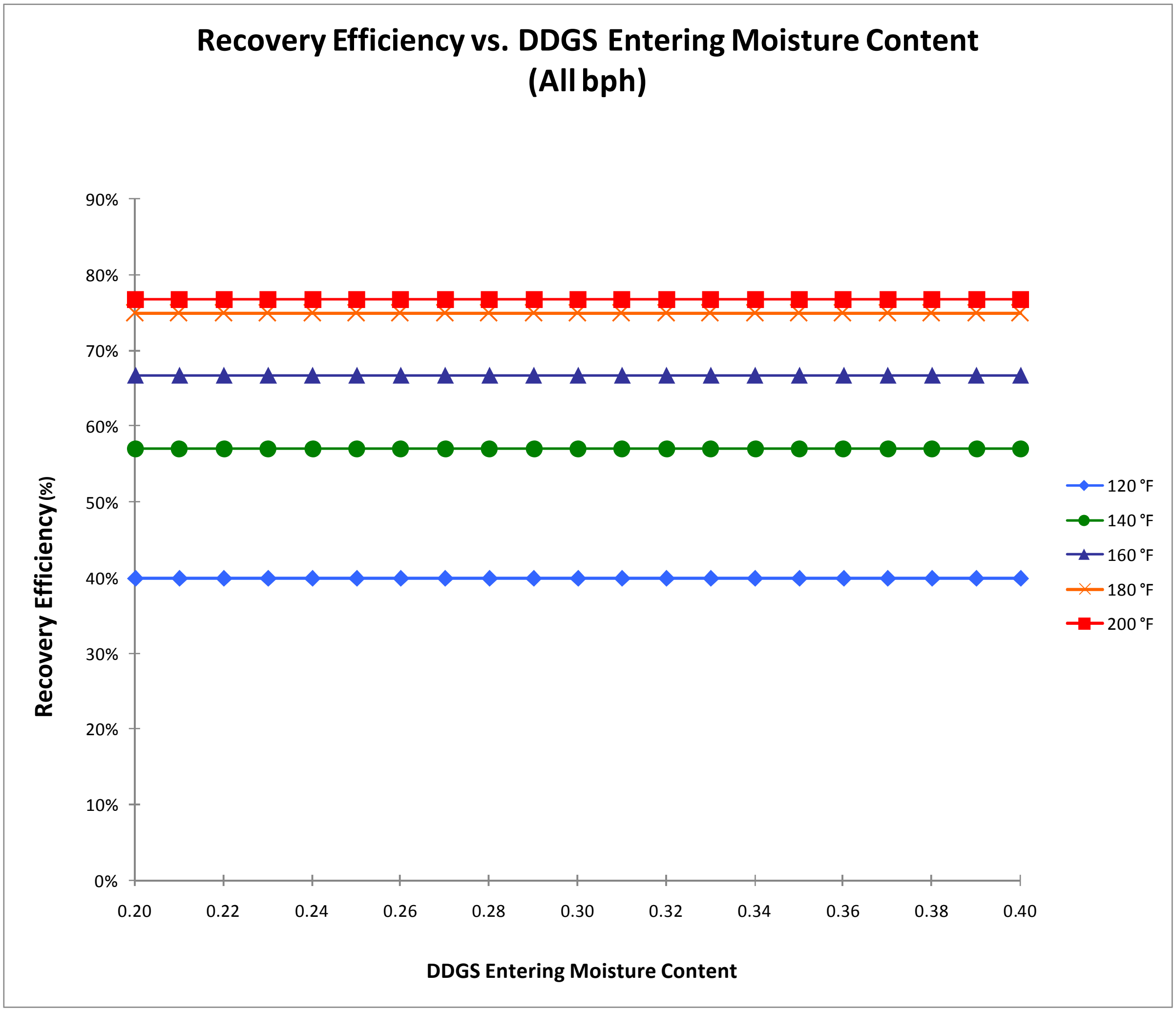

Figure 46: Recovery Efficiency vs. DDGS Entering Moisture Content

The Recovery Efficiency remains unchanged with DDGS Entering Moisture Content. The system model modifies the Air Flow Rate and Intermediate Loop Flow Rate to account for alterations in DDGS Entering Moisture content. This action results in an unchanged Recovery Efficiency. Figure 47 below illustrates the relationship between Recovery Efficiency and Operation Temperature

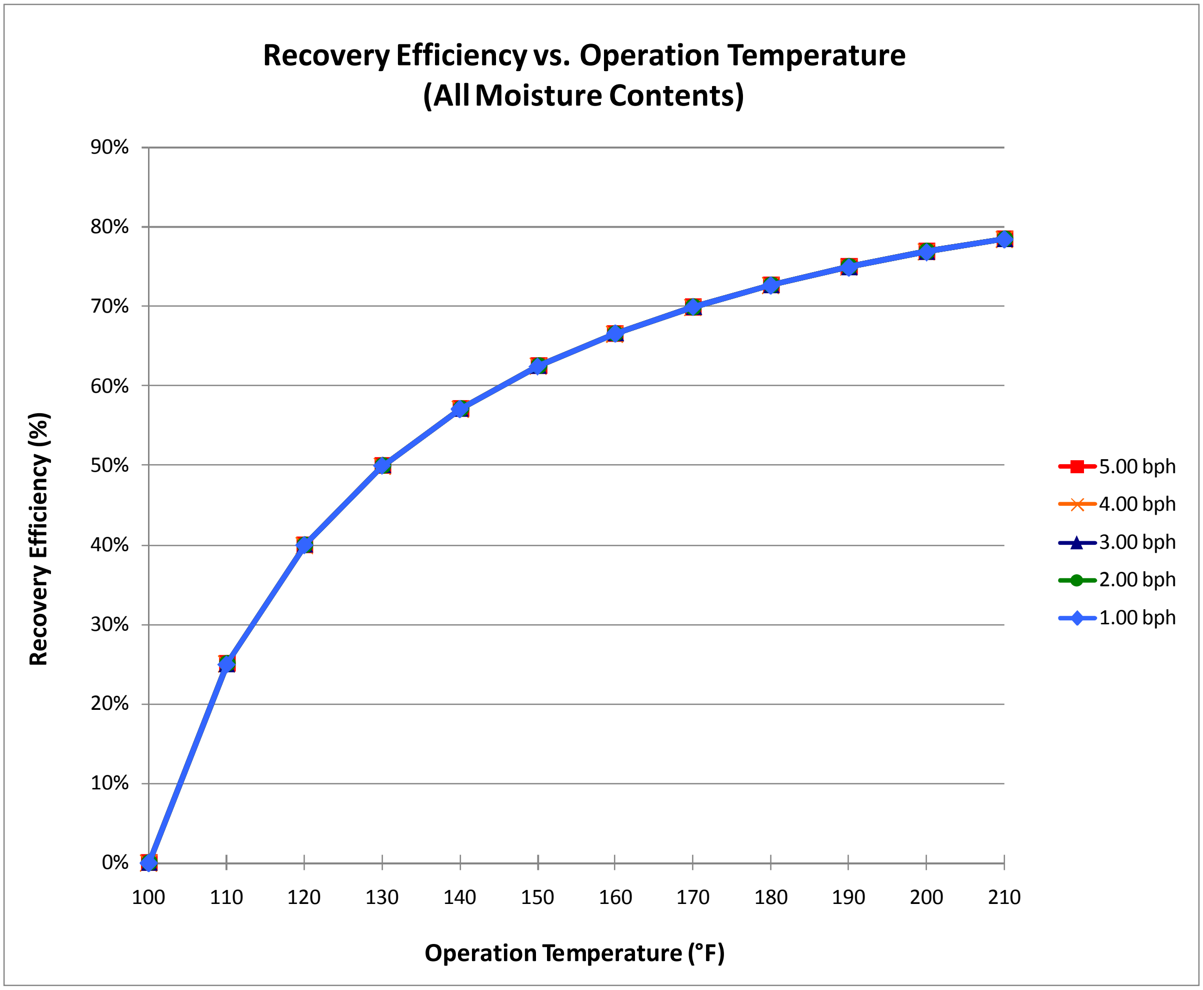

Figure 47: Recovery Efficiency vs. Operation Temperature

Recovery Efficiency exponentially increases with an increase in Operation Temperature. An increase in Operation Temperature increases the amount of water vapor removed from the DDGS Product. This increases the amount of water vapor that travels through the Heat Recovery Unit and enables an increase in water vapor condensation. This increased moisture condensation increases the amount of heat recovered and hence, increases the Recovery Efficiency. Table 26 contains values for the Recovery Efficiency as it varies with Operation Temperature.

Table 26: Recovery Efficiency vs. Operation Temperature

Operation Temperature	$\eta_{Recovery}$	**% Decrease**
120 °F	40.01%	-
130 °F	50.01%	24.99%
140 °F	57.15%	14.28%
150 °F	62.50%	9.36%
160 °F	66.66%	6.66%
170 °F	69.98%	4.98%
180 °F	72.69%	3.87%
190 °F	74.95%	3.11%
200 °F	76.86%	2.55%
% Change	**92.10%**	-

As seen in Table 26 the Recovery Efficiency increases from 40% at 120 °F to around 77% at 200 °F. This change represents an increase in Recovery Efficiency of 92% as Operation Temperature increases from 100 ’F to 200 °F. As with the Thermal Efficiency, the Recovery Efficiency asymptotes near a value of 200 °F. The incremental increase in Recovery Efficiency also decreases as the Operation Temperature increases, which also indicates possible balances between increased Recovery Efficiency and increased Operational Cost.

External Efficiency

The External Efficiency ($\eta_{External}$) describes how well the drying system utilizes the heat provided for drying. The ratio of external heat provided to the system per pound of moisture removed divided by the amount of heat required to raise the DDGS up to the operation temperature added to the amount of energy required to change the phase of the moisture defines the External Efficiency. Equation 78 below shows this calculation.

$$\eta_{External} = 1 - \left[\frac{q_{heater}}{h_{fg} + (h_2 - h_1)} \right] \qquad (78)$$

Figure 48shows the relationship between the External Efficiency and DDGS Flow Rate

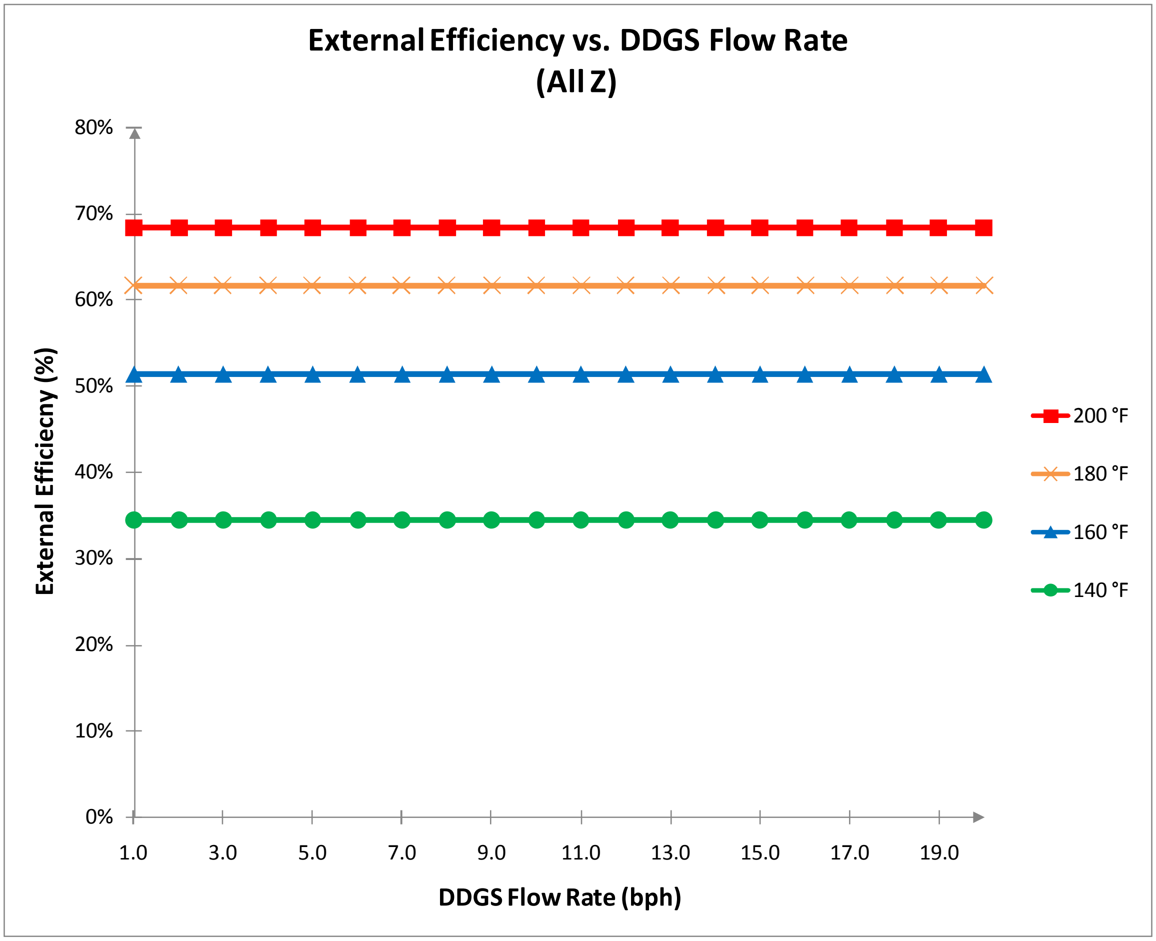

Figure 48: External Efficiency vs. DDGS Flow Rate

The External Efficiency remains independent of DDGS Flow Rate. As with other outputs discussed in this report, the drying system model adjusts the Air and Intermediate Loop Flow Rates to accommodate for changes in the DDGS Flow. This fact causes the External Efficiency to remain unaffected by fluctuations in the DDGS Flow Rate. Figure 49 conveys the interaction between the External Efficiency and the DDGS Entering Moisture Content.

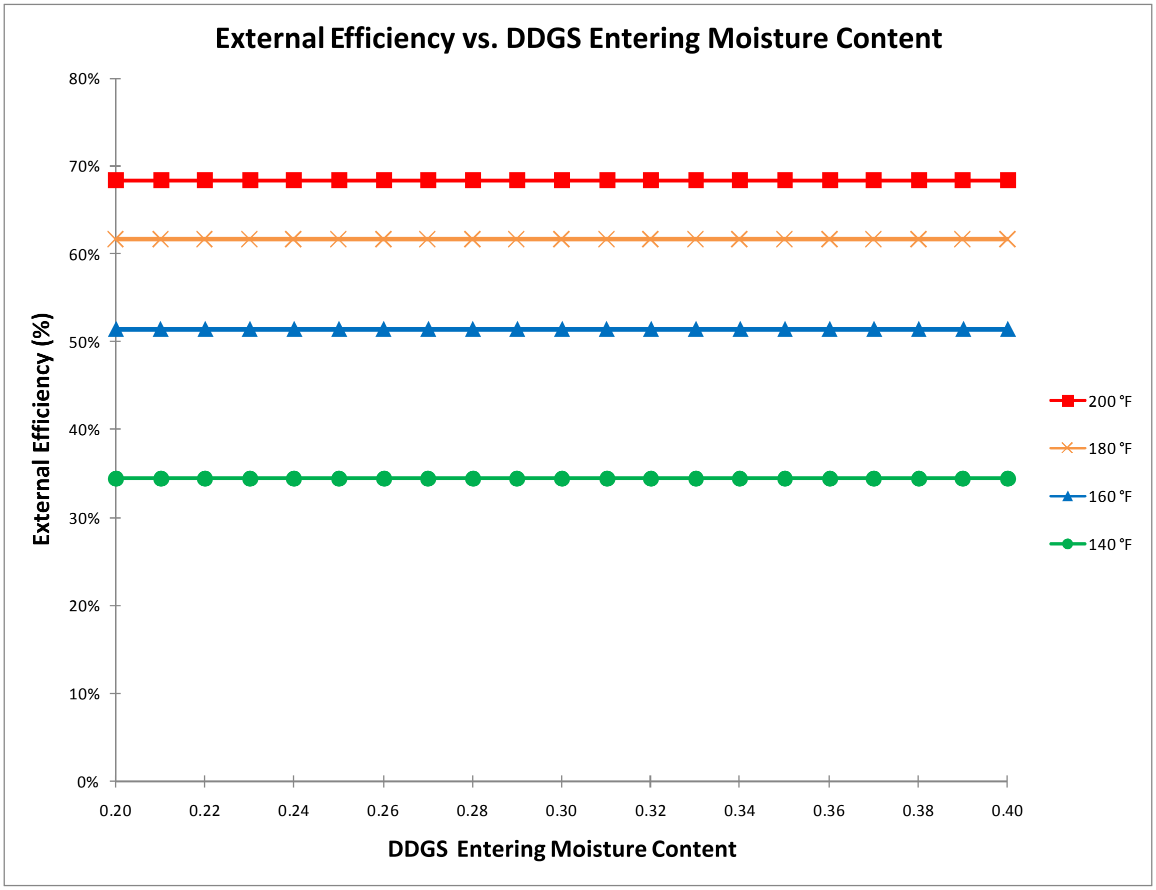

Figure 49: External Efficiency vs. DDGS Entering Moisture Content

The External Efficiency remains unaffected by changes in the DDGS Entering Moisture Content. Again, the Air and Intermediate Loop Water Flow Rates adjust to account for the changes in moisture entering the system and the External Efficiency remains unchanged. Figure 50 below illustrates the relationship between the External Efficiency and the Operation Temperature.

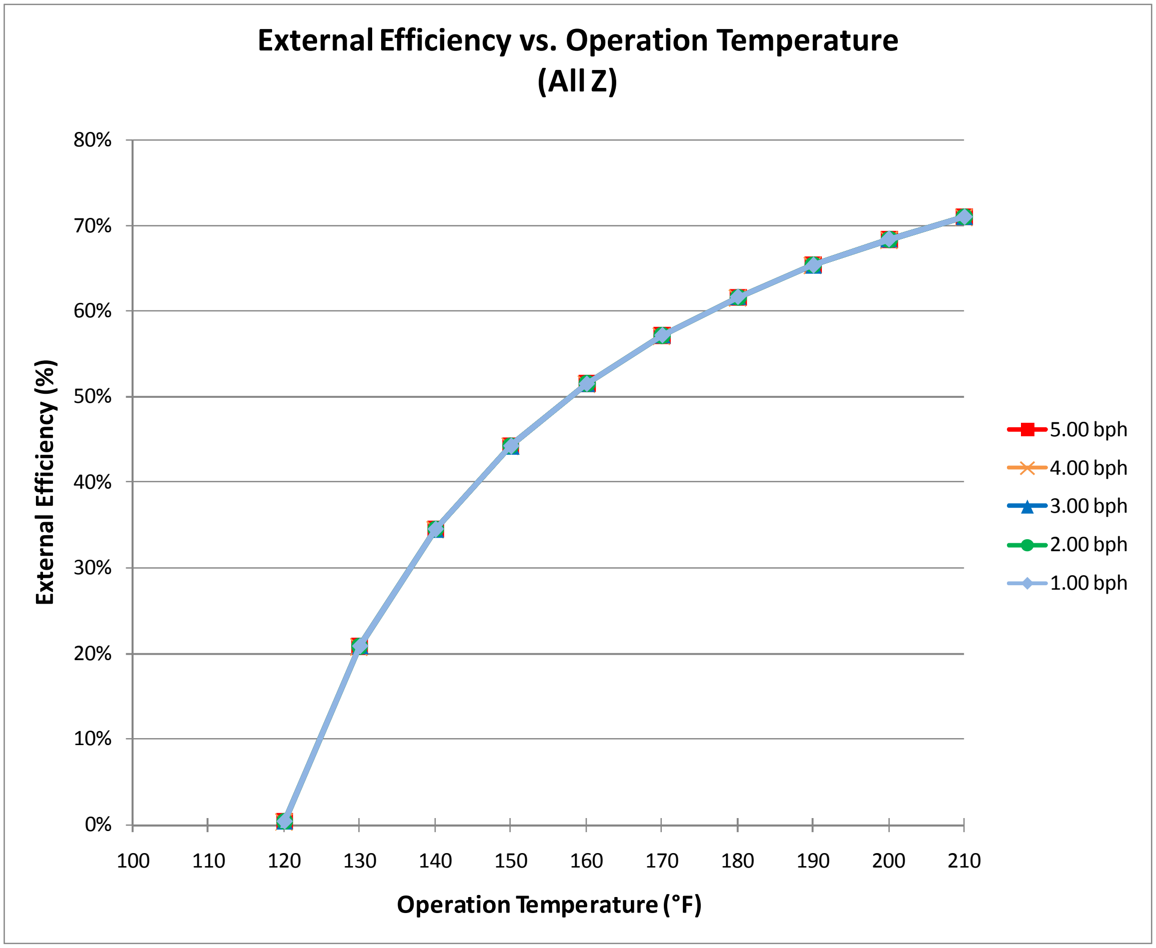

Figure 50: External Efficiency vs. Operation Temperature

The External Efficiency exponentially increases with Operation Temperature. As the Operation Temperature increases the Specific External Heater Energy required decreases, which means the amount of External Heater Energy required per pound of DDGS Moisture removed decreases. The Specific External Heater Energy divided by the latent and sensible heat required to facilitate drying represents the fraction of External Heater Energy required over the total energy required for drying and as this fraction decreases the External Efficiency increases. Table 27 contains values for External Efficiency as a function of Operation Temperature.

Table 27: External Efficiency vs. Operation Temperature

$T_{operation}$	$\eta_{External}$	**% Change**
130 °F	20.80%	N/A
140 °F	34.44%	65.58%
150 °F	44.16%	28.22%
160 °F	51.44%	16.49%
170 °F	57.09%	10.98%
180 °F	61.60%	7.90%
190 °F	65.28%	5.97%
200 °F	68.34%	4.69%
210 °F	70.92%	3.78%

The External Efficiency increases from 20% at 130 °F to 71% at 210 °F. Also, the change between Operation Temperature increments varies from 66% between 130 °F and 140 °F to 3.78% at 210 °F which represents and exponentially decreasing improvement in External Efficiency with an increase in Operation Temperature. This decreasing improvement once again raises the need for a balance between increased Thermal Efficiency and increase Operational Cost.

CHAPTER 5: EXPERIMENTAL DATA ANALYSIS

Shivvers provided experimental data from a DDGS Drying System with the components and setup described similar to those described in the System Model section of this report. This experimental data provided temperatures for each of the labeled states (i.e. 1, a, etc.) shown below in Figure 51.

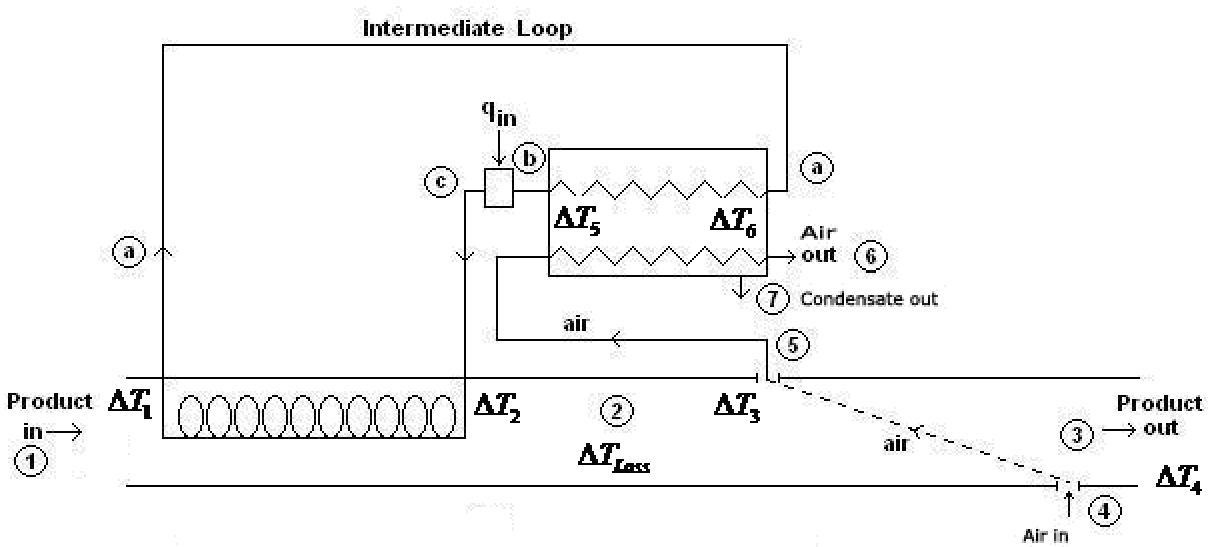

Figure 51: DDGS Drying System Schematic (Experimental Setup)

The experimental data provides the temperature of DDGS product entering the system (T_1) at 59.5 °F, which is nearly the same as the 60 °F used in the theoretical model. Also, the temperature of intermediate loop water leaving the Product Heater (T_a) is 69.4 °F, which also mirrors the theoretical assumed value of 70 °F. These temperatures result in an approach temperature difference between the DDGS entering the Product Heater and the intermediate loop water exiting the Product Heater (ΔT_1) of 9.9 °F.

A temperature of 198.9 °F for the intermediate loop water that enters the Product Heater sets the Operation Temperature (T_c) for the system, which falls in the range of values for Operation Temperature (T_c) investigated in this study. This Operation Temperature value results in a 171.8 °F temperature for the DDGS product exiting the Product Heater (T_2). The difference of the Operation Temperature (T_c) and DDGS product exiting the Product Heater (T_2) produce a temperature difference (ΔT_2) of 27.1 °F. During the product's travel between the Product Heater and the Air Drying Unit, the product losses some heat, which creates a temperature loss between these parts of the drying system. According to experimental data, the DDGS product exits the Product Heater at a temperature (T_2) of 171.8 °F and it enters the Air Drying Unit at a temperature (T_{2a}) of 168.5 °F. This difference corresponds to a temperature loss between the Product Heater and Air Drying Unit (ΔT_{Loss}) of 3.3 °F.

The DDGS product entering the Air Drying Unit (T_{2a}) at 168.5 °F interacts with air entering (T_4) at 70.8 °F with an assumed relative humidity of 50%. This interaction lowers the DDGS product to a temperature of 83.5 °F (T_3) as it exits the drying system. Meanwhile, the combination of the sensible heat release by the exiting DDGS and the moisture removed from the product raises the temperature of the air-vapor mixture exiting the Air Drying Unit (T_5) to 151.7 °F. The approach temperature difference in the Air Drying Unit (ΔT_3) between the entering DDGS product temperature (T_{2a}) and exiting air-vapor temperature (T_5) becomes 16.8 °F. Similarly, the approach temperature difference in the Air Drying Unit (ΔT_4) between the entering ambient air temperature (T_4) and exiting DDGS product temperature (T_3) becomes 12.7 °F.

The air-vapor mixture exiting the Air Drying Unit enters the Heat Recovery Unit (T_5) at a temperature of 151.7 °F. The Heat Recovery Unit removes energy from the air-vapor mixture passing through and, as a result, the air temperature falls to 83.3 °F at the air-vapor exit. The temperature of the moisture condensed from the system (T_7) also remains at 83.3 °F. Meanwhile, the intermediate loop water enters the Heat Recovery Unit at the same temperature it exits the Product Heater at a value of 69.4 °F. As it gains heat from the exiting air-vapor mixture, the intermediate loop water temperature raises to a value of 148.5 °F at the exit of the Heat Recovery Unit (T_b). The approach temperature difference (ΔT_5) between the air-vapor mixture entering the Heat Recovery Unit (T_5) and the intermediate loop water exiting the Heat Recovery Unit (T_b) becomes 3.2 °F. Similarly, the approach temperature difference (ΔT_6) between the air exiting the Heat Recovery Unit (T_6) and the intermediate loop water entering the Heat Recovery Unit (T_a) becomes 13.9 °F. Table 28 below contains values for the experimental temperatures conferred above.

Table 28: State Temperature from Experimental Data

Reference State	Temperature (°F)
T_1	59.5
T_2	171.8
T_{2a}	168.5
T_3	83.5
T_4	70.8
T_5	151.7
T_6	83.3
T_7	83.3
T_a	69.42
T_b	148.5
T_c	198.8

The temperatures and calculated approach temperature differences discussed above provide a basis to analyze the experimental data provided by Shivvers. Table 29 below contains values for the calculated experimental approach temperature differences.

Table 29: Experimental Approach Temperature Differences

Approach Temperature Difference	Experimental (°F)	Theoretical (°F)	Difference (°F)
$\Delta T_1 = T_a - T_1$	9.9	10.0	-0.01
$\Delta T_2 = T_c - T_2$	27.1	10.0	17.1
$\Delta T_3 = T_{2a} - T_5$	16.8	10.0	6.8
$\Delta T_4 = T_3 - T_4$	12.7	10.0	2.7
$\Delta T_5 = T_5 - T_b$	3.2	10.0	-6.8
$\Delta T_6 = T_6 - T_a$	13.9	10.0	3.9
$\Delta T_{loss} = T_2 - T_{2a}$	3.3	0.0	3.3

Upon investigation of the approach temperature differences calculated from experimental data in the Product Heater, it appears that the approach temperature difference ΔT_1, which represents the temperature difference between the entering DDGS product and exiting intermediate loop water, with a value of 9.9 °F, matches the theoretical model very closely. Conversely, the approach temperature difference ΔT_2 is very large with a value of 27.1 °F. This approach temperature difference represents the difference in temperature between the intermediate loop water entering at the Operation Temperature and the DDGS product exiting the Product Heater. This value suggests a possibility for improvement in the transfer of energy between the intermediate water loop and the DDGS product. Additionally, as the DDGS product transferred from the Product Heater to the Air Drying Unit it dropped 3.3 °F in temperature. This temperature drop is reasonable and has a minimal effect on the system performance.

Examination of the approach temperature differences in the Air Drying Unit shows that the ΔT_4 approach temperature difference of 12.7 °F is fairly close to theoretical values. Meanwhile, the ΔT_3 approach temperature difference of 16.8 °F is very large. This detail indicates another opportunity for improvement in the energy transfer between the DDGS product and air utilized to facilitate drying.

Inspection of the approach temperature differences in the Heat Recovery Unit reports a 3.2 °F temperature difference in the ΔT_5 approach temperature difference, which is well below the theoretical value used. In addition, the ΔT_6 approach temperature difference of 13.9 °F remains consistent with the values used in the theoretical model.

From the discussion of the experimental approach temperature differences it is apparent that the major limiting factor in the performance of the drying system is the ability of the DDGS to transfer heat. The highest approach temperature differences occurred in the interactions of the DDGS product with the other components of the drying system. An opportunity to increase the performance of the system exists by possibly changing or enhancing the way the DDGS interacts with the other components of the drying system.

The analysis of the Shivvers data utilizes the same energy and mass balance relationships determined in the System Model section of this report. However, instead of assuming ambient conditions and a constant approach temperature difference, the ambient temperatures provided by the experimental data are combined with the approach temperature differences summarized in Table 29 above to create a working experimental model that functions the same as the theoretical model. This model assumes that the approach temperature differences calculated from the experimental data remain unchanged as the Operation Temperature, DDGS Flow Rate and DDGS Entering Moisture Content vary. These Approach Temperature Differences replace the constant 10 °F approach temperature difference assumed in the theoretical model and provides the basis for the analysis and discussion presented below.

The Theoretical Results section discusses several system behavioral and performance characteristics. The analysis of the experimental data focuses on two major Figures of Merit important in ascertaining the performance of the drying system, namely the External Efficiency ($\eta_{External}$) and the Specific External Heater Energy (q_{Heater}).

Figure of Merit #1: Specific External Heater Energy

One of the Figures of Merit analyzed is the Specific External Heater Energy (q_{Heater}), which describes the External Heater Energy provided per pound of moisture removed as shown in the equation below.

$$q_{Heater} = \frac{\dot{Q}_{Heater}}{\dot{m}_{dried}} \tag{79}$$

The experimental data for the Specific External Heater Energy shows that the Specific External Heater Energy remains independent of both DDGS Flow Rate and DDGS Entering Moisture content. This result follows the same trends as the theoretical model and therefore the main input of interest becomes the Operation Temperature. Figure 52 below illustrates the interaction between the Specific External Heater Energy and Operation Temperature.

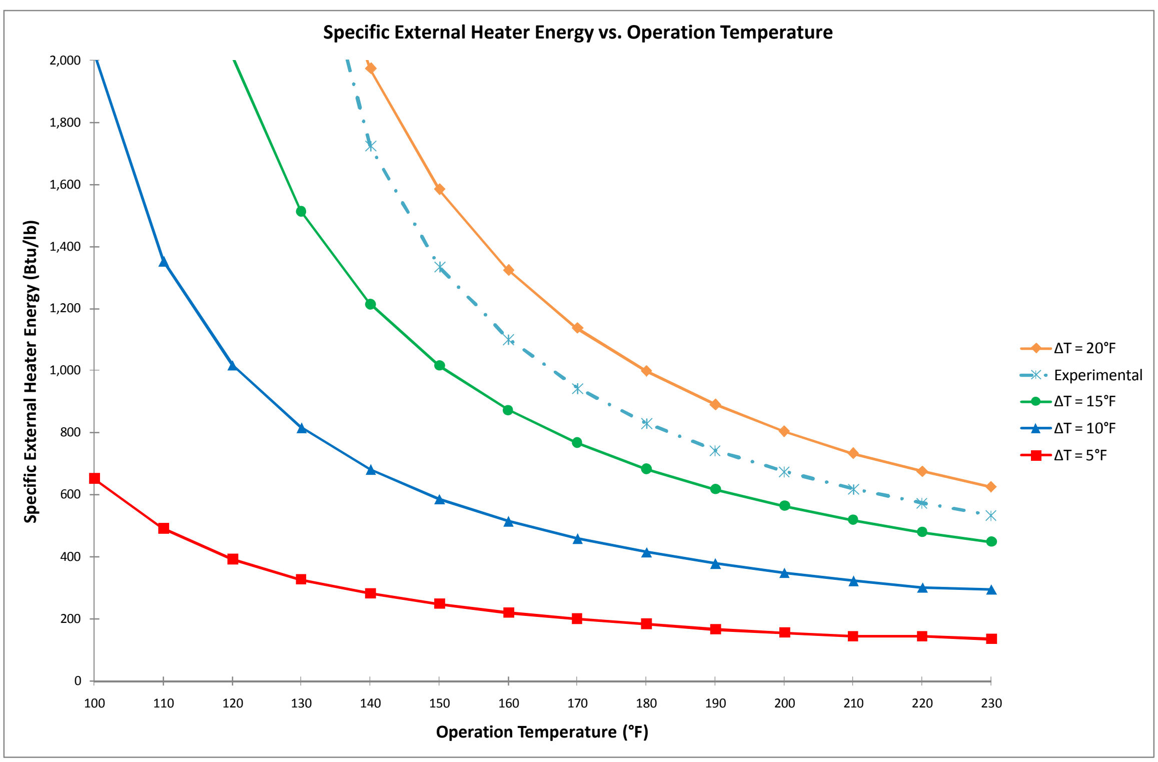

Figure 52: Specific External Heater Energy vs. Operation Temperature

As seen in the plot above, the Specific External Energy exponentially decreases as the Operation Temperature increases. This trend suggests that an increase in Operation Temperature increases the effectiveness of the DDGS Drying System. It also suggests that Operation Temperatures near 200 °F represent a possible balance of external heat added to the system to the amount of effectiveness gained by this increase as each of the data sets begins to asymptote near this temperature. The Specific External Energy also decreases as the theoretical approach temperature difference decreases. This result appears consistent with expectations as lower approach temperature differences result in higher system effectiveness. The experimental data for the Specific External Energy follows the theoretical data trends discussed above in the typical Operation Range. This data shows that Operation Temperatures below 140 °F do not effectively facilitate DDGS drying for the current system setup. The experimental data also shows that the current system behaves as if it maintains a theoretical approach temperature difference around 17.5 °F. This outcome suggests the possibility for improvement in the system and the need for further investigation.

