IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Mechanical Engineering Department
2025 Black Engineering Building
Ames, Iowa 50011-2161
515/294-1423
FAX 515/294-3261
http://www.me.iastate.edu/

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To: Steve Shivvers
From: Dr. Michael Pate, Iowa State University

Dear Steve,

The Executive Summary for the drying project is presented below. Please let me know if you have any additional questions.

Sincerely,
Mike Pate

<u>Executive Summary</u>

An Analysis of a DDGS Drying System Utilizing the Shivvers Heat Recovery Process

Michael Pate
Chris Hoeck

Several applications depend on the ability of a drying process to remove moisture from a product 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 Shivvers Heat Recovery Process utilizes an Air Drying System combined with an integrated 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 (A), the Intermediate Water Loop (B), the Air Drying Unit (C), and the Heat Recovery Unit (D). The Heat Recovery Unit reclaims latent heat of evaporation by condensing moisture out of the air stream, utilizing a common air to liquid heat exchanger. Supplemental heat must be added using an External Heater. The process is fully explained in the full text of this report.

Energy and mass balances around the major components listed above form the theoretical basis for a mathematical engineering model of the DDGS Drying System. The DDGS Flow Rate, the DDGS Entering Moisture Content and the 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.

The engineering model described above outputs several system performance characteristics. One important Figure of Merit is the amount of external heater energy required per pound of moisture removed. The analysis of the model showed that this Figure of Merit remains independent of DDGS Flow Rate and DDGS Entering Moisture Content as it only depends on the system's Operation Temperature.

Figure 2 below illustrates the interaction between the Figure of Merit and the Operation Temperature. This figure shows how different approach differences (ΔT) affect theoretical data generated by the model. It also presents a plot of the Figure of Merit based on approach temperature differences determined by experimental data collected by Shivvers Inc.

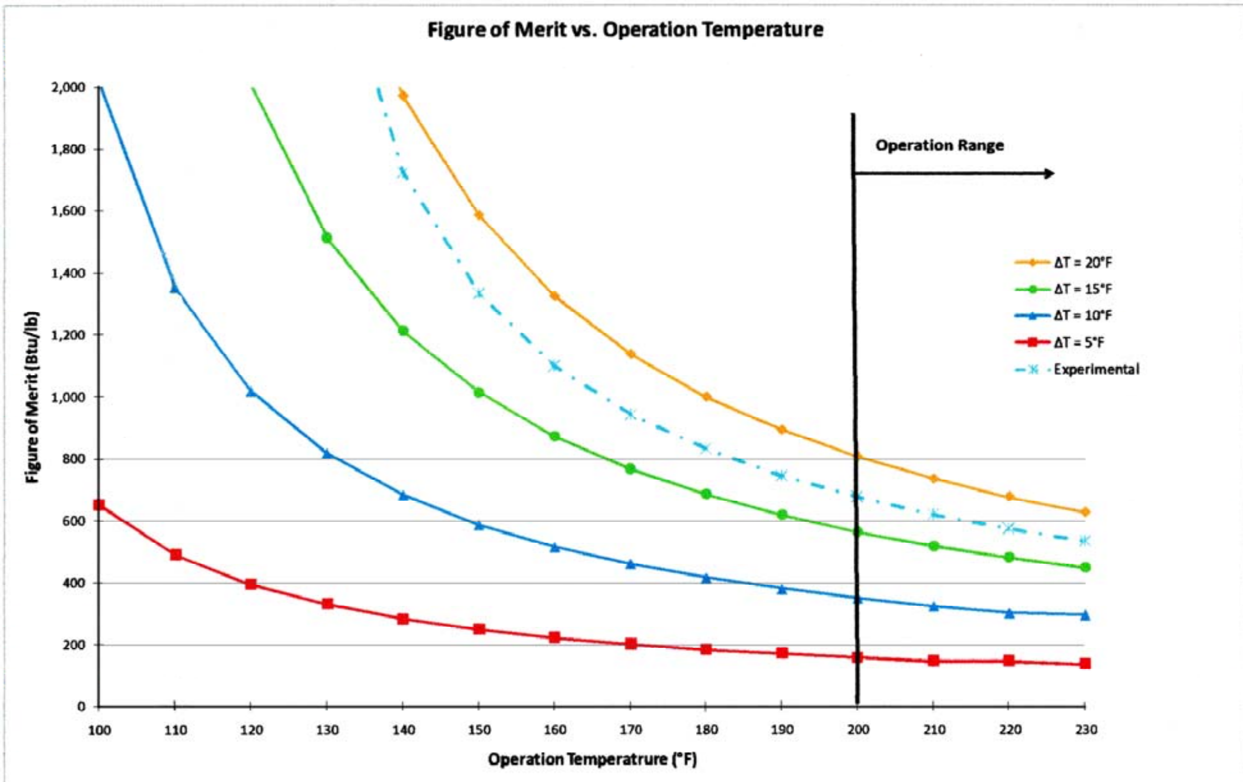

Figure 1: Figure of Merit (External Heater Energy Required per Mass of Moisture Removed – Btu/lb$_w$) vs. Operation Temperature

As seen in the plot above, the Figure of Merit 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 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. One can conclude that most applications will be designed with Operation Temperatures at and above 200 °F.

The Figure of Merit also decreases as the approach temperature difference (ΔT) decreases. This result appears consistent with the expectation that lower approach temperature differences result in higher system effectiveness. The experimental data for the Figure of Merit follows the theoretical data trends discussed above in the typical Operation Range.

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 substantial design improvements of the small scale prototype system that was tested. Such improvements have the potential to result in substantial increased energy utilization efficiencies by the prototype system.

While it may be difficult to achieve designs that meet the ΔT = 5^o F graph, one can reasonably expect to design dryers utilizing the Shivvers Heat Recovery Process that operate in the ΔT = 10^o F to ΔT = 15^o F range. As one can see by close study of Figure 1, such dryers will operate with theoretical energy consumptions from 350 to 600 BTU/pound of moisture removed when operated above 200^o F.