Evaluating the Performance of Oil-Free Floating Scroll Pumps in Multiphase Flow Applications

Dave Cai[1]* & Oliver Ni[1]

[1] Scroll Laboratories, Inc., 479 Quadrangle Dr Suite G
Bolingbrook, Illinois 60440, USA; Tel: (630) 783-2608
Email: dcai@scrolllabs.com

ABSTRACT

The growth of multiphase flow applications of vacuum pumps requires the reexamination of traditional pump variants, which have struggled with low energy efficiency, frequent maintenance needs, unstable vacuum pressures, and high internal leakage rates. The development of an oil-free floating scroll design, which balances separating forces within the scrolls both radially and axially, minimizes overall wear and allows for the proper disposal of system byproducts. Performance tests between the SVF-series floating scroll pumps, and other traditional pumps showcase increased efficiency, decreased long-term costs, minimal maintenance requirements, and significant environmental improvements in applications such as hydrogen recirculation units for fuel cells, helium leak detection, freeze dryers, TOPCon processes within photovoltaic (PV) cells, and plasma-enhanced chemical vapor deposition (PECVD).

1. INTRODUCTION

1.1 Comparisons of Traditional Wet and Dry Vacuum Pumps

Positive-displacement pumps are crucial to an increasingly diverse array of applications in industrial, research, and commercial contexts in handling multiphase flow such as gas with solids and/or liquids. The considerable growth in quality and quantity demands necessitate an evaluation of the efficiency, affordability, and cleanliness of various vacuum pump types to optimize the performance of related processes.

Traditional wet vacuum pumps, such as liquid-ring pumps and oil rotary vane pumps, have long been the standard for their comparatively low front-end costs and high flow rates. Indeed, in common industrial applications such as freeze drying and cannabis extraction, wet vacuum pumps constitute the most popular option amongst vacuum pumps. Despite their general effectiveness, the utilization of a liquid lubricant presents three major drawbacks: first, this usage necessitates frequent maintenance on the pump, both necessitating system downtime and increasing long-term costs; second, wet pumps require auxiliary equipment such as chillers for liquid-ring pumps to achieve liquid cooldown; third, oil pumps, particularly rotary vane pumps, need ballast valves to release water vapor before condensation, which in turn leads to oil molecules being discharged along water vapor into the ambient or into a separate filtration system.

Dry pumps, such as diaphragm pumps, screw pumps, and non-floating dry scroll pumps, offer a cleaner alternative with the absence of liquid lubricants, thereby leading to a lower risk of contamination. Compared to most wet pumps, however, dry pumps are often unable to offer equivalent flow rates or vacuum levels due to internal leakages. Furthermore, wearing parts such as tip seals on non-floating dry scroll pumps can increase debris generation due to dry friction; diaphragms, too, may crack due to fatigue failure, meaning that overall maintenance costs may not necessarily be lower than their wet counterparts.

1.2 Unique Challenges of Traditional Vacuum Pumps in Multiphase Flow Applications

While standard vacuum pump applications can accommodate traditional wet or dry variants based on individual needs, processes containing a multiphase flow, or the simultaneous flow of multiple fluid phases, present further challenges for all traditional choices. In such processes, changes to inputs may be induced by extreme temperature conditions or reactions between two different substances, thus requiring pumps to be able to handle the associated pressures and byproducts generated.

Traditional pumps, when attempting to achieve positive displacement, often cannot surmount the immense pressure caused by a shift of fluid phase. The conversion of vapors into liquids and/or directly incorporated liquids, in particular, poses the problem of hydraulic shock, or fluid hammer (Kozubkova et al, 2019). Liquids, which are generally incompressible, generate immense amounts of pressure and can damage the components of the pump as it is incapable of withstanding the strength of the acting force.

Pump damage and contamination can also occur as a result of the accumulation of solid or liquid byproducts if there is no efficient disposal method. Pumps that are unable to discharge water or other debris risk further corrosion, wear, and blockages warranting the need for replacements or additional maintenance. Furthermore, contamination can take place through the diffusion of oil in the work chambers of wet pumps and the improper management of waste gases, leading to significant harm to both the pumps themselves and their surrounding environment.

