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Modeling Offgas Systems for the Hanford Waste Treatment Plant

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Modeling Offgas Systems for the Hanford Waste Treatment Plant

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Abstract

To augment steady-state design calculations, dynamic models of three offgas systems that will be used in the Waste Treatment Plant now under construction at the Hanford Site were developed using Aspen Custom Modeler™. The offgas systems modeled were those for the High Level Waste (HLW) melters, Low Activity Waste (LAW) melters and HLW Pulse Jet Ventilation (PJV) system. The models do not include offgas chemistry but only consider the two major species in the offgas stream which are air and water vapor. This is sufficient to perform material and energy balance calculations that accurately show the dynamic behavior of gas pressure, temperature, humidity and flow throughout the systems. The models are structured to perform pressure drop calculations across the various unit operations using a combination of standard engineering calculations and empirical data based correlations for specific pieces of equipment. The models include process controllers, gas ducting, control valves, exhaust fans and the offgas treatment equipment. The models were successfully used to analyze a large number of operating scenarios including both normal and off-normal conditions.

Introduction

Work is currently in progress to design and build a radioactive waste treatment plant at the Hanford site in Richland, WA. As part of the plant, four large melters will be constructed to vitrify both high level and low activity radioactive waste. Two melters will be dedicated to HLW processing and another two melters will be used to vitrify LAW waste. The two HLW melters have dedicated primary and secondary offgas treatment systems but the systems are coupled to each other since the exhaust fans are also used to ventilate process vessels that connect to both melter systems. The two melters in the LAW system have dedicated primary offgas treatment systems but use a common secondary offgas treatment system that is again also used for process vessel ventilation. This interaction between the melters and between the melters and process vessels increases the difficulty of maintaining adequate pressure control. In addition to the melter offgas systems, the system that exhausts air flow from pulse-jet mixers in another set of HLW process vessels was also modeled. Pulse-jet mixers operate by drawing a significant volume of liquid from the vessel into a holding chamber and then discharging the liquid back into the vessel to mix the contents. The suction and discharge phases of operation are activated by eductor air flows that first draw a vacuum on the holding chamber and then pressurize the chamber. There are typically four pulse-jet mixers in each process vessel and four such vessels along with two unmixed tanks are ventilated by a common offgas system. Ideally the offgas system would like to maintain a constant gas flow. However, the rapid and large changes in gas flow created by operating the pulse-jet mixers are difficult to control. In all of the systems, the melters and process vessels must be maintained under a slight vacuum at all times to avoid releasing radioactivity to the surroundings. The system design and control must ensure that this safety feature is maintained under normal and off-normal operating conditions. Dynamic modeling of these systems provided valuable insight into how the systems would perform prior to construction and operation.

The work reported here describes the computer modeling of the offgas systems and their associated control systems. The models perform dynamic material and energy balance calculations solving a relatively complicated flowsheet. Among other applications, the models have been used to:

- Evaluate different strategies to control Process Vessel Ventilation (PVV) pressure.
- Evaluate different strategies to operate Pulse-jet Mixers (PJM) in the process vessels.
- Assess the impact of steam surges in the HLW and LAW melter.
- Assess the impact of air sparging in HLW Feed Preparation (HFP) vessels.
- Provide preliminary control system tuning parameters.
- Evaluate system performance under off-normal operating conditions such as steam surges, fan failures, loss of power, line breaks and line pluggage.
- Evaluate system performance during normal equipment maintenance operations that require bypassing some sections of the process.
- Simulate process startup and shutdown.

System Description

Since space does not permit a description of all three offgas models and results from the many case studies performed, this paper will focus on the HLW melter offgas system. Figure 1 shows a diagram of the flowsheet used to model the offgas system on one HLW melter. The flowsheet diagrams were printed directly from ACMTM to show the actual model representation of the system. Solid lines in the figure indicate gas flow paths while dashed lines indicate control signals. Labeled gas lines (e.g. HMP11_1) are models of gas ducting where pressure drop calculations are performed. Unlabeled gas lines are simply connecting lines that transfer gas from the source to the destination without performing a pressure drop calculation. The primary flowpath for melter offgas is indicated in bold. To view adequately, the figure must be either printed out or magnified by a factor of two.

The melter gas plenum (HLW_MLTR) in the upper left-hand side of Fig. 1 is the starting point for the HLW model. Air and steam are added to the plenum to simulate gas generated during melter feeding, air leakage and steam surges. Off-gas leaving the melter plenum is approximately 450 °C. As shown in Fig. 1, the off-gas first passes through a film cooler where the temperature is reduced to about 250 °C by mixing with air. From the film cooler, the gas flows to the pressure control point where control air, metered through PC_Valve, is added to control the melter pressure. PI controller (PC_Melter) uses the melter pressure to set the control valve position to maintain a melter plenum pressure of -5 inches of water relative to the local cell pressure. From the pressure control mixer, gas flows through a Submerged Bed Scrubber (SBS) and Wet Electrostatic Precipitator (WESP) which remove particulates. The current SBS design is for a bed 24 inches tall with a 3 inch head of water above the bed. Gas is introduced at the bottom of the scrubber and the exhaust fans must overcome this liquid head to establish flow in the offgas system. Based on experimental data, gas leaving the SBS is saturated air at 50 °C, under all operating conditions. This means that gas flow past the scrubber can actually decrease as a result of steam condensation. Gas volumes in the SBS outlet plenum, WESP inlet, and WESP outlet are included in the model. Experimental data also shows that the operation of the SBS introduces pressure fluctuations in the system. This data was fit to an empirical expression that was included in the scrubber pressure drop calculation.

