IMPACT OF VENTILATION SYSTEM OPERATION ON STORED POTATO QUALITY, SHRINKAGE AND ENERGY USE FFICIENCY

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INTRODUCTION

Potato storage is critical to all facets of the modern potato industry. Efficient and effective storage should be a top priority for growers or storage managers involved in the fresh, processed, or seed segments of the industry. The goal of storage is to maintain both the quality and quantity of marketable tubers throughout the storage period in order to maximize economic returns. Clearly, profitability is tightly linked to both tuber quality and mass loss (shrinkage). Tuber quality is defined relative to the intended end-use of the raw product. For example, potatoes intended for chipping or frying must meet specific quality standards in terms of reducing sugar concentration, solids, and finished product color. In contrast, potatoes for fresh-market distribution are not subject to these same quality standards. Although successful storage results from the interaction of numerous pre- and post-harvest factors, ventilation system management is likely the single most important post-harvest factor.

The ventilation system is expected to uniformly deliver the desired airflow volume, at the desired temperature and relative humidity (RH) to the potatoes. Ventilation system operation impacts several key environmental parameters (Fig. 1) that are direct effecters of tuber quality and shrinkage (Figs. 2-3). For example, ventilation is required to remove the field- and respiratory-heat of the potatoes as well as eliminate respiratory CO_2 accumulation from the storage structure (Fig. 4). Airflow requirements are the highest shortly after harvest and typically decrease through the winter holding period. In other words, the volume of airflow required during the bulk of the storage season may be significantly less than the airflow capacity of the ventilation system. Historically, in order to avoid over-ventilation, storage managers have had limited options for ventilation system operation. These options include reducing the number of hours of fan operation (e.g. 12-hr-on 12-hr-off) or reducing the number operating fans (e.g. shut off one or more fans). In recent years another option has become available. Variable frequency drive (VFD) fan speed control systems are now economically viable options for growers and storage managers.

A VFD, also know as variable speed or adjustable speed drive, is an electronic device that varies the frequency (Hz) and voltage of the current delivered to the fan motor(s). This variable frequency output allows a fixed-speed fan to operate at any speed from 0 to 100% of full speed. VFDs can be controlled manually or adjusted via automated control systems that interface with existing ventilation system controls. The physical

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relationship between fan speed and energy consumption dictates that at reduced fan speeds significant energy savings exist. For example, at 50% speed a fan will deliver approximately 50% airflow, but consume only 15% of the energy required at full speed (Fig. 5). The concept of VFD fan control is to reduce fan speed, and thus volumetric airflow, in place of reducing hours of fan operation or shutting off individual fans. In this manner a storage manager would employ continuous ventilation (given appropriate outside air conditions) at reduced fan speeds in order to provide only the volume of airflow required to maintain the desired pile temperature and avoid CO_2 accumulation. This would prevent over-ventilation, reduce energy consumption and continually maintain the desired temperature, RH, and oxygen concentration in the storage structure. Other factors must be carefully considered when reducing airflow, including the presence and nature of disease, level of soil or vines in the potato pile, and airflow uniformity within a given storage. A three-year study designed to examine impact of VFD fan speed control on raw and processed product quality, shrinkage, and energy use is currently underway.

PROCEDURES

The study is carried out in a 200,000 cwt capacity, center plenum, split bay commercial storage. Each bay is equipped with independent control systems, fans, and humidification equipment. Airflow in each bay is rated at 20.6 cfm/ton (at 1.25 in. water column static pressure). One bay is equipped with an automated VFD fan speed control system (The Gellert Co., Twin Falls, ID). This system automatically adjusts fan speed based upon the temperature differential (ΔT) from plenum to return air, in order to maintain the desired ΔT. The ventilation system in the second bay was managed conventionally by shutting off one fan during winter holding. All temperature and humidity set-points were the same for both bays and both ventilation systems operated continuously whenever outside cooling air was available. At piling pre-weighed sample bags were placed in each bay to form a network of sample bags throughout the pile. Additionally, multiple temperature and RH sensors were placed within the potato pile and throughout the storage structure. Throughout the duration of storage data from sensors and control panel parameters were logged at 30-minute intervals. Each bay was also equipped with independent energy meters to monitor fan power consumption. At each day of piling samples were collected and analyzed for glucose and sucrose content, fry color, and specific gravity. Upon unloading of each bay, the sample bags are retrieved, weighed to determine shrinkage, and analyzed for sugar concentrations and fry color. Data were analyzed to determine the impact of VFD fan speed control on the noted parameters, shrinkage, and energy use.

