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VP-Series Pumps

USER GUIDE

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User Guide Version 2.2 (Dec 2020)
Based on VPware 1.2.66 and
Firmware Version 298.hex,
or later versions. Contact Vindum
Engineering for latest versions.

We recommend that you read this Installation and Operation Manual completely prior to using your VP-Series pump for the first time.

Vindum Engineering Technical Support is available to help with any questions or issues regarding use of your VP-Series Pump.

Technical Support

Phone: 281.782.8312

Email: support@vindum.com

Pump Support: please include the following if you need support

1. Pump serial number
2. Version of VPware pump control software
3. Firmware version
4. Copy of EventLog.txt file
5. Copies of ErrorState_Pump files containing the pump error
6. Short description of problem

With this information, we will respond with assessment and recommendation(s), usually within 24 hours.

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IMPORTANT SAFETY SYMBOLS & WARNINGS

This manual uses the following symbols and notations for emphasis. PLEASE PAY SPECIAL ATTENTION TO THE INFORMATION THAT APPEARS NEXT TO THESE SYMBOLS.

WARNING - AVOID HAZARDOUS PRACTICE

EXPLOSION HAZARD WARNING

ELECTRICAL SHOCK WARNING

PINCH POINT WARNING

HEAVY OBJECT LIFT WARNING

IMPORTANT INFORMATION - READ CAREFULLY

PLEASE ENSURE THAT YOU READ AND UNDERSTAND THE LIST OF-WARNINGS ON THE FOLLOWING PAGES. IF YOU HAVE ANY QUESTIONS ABOUT THESE WARNINGS OR THE SAFE OPERATION OF THE PUMP, CONTACT VINDUM ENGINEERING TECHNICAL SUPPORT BEFORE USING YOUR VP PUMP.(support@vindum.com or +1 281-782-8312).

! EXPLOSION HAZARD WARNING !

VP-Series Pumps are NOT EXPLOSION PROOF !!!

VP-Series pumps are not explosion proof and are not designed for use with fluids (liquids or gases) that are flammable or explosive, or that become explosive or flammable under pressure. USE OF VP-SERIES PUMPS IN THESE CONDITIONS IS AT THE USER'S SOLE RISK! Even with precautions, such as placing the pump in a functioning vent hood, there is still a risk that seals and pump fittings can leak in the course of normal use, releasing the fluids and creating an explosion risk.

RISK OF ELECTRICAL SHOCK: Disconnect electrical power before servicing the pump.

PINCH POINT WARNING: Avoid placing fingers or hands inside the pump if the transparent front cover is removed, as serious injury could occur if placed in the path of the moving piston assemblies.

HEAVY OBJECT LIFT WARNING: To reduce the risk of injury, take care in lifting and carrying the pump. Depending on the model, VP-Series pumps can weigh 65 lbs. (30 kg) or more.

SPILL RISK: Plan for leaks by working in an environment designed for the types of fluids you are using. Refer to the Material Safety Data Sheet (MSDS) for the type of fluid you are using. Ensure that the environment surrounding the pump complies with federal, state, and local laws, and those of your company, for the fluids being used.

FLUID COMPATIBILITY RISK: Avoid using fluids that are incompatible with the metallurgy and seals of your pump to prevent premature failure resulting in leaks that can cause damage and/or severe bodily harm. Metallurgy of the wetted parts and seal materials are summarized on a label found on the back of the pump.

AVOID HAZARDOUS PRACTICES: Use of this pump in any manner not specified by the manufacturer may impair the protection provided by the equipment and increase the risk of injury to the user. The VP-Series pump can operate at very high pressures (up to 25,000 psi in some models). **Fluids at these pressures, especially compressible fluids or gases, are capable of causing serious bodily harm or death if handled incorrectly.** Before using the VP-Series pumps, ensure that you have the proper training, protective equipment, and environment for working with fluids at elevated pressures.

