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The Importance of Managing the Performance of Particle Lift and Flow Control Systems in Research CST Plants to Facilitate Commercialization

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Abstract. Concentrated Solar Thermal (CST) with integrated thermal energy storage has shown significant potential for the provision of electricity or process heat in a predictable manner. This paper explores the relationship between Feed temperature, solar flux and measured knife gate gap on particle flow, Correlations to predict flow based on these parameters are proposed and tested. The behaviour of vertical screw lifts was examined with respect to flow history and temperature. The lack of a clear correlation of flow with screw speed highlights the critical need for accurate independent flow measurement practices.

Keywords: CST, Particles, Flow Measurement

1. Introduction

Concentrated Solar Thermal (CST) with integrated thermal energy storage has shown significant potential for the provision of electricity or process heat in a predictable manner. Molten salt systems have been deployed at commercial scale, but wide scale adoption has been thwarted by the significant challenges of containing large amounts of molten material and mitigating the risk of freezing. CST using particle technology has the potential to employ receivers with significant operational latitude and bulk heat storage within silos whose construction is conventional and robust. At there is no change of phase, much broader ranges of sensible heat storage may be possible, it is much easier to contain, and its mechanical properties are very similar from ambient to operational temperatures. However, in order to develop confidence in the technology, detailed research is needed in the 100's of kW_t to MW_t scale to identify and address the technical challenges including thermal expansion, particle lifting and flow control.

Due to the temperatures involved, positional and flow sensing needs to be located in situations that are not exposed to the temperature extremes experienced by the particles. Therefore, the location of control surfaces needs to be inferred indirectly based on an external position measurement plus an understanding of the thermal expansion potential between the measurement point and the control surface. Flow can be measured determined by intermittently stopping inflow into the feed hopper and measuring the loss in weight over time then feeding into the hopper at rates higher than average flow to facilitate repeated measurement. However, in order for loss in weight measurement to work, the hopper needs to be designed such that any expansion of the hopper during operation does not either interfere with the loadcell operation or have the hopper 'rest' its weight on any other part of the plant when it expands. The particle lifting system needs to be sized to account for any loss in performance due to thermal expansion and be able to provide 'catch-up' feed rates well above average so that routine loss in weight cycles can be performed. Without consistent flow control and measurement, the performance of the receiver cannot be determined as energy collection efficiency needs both the temperature rise and mass flow rate to be known.

2. Methodology

The experimental Falling Particle Receiver (FPR) is located at the Newcastle energy center with a solar field capable of over 1MW$_t$ with a practical receiver capacity of about 700kW$_t$ and can irradiate between 2 to 4 kgs^{-1} particle flow. Above the receiver is a feed hopper supported on load cells to provide mass distribution for the particle curtain and enough buffer capacity to enable periodic loss in weight flow measurements to be performed without affecting particle flow. Between the hopper and receiver, a flow control valve is used that consists of a broad blade that is the same width as the receiver that is controlled and measured from the back of this blade. The position of the blade has been calibrated at ambient temperatures. Adjustments required to maintain designed flow over a range of temperatures has been collected. In addition, the speed and power draw of the particle lift system was monitored to investigate its performance over the operational temperature range.

3. Summary of results

The apparent slide gate position needed to maintain a particular flow rate increased with temperature (Figure 1). This is because the slide gate expands with temperature, so the apparent position needs to be larger to maintain an equivalent gap in the flow metering section.