These drawbacks significantly hamper the overall productivity of various industrial processes involving multiphase flows including, but not limited to, hydrogen recirculation systems in fuel cells, freeze dryers, rotary evaporators, PECVD, PV cells, vacuum ovens, and carbon dioxide refrigeration systems.

1.3 Floating Scroll Design and Associated Benefits

The ideal solution to the previous concerns would entail a pump that could simultaneously handle the pressure buildup caused by multiphase flows and straddle the efficiency and cleanliness benefits presented by wet and dry pumps, respectively. A dry floating scroll design provides a balancing force that slightly exceeds the separating force within the system. The result force, which is optimized, creates light contact between the spiral walls and tip and base of the involved scrolls (Ni, 2007).

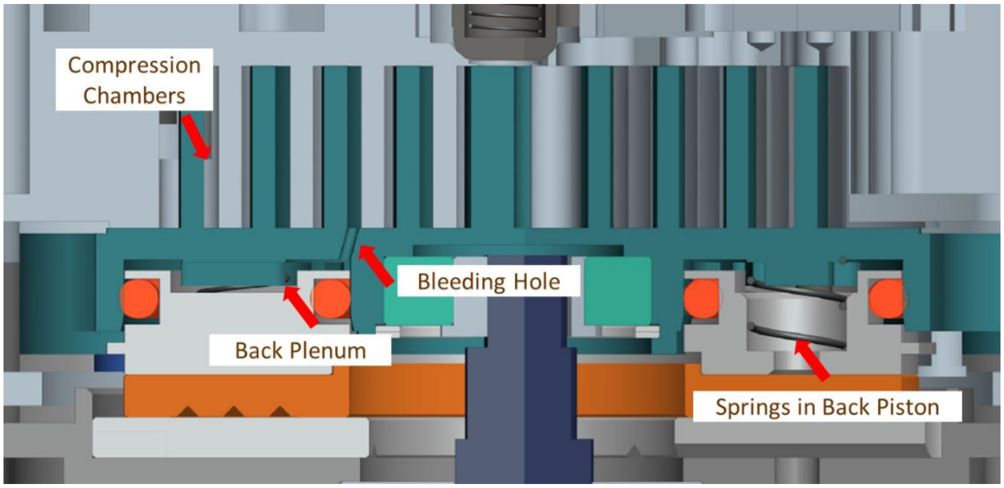


Figure 1 | Fully compliant floating scroll mechanism. The piston on the back of orbiting scroll forms a back plenum pressurized through a bleeding hole connected to compression chamber. The load in the plenum is optimized to overcome the separating force generated in compression chambers, minimizing the result force on the tip and base of orbiting scroll.

This light contact is crucial to the proper disposal of byproducts. As various materials are produced in their respective processes, the pressure produced will reach a critical point in which hydraulic shock would occur if any further compression is applied (Ni & Cai, 2002). Instead of risking damage, a floating scroll device is able to yield backwards in order to expand the volume of the debris and allow for the continued passing of all products through the overall system. As such, the floating scroll design avoids the accumulation of all byproducts in theory.

2. METHODOLOGIES AND RESULTS

2.1 Methodology of Performance Comparisons between Selected Pumps and SVF-Series Pumps

The SVF-series pumps are a line of oil-free, scroll vacuum pumps manufactured by Scroll Labs, and will serve as the benchmark for performance comparison tests with selected traditional vacuum pumps. Two pumps are selected for the comparisons: the SVF-100, which is the standard oil-free floating scroll model, and the SVF-300, which has a larger flow rate and lower ultimate vacuum pressure at the expense of greater size and power consumption.

The selected traditional pumps include an existing water-ring pump and a rotary vane oil pump, which are both wet pumps. The pumps were tested under a controlled environment with the applications being the winterization process, rotary evaporation process, and distillation process of cannabis ethanol extraction. The two main focuses of the performance tests involved overall productivity and associated costs, the two foremost concerns of vacuum pump consumers. Only wet pumps were chosen for these specific comparisons, as traditional dry pumps are far more expensive and are not widely utilized within this context.

