Vacuum System Audit Report

for

General Process Inc.

Mobile, AL

<u>FINAL REPORT</u>

Note: This is a Sample Audit Report generated for demonstration purposes only. Any resemblance to an actual installed vacuum system is coincidental.

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Executive Summary

The audit was initiated to investigate methods for increasing vacuum delivery to production machinery and to avert the potential purchase and operation of an additional vacuum pump. The central vacuum system is currently configured to run four of six installed vacuum pumps. Vacuum pumps are turned on and off manually when needed. There is a total of 430 nameplate horsepower in operating vacuum pumps needed to run the system during normal production levels and 175 horsepower in back-up equipment. Although the present system is meeting production requirements at the site, there are several areas where improvements in efficiency can be made to this system.

Opportunities exist to improve vacuum delivery to production based on identified system operating conditions:

Supply Vacuum pumps

- Eliminate pressure drop across inlet filtration equipment to increase the available pressure differential to production machinery. Dual inlet filters that exhibit low pressure-drop should be installed on the inlet to each vacuum pump.
- Although the liquid ring vacuum pumps appear to be in good overall working order, there is a discrepancy between amperage on the two machines. This should be further investigated.
- The reciprocating vacuum pumps provide a good back-up system and can be used to assist the liquid ring pump during modifications to the distribution system.

Demand Equipment

- Tubing and vacuum delivery systems within production machinery are causing poor vacuum performance. Internal distribution systems with 1” tubing are inadequately sized to remove intake air from use points quickly enough so that adequate recovery is made prior to the next machine cycle.
- Several piping modifications are necessary in the Silicon production machines so that system pressure drop is lowered and vacuum delivery to use points is increased. When piping modifications are made, existing pipes and tubing should be

cleaned so there is unrestricted flow from use points to the central vacuum system header.

Distribution System

- Pressure drop in the distribution piping from the primary supply headers in the High Silicon and Low Silicon areas is one of the primary causes of poor vacuum delivery in production. Distribution sub-headers and 2” diameter drop legs can not handle the volume of flow required from production machinery and must be enlarged to at least 3” diameter. Sub header diameters should be enlarged and interconnected.
- Spinner-type, low maintenance inlet filters can be installed directly at use points so that contamination does not block portions of the distribution system. The majority of Glycol contamination should be kept out of the primary system headers.
- Centrifugal separators should be installed in the Equipment Room prior to the vacuum pump inlet filters. Centrifugal separators will remove 99% of the liquid Glycol prior to particulate inlet filters on vacuum equipment.

A vacuum system upgrade project is proposed that will reconfigure the system in a manner that will provide for the desired production requirements while reducing energy costs. The implementation of the system upgrade will result in a savings of **$49,343** in energy and maintenance costs by allowing one 250 HP vacuum pump to be shut down and operating one 60 HP reciprocating vacuum pump instead. These savings do not include a cost avoidance of **$85,300** for the purchase of a new vacuum pump and **$65,240** per year in electrical and water consumption for that vacuum pump. The system upgrade project is estimated to cost **$74,500**. The project has a simple payback of 18.1 months.

<u>Vacuum Distribution Issues</u>

1. The distribution system is the primary cause of poor vacuum performance to production use points. Both Low Silicon and High Silicon distribution system header layouts are illustrated in **Attachment B**. Note that each system has a 8” diameter loop that covers each production area. The 8” diameter loop is adequately sized for current production flow rates but if more production machinery is added sections of each loop should be replaced with 10” diameter pipe. Pressure drop from the High Silicon vacuum pump to drop legs is 5.2” Hg and pressure drop in the Low Silicon area from the vacuum pump to drop legs is 11” HgV. Note that not all drop legs were tested but it is estimated that they are similar in pressure drop characteristics. See **Attachment B** for graphs on pressure drop in the vacuum supply and distribution systems. Pressure drop of this magnitude is significant in that reducing pressure drop in supply piping will directly increase vacuum holding force at use points. Increased holding force results in fewer machine problems related to vacuum or a possible increase in machine production throughput. Also, it is probable that the production machines with the worst supply differential have the greatest number of problems.