Figure of Merit #2: External Efficiency

The other Figure of Merit analyzed in this study is the External Efficiency ($\eta_{External}$), which ratios the energy provided by the External Heater to evaporate moisture to the latent and sensible energy required to facilitate this phase change. Like the theoretical model, the experimental data remains independent of both the DDGS Flow Rate and DDGS Entering Moisture Content. The expression below represents the equation for External Efficiency.

$$\eta_{External} = 1 - \left[\frac{q_{heater}}{h_{fg} + \left(h_2 - h_1 \right)} \right] \qquad (80)$$

Figure 53 shows the relationship between the External Efficiency and Operation Temperature.

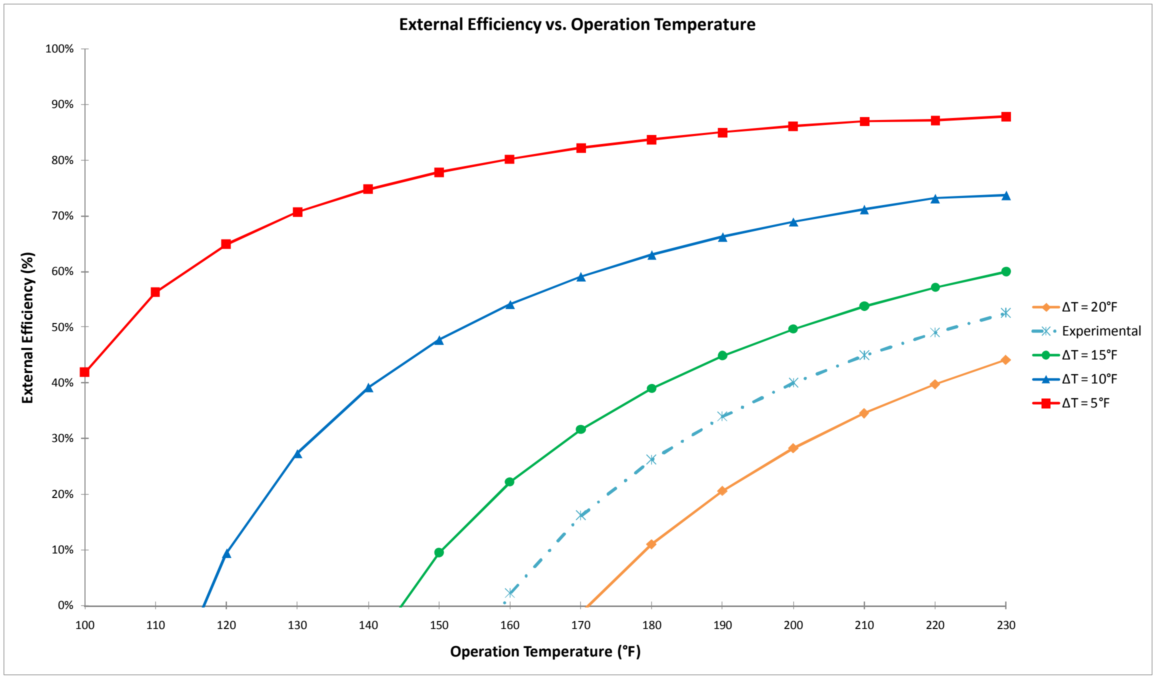

Figure 53: External Efficiency vs. Operation Temperature

The experimental data follows a similar trend to the theoretical data as it increases with an increase in Operation Temperature. This result confirms the reoccurring trend in which an increase in Operation Temperature increases the effectiveness of the system's heating, drying and recovery processes; particularly it reinforces the validity of the experimental data following the theoretical trends. The External Efficiency increases as the approach temperature difference decreases. This is an expected result as a decrease in approach temperature difference infers an increased effectiveness of the drying system.

As the Operation Temperature increases, the External Efficiency begins to asymptote near temperatures of 200 °F. This asymptote is more noticeable at lower approach temperature differences than at higher temperature difference, which suggests the need for higher Operation Temperatures in systems with higher approach temperature differences. For example, an increase in Operation Temperature from 200 °F to 210 °F increases the External Efficiency from 86.12% to 87.06% when the system uses an approach temperature difference of 5 °F. Meanwhile, an increase in Operation Temperature from 200 °F to 210 °F increases the External Efficiency from 49.8 to 53.8% when the system uses an approach temperature difference of 15 °F.

The experimental data from an External Efficiency standpoint shows that Operation Temperatures below 160 °F do not effectively facilitate DDGS drying. This lower Operation Temperature limit is 20 °F higher than the value of 140 °F discussed in the Specific External Heater Energy discussion presented above. The experimental data for the External Efficiency also shows that the current system behaves as if it maintains a theoretical approach temperature difference around 17.5 °F, which is consistent with the Specific External Heater Energy discussion and suggests the possibility for improvement in the system and the need for further investigation.

CHAPTER 6: THEORETICAL SYSTEM OPERATION GUIDELINES

One objective of this project includes the use of the established behavioral metrics to provide system behavioral relationships for possibly improving the current experimental setup. Two dimensionless ratios, namely the Air-DDGS Ratio and the Loop-DDGS Ratio, provide a method to calculate the necessary Air and Intermediate Loop Flow Rates to maintain the desired system performance at a specific DDGS Flow Rate. The following section describes and discusses these dimensionless ratios.

Air-DDGS Ratio

The Air-DDGS Ratio ($R_{A/D}$) describes the amount of mass or mass flow of Air required to maintain operation conditions based on the amount of the mass or mass flow of DDGS that enters the system. This dimensionless parameter is found by dividing the Air Flow Rate by the DDGS Flow Rate, which is shown in the equation below.

$$R_{A/D} = \frac{\dot{m}_{air}}{\dot{m}_g + \dot{m}_w} \qquad (81)$$

Figure 54 below shows the relationship between the Air-DDGS ratio and the DDGS Flow Rate.

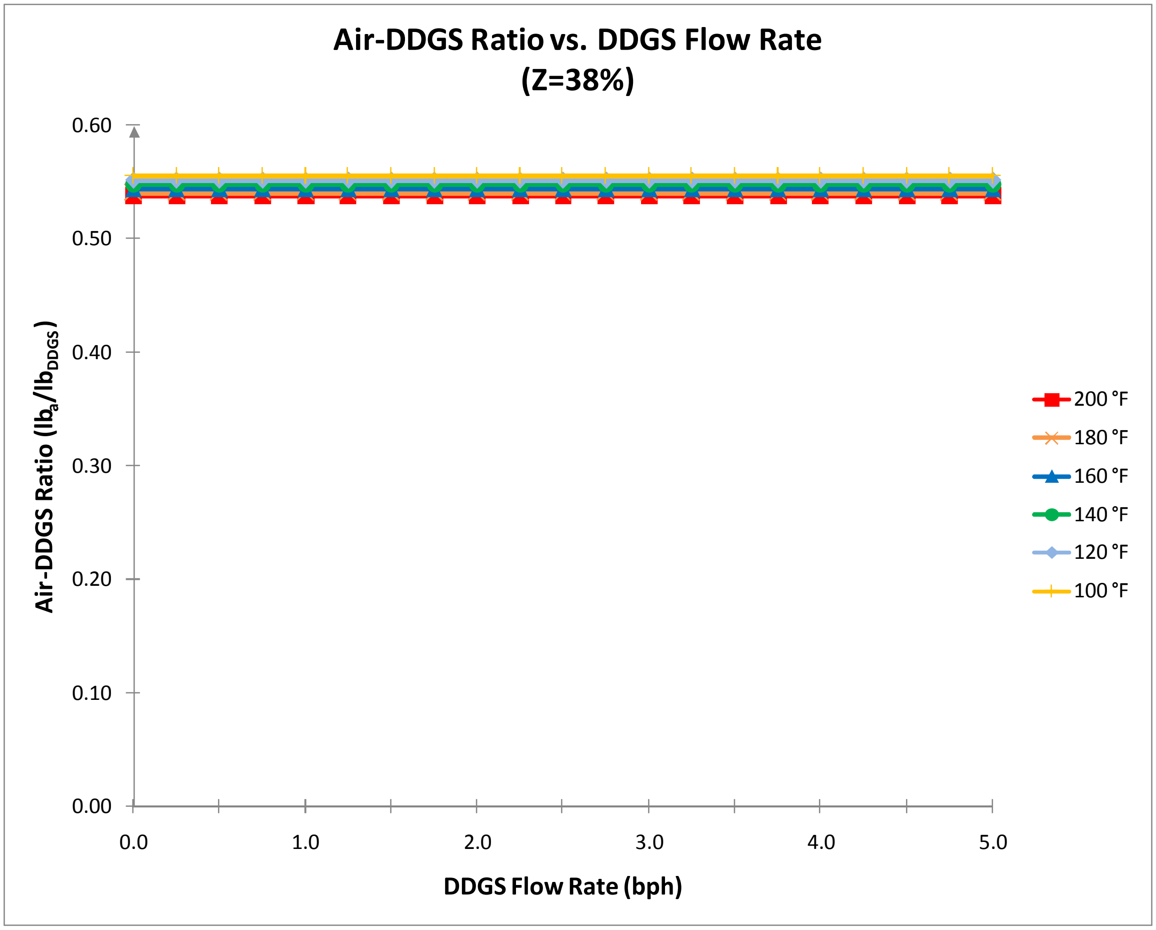

Figure 54: Air-DDGS Ratio vs. DDGS Flow Rate

The Air-DDGS ratio is independent of the DDGS Flow Rate. This parameter represents the slope of the line shown in the Air Flow Rate vs. DDGS Flow Rate plot discussed in the Air Flow Rate section. This plot establishes the linear relationship between Air Flow Rate and DDGS Flow Rate and confirms the discussion on the change in Air Flow Rate with a change in DDGS Flow Rate. Figure 55 below demonstrates the connection between the Air-DDGS ratio and the Operation Temperature.

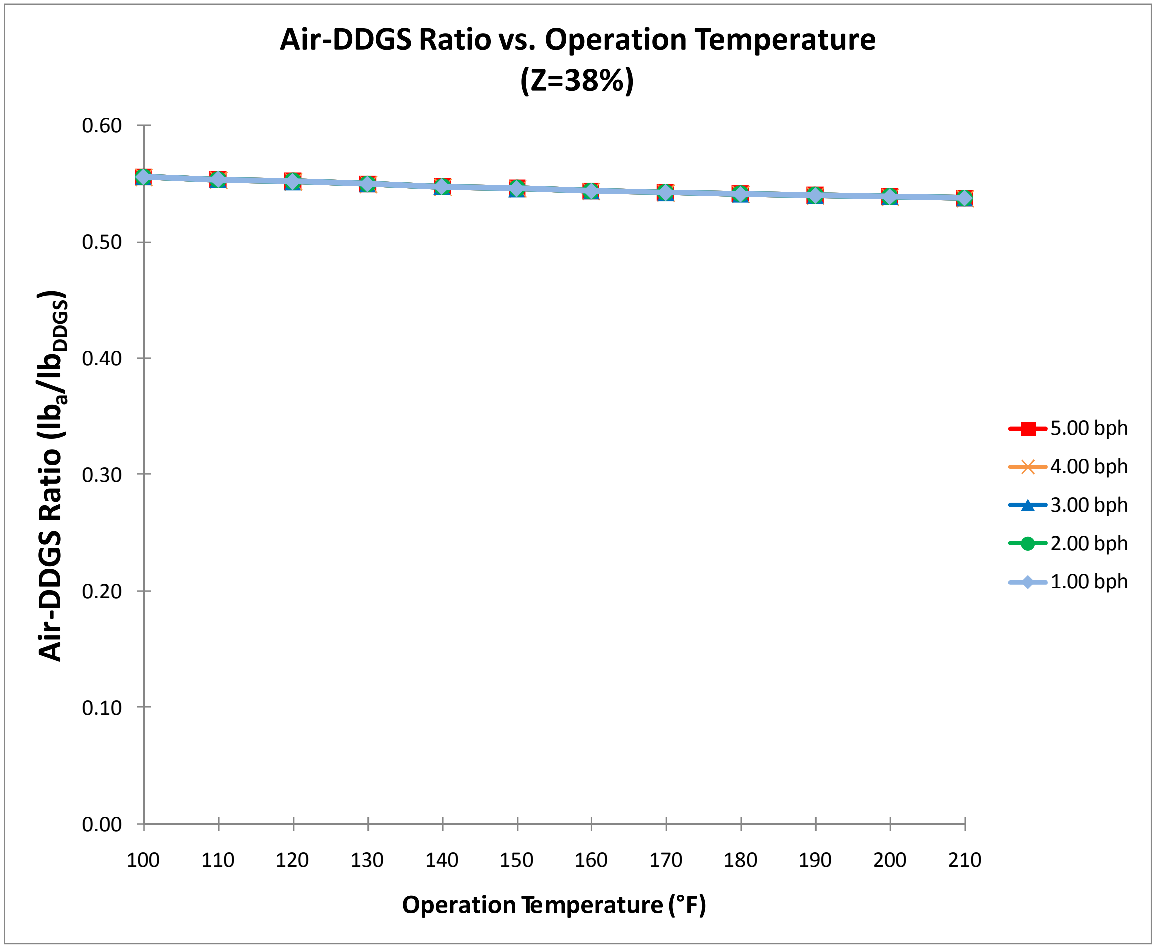

Figure 55: Air-DDGS Ratio vs. Operation Temperature

The Air-DDGS Ratio decreases slightly with an increase in Operation Temperature. This result occurs because the Air Flow Rate slightly decreases with an increase in Operation Temperature Conversely; the DDGS Flow Rate is independent of Operation Temperature, which creates the decreasing slope in the Figure above. As the Operation Temperature increases, the air holds more water vapor causing the Air Flow Rate to decrease, which results in the decrease of the Air-DDGS Ratio with an increase in Operation Temperature. Figure 56 below presents the connection between Air-DDGS Ratio and DDGS Entering Moisture Content

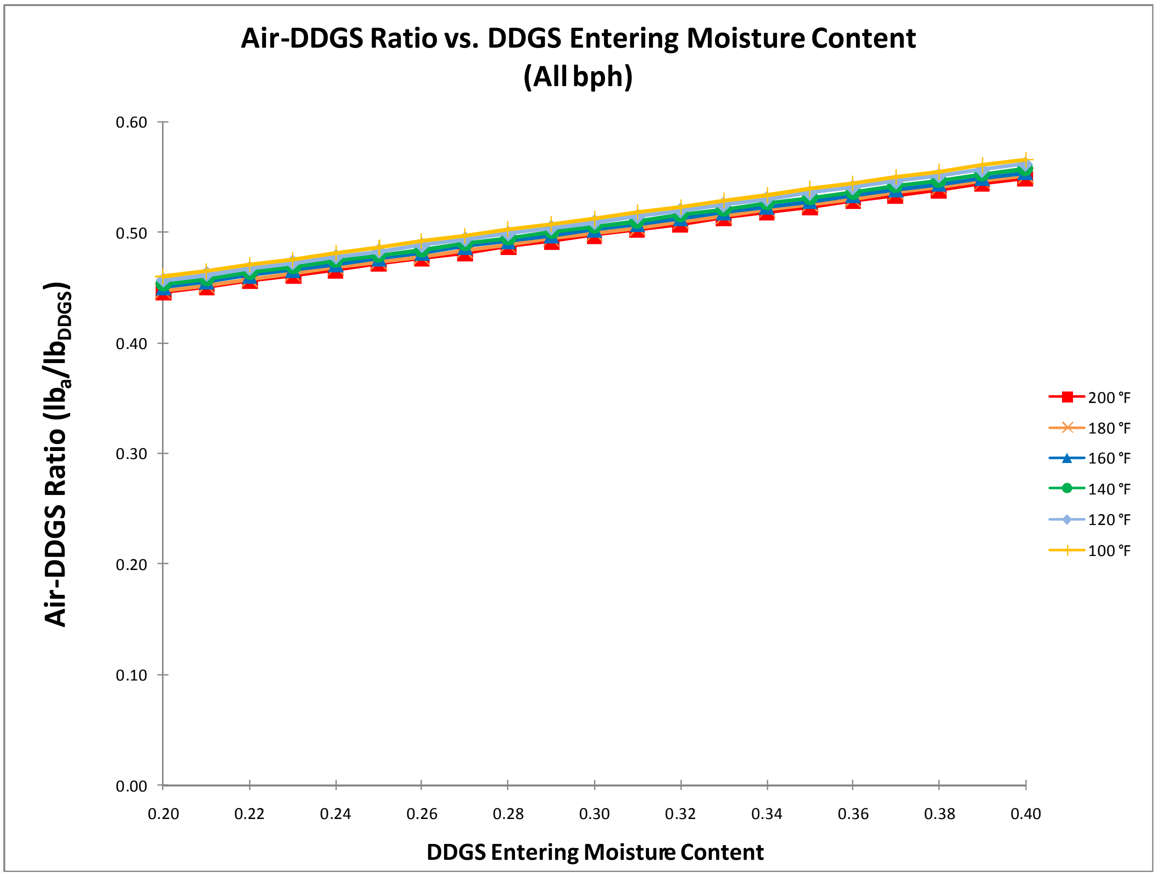

Figure 56: Air-DDGS Ratio vs. DDGS Entering Moisture Content

The Air-DDGS Ratio increases with an increase in DDGS Entering Moisture Content.
As shown earlier, the Air Flow Rate increases with DDGS Entering Moisture Content and the DDGS Flow Rate is independent of DDGS Entering Moisture Content. Therefore, the Air-DDGS Ratio increases as DDGS Entering Moisture Content increases as seen in the plot above. Table 30 below contains values for the Air-DDGS Ratio as it varies with Operation Temperature and DDGS Flow Rate.

Table 30: Air-DDGS Ratio vs. Operation Temperature and DDGS Flow Rate (lb_a/lb_{DDGS})

Bph/T_{op}	100	120	140	160	180	200	% Change	Average
1.00	0.5558	0.5516	0.5474	0.5437	0.5407	0.5385	-3.11%	0.5455
2.00	0.5558	0.5516	0.5474	0.5437	0.5407	0.5385	-3.11%	0.5455
3.00	0.5558	0.5516	0.5474	0.5437	0.5407	0.5385	-3.11%	0.5455
4.00	0.5558	0.5516	0.5474	0.5437	0.5407	0.5385	-3.11%	0.5455
5.00	0.5558	0.5516	0.5474	0.5437	0.5407	0.5385	-3.11%	0.5455

The Air-DDGS ratio varies slightly at a percent change of around 3% as Operation Temperature changes with a 0.5558 value at 100 °F and a 0.5385 value at 200 °F with an average of 0.5455. It also does not vary at all with DDGS Flow Rate as indicated in the trends discussed above. Table 31 includes values for Air-DDGS ratio as it changes from 20% to 40% DDGS Entering Moisture Content.

Table 31: Air-DDGS Ratio vs.
Operation Temperature and DDGS Entering Moisture Content (lb_a/lb_{DDGS})

Z/T_{op}	100	120	140	160	180	200	Average
0.20	0.4603	0.4568	0.4534	0.4503	0.4478	0.4459	0.4524
0.22	0.4709	0.4673	0.4638	0.4607	0.4581	0.4561	0.4628
0.24	0.4815	0.4779	0.4743	0.4711	0.4685	0.4664	0.4733
0.26	0.4921	0.4884	0.4847	0.4815	0.4788	0.4767	0.4837
0.28	0.5027	0.4989	0.4952	0.4919	0.4891	0.4870	0.4941
0.30	0.5133	0.5094	0.5056	0.5022	0.4994	0.4973	0.5045
0.32	0.5239	0.5200	0.5161	0.5126	0.5098	0.5076	0.5150
0.34	0.5345	0.5305	0.5265	0.5230	0.5201	0.5179	0.5254
0.36	0.5452	0.5410	0.5370	0.5334	0.5304	0.5282	0.5359
0.38	0.5558	0.5516	0.5474	0.5437	0.5407	0.5385	0.5463
0.40	0.5664	0.5621	0.5579	0.5541	0.5511	0.5487	0.5567
% Change	23.1%	23.1%	23.0%	23.1%	23.1%	23.1%	-

The Air-DDGS Ratio increases by 23.1% as the DDGS Entering Moisture Content changes from 20% to 40%. The 3% change due to the variation over the full range of Operation Temperatures, as seen in Table 30 above, is very small compared to the 23.1% change in Air-DDGS Ratio over the range of DDGS Entering Moisture Contents. For this reason, the Air-DDGS Ratio can be assumed constant for all Operation Temperatures and the average value for the Air-DDGS Ratio over the entire range of Operation Temperatures can be used for this analysis.

The average values for Air-DDGS Ratio range from 0.4524 at a 20% DDGS Entering Moisture Content to 0.5567 at a 40% DDGS Entering Moisture Content. Theses averages values acceptably determine the Air-DDGS Ratio as they only deviate by about 1.55% from any specific Air-DDGS Ratio. These results indicate that in application the user should base the Air-DDGS Ratio on the DDGS Entering Moisture Content. The equation below provides the relationship between required Air-DDGS Ratio ($R_{A/D}$) and DDGS Entering Moisture Content (Z) based on the average values shown above.

$$R_{A/D} = 0.5125(Z) + 0.3481 \quad (82)$$

Table 32 shows that the equation accurately depicts the modeled average values for Air-DDGS Ratio based on DDGS Entering Moisture Content.

Table 32: Average and Equation Based Air-DDGS Ratios (lba/lb_{DDGS})

Z/T_{op}	Average	Equation
0.20	0.4524	0.4524
0.25	0.4785	0.4785
0.30	0.5045	0.5046
0.35	0.5306	0.5306
0.40	0.5567	0.5567

The above Air-DDGS Ratio is based on a reference Approach Temperature Difference of 10 °F. Figure 57 investigates changes in the Air-DDGS Ratio as a function of the Approach Temperature Difference.

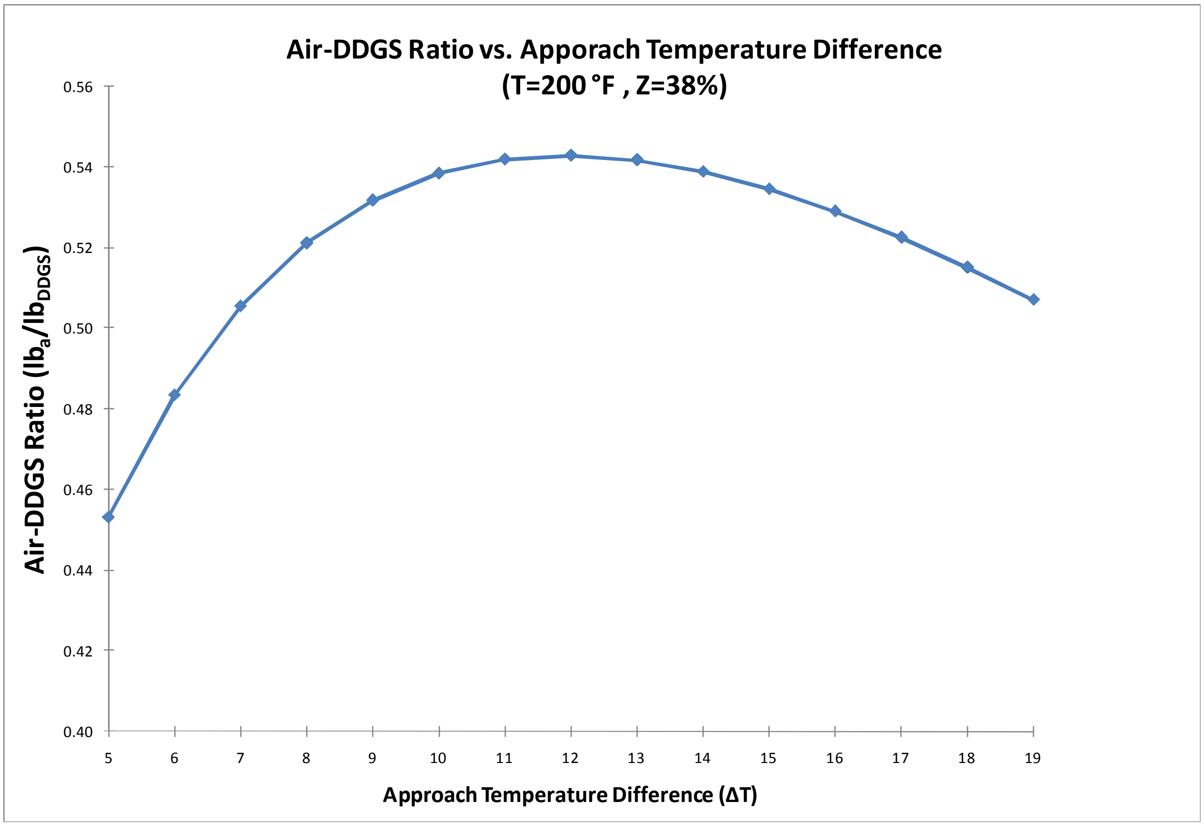

Figure 57: Air-DDGS Ratio vs. Approach Temperature Difference at T=200 °F and Z = 38%

The Air-DDGS Ratio varies greatly with the Approach Temperature Difference, therefore as a reference the Air-DDGS ratio as a function of DDGS Moisture Content at different Approach Temperatures is provided in Figure 58 below.

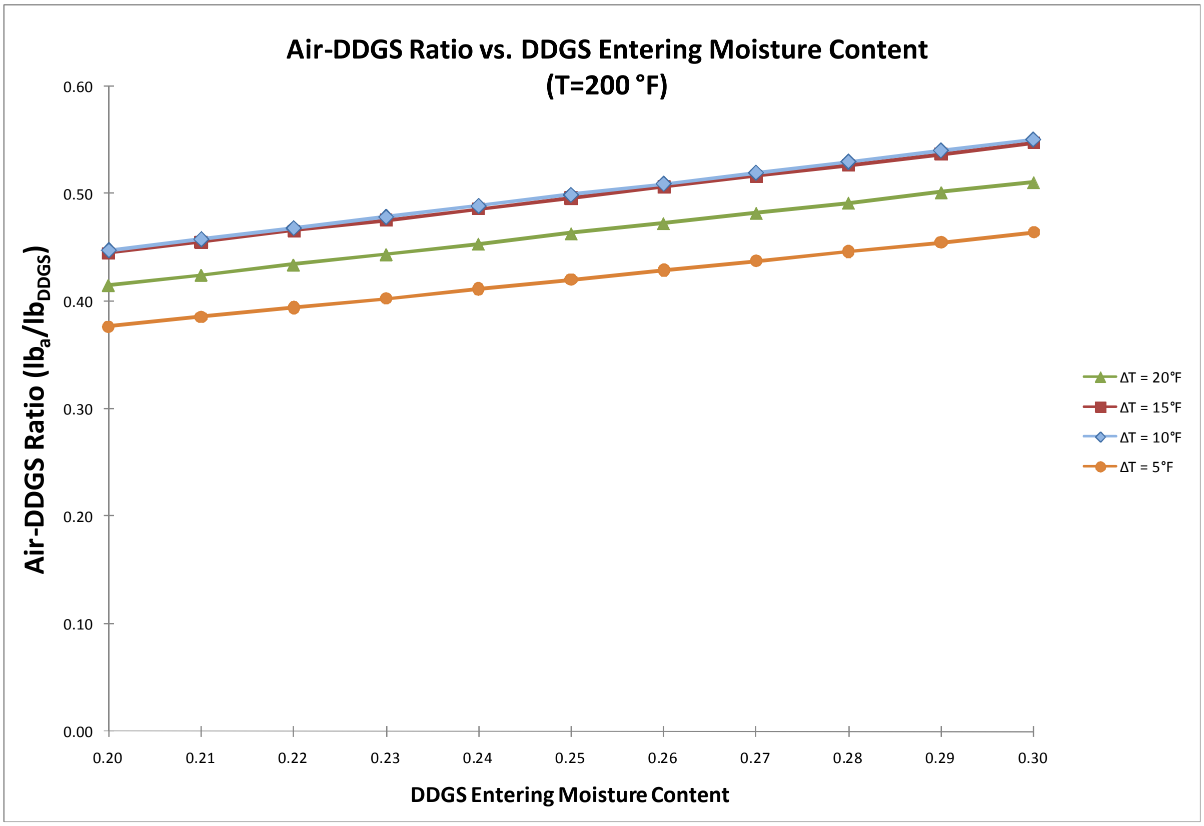

Figure 58: Air-DDGS Ratio vs. DDGS Entering Moisture Content at Different Approach Temperature Differences

Table 33 below contains equations for each of the Air-DDGS Ratio trends represented in the Figure above.

Table 33: Air DDGS Ratio vs. DDGS Entering Moisture Content Equations For Various Approach Temperature Differences

$R_{A/D} = m(Z) + b$		
ΔT	m	b
ΔT = 5 °F	0.4345	0.29
ΔT = 10 °F	0.5125	0.3481
ΔT = 15 °F	0.513	0.3423
ΔT = 20 °F	0.4785	0.3196

Loop-DDGS Ratio

The Loop-DDGS Ratio ($R_{L/D}$) describes the mass flow rate of intermediate loop water needed per mass of DDGS in the drying system to sustain operation conditions. This dimensionless parameter is found by dividing the Intermediate Loop Flow Rate by the DDGS Flow Rate. The equation below shows the calculation of Loop-DDGS Ratio.

$$R_{L/D} = \frac{\dot{m}_{loop}}{\dot{m}_g + \dot{m}_w} \qquad (83)$$

Figure 59 below shows the relationship between Loop-DDGS Ratio and DDGS Flow Rate.

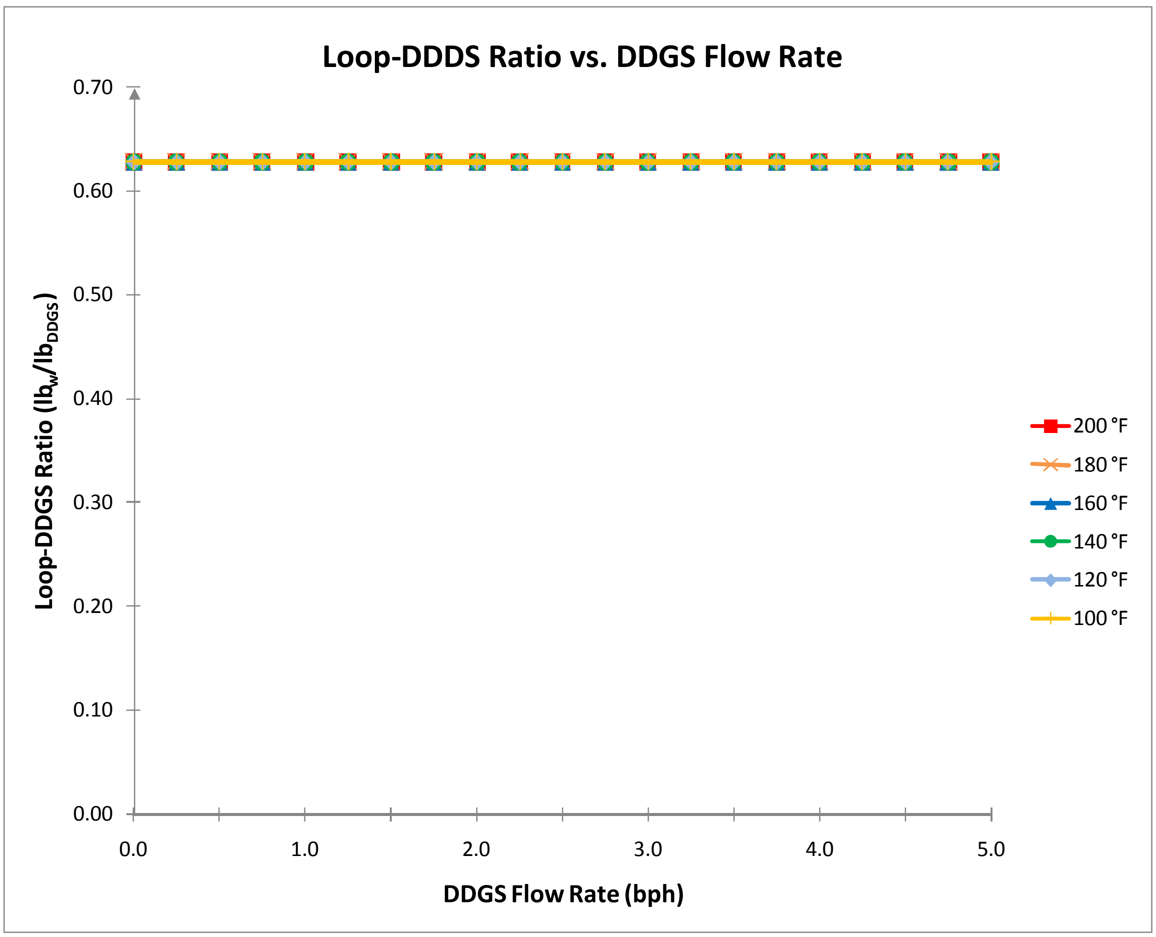

Figure 59: Loop-DDGS Ratio vs. DDGS Flow Rate

The Loop-DDGS Ratio remains independent of DDGS Flow Rate. This result occurs because the Intermediate Loop Flow Rate increases as the DDGS Flow Rate increases resulting in the constant Loop-DDGS Ratio shown above. Figure 60 below conveys the connection between Loop-DDGS Ratio and Operation Temperature.