RISK FROM OPENING FLUID INLET AND OUTLET VALVES ON SAME CYLINDER: Avoid having the pump's Fluid-In and Fluid-Out valves on the same cylinder open at the same time, as this creates an flow path through the pump's cylinder(s). Unexpected flow of high pressure fluid through the cylinder can result, which can damage connected equipment and/or cause injury to the user. **For instance, concurrently opening both inlet and outlet valves on the same cylinder could allow high pressure fluid to be forced backwards through the pump and into the fluid reservoir, possibly rupturing the reservoir and causing damage or injury.**

SAFE SHUT DOWN WARNING: Do not leave a pump with pressurized fluids in the cylinders, as could cause harm to the next user. **The fluid inlet and outlet valves close automatically with any interruption of power to the pump, caused by either switching off power to the pump or by activating the E-Stop circuit. This can leave high-**

pressure fluids in the pump cylinders. See Section 6 for instruction on how to safely relieve pressure from cylinder with closed valves.

LOSS OF COMPRESSED AIR SUPPLY: VP-Series pumps require a constant supply of compressed air to operate the pump's fluid-control valves. Do not attempt to run the pump without supply of 70-100 psi of clean compressed air to the pump. If the supply of compressed air to the pump is lost, stop the pump immediately. Without compressed air, the actual position of the fluid-control valves may be different than shown by the VPware application. There is no way to know the position of the valves after losing compressed air supply. To prevent high pressure fluids connected to the pump from possibly being pushed into or through the pump's cylinders in the event of losing compressed air supply, install a check-valve on the fluid outlet line connected to the pump.

MAINTAIN ACCESS TO POWER SWITCH: For emergency preparedness, do not block or impede user access to the power switch on the back of pump.

DO NOT BLOCK COOLING VENTS: To prevent the pump from overheating and shutting down, do not block the cooling vent holes on the sides and bottom of the pump. An internal fan provides air circulation by drawing air through holes in the bottom and out through the vent holes on the sides of the pump. Keep these areas clear.

PRESSURE TRANSDUCERS SELECTION: Vindum Engineering offers several transducer models to provide users with option of selecting transducers to fit different pressure ranges. In the event that the user changes the model of transducer installed on their pump, it is very important that they also change the transducer model on the VPware configure screen so that VPware can apply the correct transducer gain setting. Otherwise, serious damage or injury can result.

PRESSURE TRANSDUCER CALIBRATION: Regularly calibrate the pump's two pressure transducers. The transducer Zero Offset should be reset every time the pump is used. The transducer Gain settings should be checked annually or more often. Failure to reset the "pressure zero offset" and/or the transducer gain setting can lead to incorrect pressure readings, which can prevent the pump from operating correctly and can result in damage to the pump and/or injury to the pump operator.

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1. INTRODUCTION TO VINDUM VP-SERIES PUMPS

1.1 Introduction and Intended Use

ENSURE THAT YOU HAVE READ AND UNDERSTAND ALL OF THE IMPORTANT SAFETY WARNINGS IN THE PRECEEDING SECTION OF THIS MANUAL BEFORE SETTING UP AND OPERATING YOUR NEW PUMP. CONTACT VINDUM ENGINEERING BEFORE USING THE PUMP IF YOU HAVE ANY QUESTIONS.

Thank you for your purchase of a continuous-flow, pulse-free VP-Series Pump, designed and manufactured by Vindum Engineering in California, USA. The VP-Series pumps have been designed by an experienced team, which has over 100 man-years of pump development experience, to deliver the best combination of performance, quality, and value available today.

A good understanding of your new pump's design, operation, and preventative maintenance will ensure years of trouble-free operation. Please take the time to read and understand this user manual before using your VP-Series pump. **If you have any questions or need assistance, please contact Vindum Engineering at the email address or phone number listed at the front of this user manual.**

The VP-Series pumps have been designed to pump fluids continuously, very accurately, and at very high pressure. Each VP-Series pump has two cylinders for delivering or receiving fluids. These cylinders may be operated either independently or in "paired mode," whereby the pump will deliver or receive fluid continuously at either constant-rate or constant-pressure (selected by the user). In paired modes, sophisticated electronics, two pressure transducers, and two sets of patented automated valves enable the pump to operate in a continuous manner, with pulse-free delivery or receipt of fluids at high pressures with high accuracy.

The VP-Series pumps are controlled by proprietary software, **VPware**, that uses Windows PC (Windows 7 or later) connected to the pump via a USB-USB cable, USB-RS232 cable, or third party Serial-to-Ethernet converter gateway device. In addition to the VPware pump-control software, there are several other means of controlling the pump that provide the user great flexibility of using the pump with other control systems. Pump control options are explained in Section 9 of this manual.