RESULTS AND DISCUSSION

In both years of the study VFD fan control has no impact on sugar concentrations or fry color relative to conventional ventilation system management. This result was not surprising given that in most cases maximum airflow is not required through all phases of the storage season. Energy consumption was significantly reduced using the VFD fan speed control system in both years. For example, in ‘Russet Burbank’ potatoes, during the 2001-2002 storage season, fan motor energy consumption was reduced by 45% over the 120-day storage season (Fig-6). This equates to an average energy savings of $403 per month of storage (using Idaho Power, Rate-9 energy costs). Recall that at 50% fan speed only 15% of the energy is consumed compared to full speed. This relationship accounts for the energy savings even though the hours of fan operation were equal for both bays. Fan speed was first reduced following curing and operated at 40-50% speed for the remainder of the storage season. Energy savings will be maximized in cases with high energy rates, high airflow rates, and long season storage.

VFD fan speed control significantly reduced shrinkage when compared with conventional ventilation system control in both years. For example, shrinkage was reduced by 0.5% in 'Russet Burbank' tubers over the course of the 120-day, 2001-2002 storage season. This is likely the result of providing the stored potatoes with the volume of airflow required to remove the respiratory heat and CO_2 evolution and avoiding excessive ventilation. Potential reductions in shrinkage will vary based upon a given storage managers current ventilation system management practices.

Accounting for both the energy and shrinkage savings, payback for VFD installation was determined (Fig. 7). Assuming a project cost of $175 per fan horsepower, the calculated simple payback from energy savings would be 1.8 years. When the shrinkage savings are included the project payback is only one year (assuming a potato value of $5.00 / cwt). Rapid project payback is favored by long storage duration (> 90 days), high airflow capacity (>15 cfm / ton), high electricity rates, and the availability of incentives from utility companies and/or public utility districts.

CONCLUSIONS

VFD fan speed control is an economically viable tool that has many potential benefits for growers and storage managers. VFD use can provide enhanced operational flexibility by allowing for precise airflow control during harvest, throughout the storage season, and during unloading when dealing with partially full storages. Data from commercial-scale research indicates that returns to growers can be maximized by potentially reducing both energy consumption and shrinkage. Continuing research at the University of Idaho, Potato Storage Research Facility, Kimberly, Idaho is working to optimize guidelines for VFD adoption, use, and control. The authors wish to thank the Idaho Potato Commission, the Agri-Stor Co., Cascade Energy Engineering, and the Northwest Energy Efficiency Alliance for their support of this research.

Ventilation System Management

- **Potato Temperature**
- **Air Temperature**
- **Relative Humidity**
- **CO_2 Concentration**
- **Condensation**
- **Shrinkage**
- **Energy Use Efficiency**

Figure 1. Factors influenced by ventilation system management.

Shrinkage in Storage

- Storage Temperature
  - **Warmer Temp = Greater Shrink**
- Airflow Volume
  - **Excess Airflow = Greater Shrink**
- Fan Run-Time Profile
  - **Fan Cycling = ? Shrink**
- Relative Humidity
  - **Lower RH = Greater Shrink**

Figure 2. Factors influencing shrinkage.

RH and Shrinkage

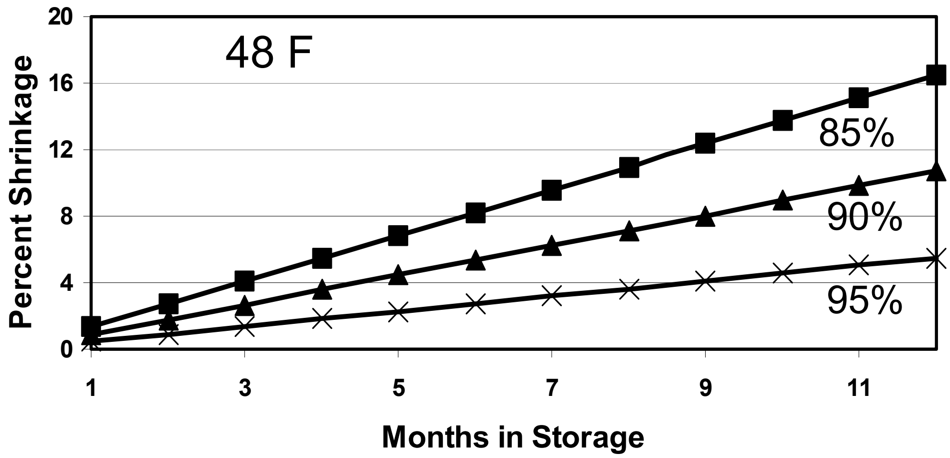

Figure 3. Modeled impact of RH on tuber shrinkage at 48 F.