Following the WESP, the gas flow enters the vent mixer where it is mixed with the offgas from the Process Vessel Ventilation (PVV) system. The vessel ventilation system contains 10 vessels, the connecting laterals, gas headers, and mixing tees arranged in a flow network shown in Fig. 2. Each

“vessel” in the PVV network is actually a composite model that includes a fixed source of gas flow into the vessel gas space representing purge air and other additions to the vessel, a variable gas source representing air inleakage into the vessel from the surrounding cell, an orifice, and the vessel gas space itself. Air inleakage is modeled as flow through a circular orifice and is consequently a function of the pressure difference between the vessel gas space and the surrounding cell. Note the gas pumps connected to vessels RLD_V07 and RLD_V08 in Fig. 2. These pumps were used to simulate the action of pulse-jet mixers in these vessels.

After mixing with the vessel ventilation gas, the melter offgas stream flows through a High Efficiency Mist Eliminator (HEME), a preheater, and two banks of High Efficiency Particulate Air (HEPA) filters as shown in the upper right-hand part of Fig. 1. A solids loading of 20 g/m² is assumed in calculating the pressure drop across the first HEPA while the second filter is modeled with no solids loading. Two filtration trains are included in the model and switchover from one train to the other was one of the normal operating cases investigated. Following the HEPA filters (the flow now moves to the lower left of Fig. 1), the stream is split between two identical booster fans operating in parallel. Both fans are included in the model to allow the simulation of single fan failure scenarios. Fan operation is modeled using a full set of operating curves supplied by the manufacturer. Exiting the fans, the gas streams are recombined before passing through two mercury removal columns (ABDR). The flow then enters through the cold side of a heat exchanger (HX2), through a carbon bed absorber (ABS) and into a catalyst skid. The skid has been broken down into its individual units for modeling purposes. These units are: the cold side of a second heat exchanger (HX1), a heater, a catalytic oxidizer (SCO), and a selective catalytic reducer (SCR), and the hot side of the second heat exchanger. Operation of the preheaters and heat exchangers is modeled by specifying the outlet gas temperatures and calculating the required heat load. Since the only chemical species in the model are air and water vapor, chemical reactions in the catalytic oxidizer, reducer and silver mordenite beds used to clean the off-gas are not explicitly accounted for. From the catalyst skid, the offgas passes back through the hot side of the first heat exchanger, and is again split into two streams that are drawn through two identical stack fans operating in parallel. After the stack fans, the offgas streams are recombined and exit the system at the discharge of HOP31.

The second HLW melter offgas system is identical to that shown in Fig. 1. The first melter offgas system is connected to the PVV by a gas line running from Vent_Mixer_1 to the outlet of control valve VVS_Valve_1 (not shown in the figures). In a similar manner, the second melter offgas system connects to the PVV system at VVS_Valve_2. Because both offgas systems are drawing on the PVV system the gas flow direction through the PVV system is not clear and, as indicated in Fig. 2, flow can go in either direction through the PVV network.

Case Study

The models have been used to simulate over 30 different scenarios for the various offgas systems. Since it is not possible to describe all of these case studies and results, we will focus on a single example in this paper. One case study of interest was modeling various strategies to control pressure in the PVV system. As indicated in Fig. 2, two vessels in the PVV system (RLD_V07 and RLD_V08) used pulse-jet mixers to mix the liquid contents. The PJMs pump a significant volume out of and back into the vessel liquid space over a 30 second cycle. This liquid pumping changes the gas volume in the vessel. As the gas volume changes, the gas in the vessel is either expanded or compressed and may flow either into or out of the vessel. The resulting PVV gas flows are calculated by the model by balancing the flow network consisting for the two melter offgas systems and the PVV system.

Various methods to control pressure in the PVV system can be devised. The methods tested by dynamic system modeling were:

1. No control, where the PVV system is tied directly to both offgas systems but no attempt is made to directly control the pressure.
2. Using two separate pressure controllers, where individual pressure control on the gas lines connecting the PVV system to the two melter offgas systems is used to maintain the pressure in the PVV vessels to less than –5 inches WG.
3. Using two separate flow controllers, where flow control on the connections between the PVV system and the two melter offgas systems is used to maintain pressure in the PVV vessels less than –5 inches WG.
4. Integrated pressure control, where a single pressure controller using the average of the pressures measured in the lines connecting the PVV system with the melter offgas systems controls separate valves in each line to maintain pressure in the PVV vessels less than –5 inches WG. This is the control scheme shown in Fig. 2.
5. Polling pressure control, where a single pressure controller would monitor the pressure in all of the vessels and use the vessel with the minimum vacuum (maximum pressure) at any one time as the controlling factor. Based on this minimum vacuum, the controller would simultaneously control both PVV control valves (i.e., the same valve position signal would be sent to both valves) so that a minimum vacuum set point of –5 inches WG is maintained. The goal of this approach is to maintain just enough vacuum in the vessels to be compliant. Minimizing vacuum minimizes inleakage into the system and therefore minimizes the overall PVV offgas flow rate. However, the penalty is a fairly complicate control algorithm.