1.2 Environmental Requirements for Pump Operation

VINDUM VP-SERIES PUMPS ARE NOT DESIGNED FOR USE WITH FLUIDS THAT ARE VOLATILE, FLAMMABLE, EXPLOSIVE, OR OTHERWISE HAZARDOUS. USING THE PUMP IN ANY SUCH APPLICATION OR ENVIRONMENT IS AT THE USER'S SOLE DISCRETION AND RESPONSIBILITY.

VP-Series Pumps have been tested for operation within the following environmental

conditions:

- Indoor use only;
- Altitude: up to 2,000 m;
- Ambient temperature: 5°C to 40°C for all pump models, except High-Temperature Pump models, which are 5°C to 160°C;
- Maximum relative humidity: 80% for temperatures up to 31°C, decreasing linearly to 50% relative humidity at 40°C;
- Pollution Degree: 2 (amount of dry pollution and condensation present)
-  **Cooling Ventilation: VP-Series pumps contain a small cooling fan located in the base of the pump, which draws air from the space under the pump and exhausts it through the holes on the sides and back of the pump. In order to ensure adequate cooling of the internal components, it is important that these areas are not blocked from circulating air through the pump. Otherwise internal components could overheat and cause the pump to stop.**

1.3 Power Requirements

Power input specifications of the VP-Series Pumps:

- Measurement Category: II (resistance to voltage spikes)
- Power supply is capable of supplying full rated power in continuous operation throughout the ranges of voltages and frequencies shown in the following table.

Parameter	Minimum	Rated	Maximum
RMS Input Voltage	90 VAC	100-240 VAC	264 VAC
RMS Input Current	—		4.1A @ 100V 1.7A @ 240V
Input Frequency	47 Hz	50-60 Hz	63 Hz

1.4 Specifications For VP-Series Pumps

The table below lists the specifications for the different models of VP-Series pumps, including “Ambient Temperature”, “EXT Temperature”, and “High Temperature” models.

VP-Series Pump Specifications

Vindum Pump Model	VP-3K Ambient VP-3K Extended Temp VP-3K High Temp	VP-6K Ambient VP-6K Extended Temp VP-6K High Temp	VP-12K Ambient VP-12K Extended Temp VP-12K High Temp	VP-20K Ambient VP-25K Ambient
Maximum Pressure Rating	3,500 psi (207 bar)	6,500 psi (413 bar)	12,000 psi (827 bar)	20,000 psi (1,379 bar) 25,000 psi (1,725 bar)
Minimum Flow Rate	0.0001 ml/min	0.00005 ml/min	0.00001 ml/min	0.00001 ml/min
Maximum Flow Rate	97 ml/min (0-2,000 psi)	54 ml/min (0-4,000 psi)	29 ml/min (0-7,500 psi)	12 ml/min (0-12,000 psi)
Flow rate & volume accuracy	+/- 0.1% of set point	+/- 0.1% of set point	+/- 0.1% of set point	+/- 0.1% of set point
Rate & volume repeatability	+/-0.05% of set point	+/-0.05% of set point	+/-0.05% of set point	+/-0.05% of set point
Displacement Resolution	0.0240 µl/step	0.0135 µl/step	0.0074 µl/step	0.0034 µl/step
Single Stroke Displacement, per cylinder (approx.)	40 ml	20 ml	10 ml	5 ml
Compression Ratio	5.4 : 1	4.5 : 1	3.7 : 1	3.8 : 1
Pressure Accuracy	+/- 0.1% of Full Scale	+/- 0.1% of Full Scale	+/- 0.1% of Full Scale	+/- 0.1% of Full Scale
Pressure Resolution	0.1 psi	0.1 psi	0.1 psi	0.1 psi
Capable of Vacuum Filling	Yes	Yes	Yes	Yes
Operating Environment **Operating Environment (EXT)** **Operating Environment (HT) (portion of pump inside oven)**	5°C - 40°C (41°F-104°F) 5°C - 40°C (41°F-104°F) 5°C-160°C (41°F-320°F)	5°C - 40°C (41°F-104°F) 5°C - 40°C (41°F-104°F) 5°C-160°C (41°F-320°F)	5°C - 40°C (41°F-104°F) 5°C - 40°C (41°F-104°F 5°C-160°C (41°F-320°F)	5°C - 40°C (41°F-104°F)
Fluid Temp. (Ambient Pumps) **Fluid Temp (EXT Pumps)** **Fluid Temp (HT Pumps)**	To 65°C (150°F) To 120°C (250°F) To 160°C (320°F)	To 65°C (150°F) To 120°C (250°F) To 160°C (320°F)	To 65°C (150°F) To 120°C (250°F) To 160°C (320°F)	To 65°C (150°F)
Pump Dimensions (HxWxL) (excludes cables)	19 x 6 x 9 inches 19 x 6 x 9 inches 26 x 9 x 10 inches	19 x 6 x 9 inches 19 x 6 x 9 inches 26 x 9 x 10 inches	19 x 6 x 9 inches 19 x 6 x 9 inches 26 x 9 x 10 inches	19 x 6 x 9 inches
Fluid Connection Fittings	Autoclave Engineers SW250 Female (1/4” Speed-Bite)	Autoclave Engineers SW250 Female (1/4” Speed-Bite)	Autoclave Engineers W125 Female (1/8” Speed-Bite)	Autoclave Engineers F250C Female (1/4” High Pressure)
Safety Blowout Disk Port Connection (tubing connection to SBD assembly)	Autoclave Engineers W125 Female (1/8” Speed-Bite)	Autoclave Engineers W125 Female (1/8” Speed-Bite)	Autoclave Engineers W125 Female (1/8” Speed-Bite)	3/8” NPT Female
Power Supply Requirement	100-240VAC, 47-63 Hz	100-240VAC, 47-63 Hz	100-240VAC, 47-63 Hz	100-240VAC, 47-63 Hz