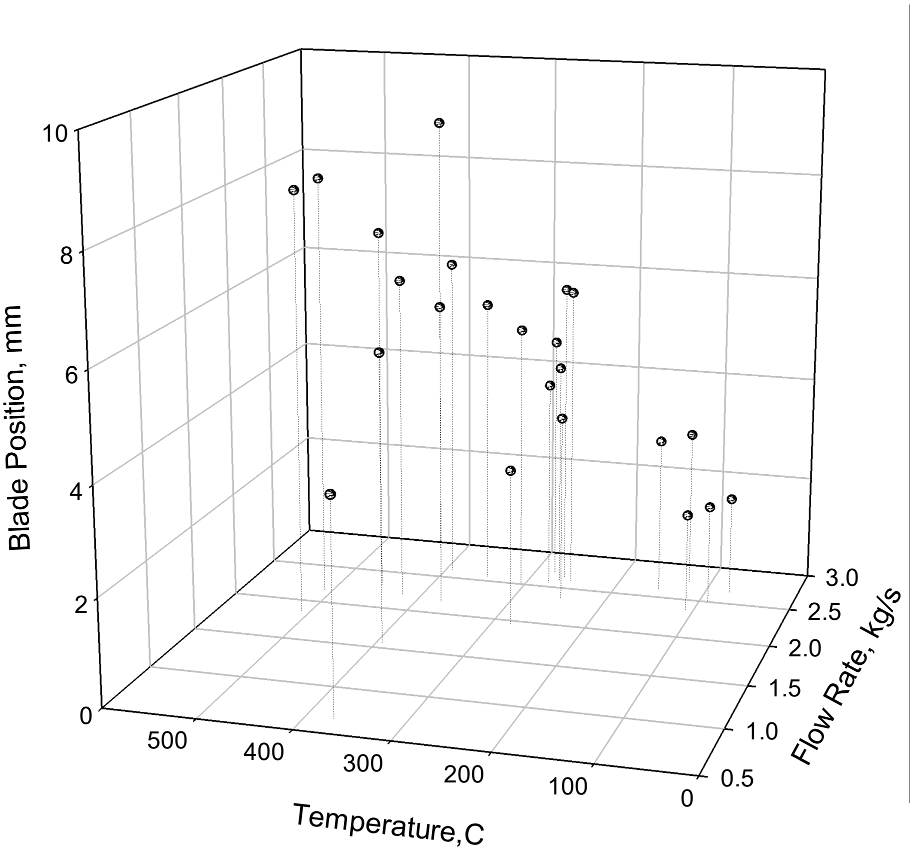

Figure 1. *Blade position with temperature for a range of mass flows, typically ~2.5kg/s.*

Attempts were made to correlate the flow rate from blade position, inlet temperature and delta T across the FPR using multiple linear regression. Four different options were chosen, which are laid out in Table 1. Two taking into account delta T across the FPR and two where a constant could be included in the correlation. Notionally a constant does not make physical sense because there should be no flow when the blade is at position 0, however as most of the data was collected at flow rates of around 2.5 to 3 kg/s, having the constant may make for a better correlation in the flow rates typically sought. The results were summarized in the table below:

Table 1. *Flow rate estimation correlation values.*

Flow rate estimation method number.	x_1 Blade Position, mm	x_2 FPR DT, °C	x_3 FPR Inlet T, °C	Constant
1	0.311907	0.002234	-0.00612	2.556532
2	0.848566	0.012965	-0.00948	0
3	0.321911	-	-00062	2.676231
4	1.111656	-	-0.01122	0