In addition to the gas volume fluctuations induced by PJM operations, vessel liquid volumes are also changing over time from process operations. This is illustrated in Fig. 3 which shows the time history of the gas space volume in vessel RLD_V07 caused by the projected process schedule. All ten of the process vessels have a preprogrammed change in gas volume from an input process schedule. Figure 4 shows the PJM operating cycle for vessel RLD_V08. The cycle changes as liquid level varies from 0% to 100% of the operating batch volume. The process model included all of these various factors when calculating the system response. Vessel gas volumes were varied to match the proposed operating cycle and the PJM cycling was varied as a function of vessel volume. At each time step the dynamic model calculated pressures in each gas volume, gas flows through the system as well as gas temperatures and water content.

Simulation Results

Some results from this simulation study are presented in Figs. 5–8 where the pressure in vessel RLD_V08 and the gas flow in the line connecting the PVV system to the first melter offgas system are plotted for four of the control strategies. Results obtained using separate pressure controllers on each PVV header and using a single controller with the average header pressure as input (schemes 2 and 4 above) were very similar and only one set of these results is presented. In all calculations, PJM operation in vessels RLD_V07 and RLD_V08 was sequenced such that the drive phases where liquid is pushed back into the vessel did not overlap. That is, the four mixers in each vessel operated simultaneously but the PJM cycles in the two vessels were timed such that both would not simultaneously pump gas into the offgas system.

Figure 5 shows results obtained with no active pressure control. The very dense appearance of the data plots indicates fast fluctuations that are not resolved on the scale of the plot. These fluctuations in, for example, the pressure in vessel RLD_V08 are on the order of the 30 second cycles driven by the PJM pumping. Model data was collected at two second intervals while simulating 20 hours of operation so

there are some 36,000 data points on each plot. The gas space in vessel RLD_V08 is vented to RLD_V07 through an 8 inch diameter pipe. This pipe is large enough to equilibrate the pressure in the two vessels. Without pressure control, the average pressure in the vessels is -41.5 in WG with a range of about -35 to -50 in WG.

Results obtained using either separate pressure controllers on each PVV header or a single controller using the average header pressure as input are plotted in Fig. 6. Through several trial runs with the PVV model, it was determined that using a PVV controller set point of -14 inches WG the maximum gas pressure in any of the PVV vessels was held below -5 inches WG throughout the transient. Maximum PVV pressures occurred in vessels RLD_V07 and RLD_V08. Because of the PJM gas pumping, these vessels also experienced the lowest pressure and showed the greatest variation in pressure during the transient. Using the average control methodology instead of separate controllers distributed the PVV gas flow slightly more evenly between the two melter systems. On this basis, the average control scheme performs slightly better than using separate controllers on each PVV system.

Figure 7 shows results obtained using flow control. Large pressure swings occur in the process vessels with this control methodology. Air flow into both melter offgas systems was maintained close to the 88 ACFM set-point throughout the transient. However, between 500 and 560 minutes and again between 930 and 980 minutes the PVV control valve fully opened and control action was lost. As seen in Fig. 8, the polling control methodology controlled the maximum vessel pressure as well as header pressure control but produced large variations in gas flow from the PVV system. Large variations in PVV header pressure and control valve position were also found with this control scheme. Therefore, there appears to be no advantage to using this more complex control methodology.

In general, an integrated pressure control strategy using a single pressure controller and the average of pressures measured just upstream of the two PVV control valves produced the best results of the various control configurations tested. The strategy maintained good pressure control in the vessels while at the same time minimizing PVV gas flow and balancing the gas flow between the two melter offgas systems.

Conclusions

To provide a realistic simulation of process operations, the HLW offgas model includes transient changes in process vessel volumes and includes the operation of pulse-jet mixers in some of the vessels. To obtain reasonable computer run times, the simulation of long term plant operation with simultaneous filling and emptying of the process vessels was somewhat compressed into a 20 hour time period. This compression means that some gas flows out of the vessels during tank filling and into the vessels when the tanks are emptied may be higher than actual plant flows introducing a slight conservatism into the calculation. Even with this time compression, the full model required from 24 to 36 hours of run time on a 3 GHz workstation to complete a full simulation. This long run time is a direct result of the large flowsheet being solved and the fast transients that continually occur throughout the simulation since both PJM and melter feed cycling take place in times that are on the order of 20 to 30 seconds. Despite the long run times, results from the dynamic simulation were successfully obtained for many case studies and provided valuable guidance to design engineers considering different system configurations.