2. The High Silicon distribution header consists of a primary 8” diameter loop and multiple 4” diameter sub-headers that supply production machinery with vacuum. See **Attachment B** for a layout of the High Silicon header arrangement. While the 8” diameter loop is adequate, problems exist in the 4” diameter sub-headers. There are two possibilities to correct this situation. The lowest cost method would be to connect the individual 4” diameter sub-headers with each other and at more locations on the 8” diameter primary header. This would reduce the pressure drop to sub-headers but would not eliminate it. The other, more suitable and more costly alternative is to replace the 4” diameter sub headers with 6” diameter sub-headers. The proposed layout can be found in **Attachment C**. Connecting the sub-headers to the primary header in more places reduces the amount of air flow through any given section of pipe and therefore reduces the pressure drop. Note that for every three machine connections to the sub-header there should be at least one connection to the primary header. **Also note: use only large radius elbows and full port or gate isolation valves for straight through flow. This holds true for central system piping and drops legs. Keep piping as short and straight as possible.** Standard port valves and plunger type valves create excessive pressure restriction due to changes in flow

direction. All drop legs should be at least 3” diameter. PVC and copper are acceptable materials for use in vacuum systems.

3. The Low Silicon distribution header also consists of an 8” diameter primary header and there are two sub-headers branching off the main: (1) 3” diameter sub-header and (1) 4” diameter sub-header. There are 5 production machines on each of the 3” diameter sub-headers and 9 production machines on the 4” diameter sub-header. See **Attachment B** for a layout of the Low Silicon header arrangement. One of the primary problems with the 4” diameter sub-header is that it has a majority of production machine connections and only two connections to the primary 8” header. This is creating a significant amount of pressure drop. The optimum solution would be to replace the 4” diameter sub-header with an 8” diameter PVC sub-header. Connections should be made in seven places to the primary header. Six connections should be 8” and one connection should be 4” diameter. A 3” diameter sub header was evaluated and it turned out that the number of connections to the primary header was excessive to keep pressure drop at a minimum. The 8” diameter sub-header will allow for all seven connections to the primary header and the 2” diameter drop legs to both rows of production machinery can be connected directly to the sub-header itself so that only one direct line sub-header is necessary. The (5) 4” diameter sub-headers should be replaced with 6” diameter PVC pipe also with 2” diameter drop legs. A proposed layout can be found in **Attachment C**. Making these changes in the distribution system will allow for maximum vacuum delivery to use points. Note that any connection to the primary 8” header loops should be made with full ports, i.e. 8” diameter branch pipes connected to 8” diameter headers. Do not use the existing 4” diameter connection for 8” diameter pipe.

4. There is currently a large amount of Glycol getting into the central vacuum system from Low Silicon production processes. There are two methods that can be used individually or in tandem to keep oil out of the vacuum piping and vacuum pumps. Point-of-use “spinner” type filters can be used at each production machine suspected of contributing to this problem. These filters use no filter element and use a rotating impeller to remove solids and liquids from an air stream. Clean out involves releasing four wire spring clips and emptying the separated contaminates. Small canister style filters with elements can be used as well. In either case, these should be tested over the course of a few months to ensure they are removing the debris and are maintaining a low pressure drop. The second method is to install centrifugal

separators at each entry point into the central vacuum room. This system requires three 10” WSV-T-10 Burgess-Manning separators with installed automatic drains. The 10” separators will provide for very good separation efficiency and low pressure drop at production conditions. A proposed layout can be found in **Attachment C**.