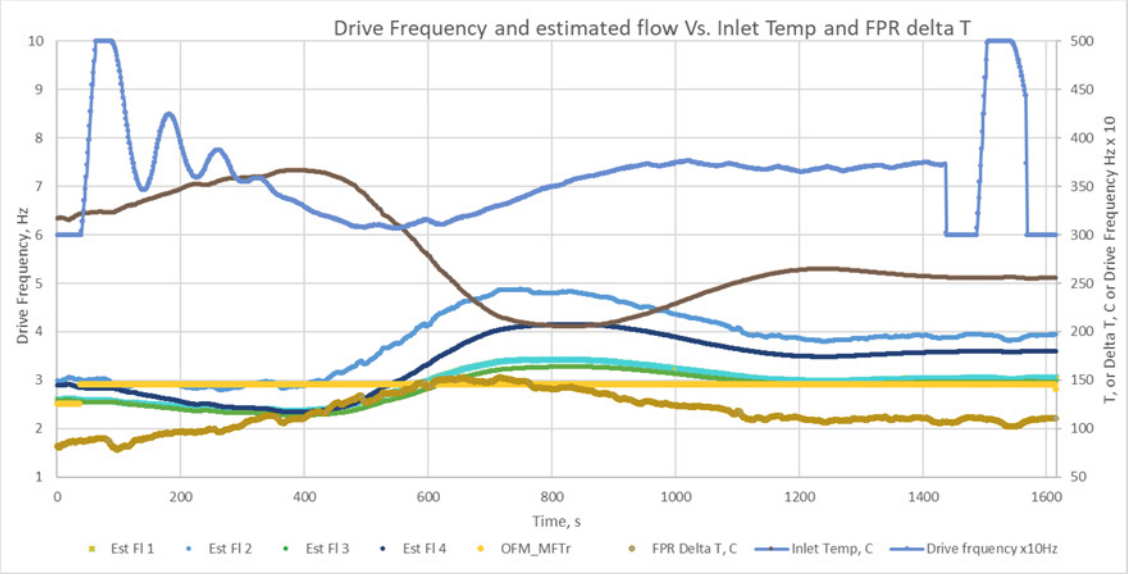

Figure 2. *Four flow estimation methods tested against operational data.*

Figure 2 showed that in practice, it would appear that flow estimate 1 and 3 appear closest to actual data (confirmed at 2.8kg/s at 1615s) followed by method 4 followed by method 2. To improve correlation accuracy, broader flow rates would need to be deliberately built into the experimental matrix. However, this may be limited by minimum flows needed to collect all the solar energy directed at the FPR.

The slope increases with temperature in part due to the increased flux needed to achieve higher temperatures (Figure 3). This may increase the blade temperature relative to the inlet temperature as more heat will be flowing to the blade from the FPR rather than just conduction from the flow of inlet materials.

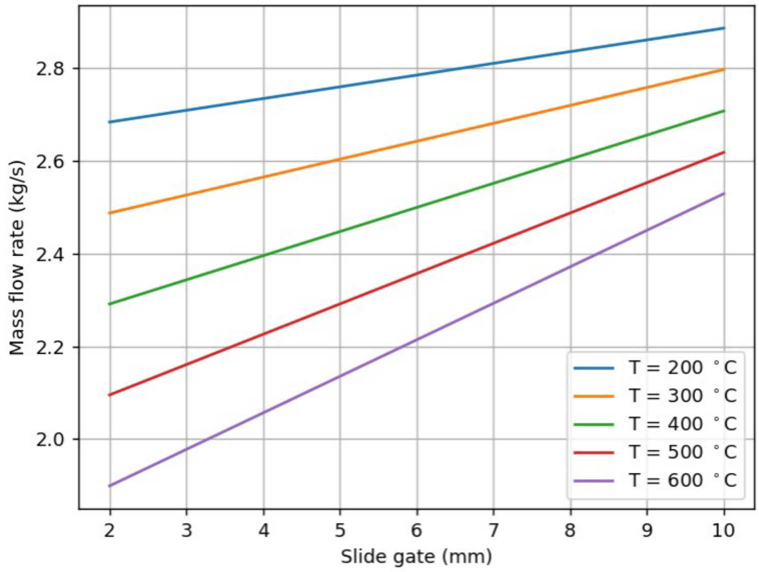

Figure 3. *Correlated mass flow with temperature for selected blade positions.*

Attempts to correlate the particle lift flow rate to screw rotational speed were not universally successful as the mass flow for a given speed was a significant function of prior motor speed (Figure 4). When the screw conveyor was started at the beginning of a run, the screw flights would be empty. Consequently, when operating on the first fill, peak performance was briefly 5kg/s, settling on about 4.5kg/s.