Acknowledgement

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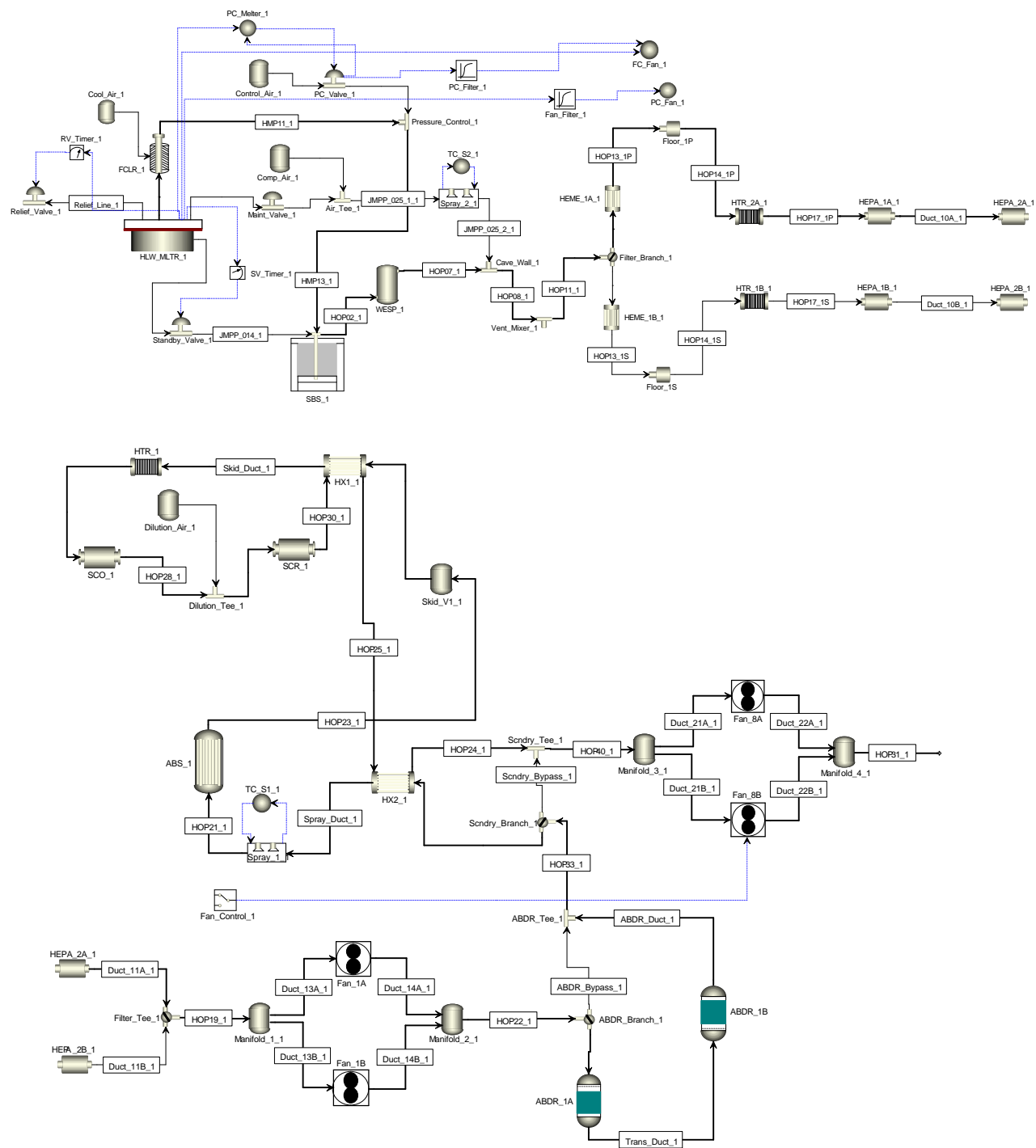


Figure 1. ACM model of HLW melter offgas system.