Continued on Next Page

Specifications For VP-Series Pumps (continued)

Wetted Parts	VP-3K Ambient VP-3K Extended Temp VP-3K High Temp	VP-6K Ambient VP-6K Extended Temp VP-6K High Temp	VP-12K Ambient VP-12K Extended Temp VP-12K High Temp	VP-20K Ambient VP-25K Ambient
Cylinder Barrel	316 Stainless Steel or Hastelloy© C276	316 Stainless Steel or Hastelloy© C276	316 Stainless Steel or Hastelloy© C276	316 Stainless Steel or Hastelloy© C276
Piston	Zirconia Silicon-Carbide Silicon-Carbide	Zirconia Silicon-Carbide Silicon-Carbide	Zirconia Silicon-Carbide Silicon-Carbide	Silicon-Carbide
Main Piston Seal	UHMW-PE Tivar® H.O.T. or Flouraz Flouraz	UHMW-PE Tivar® H.O.T. or Flouraz Flouraz	UHMW-PE Tivar® H.O.T. or Flouraz Flouraz	UHMW-PE
Standard Valve Seals **(Other options available, contact Vindum Engineering)**	Viton or AFLAS Viton or AFLAS Viton or AFLAS	Viton or AFLAS Viton or AFLAS Viton or AFLAS	Viton or AFLAS Viton or AFLAS Viton or AFLAS	Viton, AFLAS, or other custom materials by request
Standard Manifold Face Seals **(Other options available)**	Viton or UHMW-PE Viton or AFLAS Viton or AFLAS	Viton or UHMW-PE Viton or AFLAS Viton or AFLAS	Viton or UHMW-PE Viton or AFLAS Viton or AFLAS	Viton or AFLAS

1.5 Warranty for VP-Series Pumps

Vindum Engineering Inc. - Two Year Limited Factory Service Warranty

This warranty covers your Vindum Engineering Inc. (VEI) VP-Series pump.. The original company or individual who purchased the pump from VEI is entitled to this warranty. This warranty is not transferrable.

If any shipping damage is evident when receiving a new pump, the customer should immediately notify VEI. Photos of the damager are very helpful.

Any owner of a VP-Series pump, who purchased the pump directly from VEI, that fails during the warranty period due to either a faulty part or assembly issue will be repaired at VEI's California factory at no charge. VEI liability is limited to repair or replacement of the defective VP-Series pump. VEI is not liable for consequential damages. This warranty does not extend to the pump's normal wear and maintenance items, including: 1) Main Piston Seals; 2) Other Fluid Seals, including valve seals and face seals; 3) Safety Burst Discs, or to any parts or equipment subjected to misuse, neglect, accident, improper maintenance, alterations or modifications. No person, agent, distributor, or dealer is authorized to change, modify, or extend the terms of these warranties in any manner.