Vacuum Demand Issues

1. Testing was completed on five production machines to determine the shape of the vacuum supply profile inside production machinery. Testing was completed with high-speed dataloggers that read pressure levels 25 times per second. The results of these tests on each machine can be found in **Attachment A**. High-speed production machines were tested at each of the sixteen vacuum use points in each machine. The critical pressures at each station were found to fluctuate from 15.2” HgV to 4.2” HgV at the injection ports on each station. The test locations were intended to be as close to the actual use points as possible. Even with these types of vacuum fluctuations, the machines were working normally and no problems related to vacuum were experienced. The fluctuations are the result of air not being removed fast enough from the 1” supply tubing feeding the injection ports. Production machinery will run normally with this type of pressure profile until central system pressure begins to fall. At some point there will not be enough holding force to move wafers from the tank to the machine and the injection process will stop. To alleviate the problem, it is necessary to remove air more quickly and reduce the range of vacuum fluctuations. Testing was accomplished on high-speed production machine Alpha Z 2 with a 2” diameter copper pipe that bypassed the supply reservoir and 1” supply tubing. The 2” diameter tube was connected directly to the injection port connection and retesting was completed. The results of the test are also in **Attachment A**. After installation of the 2” diameter tube, the pressure fluctuation range was 15.2” HgV to 14.1” HgV and was overall very close to supply pressure in the drop leg. We are recommending that the High Silicon production machines be modified over time with 2” diameter supply tubing as far into the process as possible. All internal restrictions to vacuum flow should be removed or alleviated. These changes can be made during normal maintenance intervals until all production machines have been modified.

2. Testing was also completed in the Low Silicon area to determine if the same pressure profiles existed in High Silicon production machinery. Test results can be found in **Attachment A**. A much more alarming situation exists in

the Low Silicon Area due to the fact that drop leg pressures at the farthest production machine are approximately 8” HgV. This is 12” HgV lower than the vacuum measured at the vacuum pump room and is addressed in the section on Vacuum Distribution. Vacuum is used in sixteen locations on these machines and the vacuum profiles vary significantly. The primary injection and secondary injection vacuum profiles exhibited the greatest pressure range of approximately 6” HgV and the relief ports showed low pressure drop between the use point and the header. This is a very low pressure range indicating good piping characteristics at that portion of the machine. Injection vacuum supply tubing was adequate but could be somewhat improved in locations where pipe reducers were used and where an excessive number of 90 degree elbows were in place. Larger diameter tubing is always beneficial in vacuum supply. We are recommending that each Low Silicon production machine be evaluated for vacuum flow characteristics based on the information in this report and on-site observations. Tubing restrictions should be eliminated and other internal restrictions should be removed or alleviated. Similar to High Silicon modifications, these changes can be made over time during maintenance intervals.

3. Automatic shutoff valves to the central vacuum system are installed on most of the production machines and should be installed on all remaining units so that when production machinery is off or in standby mode, the vacuum supply is also off. Addition of positive closure valves will keep non-productive vacuum use to a minimum by ensuring supply closure during machine downtime. The shut-off valves in place should be checked for proper functioning.

4. Reliability can be increased on primary and secondary injection mechanisms by enlarging the opening to suction holes. This will increase the surface area exposed to vacuum. The greater the surface area exposed to vacuum, the greater the holding force. **Attachment A** includes a chart that illustrates the change in absolute holding force when orifice size is increased or decreased. Problems occur in production machinery when wafers are not picked up or slip off during transport. When orifice size is increased, production machinery will not be as sensitive to fluctuations in central vacuum system pressure and will be able to operate adequately at lowered vacuum levels. This will also be important if a production machine speed increase is required. One caution regarding this practice however. Increasing hole diameter will increase the amount of air that is allowed into the vacuum system. If diameters are increased on a large scale, the amount

of air entering the system will cause vacuum levels to drop. It is recommended that production machinery supply tubing and distribution system changes are made first and modifications to orifice diameters be made only where necessary.

5. All new production equipment scheduled for this facility should have specifications for normal operation with supply vacuum at 15” HgV or below. This will ensure that all new production equipment will be able to work within the new system parameters.

Vacuum Supply Issues

1. The three existing Liquid Ring vacuum pumps supply site requirements for vacuum demand. There is 700 nameplate horsepower in vacuum pumps of which 430 actual brake horsepower is being used during normal production. These pumps deliver a total of 7,000 ACFM at an average header vacuum level of approximately 24” HgV. See **Attachments A and B** for datalogger graphs of system operating pressure and vacuum pump performance during the course of the audit. Vacuum pump amp draw and vacuum level at each vacuum pump varied little during the audit indicating a steady demand load at the equipment. The only significant change in vacuum level occurred during High Silicon shutdown which occurs three times daily. Vacuum levels during this time increased to 28” HgV. Note that datalogger graphs read vacuum in PSIA. Readings are converted on each graph to “HgV to illustrate significant points. If further conversions are necessary, the formula to convert PSIA to “HgV is: **“HgV = 29.92 – (PSIA x 2.04)**. There was a discrepancy between the amperage drawn on the two liquid ring vacuum pumps. Liquid Ring A drew an average of 198 amps and Liquid Ring B drew an average of 171 amps. While the discrepancy is not large, it could indicate problems with water flow, motor condition or pump mechanical problems. Amps for both pumps should be monitored over the course of the next few months to ensure the difference does not increase.