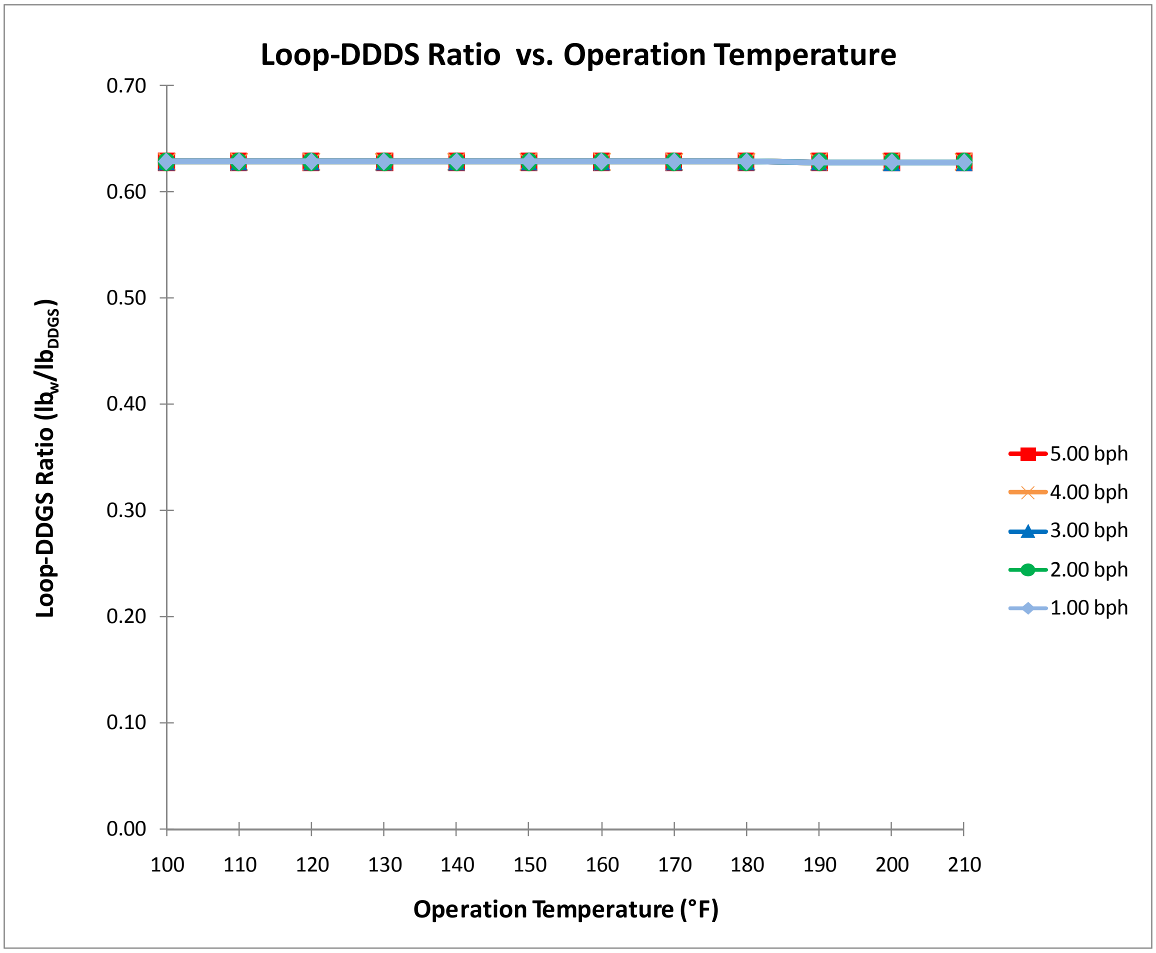

Figure 60: Loop-DDGS Ratio vs. Operation Temperature

The Loop-DDGS Ratio is independent of Operation Temperature. As the Operation Temperature varies the Intermediate Loop Flow Rate and the DDGS Flow Rate remains constant, therefore the ratio of these two system outputs remains constant. Figure 61 shows the interaction between Loop-DDGS Ratio and DDGS Entering Moisture Content.

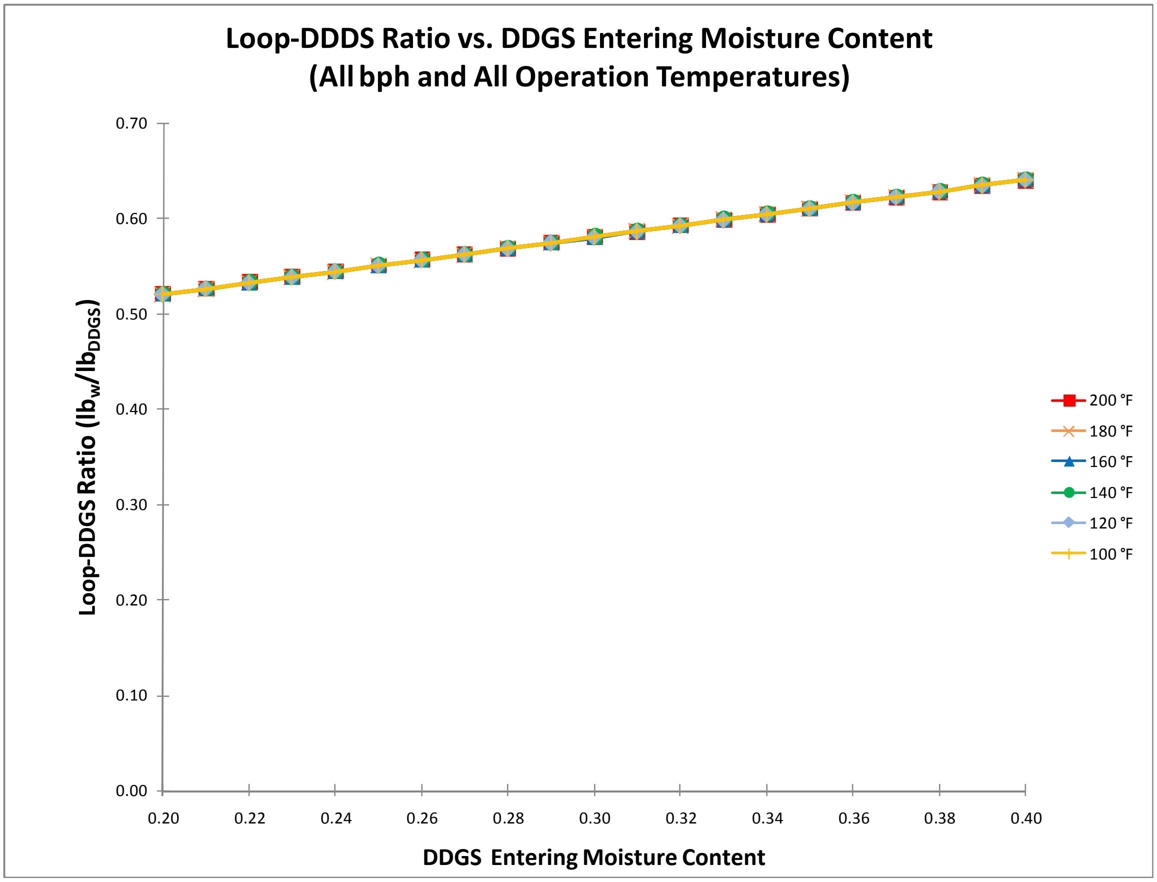

Figure 61: Loop-DDGS Ratio vs. DDGS Entering Moisture Content

As shown earlier in this section, the Intermediate Loop Flow Rate increases as the DDGS Entering Moisture Content increases, therefore an expected increase in the Loop-DDGS Ratio occurs as the DDGS Entering Moisture Content increases.

Table 34 contains values for the Loop-DDGS Ratio as it varies with DDGS Entering Moisture Content.

Table 34: Loop-DDGS Ratio vs. DDGS Entering Moisture Content (lb_w/lb_{DDGS})

DDGS Entering Moisture Content (lb_w/ lb_g + lb_w)	**Loop-DDGS Ratio (lb_w/lb_{DDGS})**
0.20	0.52
0.22	0.53
0.24	0.54
0.26	0.56
0.28	0.57
0.30	0.58
0.32	0.59
0.34	0.60
0.36	0.62
0.38	0.63
0.40	0.64
% Change	23.0%

The Loop-DDGS Ratio increases from 0.52 to 0.64 as the DDGS Entering Moisture Content increases from 20 to 40%. This increase represents a 23% change in Loop-DDGS Ratio. These results indicate that the settings for the Intermediate Loop Flow Rate for a given DDGS Flow Rate should be based on the DDGS Entering Moisture Content of the product entering the Drying System. The equation below relates Loop-DDGS Ratio ($R_{L/D}$) to DDGS Entering Moisture Content.

$$R_{L/D} = 0.5995(Z) + 0.4004 \quad (84)$$

Table 35: Data and Equation Based Value for Loop-DDGS Ratio (lbw/lbDDGS)

DDGS Entering Moisture Content (lb_w/ $lb_g + lb_w$)	Loop-DDGS Ratio (lb_w/lb_{DDGS})	Equation (lb_w/lb_{DDGS})
0.20	0.52	0.52
0.22	0.53	0.53
0.24	0.54	0.54
0.26	0.56	0.56
0.28	0.57	0.57
0.30	0.58	0.58
0.32	0.59	0.59
0.34	0.60	0.60
0.36	0.62	0.62
0.38	0.63	0.63
0.40	0.64	0.64

Table 35 above shows that the equation accurately models the theoretical results. These results were based on a reference Approach Temperature Difference of 10 °F. Figure 62 below shows the relationship between the Loop-DDGS Ratio and DDGS Entering Moisture Content at various Approach Temperature Differences. In this figure, the Loop-DDGS Ratio remains independent of the Approach Temperature Difference and therefore the above data and equations holds true for all Approach Temperature Differences.

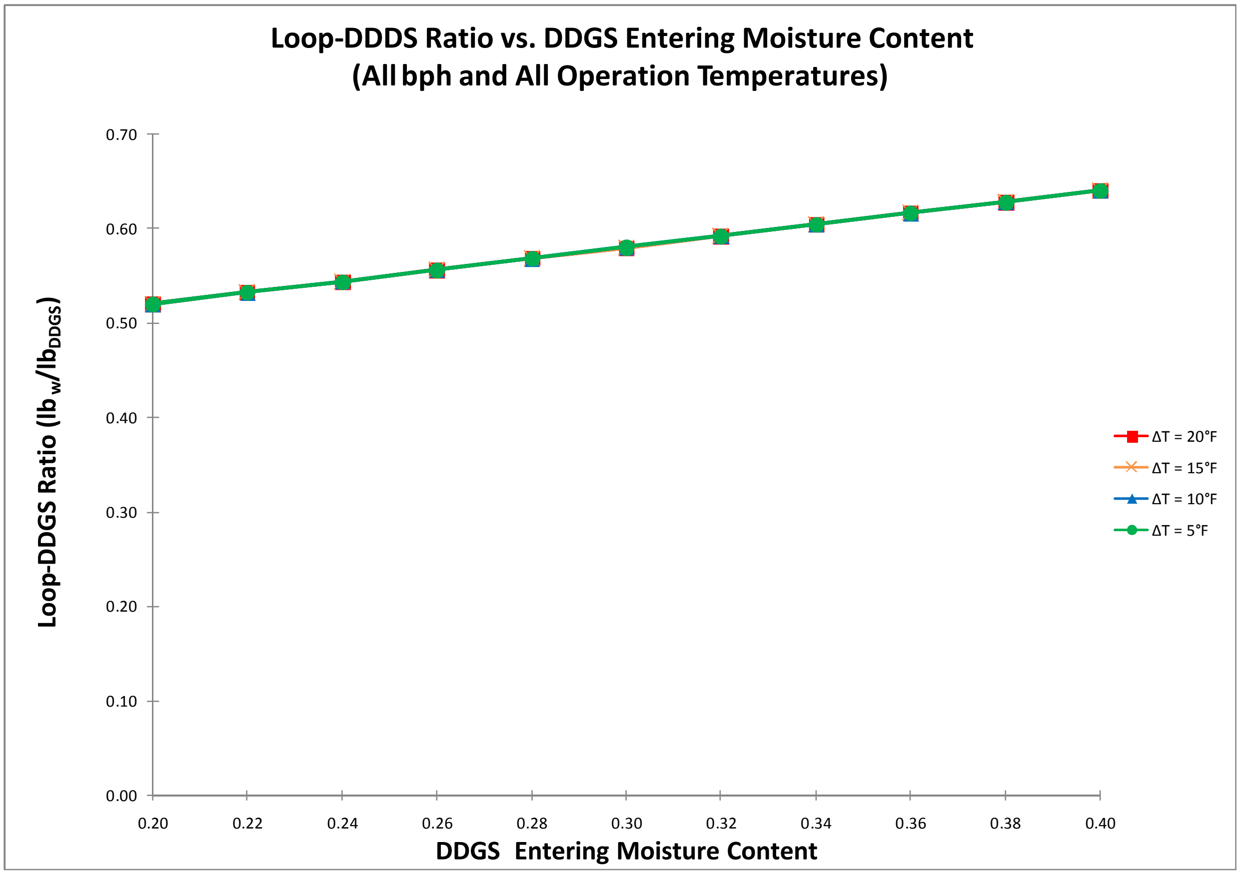

Figure 62: Loop-DDGS Ratio vs. DDGS Entering Moisture Content

At Various Approach Temperature Differences

CONCLUSION

This project encompassed several objectives. The first object of this project included the creation of a theoretical model that depicts the behavior and performance of an Air Drying System that utilizes a heat recovery process. Four components comprised the setup for the DDGS Drying System, namely the Product Heater, External Heater, Air Drying Unit and Heat Recovery Unit. Energy and Mass balances around each of these components along with several assumptions provided the basis for the theoretical model created.

The second objective of this project involved utilizing this model to ascertain the theoretical behavior of the system as its inputs vary. Specifically, the analysis considered three inputs, namely the DDGS Flow Rate, the DDGS Entering Moisture Content, and the Operation Temperature. The model produced results that showed how system characteristics such as the Air Flow Rate, Intermediate Loop Flow Rate and External Heater Power changed with variations in the inputs mentioned previously. The Dry Grain Flow Rate and the Grain Moisture Flow Rate only depended on the DDGS Flow Rate as expected. Interestingly, the Intermediate Loop Flow Rate remained independent on Operation Temperature, while the Air Flow Rate and External Heater Power only slightly depended on the Operation Temperature. The DDGS Flow Rate greatly affected the Air Flow Rate, External Heater Power and the Intermediate Loop Flow Rate while each of theses characteristics showed some dependence on DDGS Entering Moisture Content.

Meanwhile, the Moisture Removal Flow Rate, Remaining Moisture Flow Rate, Moisture Condensed Flow Rate and Recovery Air Humidity Ratio showed dependence on all three input variables (i.e. Operation Temperature, DDGS Flow Rate, and DDGS Entering Moisture Content). These characteristics all relied on the amount of moisture that entered into the DDGS Drying System. This trend explained the dependence of these characteristics on variations in DDGS Flow Rate and DDGS Entering Moisture Content. The Operation Temperature affect fore mentioned characteristics due to fact that air has a greater ability to hold moisture at higher temperatures, therefore, these characteristics changed with variations in Operation Temperature. Further analysis with quantitative data for the theoretical behavior characteristics can be found in the Theoretical Metrics of Behavior Section of this report.

The third objective of this project incorporated the theoretical behavior of the model with the variation of the inputs to establish the theoretical performance of the modeled DDGS Drying System. Specifically, the model provided data to calculate the DDGS Exiting Moisture Content, the Specific External Heater Energy, the Moisture Removed-Air Ratio and three types of Efficiency, namely the Thermal Efficiency, Recovery Efficiency and External Efficiency. Interestingly, all of the fore mentioned Metrics of System Performance remained independent of the DDGS Flow Rate. This trend occurred because the Metrics of System Behavior already accounted for variations in the DDGS Flow Rate and therefore the Metrics of System Performance listed above remain unchanged. The DDGS Exiting Moisture Content was the only Metric of Performance to change with variations in the DDGS Entering Moisture Content. This dependence shows an expected trend that the amount of moisture available for drying affects the amount of moisture dried. Also the analysis showed a drop of 3% in Moisture Content between the DDGS Entrance and DDGS Exit. This results suggested the need for staging and the need for additional research in optimizing these stages.

The Operation Temperature controlled the Metrics of System Performance listed above. Specifically, the Specific External Heater Energy and DDGS Exiting Moisture content decreased as the Operation Temperature increased. Meanwhile, all three Efficiencies, Thermal, Recovery and External, increased as the Operation Temperature increased. Overall, this analysis showed that an increase in Operation Temperature increased the DDGS Drying System Performance.

The fourth objective of this project included the use of experimental data to compare and contrast the similarities and differences between this data and the theoretical model. The analysis of the Experimental Data used two Figures of Merit, namely the Specific External Heater Energy and the External Efficiency to gauge the experimental system's performance. This analysis showed that the Experimental Data followed the same trends as the Theoretical

Model. The Operation Temperature also controlled the Experimental Figures of Merit and the analysis showed that an increase in Operation Temperature also increases the Experimental System Performance.

The analysis of the Experimental Data also included a study of the system's Approach Temperature Difference. This analysis showed that as the Approach Temperature Difference decreased the performance of the drying system increased. It also showed that an increase in Operation Temperature to increase system performance has less of an effect at lower Approach Temperature Differences.

Additionally, the analysis of experimental data provided a baseline for the current experimental setup and showed that the experimental setup behaves as though it has a Theoretical Approach Temperature Difference of 17.5 °F. The analysis also showed that the major cause of inefficiency was the interaction between DDGS and the other components of the DDGS Drying System; specifically, the interaction between the DDGS product and the Intermediate Product Loop. These interactions are crucial to the DDGS Drying System Performance and improvement in these areas will require additional research.

The fifth and last objective of this project included the use of the established behavioral metrics to provide operation guidelines for possibly improving the current experimental setup. Specifically, this analysis provided two dimensionless ratios, namely the Air-DDGS Ratio and the Loop-DDGS Ratio, which report the necessary Air and Intermediate Loop Flow Rates to maintain the desired system performance at a specific DDGS Flow Rate.

The analysis of the theoretical model showed that these ratios only depend on the DDGS Entering Moisture Content. Specifically, based on a 10 °F Theoretical Approach Temperature Difference, the Air-DDGS Ratio as a function of DDGS Entering Moisture Content follows the following expression:

$$R_{A/D} = 0.5125(Z) + 0.3481 \qquad (85)$$

Similarly, the Loop-DDGS Ratio as a function of DDGS Entering Moisture Content follows the following expression:

$$R_{L/D} = 0.5995(Z) + 0.4004 \tag{86}$$

This report completed the objectives discussed above and provided a valuable description, analysis and discussion of an air-based DDGS Drying System with Heat Recovery. Recommendations for the future include; the validation of the dimensionless ratios formulated in this project, additional research into the interaction between the DDGS product and the other drying system components, additional research into DDGS Drying System Stages and an economic analysis of cost endured due to increase in Operation Temperature weighed against the cost saved by the increase in system performance.

APPENDIX A: THEORETICAL MODEL EES CODE

```
"*********************************************"
"DDGS AIR DRYING SYSTEM WITH HEAT RECOVERY"
"THEORETICAL MODEL"
"BY: CHRIS HOECK"
"IOWA STATE UNIVERSITY"
"NOVEMBER 2007"
"*********************************************"
"*********************************************"
"Design Variables"
"*********************************************"
"These variables are entered in by the user and/or commented out to run in a parametric table"
bph=1.25                                   "<- Bushels of DDGS entering the system per hour"
T_operation=200                            "<- Operating Temperature"
Z_in=0.38 "lb_w/lb_g"                      "<- Moisture content of DDGS"
T_ambient=60                               "<- Ambient Temperature"
DELTAT=10                                  "<- Approach Temperature Difference"
P=14.7                                     "<-Ambient Pressure"
P_loop=50                                  "<- Intermediate Loop Pressure"
"*********************************************"
"Properties of DDGS on a 14.7% Dry Basis"
"*********************************************"
x_14.7= 0.147 "lb_w/lb_g"                  "<-Water mass to DDGS mass on a 14.7% dry mass basis"
Z_14.7=x_14.7/(1+x_14.7) "lb_w/lb_w+lb_g"  "<- Moisture content of DDGS on a 14.7% dry mass basis"
rho=30.171 "(lb_w + lb_g)/ft^3"            "<- Density of Wet DDGS"
V_b=1.244  "ft^3"                          "<- Volume of a Bushel"
m_g_w_14.7=V_b*rho "(lb_w + lb_ g)/bushel" "<-Total mass of a DDGS Bushel (water + dry grain)"
m_w_14.7=Z_14.7*m_g_w_14.7 "lb_w/bushel"   "<- Mass of water in a DDGS Bushel"
m_g=m_g_w_14.7-m_w_14.7 "lb_g/bushel"      "<-Mass of dry DDGS Bushel"

"*********************************************"
"Properties of DDGS  "
"*********************************************"

x_in=Z_in/(1-Z_in) "lb_w/lb_g"             "<-Water mass to DDGS mass "
m_w=m_g*x_in "lb_w/bushel"                 "<- Mass of water in a DDGS Bushel"
cp_g=0.4 "Btu/lb_g-F"                      "<- Specific Heat of DDGS dry grain"

"*********************************************"
"Heat of Vaporization for H2O"
"*********************************************"
T_boil=212 "F"                             "<- Boiling Point of Water"
P_sat_boil=P_sat(Steam,T=T_boil)           "<- Saturation Pressure at Boiling Point"
h_f_boil=Enthalpy(Steam,T=T_boil,P=P)      "<- Enthalpy of Saturated Liquid at Boiling Point"
h_g_boil=Enthalpy(Steam,T=T_boil,P=P_sat_boil) "<- Enthalpy of Saturated Vapor at Boiling Point"
h_f_g_boil=h_g_boil-h_f_boil               "<-Heat of Vaporization for Water"


"*********************************************"
"Product Heater"
"*********************************************"
"State 1 - DDGS Entering Conditions"
m_dot_g=bph*m_g "lb_g/hr"                  "<- Mass of DDGS entering the system per hour"
m_dot_w=bph*m_w "lb_w/hr"                  "<- Mass of Water entering the system per hour"
T_1=T_ambient                              "<- DDGS Entering Temperature"
```

```
h_f_1=Enthalpy(Steam,T=T_1,P=P)                    "<- Enthalpy of Saturated Liquid at DDGS Entrance"

"State 2 - DDGS After Drying"
T_2=T_operation-DELTAT                             "<-Temperature at DDGS Exit"
P_sat_2=P_sat(Steam,T=T_2)                         "<-Saturation Pressure at DDGS Exit"
h_f_2=Enthalpy(Steam,T=T_2,P=P)                    "<-Enthalpy of Saturated Liquid at DDGS Exit"
h_g_2=Enthalpy(Steam,T=T_2,P=P_sat_2)              "<-Enthalpy of Saturated Vapor at DDGS Exit"

"State a - Intermediate Side Dryer Out"
T_a=T_1+DELTAT                                     "<- Temperature at Loop Water Exit"
h_f_a=Enthalpy(Steam,T=T_a,P=P_loop)               "<- Enthalpy of Saturated Liquid at Loop Water Entrance Exit"

"State c - Intermediate Side Dryer In"
T_c=T_operation                                    "Temperature at Loop Water Entrance "
h_f_c=Enthalpy(Steam,T=T_c,P=P_loop)               "<-Enthalpy of Saturated Liquid at Loop Water Entrance"


"Energy Balance"
(m_dot_g*cp_g*T_1)+(m_dot_w*h_f_1)+(m_dot_loop*h_f_c)=(m_dot_g*cp_g*T_2)+(m_dot_w*h_f_2)+(m_dot_loop*h_f_a)


"*********************************************"
" Air Drying Unit"
"*********************************************"
"State 3 -  DDGS After Steam Extraction"
T_3=T_ambient+DELTAT                               "<-Temperature at DDGS Exit "
h_f_3=Enthalpy(Steam,T=T_3,P=P)                    "<-Enthalpy of Saturated Liquid at DDGS exit"

"State 4 - Entering Air"
T_4=T_ambient                                      "<- Temperature at Air Entrance"
cp_a=Cp(Air_ha,T=T_4,P=P)                          "<- Specific Heat of Air"
P_sat_4=P_sat(Steam,T=T_4)                         "<- Saturation Pressure at Air Entrance"
phi_4=50                                           "<- Relative Humdity at Air Entrance"
h_a_4=Enthalpy(Air_ha,T=T_4,P=P)                   "<- Enthalpy of Dry Air at Air Entrance"
h_g_4=Enthalpy(Steam,T=T_4,P=P_sat_4)              "<- Enthalpy of Saturated Vapor at Air Entrance"
omega_4=HumRat(AirH2O,T=T_4,r=phi_4/100,P=P)       "<- Humidity Ratio at Air Entrance"

"State 5 - Air Exiting Steam Extraction"
T_5=T_2-DELTAT                                     "<- Temperature after Steam Extraction"
P_sat_5=P_sat(Steam,T=T_5)                         "<- Saturation Pressure after Steam Extraction"
h_g_5=Enthalpy(Steam,T=T_5,P=P_sat_5)              "<- Enthalpy of Saturated Vapor after Steam Extraction"
h_a_5=Enthalpy(Air_ha,T=T_5,P=P)

"Mass Balance"
m_dot_w+m_dot_air*omega_4=m_dot_w_out+m_dot_air*omega_5
"Energy Balance"
(m_dot_g*cp_g*T_2)+(m_dot_w*h_f_2)+(m_dot_air*h_a_4)+(m_dot_air*omega_4*h_g_4)=(m_dot_g*cp_g*T_3)
+(m_dot_w_out*h_f_3)+(m_dot_air*h_a_5)+(m_dot_air*omega_5*h_g_5)

"*********************************************"
"Heat Recovery Unit"
"*********************************************"
"State b"
```

```
T_b=T_5-DELTAT                                  "<- Temperature at Loop Water Exit"
h_f_b=Enthalpy(Steam,T=T_b,P=P_loop)            "<- Enthalpy of Saturated Liquid at Loop Water Exit"

"State 6 - Air Exiting Loop"
T_6=T_ambient+2*DELTAT                          "<- Temperature at Air Exit"
P_sat_6=P_sat(Steam,T=T_6)                      "<- Saturation Pressure at Air Exit"
h_g_6=Enthalpy(Steam,T=T_6,P=P_sat_6)           "<- Enthalpy of Saturated Vapor at Air Exit"
phi_6=100                                       "<- Exiting Air  Relative Humidity"
omega_6=HumRat(AirH2O,T=T_6,r=phi_6/100,P=P)    "<- Humidity Ratio at Air Exit"
h_a_6=Enthalpy(Air_ha,T=T_6,P=P)                "<- Enthalpy of Dry Air at Air Exit"

"State 7 - Water Condensation from Loop"
T_7=T_6                                         "<- Temperature at Condensed Water Exit"
h_f_7=Enthalpy(Steam,T=T_7,P=P)                 "<- Enthalpy of Saturated Liquid at Condensed Water Exit"

"Mass Balance"
m_dot_cond=m_dot_air*(omega_5-omega_6)          "<- Condensation Mass Flow Rate"

"Energy Balance"
(m_dot_air*h_a_5)+(m_dot_air*omega_5*h_g_5)+(m_dot_loop*h_f_a)=(m_dot_air*h_a_6)+(m_dot_air*omega_6*h_g_6)
+(m_dot_loop*h_f_b)+(m_dot_cond*h_f_7)


"*********************************************"
"External Heater "
"*********************************************"
"Energy Balance"
Q_dot_heater=m_dot_loop*(h_f_c-h_f_b)           "<- Power Supplied by the External Heater"


"*********************************************"
"Program Outputs "
"*********************************************"
m_dot_w_dried=m_dot_w-m_dot_w_out
Q_dot_drying=(m_dot_loop*h_f_c)-(m_dot_loop*h_f_a) "<-Heat Transfered from Intermediate Loop of DDGS drying"
Q_dot_recovered=m_dot_loop*(h_f_b-h_f_a)

"Drying Efficiency"
eta=((m_dot_w_dried*h_f_g_boil)/(Q_dot_drying))            "<- Exergetic Efficiency of System"
eta_external=(1-(q_heater/(h_f_g_boil+(h_f_boil-h_f_1))))   "<- External Efficiency"
eta_thermal=Q_dot_recovered/Q_dot_drying                    "<- Thermal Efficiency"

"Change in percent moisture of DDGS on a dry basis"
x_out=m_dot_w_out/m_dot_g                       "<-Water mass to DDGS mass leaving the system"
Z_out=(x_out)/(1+x_out)                         "<- Moisture content of DDGS leaving the system "

"Volumetric Air Flow Rate"
rho_air=Density(Air_ha,T=T_4,P=P)
V_dot_air=(m_dot_air/rho_air)/convert(hr,min)   "<- Volumetric Flow Rate of Air"

"Power Consumed by Heater"
P_heater=Q_dot_heater/convert(kW,Btu/hr)        "<- Power consumed by Heater"
```

```
"Heat Required"
q_heater=Q_dot_heater/m_dot_w_dried                "<- Power per Pound of Moisture Removed"

"Dimensionless Values"
m_dot_in=m_dot_g+m_dot_w                           "<-Mass Flow Rate of DDGS"
R_Air_DDGS=m_dot_air/(m_dot_in)                    "<-Air to DDGS Ratio"
R_Loop_DDGS=m_dot_loop/(m_dot_in)                  "<- Loop to DDGS Ratio"
R_Dried_Air=m_dot_w_dried/m_dot_air                "<- Moisture Removed to Air Ratio"
R_Loop_Dried=m_dot_loop/(m_dot_w_dried)            "<- Loop to Moisture Removed Ratio"

"********************************************"
"Program Checks "
"********************************************"
Q_dot_drying_check=-(m_dot_g*cp_g*T_1)-(m_dot_w*h_f_1)+(m_dot_g*cp_g*T_2)+(m_dot_w*h_f_2)"<-Heat Used By
 DDGS for Drying"
Q_dot_recovered_check=(m_dot_air*h_a_5)+(m_dot_air*omega_5*h_g_5)-(m_dot_air*h_a_6)-(m_dot_air*omega_6*h_g_6)
-(m_dot_cond*h_f_7) "<- Energy Transfered in the Heat Recovery Unit"
Q_dot_heater_check=Q_dot_drying-Q_dot_recovered      "<- Energy Received by the Water Loop"
```

APPENDIX B: EXPERIMENTAL DATA ANALYSIS EES CODE

```
"*********************************************"
"DDGS AIR DRYING SYSTEM WITH HEAT RECOVERY"
"EXPERIMENTAL DATA ANALYSIS MODEL"
"BY: CHRIS HOECK"
"IOWA STATE UNIVERSITY"
"DECEMBER 2007"
"*********************************************"

"*********************************************"
"Design Variables"
"*********************************************"
T_operation=198.9                    "<- Operating Temperature"
bph=1.0                              "<- Bushels of DDGS entering the system per hour"
Z_in=0.40                            "<- Moisture content of DDGS lb_w/lb_g"

"*********************************************"
"Input Variables"
"*********************************************"
P=14.7                               "<-Ambient Pressure"
P_loop=50                            "<- Intermediate Loop Pressure"
T_grain=59.46                        "<-DDGS Entering Temperature"
T_air=70.8                           "<-Air Entering Tempeaature"
DELTAT_1=9.96                        "<- Experimental Approach Temperature Difference"
DELTAT_2=27.1                        "<- Experimental Approach Temperature Difference"
DELTAT_3=16.8                        "<- Experimental Approach Temperature Difference"
DELTAT_4=12.7                        "<- Experimental Approach Temperature Difference"
DELTAT_5=3.2                         "<- Experimental Approach Temperature Difference"
DELTAT_6=13.88                       "<- Losses Due to Product Transfer"
DELTAT_loss_1=3.3                    "<-Losses Due to Water Transfer"
DELTAT_loss_2=0

"*********************************************"
"Properties of DDGS on a 14.7% Dry Basis"
"*********************************************"
x_14.7= 0.147 "lb_w/lb_g"            "<-Water mass to DDGS mass on a 14.7% dry mass basis"
Z_14.7=x_14.7/(1+x_14.7) "lb_w/lb_w+lb_g"   "<- Moisture content of DDGS on a 14.7% dry mass basis"
rho=30.171 "(lb_w + lb_g)/ft^3"      "<- Density of Wet DDGS"
V_b=1.244   "ft^3"                   "<- Volume of a Bushel"
m_g_w_14.7=V_b*rho "(lb_w + lb_ g)/bushel"  "<-Total mass of a DDGS Bushel (water + dry grain)"
m_w_14.7=Z_14.7*m_g_w_14.7 "lb_w/bushel"    "<- Mass of water in a DDGS Bushel"
m_g=m_g_w_14.7-m_w_14.7 "lb_g/bushel"       "<-Mass of dry DDGS Bushel"

"*********************************************"
"Properties of DDGS  "
"*********************************************"

x_in=Z_in/(1-Z_in) "lb_w/lb_g"       "<-Water mass to DDGS mass "
m_w=m_g*x_in "lb_w/bushel"           "<- Mass of water in a DDGS Bushel"
cp_g=0.4 "Btu/lb_g-F"                "<- Specific Heat of DDGS dry grain"

"*********************************************"
"Heat of Vaporization"
"*********************************************"
T_boil=212 "F"                       "<- Boiling Point of Water"
P_sat_boil=P_sat(Steam,T=T_boil)     "<- Saturation Pressure at Boiling Point"
```

```
h_f_boil=Enthalpy(Steam,T=T_boil,P=P)            "<- Enthalpy of Saturated Liquid at Boiling Point"
h_g_boil=Enthalpy(Steam,T=T_boil,P=P_sat_boil)   "<- Enthalpy of Saturated Vapor at Boiling Point"
h_f_g_boil=h_g_boil-h_f_boil                     "<-Heat of Vaporization for Water"

"*********************************************"
"Product Heater"
"*********************************************"
"State 1 - DDGS Entering Conditions"
m_dot_g=bph*m_g "lb_g/hr"                        "<- Mass of DDGS entering the system per hour"
m_dot_w=bph*m_w "lb_w/hr"                        "<- Mass of Water entering the system per hour"
T_1=T_grain                                      "<- DDGS Entering Temperature"
h_f_1=Enthalpy(Steam,T=T_1,P=P)                  "<- Enthalpy of Saturated Liquid at DDGS Entrance"

"State 2 - DDGS After Heating"
T_2=T_c-DELTAT_2                                 "<-Temperature at DDGS Exit"
P_sat_2=P_sat(Steam,T=T_2)                       "<-Saturation Pressure at DDGS Exit"
h_f_2=Enthalpy(Steam,T=T_2,P=P)                  "<-Enthalpy of Saturated Liquid at DDGS Exit"
h_g_2=Enthalpy(Steam,T=T_2,P=P_sat_2)            "<-Enthalpy of Saturated Vaport at DDGS Exit"

"State a - Intermediate Side Dryer Out"
T_a_1=T_1+DELTAT_1                               "<- Temperature at Loop Water Exit"
h_f_a_1=Enthalpy(Steam,T=T_a_1,P=P_loop)         "<- Enthalpy of Saturated Liquid at Loop Water Entrance Exit"

"State c - Intermediate Side Dryer In"
T_c=T_operation                                  "Temperature at Loop Water Entrance "
h_f_c=Enthalpy(Steam,T=T_c,P=P_loop)             "<-Enthalpy of Saturated Liquid at Loop Water Entrance"


"Energy Balance"
(m_dot_g*cp_g*T_1)+(m_dot_w*h_f_1)+(m_dot_loop*h_f_c)=(m_dot_g*cp_g*T_2)+(m_dot_w*h_f_2)+(m_dot_loop*h_f_a_1
)


"*********************************************"
" Air Drying Unit"
"*********************************************"

"State 2a - DDGS Before Drying"
T_2_a=T_2-DELTAT_loss_1
P_sat_2_a=P_sat(Steam,T=T_2_a)                   "<-Saturation Pressure at DDGS Exit"
h_f_2_a=Enthalpy(Steam,T=T_2_a,P=P)              "<-Enthalpy of Saturated Liquid at DDGS Exit"
h_g_2_a=Enthalpy(Steam,T=T_2_a,P=P_sat_2_a)      "<-Enthalpy of Saturated Vaport at DDGS Exit"

"State 3 -  DDGS After Drying"
T_3=T_4+DELTAT_4                                 "<-Temperature at DDGS Exit "
h_f_3=Enthalpy(Steam,T=T_3,P=P)                  "<-Enthalpy of Saturated Liquid at DDGS exit"

"State 4 - Entering Air"
T_4=T_air                                        "<- Temperature at Air Entrance"
cp_a=Cp(Air_ha,T=T_4,P=P)                        "<- Specific Heat of Air"
P_sat_4=P_sat(Steam,T=T_4)                       "<- Saturation Pressure at Air Entrance"
phi_4=50                                         "<- Relative Humdity at Air Entrance"
```

```
h_a_4=Enthalpy(Air_ha,T=T_4,P=P)
h_g_4=Enthalpy(Steam,T=T_4,P=P_sat_4)              "<- Enthalpy of Saturated Vapor at Air Entrance"
omega_4=HumRat(AirH2O,T=T_4,r=phi_4/100,P=P)       "<- Humidity Ratio at Air Entrance"

"State 5 - Air Exiting Steam Extraction"
T_5=T_2_a-DELTAT_3                                 "<- Temperature after Steam Extraction"
P_sat_5=P_sat(Steam,T=T_5)                         "<- Saturation Pressure after Steam Extraction"
h_g_5=Enthalpy(Steam,T=T_5,P=P_sat_5)              "<- Enthalpy of Saturated Vapor after Steam Extraction"
h_a_5=Enthalpy(Air_ha,T=T_5,P=P)

omega_5_max=HumRat(AirH2O,T=T_5,r=1,P=P)
"Mass Balance"
m_dot_w+m_dot_air*omega_4=m_dot_w_out+m_dot_air*omega_5
"Energy Balance"
(m_dot_g*cp_g*T_2_a)+(m_dot_w*h_f_2_a)+(m_dot_air*h_a_4)+(m_dot_air*omega_4*h_g_4)=(m_dot_g*cp_g*T_3)
+(m_dot_w_out*h_f_3)+(m_dot_air*h_a_5)+(m_dot_air*omega_5*h_g_5)


"********************************************"
"Heat Recovery Unit"
"********************************************"
"State a_2 - Heat Recovery Unit In"
T_a_2=T_a_1-DELTAT_loss_2                          "<- Temperature at Loop Water Exit"
h_f_a_2=Enthalpy(Steam,T=T_a_2,P=P_loop)           "<- Enthalpy of Saturated Liquid at Loop Water Entrance Exit"

"State b"
T_b=T_5-DELTAT_5                                   "<- Temperature at Loop Water Exit"
h_f_b=Enthalpy(Steam,T=T_b,P=P_loop)               "<- Enthalpy of Saturated Liquid at Loop Water Exit"

"State 6 - Air Exiting Loop"
T_6=T_a_2+DELTAT_6                                 "<- Temperature at Air Exit"
P_sat_6=P_sat(Steam,T=T_6)                         "<- Saturation Pressure at Air Exit"
h_g_6=Enthalpy(Steam,T=T_6,P=P_sat_6)              "<- Enthalpy of Saturated Vapor at Air Exit"
phi_6=100                                          "<- Exiting Air  Relative Humidity"
omega_6=HumRat(AirH2O,T=T_6,r=phi_6/100,P=P)       "<- Humidity Ratio at Air Exit"
h_a_6=Enthalpy(Air_ha,T=T_6,P=P)

"State 7 - Water Condensation from Loop"
T_7=T_6                                            "<- Temperature at Condensed Water Exit"
h_f_7=Enthalpy(Steam,T=T_7,P=P)                    "<- Enthalpy of Saturated Liquid at Condensed Water Exit"

"Mass Balance"
m_dot_cond=m_dot_air*(omega_5-omega_6)             "<- Condensation Mass Flow Rate"

"Energy Balance"
(m_dot_air*h_a_5)+(m_dot_air*omega_5*h_g_5)+(m_dot_loop*h_f_a_2)=(m_dot_air*h_a_6)+(m_dot_air*omega_6*h_g_6)
+(m_dot_loop*h_f_b)+(m_dot_cond*h_f_7)


"********************************************"
"Heater "
"********************************************"
```

```
"Energy Balance"
Q_dot_heater=m_dot_loop*(h_f_c-h_f_b)                    "<- Power Supplied by the External Heater"


"********************************************"
"Program Outputs "
"********************************************"
m_dot_w_dried=m_dot_w-m_dot_w_out
Q_dot_drying=(m_dot_loop*h_f_c)-(m_dot_loop*h_f_a_1) "<-Heat Transfered from Intermediate Loop of DDGS drying"
Q_dot_recovered=m_dot_loop*(h_f_b-h_f_a_2)

"Drying Efficiency"
eta_exergetic=((m_dot_w_dried*h_f_g_boil)/(Q_dot_drying)) "<- Exergetic Efficiency of System"
eta_external=(1-(q_heater/(h_f_g_boil+(h_f_boil-h_f_1))))                              "<- External
 Efficiency"
eta_thermal=Q_dot_recovered/Q_dot_drying                 "<- Thermal Efficiency"

DELTAT_Recovery=(T_b-T_a_2)                              "<-Loop Temperature Change in Heat Recovery Unit"
DELTAT_Heater=(T_c-T_a_1)                                "<-Loop Temperature Change in External Heater"
eta_temperature=DELTAT_Recovery/DELTAT_Heater            "<- Recovery Efficiency"

"Change in percent moisture of DDGS on a dry basis"
x_out=m_dot_w_out/m_dot_g                                "<-Water mass to DDGS mass leaving the system"
Z_out=(x_out)/(1+x_out)                                  "<- Moisture content of DDGS leaving the system "

"Volumetric Air Flow Rate"
rho_air=Density(Air_ha,T=T_4,P=P)
V_dot_air=(m_dot_air/rho_air)/convert(hr,min)            "<- Volumetric Flow Rate of Air"

"Power Consumed by Heater"
P_heater=Q_dot_heater/convert(kW,Btu/hr)                 "<- Power consumed by Heater"

"Heat Required"
q_heater=Q_dot_heater/m_dot_w_dried                      "<- Power per Pound of Moisture Dried"

"Dimensionless Values"
m_dot_in=m_dot_g+m_dot_w                                 "<-Mass Flow Rate of DDGS"
R_Air_DDGS=m_dot_air/(m_dot_in)                          "<-Air to DDGS Ratio"
R_Loop_DDGS=m_dot_loop/(m_dot_in)                        "<- Loop to DDGS Ratio"
R_Dried_Air=m_dot_w_dried/m_dot_air                      "<- Moisture Removed to Air Ratio"
R_Loop_Dried=m_dot_loop/(m_dot_w_dried)                  "<- Loop to Moisture Removed Ratio"

"********************************************"
"Program Checks "
"********************************************"
Q_dot_drying_check=-(m_dot_g*cp_g*T_1)-(m_dot_w*h_f_1)+(m_dot_g*cp_g*T_2)+(m_dot_w*h_f_2)"<-Heat Used By
 DDGS for Drying"
Q_dot_recovered_check=(m_dot_air*h_a_5)+(m_dot_air*omega_5*h_g_5)-(m_dot_air*h_a_6)-(m_dot_air*omega_6*h_g_6)
-(m_dot_cond*h_f_7)
Q_dot_heater_check=Q_dot_drying-Q_dot_recovered          "<- Energy Received by the Water Loop"
```