2.2 Performance Comparison between Water-ring pump and SVF-100 oil-free scroll vacuum pump

The SVF-100 oil-free scroll vacuum pump is compared to a traditional water-ring pump in the winterization process and rotary evaporation process of cannabis ethanol extraction. Of note is the difference in ultimate vacuums between the two pumps: the SVF-100's 0.1mbara is considerably lower than the 33mbara of the water-ring pump. This low vacuum pressure ensures a continuous, stable suction flow for extracted materials, improving the quality of the multiphase fluid extraction and raising productivity by 20%~30%.

Specification Comparison

Model	Water-Ring Pump	SVF-100 Scroll Pump
		
Power	700 W (including chiller and water circulation)	<180 W
Pump Flow	90 L/min	100 L/min
Voltage	220VAC / 60HZ	115VAC (90~132VAC) 230VAC (180~230VAC) Convert to 48DC BLDC motor
Max. vacuum	33mbara	0.1mbara
Dimensions	450mm × 340mm × 870mm	324mm x 215mm x 206 mm
Net weight	37kg	8.5 kg

Based on the performance test, SVF-100 is far more efficient than the chosen water-ring pump, consuming roughly 25% of the power used by its counterpart. Furthermore, the utilization of a water-ring pump system is far more complex with the usage of a separate chiller and water circulation system. While water-ring pumps are regarded for their durability, the SVF-series pumps have lifespans exceeding 20,000 hours in actual applications. The overall operating costs of SVF-100 are significantly lower, and no operational down-time is expected.

2.3 Performance Comparison SVF-100 and SVF-300 Oil-Free Scroll Pump vs. Rotary Vane Pump

In this performance test, lower pressures were utilized for the distillation process of the cannabis ethanol extraction application. The selected rotary vane oil pump is compared with both the SVF-100 and the SVF-300, the latter of which yields a more representative comparison with the traditional pump.

Specification Comparison

Model	**Typical Rotary Pump**	**SVF-100**	**SVF-300**
			
Power	750 W	<180 W	≤400 W
Pump Flow	360 L/min	100 L/min	300 L/min
Voltage	380VAC / 60Hz	115VAC (90~132VAC) 230VAC (180~230VAC) Convert to 48DC BLDC motor	115VAC (90~132VAC) 230VAC (180~230VAC) Convert to 48DC BLDC motor
Ultimate Vacuum Pressure	≤1Pa (with ballast valve)	≤1 Pa (no ballast valve needed)	≤1Pa (no ballast valve needed)
Dimensions	560mm × 200mm × 340mm	324mm × 215mm × 206 mm	430mm × 320mm × 334mm
Net weight	40kg	8.5 kg	30kg
Noise level	76 dB(A)	55 dB(A)	≤60 dB(A)

The SVF-100 has a pumping speed just over a quarter of the selected rotary vane pump and maintain its vacuum pressure at 0.77mbara, higher than the 0.45mbara mark of the rotary vane pump. The SVF-300, too, has a lower flow rate at 300 L/min and can maintain a comparable vacuum pressure no higher than 0.45mbara, showcasing its higher operational efficiency.