2. All vacuum pumps were tested to determine horsepower performance versus vacuum level. Graphs of these tests are included in Attachment B for each pump. The results of the tests indicated that the horsepower draw from each of the Reciprocating vacuum pumps was higher than specifications called for and was consistent across all installed pumps. Reasons for the higher than expected horsepower could not be determined and it is recommended that these pumps be checked for proper operation. Excessive back pressure

is sometimes the cause of high energy consumption but all pumps were checked and all back pressure readings were under 5 PSIG. In all other aspects, these vacuum pumps seemed to be in good working order and are well maintained. Their continued use as back-up pumps to the Liquid Ring systems is recommended and when distribution modifications are made they should be able to adequately supply production with vacuum.

3. Both of the Rotary Screw vacuum pumps have custom built inlet filters installed on each pump inlet. Pressure differential was tested and it was found that Rotary Screw A inlet filter exhibited 1” Hg pressure differential and Rotary Screw B 0.75” Hg pressure differential. Since both filters had new elements recently installed, the pressure differential is elevated given the vacuum level at the pumps. Excessive pressure differential at inlet filters to vacuum pumps is directly proportional to the loss at use points. In other words, reducing pressure differential at the vacuum filters will increase production vacuum by a corresponding level. Therefore we are recommending the installation of dual inlet filters for each vacuum pump. Solberg Model CSL-685P-1000F inlet filters will each handle the flow from one Rotary Screw vacuum pump. The dual arrangement will allow for both lower pressure drop and change-out without having the shut the vacuum pumps off. Quotations for inlet filtration can be found in **Attachments G**. Inlet filters on the Reciprocating vacuum pumps could not be tested due to lack of available test ports. Discussions with site personnel indicated that when the Reciprocating pumps are run in place of the Rotary Screw pumps, complaints about production vacuum occur. This could be due to excessive pressure differential across the inlet filters. It was noted that Glycol was found in the inlets to all vacuum pumps. Glycol will increase the pressure differential across cartridge-style vacuum inlet filters. Installation of the recommended centrifugal separators will significantly reduce the amount of Glycol reaching the filter elements.

4. During the audit, power and pressure were monitored in the system continuously. The results of these recordings were utilized to calculate actual power and air consumed during the audit period. **Attachment B** contains graphs of the normal system performance based on these recordings. These values were compared to known operating practices for the system to calculate operating total costs. The power and volume relationship will vary based on individual operating profiles but will be consistent for the system on an annual basis. The proposed performance of the system as calculated is based on performing all of the actions as described in this report and in the action plan. The vacuum pump power and

energy calculations are provided in **Attachment C**. The proposed power is based on supporting the proposed demand as depicted in the Constituents of Demand in **Attachment A**.

6. When distribution and production machine supply modifications are completed, it will allow for one Liquid Ring vacuum pump to be shut down with operation of one Reciprocating vacuum pump. While the overall central system vacuum level will be lowered, production machine vacuum delivery will be increased. These two conditions will offset one another and allow for a more energy efficient supply.

Action Plan

A prioritized action plan is included in **Attachment E.** There are estimates for each line item. The prices listed under capital equipment for filters are based on valid bids received during the course of the audit and report preparation. The costs under installation are quick estimates based on experience with similar projects. To determine actual costs in your area, these estimates should be verified through local contractors. **If there is a question about any item, the local supplier should be contacted to resolve the issue.**

The basic objectives to be accomplished by the action plan are:

1. The system will be modified to ensure the reliability of vacuum supply and targeted system vacuum control at 20” HgV with an ultimate goal of 14” HgV.