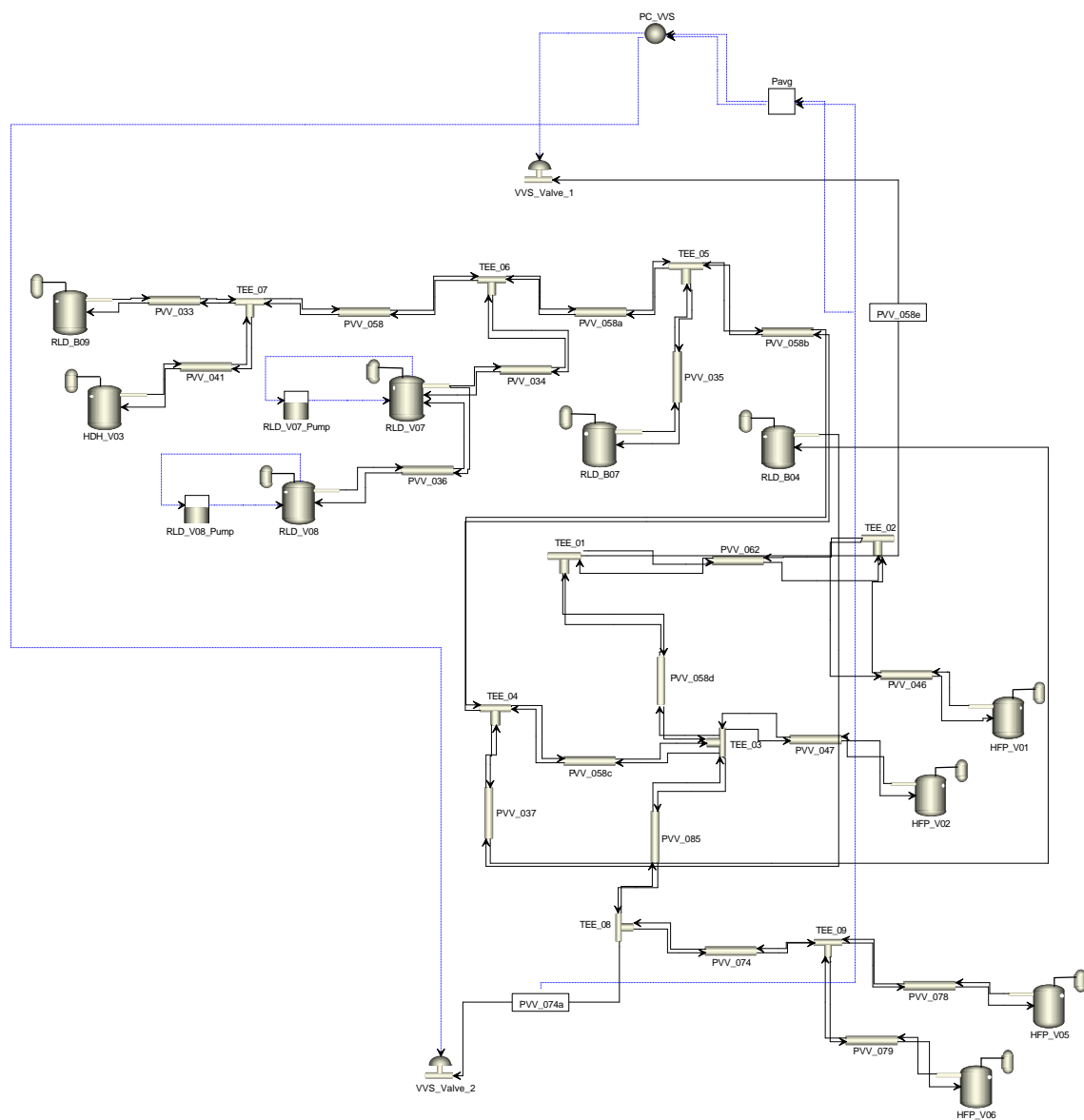


Figure 2. ACM model of HLW melter process vessel ventilation system.

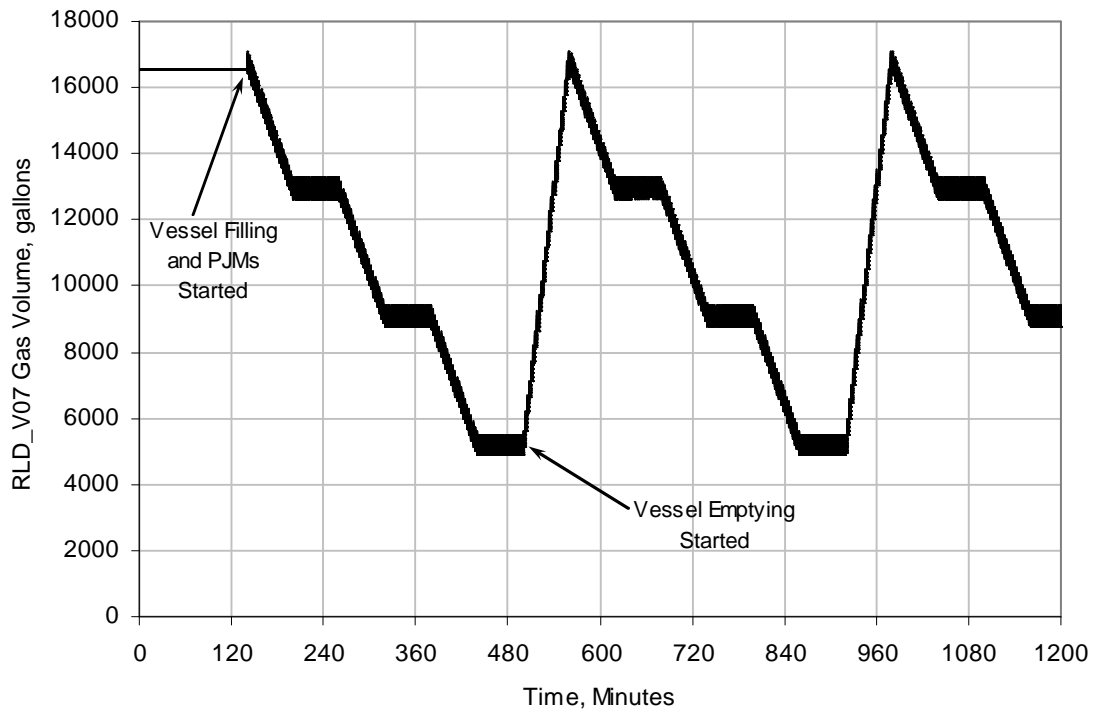


Figure 3. Transient gas volume in vessel RLD_V07.

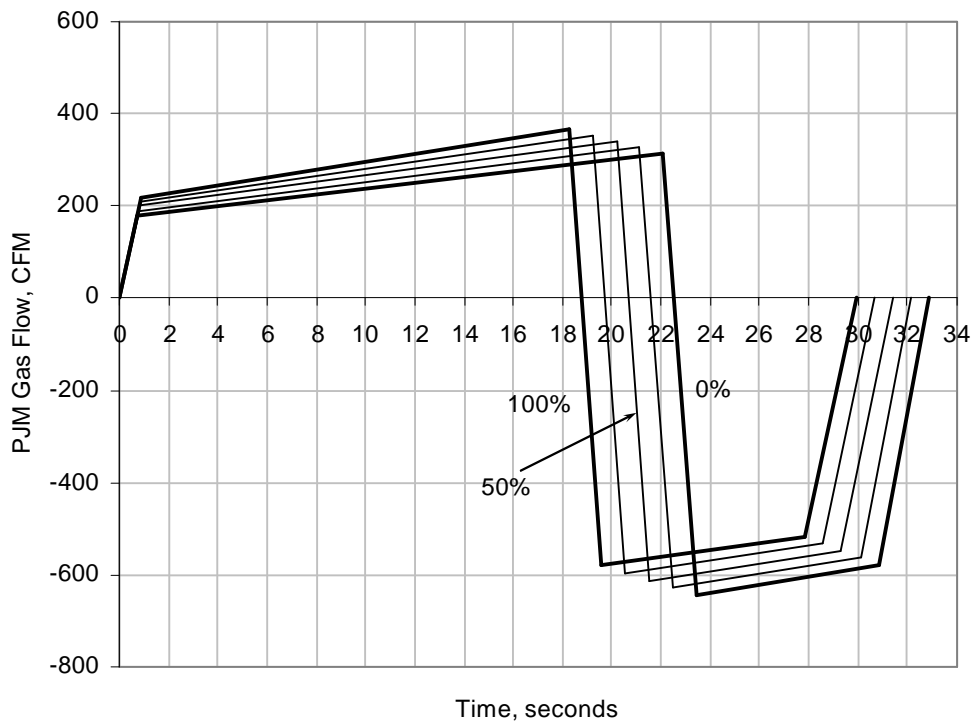


Figure 4. PJM pumping curves for vessel RLD_V08.