APPENDIX C: RAW DATA

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
100	0.25	48	8.181	5.014	7.333	8.289	4.891	0.1229	0.02223	248.5	0.07281	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	0.50	48	16.36	10.03	14.67	16.58	9.782	0.2458	0.02223	496.9	0.1456	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	0.75	48	24.54	15.04	22	24.87	14.67	0.3687	0.02223	745.4	0.2184	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	1.00	48	32.72	20.06	29.33	33.16	19.56	0.4916	0.02223	993.8	0.2913	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	1.25	48	40.9	25.07	36.67	41.45	24.46	0.6146	0.02223	1242	0.3641	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	1.50	48	49.08	30.08	44	49.74	29.35	0.7375	0.02223	1491	0.4369	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	1.75	48	57.26	35.1	51.33	58.03	34.24	0.8604	0.02223	1739	0.5097	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	2.00	48	65.45	40.11	58.66	66.31	39.13	0.9833	0.02223	1988	0.5825	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	2.25	48	73.63	45.13	66	74.6	44.02	1.106	0.02223	2236	0.6553	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	2.50	48	81.81	50.14	73.33	82.89	48.91	1.229	0.02223	2485	0.7281	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	2.75	48	89.99	55.15	80.66	91.18	53.8	1.352	0.02223	2733	0.801	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	3.00	48	98.17	60.17	88	99.47	58.69	1.475	0.02223	2981	0.8738	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	3.25	48	106.3	65.18	95.33	107.8	63.58	1.598	0.02223	3230	0.9466	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	3.50	48	114.5	70.2	102.7	116.1	68.47	1.721	0.02223	3478	1.019	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	3.75	48	122.7	75.21	110	124.3	73.37	1.844	0.02223	3727	1.092	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	4.00	48	130.9	80.22	117.3	132.6	78.26	1.967	0.02223	3975	1.165	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	4.25	48	139.1	85.24	124.7	140.9	83.15	2.09	0.02223	4224	1.238	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	4.50	48	147.3	90.25	132	149.2	88.04	2.212	0.02223	4472	1.311	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	4.75	48	155.4	95.26	139.3	157.5	92.93	2.335	0.02223	4721	1.383	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0
100	5.00	48	163.6	100.3	146.7	165.8	97.82	2.458	0.02223	4969	1.456	2021	0.3742	0.00	-0.8012	0.5558	0.6282	59.66	0

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
110	0.25	53.83	8.181	5.014	7.306	8.29	4.83	0.1838	0.03063	248.4	0.07281	1352	0.3712	0.06135	-0.2045	0.5537	0.6283	39.75	0.25
110	0.5	53.83	16.36	10.03	14.61	16.58	9.66	0.3676	0.03063	496.9	0.1456	1352	0.3712	0.1227	-0.2045	0.5537	0.6283	39.75	0.25
110	0.75	53.83	24.54	15.04	21.92	24.87	14.49	0.5514	0.03063	745.3	0.2184	1352	0.3712	0.184	-0.2045	0.5537	0.6283	39.75	0.25
110	1	53.83	32.72	20.06	29.22	33.16	19.32	0.7352	0.03063	993.8	0.2912	1352	0.3712	0.2454	-0.2045	0.5537	0.6283	39.75	0.25
110	1.25	53.83	40.9	25.07	36.53	41.45	24.15	0.919	0.03063	1242	0.3641	1352	0.3712	0.3067	-0.2045	0.5537	0.6283	39.75	0.25
110	1.5	53.83	49.08	30.08	43.83	49.74	28.98	1.103	0.03063	1491	0.4369	1352	0.3712	0.3681	-0.2045	0.5537	0.6283	39.75	0.25
110	1.75	53.83	57.26	35.1	51.14	58.03	33.81	1.287	0.03063	1739	0.5097	1352	0.3712	0.4294	-0.2045	0.5537	0.6283	39.75	0.25
110	2	53.83	65.45	40.11	58.44	66.32	38.64	1.47	0.03063	1988	0.5825	1352	0.3712	0.4908	-0.2045	0.5537	0.6283	39.75	0.25
110	2.25	53.83	73.63	45.13	65.75	74.61	43.47	1.654	0.03063	2236	0.6553	1352	0.3712	0.5521	-0.2045	0.5537	0.6283	39.75	0.25
110	2.5	53.83	81.81	50.14	73.06	82.9	48.3	1.838	0.03063	2484	0.7281	1352	0.3712	0.6135	-0.2045	0.5537	0.6283	39.75	0.25
110	2.75	53.83	89.99	55.15	80.36	91.19	53.13	2.022	0.03063	2733	0.8009	1352	0.3712	0.6748	-0.2045	0.5537	0.6283	39.75	0.25
110	3	53.83	98.17	60.17	87.67	99.48	57.96	2.206	0.03063	2981	0.8737	1352	0.3712	0.7362	-0.2045	0.5537	0.6283	39.75	0.25
110	3.25	53.83	106.3	65.18	94.97	107.8	62.79	2.389	0.03063	3230	0.9466	1352	0.3712	0.7975	-0.2045	0.5537	0.6283	39.75	0.25
110	3.5	53.83	114.5	70.2	102.3	116.1	67.62	2.573	0.03063	3478	1.019	1352	0.3712	0.8589	-0.2045	0.5537	0.6283	39.75	0.25
110	3.75	53.83	122.7	75.21	109.6	124.3	72.45	2.757	0.03063	3727	1.092	1352	0.3712	0.9202	-0.2045	0.5537	0.6283	39.75	0.25
110	4	53.83	130.9	80.22	116.9	132.6	77.28	2.941	0.03063	3975	1.165	1352	0.3712	0.9816	-0.2045	0.5537	0.6283	39.75	0.25
110	4.25	53.83	139.1	85.24	124.2	140.9	82.11	3.125	0.03063	4224	1.238	1352	0.3712	1.043	-0.2045	0.5537	0.6283	39.75	0.25
110	4.5	53.83	147.3	90.25	131.5	149.2	86.94	3.308	0.03063	4472	1.311	1352	0.3712	1.104	-0.2045	0.5537	0.6283	39.75	0.25
110	4.75	53.83	155.4	95.26	138.8	157.5	91.77	3.492	0.03063	4720	1.383	1352	0.3712	1.166	-0.2045	0.5537	0.6283	39.75	0.25
110	5	53.83	163.6	100.3	146.1	165.8	96.6	3.676	0.03063	4969	1.456	1352	0.3712	1.227	-0.2045	0.5537	0.6283	39.75	0.25

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{w,in}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{w,out}$	$\dot{m}_{w,dried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{w,cond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
120	0.25	57.24	8.181	5.014	7.278	8.29	4.77	0.2443	0.03904	248.4	0.07281	1017	0.3683	0.1223	0.09396	0.5516	0.6283	29.79	0.4001
120	0.5	57.24	16.36	10.03	14.56	16.58	9.539	0.4886	0.03904	496.8	0.1456	1017	0.3683	0.2447	0.09396	0.5516	0.6283	29.79	0.4001
120	0.75	57.24	24.54	15.04	21.83	24.87	14.31	0.7329	0.03904	745.3	0.2184	1017	0.3683	0.367	0.09396	0.5516	0.6283	29.79	0.4001
120	1	57.24	32.72	20.06	29.11	33.16	19.08	0.9773	0.03904	993.7	0.2912	1017	0.3683	0.4893	0.09396	0.5516	0.6283	29.79	0.4001
120	1.25	57.24	40.9	25.07	36.39	41.45	23.85	1.222	0.03904	1242	0.364	1017	0.3683	0.6117	0.09396	0.5516	0.6283	29.79	0.4001
120	1.5	57.24	49.08	30.08	43.67	49.74	28.62	1.466	0.03904	1491	0.4368	1017	0.3683	0.734	0.09396	0.5516	0.6283	29.79	0.4001
120	1.75	57.24	57.26	35.1	50.94	58.03	33.39	1.71	0.03904	1739	0.5096	1017	0.3683	0.8563	0.09396	0.5516	0.6283	29.79	0.4001
120	2	57.24	65.45	40.11	58.22	66.32	38.16	1.955	0.03904	1987	0.5824	1017	0.3683	0.9787	0.09396	0.5516	0.6283	29.79	0.4001
120	2.25	57.24	73.63	45.13	65.5	74.61	42.93	2.199	0.03904	2236	0.6552	1017	0.3683	1.101	0.09396	0.5516	0.6283	29.79	0.4001
120	2.5	57.24	81.81	50.14	72.78	82.9	47.7	2.443	0.03904	2484	0.7281	1017	0.3683	1.223	0.09396	0.5516	0.6283	29.79	0.4001
120	2.75	57.24	89.99	55.15	80.05	91.19	52.47	2.687	0.03904	2733	0.8009	1017	0.3683	1.346	0.09396	0.5516	0.6283	29.79	0.4001
120	3	57.24	98.17	60.17	87.33	99.48	57.24	2.932	0.03904	2981	0.8737	1017	0.3683	1.468	0.09396	0.5516	0.6283	29.79	0.4001
120	3.25	57.24	106.3	65.18	94.61	107.8	62.01	3.176	0.03904	3229	0.9465	1017	0.3683	1.59	0.09396	0.5516	0.6283	29.79	0.4001
120	3.5	57.24	114.5	70.2	101.9	116.1	66.77	3.42	0.03904	3478	1.019	1017	0.3683	1.713	0.09396	0.5516	0.6283	29.79	0.4001
120	3.75	57.24	122.7	75.21	109.2	124.3	71.54	3.665	0.03904	3726	1.092	1017	0.3683	1.835	0.09396	0.5516	0.6283	29.79	0.4001
120	4	57.24	130.9	80.22	116.4	132.6	76.31	3.909	0.03904	3975	1.165	1017	0.3683	1.957	0.09396	0.5516	0.6283	29.79	0.4001
120	4.25	57.24	139.1	85.24	123.7	140.9	81.08	4.153	0.03904	4223	1.238	1017	0.3683	2.08	0.09396	0.5516	0.6283	29.79	0.4001
120	4.5	57.24	147.3	90.25	131	149.2	85.85	4.398	0.03904	4472	1.31	1017	0.3683	2.202	0.09396	0.5516	0.6283	29.79	0.4001
120	4.75	57.24	155.4	95.26	138.3	157.5	90.62	4.642	0.03904	4720	1.383	1017	0.3683	2.324	0.09396	0.5516	0.6283	29.79	0.4001
120	5	57.24	163.6	100.3	145.6	165.8	95.39	4.886	0.03904	4968	1.456	1017	0.3683	2.447	0.09396	0.5516	0.6283	29.79	0.4001

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
130	0.25	59.45	8.181	5.014	7.25	8.29	4.709	0.3045	0.04747	248.4	0.0728	815.9	0.3654	0.183	0.273	0.5495	0.6283	23.81	0.5001
130	0.5	59.45	16.36	10.03	14.5	16.58	9.419	0.6089	0.04747	496.8	0.1456	815.9	0.3654	0.3659	0.273	0.5495	0.6283	23.81	0.5001
130	0.75	59.45	24.54	15.04	21.75	24.87	14.13	0.9134	0.04747	745.2	0.2184	815.9	0.3654	0.5489	0.273	0.5495	0.6283	23.81	0.5001
130	1	59.45	32.72	20.06	29	33.16	18.84	1.218	0.04747	993.6	0.2912	815.9	0.3654	0.7318	0.273	0.5495	0.6283	23.81	0.5001
130	1.25	59.45	40.9	25.07	36.25	41.45	23.55	1.522	0.04747	1242	0.364	815.9	0.3654	0.9148	0.273	0.5495	0.6283	23.81	0.5001
130	1.5	59.45	49.08	30.08	43.5	49.74	28.26	1.827	0.04747	1490	0.4368	815.9	0.3654	1.098	0.273	0.5495	0.6283	23.81	0.5001
130	1.75	59.45	57.26	35.1	50.75	58.03	32.97	2.131	0.04747	1739	0.5096	815.9	0.3654	1.281	0.273	0.5495	0.6283	23.81	0.5001
130	2	59.45	65.45	40.11	58	66.32	37.68	2.436	0.04747	1987	0.5824	815.9	0.3654	1.464	0.273	0.5495	0.6283	23.81	0.5001
130	2.25	59.45	73.63	45.13	65.25	74.61	42.39	2.74	0.04747	2236	0.6552	815.9	0.3654	1.647	0.273	0.5495	0.6283	23.81	0.5001
130	2.5	59.45	81.81	50.14	72.5	82.9	47.09	3.045	0.04747	2484	0.728	815.9	0.3654	1.83	0.273	0.5495	0.6283	23.81	0.5001
130	2.75	59.45	89.99	55.15	79.75	91.19	51.8	3.349	0.04747	2732	0.8008	815.9	0.3654	2.012	0.273	0.5495	0.6283	23.81	0.5001
130	3	59.45	98.17	60.17	87	99.48	56.51	3.654	0.04747	2981	0.8736	815.9	0.3654	2.195	0.273	0.5495	0.6283	23.81	0.5001
130	3.25	59.45	106.3	65.18	94.25	107.8	61.22	3.958	0.04747	3229	0.9464	815.9	0.3654	2.378	0.273	0.5495	0.6283	23.81	0.5001
130	3.5	59.45	114.5	70.2	101.5	116.1	65.93	4.263	0.04747	3478	1.019	815.9	0.3654	2.561	0.273	0.5495	0.6283	23.81	0.5001
130	3.75	59.45	122.7	75.21	108.7	124.3	70.64	4.567	0.04747	3726	1.092	815.9	0.3654	2.744	0.273	0.5495	0.6283	23.81	0.5001
130	4	59.45	130.9	80.22	116	132.6	75.35	4.871	0.04747	3974	1.165	815.9	0.3654	2.927	0.273	0.5495	0.6283	23.81	0.5001
130	4.25	59.45	139.1	85.24	123.2	140.9	80.06	5.176	0.04747	4223	1.238	815.9	0.3654	3.11	0.273	0.5495	0.6283	23.81	0.5001
130	4.5	59.45	147.3	90.25	130.5	149.2	84.77	5.48	0.04747	4471	1.31	815.9	0.3654	3.293	0.273	0.5495	0.6283	23.81	0.5001
130	4.75	59.45	155.4	95.26	137.7	157.5	89.48	5.785	0.04747	4720	1.383	815.9	0.3654	3.476	0.273	0.5495	0.6283	23.81	0.5001
130	5	59.45	163.6	100.3	145	165.8	94.19	6.089	0.04747	4968	1.456	815.9	0.3654	3.659	0.273	0.5495	0.6283	23.81	0.5001

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
140	0.25	60.97	8.181	5.014	7.223	8.29	4.65	0.3643	0.0559	248.4	0.0728	681.9	0.3624	0.2432	0.3924	0.5474	0.6283	19.83	0.5715
140	0.5	60.97	16.36	10.03	14.45	16.58	9.299	0.7285	0.0559	496.8	0.1456	681.9	0.3624	0.4864	0.3924	0.5474	0.6283	19.83	0.5715
140	0.75	60.97	24.54	15.04	21.67	24.87	13.95	1.093	0.0559	745.2	0.2184	681.9	0.3624	0.7296	0.3924	0.5474	0.6283	19.83	0.5715
140	1	60.97	32.72	20.06	28.89	33.16	18.6	1.457	0.0559	993.6	0.2912	681.9	0.3624	0.9728	0.3924	0.5474	0.6283	19.83	0.5715
140	1.25	60.97	40.9	25.07	36.11	41.45	23.25	1.821	0.0559	1242	0.364	681.9	0.3624	1.216	0.3924	0.5474	0.6283	19.83	0.5715
140	1.5	60.97	49.08	30.08	43.34	49.74	27.9	2.186	0.0559	1490	0.4368	681.9	0.3624	1.459	0.3924	0.5474	0.6283	19.83	0.5715
140	1.75	60.97	57.26	35.1	50.56	58.03	32.55	2.55	0.0559	1739	0.5096	681.9	0.3624	1.702	0.3924	0.5474	0.6283	19.83	0.5715
140	2	60.97	65.45	40.11	57.78	66.32	37.2	2.914	0.0559	1987	0.5824	681.9	0.3624	1.946	0.3924	0.5474	0.6283	19.83	0.5715
140	2.25	60.97	73.63	45.13	65.01	74.61	41.85	3.278	0.0559	2236	0.6552	681.9	0.3624	2.189	0.3924	0.5474	0.6283	19.83	0.5715
140	2.5	60.97	81.81	50.14	72.23	82.9	46.5	3.643	0.0559	2484	0.728	681.9	0.3624	2.432	0.3924	0.5474	0.6283	19.83	0.5715
140	2.75	60.97	89.99	55.15	79.45	91.19	51.15	4.007	0.0559	2732	0.8008	681.9	0.3624	2.675	0.3924	0.5474	0.6283	19.83	0.5715
140	3	60.97	98.17	60.17	86.68	99.48	55.8	4.371	0.0559	2981	0.8736	681.9	0.3624	2.918	0.3924	0.5474	0.6283	19.83	0.5715
140	3.25	60.97	106.3	65.18	93.9	107.8	60.45	4.735	0.0559	3229	0.9464	681.9	0.3624	3.162	0.3924	0.5474	0.6283	19.83	0.5715
140	3.5	60.97	114.5	70.2	101.1	116.1	65.1	5.1	0.0559	3478	1.019	681.9	0.3624	3.405	0.3924	0.5474	0.6283	19.83	0.5715
140	3.75	60.97	122.7	75.21	108.3	124.3	69.75	5.464	0.0559	3726	1.092	681.9	0.3624	3.648	0.3924	0.5474	0.6283	19.83	0.5715
140	4	60.97	130.9	80.22	115.6	132.6	74.39	5.828	0.0559	3974	1.165	681.9	0.3624	3.891	0.3924	0.5474	0.6283	19.83	0.5715
140	4.25	60.97	139.1	85.24	122.8	140.9	79.04	6.192	0.0559	4223	1.238	681.9	0.3624	4.134	0.3924	0.5474	0.6283	19.83	0.5715
140	4.5	60.97	147.3	90.25	130	149.2	83.69	6.557	0.0559	4471	1.31	681.9	0.3624	4.377	0.3924	0.5474	0.6283	19.83	0.5715
140	4.75	60.97	155.4	95.26	137.2	157.5	88.34	6.921	0.0559	4720	1.383	681.9	0.3624	4.621	0.3924	0.5474	0.6283	19.83	0.5715
140	5	60.97	163.6	100.3	144.5	165.8	92.99	7.285	0.0559	4968	1.456	681.9	0.3624	4.864	0.3924	0.5474	0.6283	19.83	0.5715

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
150	0.25	62.05	8.181	5.014	7.198	8.29	4.59	0.4237	0.06434	248.4	0.07281	586.3	0.3594	0.303	0.4775	0.5455	0.6283	16.99	0.625
150	0.5	62.05	16.36	10.03	14.4	16.58	9.18	0.8474	0.06434	496.8	0.1456	586.3	0.3594	0.6061	0.4775	0.5455	0.6283	16.99	0.625
150	0.75	62.05	24.54	15.04	21.59	24.87	13.77	1.271	0.06434	745.3	0.2184	586.3	0.3594	0.9091	0.4775	0.5455	0.6283	16.99	0.625
150	1	62.05	32.72	20.06	28.79	33.16	18.36	1.695	0.06434	993.7	0.2912	586.3	0.3594	1.212	0.4775	0.5455	0.6283	16.99	0.625
150	1.25	62.05	40.9	25.07	35.99	41.45	22.95	2.118	0.06434	1242	0.364	586.3	0.3594	1.515	0.4775	0.5455	0.6283	16.99	0.625
150	1.5	62.05	49.08	30.08	43.19	49.74	27.54	2.542	0.06434	1491	0.4368	586.3	0.3594	1.818	0.4775	0.5455	0.6283	16.99	0.625
150	1.75	62.05	57.26	35.1	50.38	58.03	32.13	2.966	0.06434	1739	0.5096	586.3	0.3594	2.121	0.4775	0.5455	0.6283	16.99	0.625
150	2	62.05	65.45	40.11	57.58	66.32	36.72	3.39	0.06434	1987	0.5824	586.3	0.3594	2.424	0.4775	0.5455	0.6283	16.99	0.625
150	2.25	62.05	73.63	45.13	64.78	74.61	41.31	3.813	0.06434	2236	0.6552	586.3	0.3594	2.727	0.4775	0.5455	0.6283	16.99	0.625
150	2.5	62.05	81.81	50.14	71.98	82.9	45.9	4.237	0.06434	2484	0.7281	586.3	0.3594	3.03	0.4775	0.5455	0.6283	16.99	0.625
150	2.75	62.05	89.99	55.15	79.17	91.18	50.49	4.661	0.06434	2733	0.8009	586.3	0.3594	3.334	0.4775	0.5455	0.6283	16.99	0.625
150	3	62.05	98.17	60.17	86.37	99.47	55.08	5.084	0.06434	2981	0.8737	586.3	0.3594	3.637	0.4775	0.5455	0.6283	16.99	0.625
150	3.25	62.05	106.3	65.18	93.57	107.8	59.67	5.508	0.06434	3229	0.9465	586.3	0.3594	3.94	0.4775	0.5455	0.6283	16.99	0.625
150	3.5	62.05	114.5	70.2	100.8	116.1	64.26	5.932	0.06434	3478	1.019	586.3	0.3594	4.243	0.4775	0.5455	0.6283	16.99	0.625
150	3.75	62.05	122.7	75.21	108	124.3	68.85	6.355	0.06434	3726	1.092	586.3	0.3594	4.546	0.4775	0.5455	0.6283	16.99	0.625
150	4	62.05	130.9	80.22	115.2	132.6	73.44	6.779	0.06434	3975	1.165	586.3	0.3594	4.849	0.4775	0.5455	0.6283	16.99	0.625
150	4.25	62.05	139.1	85.24	122.4	140.9	78.03	7.203	0.06434	4223	1.238	586.3	0.3594	5.152	0.4775	0.5455	0.6283	16.99	0.625
150	4.5	62.05	147.3	90.25	129.6	149.2	82.62	7.626	0.06434	4472	1.31	586.3	0.3594	5.455	0.4775	0.5455	0.6283	16.99	0.625
150	4.75	62.05	155.4	95.26	136.8	157.5	87.21	8.05	0.06434	4720	1.383	586.3	0.3594	5.758	0.4775	0.5455	0.6283	16.99	0.625
150	5	62.05	163.6	100.3	144	165.8	91.8	8.474	0.06434	4968	1.456	586.3	0.3594	6.061	0.4775	0.5455	0.6283	16.99	0.625

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
160	0.25	62.84	8.181	5.014	7.174	8.289	4.531	0.4828	0.07276	248.5	0.07283	514.7	0.3565	0.3625	0.5413	0.5437	0.6282	14.86	0.6666
160	0.5	62.84	16.36	10.03	14.35	16.58	9.062	0.9655	0.07276	497	0.1457	514.7	0.3565	0.725	0.5413	0.5437	0.6282	14.86	0.6666
160	0.75	62.84	24.54	15.04	21.52	24.87	13.59	1.448	0.07276	745.5	0.2185	514.7	0.3565	1.088	0.5413	0.5437	0.6282	14.86	0.6666
160	1	62.84	32.72	20.06	28.7	33.16	18.12	1.931	0.07276	994	0.2913	514.7	0.3565	1.45	0.5413	0.5437	0.6282	14.86	0.6666
160	1.25	62.84	40.9	25.07	35.87	41.44	22.66	2.414	0.07276	1242	0.3641	514.7	0.3565	1.813	0.5413	0.5437	0.6282	14.86	0.6666
160	1.5	62.84	49.08	30.08	43.05	49.73	27.19	2.897	0.07276	1491	0.437	514.7	0.3565	2.175	0.5413	0.5437	0.6282	14.86	0.6666
160	1.75	62.84	57.26	35.1	50.22	58.02	31.72	3.379	0.07276	1739	0.5098	514.7	0.3565	2.538	0.5413	0.5437	0.6282	14.86	0.6666
160	2	62.84	65.45	40.11	57.4	66.31	36.25	3.862	0.07276	1988	0.5826	514.7	0.3565	2.9	0.5413	0.5437	0.6282	14.86	0.6666
160	2.25	62.84	73.63	45.13	64.57	74.6	40.78	4.345	0.07276	2236	0.6554	514.7	0.3565	3.263	0.5413	0.5437	0.6282	14.86	0.6666
160	2.5	62.84	81.81	50.14	71.74	82.89	45.31	4.828	0.07276	2485	0.7283	514.7	0.3565	3.625	0.5413	0.5437	0.6282	14.86	0.6666
160	2.75	62.84	89.99	55.15	78.92	91.18	49.84	5.31	0.07276	2733	0.8011	514.7	0.3565	3.988	0.5413	0.5437	0.6282	14.86	0.6666
160	3	62.84	98.17	60.17	86.09	99.47	54.37	5.793	0.07276	2982	0.8739	514.7	0.3565	4.35	0.5413	0.5437	0.6282	14.86	0.6666
160	3.25	62.84	106.3	65.18	93.27	107.8	58.91	6.276	0.07276	3230	0.9467	514.7	0.3565	4.713	0.5413	0.5437	0.6282	14.86	0.6666
160	3.5	62.84	114.5	70.2	100.4	116	63.44	6.759	0.07276	3479	1.02	514.7	0.3565	5.075	0.5413	0.5437	0.6282	14.86	0.6666
160	3.75	62.84	122.7	75.21	107.6	124.3	67.97	7.241	0.07276	3727	1.092	514.7	0.3565	5.438	0.5413	0.5437	0.6282	14.86	0.6666
160	4	62.84	130.9	80.22	114.8	132.6	72.5	7.724	0.07276	3976	1.165	514.7	0.3565	5.8	0.5413	0.5437	0.6282	14.86	0.6666
160	4.25	62.84	139.1	85.24	122	140.9	77.03	8.207	0.07276	4224	1.238	514.7	0.3565	6.163	0.5413	0.5437	0.6282	14.86	0.6666
160	4.5	62.84	147.3	90.25	129.1	149.2	81.56	8.69	0.07276	4473	1.311	514.7	0.3565	6.525	0.5413	0.5437	0.6282	14.86	0.6666
160	4.75	62.84	155.4	95.26	136.3	157.5	86.09	9.172	0.07276	4721	1.384	514.7	0.3565	6.888	0.5413	0.5437	0.6282	14.86	0.6666
160	5	62.84	163.6	100.3	143.5	165.8	90.62	9.655	0.07276	4970	1.457	514.7	0.3565	7.25	0.5413	0.5437	0.6282	14.86	0.6666

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
170	0.25	63.44	8.181	5.014	7.153	8.288	4.472	0.5415	0.08117	248.6	0.07286	459.1	0.3535	0.4216	0.5909	0.5422	0.6281	13.21	0.6998
170	0.5	63.44	16.36	10.03	14.31	16.58	8.945	1.083	0.08117	497.2	0.1457	459.1	0.3535	0.8432	0.5909	0.5422	0.6281	13.21	0.6998
170	0.75	63.44	24.54	15.04	21.46	24.86	13.42	1.624	0.08117	745.8	0.2186	459.1	0.3535	1.265	0.5909	0.5422	0.6281	13.21	0.6998
170	1	63.44	32.72	20.06	28.61	33.15	17.89	2.166	0.08117	994.4	0.2914	459.1	0.3535	1.686	0.5909	0.5422	0.6281	13.21	0.6998
170	1.25	63.44	40.9	25.07	35.77	41.44	22.36	2.707	0.08117	1243	0.3643	459.1	0.3535	2.108	0.5909	0.5422	0.6281	13.21	0.6998
170	1.5	63.44	49.08	30.08	42.92	49.73	26.83	3.249	0.08117	1492	0.4372	459.1	0.3535	2.529	0.5909	0.5422	0.6281	13.21	0.6998
170	1.75	63.44	57.26	35.1	50.07	58.02	31.31	3.79	0.08117	1740	0.51	459.1	0.3535	2.951	0.5909	0.5422	0.6281	13.21	0.6998
170	2	63.44	65.45	40.11	57.23	66.3	35.78	4.332	0.08117	1989	0.5829	459.1	0.3535	3.373	0.5909	0.5422	0.6281	13.21	0.6998
170	2.25	63.44	73.63	45.13	64.38	74.59	40.25	4.873	0.08117	2237	0.6557	459.1	0.3535	3.794	0.5909	0.5422	0.6281	13.21	0.6998
170	2.5	63.44	81.81	50.14	71.53	82.88	44.72	5.415	0.08117	2486	0.7286	459.1	0.3535	4.216	0.5909	0.5422	0.6281	13.21	0.6998
170	2.75	63.44	89.99	55.15	78.69	91.17	49.2	5.956	0.08117	2735	0.8015	459.1	0.3535	4.637	0.5909	0.5422	0.6281	13.21	0.6998
170	3	63.44	98.17	60.17	85.84	99.46	53.67	6.498	0.08117	2983	0.8743	459.1	0.3535	5.059	0.5909	0.5422	0.6281	13.21	0.6998
170	3.25	63.44	106.3	65.18	92.99	107.7	58.14	7.039	0.08117	3232	0.9472	459.1	0.3535	5.481	0.5909	0.5422	0.6281	13.21	0.6998
170	3.5	63.44	114.5	70.2	100.1	116	62.61	7.581	0.08117	3481	1.02	459.1	0.3535	5.902	0.5909	0.5422	0.6281	13.21	0.6998
170	3.75	63.44	122.7	75.21	107.3	124.3	67.09	8.122	0.08117	3729	1.093	459.1	0.3535	6.324	0.5909	0.5422	0.6281	13.21	0.6998
170	4	63.44	130.9	80.22	114.5	132.6	71.56	8.664	0.08117	3978	1.166	459.1	0.3535	6.745	0.5909	0.5422	0.6281	13.21	0.6998
170	4.25	63.44	139.1	85.24	121.6	140.9	76.03	9.205	0.08117	4226	1.239	459.1	0.3535	7.167	0.5909	0.5422	0.6281	13.21	0.6998
170	4.5	63.44	147.3	90.25	128.8	149.2	80.5	9.747	0.08117	4475	1.311	459.1	0.3535	7.588	0.5909	0.5422	0.6281	13.21	0.6998
170	4.75	63.44	155.4	95.26	135.9	157.5	84.98	10.29	0.08117	4724	1.384	459.1	0.3535	8.01	0.5909	0.5422	0.6281	13.21	0.6998
170	5	63.44	163.6	100.3	143.1	165.8	89.45	10.83	0.08117	4972	1.457	459.1	0.3535	8.432	0.5909	0.5422	0.6281	13.21	0.6998