2. The vacuum pumps will receive only clean, dry air from production processes. Vacuum distribution systems will exhibit low pressure drop and will be matched to full system capability.

3. Production machinery will be modified so that there is minimal pressure drop within each machine. Small diameter tubing will be replaced with larger tubing and other restrictions removed.

4. Distribution headers will be modified to ensure adequate flow rate and low pressure drop from vacuum generation to termination points.

5. Centrifugal separators will be installed to remove Glycol from the process gas stream so that it can be removed prior to vacuum pump inlet filtration packages.

6. Dual, low pressure drop inlet filters will be installed on each vacuum pump so that element change-out can be accomplished while vacuum pumps are in operation.

7. Optional point-of-use separators will remove Glycol and particulate at each production machine prior to the central vacuum system. This will ensure a clean, low pressure drop central system.

Financials

1. There is the potential to reduce the annual energy costs for operating the vacuum system while enhancing system reliability. This can be achieved by eliminating waste at point-of-use applications, minimizing the number of on-line vacuum pumps and optimizing system configuration. A cost analysis has been developed based on the operating levels that were in effect at the time of the audit. This has been projected into a full year operating scenario. The annual cost to produce vacuum today is **$152,340** based on the information provided for energy and maintenance costs. The actual indirect costs that are associated with the vacuum system were not available. The maintenance costs for the present configuration are estimated as 15% of the electric cost based discussions with plant personnel regarding the situation at General Process Inc. Mobile. This percent is within the normal 15-20% level that we have found over our experience in auditing vacuum systems. See **Attachment D** for details on the financial analysis.

2. The current and future electrical costs are based on an overall average electrical rate for electricity of $0.064 per kWh. The electrical savings are calculated as the difference between the present operating power levels and the proposed operating power levels.

3. The audit indicates that an improved system with the addition of the new equipment listed in the Action Plan will meet current and future production requirements and reduce costs by **33%** under the proposed plan. The new operating cost will be **$102,997**. This is based on a projection of the present and proposed operating practices at present plant operating levels. The savings associated with the proposed system are **$49,343**. The simple payback on the investment needed to achieve these savings is 18.1 months. The cost of the Action Plan is **$74,500**.

4. Savings analysis does not include a cost avoidance of approximately **$85,300** for a new vacuum pump and **$65,240/year** of electrical cost. A new Liquid Ring vacuum pump would be required if no other changes are made to the system to improve delivery.

5. The projected savings in the vacuum system operating costs are truly valid and are achievable by General Process Inc. Mobile if the Action Plan is fully implemented. Stabilizing the vacuum system supply can provide savings in production areas by improving consistency of supply. These savings have not been included.

Summary

Every attempt has been made to incorporate the priorities conveyed by General Process Inc. Mobile personnel during the audit. System reliability has been incorporated in all items proposed and in the system reconfiguration. This system will continue to provide high quality vacuum supply to all users. The entire system will have stable pressure and the volume that is needed for individual applications.

It is very important that the plant supervise vacuum the same as it does with the electrical utility. All individuals that are involved with vacuum in any way need to be educated in order to make decisions that are cost conscious. Additions and deletions to the vacuum system should be reviewed and approved before implementation. The influence on operating cost and the initial purchase price are all part of the decision to purchase. Vacuum supply is not free as employees treat it now.

We express our appreciation for the support and interest demonstrated by all personnel. This has greatly enhanced the outcome of the audit. We are available to assist you until the proposed actions of the audit are fully implemented. Any questions concerning this audit or other matters relating to vacuum will be answered and explained. Please feel free to contact us when the need arises.

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Vacuum Systems Specialist

List of Attachments

A.	Existing Conditions:	Constituents of Demand System Operating Graphs
B.	Supply Information: -	Present Operating Scenarios (as audited) Existing Process Flow Diagrams
C.	Proposed Conditions:	Proposed Operating Scenarios Proposed Flow Diagrams
D.	Financial Items -	Financial Analysis Energy Calculations
E.	Action Items	Prioritized Action Plan

F. General Comments Concerning Savings Potential

G. Vendor Quotations

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