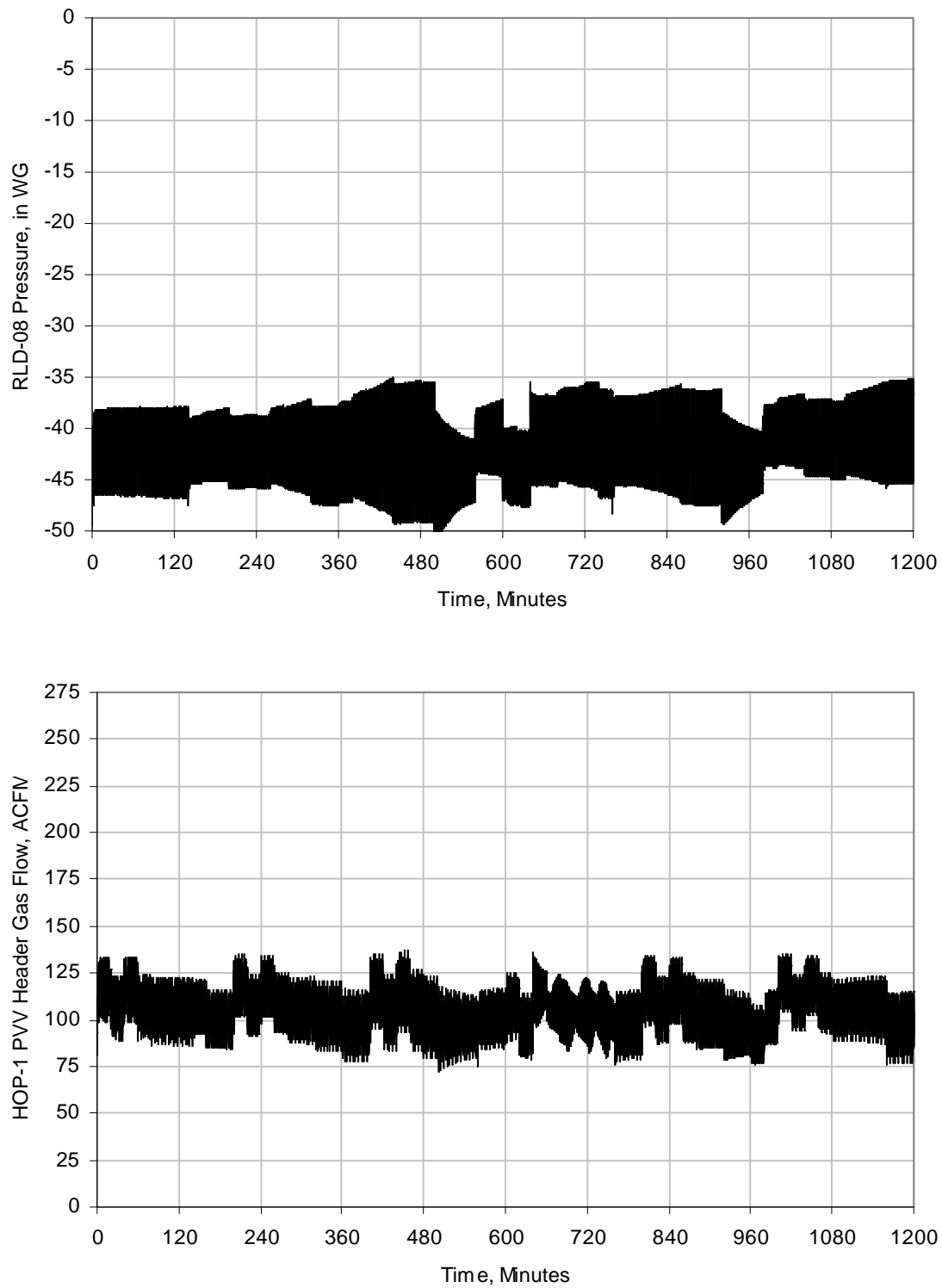


Figure 5. Pressure in RLD_V08 and gas flow in HOP-1 header with no control.