Stored Tuber Respiration

- **CO_2 Evolution**
  - **1 to 12 ton CO_2 / 100,000 cwt / day**
- **Heat Generation**
  - **1 to 22 million Btu / 100,000 cwt / day**

Figure 4. Impact of tuber respiration on the storage environment.

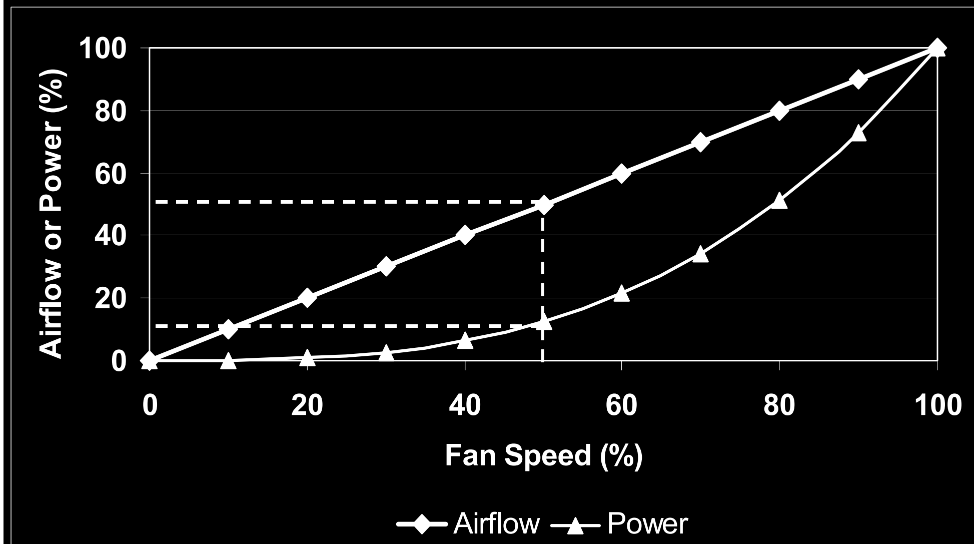

Figure 5. Influence of VFD fan speed control on airflow and energy consumption.

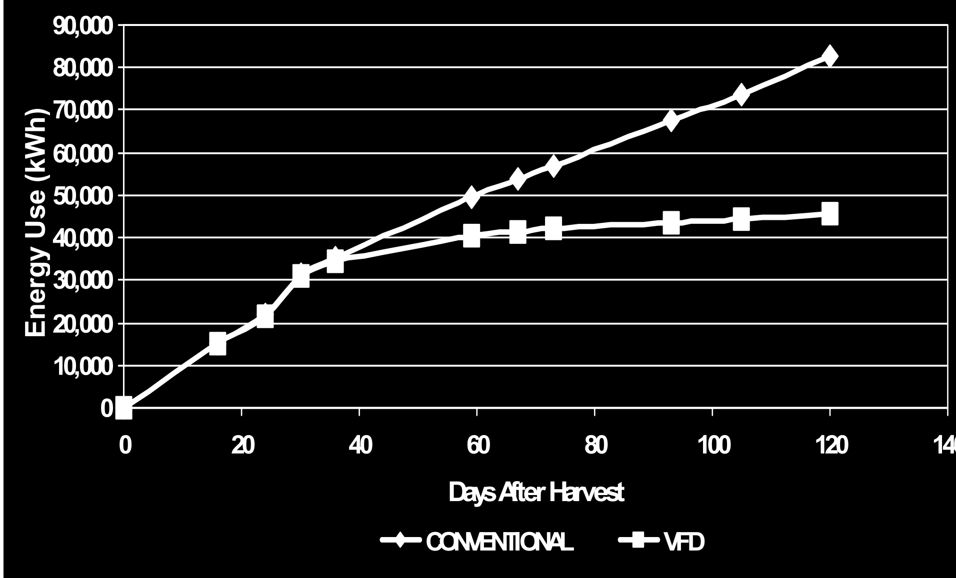

Figure 6. Impact of VFD fan speed control on energy consumption.

VFD Payback Model
2001-2002 Commercial Trial

- **Project Cost = $175/hp X 37.5 hp = *$6562.5***
- **Energy Savings (9 mo) = *$3627***
- **Simple Payback = *1.8 yr***
- **Shrink Savings = 500 cwt x $5.00 = *$2500***
- **Payback with Shrink Savings = *1 yr***

Figure 7. VFD installation payback model.