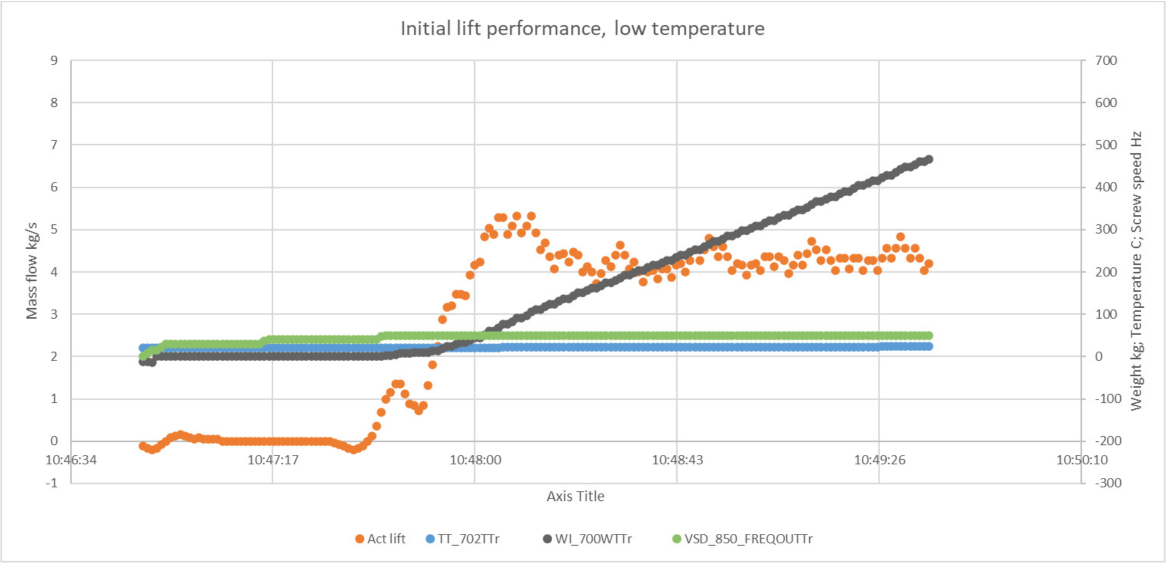

Figure 4. *Cold performance of screw conveyor initial filling.*

Once the feed hopper was filled, the control system would move into a loss in weight measurement mode. In this mode (illustrated in Figure 5) the screw would slow to ~30Hz plus a bypass valve would open so no fresh material was fed into the feed hopper. During this time, whilst there would be no flow from the top of the screw, the screw flights themselves would be filled with more material. Thus, when the screw lift retuned to maximum speed, it would outperform its steady state lifting capacity by a significant margin ~7kg/s.