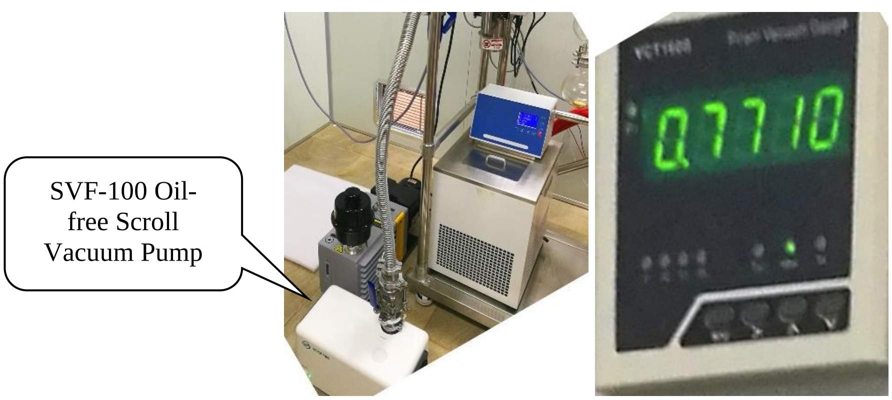


Figure 2 | Single SVF-100 in a distillation process

Compared to oil pumps, it is more economical to use SVF oil-free scroll vacuum pumps. The overall operating cost is lower. Here are the minimum costs of both the SVF pump and rotary vane oil pump.

3. DISCUSSION

3.1 Performance Differences between SVF-Series Pumps and Selected Traditional Pumps

As demonstrated through the results, the SVF-series pumps demonstrate a comparable flow rate, power consumption and vacuum pressure as the selected wet pumps while holding significant advantages in overall costs and ease of use. These advantages mean that in difficult multiphase applications, floating scroll pumps are preferable to consumers than traditional wet pumps. Comparison tests in other applications yield similar results between the SVF-series pumps and traditional dry pumps, which are significantly more expensive in general.

3.1.1 SVF-300 and Dry Rotary Vane Pump

SVF-300 displayed overall better performance statistics than standard dry rotary vane pumps. SVF-300 has a higher pumping speed when inlet pressure is lower than 35mbara, and since the overall power consumption of SVF-300 is much lower, this means that SVF-300 is preferable in applications such as vacuum conveying, packaging, and vacuum holding.

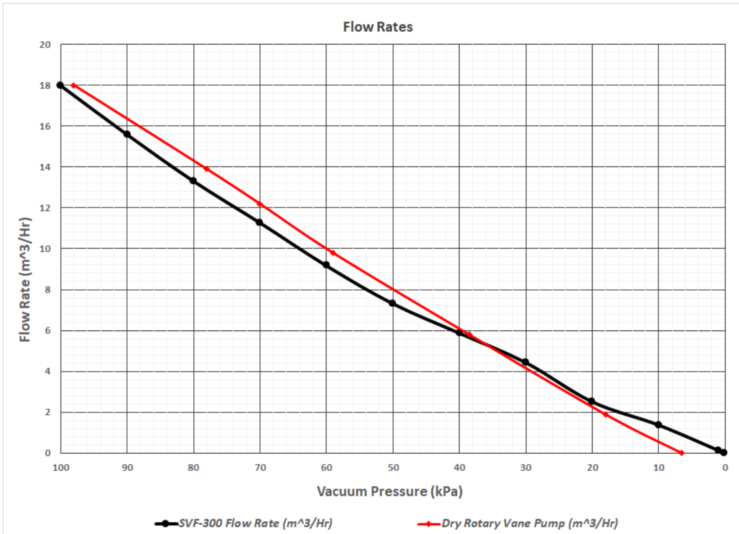


Figure 3 | Pumping Speeds of SVF-300 and Dry Rotary Vane Pump at Different Inlet Pressures