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
180	0.25	63.88	8.181	5.014	7.135	8.287	4.414	0.5998	0.08954	248.8	0.07291	414.7	0.3505	0.4803	0.6304	0.5407	0.6281	11.89	0.7269
180	0.5	63.88	16.36	10.03	14.27	16.57	8.828	1.2	0.08954	497.5	0.1458	414.7	0.3505	0.9605	0.6304	0.5407	0.6281	11.89	0.7269
180	0.75	63.88	24.54	15.04	21.4	24.86	13.24	1.8	0.08954	746.3	0.2187	414.7	0.3505	1.441	0.6304	0.5407	0.6281	11.89	0.7269
180	1	63.88	32.72	20.06	28.54	33.15	17.66	2.399	0.08954	995.1	0.2916	414.7	0.3505	1.921	0.6304	0.5407	0.6281	11.89	0.7269
180	1.25	63.88	40.9	25.07	35.67	41.43	22.07	2.999	0.08954	1244	0.3645	414.7	0.3505	2.401	0.6304	0.5407	0.6281	11.89	0.7269
180	1.5	63.88	49.08	30.08	42.81	49.72	26.48	3.599	0.08954	1493	0.4375	414.7	0.3505	2.882	0.6304	0.5407	0.6281	11.89	0.7269
180	1.75	63.88	57.26	35.1	49.94	58.01	30.9	4.199	0.08954	1741	0.5104	414.7	0.3505	3.362	0.6304	0.5407	0.6281	11.89	0.7269
180	2	63.88	65.45	40.11	57.08	66.3	35.31	4.799	0.08954	1990	0.5833	414.7	0.3505	3.842	0.6304	0.5407	0.6281	11.89	0.7269
180	2.25	63.88	73.63	45.13	64.21	74.58	39.73	5.399	0.08954	2239	0.6562	414.7	0.3505	4.322	0.6304	0.5407	0.6281	11.89	0.7269
180	2.5	63.88	81.81	50.14	71.35	82.87	44.14	5.998	0.08954	2488	0.7291	414.7	0.3505	4.803	0.6304	0.5407	0.6281	11.89	0.7269
180	2.75	63.88	89.99	55.15	78.48	91.16	48.55	6.598	0.08954	2737	0.802	414.7	0.3505	5.283	0.6304	0.5407	0.6281	11.89	0.7269
180	3	63.88	98.17	60.17	85.62	99.44	52.97	7.198	0.08954	2985	0.8749	414.7	0.3505	5.763	0.6304	0.5407	0.6281	11.89	0.7269
180	3.25	63.88	106.3	65.18	92.75	107.7	57.38	7.798	0.08954	3234	0.9478	414.7	0.3505	6.243	0.6304	0.5407	0.6281	11.89	0.7269
180	3.5	63.88	114.5	70.2	99.89	116	61.8	8.398	0.08954	3483	1.021	414.7	0.3505	6.724	0.6304	0.5407	0.6281	11.89	0.7269
180	3.75	63.88	122.7	75.21	107	124.3	66.21	8.998	0.08954	3732	1.094	414.7	0.3505	7.204	0.6304	0.5407	0.6281	11.89	0.7269
180	4	63.88	130.9	80.22	114.2	132.6	70.63	9.597	0.08954	3980	1.167	414.7	0.3505	7.684	0.6304	0.5407	0.6281	11.89	0.7269
180	4.25	63.88	139.1	85.24	121.3	140.9	75.04	10.2	0.08954	4229	1.239	414.7	0.3505	8.164	0.6304	0.5407	0.6281	11.89	0.7269
180	4.5	63.88	147.3	90.25	128.4	149.2	79.45	10.8	0.08954	4478	1.312	414.7	0.3505	8.645	0.6304	0.5407	0.6281	11.89	0.7269
180	4.75	63.88	155.4	95.26	135.6	157.5	83.87	11.4	0.08954	4727	1.385	414.7	0.3505	9.125	0.6304	0.5407	0.6281	11.89	0.7269
180	5	63.88	163.6	100.3	142.7	165.7	88.28	12	0.08954	4975	1.458	414.7	0.3505	9.605	0.6304	0.5407	0.6281	11.89	0.7269

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
190	0.25	64.21	8.181	5.014	7.119	8.286	4.356	0.6579	0.09789	249	0.07297	378.5	0.3475	0.5385	0.6627	0.5395	0.628	10.82	0.7495
190	0.5	64.21	16.36	10.03	14.24	16.57	8.712	1.316	0.09789	498	0.1459	378.5	0.3475	1.077	0.6627	0.5395	0.628	10.82	0.7495
190	0.75	64.21	24.54	15.04	21.36	24.86	13.07	1.974	0.09789	747	0.2189	378.5	0.3475	1.616	0.6627	0.5395	0.628	10.82	0.7495
190	1	64.21	32.72	20.06	28.47	33.14	17.42	2.631	0.09789	996	0.2919	378.5	0.3475	2.154	0.6627	0.5395	0.628	10.82	0.7495
190	1.25	64.21	40.9	25.07	35.59	41.43	21.78	3.289	0.09789	1245	0.3649	378.5	0.3475	2.693	0.6627	0.5395	0.628	10.82	0.7495
190	1.5	64.21	49.08	30.08	42.71	49.71	26.14	3.947	0.09789	1494	0.4378	378.5	0.3475	3.231	0.6627	0.5395	0.628	10.82	0.7495
190	1.75	64.21	57.26	35.1	49.83	58	30.49	4.605	0.09789	1743	0.5108	378.5	0.3475	3.77	0.6627	0.5395	0.628	10.82	0.7495
190	2	64.21	65.45	40.11	56.95	66.28	34.85	5.263	0.09789	1992	0.5838	378.5	0.3475	4.308	0.6627	0.5395	0.628	10.82	0.7495
190	2.25	64.21	73.63	45.13	64.07	74.57	39.2	5.921	0.09789	2241	0.6567	378.5	0.3475	4.847	0.6627	0.5395	0.628	10.82	0.7495
190	2.5	64.21	81.81	50.14	71.19	82.86	43.56	6.579	0.09789	2490	0.7297	378.5	0.3475	5.385	0.6627	0.5395	0.628	10.82	0.7495
190	2.75	64.21	89.99	55.15	78.31	91.14	47.92	7.237	0.09789	2739	0.8027	378.5	0.3475	5.924	0.6627	0.5395	0.628	10.82	0.7495
190	3	64.21	98.17	60.17	85.42	99.43	52.27	7.894	0.09789	2988	0.8757	378.5	0.3475	6.463	0.6627	0.5395	0.628	10.82	0.7495
190	3.25	64.21	106.3	65.18	92.54	107.7	56.63	8.552	0.09789	3237	0.9486	378.5	0.3475	7.001	0.6627	0.5395	0.628	10.82	0.7495
190	3.5	64.21	114.5	70.2	99.66	116	60.98	9.21	0.09789	3486	1.022	378.5	0.3475	7.54	0.6627	0.5395	0.628	10.82	0.7495
190	3.75	64.21	122.7	75.21	106.8	124.3	65.34	9.868	0.09789	3735	1.095	378.5	0.3475	8.078	0.6627	0.5395	0.628	10.82	0.7495
190	4	64.21	130.9	80.22	113.9	132.6	69.7	10.53	0.09789	3984	1.168	378.5	0.3475	8.617	0.6627	0.5395	0.628	10.82	0.7495
190	4.25	64.21	139.1	85.24	121	140.9	74.05	11.18	0.09789	4233	1.241	378.5	0.3475	9.155	0.6627	0.5395	0.628	10.82	0.7495
190	4.5	64.21	147.3	90.25	128.1	149.1	78.41	11.84	0.09789	4482	1.313	378.5	0.3475	9.694	0.6627	0.5395	0.628	10.82	0.7495
190	4.75	64.21	155.4	95.26	135.3	157.4	82.77	12.5	0.09789	4731	1.386	378.5	0.3475	10.23	0.6627	0.5395	0.628	10.82	0.7495
190	5	64.21	163.6	100.3	142.4	165.7	87.12	13.16	0.09789	4980	1.459	378.5	0.3475	10.77	0.6627	0.5395	0.628	10.82	0.7495

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
200	0.25	64.46	8.181	5.014	7.105	8.284	4.298	0.7156	0.1062	249.3	0.07305	348.3	0.3444	0.5965	0.6896	0.5385	0.6278	9.929	0.7686
200	0.5	64.46	16.36	10.03	14.21	16.57	8.597	1.431	0.1062	498.5	0.1461	348.3	0.3444	1.193	0.6896	0.5385	0.6278	9.929	0.7686
200	0.75	64.46	24.54	15.04	21.31	24.85	12.9	2.147	0.1062	747.8	0.2191	348.3	0.3444	1.789	0.6896	0.5385	0.6278	9.929	0.7686
200	1	64.46	32.72	20.06	28.42	33.14	17.19	2.862	0.1062	997	0.2922	348.3	0.3444	2.386	0.6896	0.5385	0.6278	9.929	0.7686
200	1.25	64.46	40.9	25.07	35.52	41.42	21.49	3.578	0.1062	1246	0.3652	348.3	0.3444	2.982	0.6896	0.5385	0.6278	9.929	0.7686
200	1.5	64.46	49.08	30.08	42.63	49.7	25.79	4.293	0.1062	1496	0.4383	348.3	0.3444	3.579	0.6896	0.5385	0.6278	9.929	0.7686
200	1.75	64.46	57.26	35.1	49.73	57.99	30.09	5.009	0.1062	1745	0.5113	348.3	0.3444	4.175	0.6896	0.5385	0.6278	9.929	0.7686
200	2	64.46	65.45	40.11	56.84	66.27	34.39	5.724	0.1062	1994	0.5844	348.3	0.3444	4.772	0.6896	0.5385	0.6278	9.929	0.7686
200	2.25	64.46	73.63	45.13	63.94	74.56	38.69	6.44	0.1062	2243	0.6574	348.3	0.3444	5.368	0.6896	0.5385	0.6278	9.929	0.7686
200	2.5	64.46	81.81	50.14	71.05	82.84	42.98	7.156	0.1062	2493	0.7305	348.3	0.3444	5.965	0.6896	0.5385	0.6278	9.929	0.7686
200	2.75	64.46	89.99	55.15	78.15	91.12	47.28	7.871	0.1062	2742	0.8035	348.3	0.3444	6.561	0.6896	0.5385	0.6278	9.929	0.7686
200	3	64.46	98.17	60.17	85.26	99.41	51.58	8.587	0.1062	2991	0.8766	348.3	0.3444	7.158	0.6896	0.5385	0.6278	9.929	0.7686
200	3.25	64.46	106.3	65.18	92.36	107.7	55.88	9.302	0.1062	3240	0.9496	348.3	0.3444	7.754	0.6896	0.5385	0.6278	9.929	0.7686
200	3.5	64.46	114.5	70.2	99.47	116	60.18	10.02	0.1062	3490	1.023	348.3	0.3444	8.351	0.6896	0.5385	0.6278	9.929	0.7686
200	3.75	64.46	122.7	75.21	106.6	124.3	64.48	10.73	0.1062	3739	1.096	348.3	0.3444	8.947	0.6896	0.5385	0.6278	9.929	0.7686
200	4	64.46	130.9	80.22	113.7	132.5	68.77	11.45	0.1062	3988	1.169	348.3	0.3444	9.544	0.6896	0.5385	0.6278	9.929	0.7686
200	4.25	64.46	139.1	85.24	120.8	140.8	73.07	12.16	0.1062	4237	1.242	348.3	0.3444	10.14	0.6896	0.5385	0.6278	9.929	0.7686
200	4.5	64.46	147.3	90.25	127.9	149.1	77.37	12.88	0.1062	4487	1.315	348.3	0.3444	10.74	0.6896	0.5385	0.6278	9.929	0.7686
200	4.75	64.46	155.4	95.26	135	157.4	81.67	13.6	0.1062	4736	1.388	348.3	0.3444	11.33	0.6896	0.5385	0.6278	9.929	0.7686
200	5	64.46	163.6	100.3	142.1	165.7	85.97	14.31	0.1062	4985	1.461	348.3	0.3444	11.93	0.6896	0.5385	0.6278	9.929	0.7686

$T_{operation}$	bph	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{LD}	R_{AM}	$\eta_{Thermal}$
210	0.25	64.64	8.181	5.014	7.093	8.282	4.241	0.7729	0.1144	249.6	0.07314	322.9	0.3414	0.6541	0.7123	0.5375	0.6277	9.176	0.7849
210	0.5	64.64	16.36	10.03	14.19	16.56	8.482	1.546	0.1144	499.1	0.1463	322.9	0.3414	1.308	0.7123	0.5375	0.6277	9.176	0.7849
210	0.75	64.64	24.54	15.04	21.28	24.85	12.72	2.319	0.1144	748.7	0.2194	322.9	0.3414	1.962	0.7123	0.5375	0.6277	9.176	0.7849
210	1	64.64	32.72	20.06	28.37	33.13	16.96	3.092	0.1144	998.2	0.2926	322.9	0.3414	2.616	0.7123	0.5375	0.6277	9.176	0.7849
210	1.25	64.64	40.9	25.07	35.46	41.41	21.2	3.865	0.1144	1248	0.3657	322.9	0.3414	3.27	0.7123	0.5375	0.6277	9.176	0.7849
210	1.5	64.64	49.08	30.08	42.56	49.69	25.45	4.638	0.1144	1497	0.4388	322.9	0.3414	3.924	0.7123	0.5375	0.6277	9.176	0.7849
210	1.75	64.64	57.26	35.1	49.65	57.97	29.69	5.411	0.1144	1747	0.512	322.9	0.3414	4.578	0.7123	0.5375	0.6277	9.176	0.7849
210	2	64.64	65.45	40.11	56.74	66.26	33.93	6.183	0.1144	1996	0.5851	322.9	0.3414	5.232	0.7123	0.5375	0.6277	9.176	0.7849
210	2.25	64.64	73.63	45.13	63.83	74.54	38.17	6.956	0.1144	2246	0.6582	322.9	0.3414	5.886	0.7123	0.5375	0.6277	9.176	0.7849
210	2.5	64.64	81.81	50.14	70.93	82.82	42.41	7.729	0.1144	2496	0.7314	322.9	0.3414	6.541	0.7123	0.5375	0.6277	9.176	0.7849
210	2.75	64.64	89.99	55.15	78.02	91.1	46.65	8.502	0.1144	2745	0.8045	322.9	0.3414	7.195	0.7123	0.5375	0.6277	9.176	0.7849
210	3	64.64	98.17	60.17	85.11	99.39	50.89	9.275	0.1144	2995	0.8777	322.9	0.3414	7.849	0.7123	0.5375	0.6277	9.176	0.7849
210	3.25	64.64	106.3	65.18	92.21	107.7	55.13	10.05	0.1144	3244	0.9508	322.9	0.3414	8.503	0.7123	0.5375	0.6277	9.176	0.7849
210	3.5	64.64	114.5	70.2	99.3	115.9	59.37	10.82	0.1144	3494	1.024	322.9	0.3414	9.157	0.7123	0.5375	0.6277	9.176	0.7849
210	3.75	64.64	122.7	75.21	106.4	124.2	63.61	11.59	0.1144	3743	1.097	322.9	0.3414	9.811	0.7123	0.5375	0.6277	9.176	0.7849
210	4	64.64	130.9	80.22	113.5	132.5	67.86	12.37	0.1144	3993	1.17	322.9	0.3414	10.46	0.7123	0.5375	0.6277	9.176	0.7849
210	4.25	64.64	139.1	85.24	120.6	140.8	72.1	13.14	0.1144	4242	1.243	322.9	0.3414	11.12	0.7123	0.5375	0.6277	9.176	0.7849
210	4.5	64.64	147.3	90.25	127.7	149.1	76.34	13.91	0.1144	4492	1.316	322.9	0.3414	11.77	0.7123	0.5375	0.6277	9.176	0.7849
210	4.75	64.64	155.4	95.26	134.8	157.4	80.58	14.69	0.1144	4742	1.39	322.9	0.3414	12.43	0.7123	0.5375	0.6277	9.176	0.7849
210	5	64.64	163.6	100.3	141.9	165.6	84.82	15.46	0.1144	4991	1.463	322.9	0.3414	13.08	0.7123	0.5375	0.6277	9.176	0.7849

$T_{operation}$ 100 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
1.00	0.20	48	32.72	8.181	18.83	21.28	7.865	0.3156	0.02223	637.9	0.1869	2021	0.1938	0.00	-0.8012	0.4603	59.66	0.5203
1.00	0.21	48	32.72	8.698	19.28	21.8	8.375	0.3232	0.02223	653.4	0.1915	2021	0.2038	0.00	-0.8012	0.4656	59.66	0.5263
1.00	0.22	48	32.72	9.229	19.75	22.33	8.898	0.3311	0.02223	669.3	0.1962	2021	0.2138	0.00	-0.8012	0.4709	59.66	0.5323
1.00	0.23	48	32.72	9.774	20.24	22.88	9.435	0.3392	0.02223	685.6	0.2009	2021	0.2238	0.00	-0.8012	0.4762	59.66	0.5383
1.00	0.24	48	32.72	10.33	20.73	23.43	9.986	0.3475	0.02223	702.4	0.2059	2021	0.2338	0.00	-0.8012	0.4815	59.66	0.5443
1.00	0.25	48	32.72	10.91	21.24	24.01	10.55	0.356	0.02223	719.6	0.2109	2021	0.2438	0.00	-0.8012	0.4868	59.66	0.5503
1.00	0.26	48	32.72	11.5	21.76	24.6	11.13	0.3647	0.02223	737.3	0.2161	2021	0.2538	0.00	-0.8012	0.4921	59.66	0.5563
1.00	0.27	48	32.72	12.1	22.3	25.2	11.73	0.3737	0.02223	755.4	0.2214	2021	0.2639	0.00	-0.8012	0.4974	59.66	0.5623
1.00	0.28	48	32.72	12.73	22.85	25.83	12.34	0.383	0.02223	774.1	0.2269	2021	0.2739	0.00	-0.8012	0.5027	59.66	0.5683
1.00	0.29	48	32.72	13.37	23.41	26.47	12.97	0.3924	0.02223	793.3	0.2325	2021	0.2839	0.00	-0.8012	0.508	59.66	0.5743
1.00	0.30	48	32.72	14.02	24	27.13	13.62	0.4022	0.02223	813	0.2383	2021	0.2939	0.00	-0.8012	0.5133	59.66	0.5803
1.00	0.31	48	32.72	14.7	24.6	27.8	14.29	0.4123	0.02223	833.3	0.2442	2021	0.3039	0.00	-0.8012	0.5186	59.66	0.5863
1.00	0.32	48	32.72	15.4	25.21	28.5	14.98	0.4226	0.02223	854.2	0.2503	2021	0.314	0.00	-0.8012	0.5239	59.66	0.5923
1.00	0.33	48	32.72	16.12	25.85	29.22	15.68	0.4332	0.02223	875.8	0.2567	2021	0.324	0.00	-0.8012	0.5292	59.66	0.5983
1.00	0.34	48	32.72	16.86	26.5	29.96	16.41	0.4442	0.02223	897.9	0.2632	2021	0.334	0.00	-0.8012	0.5345	59.66	0.6043
1.00	0.35	48	32.72	17.62	27.18	30.72	17.16	0.4555	0.02223	920.8	0.2699	2021	0.3441	0.00	-0.8012	0.5398	59.66	0.6103
1.00	0.36	48	32.72	18.41	27.87	31.51	17.94	0.4672	0.02223	944.4	0.2768	2021	0.3541	0.00	-0.8012	0.5452	59.66	0.6162
1.00	0.37	48	32.72	19.22	28.59	32.32	18.74	0.4792	0.02223	968.7	0.2839	2021	0.3641	0.00	-0.8012	0.5505	59.66	0.6222
1.00	0.38	48	32.72	20.06	29.33	33.16	19.56	0.4916	0.02223	993.8	0.2913	2021	0.3742	0.00	-0.8012	0.5558	59.66	0.6282
1.00	0.39	48	32.72	20.92	30.1	34.02	20.42	0.5045	0.02223	1020	0.2989	2021	0.3842	0.00	-0.8012	0.5611	59.66	0.6342
1.00	0.40	48	32.72	21.82	30.89	34.92	21.3	0.5177	0.02223	1047	0.3067	2021	0.3942	0.00	-0.8012	0.5664	59.66	0.6402

$T_{operation}$ 100 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
2.00	0.20	48	65.45	16.36	37.65	42.56	15.73	0.6311	0.02223	1276	0.3739	2021	0.1938	0.00	-0.8012	0.4603	59.66	0.5203
2.00	0.21	48	65.45	17.4	38.57	43.6	16.75	0.6465	0.02223	1307	0.383	2021	0.2038	0.00	-0.8012	0.4656	59.66	0.5263
2.00	0.22	48	65.45	18.46	39.51	44.66	17.8	0.6622	0.02223	1339	0.3923	2021	0.2138	0.00	-0.8012	0.4709	59.66	0.5323
2.00	0.23	48	65.45	19.55	40.47	45.75	18.87	0.6784	0.02223	1371	0.4019	2021	0.2238	0.00	-0.8012	0.4762	59.66	0.5383
2.00	0.24	48	65.45	20.67	41.46	46.87	19.97	0.695	0.02223	1405	0.4117	2021	0.2338	0.00	-0.8012	0.4815	59.66	0.5443
2.00	0.25	48	65.45	21.82	42.48	48.02	21.1	0.712	0.02223	1439	0.4218	2021	0.2438	0.00	-0.8012	0.4868	59.66	0.5503
2.00	0.26	48	65.45	22.99	43.52	49.2	22.26	0.7295	0.02223	1475	0.4321	2021	0.2538	0.00	-0.8012	0.4921	59.66	0.5563
2.00	0.27	48	65.45	24.21	44.59	50.41	23.46	0.7474	0.02223	1511	0.4428	2021	0.2639	0.00	-0.8012	0.4974	59.66	0.5623
2.00	0.28	48	65.45	25.45	45.69	51.65	24.68	0.7659	0.02223	1548	0.4537	2021	0.2739	0.00	-0.8012	0.5027	59.66	0.5683
2.00	0.29	48	65.45	26.73	46.83	52.93	25.95	0.7849	0.02223	1587	0.465	2021	0.2839	0.00	-0.8012	0.508	59.66	0.5743
2.00	0.30	48	65.45	28.05	47.99	54.25	27.24	0.8044	0.02223	1626	0.4765	2021	0.2939	0.00	-0.8012	0.5133	59.66	0.5803
2.00	0.31	48	65.45	29.4	49.19	55.61	28.58	0.8245	0.02223	1667	0.4884	2021	0.3039	0.00	-0.8012	0.5186	59.66	0.5863
2.00	0.32	48	65.45	30.8	50.42	57	29.95	0.8452	0.02223	1708	0.5007	2021	0.314	0.00	-0.8012	0.5239	59.66	0.5923
2.00	0.33	48	65.45	32.23	51.7	58.44	31.37	0.8665	0.02223	1752	0.5133	2021	0.324	0.00	-0.8012	0.5292	59.66	0.5983
2.00	0.34	48	65.45	33.71	53	59.92	32.83	0.8884	0.02223	1796	0.5263	2021	0.334	0.00	-0.8012	0.5345	59.66	0.6043
2.00	0.35	48	65.45	35.24	54.35	61.44	34.33	0.9111	0.02223	1842	0.5397	2021	0.3441	0.00	-0.8012	0.5398	59.66	0.6103
2.00	0.36	48	65.45	36.81	55.75	63.02	35.88	0.9344	0.02223	1889	0.5535	2021	0.3541	0.00	-0.8012	0.5452	59.66	0.6162
2.00	0.37	48	65.45	38.44	57.18	64.64	37.48	0.9585	0.02223	1937	0.5678	2021	0.3641	0.00	-0.8012	0.5505	59.66	0.6222
2.00	0.38	48	65.45	40.11	58.66	66.31	39.13	0.9833	0.02223	1988	0.5825	2021	0.3742	0.00	-0.8012	0.5558	59.66	0.6282
2.00	0.39	48	65.45	41.84	60.2	68.05	40.83	1.009	0.02223	2039	0.5977	2021	0.3842	0.00	-0.8012	0.5611	59.66	0.6342
2.00	0.40	48	65.45	43.63	61.78	69.83	42.59	1.035	0.02223	2093	0.6134	2021	0.3942	0.00	-0.8012	0.5664	59.66	0.6402

$T_{operation}$ 100 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
3.00	0.20	48	98.17	24.54	56.48	63.85	23.6	0.9467	0.02223	1914	0.5608	2021	0.1938	0.00	-0.8012	0.4603	59.66	0.5203
3.00	0.21	48	98.17	26.1	57.85	65.4	25.13	0.9697	0.02223	1960	0.5745	2021	0.2038	0.00	-0.8012	0.4656	59.66	0.5263
3.00	0.22	48	98.17	27.69	59.26	66.99	26.69	0.9933	0.02223	2008	0.5885	2021	0.2138	0.00	-0.8012	0.4709	59.66	0.5323
3.00	0.23	48	98.17	29.32	60.71	68.63	28.31	1.018	0.02223	2057	0.6028	2021	0.2238	0.00	-0.8012	0.4762	59.66	0.5383
3.00	0.24	48	98.17	31	62.19	70.3	29.96	1.042	0.02223	2107	0.6176	2021	0.2338	0.00	-0.8012	0.4815	59.66	0.5443
3.00	0.25	48	98.17	32.72	63.72	72.03	31.65	1.068	0.02223	2159	0.6327	2021	0.2438	0.00	-0.8012	0.4868	59.66	0.5503
3.00	0.26	48	98.17	34.49	65.28	73.8	33.4	1.094	0.02223	2212	0.6482	2021	0.2538	0.00	-0.8012	0.4921	59.66	0.5563
3.00	0.27	48	98.17	36.31	66.89	75.61	35.19	1.121	0.02223	2266	0.6642	2021	0.2639	0.00	-0.8012	0.4974	59.66	0.5623
3.00	0.28	48	98.17	38.18	68.54	77.48	37.03	1.149	0.02223	2322	0.6806	2021	0.2739	0.00	-0.8012	0.5027	59.66	0.5683
3.00	0.29	48	98.17	40.1	70.24	79.4	38.92	1.177	0.02223	2380	0.6975	2021	0.2839	0.00	-0.8012	0.508	59.66	0.5743
3.00	0.30	48	98.17	42.07	71.99	81.38	40.87	1.207	0.02223	2439	0.7148	2021	0.2939	0.00	-0.8012	0.5133	59.66	0.5803
3.00	0.31	48	98.17	44.1	73.79	83.41	42.87	1.237	0.02223	2500	0.7327	2021	0.3039	0.00	-0.8012	0.5186	59.66	0.5863
3.00	0.32	48	98.17	46.2	75.64	85.5	44.93	1.268	0.02223	2563	0.751	2021	0.314	0.00	-0.8012	0.5239	59.66	0.5923
3.00	0.33	48	98.17	48.35	77.54	87.66	47.05	1.3	0.02223	2627	0.77	2021	0.324	0.00	-0.8012	0.5292	59.66	0.5983
3.00	0.34	48	98.17	50.57	79.51	89.88	49.24	1.333	0.02223	2694	0.7895	2021	0.334	0.00	-0.8012	0.5345	59.66	0.6043
3.00	0.35	48	98.17	52.86	81.53	92.16	51.49	1.367	0.02223	2762	0.8096	2021	0.3441	0.00	-0.8012	0.5398	59.66	0.6103
3.00	0.36	48	98.17	55.22	83.62	94.52	53.82	1.402	0.02223	2833	0.8303	2021	0.3541	0.00	-0.8012	0.5452	59.66	0.6162
3.00	0.37	48	98.17	57.65	85.77	96.96	56.22	1.438	0.02223	2906	0.8517	2021	0.3641	0.00	-0.8012	0.5505	59.66	0.6222
3.00	0.38	48	98.17	60.17	88	99.47	58.69	1.475	0.02223	2981	0.8738	2021	0.3742	0.00	-0.8012	0.5558	59.66	0.6282
3.00	0.39	48	98.17	62.76	90.29	102.1	61.25	1.513	0.02223	3059	0.8966	2021	0.3842	0.00	-0.8012	0.5611	59.66	0.6342
3.00	0.40	48	98.17	65.45	92.67	104.8	63.89	1.553	0.02223	3140	0.9201	2021	0.3942	0.00	-0.8012	0.5664	59.66	0.6402

$T_{operation}$ 100 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
4.00	0.20	48	130.9	32.72	75.31	85.13	31.46	1.262	0.02223	2551	0.7478	2021	0.1938	0.00	-0.8012	0.4603	59.66	0.5203
4.00	0.21	48	130.9	34.79	77.14	87.2	33.5	1.293	0.02223	2614	0.766	2021	0.2038	0.00	-0.8012	0.4656	59.66	0.5263
4.00	0.22	48	130.9	36.92	79.02	89.32	35.59	1.324	0.02223	2677	0.7846	2021	0.2138	0.00	-0.8012	0.4709	59.66	0.5323
4.00	0.23	48	130.9	39.1	80.95	91.5	37.74	1.357	0.02223	2743	0.8038	2021	0.2238	0.00	-0.8012	0.4762	59.66	0.5383
4.00	0.24	48	130.9	41.33	82.92	93.74	39.94	1.39	0.02223	2810	0.8234	2021	0.2338	0.00	-0.8012	0.4815	59.66	0.5443
4.00	0.25	48	130.9	43.63	84.96	96.04	42.21	1.424	0.02223	2878	0.8436	2021	0.2438	0.00	-0.8012	0.4868	59.66	0.5503
4.00	0.26	48	130.9	45.99	87.04	98.39	44.53	1.459	0.02223	2949	0.8643	2021	0.2538	0.00	-0.8012	0.4921	59.66	0.5563
4.00	0.27	48	130.9	48.41	89.19	100.8	46.92	1.495	0.02223	3022	0.8856	2021	0.2639	0.00	-0.8012	0.4974	59.66	0.5623
4.00	0.28	48	130.9	50.9	91.39	103.3	49.37	1.532	0.02223	3096	0.9075	2021	0.2739	0.00	-0.8012	0.5027	59.66	0.5683
4.00	0.29	48	130.9	53.46	93.65	105.9	51.89	1.57	0.02223	3173	0.93	2021	0.2839	0.00	-0.8012	0.508	59.66	0.5743
4.00	0.30	48	130.9	56.1	95.98	108.5	54.49	1.609	0.02223	3252	0.9531	2021	0.2939	0.00	-0.8012	0.5133	59.66	0.5803
4.00	0.31	48	130.9	58.81	98.38	111.2	57.16	1.649	0.02223	3333	0.9769	2021	0.3039	0.00	-0.8012	0.5186	59.66	0.5863
4.00	0.32	48	130.9	61.6	100.8	114	59.9	1.69	0.02223	3417	1.001	2021	0.314	0.00	-0.8012	0.5239	59.66	0.5923
4.00	0.33	48	130.9	64.47	103.4	116.9	62.74	1.733	0.02223	3503	1.027	2021	0.324	0.00	-0.8012	0.5292	59.66	0.5983
4.00	0.34	48	130.9	67.43	106	119.8	65.65	1.777	0.02223	3592	1.053	2021	0.334	0.00	-0.8012	0.5345	59.66	0.6043
4.00	0.35	48	130.9	70.48	108.7	122.9	68.66	1.822	0.02223	3683	1.079	2021	0.3441	0.00	-0.8012	0.5398	59.66	0.6103
4.00	0.36	48	130.9	73.63	111.5	126	71.76	1.869	0.02223	3777	1.107	2021	0.3541	0.00	-0.8012	0.5452	59.66	0.6162
4.00	0.37	48	130.9	76.87	114.4	129.3	74.96	1.917	0.02223	3875	1.136	2021	0.3641	0.00	-0.8012	0.5505	59.66	0.6222
4.00	0.38	48	130.9	80.22	117.3	132.6	78.26	1.967	0.02223	3975	1.165	2021	0.3742	0.00	-0.8012	0.5558	59.66	0.6282
4.00	0.39	48	130.9	83.68	120.4	136.1	81.67	2.018	0.02223	4079	1.195	2021	0.3842	0.00	-0.8012	0.5611	59.66	0.6342
4.00	0.40	48	130.9	87.26	123.6	139.7	85.19	2.071	0.02223	4186	1.227	2021	0.3942	0.00	-0.8012	0.5664	59.66	0.6402

$T_{operation}$ 100 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
5.00	0.20	48	163.6	40.9	94.13	106.4	39.33	1.578	0.02223	3189	0.9347	2021	0.1938	0.00	-0.8012	0.4603	59.66	0.5203
5.00	0.21	48	163.6	43.49	96.42	109	41.88	1.616	0.02223	3267	0.9575	2021	0.2038	0.00	-0.8012	0.4656	59.66	0.5263
5.00	0.22	48	163.6	46.15	98.77	111.7	44.49	1.656	0.02223	3347	0.9808	2021	0.2138	0.00	-0.8012	0.4709	59.66	0.5323
5.00	0.23	48	163.6	48.87	101.2	114.4	47.18	1.696	0.02223	3428	1.005	2021	0.2238	0.00	-0.8012	0.4762	59.66	0.5383
5.00	0.24	48	163.6	51.67	103.7	117.2	49.93	1.737	0.02223	3512	1.029	2021	0.2338	0.00	-0.8012	0.4815	59.66	0.5443
5.00	0.25	48	163.6	54.54	106.2	120	52.76	1.78	0.02223	3598	1.054	2021	0.2438	0.00	-0.8012	0.4868	59.66	0.5503
5.00	0.26	48	163.6	57.49	108.8	123	55.66	1.824	0.02223	3686	1.08	2021	0.2538	0.00	-0.8012	0.4921	59.66	0.5563
5.00	0.27	48	163.6	60.51	111.5	126	58.65	1.869	0.02223	3777	1.107	2021	0.2639	0.00	-0.8012	0.4974	59.66	0.5623
5.00	0.28	48	163.6	63.63	114.2	129.1	61.71	1.915	0.02223	3870	1.134	2021	0.2739	0.00	-0.8012	0.5027	59.66	0.5683
5.00	0.29	48	163.6	66.83	117.1	132.3	64.87	1.962	0.02223	3966	1.162	2021	0.2839	0.00	-0.8012	0.508	59.66	0.5743
5.00	0.30	48	163.6	70.12	120	135.6	68.11	2.011	0.02223	4065	1.191	2021	0.2939	0.00	-0.8012	0.5133	59.66	0.5803
5.00	0.31	48	163.6	73.51	123	139	71.45	2.061	0.02223	4167	1.221	2021	0.3039	0.00	-0.8012	0.5186	59.66	0.5863
5.00	0.32	48	163.6	76.99	126.1	142.5	74.88	2.113	0.02223	4271	1.252	2021	0.314	0.00	-0.8012	0.5239	59.66	0.5923
5.00	0.33	48	163.6	80.59	129.2	146.1	78.42	2.166	0.02223	4379	1.283	2021	0.324	0.00	-0.8012	0.5292	59.66	0.5983
5.00	0.34	48	163.6	84.29	132.5	149.8	82.06	2.221	0.02223	4490	1.316	2021	0.334	0.00	-0.8012	0.5345	59.66	0.6043
5.00	0.35	48	163.6	88.1	135.9	153.6	85.82	2.278	0.02223	4604	1.349	2021	0.3441	0.00	-0.8012	0.5398	59.66	0.6103
5.00	0.36	48	163.6	92.03	139.4	157.5	89.7	2.336	0.02223	4722	1.384	2021	0.3541	0.00	-0.8012	0.5452	59.66	0.6162
5.00	0.37	48	163.6	96.09	143	161.6	93.69	2.396	0.02223	4843	1.419	2021	0.3641	0.00	-0.8012	0.5505	59.66	0.6222
5.00	0.38	48	163.6	100.3	146.7	165.8	97.82	2.458	0.02223	4969	1.456	2021	0.3742	0.00	-0.8012	0.5558	59.66	0.6282
5.00	0.39	48	163.6	104.6	150.5	170.1	102.1	2.522	0.02223	5099	1.494	2021	0.3842	0.00	-0.8012	0.5611	59.66	0.6342
5.00	0.40	48	163.6	109.1	154.4	174.6	106.5	2.589	0.02223	5233	1.534	2021	0.3942	0.00	-0.8012	0.5664	59.66	0.6402