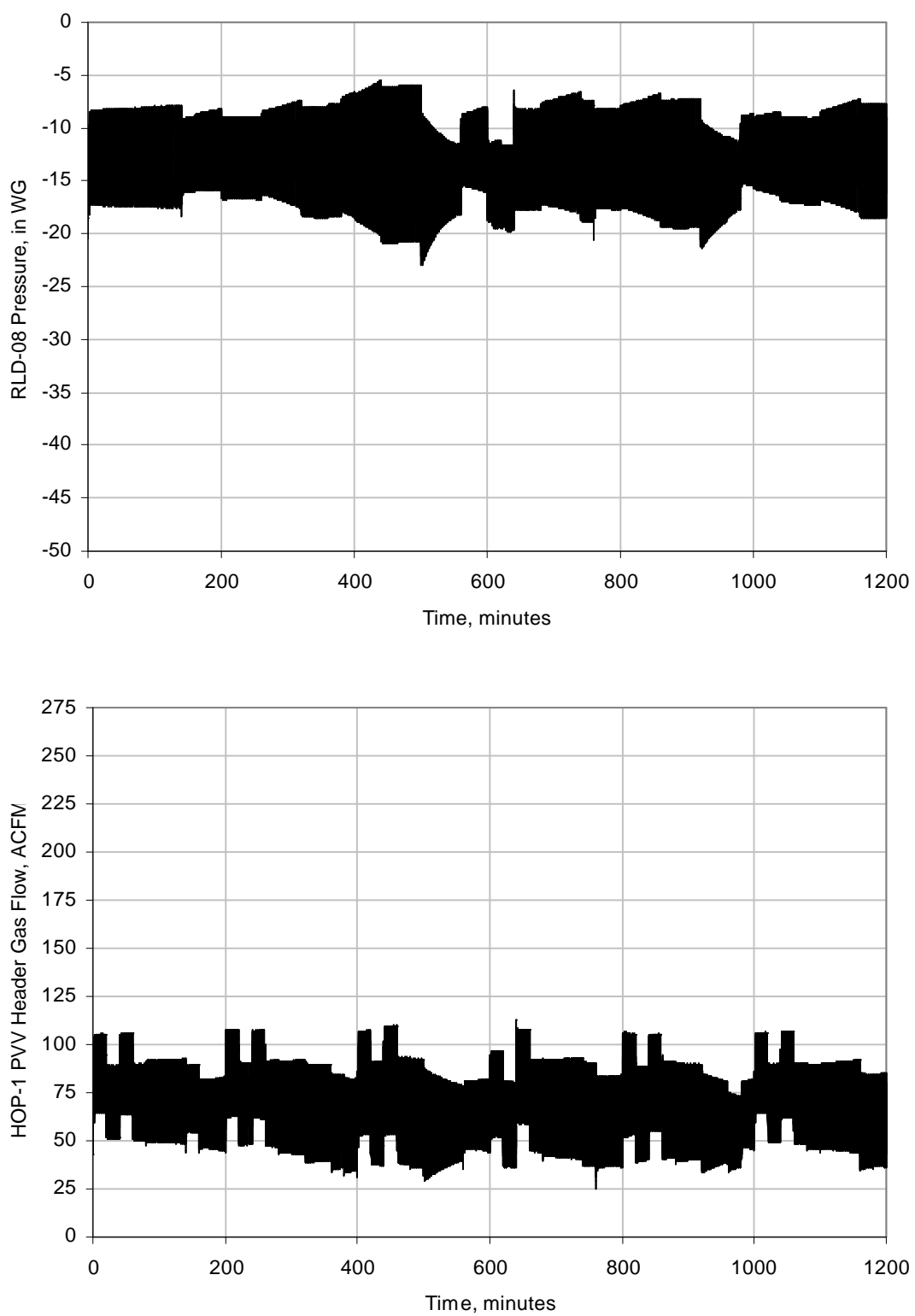


Figure 6. Pressure in RLD_V08 and gas flow in HOP-1 header with integrated pressure control.