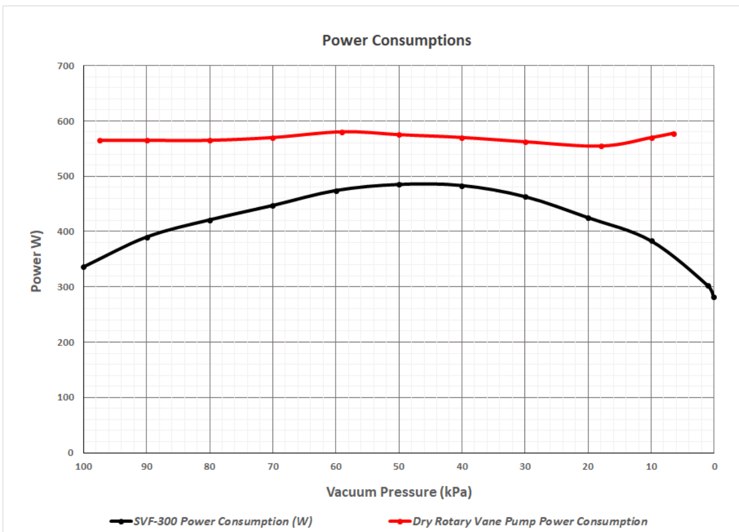
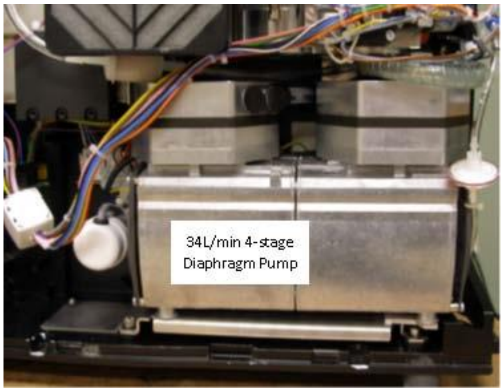


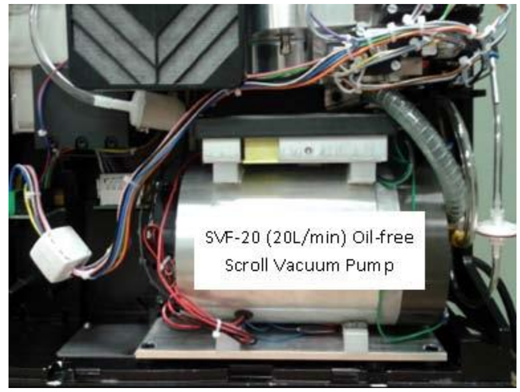
Figure 4 | Power Consumption of SVF-300 and Dry Rotary Vane Pump at Different Inlet Pressures

3.1.2 SVF-20 and multiple-stage diaphragm pump in helium leak detector

In a helium leak detector, a single-stage SVF-20 oil-free scroll pump replaces a 4-stage diaphragm pump to provide far better volumetric efficiency. The diaphragm pump consists of four stages in series to reach target base pressure. This makes the pump heavier, larger, and less efficient which results in more heat generated.



4-stage Diaphragm Pump (34L/min) in the Leak Detector



SVF-20 (20L/min) Oil-free Scroll Pump in the Leak Detector

	4-stage Diaphragm Pump	**SVF-20**
Weight	9585 grams	2750 grams

Compared to the diaphragm pump, the SVF-20 pump is much lighter and more compact. Besides, SVF-20, whose pumping speed is 20L/min, reaches lower pressure levels in the same time span.