$T_{operation}$ 120 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
1.00	0.20	57.24	32.72	8.181	18.68	21.28	7.553	0.6273	0.03904	637.8	0.1869	1017	0.1875	0.31	0.09396	0.4568	29.79	0.5203
1.00	0.21	57.24	32.72	8.698	19.14	21.8	8.056	0.6425	0.03904	653.3	0.1915	1017	0.1976	0.32	0.09396	0.4621	29.79	0.5263
1.00	0.22	57.24	32.72	9.229	19.61	22.33	8.571	0.6582	0.03904	669.2	0.1961	1017	0.2076	0.33	0.09396	0.4673	29.79	0.5323
1.00	0.23	57.24	32.72	9.774	20.08	22.88	9.1	0.6742	0.03904	685.6	0.2009	1017	0.2176	0.34	0.09396	0.4726	29.79	0.5383
1.00	0.24	57.24	32.72	10.33	20.57	23.44	9.643	0.6907	0.03904	702.3	0.2058	1017	0.2276	0.35	0.09396	0.4779	29.79	0.5443
1.00	0.25	57.24	32.72	10.91	21.08	24.01	10.2	0.7076	0.03904	719.5	0.2109	1017	0.2376	0.35	0.09396	0.4831	29.79	0.5503
1.00	0.26	57.24	32.72	11.5	21.6	24.6	10.77	0.725	0.03904	737.2	0.2161	1017	0.2477	0.36	0.09396	0.4884	29.79	0.5563
1.00	0.27	57.24	32.72	12.1	22.13	25.21	11.36	0.7429	0.03904	755.3	0.2214	1017	0.2577	0.37	0.09396	0.4937	29.79	0.5623
1.00	0.28	57.24	32.72	12.73	22.67	25.83	11.96	0.7612	0.03904	774	0.2268	1017	0.2677	0.38	0.09396	0.4989	29.79	0.5683
1.00	0.29	57.24	32.72	13.37	23.24	26.47	12.59	0.7801	0.03904	793.2	0.2325	1017	0.2778	0.39	0.09396	0.5042	29.79	0.5743
1.00	0.30	57.24	32.72	14.02	23.81	27.13	13.22	0.7995	0.03904	812.9	0.2382	1017	0.2878	0.40	0.09396	0.5094	29.79	0.5803
1.00	0.31	57.24	32.72	14.7	24.41	27.8	13.88	0.8195	0.03904	833.2	0.2442	1017	0.2979	0.41	0.09396	0.5147	29.79	0.5863
1.00	0.32	57.24	32.72	15.4	25.02	28.5	14.56	0.84	0.03904	854.1	0.2503	1017	0.3079	0.42	0.09396	0.52	29.79	0.5923
1.00	0.33	57.24	32.72	16.12	25.65	29.22	15.26	0.8612	0.03904	875.7	0.2566	1017	0.318	0.43	0.09396	0.5252	29.79	0.5983
1.00	0.34	57.24	32.72	16.86	26.3	29.96	15.97	0.883	0.03904	897.8	0.2631	1017	0.328	0.44	0.09396	0.5305	29.79	0.6043
1.00	0.35	57.24	32.72	17.62	26.97	30.72	16.71	0.9055	0.03904	920.7	0.2698	1017	0.3381	0.45	0.09396	0.5358	29.79	0.6103
1.00	0.36	57.24	32.72	18.41	27.66	31.51	17.48	0.9287	0.03904	944.3	0.2767	1017	0.3482	0.47	0.09396	0.541	29.79	0.6163
1.00	0.37	57.24	32.72	19.22	28.37	32.32	18.27	0.9526	0.03904	968.6	0.2839	1017	0.3582	0.48	0.09396	0.5463	29.79	0.6223
1.00	0.38	57.24	32.72	20.06	29.11	33.16	19.08	0.9773	0.03904	993.7	0.2912	1017	0.3683	0.49	0.09396	0.5516	29.79	0.6283
1.00	0.39	57.24	32.72	20.92	29.87	34.02	19.92	1.003	0.03904	1020	0.2988	1017	0.3784	0.50	0.09396	0.5568	29.79	0.6343
1.00	0.40	57.24	32.72	21.82	30.65	34.92	20.79	1.029	0.03904	1046	0.3067	1017	0.3885	0.52	0.09396	0.5621	29.79	0.6403

$T_{operation}$ 120 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
2.00	0.20	57.24	65.45	16.36	37.37	42.57	15.11	1.255	0.03904	1276	0.3738	1017	0.1875	0.63	0.09396	0.4568	29.79	0.5203
2.00	0.21	57.24	65.45	17.4	38.28	43.6	16.11	1.285	0.03904	1307	0.3829	1017	0.1976	0.64	0.09396	0.4621	29.79	0.5263
2.00	0.22	57.24	65.45	18.46	39.21	44.66	17.14	1.316	0.03904	1338	0.3923	1017	0.2076	0.66	0.09396	0.4673	29.79	0.5323
2.00	0.23	57.24	65.45	19.55	40.17	45.75	18.2	1.348	0.03904	1371	0.4018	1017	0.2176	0.68	0.09396	0.4726	29.79	0.5383
2.00	0.24	57.24	65.45	20.67	41.15	46.87	19.29	1.381	0.03904	1405	0.4117	1017	0.2276	0.69	0.09396	0.4779	29.79	0.5443
2.00	0.25	57.24	65.45	21.82	42.16	48.02	20.4	1.415	0.03904	1439	0.4217	1017	0.2376	0.71	0.09396	0.4831	29.79	0.5503
2.00	0.26	57.24	65.45	22.99	43.19	49.2	21.54	1.45	0.03904	1474	0.4321	1017	0.2477	0.73	0.09396	0.4884	29.79	0.5563
2.00	0.27	57.24	65.45	24.21	44.26	50.41	22.72	1.486	0.03904	1511	0.4427	1017	0.2577	0.74	0.09396	0.4937	29.79	0.5623
2.00	0.28	57.24	65.45	25.45	45.35	51.66	23.93	1.522	0.03904	1548	0.4537	1017	0.2677	0.76	0.09396	0.4989	29.79	0.5683
2.00	0.29	57.24	65.45	26.73	46.47	52.94	25.17	1.56	0.03904	1586	0.4649	1017	0.2778	0.78	0.09396	0.5042	29.79	0.5743
2.00	0.30	57.24	65.45	28.05	47.63	54.25	26.45	1.599	0.03904	1626	0.4765	1017	0.2878	0.80	0.09396	0.5094	29.79	0.5803
2.00	0.31	57.24	65.45	29.4	48.82	55.61	27.76	1.639	0.03904	1666	0.4884	1017	0.2979	0.82	0.09396	0.5147	29.79	0.5863
2.00	0.32	57.24	65.45	30.8	50.04	57	29.12	1.68	0.03904	1708	0.5006	1017	0.3079	0.84	0.09396	0.52	29.79	0.5923
2.00	0.33	57.24	65.45	32.23	51.3	58.44	30.51	1.722	0.03904	1751	0.5133	1017	0.318	0.86	0.09396	0.5252	29.79	0.5983
2.00	0.34	57.24	65.45	33.71	52.6	59.92	31.95	1.766	0.03904	1796	0.5263	1017	0.328	0.88	0.09396	0.5305	29.79	0.6043
2.00	0.35	57.24	65.45	35.24	53.94	61.45	33.43	1.811	0.03904	1841	0.5397	1017	0.3381	0.91	0.09396	0.5358	29.79	0.6103
2.00	0.36	57.24	65.45	36.81	55.32	63.02	34.96	1.857	0.03904	1889	0.5535	1017	0.3482	0.93	0.09396	0.541	29.79	0.6163
2.00	0.37	57.24	65.45	38.44	56.75	64.64	36.53	1.905	0.03904	1937	0.5677	1017	0.3582	0.95	0.09396	0.5463	29.79	0.6223
2.00	0.38	57.24	65.45	40.11	58.22	66.32	38.16	1.955	0.03904	1987	0.5824	1017	0.3683	0.98	0.09396	0.5516	29.79	0.6283
2.00	0.39	57.24	65.45	41.84	59.74	68.05	39.84	2.006	0.03904	2039	0.5976	1017	0.3784	1.00	0.09396	0.5568	29.79	0.6343
2.00	0.40	57.24	65.45	43.63	61.31	69.84	41.57	2.058	0.03904	2093	0.6133	1017	0.3885	1.03	0.09396	0.5621	29.79	0.6403

$T_{operation}$ 120 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
3.00	0.20	57.24	98.17	24.54	56.05	63.85	22.66	1.882	0.03904	1913	0.5608	1017	0.1875	0.94	0.09396	0.4568	29.79	0.5203
3.00	0.21	57.24	98.17	26.1	57.42	65.4	24.17	1.928	0.03904	1960	0.5744	1017	0.1976	0.97	0.09396	0.4621	29.79	0.5263
3.00	0.22	57.24	98.17	27.69	58.82	67	25.71	1.975	0.03904	2008	0.5884	1017	0.2076	0.99	0.09396	0.4673	29.79	0.5323
3.00	0.23	57.24	98.17	29.32	60.25	68.63	27.3	2.023	0.03904	2057	0.6028	1017	0.2176	1.01	0.09396	0.4726	29.79	0.5383
3.00	0.24	57.24	98.17	31	61.72	70.31	28.93	2.072	0.03904	2107	0.6175	1017	0.2276	1.04	0.09396	0.4779	29.79	0.5443
3.00	0.25	57.24	98.17	32.72	63.24	72.03	30.6	2.123	0.03904	2159	0.6326	1017	0.2376	1.06	0.09396	0.4831	29.79	0.5503
3.00	0.26	57.24	98.17	34.49	64.79	73.8	32.32	2.175	0.03904	2212	0.6482	1017	0.2477	1.09	0.09396	0.4884	29.79	0.5563
3.00	0.27	57.24	98.17	36.31	66.38	75.62	34.08	2.229	0.03904	2266	0.6641	1017	0.2577	1.12	0.09396	0.4937	29.79	0.5623
3.00	0.28	57.24	98.17	38.18	68.02	77.49	35.89	2.284	0.03904	2322	0.6805	1017	0.2677	1.14	0.09396	0.4989	29.79	0.5683
3.00	0.29	57.24	98.17	40.1	69.71	79.41	37.76	2.34	0.03904	2380	0.6974	1017	0.2778	1.17	0.09396	0.5042	29.79	0.5743
3.00	0.30	57.24	98.17	42.07	71.44	81.38	39.67	2.398	0.03904	2439	0.7147	1017	0.2878	1.20	0.09396	0.5094	29.79	0.5803
3.00	0.31	57.24	98.17	44.1	73.23	83.41	41.65	2.458	0.03904	2500	0.7326	1017	0.2979	1.23	0.09396	0.5147	29.79	0.5863
3.00	0.32	57.24	98.17	46.2	75.07	85.51	43.68	2.52	0.03904	2562	0.751	1017	0.3079	1.26	0.09396	0.52	29.79	0.5923
3.00	0.33	57.24	98.17	48.35	76.96	87.66	45.77	2.584	0.03904	2627	0.7699	1017	0.318	1.29	0.09396	0.5252	29.79	0.5983
3.00	0.34	57.24	98.17	50.57	78.91	89.88	47.92	2.649	0.03904	2693	0.7894	1017	0.328	1.33	0.09396	0.5305	29.79	0.6043
3.00	0.35	57.24	98.17	52.86	80.92	92.17	50.14	2.716	0.03904	2762	0.8095	1017	0.3381	1.36	0.09396	0.5358	29.79	0.6103
3.00	0.36	57.24	98.17	55.22	82.99	94.53	52.43	2.786	0.03904	2833	0.8302	1017	0.3482	1.40	0.09396	0.541	29.79	0.6163
3.00	0.37	57.24	98.17	57.65	85.12	96.97	54.8	2.858	0.03904	2906	0.8516	1017	0.3582	1.43	0.09396	0.5463	29.79	0.6223
3.00	0.38	57.24	98.17	60.17	87.33	99.48	57.24	2.932	0.03904	2981	0.8737	1017	0.3683	1.47	0.09396	0.5516	29.79	0.6283
3.00	0.39	57.24	98.17	62.76	89.61	102.1	59.75	3.008	0.03904	3059	0.8965	1017	0.3784	1.51	0.09396	0.5568	29.79	0.6343
3.00	0.40	57.24	98.17	65.45	91.96	104.8	62.36	3.087	0.03904	3139	0.92	1017	0.3885	1.55	0.09396	0.5621	29.79	0.6403

$T_{operation}$ 120 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
4.00	0.20	57.24	130.9	32.72	74.74	85.13	30.21	2.509	0.03904	2551	0.7477	1017	0.1875	1.26	0.09396	0.4568	29.79	0.5203
4.00	0.21	57.24	130.9	34.79	76.56	87.21	32.22	2.57	0.03904	2613	0.7659	1017	0.1976	1.29	0.09396	0.4621	29.79	0.5263
4.00	0.22	57.24	130.9	36.92	78.42	89.33	34.29	2.633	0.03904	2677	0.7845	1017	0.2076	1.32	0.09396	0.4673	29.79	0.5323
4.00	0.23	57.24	130.9	39.1	80.34	91.51	36.4	2.697	0.03904	2742	0.8037	1017	0.2176	1.35	0.09396	0.4726	29.79	0.5383
4.00	0.24	57.24	130.9	41.33	82.3	93.75	38.57	2.763	0.03904	2809	0.8233	1017	0.2276	1.38	0.09396	0.4779	29.79	0.5443
4.00	0.25	57.24	130.9	43.63	84.32	96.04	40.8	2.831	0.03904	2878	0.8435	1017	0.2376	1.42	0.09396	0.4831	29.79	0.5503
4.00	0.26	57.24	130.9	45.99	86.39	98.4	43.09	2.9	0.03904	2949	0.8642	1017	0.2477	1.45	0.09396	0.4884	29.79	0.5563
4.00	0.27	57.24	130.9	48.41	88.51	100.8	45.44	2.971	0.03904	3021	0.8855	1017	0.2577	1.49	0.09396	0.4937	29.79	0.5623
4.00	0.28	57.24	130.9	50.9	90.7	103.3	47.86	3.045	0.03904	3096	0.9074	1017	0.2677	1.53	0.09396	0.4989	29.79	0.5683
4.00	0.29	57.24	130.9	53.46	92.95	105.9	50.34	3.12	0.03904	3173	0.9298	1017	0.2778	1.56	0.09396	0.5042	29.79	0.5743
4.00	0.30	57.24	130.9	56.1	95.26	108.5	52.9	3.198	0.03904	3252	0.953	1017	0.2878	1.60	0.09396	0.5094	29.79	0.5803
4.00	0.31	57.24	130.9	58.81	97.64	111.2	55.53	3.278	0.03904	3333	0.9768	1017	0.2979	1.64	0.09396	0.5147	29.79	0.5863
4.00	0.32	57.24	130.9	61.6	100.1	114	58.24	3.36	0.03904	3417	1.001	1017	0.3079	1.68	0.09396	0.52	29.79	0.5923
4.00	0.33	57.24	130.9	64.47	102.6	116.9	61.02	3.445	0.03904	3503	1.027	1017	0.318	1.73	0.09396	0.5252	29.79	0.5983
4.00	0.34	57.24	130.9	67.43	105.2	119.8	63.9	3.532	0.03904	3591	1.053	1017	0.328	1.77	0.09396	0.5305	29.79	0.6043
4.00	0.35	57.24	130.9	70.48	107.9	122.9	66.86	3.622	0.03904	3683	1.079	1017	0.3381	1.81	0.09396	0.5358	29.79	0.6103
4.00	0.36	57.24	130.9	73.63	110.6	126	69.91	3.715	0.03904	3777	1.107	1017	0.3482	1.86	0.09396	0.541	29.79	0.6163
4.00	0.37	57.24	130.9	76.87	113.5	129.3	73.06	3.81	0.03904	3874	1.135	1017	0.3582	1.91	0.09396	0.5463	29.79	0.6223
4.00	0.38	57.24	130.9	80.22	116.4	132.6	76.31	3.909	0.03904	3975	1.165	1017	0.3683	1.96	0.09396	0.5516	29.79	0.6283
4.00	0.39	57.24	130.9	83.68	119.5	136.1	79.67	4.011	0.03904	4078	1.195	1017	0.3784	2.01	0.09396	0.5568	29.79	0.6343
4.00	0.40	57.24	130.9	87.26	122.6	139.7	83.14	4.116	0.03904	4186	1.227	1017	0.3885	2.06	0.09396	0.5621	29.79	0.6403

$T_{operation}$ 120 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
5.00	0.20	57.24	163.6	40.9	93.42	106.4	37.77	3.136	0.03904	3189	0.9346	1017	0.1875	1.57	0.09396	0.4568	29.79	0.5203
5.00	0.21	57.24	163.6	43.49	95.7	109	40.28	3.213	0.03904	3267	0.9573	1017	0.1976	1.61	0.09396	0.4621	29.79	0.5263
5.00	0.22	57.24	163.6	46.15	98.03	111.7	42.86	3.291	0.03904	3346	0.9807	1017	0.2076	1.65	0.09396	0.4673	29.79	0.5323
5.00	0.23	57.24	163.6	48.87	100.4	114.4	45.5	3.371	0.03904	3428	1.005	1017	0.2176	1.69	0.09396	0.4726	29.79	0.5383
5.00	0.24	57.24	163.6	51.67	102.9	117.2	48.21	3.454	0.03904	3512	1.029	1017	0.2276	1.73	0.09396	0.4779	29.79	0.5443
5.00	0.25	57.24	163.6	54.54	105.4	120.1	51	3.538	0.03904	3598	1.054	1017	0.2376	1.77	0.09396	0.4831	29.79	0.5503
5.00	0.26	57.24	163.6	57.49	108	123	53.86	3.625	0.03904	3686	1.08	1017	0.2477	1.82	0.09396	0.4884	29.79	0.5563
5.00	0.27	57.24	163.6	60.51	110.6	126	56.8	3.714	0.03904	3777	1.107	1017	0.2577	1.86	0.09396	0.4937	29.79	0.5623
5.00	0.28	57.24	163.6	63.63	113.4	129.1	59.82	3.806	0.03904	3870	1.134	1017	0.2677	1.91	0.09396	0.4989	29.79	0.5683
5.00	0.29	57.24	163.6	66.83	116.2	132.3	62.93	3.9	0.03904	3966	1.162	1017	0.2778	1.95	0.09396	0.5042	29.79	0.5743
5.00	0.30	57.24	163.6	70.12	119.1	135.6	66.12	3.997	0.03904	4065	1.191	1017	0.2878	2.00	0.09396	0.5094	29.79	0.5803
5.00	0.31	57.24	163.6	73.51	122	139	69.41	4.097	0.03904	4166	1.221	1017	0.2979	2.05	0.09396	0.5147	29.79	0.5863
5.00	0.32	57.24	163.6	76.99	125.1	142.5	72.79	4.2	0.03904	4271	1.252	1017	0.3079	2.10	0.09396	0.52	29.79	0.5923
5.00	0.33	57.24	163.6	80.59	128.3	146.1	76.28	4.306	0.03904	4378	1.283	1017	0.318	2.16	0.09396	0.5252	29.79	0.5983
5.00	0.34	57.24	163.6	84.29	131.5	149.8	79.87	4.415	0.03904	4489	1.316	1017	0.328	2.21	0.09396	0.5305	29.79	0.6043
5.00	0.35	57.24	163.6	88.1	134.9	153.6	83.57	4.527	0.03904	4603	1.349	1017	0.3381	2.27	0.09396	0.5358	29.79	0.6103
5.00	0.36	57.24	163.6	92.03	138.3	157.6	87.39	4.643	0.03904	4721	1.384	1017	0.3482	2.33	0.09396	0.541	29.79	0.6163
5.00	0.37	57.24	163.6	96.09	141.9	161.6	91.33	4.763	0.03904	4843	1.419	1017	0.3582	2.39	0.09396	0.5463	29.79	0.6223
5.00	0.38	57.24	163.6	100.3	145.6	165.8	95.39	4.886	0.03904	4968	1.456	1017	0.3683	2.45	0.09396	0.5516	29.79	0.6283
5.00	0.39	57.24	163.6	104.6	149.3	170.1	99.59	5.014	0.03904	5098	1.494	1017	0.3784	2.51	0.09396	0.5568	29.79	0.6343
5.00	0.40	57.24	163.6	109.1	153.3	174.6	103.9	5.146	0.03904	5232	1.533	1017	0.3885	2.58	0.09396	0.5621	29.79	0.6403

$T_{operation}$ 140 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
1.00	0.20	60.97	32.72	8.181	18.55	21.28	7.245	0.9352	0.0559	637.7	0.1869	681.9	0.1813	0.62	0.3924	0.4534	19.83	0.5203
1.00	0.21	60.97	32.72	8.698	19	21.8	7.74	0.958	0.0559	653.3	0.1915	681.9	0.1913	0.64	0.3924	0.4586	19.83	0.5263
1.00	0.22	60.97	32.72	9.229	19.46	22.33	8.248	0.9813	0.0559	669.2	0.1961	681.9	0.2013	0.66	0.3924	0.4638	19.83	0.5323
1.00	0.23	60.97	32.72	9.774	19.93	22.88	8.769	1.005	0.0559	685.5	0.2009	681.9	0.2113	0.67	0.3924	0.4691	19.83	0.5383
1.00	0.24	60.97	32.72	10.33	20.42	23.44	9.304	1.03	0.0559	702.3	0.2058	681.9	0.2214	0.69	0.3924	0.4743	19.83	0.5443
1.00	0.25	60.97	32.72	10.91	20.92	24.01	9.852	1.055	0.0559	719.5	0.2109	681.9	0.2314	0.70	0.3924	0.4795	19.83	0.5503
1.00	0.26	60.97	32.72	11.5	21.43	24.6	10.42	1.081	0.0559	737.1	0.216	681.9	0.2415	0.72	0.3924	0.4847	19.83	0.5563
1.00	0.27	60.97	32.72	12.1	21.96	25.21	11	1.108	0.0559	755.3	0.2213	681.9	0.2515	0.74	0.3924	0.49	19.83	0.5623
1.00	0.28	60.97	32.72	12.73	22.5	25.83	11.59	1.135	0.0559	773.9	0.2268	681.9	0.2616	0.76	0.3924	0.4952	19.83	0.5683
1.00	0.29	60.97	32.72	13.37	23.06	26.47	12.2	1.163	0.0559	793.1	0.2324	681.9	0.2716	0.78	0.3924	0.5004	19.83	0.5743
1.00	0.30	60.97	32.72	14.02	23.64	27.13	12.83	1.192	0.0559	812.8	0.2382	681.9	0.2817	0.80	0.3924	0.5056	19.83	0.5803
1.00	0.31	60.97	32.72	14.7	24.23	27.8	13.48	1.222	0.0559	833.1	0.2442	681.9	0.2918	0.82	0.3924	0.5109	19.83	0.5863
1.00	0.32	60.97	32.72	15.4	24.83	28.5	14.15	1.252	0.0559	854	0.2503	681.9	0.3018	0.84	0.3924	0.5161	19.83	0.5923
1.00	0.33	60.97	32.72	16.12	25.46	29.22	14.83	1.284	0.0559	875.6	0.2566	681.9	0.3119	0.86	0.3924	0.5213	19.83	0.5983
1.00	0.34	60.97	32.72	16.86	26.1	29.96	15.54	1.316	0.0559	897.7	0.2631	681.9	0.322	0.88	0.3924	0.5265	19.83	0.6043
1.00	0.35	60.97	32.72	17.62	26.77	30.72	16.27	1.35	0.0559	920.6	0.2698	681.9	0.3321	0.90	0.3924	0.5317	19.83	0.6103
1.00	0.36	60.97	32.72	18.41	27.45	31.51	17.02	1.385	0.0559	944.2	0.2767	681.9	0.3422	0.92	0.3924	0.537	19.83	0.6163
1.00	0.37	60.97	32.72	19.22	28.16	32.32	17.8	1.42	0.0559	968.5	0.2838	681.9	0.3523	0.95	0.3924	0.5422	19.83	0.6223
1.00	0.38	60.97	32.72	20.06	28.89	33.16	18.6	1.457	0.0559	993.6	0.2912	681.9	0.3624	0.97	0.3924	0.5474	19.83	0.6283
1.00	0.39	60.97	32.72	20.92	29.65	34.02	19.43	1.495	0.0559	1020	0.2988	681.9	0.3725	1.00	0.3924	0.5526	19.83	0.6343
1.00	0.40	60.97	32.72	21.82	30.42	34.92	20.28	1.534	0.0559	1046	0.3066	681.9	0.3826	1.02	0.3924	0.5579	19.83	0.6403

$T_{operation}$ 140 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
2.00	0.20	60.97	65.45	16.36	37.09	42.57	14.49	1.87	0.0559	1275	0.3738	681.9	0.1813	1.25	0.3924	0.4534	19.83	0.5203
2.00	0.21	60.97	65.45	17.4	37.99	43.6	15.48	1.916	0.0559	1307	0.3829	681.9	0.1913	1.28	0.3924	0.4586	19.83	0.5263
2.00	0.22	60.97	65.45	18.46	38.92	44.67	16.5	1.963	0.0559	1338	0.3922	681.9	0.2013	1.31	0.3924	0.4638	19.83	0.5323
2.00	0.23	60.97	65.45	19.55	39.87	45.76	17.54	2.011	0.0559	1371	0.4018	681.9	0.2113	1.34	0.3924	0.4691	19.83	0.5383
2.00	0.24	60.97	65.45	20.67	40.84	46.87	18.61	2.06	0.0559	1405	0.4116	681.9	0.2214	1.38	0.3924	0.4743	19.83	0.5443
2.00	0.25	60.97	65.45	21.82	41.84	48.02	19.7	2.11	0.0559	1439	0.4217	681.9	0.2314	1.41	0.3924	0.4795	19.83	0.5503
2.00	0.26	60.97	65.45	22.99	42.87	49.2	20.83	2.162	0.0559	1474	0.4321	681.9	0.2415	1.44	0.3924	0.4847	19.83	0.5563
2.00	0.27	60.97	65.45	24.21	43.92	50.41	21.99	2.215	0.0559	1511	0.4427	681.9	0.2515	1.48	0.3924	0.49	19.83	0.5623
2.00	0.28	60.97	65.45	25.45	45.01	51.66	23.18	2.27	0.0559	1548	0.4536	681.9	0.2616	1.52	0.3924	0.4952	19.83	0.5683
2.00	0.29	60.97	65.45	26.73	46.13	52.94	24.4	2.326	0.0559	1586	0.4649	681.9	0.2716	1.55	0.3924	0.5004	19.83	0.5743
2.00	0.30	60.97	65.45	28.05	47.27	54.25	25.66	2.384	0.0559	1626	0.4764	681.9	0.2817	1.59	0.3924	0.5056	19.83	0.5803
2.00	0.31	60.97	65.45	29.4	48.45	55.61	26.96	2.444	0.0559	1666	0.4883	681.9	0.2918	1.63	0.3924	0.5109	19.83	0.5863
2.00	0.32	60.97	65.45	30.8	49.67	57	28.29	2.505	0.0559	1708	0.5006	681.9	0.3018	1.67	0.3924	0.5161	19.83	0.5923
2.00	0.33	60.97	65.45	32.23	50.92	58.44	29.67	2.568	0.0559	1751	0.5132	681.9	0.3119	1.71	0.3924	0.5213	19.83	0.5983
2.00	0.34	60.97	65.45	33.71	52.21	59.92	31.08	2.633	0.0559	1795	0.5262	681.9	0.322	1.76	0.3924	0.5265	19.83	0.6043
2.00	0.35	60.97	65.45	35.24	53.54	61.45	32.54	2.7	0.0559	1841	0.5396	681.9	0.3321	1.80	0.3924	0.5317	19.83	0.6103
2.00	0.36	60.97	65.45	36.81	54.91	63.02	34.04	2.769	0.0559	1888	0.5534	681.9	0.3422	1.85	0.3924	0.537	19.83	0.6163
2.00	0.37	60.97	65.45	38.44	56.32	64.64	35.6	2.84	0.0559	1937	0.5677	681.9	0.3523	1.90	0.3924	0.5422	19.83	0.6223
2.00	0.38	60.97	65.45	40.11	57.78	66.32	37.2	2.914	0.0559	1987	0.5824	681.9	0.3624	1.95	0.3924	0.5474	19.83	0.6283
2.00	0.39	60.97	65.45	41.84	59.29	68.05	38.85	2.99	0.0559	2039	0.5976	681.9	0.3725	2.00	0.3924	0.5526	19.83	0.6343
2.00	0.40	60.97	65.45	43.63	60.85	69.84	40.56	3.069	0.0559	2093	0.6133	681.9	0.3826	2.05	0.3924	0.5579	19.83	0.6403

$T_{operation}$ 140 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
3.00	0.20	60.97	98.17	24.54	55.64	63.85	21.74	2.806	0.0559	1913	0.5607	681.9	0.1813	1.87	0.3924	0.4534	19.83	0.5203
3.00	0.21	60.97	98.17	26.1	56.99	65.41	23.22	2.874	0.0559	1960	0.5744	681.9	0.1913	1.92	0.3924	0.4586	19.83	0.5263
3.00	0.22	60.97	98.17	27.69	58.38	67	24.74	2.944	0.0559	2008	0.5883	681.9	0.2013	1.97	0.3924	0.4638	19.83	0.5323
3.00	0.23	60.97	98.17	29.32	59.8	68.63	26.31	3.016	0.0559	2057	0.6027	681.9	0.2113	2.01	0.3924	0.4691	19.83	0.5383
3.00	0.24	60.97	98.17	31	61.26	70.31	27.91	3.089	0.0559	2107	0.6174	681.9	0.2214	2.06	0.3924	0.4743	19.83	0.5443
3.00	0.25	60.97	98.17	32.72	62.76	72.03	29.56	3.165	0.0559	2158	0.6326	681.9	0.2314	2.11	0.3924	0.4795	19.83	0.5503
3.00	0.26	60.97	98.17	34.49	64.3	73.8	31.25	3.243	0.0559	2211	0.6481	681.9	0.2415	2.17	0.3924	0.4847	19.83	0.5563
3.00	0.27	60.97	98.17	36.31	65.89	75.62	32.99	3.323	0.0559	2266	0.664	681.9	0.2515	2.22	0.3924	0.49	19.83	0.5623
3.00	0.28	60.97	98.17	38.18	67.51	77.49	34.77	3.405	0.0559	2322	0.6805	681.9	0.2616	2.27	0.3924	0.4952	19.83	0.5683
3.00	0.29	60.97	98.17	40.1	69.19	79.41	36.61	3.489	0.0559	2379	0.6973	681.9	0.2716	2.33	0.3924	0.5004	19.83	0.5743
3.00	0.30	60.97	98.17	42.07	70.91	81.38	38.5	3.576	0.0559	2439	0.7147	681.9	0.2817	2.39	0.3924	0.5056	19.83	0.5803
3.00	0.31	60.97	98.17	44.1	72.68	83.41	40.44	3.665	0.0559	2499	0.7325	681.9	0.2918	2.45	0.3924	0.5109	19.83	0.5863
3.00	0.32	60.97	98.17	46.2	74.5	85.51	42.44	3.757	0.0559	2562	0.7509	681.9	0.3018	2.51	0.3924	0.5161	19.83	0.5923
3.00	0.33	60.97	98.17	48.35	76.38	87.66	44.5	3.852	0.0559	2627	0.7698	681.9	0.3119	2.57	0.3924	0.5213	19.83	0.5983
3.00	0.34	60.97	98.17	50.57	78.31	89.88	46.62	3.949	0.0559	2693	0.7893	681.9	0.322	2.64	0.3924	0.5265	19.83	0.6043
3.00	0.35	60.97	98.17	52.86	80.31	92.17	48.81	4.05	0.0559	2762	0.8094	681.9	0.3321	2.70	0.3924	0.5317	19.83	0.6103
3.00	0.36	60.97	98.17	55.22	82.36	94.53	51.07	4.154	0.0559	2832	0.8301	681.9	0.3422	2.77	0.3924	0.537	19.83	0.6163
3.00	0.37	60.97	98.17	57.65	84.49	96.97	53.39	4.261	0.0559	2905	0.8515	681.9	0.3523	2.85	0.3924	0.5422	19.83	0.6223
3.00	0.38	60.97	98.17	60.17	86.68	99.48	55.8	4.371	0.0559	2981	0.8736	681.9	0.3624	2.92	0.3924	0.5474	19.83	0.6283
3.00	0.39	60.97	98.17	62.76	88.94	102.1	58.28	4.485	0.0559	3059	0.8964	681.9	0.3725	2.99	0.3924	0.5526	19.83	0.6343
3.00	0.40	60.97	98.17	65.45	91.27	104.8	60.84	4.603	0.0559	3139	0.9199	681.9	0.3826	3.07	0.3924	0.5579	19.83	0.6403