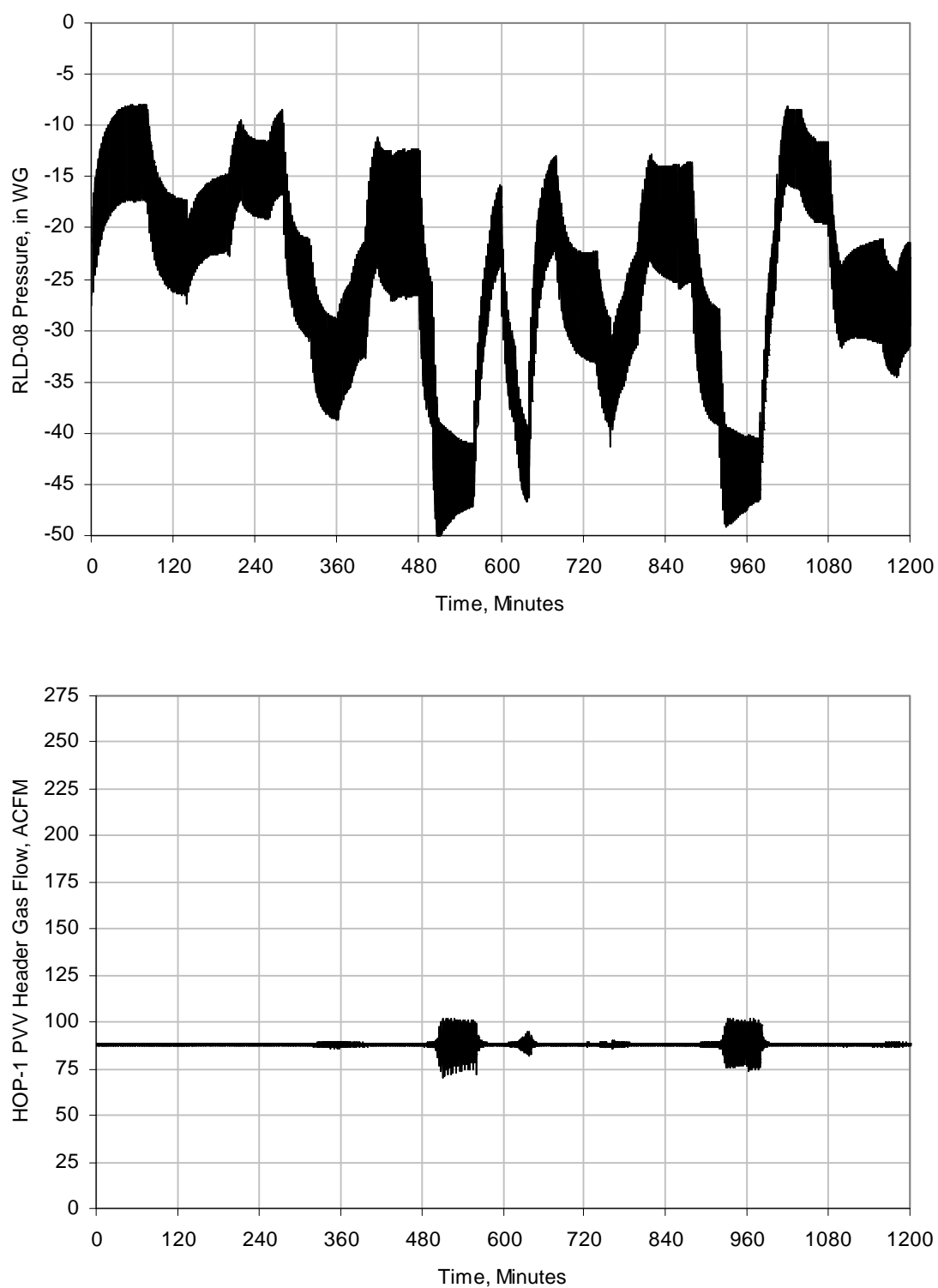


Figure 7. Pressure in RLD_V08 and gas flow in HOP-1 header with separate flow control.

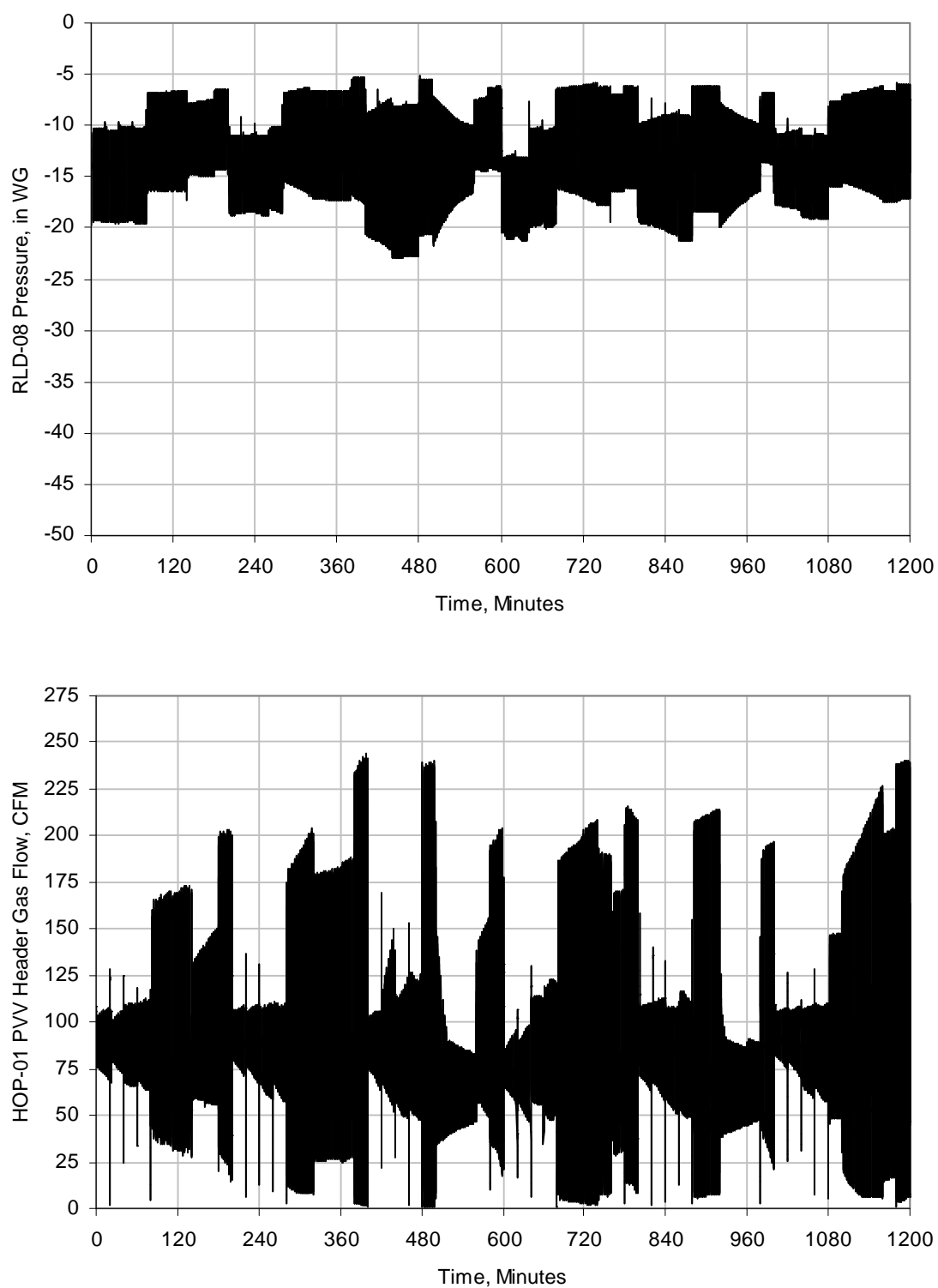


Figure 8. Pressure in RLD_V08 and gas flow in HOP-1 header with polling pressure control.