VEI will pay for round-trip shipping charges for any unit that we, solely, deem to be defective within 90 days of original pump shipment date. After the 90-day period, and for the remainder of the warranty period, the customer will pay shipping costs to return a defective pump to VEI and VEI will pay transportation to return the repaired pump to the same customer and location. VEI will not pay for costs associated with the customer's packing and/or crating of the pump. This warranty does not cover loss, damage, or defects resulting from transportation between the customer's facility and VEI's repair facility, which are the responsibility of the customer.

The warranty period begins on the shipping date that the pump leaves VEI's California manufacturing facility.

Many problems can often be diagnosed and corrected over the phone or by email, without returning the pump to the factory. If the user suspects a problem or issue with their pump, please contact VEI at support@vindum.com or +1 281-782-8312.

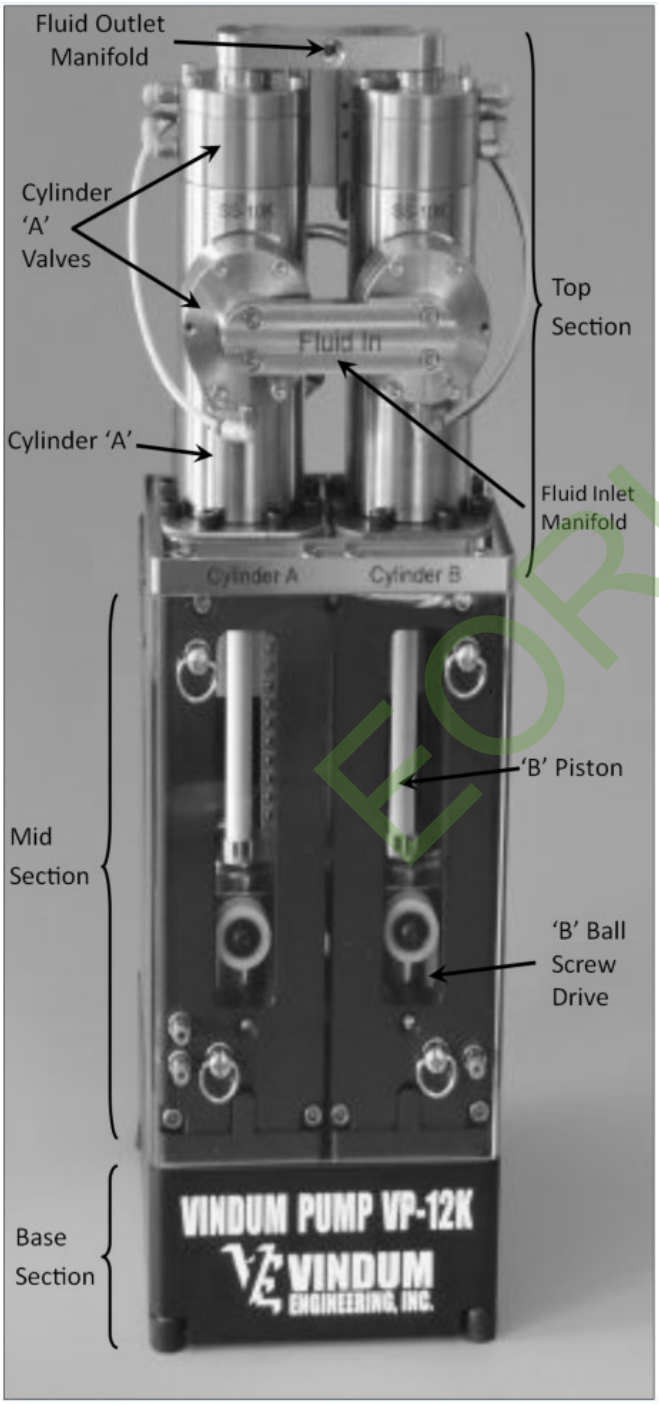
Before returning any pump for repair, the user must contact VEI to receive a Return Authorization. Phone: 281.782.8312 Email: support@vindum.com

Pumps needing factory repair must have all fluid evacuated and should be packed carefully for shipment. Before returning any pump to Vindum Engineering for repair or service, our Service Department will contact the customer and will provide a Return Authorization (RA) Number as well as the shipping address to VEI's Service Facility.