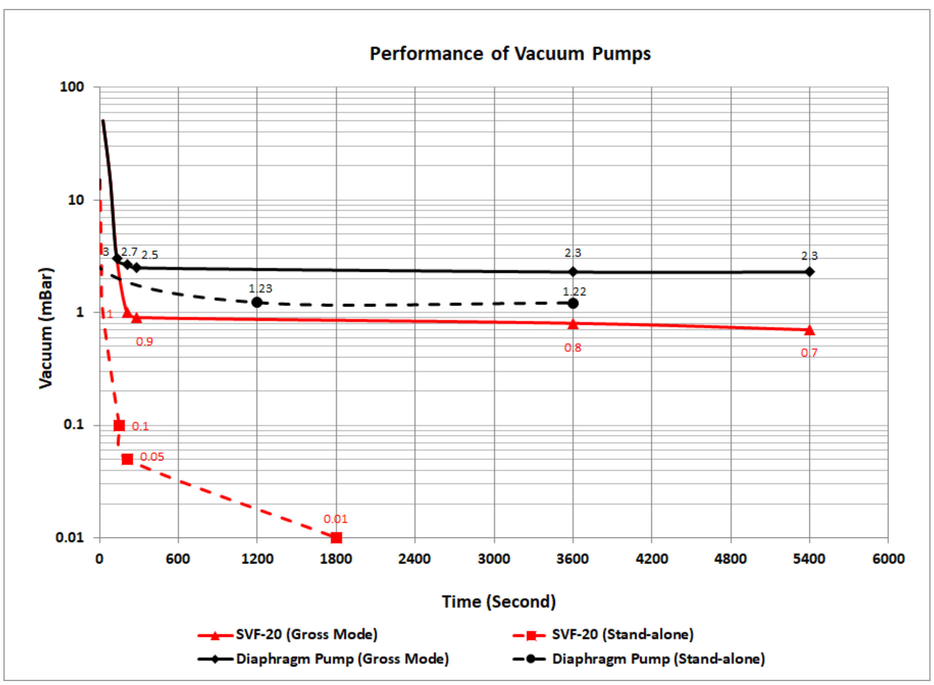


Figure 5 | Performance Comparison of SVF-20 and the Diaphragm Pump

The test results show that SVF-20 has much better performance both working as a stand-alone pump and backing up the turbo molecule pump in the leak detector (gross mode).

3.2 Case Study: Hydrogen Recirculation

Hydrogen recirculation is particularly crucial in fuel cells to reclaim exhaust hydrogen and minimize operational costs. Most traditional pumps are generally unable to handle the multiphase water byproducts found in fuel cells as hydraulic shock can cause significant damage. Now, with a floating scroll design, Scroll Labs can provide a hydrogen recirculation compressor, SCF-100H2, that is capable of handling high levels of humidity. The specifications are listed below.

#	Item	Specifications	Notes
1	Medium	Hydrogen	
2	Rated Speed	3300 RPM	±50 rev/min
3	Inlet Pressure	46.2 kPa (gauge)	
4	Outlet Pressure	60.2 kPa (gauge)	
5	Flow Rate	130 SLPM	±5 SLPM
6	Rated Power Consumption	210 W	Including cooling fans
7	Motor	48VDC, 350W Brushless DC motor	
8	Leak Rate	1×10^{-8} Pa·m³/s	
9	Dimension	189mm × 228mm × 324mm	
10	Weight	7kg	
11	Life	10,000 hours	Maintenance free
12	Noise Level	60dB(A)	Measured 1 meter from the compressor
13	Cooling	Air Cooled	
14	Allowable Ambient Temperature	-40 ~ +60℃	

3.3 Case Study: PV TOPCon

SVFA-200

SVFA-300

Diaphragm Pump

In the TOPCon process of PV cells, floating scroll pumps such as the SVFA-200 and SVFA-300 yield better results than traditional diaphragm pumps due to better performance, longer life, and no downtime maintenance. Unlike diaphragm pumps, which can accumulate significant polymer debris and necessitate frequent maintenance, controls can switch off individual floating scroll pumps for maintenance purposes without shutting down the entire system.

4. CONCLUSION

The SVF-series oil-free floating scroll pumps are ideal for processes that involve multiphase flows. In addition to yielding similar vacuum pressures, SVF pumps are more compact and lighter, less power-intensive, quieter, less polluting, and require less maintenance, leading to pumps that are far more efficient on aggregate. These benefits extend beyond the discussed applications and apply to medical and pharmaceutical appliances, analytical devices, and any clean, low base pressure applications.

5. REFERENCES

Kozubkova, M., Jablonska, J., Bojko, M., Dvorak, L., & Carnogurska, M. (2019). Multiphase fluid models to deal with Fluid Flow Dynamics. MM Science Journal, 2891–2896. https://doi.org/10.17973/mmsj.2019_06_201880.

Ni, S. (2007, July 26). Scroll-Type Fluid Displacement Apparatus with Fully Compliant Floating Scrolls.

Ni, S. S. and Cai, D. K., “Oil-Free ‘Floating Scroll’ Compressor” (2002). International Compressor Engineering Conference. Paper 1599. https://docs.lib.purdue.edu/icec/1599

ACKNOWLEDGEMENT

The authors are grateful for the assistance and guidance of Shimao Ni throughout the research and writing process of the paper. Further thanks are given to the R&D team at Scroll Laboratories for all test results.