$T_{operation}$ 140 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
4.00	0.20	60.97	130.9	32.72	74.18	85.14	28.98	3.741	0.0559	2551	0.7476	681.9	0.1813	2.50	0.3924	0.4534	19.83	0.5203
4.00	0.21	60.97	130.9	34.79	75.98	87.21	30.96	3.832	0.0559	2613	0.7658	681.9	0.1913	2.56	0.3924	0.4586	19.83	0.5263
4.00	0.22	60.97	130.9	36.92	77.84	89.33	32.99	3.925	0.0559	2677	0.7845	681.9	0.2013	2.62	0.3924	0.4638	19.83	0.5323
4.00	0.23	60.97	130.9	39.1	79.73	91.51	35.08	4.021	0.0559	2742	0.8036	681.9	0.2113	2.69	0.3924	0.4691	19.83	0.5383
4.00	0.24	60.97	130.9	41.33	81.68	93.75	37.21	4.119	0.0559	2809	0.8232	681.9	0.2214	2.75	0.3924	0.4743	19.83	0.5443
4.00	0.25	60.97	130.9	43.63	83.68	96.04	39.41	4.22	0.0559	2878	0.8434	681.9	0.2314	2.82	0.3924	0.4795	19.83	0.5503
4.00	0.26	60.97	130.9	45.99	85.74	98.4	41.66	4.324	0.0559	2949	0.8641	681.9	0.2415	2.89	0.3924	0.4847	19.83	0.5563
4.00	0.27	60.97	130.9	48.41	87.85	100.8	43.98	4.43	0.0559	3021	0.8854	681.9	0.2515	2.96	0.3924	0.49	19.83	0.5623
4.00	0.28	60.97	130.9	50.9	90.02	103.3	46.36	4.54	0.0559	3096	0.9073	681.9	0.2616	3.03	0.3924	0.4952	19.83	0.5683
4.00	0.29	60.97	130.9	53.46	92.25	105.9	48.81	4.652	0.0559	3172	0.9298	681.9	0.2716	3.11	0.3924	0.5004	19.83	0.5743
4.00	0.30	60.97	130.9	56.1	94.55	108.5	51.33	4.768	0.0559	3251	0.9529	681.9	0.2817	3.18	0.3924	0.5056	19.83	0.5803
4.00	0.31	60.97	130.9	58.81	96.91	111.2	53.92	4.887	0.0559	3333	0.9767	681.9	0.2918	3.26	0.3924	0.5109	19.83	0.5863
4.00	0.32	60.97	130.9	61.6	99.34	114	56.59	5.01	0.0559	3416	1.001	681.9	0.3018	3.35	0.3924	0.5161	19.83	0.5923
4.00	0.33	60.97	130.9	64.47	101.8	116.9	59.33	5.136	0.0559	3502	1.026	681.9	0.3119	3.43	0.3924	0.5213	19.83	0.5983
4.00	0.34	60.97	130.9	67.43	104.4	119.8	62.16	5.266	0.0559	3591	1.052	681.9	0.322	3.52	0.3924	0.5265	19.83	0.6043
4.00	0.35	60.97	130.9	70.48	107.1	122.9	65.08	5.4	0.0559	3682	1.079	681.9	0.3321	3.61	0.3924	0.5317	19.83	0.6103
4.00	0.36	60.97	130.9	73.63	109.8	126	68.09	5.538	0.0559	3777	1.107	681.9	0.3422	3.70	0.3924	0.537	19.83	0.6163
4.00	0.37	60.97	130.9	76.87	112.6	129.3	71.19	5.681	0.0559	3874	1.135	681.9	0.3523	3.79	0.3924	0.5422	19.83	0.6223
4.00	0.38	60.97	130.9	80.22	115.6	132.6	74.39	5.828	0.0559	3974	1.165	681.9	0.3624	3.89	0.3924	0.5474	19.83	0.6283
4.00	0.39	60.97	130.9	83.68	118.6	136.1	77.7	5.98	0.0559	4078	1.195	681.9	0.3725	3.99	0.3924	0.5526	19.83	0.6343
4.00	0.40	60.97	130.9	87.26	121.7	139.7	81.12	6.137	0.0559	4185	1.227	681.9	0.3826	4.10	0.3924	0.5579	19.83	0.6403

$T_{operation}$ 140 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
5.00	0.20	60.97	163.6	40.9	92.73	106.4	36.23	4.676	0.0559	3189	0.9345	681.9	0.1813	3.12	0.3924	0.4534	19.83	0.5203
5.00	0.21	60.97	163.6	43.49	94.98	109	38.7	4.79	0.0559	3266	0.9573	681.9	0.1913	3.20	0.3924	0.4586	19.83	0.5263
5.00	0.22	60.97	163.6	46.15	97.29	111.7	41.24	4.907	0.0559	3346	0.9806	681.9	0.2013	3.28	0.3924	0.4638	19.83	0.5323
5.00	0.23	60.97	163.6	48.87	99.67	114.4	43.85	5.026	0.0559	3428	1.005	681.9	0.2113	3.36	0.3924	0.4691	19.83	0.5383
5.00	0.24	60.97	163.6	51.67	102.1	117.2	46.52	5.149	0.0559	3511	1.029	681.9	0.2214	3.44	0.3924	0.4743	19.83	0.5443
5.00	0.25	60.97	163.6	54.54	104.6	120.1	49.26	5.275	0.0559	3597	1.054	681.9	0.2314	3.52	0.3924	0.4795	19.83	0.5503
5.00	0.26	60.97	163.6	57.49	107.2	123	52.08	5.405	0.0559	3686	1.08	681.9	0.2415	3.61	0.3924	0.4847	19.83	0.5563
5.00	0.27	60.97	163.6	60.51	109.8	126	54.98	5.538	0.0559	3776	1.107	681.9	0.2515	3.70	0.3924	0.49	19.83	0.5623
5.00	0.28	60.97	163.6	63.63	112.5	129.1	57.95	5.675	0.0559	3870	1.134	681.9	0.2616	3.79	0.3924	0.4952	19.83	0.5683
5.00	0.29	60.97	163.6	66.83	115.3	132.3	61.01	5.815	0.0559	3966	1.162	681.9	0.2716	3.88	0.3924	0.5004	19.83	0.5743
5.00	0.30	60.97	163.6	70.12	118.2	135.6	64.16	5.96	0.0559	4064	1.191	681.9	0.2817	3.98	0.3924	0.5056	19.83	0.5803
5.00	0.31	60.97	163.6	73.51	121.1	139	67.4	6.109	0.0559	4166	1.221	681.9	0.2918	4.08	0.3924	0.5109	19.83	0.5863
5.00	0.32	60.97	163.6	76.99	124.2	142.5	70.73	6.262	0.0559	4270	1.251	681.9	0.3018	4.18	0.3924	0.5161	19.83	0.5923
5.00	0.33	60.97	163.6	80.59	127.3	146.1	74.17	6.42	0.0559	4378	1.283	681.9	0.3119	4.29	0.3924	0.5213	19.83	0.5983
5.00	0.34	60.97	163.6	84.29	130.5	149.8	77.7	6.582	0.0559	4489	1.316	681.9	0.322	4.40	0.3924	0.5265	19.83	0.6043
5.00	0.35	60.97	163.6	88.1	133.8	153.6	81.35	6.75	0.0559	4603	1.349	681.9	0.3321	4.51	0.3924	0.5317	19.83	0.6103
5.00	0.36	60.97	163.6	92.03	137.3	157.6	85.11	6.923	0.0559	4721	1.384	681.9	0.3422	4.62	0.3924	0.537	19.83	0.6163
5.00	0.37	60.97	163.6	96.09	140.8	161.6	88.99	7.101	0.0559	4842	1.419	681.9	0.3523	4.74	0.3924	0.5422	19.83	0.6223
5.00	0.38	60.97	163.6	100.3	144.5	165.8	92.99	7.285	0.0559	4968	1.456	681.9	0.3624	4.86	0.3924	0.5474	19.83	0.6283
5.00	0.39	60.97	163.6	104.6	148.2	170.1	97.13	7.475	0.0559	5098	1.494	681.9	0.3725	4.99	0.3924	0.5526	19.83	0.6343
5.00	0.40	60.97	163.6	109.1	152.1	174.6	101.4	7.672	0.0559	5232	1.533	681.9	0.3826	5.12	0.3924	0.5579	19.83	0.6403

$T_{operation}$ 160 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
1.00	0.20	62.84	32.72	8.181	18.42	21.28	6.941	1.239	0.07276	638	0.187	514.7	0.175	0.93	0.5413	0.4503	14.86	0.5203
1.00	0.21	62.84	32.72	8.698	18.87	21.8	7.429	1.27	0.07276	653.5	0.1915	514.7	0.185	0.95	0.5413	0.4555	14.86	0.5263
1.00	0.22	62.84	32.72	9.229	19.33	22.33	7.929	1.301	0.07276	669.4	0.1962	514.7	0.195	0.98	0.5413	0.4607	14.86	0.5323
1.00	0.23	62.84	32.72	9.774	19.8	22.87	8.442	1.332	0.07276	685.8	0.201	514.7	0.2051	1.00	0.5413	0.4659	14.86	0.5383
1.00	0.24	62.84	32.72	10.33	20.28	23.43	8.969	1.365	0.07276	702.5	0.2059	514.7	0.2151	1.03	0.5413	0.4711	14.86	0.5443
1.00	0.25	62.84	32.72	10.91	20.78	24.01	9.509	1.398	0.07276	719.7	0.2109	514.7	0.2252	1.05	0.5413	0.4763	14.86	0.5503
1.00	0.26	62.84	32.72	11.5	21.29	24.6	10.06	1.433	0.07276	737.4	0.2161	514.7	0.2352	1.08	0.5413	0.4815	14.86	0.5563
1.00	0.27	62.84	32.72	12.1	21.81	25.2	10.63	1.468	0.07276	755.6	0.2214	514.7	0.2453	1.10	0.5413	0.4867	14.86	0.5623
1.00	0.28	62.84	32.72	12.73	22.35	25.83	11.22	1.504	0.07276	774.2	0.2269	514.7	0.2554	1.13	0.5413	0.4919	14.86	0.5683
1.00	0.29	62.84	32.72	13.37	22.91	26.47	11.82	1.541	0.07276	793.4	0.2325	514.7	0.2654	1.16	0.5413	0.497	14.86	0.5742
1.00	0.30	62.84	32.72	14.02	23.48	27.12	12.44	1.58	0.07276	813.2	0.2383	514.7	0.2755	1.19	0.5413	0.5022	14.86	0.5802
1.00	0.31	62.84	32.72	14.7	24.06	27.8	13.08	1.619	0.07276	833.5	0.2443	514.7	0.2856	1.22	0.5413	0.5074	14.86	0.5862
1.00	0.32	62.84	32.72	15.4	24.67	28.5	13.74	1.66	0.07276	854.4	0.2504	514.7	0.2957	1.25	0.5413	0.5126	14.86	0.5922
1.00	0.33	62.84	32.72	16.12	25.29	29.22	14.42	1.702	0.07276	875.9	0.2567	514.7	0.3058	1.28	0.5413	0.5178	14.86	0.5982
1.00	0.34	62.84	32.72	16.86	25.93	29.96	15.11	1.745	0.07276	898.1	0.2632	514.7	0.3159	1.31	0.5413	0.523	14.86	0.6042
1.00	0.35	62.84	32.72	17.62	26.59	30.72	15.83	1.789	0.07276	920.9	0.2699	514.7	0.326	1.34	0.5413	0.5282	14.86	0.6102
1.00	0.36	62.84	32.72	18.41	27.27	31.51	16.57	1.835	0.07276	944.5	0.2768	514.7	0.3362	1.38	0.5413	0.5334	14.86	0.6162
1.00	0.37	62.84	32.72	19.22	27.97	32.32	17.34	1.882	0.07276	968.9	0.2839	514.7	0.3463	1.41	0.5413	0.5386	14.86	0.6222
1.00	0.38	62.84	32.72	20.06	28.7	33.16	18.12	1.931	0.07276	994	0.2913	514.7	0.3565	1.45	0.5413	0.5437	14.86	0.6282
1.00	0.39	62.84	32.72	20.92	29.45	34.02	18.94	1.981	0.07276	1020	0.2989	514.7	0.3666	1.49	0.5413	0.5489	14.86	0.6342
1.00	0.40	62.84	32.72	21.82	30.22	34.91	19.78	2.034	0.07276	1047	0.3068	514.7	0.3768	1.53	0.5413	0.5541	14.86	0.6402

$T_{operation}$ 160 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
2.00	0.20	62.84	65.45	16.36	36.84	42.56	13.88	2.479	0.07276	1276	0.374	514.7	0.175	1.86	0.5413	0.4503	14.86	0.5203
2.00	0.21	62.84	65.45	17.4	37.74	43.6	14.86	2.539	0.07276	1307	0.3831	514.7	0.185	1.91	0.5413	0.4555	14.86	0.5263
2.00	0.22	62.84	65.45	18.46	38.66	44.66	15.86	2.601	0.07276	1339	0.3924	514.7	0.195	1.95	0.5413	0.4607	14.86	0.5323
2.00	0.23	62.84	65.45	19.55	39.6	45.75	16.88	2.665	0.07276	1372	0.402	514.7	0.2051	2.00	0.5413	0.4659	14.86	0.5383
2.00	0.24	62.84	65.45	20.67	40.57	46.87	17.94	2.73	0.07276	1405	0.4118	514.7	0.2151	2.05	0.5413	0.4711	14.86	0.5443
2.00	0.25	62.84	65.45	21.82	41.56	48.02	19.02	2.797	0.07276	1439	0.4219	514.7	0.2252	2.10	0.5413	0.4763	14.86	0.5503
2.00	0.26	62.84	65.45	22.99	42.58	49.2	20.13	2.865	0.07276	1475	0.4322	514.7	0.2352	2.15	0.5413	0.4815	14.86	0.5563
2.00	0.27	62.84	65.45	24.21	43.63	50.41	21.27	2.936	0.07276	1511	0.4429	514.7	0.2453	2.20	0.5413	0.4867	14.86	0.5623
2.00	0.28	62.84	65.45	25.45	44.71	51.65	22.44	3.008	0.07276	1548	0.4538	514.7	0.2554	2.26	0.5413	0.4919	14.86	0.5683
2.00	0.29	62.84	65.45	26.73	45.82	52.93	23.65	3.083	0.07276	1587	0.4651	514.7	0.2654	2.32	0.5413	0.497	14.86	0.5742
2.00	0.30	62.84	65.45	28.05	46.95	54.25	24.89	3.16	0.07276	1626	0.4766	514.7	0.2755	2.37	0.5413	0.5022	14.86	0.5802
2.00	0.31	62.84	65.45	29.4	48.13	55.6	26.16	3.238	0.07276	1667	0.4885	514.7	0.2856	2.43	0.5413	0.5074	14.86	0.5862
2.00	0.32	62.84	65.45	30.8	49.33	57	27.48	3.32	0.07276	1709	0.5008	514.7	0.2957	2.49	0.5413	0.5126	14.86	0.5922
2.00	0.33	62.84	65.45	32.23	50.58	58.43	28.83	3.403	0.07276	1752	0.5134	514.7	0.3058	2.56	0.5413	0.5178	14.86	0.5982
2.00	0.34	62.84	65.45	33.71	51.86	59.91	30.22	3.49	0.07276	1796	0.5264	514.7	0.3159	2.62	0.5413	0.523	14.86	0.6042
2.00	0.35	62.84	65.45	35.24	53.18	61.44	31.66	3.578	0.07276	1842	0.5398	514.7	0.326	2.69	0.5413	0.5282	14.86	0.6102
2.00	0.36	62.84	65.45	36.81	54.54	63.01	33.14	3.67	0.07276	1889	0.5536	514.7	0.3362	2.76	0.5413	0.5334	14.86	0.6162
2.00	0.37	62.84	65.45	38.44	55.95	64.64	34.67	3.765	0.07276	1938	0.5679	514.7	0.3463	2.83	0.5413	0.5386	14.86	0.6222
2.00	0.38	62.84	65.45	40.11	57.4	66.31	36.25	3.862	0.07276	1988	0.5826	514.7	0.3565	2.90	0.5413	0.5437	14.86	0.6282
2.00	0.39	62.84	65.45	41.84	58.89	68.04	37.88	3.963	0.07276	2040	0.5978	514.7	0.3666	2.98	0.5413	0.5489	14.86	0.6342
2.00	0.40	62.84	65.45	43.63	60.44	69.83	39.56	4.067	0.07276	2093	0.6135	514.7	0.3768	3.05	0.5413	0.5541	14.86	0.6402

$T_{operation}$ 160 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
3.00	0.20	62.84	98.17	24.54	55.26	63.84	20.82	3.718	0.07276	1914	0.5609	514.7	0.175	2.79	0.5413	0.4503	14.86	0.5203
3.00	0.21	62.84	98.17	26.1	56.61	65.4	22.29	3.809	0.07276	1961	0.5746	514.7	0.185	2.86	0.5413	0.4555	14.86	0.5263
3.00	0.22	62.84	98.17	27.69	57.98	66.99	23.79	3.902	0.07276	2008	0.5886	514.7	0.195	2.93	0.5413	0.4607	14.86	0.5323
3.00	0.23	62.84	98.17	29.32	59.4	68.62	25.33	3.997	0.07276	2057	0.6029	514.7	0.2051	3.00	0.5413	0.4659	14.86	0.5383
3.00	0.24	62.84	98.17	31	60.85	70.3	26.91	4.095	0.07276	2108	0.6177	514.7	0.2151	3.08	0.5413	0.4711	14.86	0.5443
3.00	0.25	62.84	98.17	32.72	62.34	72.02	28.53	4.195	0.07276	2159	0.6328	514.7	0.2252	3.15	0.5413	0.4763	14.86	0.5503
3.00	0.26	62.84	98.17	34.49	63.87	73.79	30.19	4.298	0.07276	2212	0.6483	514.7	0.2352	3.23	0.5413	0.4815	14.86	0.5563
3.00	0.27	62.84	98.17	36.31	65.44	75.61	31.9	4.404	0.07276	2267	0.6643	514.7	0.2453	3.31	0.5413	0.4867	14.86	0.5623
3.00	0.28	62.84	98.17	38.18	67.06	77.48	33.66	4.512	0.07276	2323	0.6807	514.7	0.2554	3.39	0.5413	0.4919	14.86	0.5683
3.00	0.29	62.84	98.17	40.1	68.72	79.4	35.47	4.624	0.07276	2380	0.6976	514.7	0.2654	3.47	0.5413	0.497	14.86	0.5742
3.00	0.30	62.84	98.17	42.07	70.43	81.37	37.33	4.739	0.07276	2439	0.7149	514.7	0.2755	3.56	0.5413	0.5022	14.86	0.5802
3.00	0.31	62.84	98.17	44.1	72.19	83.41	39.25	4.858	0.07276	2500	0.7328	514.7	0.2856	3.65	0.5413	0.5074	14.86	0.5862
3.00	0.32	62.84	98.17	46.2	74	85.5	41.22	4.98	0.07276	2563	0.7512	514.7	0.2957	3.74	0.5413	0.5126	14.86	0.5922
3.00	0.33	62.84	98.17	48.35	75.87	87.65	43.25	5.105	0.07276	2628	0.7701	514.7	0.3058	3.83	0.5413	0.5178	14.86	0.5982
3.00	0.34	62.84	98.17	50.57	77.79	89.87	45.34	5.234	0.07276	2694	0.7896	514.7	0.3159	3.93	0.5413	0.523	14.86	0.6042
3.00	0.35	62.84	98.17	52.86	79.77	92.16	47.49	5.368	0.07276	2763	0.8097	514.7	0.326	4.03	0.5413	0.5282	14.86	0.6102
3.00	0.36	62.84	98.17	55.22	81.81	94.52	49.71	5.505	0.07276	2834	0.8304	514.7	0.3362	4.13	0.5413	0.5334	14.86	0.6162
3.00	0.37	62.84	98.17	57.65	83.92	96.95	52.01	5.647	0.07276	2907	0.8518	514.7	0.3463	4.24	0.5413	0.5386	14.86	0.6222
3.00	0.38	62.84	98.17	60.17	86.09	99.47	54.37	5.793	0.07276	2982	0.8739	514.7	0.3565	4.35	0.5413	0.5437	14.86	0.6282
3.00	0.39	62.84	98.17	62.76	88.34	102.1	56.82	5.944	0.07276	3060	0.8967	514.7	0.3666	4.46	0.5413	0.5489	14.86	0.6342
3.00	0.40	62.84	98.17	65.45	90.66	104.7	59.34	6.101	0.07276	3140	0.9203	514.7	0.3768	4.58	0.5413	0.5541	14.86	0.6402

$T_{operation}$ 160 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
4.00	0.20	62.84	130.9	32.72	73.68	85.13	27.76	4.958	0.07276	2552	0.7479	514.7	0.175	3.72	0.5413	0.4503	14.86	0.5203
4.00	0.21	62.84	130.9	34.79	75.47	87.2	29.72	5.079	0.07276	2614	0.7661	514.7	0.185	3.81	0.5413	0.4555	14.86	0.5263
4.00	0.22	62.84	130.9	36.92	77.31	89.32	31.72	5.202	0.07276	2678	0.7848	514.7	0.195	3.91	0.5413	0.4607	14.86	0.5323
4.00	0.23	62.84	130.9	39.1	79.2	91.5	33.77	5.329	0.07276	2743	0.8039	514.7	0.2051	4.00	0.5413	0.4659	14.86	0.5383
4.00	0.24	62.84	130.9	41.33	81.13	93.74	35.87	5.459	0.07276	2810	0.8236	514.7	0.2151	4.10	0.5413	0.4711	14.86	0.5443
4.00	0.25	62.84	130.9	43.63	83.12	96.03	38.04	5.593	0.07276	2879	0.8437	514.7	0.2252	4.20	0.5413	0.4763	14.86	0.5503
4.00	0.26	62.84	130.9	45.99	85.16	98.39	40.26	5.73	0.07276	2950	0.8645	514.7	0.2352	4.30	0.5413	0.4815	14.86	0.5563
4.00	0.27	62.84	130.9	48.41	87.26	100.8	42.54	5.872	0.07276	3022	0.8857	514.7	0.2453	4.41	0.5413	0.4867	14.86	0.5623
4.00	0.28	62.84	130.9	50.9	89.41	103.3	44.89	6.017	0.07276	3097	0.9076	514.7	0.2554	4.52	0.5413	0.4919	14.86	0.5683
4.00	0.29	62.84	130.9	53.46	91.63	105.9	47.3	6.166	0.07276	3174	0.9301	514.7	0.2654	4.63	0.5413	0.497	14.86	0.5742
4.00	0.30	62.84	130.9	56.1	93.91	108.5	49.78	6.319	0.07276	3253	0.9532	514.7	0.2755	4.75	0.5413	0.5022	14.86	0.5802
4.00	0.31	62.84	130.9	58.81	96.25	111.2	52.33	6.477	0.07276	3334	0.9771	514.7	0.2856	4.86	0.5413	0.5074	14.86	0.5862
4.00	0.32	62.84	130.9	61.6	98.67	114	54.96	6.639	0.07276	3417	1.002	514.7	0.2957	4.99	0.5413	0.5126	14.86	0.5922
4.00	0.33	62.84	130.9	64.47	101.2	116.9	57.66	6.807	0.07276	3504	1.027	514.7	0.3058	5.11	0.5413	0.5178	14.86	0.5982
4.00	0.34	62.84	130.9	67.43	103.7	119.8	60.45	6.979	0.07276	3592	1.053	514.7	0.3159	5.24	0.5413	0.523	14.86	0.6042
4.00	0.35	62.84	130.9	70.48	106.4	122.9	63.32	7.157	0.07276	3684	1.08	514.7	0.326	5.37	0.5413	0.5282	14.86	0.6102
4.00	0.36	62.84	130.9	73.63	109.1	126	66.29	7.34	0.07276	3778	1.107	514.7	0.3362	5.51	0.5413	0.5334	14.86	0.6162
4.00	0.37	62.84	130.9	76.87	111.9	129.3	69.34	7.529	0.07276	3875	1.136	514.7	0.3463	5.65	0.5413	0.5386	14.86	0.6222
4.00	0.38	62.84	130.9	80.22	114.8	132.6	72.5	7.724	0.07276	3976	1.165	514.7	0.3565	5.80	0.5413	0.5437	14.86	0.6282
4.00	0.39	62.84	130.9	83.68	117.8	136.1	75.76	7.926	0.07276	4080	1.196	514.7	0.3666	5.95	0.5413	0.5489	14.86	0.6342
4.00	0.40	62.84	130.9	87.26	120.9	139.7	79.13	8.134	0.07276	4187	1.227	514.7	0.3768	6.11	0.5413	0.5541	14.86	0.6402

$T_{operation}$ 160 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
5.00	0.20	62.84	163.6	40.9	92.1	106.4	34.71	6.197	0.07276	3190	0.9349	514.7	0.175	4.65	0.5413	0.4503	14.86	0.5203
5.00	0.21	62.84	163.6	43.49	94.34	109	37.14	6.348	0.07276	3268	0.9576	514.7	0.185	4.77	0.5413	0.4555	14.86	0.5263
5.00	0.22	62.84	163.6	46.15	96.64	111.7	39.64	6.503	0.07276	3347	0.981	514.7	0.195	4.88	0.5413	0.4607	14.86	0.5323
5.00	0.23	62.84	163.6	48.87	99	114.4	42.21	6.661	0.07276	3429	1.005	514.7	0.2051	5.00	0.5413	0.4659	14.86	0.5383
5.00	0.24	62.84	163.6	51.67	101.4	117.2	44.84	6.824	0.07276	3513	1.029	514.7	0.2151	5.12	0.5413	0.4711	14.86	0.5443
5.00	0.25	62.84	163.6	54.54	103.9	120	47.55	6.991	0.07276	3599	1.055	514.7	0.2252	5.25	0.5413	0.4763	14.86	0.5503
5.00	0.26	62.84	163.6	57.49	106.5	123	50.32	7.163	0.07276	3687	1.081	514.7	0.2352	5.38	0.5413	0.4815	14.86	0.5563
5.00	0.27	62.84	163.6	60.51	109.1	126	53.17	7.339	0.07276	3778	1.107	514.7	0.2453	5.51	0.5413	0.4867	14.86	0.5623
5.00	0.28	62.84	163.6	63.63	111.8	129.1	56.11	7.521	0.07276	3871	1.135	514.7	0.2554	5.65	0.5413	0.4919	14.86	0.5683
5.00	0.29	62.84	163.6	66.83	114.5	132.3	59.12	7.707	0.07276	3967	1.163	514.7	0.2654	5.79	0.5413	0.497	14.86	0.5742
5.00	0.30	62.84	163.6	70.12	117.4	135.6	62.22	7.899	0.07276	4066	1.192	514.7	0.2755	5.93	0.5413	0.5022	14.86	0.5802
5.00	0.31	62.84	163.6	73.51	120.3	139	65.41	8.096	0.07276	4167	1.221	514.7	0.2856	6.08	0.5413	0.5074	14.86	0.5862
5.00	0.32	62.84	163.6	76.99	123.3	142.5	68.69	8.299	0.07276	4272	1.252	514.7	0.2957	6.23	0.5413	0.5126	14.86	0.5922
5.00	0.33	62.84	163.6	80.59	126.4	146.1	72.08	8.508	0.07276	4379	1.284	514.7	0.3058	6.39	0.5413	0.5178	14.86	0.5982
5.00	0.34	62.84	163.6	84.29	129.6	149.8	75.56	8.724	0.07276	4490	1.316	514.7	0.3159	6.55	0.5413	0.523	14.86	0.6042
5.00	0.35	62.84	163.6	88.1	132.9	153.6	79.15	8.946	0.07276	4605	1.35	514.7	0.326	6.72	0.5413	0.5282	14.86	0.6102
5.00	0.36	62.84	163.6	92.03	136.4	157.5	82.86	9.175	0.07276	4723	1.384	514.7	0.3362	6.89	0.5413	0.5334	14.86	0.6162
5.00	0.37	62.84	163.6	96.09	139.9	161.6	86.68	9.411	0.07276	4844	1.42	514.7	0.3463	7.07	0.5413	0.5386	14.86	0.6222
5.00	0.38	62.84	163.6	100.3	143.5	165.8	90.62	9.655	0.07276	4970	1.457	514.7	0.3565	7.25	0.5413	0.5437	14.86	0.6282
5.00	0.39	62.84	163.6	104.6	147.2	170.1	94.7	9.907	0.07276	5100	1.495	514.7	0.3666	7.44	0.5413	0.5489	14.86	0.6342
5.00	0.40	62.84	163.6	109.1	151.1	174.6	98.91	10.17	0.07276	5234	1.534	514.7	0.3768	7.64	0.5413	0.5541	14.86	0.6402

$T_{operation}$ 180 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
1.00	0.20	63.88	32.72	8.181	18.32	21.28	6.641	1.54	0.08954	638.7	0.1872	414.7	0.1687	1.23	0.6304	0.4478	11.89	0.5201
1.00	0.21	63.88	32.72	8.698	18.76	21.79	7.121	1.577	0.08954	654.2	0.1917	414.7	0.1787	1.26	0.6304	0.453	11.89	0.5261
1.00	0.22	63.88	32.72	9.229	19.22	22.32	7.614	1.616	0.08954	670.2	0.1964	414.7	0.1888	1.29	0.6304	0.4581	11.89	0.5321
1.00	0.23	63.88	32.72	9.774	19.69	22.87	8.119	1.655	0.08954	686.5	0.2012	414.7	0.1988	1.33	0.6304	0.4633	11.89	0.5381
1.00	0.24	63.88	32.72	10.33	20.17	23.43	8.638	1.696	0.08954	703.3	0.2061	414.7	0.2088	1.36	0.6304	0.4685	11.89	0.5441
1.00	0.25	63.88	32.72	10.91	20.66	24	9.17	1.737	0.08954	720.5	0.2112	414.7	0.2189	1.39	0.6304	0.4736	11.89	0.5501
1.00	0.26	63.88	32.72	11.5	21.17	24.59	9.717	1.78	0.08954	738.2	0.2164	414.7	0.229	1.43	0.6304	0.4788	11.89	0.5561
1.00	0.27	63.88	32.72	12.1	21.69	25.2	10.28	1.824	0.08954	756.4	0.2217	414.7	0.239	1.46	0.6304	0.484	11.89	0.5621
1.00	0.28	63.88	32.72	12.73	22.23	25.82	10.86	1.869	0.08954	775.1	0.2272	414.7	0.2491	1.50	0.6304	0.4891	11.89	0.5681
1.00	0.29	63.88	32.72	13.37	22.78	26.46	11.45	1.915	0.08954	794.3	0.2328	414.7	0.2592	1.53	0.6304	0.4943	11.89	0.5741
1.00	0.30	63.88	32.72	14.02	23.35	27.12	12.06	1.963	0.08954	814.1	0.2386	414.7	0.2693	1.57	0.6304	0.4994	11.89	0.5801
1.00	0.31	63.88	32.72	14.7	23.93	27.79	12.69	2.012	0.08954	834.4	0.2445	414.7	0.2794	1.61	0.6304	0.5046	11.89	0.5861
1.00	0.32	63.88	32.72	15.4	24.53	28.49	13.34	2.062	0.08954	855.3	0.2507	414.7	0.2896	1.65	0.6304	0.5098	11.89	0.5921
1.00	0.33	63.88	32.72	16.12	25.15	29.21	14	2.114	0.08954	876.9	0.257	414.7	0.2997	1.69	0.6304	0.5149	11.89	0.5981
1.00	0.34	63.88	32.72	16.86	25.79	29.95	14.69	2.168	0.08954	899.1	0.2635	414.7	0.3098	1.74	0.6304	0.5201	11.89	0.6041
1.00	0.35	63.88	32.72	17.62	26.44	30.71	15.4	2.223	0.08954	922	0.2702	414.7	0.32	1.78	0.6304	0.5253	11.89	0.6101
1.00	0.36	63.88	32.72	18.41	27.12	31.5	16.13	2.28	0.08954	945.6	0.2771	414.7	0.3301	1.83	0.6304	0.5304	11.89	0.6161
1.00	0.37	63.88	32.72	19.22	27.82	32.31	16.88	2.339	0.08954	970	0.2843	414.7	0.3403	1.87	0.6304	0.5356	11.89	0.6221
1.00	0.38	63.88	32.72	20.06	28.54	33.15	17.66	2.399	0.08954	995.1	0.2916	414.7	0.3505	1.92	0.6304	0.5407	11.89	0.6281
1.00	0.39	63.88	32.72	20.92	29.28	34.01	18.46	2.462	0.08954	1021	0.2992	414.7	0.3607	1.97	0.6304	0.5459	11.89	0.634
1.00	0.40	63.88	32.72	21.82	30.05	34.91	19.29	2.527	0.08954	1048	0.3071	414.7	0.3709	2.02	0.6304	0.5511	11.89	0.64

$T_{operation}$ 180 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
2.00	0.20	63.88	65.45	16.36	36.63	42.55	13.28	3.08	0.08954	1277	0.3744	414.7	0.1687	2.47	0.6304	0.4478	11.89	0.5201
2.00	0.21	63.88	65.45	17.4	37.53	43.59	14.24	3.155	0.08954	1308	0.3835	414.7	0.1787	2.53	0.6304	0.453	11.89	0.5261
2.00	0.22	63.88	65.45	18.46	38.44	44.65	15.23	3.232	0.08954	1340	0.3928	414.7	0.1888	2.59	0.6304	0.4581	11.89	0.5321
2.00	0.23	63.88	65.45	19.55	39.38	45.74	16.24	3.311	0.08954	1373	0.4024	414.7	0.1988	2.65	0.6304	0.4633	11.89	0.5381
2.00	0.24	63.88	65.45	20.67	40.34	46.86	17.28	3.392	0.08954	1407	0.4122	414.7	0.2088	2.72	0.6304	0.4685	11.89	0.5441
2.00	0.25	63.88	65.45	21.82	41.33	48	18.34	3.475	0.08954	1441	0.4223	414.7	0.2189	2.78	0.6304	0.4736	11.89	0.5501
2.00	0.26	63.88	65.45	22.99	42.34	49.18	19.43	3.56	0.08954	1476	0.4327	414.7	0.229	2.85	0.6304	0.4788	11.89	0.5561
2.00	0.27	63.88	65.45	24.21	43.39	50.39	20.56	3.648	0.08954	1513	0.4434	414.7	0.239	2.92	0.6304	0.484	11.89	0.5621
2.00	0.28	63.88	65.45	25.45	44.46	51.64	21.71	3.738	0.08954	1550	0.4543	414.7	0.2491	2.99	0.6304	0.4891	11.89	0.5681
2.00	0.29	63.88	65.45	26.73	45.56	52.92	22.9	3.83	0.08954	1589	0.4656	414.7	0.2592	3.07	0.6304	0.4943	11.89	0.5741
2.00	0.30	63.88	65.45	28.05	46.69	54.23	24.12	3.926	0.08954	1628	0.4772	414.7	0.2693	3.14	0.6304	0.4994	11.89	0.5801
2.00	0.31	63.88	65.45	29.4	47.86	55.59	25.38	4.024	0.08954	1669	0.4891	414.7	0.2794	3.22	0.6304	0.5046	11.89	0.5861
2.00	0.32	63.88	65.45	30.8	49.06	56.98	26.67	4.125	0.08954	1711	0.5013	414.7	0.2896	3.30	0.6304	0.5098	11.89	0.5921
2.00	0.33	63.88	65.45	32.23	50.3	58.42	28.01	4.229	0.08954	1754	0.514	414.7	0.2997	3.39	0.6304	0.5149	11.89	0.5981
2.00	0.34	63.88	65.45	33.71	51.57	59.9	29.38	4.336	0.08954	1798	0.527	414.7	0.3098	3.47	0.6304	0.5201	11.89	0.6041
2.00	0.35	63.88	65.45	35.24	52.89	61.42	30.79	4.446	0.08954	1844	0.5404	414.7	0.32	3.56	0.6304	0.5253	11.89	0.6101
2.00	0.36	63.88	65.45	36.81	54.24	63	32.25	4.56	0.08954	1891	0.5543	414.7	0.3301	3.65	0.6304	0.5304	11.89	0.6161
2.00	0.37	63.88	65.45	38.44	55.64	64.62	33.76	4.677	0.08954	1940	0.5685	414.7	0.3403	3.75	0.6304	0.5356	11.89	0.6221
2.00	0.38	63.88	65.45	40.11	57.08	66.3	35.31	4.799	0.08954	1990	0.5833	414.7	0.3505	3.84	0.6304	0.5407	11.89	0.6281
2.00	0.39	63.88	65.45	41.84	58.57	68.03	36.92	4.924	0.08954	2042	0.5985	414.7	0.3607	3.94	0.6304	0.5459	11.89	0.634
2.00	0.40	63.88	65.45	43.63	60.11	69.81	38.58	5.053	0.08954	2096	0.6142	414.7	0.3709	4.05	0.6304	0.5511	11.89	0.64