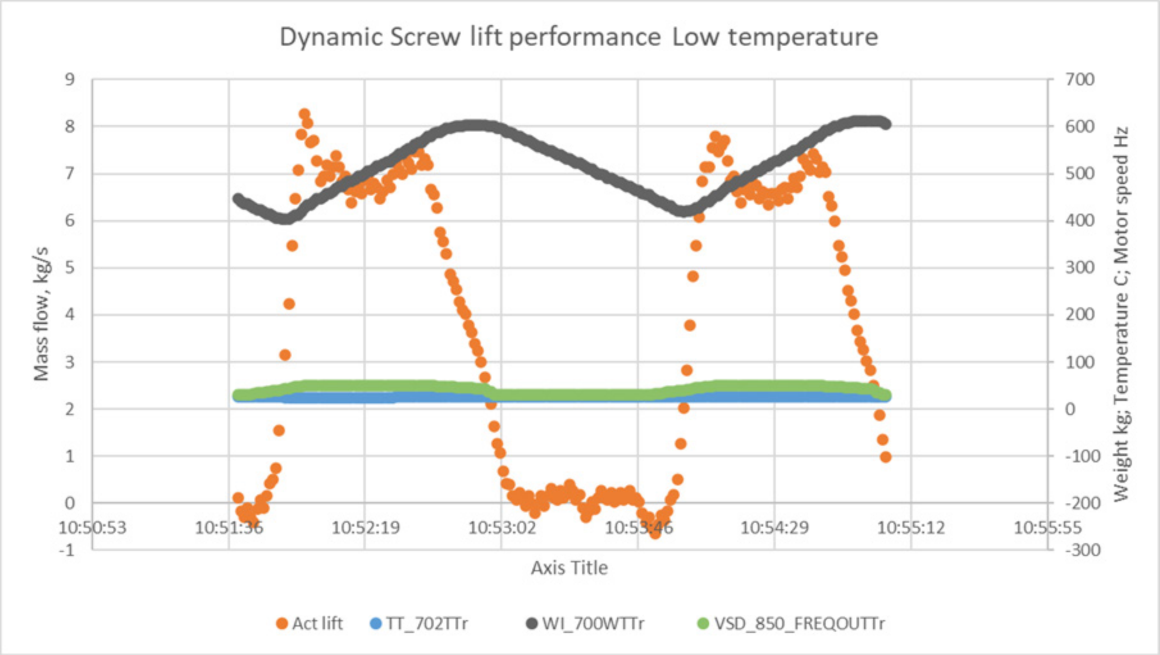

Figure 5. *Cold performance of screw conveyor dynamic filling.*

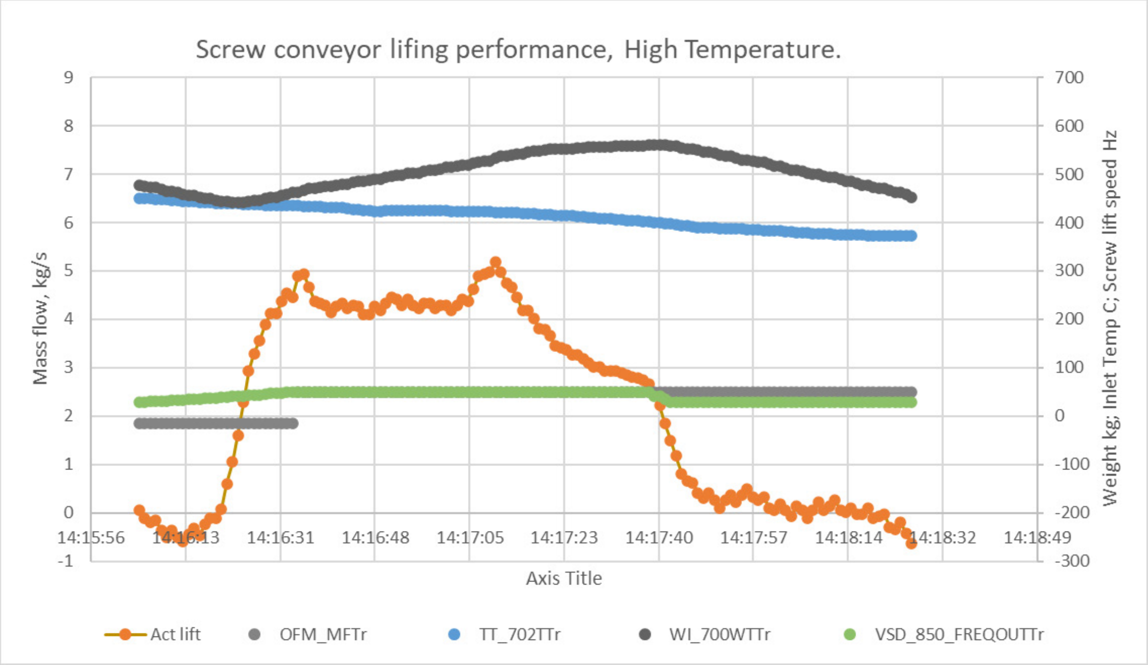

Figure 6. *Hot performance of screw conveyor dynamic filling.*

The over performance factor meant that loss of screw lift performance with temperature would be disguised until insufficient material would be lifted during the overperformance phase to enable a repeated loss in weight measurement. If the feed hopper is not sufficiently full to make another flow measurement, then the period between flow measurements can extend significantly (Figure 6). Even at maximum speed the screw may only be able to just keep up with the flow from the feed bin making flow measurement infrequent if at all (Table 2).

Table 2. *Mass flow after being returned to full speed initially and after clearing excess material.*

Time	Speed, Hz	Power, kVA	Mass Flow kgs^{-1}
9:35:30 AM	50	16.38	6.44
9:35:55 AM	50	14.85	4.43

4. Conclusion

The lack of correlation between instantaneous screw speed and particle lift flow rate makes the accuracy of loss in weight flow measurement critical to the control of operational FPR's. Also there needs to be significantly more data collected over a wider range of flow rates in order to accurately correlate flow via blade position, temperature and thermal load on the system.

Data availability statement

The underlying data used in this paper may be restricted due to commercialization agreements for the technology being developed. Access to the underlying data may be available on a case-by-case basis subject to contacting the author. The author will engage with the commercial partner to see if the data may be released and on what conditions this may occur.

Author contributions

Geoff Drewer was responsible for; conceptualization, investigation, methodology visualization and writing - original draft plus review & editing. Jin-Soo Kim was responsible for; funding acquisition, investigation, project administration, resources, supervision and writing review & editing. Daniel Potter was responsible for; formal analysis, visualization and writing – review & editing.

Competing interests

The authors declare that they have no competing interests.

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References

N/A