$T_{operation}$ 180 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
3.00	0.20	63.88	98.17	24.54	54.95	63.83	19.92	4.62	0.08954	1916	0.5615	414.7	0.1687	3.70	0.6304	0.4478	11.89	0.5201
3.00	0.21	63.88	98.17	26.1	56.29	65.38	21.36	4.732	0.08954	1963	0.5752	414.7	0.1787	3.79	0.6304	0.453	11.89	0.5261
3.00	0.22	63.88	98.17	27.69	57.66	66.97	22.84	4.848	0.08954	2010	0.5892	414.7	0.1888	3.88	0.6304	0.4581	11.89	0.5321
3.00	0.23	63.88	98.17	29.32	59.07	68.61	24.36	4.966	0.08954	2060	0.6036	414.7	0.1988	3.98	0.6304	0.4633	11.89	0.5381
3.00	0.24	63.88	98.17	31	60.51	70.28	25.91	5.087	0.08954	2110	0.6184	414.7	0.2088	4.07	0.6304	0.4685	11.89	0.5441
3.00	0.25	63.88	98.17	32.72	61.99	72	27.51	5.212	0.08954	2162	0.6335	414.7	0.2189	4.17	0.6304	0.4736	11.89	0.5501
3.00	0.26	63.88	98.17	34.49	63.52	73.77	29.15	5.34	0.08954	2215	0.6491	414.7	0.229	4.28	0.6304	0.4788	11.89	0.5561
3.00	0.27	63.88	98.17	36.31	65.08	75.59	30.84	5.472	0.08954	2269	0.665	414.7	0.239	4.38	0.6304	0.484	11.89	0.5621
3.00	0.28	63.88	98.17	38.18	66.69	77.46	32.57	5.607	0.08954	2325	0.6815	414.7	0.2491	4.49	0.6304	0.4891	11.89	0.5681
3.00	0.29	63.88	98.17	40.1	68.34	79.38	34.35	5.746	0.08954	2383	0.6984	414.7	0.2592	4.60	0.6304	0.4943	11.89	0.5741
3.00	0.30	63.88	98.17	42.07	70.04	81.35	36.18	5.889	0.08954	2442	0.7157	414.7	0.2693	4.72	0.6304	0.4994	11.89	0.5801
3.00	0.31	63.88	98.17	44.1	71.79	83.38	38.07	6.036	0.08954	2503	0.7336	414.7	0.2794	4.83	0.6304	0.5046	11.89	0.5861
3.00	0.32	63.88	98.17	46.2	73.59	85.48	40.01	6.187	0.08954	2566	0.752	414.7	0.2896	4.95	0.6304	0.5098	11.89	0.5921
3.00	0.33	63.88	98.17	48.35	75.45	87.63	42.01	6.343	0.08954	2631	0.771	414.7	0.2997	5.08	0.6304	0.5149	11.89	0.5981
3.00	0.34	63.88	98.17	50.57	77.36	89.85	44.07	6.504	0.08954	2697	0.7905	414.7	0.3098	5.21	0.6304	0.5201	11.89	0.6041
3.00	0.35	63.88	98.17	52.86	79.33	92.14	46.19	6.669	0.08954	2766	0.8106	414.7	0.32	5.34	0.6304	0.5253	11.89	0.6101
3.00	0.36	63.88	98.17	55.22	81.36	94.5	48.38	6.84	0.08954	2837	0.8314	414.7	0.3301	5.48	0.6304	0.5304	11.89	0.6161
3.00	0.37	63.88	98.17	57.65	83.46	96.93	50.64	7.016	0.08954	2910	0.8528	414.7	0.3403	5.62	0.6304	0.5356	11.89	0.6221
3.00	0.38	63.88	98.17	60.17	85.62	99.44	52.97	7.198	0.08954	2985	0.8749	414.7	0.3505	5.76	0.6304	0.5407	11.89	0.6281
3.00	0.39	63.88	98.17	62.76	87.85	102	55.38	7.386	0.08954	3063	0.8977	414.7	0.3607	5.91	0.6304	0.5459	11.89	0.634
3.00	0.40	63.88	98.17	65.45	90.16	104.7	57.86	7.58	0.08954	3144	0.9213	414.7	0.3709	6.07	0.6304	0.5511	11.89	0.64

$T_{operation}$ 180 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
4.00	0.20	63.88	130.9	32.72	73.27	85.1	26.56	6.16	0.08954	2555	0.7487	414.7	0.1687	4.93	0.6304	0.4478	11.89	0.5201
4.00	0.21	63.88	130.9	34.79	75.05	87.17	28.48	6.31	0.08954	2617	0.7669	414.7	0.1787	5.05	0.6304	0.453	11.89	0.5261
4.00	0.22	63.88	130.9	36.92	76.88	89.3	30.45	6.464	0.08954	2681	0.7856	414.7	0.1888	5.18	0.6304	0.4581	11.89	0.5321
4.00	0.23	63.88	130.9	39.1	78.76	91.47	32.48	6.621	0.08954	2746	0.8048	414.7	0.1988	5.30	0.6304	0.4633	11.89	0.5381
4.00	0.24	63.88	130.9	41.33	80.68	93.71	34.55	6.783	0.08954	2813	0.8245	414.7	0.2088	5.43	0.6304	0.4685	11.89	0.5441
4.00	0.25	63.88	130.9	43.63	82.66	96.01	36.68	6.949	0.08954	2882	0.8447	414.7	0.2189	5.56	0.6304	0.4736	11.89	0.5501
4.00	0.26	63.88	130.9	45.99	84.69	98.36	38.87	7.12	0.08954	2953	0.8654	414.7	0.229	5.70	0.6304	0.4788	11.89	0.5561
4.00	0.27	63.88	130.9	48.41	86.77	100.8	41.12	7.295	0.08954	3026	0.8867	414.7	0.239	5.84	0.6304	0.484	11.89	0.5621
4.00	0.28	63.88	130.9	50.9	88.92	103.3	43.43	7.476	0.08954	3100	0.9086	414.7	0.2491	5.99	0.6304	0.4891	11.89	0.5681
4.00	0.29	63.88	130.9	53.46	91.12	105.8	45.8	7.661	0.08954	3177	0.9311	414.7	0.2592	6.13	0.6304	0.4943	11.89	0.5741
4.00	0.30	63.88	130.9	56.1	93.39	108.5	48.24	7.851	0.08954	3256	0.9543	414.7	0.2693	6.29	0.6304	0.4994	11.89	0.5801
4.00	0.31	63.88	130.9	58.81	95.72	111.2	50.76	8.048	0.08954	3338	0.9782	414.7	0.2794	6.44	0.6304	0.5046	11.89	0.5861
4.00	0.32	63.88	130.9	61.6	98.12	114	53.35	8.249	0.08954	3421	1.003	414.7	0.2896	6.61	0.6304	0.5098	11.89	0.5921
4.00	0.33	63.88	130.9	64.47	100.6	116.8	56.01	8.457	0.08954	3508	1.028	414.7	0.2997	6.77	0.6304	0.5149	11.89	0.5981
4.00	0.34	63.88	130.9	67.43	103.1	119.8	58.76	8.672	0.08954	3596	1.054	414.7	0.3098	6.94	0.6304	0.5201	11.89	0.6041
4.00	0.35	63.88	130.9	70.48	105.8	122.8	61.59	8.892	0.08954	3688	1.081	414.7	0.32	7.12	0.6304	0.5253	11.89	0.6101
4.00	0.36	63.88	130.9	73.63	108.5	126	64.51	9.12	0.08954	3782	1.109	414.7	0.3301	7.30	0.6304	0.5304	11.89	0.6161
4.00	0.37	63.88	130.9	76.87	111.3	129.2	67.52	9.355	0.08954	3880	1.137	414.7	0.3403	7.49	0.6304	0.5356	11.89	0.6221
4.00	0.38	63.88	130.9	80.22	114.2	132.6	70.63	9.597	0.08954	3980	1.167	414.7	0.3505	7.68	0.6304	0.5407	11.89	0.6281
4.00	0.39	63.88	130.9	83.68	117.1	136.1	73.84	9.848	0.08954	4084	1.197	414.7	0.3607	7.89	0.6304	0.5459	11.89	0.634
4.00	0.40	63.88	130.9	87.26	120.2	139.6	77.15	10.11	0.08954	4192	1.228	414.7	0.3709	8.09	0.6304	0.5511	11.89	0.64

$T_{operation}$ 180 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
5.00	0.20	63.88	163.6	40.9	91.59	106.4	33.2	7.7	0.08954	3193	0.9359	414.7	0.1687	6.17	0.6304	0.4478	11.89	0.5201
5.00	0.21	63.88	163.6	43.49	93.82	109	35.6	7.887	0.08954	3271	0.9587	414.7	0.1787	6.32	0.6304	0.453	11.89	0.5261
5.00	0.22	63.88	163.6	46.15	96.1	111.6	38.07	8.079	0.08954	3351	0.982	414.7	0.1888	6.47	0.6304	0.4581	11.89	0.5321
5.00	0.23	63.88	163.6	48.87	98.45	114.3	40.59	8.277	0.08954	3433	1.006	414.7	0.1988	6.63	0.6304	0.4633	11.89	0.5381
5.00	0.24	63.88	163.6	51.67	100.9	117.1	43.19	8.479	0.08954	3516	1.031	414.7	0.2088	6.79	0.6304	0.4685	11.89	0.5441
5.00	0.25	63.88	163.6	54.54	103.3	120	45.85	8.687	0.08954	3603	1.056	414.7	0.2189	6.96	0.6304	0.4736	11.89	0.5501
5.00	0.26	63.88	163.6	57.49	105.9	123	48.59	8.9	0.08954	3691	1.082	414.7	0.229	7.13	0.6304	0.4788	11.89	0.5561
5.00	0.27	63.88	163.6	60.51	108.5	126	51.4	9.119	0.08954	3782	1.108	414.7	0.239	7.30	0.6304	0.484	11.89	0.5621
5.00	0.28	63.88	163.6	63.63	111.1	129.1	54.28	9.344	0.08954	3875	1.136	414.7	0.2491	7.48	0.6304	0.4891	11.89	0.5681
5.00	0.29	63.88	163.6	66.83	113.9	132.3	57.25	9.576	0.08954	3972	1.164	414.7	0.2592	7.67	0.6304	0.4943	11.89	0.5741
5.00	0.30	63.88	163.6	70.12	116.7	135.6	60.31	9.814	0.08954	4070	1.193	414.7	0.2693	7.86	0.6304	0.4994	11.89	0.5801
5.00	0.31	63.88	163.6	73.51	119.7	139	63.45	10.06	0.08954	4172	1.223	414.7	0.2794	8.05	0.6304	0.5046	11.89	0.5861
5.00	0.32	63.88	163.6	76.99	122.7	142.5	66.68	10.31	0.08954	4277	1.253	414.7	0.2896	8.26	0.6304	0.5098	11.89	0.5921
5.00	0.33	63.88	163.6	80.59	125.7	146	70.01	10.57	0.08954	4384	1.285	414.7	0.2997	8.46	0.6304	0.5149	11.89	0.5981
5.00	0.34	63.88	163.6	84.29	128.9	149.7	73.45	10.84	0.08954	4495	1.317	414.7	0.3098	8.68	0.6304	0.5201	11.89	0.6041
5.00	0.35	63.88	163.6	88.1	132.2	153.6	76.98	11.12	0.08954	4610	1.351	414.7	0.32	8.90	0.6304	0.5253	11.89	0.6101
5.00	0.36	63.88	163.6	92.03	135.6	157.5	80.63	11.4	0.08954	4728	1.386	414.7	0.3301	9.13	0.6304	0.5304	11.89	0.6161
5.00	0.37	63.88	163.6	96.09	139.1	161.6	84.4	11.69	0.08954	4850	1.421	414.7	0.3403	9.36	0.6304	0.5356	11.89	0.6221
5.00	0.38	63.88	163.6	100.3	142.7	165.7	88.28	12	0.08954	4975	1.458	414.7	0.3505	9.61	0.6304	0.5407	11.89	0.6281
5.00	0.39	63.88	163.6	104.6	146.4	170.1	92.29	12.31	0.08954	5105	1.496	414.7	0.3607	9.86	0.6304	0.5459	11.89	0.634
5.00	0.40	63.88	163.6	109.1	150.3	174.5	96.44	12.63	0.08954	5240	1.536	414.7	0.3709	10.11	0.6304	0.5511	11.89	0.64

$T_{operation}$ 200 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
1.00	0.20	64.46	32.72	8.181	18.24	21.27	6.344	1.837	0.1062	639.8	0.1875	348.3	0.1624	1.53	0.6896	0.4459	9.928	0.5199
1.00	0.21	64.46	32.72	8.698	18.68	21.78	6.817	1.882	0.1062	655.4	0.1921	348.3	0.1724	1.57	0.6896	0.451	9.928	0.5259
1.00	0.22	64.46	32.72	9.229	19.14	22.31	7.302	1.927	0.1062	671.4	0.1968	348.3	0.1824	1.61	0.6896	0.4561	9.928	0.5319
1.00	0.23	64.46	32.72	9.774	19.6	22.86	7.8	1.974	0.1062	687.8	0.2016	348.3	0.1925	1.65	0.6896	0.4613	9.928	0.5379
1.00	0.24	64.46	32.72	10.33	20.08	23.42	8.311	2.023	0.1062	704.6	0.2065	348.3	0.2025	1.69	0.6896	0.4664	9.928	0.5439
1.00	0.25	64.46	32.72	10.91	20.57	23.99	8.835	2.072	0.1062	721.9	0.2116	348.3	0.2126	1.73	0.6896	0.4716	9.928	0.5499
1.00	0.26	64.46	32.72	11.5	21.08	24.58	9.374	2.123	0.1062	739.6	0.2168	348.3	0.2227	1.77	0.6896	0.4767	9.928	0.5559
1.00	0.27	64.46	32.72	12.1	21.6	25.19	9.927	2.176	0.1062	757.8	0.2221	348.3	0.2328	1.81	0.6896	0.4819	9.928	0.5619
1.00	0.28	64.46	32.72	12.73	22.13	25.81	10.5	2.229	0.1062	776.5	0.2276	348.3	0.2429	1.86	0.6896	0.487	9.928	0.5679
1.00	0.29	64.46	32.72	13.37	22.68	26.45	11.08	2.285	0.1062	795.8	0.2332	348.3	0.253	1.90	0.6896	0.4922	9.929	0.5739
1.00	0.30	64.46	32.72	14.02	23.25	27.11	11.68	2.341	0.1062	815.6	0.239	348.3	0.2631	1.95	0.6896	0.4973	9.929	0.5799
1.00	0.31	64.46	32.72	14.7	23.83	27.78	12.3	2.4	0.1062	836	0.245	348.3	0.2732	2.00	0.6896	0.5024	9.929	0.5859
1.00	0.32	64.46	32.72	15.4	24.43	28.48	12.94	2.46	0.1062	856.9	0.2511	348.3	0.2834	2.05	0.6896	0.5076	9.929	0.5919
1.00	0.33	64.46	32.72	16.12	25.04	29.2	13.59	2.522	0.1062	878.5	0.2575	348.3	0.2935	2.10	0.6896	0.5127	9.929	0.5978
1.00	0.34	64.46	32.72	16.86	25.68	29.94	14.27	2.586	0.1062	900.8	0.264	348.3	0.3037	2.16	0.6896	0.5179	9.929	0.6038
1.00	0.35	64.46	32.72	17.62	26.33	30.7	14.97	2.652	0.1062	923.7	0.2707	348.3	0.3139	2.21	0.6896	0.523	9.929	0.6098
1.00	0.36	64.46	32.72	18.41	27	31.49	15.69	2.72	0.1062	947.4	0.2777	348.3	0.324	2.27	0.6896	0.5282	9.929	0.6158
1.00	0.37	64.46	32.72	19.22	27.7	32.3	16.43	2.79	0.1062	971.8	0.2848	348.3	0.3342	2.33	0.6896	0.5333	9.929	0.6218
1.00	0.38	64.46	32.72	20.06	28.42	33.14	17.19	2.862	0.1062	997	0.2922	348.3	0.3444	2.39	0.6896	0.5385	9.929	0.6278
1.00	0.39	64.46	32.72	20.92	29.16	34	17.98	2.937	0.1062	1023	0.2998	348.3	0.3547	2.45	0.6896	0.5436	9.929	0.6338
1.00	0.40	64.46	32.72	21.82	29.93	34.89	18.8	3.014	0.1062	1050	0.3077	348.3	0.3649	2.51	0.6896	0.5487	9.929	0.6398

$T_{operation}$ 200 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
2.00	0.20	64.46	65.45	16.36	36.47	42.53	12.69	3.674	0.1062	1280	0.375	348.3	0.1624	3.06	0.6896	0.4459	9.928	0.5199
2.00	0.21	64.46	65.45	17.4	37.36	43.57	13.63	3.763	0.1062	1311	0.3842	348.3	0.1724	3.14	0.6896	0.451	9.928	0.5259
2.00	0.22	64.46	65.45	18.46	38.27	44.63	14.6	3.855	0.1062	1343	0.3935	348.3	0.1824	3.21	0.6896	0.4561	9.928	0.5319
2.00	0.23	64.46	65.45	19.55	39.21	45.72	15.6	3.949	0.1062	1376	0.4031	348.3	0.1925	3.29	0.6896	0.4613	9.928	0.5379
2.00	0.24	64.46	65.45	20.67	40.17	46.83	16.62	4.046	0.1062	1409	0.413	348.3	0.2025	3.37	0.6896	0.4664	9.928	0.5439
2.00	0.25	64.46	65.45	21.82	41.15	47.98	17.67	4.145	0.1062	1444	0.4231	348.3	0.2126	3.46	0.6896	0.4716	9.928	0.5499
2.00	0.26	64.46	65.45	22.99	42.16	49.16	18.75	4.247	0.1062	1479	0.4335	348.3	0.2227	3.54	0.6896	0.4767	9.928	0.5559
2.00	0.27	64.46	65.45	24.21	43.2	50.37	19.85	4.351	0.1062	1516	0.4442	348.3	0.2328	3.63	0.6896	0.4819	9.928	0.5619
2.00	0.28	64.46	65.45	25.45	44.27	51.62	20.99	4.459	0.1062	1553	0.4552	348.3	0.2429	3.72	0.6896	0.487	9.928	0.5679
2.00	0.29	64.46	65.45	26.73	45.36	52.9	22.16	4.569	0.1062	1592	0.4664	348.3	0.253	3.81	0.6896	0.4922	9.929	0.5739
2.00	0.30	64.46	65.45	28.05	46.49	54.21	23.37	4.683	0.1062	1631	0.4781	348.3	0.2631	3.90	0.6896	0.4973	9.929	0.5799
2.00	0.31	64.46	65.45	29.4	47.66	55.57	24.6	4.8	0.1062	1672	0.49	348.3	0.2732	4.00	0.6896	0.5024	9.929	0.5859
2.00	0.32	64.46	65.45	30.8	48.85	56.96	25.88	4.92	0.1062	1714	0.5023	348.3	0.2834	4.10	0.6896	0.5076	9.929	0.5919
2.00	0.33	64.46	65.45	32.23	50.08	58.4	27.19	5.044	0.1062	1757	0.515	348.3	0.2935	4.21	0.6896	0.5127	9.929	0.5978
2.00	0.34	64.46	65.45	33.71	51.35	59.88	28.54	5.172	0.1062	1802	0.528	348.3	0.3037	4.31	0.6896	0.5179	9.929	0.6038
2.00	0.35	64.46	65.45	35.24	52.66	61.4	29.94	5.304	0.1062	1847	0.5414	348.3	0.3139	4.42	0.6896	0.523	9.929	0.6098
2.00	0.36	64.46	65.45	36.81	54.01	62.97	31.37	5.44	0.1062	1895	0.5553	348.3	0.324	4.53	0.6896	0.5282	9.929	0.6158
2.00	0.37	64.46	65.45	38.44	55.4	64.6	32.86	5.58	0.1062	1944	0.5696	348.3	0.3342	4.65	0.6896	0.5333	9.929	0.6218
2.00	0.38	64.46	65.45	40.11	56.84	66.27	34.39	5.724	0.1062	1994	0.5844	348.3	0.3444	4.77	0.6896	0.5385	9.929	0.6278
2.00	0.39	64.46	65.45	41.84	58.32	68	35.97	5.874	0.1062	2046	0.5996	348.3	0.3547	4.90	0.6896	0.5436	9.929	0.6338
2.00	0.40	64.46	65.45	43.63	59.85	69.79	37.6	6.028	0.1062	2100	0.6154	348.3	0.3649	5.03	0.6896	0.5487	9.929	0.6398

$T_{operation}$ 200 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
3.00	0.20	64.46	98.17	24.54	54.71	63.8	19.03	5.511	0.1062	1920	0.5626	348.3	0.1624	4.59	0.6896	0.4459	9.928	0.5199
3.00	0.21	64.46	98.17	26.1	56.04	65.35	20.45	5.645	0.1062	1966	0.5763	348.3	0.1724	4.71	0.6896	0.451	9.928	0.5259
3.00	0.22	64.46	98.17	27.69	57.41	66.94	21.91	5.782	0.1062	2014	0.5903	348.3	0.1824	4.82	0.6896	0.4561	9.928	0.5319
3.00	0.23	64.46	98.17	29.32	58.81	68.58	23.4	5.923	0.1062	2063	0.6047	348.3	0.1925	4.94	0.6896	0.4613	9.928	0.5379
3.00	0.24	64.46	98.17	31	60.25	70.25	24.93	6.068	0.1062	2114	0.6195	348.3	0.2025	5.06	0.6896	0.4664	9.928	0.5439
3.00	0.25	64.46	98.17	32.72	61.72	71.97	26.51	6.217	0.1062	2166	0.6347	348.3	0.2126	5.18	0.6896	0.4716	9.928	0.5499
3.00	0.26	64.46	98.17	34.49	63.24	73.74	28.12	6.37	0.1062	2219	0.6503	348.3	0.2227	5.31	0.6896	0.4767	9.928	0.5559
3.00	0.27	64.46	98.17	36.31	64.8	75.56	29.78	6.527	0.1062	2273	0.6663	348.3	0.2328	5.44	0.6896	0.4819	9.928	0.5619
3.00	0.28	64.46	98.17	38.18	66.4	77.42	31.49	6.688	0.1062	2330	0.6827	348.3	0.2429	5.58	0.6896	0.487	9.928	0.5679
3.00	0.29	64.46	98.17	40.1	68.05	79.34	33.24	6.854	0.1062	2387	0.6997	348.3	0.253	5.71	0.6896	0.4922	9.929	0.5739
3.00	0.30	64.46	98.17	42.07	69.74	81.32	35.05	7.024	0.1062	2447	0.7171	348.3	0.2631	5.86	0.6896	0.4973	9.929	0.5799
3.00	0.31	64.46	98.17	44.1	71.48	83.35	36.9	7.2	0.1062	2508	0.735	348.3	0.2732	6.00	0.6896	0.5024	9.929	0.5859
3.00	0.32	64.46	98.17	46.2	73.28	85.44	38.82	7.38	0.1062	2571	0.7534	348.3	0.2834	6.15	0.6896	0.5076	9.929	0.5919
3.00	0.33	64.46	98.17	48.35	75.12	87.6	40.78	7.566	0.1062	2636	0.7724	348.3	0.2935	6.31	0.6896	0.5127	9.929	0.5978
3.00	0.34	64.46	98.17	50.57	77.03	89.81	42.81	7.758	0.1062	2702	0.792	348.3	0.3037	6.47	0.6896	0.5179	9.929	0.6038
3.00	0.35	64.46	98.17	52.86	78.99	92.1	44.9	7.956	0.1062	2771	0.8122	348.3	0.3139	6.63	0.6896	0.523	9.929	0.6098
3.00	0.36	64.46	98.17	55.22	81.01	94.46	47.06	8.159	0.1062	2842	0.833	348.3	0.324	6.80	0.6896	0.5282	9.929	0.6158
3.00	0.37	64.46	98.17	57.65	83.1	96.89	49.28	8.37	0.1062	2915	0.8544	348.3	0.3342	6.98	0.6896	0.5333	9.929	0.6218
3.00	0.38	64.46	98.17	60.17	85.26	99.41	51.58	8.587	0.1062	2991	0.8766	348.3	0.3444	7.16	0.6896	0.5385	9.929	0.6278
3.00	0.39	64.46	98.17	62.76	87.48	102	53.95	8.811	0.1062	3069	0.8995	348.3	0.3547	7.35	0.6896	0.5436	9.929	0.6338
3.00	0.40	64.46	98.17	65.45	89.78	104.7	56.4	9.042	0.1062	3150	0.9231	348.3	0.3649	7.54	0.6896	0.5487	9.929	0.6398

$T_{operation}$ 200 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
4.00	0.20	64.46	130.9	32.72	72.95	85.06	25.37	7.348	0.1062	2559	0.7501	348.3	0.1624	6.13	0.6896	0.4459	9.928	0.5199
4.00	0.21	64.46	130.9	34.79	74.72	87.13	27.27	7.526	0.1062	2622	0.7683	348.3	0.1724	6.27	0.6896	0.451	9.928	0.5259
4.00	0.22	64.46	130.9	36.92	76.54	89.25	29.21	7.71	0.1062	2686	0.7871	348.3	0.1824	6.43	0.6896	0.4561	9.928	0.5319
4.00	0.23	64.46	130.9	39.1	78.41	91.43	31.2	7.898	0.1062	2751	0.8063	348.3	0.1925	6.58	0.6896	0.4613	9.928	0.5379
4.00	0.24	64.46	130.9	41.33	80.33	93.67	33.24	8.091	0.1062	2818	0.826	348.3	0.2025	6.75	0.6896	0.4664	9.928	0.5439
4.00	0.25	64.46	130.9	43.63	82.3	95.96	35.34	8.289	0.1062	2887	0.8462	348.3	0.2126	6.91	0.6896	0.4716	9.928	0.5499
4.00	0.26	64.46	130.9	45.99	84.32	98.32	37.5	8.493	0.1062	2958	0.867	348.3	0.2227	7.08	0.6896	0.4767	9.928	0.5559
4.00	0.27	64.46	130.9	48.41	86.4	100.7	39.71	8.702	0.1062	3031	0.8884	348.3	0.2328	7.25	0.6896	0.4819	9.928	0.5619
4.00	0.28	64.46	130.9	50.9	88.53	103.2	41.98	8.917	0.1062	3106	0.9103	348.3	0.2429	7.43	0.6896	0.487	9.928	0.5679
4.00	0.29	64.46	130.9	53.46	90.73	105.8	44.32	9.138	0.1062	3183	0.9329	348.3	0.253	7.62	0.6896	0.4922	9.929	0.5739
4.00	0.30	64.46	130.9	56.1	92.99	108.4	46.73	9.366	0.1062	3262	0.9561	348.3	0.2631	7.81	0.6896	0.4973	9.929	0.5799
4.00	0.31	64.46	130.9	58.81	95.31	111.1	49.21	9.6	0.1062	3344	0.98	348.3	0.2732	8.00	0.6896	0.5024	9.929	0.5859
4.00	0.32	64.46	130.9	61.6	97.7	113.9	51.75	9.841	0.1062	3428	1.005	348.3	0.2834	8.20	0.6896	0.5076	9.929	0.5919
4.00	0.33	64.46	130.9	64.47	100.2	116.8	54.38	10.09	0.1062	3514	1.03	348.3	0.2935	8.41	0.6896	0.5127	9.929	0.5978
4.00	0.34	64.46	130.9	67.43	102.7	119.8	57.08	10.34	0.1062	3603	1.056	348.3	0.3037	8.62	0.6896	0.5179	9.929	0.6038
4.00	0.35	64.46	130.9	70.48	105.3	122.8	59.87	10.61	0.1062	3695	1.083	348.3	0.3139	8.84	0.6896	0.523	9.929	0.6098
4.00	0.36	64.46	130.9	73.63	108	125.9	62.75	10.88	0.1062	3790	1.111	348.3	0.324	9.07	0.6896	0.5282	9.929	0.6158
4.00	0.37	64.46	130.9	76.87	110.8	129.2	65.71	11.16	0.1062	3887	1.139	348.3	0.3342	9.30	0.6896	0.5333	9.929	0.6218
4.00	0.38	64.46	130.9	80.22	113.7	132.5	68.77	11.45	0.1062	3988	1.169	348.3	0.3444	9.54	0.6896	0.5385	9.929	0.6278
4.00	0.39	64.46	130.9	83.68	116.6	136	71.94	11.75	0.1062	4092	1.199	348.3	0.3547	9.79	0.6896	0.5436	9.929	0.6338
4.00	0.40	64.46	130.9	87.26	119.7	139.6	75.2	12.06	0.1062	4200	1.231	348.3	0.3649	10.05	0.6896	0.5487	9.929	0.6398

$T_{operation}$ 200 °F

bph	Z_{in}	$\eta_{Exergetic}$	$\dot{m}_g$	$\dot{m}_{win}$	$\dot{m}_{air}$	$\dot{m}_{loop}$	$\dot{m}_{wout}$	$\dot{m}_{wdried}$	w_5	$\dot{Q}_{heater}$	$\dot{Q}_{heater}$	q_{heater}	Z_{out}	$\dot{m}_{wcond}$	$\eta_{External}$	R_{AD}	R_{AM}	R_{LD}
5.00	0.20	64.46	163.6	40.9	91.18	106.3	31.72	9.184	0.1062	3199	0.9376	348.3	0.1624	7.66	0.6896	0.4459	9.928	0.5199
5.00	0.21	64.46	163.6	43.49	93.4	108.9	34.08	9.408	0.1062	3277	0.9604	348.3	0.1724	7.84	0.6896	0.451	9.928	0.5259
5.00	0.22	64.46	163.6	46.15	95.68	111.6	36.51	9.637	0.1062	3357	0.9838	348.3	0.1824	8.03	0.6896	0.4561	9.928	0.5319
5.00	0.23	64.46	163.6	48.87	98.02	114.3	39	9.872	0.1062	3439	1.008	348.3	0.1925	8.23	0.6896	0.4613	9.928	0.5379
5.00	0.24	64.46	163.6	51.67	100.4	117.1	41.55	10.11	0.1062	3523	1.032	348.3	0.2025	8.43	0.6896	0.4664	9.928	0.5439
5.00	0.25	64.46	163.6	54.54	102.9	120	44.18	10.36	0.1062	3609	1.058	348.3	0.2126	8.64	0.6896	0.4716	9.928	0.5499
5.00	0.26	64.46	163.6	57.49	105.4	122.9	46.87	10.62	0.1062	3698	1.084	348.3	0.2227	8.85	0.6896	0.4767	9.928	0.5559
5.00	0.27	64.46	163.6	60.51	108	125.9	49.64	10.88	0.1062	3789	1.11	348.3	0.2328	9.07	0.6896	0.4819	9.928	0.5619
5.00	0.28	64.46	163.6	63.63	110.7	129	52.48	11.15	0.1062	3883	1.138	348.3	0.2429	9.29	0.6896	0.487	9.928	0.5679
5.00	0.29	64.46	163.6	66.83	113.4	132.2	55.4	11.42	0.1062	3979	1.166	348.3	0.253	9.52	0.6896	0.4922	9.929	0.5739
5.00	0.30	64.46	163.6	70.12	116.2	135.5	58.41	11.71	0.1062	4078	1.195	348.3	0.2631	9.76	0.6896	0.4973	9.929	0.5799
5.00	0.31	64.46	163.6	73.51	119.1	138.9	61.51	12	0.1062	4180	1.225	348.3	0.2732	10.00	0.6896	0.5024	9.929	0.5859
5.00	0.32	64.46	163.6	76.99	122.1	142.4	64.69	12.3	0.1062	4285	1.256	348.3	0.2834	10.25	0.6896	0.5076	9.929	0.5919
5.00	0.33	64.46	163.6	80.59	125.2	146	67.97	12.61	0.1062	4393	1.287	348.3	0.2935	10.51	0.6896	0.5127	9.929	0.5978
5.00	0.34	64.46	163.6	84.29	128.4	149.7	71.36	12.93	0.1062	4504	1.32	348.3	0.3037	10.78	0.6896	0.5179	9.929	0.6038
5.00	0.35	64.46	163.6	88.1	131.7	153.5	74.84	13.26	0.1062	4619	1.354	348.3	0.3139	11.05	0.6896	0.523	9.929	0.6098
5.00	0.36	64.46	163.6	92.03	135	157.4	78.43	13.6	0.1062	4737	1.388	348.3	0.324	11.34	0.6896	0.5282	9.929	0.6158
5.00	0.37	64.46	163.6	96.09	138.5	161.5	82.14	13.95	0.1062	4859	1.424	348.3	0.3342	11.63	0.6896	0.5333	9.929	0.6218
5.00	0.38	64.46	163.6	100.3	142.1	165.7	85.97	14.31	0.1062	4985	1.461	348.3	0.3444	11.93	0.6896	0.5385	9.929	0.6278
5.00	0.39	64.46	163.6	104.6	145.8	170	89.92	14.68	0.1062	5115	1.499	348.3	0.3547	12.24	0.6896	0.5436	9.929	0.6338
5.00	0.40	64.46	163.6	109.1	149.6	174.5	94	15.07	0.1062	5250	1.539	348.3	0.3649	12.56	0.6896	0.5487	9.929	0.6398

APPENDIX D: RAW EXPERIMENTAL DATA

ROTARY DRUM PILOT DRYER

Temperature Differentials of Various Heat Exchange Elements

TEST # 9

DATE 11/28/2007

11/02/07 mjs

TEMP POINT	DATUM POINT	LOCATION	NEAR STEADY STATE DATA	NEAR STEADY STATE DATA
			3:45 test	7:50 test
		Grain Input End of Rotating Drum		
7	a1	Cold Water Out of Rotating Drum	73.8	69.42
1	1	Grain Input	59.41	59.46
		Difference	14.39	9.96
		Grain Exit End of Rotating Drum		
10	c	Water Out of Fluid Heater & Into Rotating Drum	198.3	198.9
2	2	Grain Out of Rotating Drum (in hopper)	178.4	171.8
		Difference	19.9	27.1
		Cooling/Drying Chamber		
14	2a	Grain Out of Rotating Drum (top of flex auger)	174.4	168.5
5	5	Air Into Heat Exchanger	152.8	151.7
		Difference	21.6	16.8
3	3	Exit Grain Temperature	81.5	83.5
12	4a	Ambient Air Temperature	73.6	70.8
		Difference	7.9	12.7
		Heat Exchanger		
5	5	Air Into Heat Exchanger	152.8	151.7
9	b	Water Out of Heat Exchanger	148.5	148.5
		Difference	4.3	3.2
6	6	Air Out of Heat Exchanger	98.8	83.3
8	a2	Water Into Heat Exchanger	73.6	69.61
		Difference	25.2	13.69
		Overall Effectiveness		
10	c	Water Out of Fluid Heater & Into Rotating Drum	198.3	198.9
9	b	Water Out of Heat Exchanger	148.5	148.5
		Difference A	49.8	50.4
10	c	Water Out of Fluid Heater & Into Rotating Drum	198.3	198.9
8	a2	Water Into Heat Exchanger	73.6	69.61
		Difference B	124.7	129.29
		(A/B) **% Difference A is of Difference B**	39.94%	38.98%
		(°F added by Fluid Heater) / (°F added by Heat Exchanger & Fluid Heater)		