2. OVERVIEW OF VP-SERIES PUMPS

2.1 Pump Elements

The figure below shows the front of a VP-Series Ambient Temperature pump and it's elements. The Ambient Temperature VP-Series pump models are best described by the three main sections that are common to all VP-Series pumps and are noted in the figure:



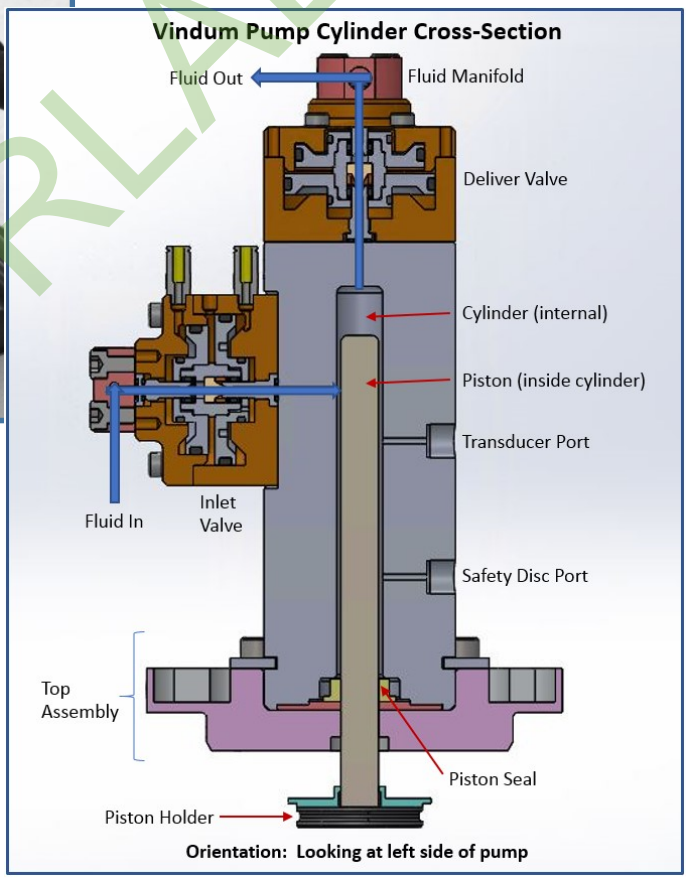
- **Base Section:** Houses the power supply, power cable attachment point, power switch, and belt drives connecting the gear boxes to the two ball-screw drive units. For convenience, a handle is integrated into the base on the back of the pump for lifting and moving.

IMPORTANT: the pump's cooling fan draws air from the bottom of the pump and exhausts the air through vent holes in the pump's mid-section. Ensure that these areas are not blocked or the pump could overheat and stop.

- **Mid Section:** Visible behind the transparent front cover are the two ball-screw drives and pistons. The two pistons sit atop the ball screw mechanisms and extend into the cylinders that sit atop the pump body. Inside the pump's case are the two motors and planetary-type gearboxes, electronic circuitry, and ventilation fan. On the backside of the pump are the electrical connectors for the pressure transducers, USB, RS232, valves, and an optional emergency shutoff switch connection (for user-installed switch).

- **Top Section:** The pump cylinders and integrated inlet/outlet valves are the most prominent elements of the top section of the pump. Each vertical pump cylinder has a pair of integrated inlet and outlet valves, which are air-actuated via the small colored Teflon tubes. The Fluid Inlet and Fluid Outlet manifolds, marked "FLUID IN" and "FLUID OUT", are mounted on the inlet and outlet valve pairs to provide a com-

mon pathway for fluid to enter and exit each of the two pump cylinders. The figure at left below shows the components on the rear of the pump's Top Section. A safety burst disc assembly is located on each cylinder. Above the safety burst discs are the two pressure transducers which provide continuous pressure readings of the cylinder pressure. At the top portion are four solenoids pilot valves which control the flow of compressed air used to open and close the fluid inlet and outlet valves. Also visible is the compressed air inlet quick-connect port that is used to open/close the fluid inlet and outlet valves. The compressed air is routed to the four inlet/outlet valves to open or close them via the valve solenoids. Small mufflers are mounted on the back of the valve solenoid manifold to quiet the small volume of compressed air that is released when a valve opens or closes. Not shown in this figure are the certificates for the safety burst discs that are included with each pump (in spares kit).



A cutaway view of a VP cylinder and inlet and outlet valves is shown at right. This illustration helps to visualize the internal design and the path of fluid flow through the pump. Note that the piston seal is located at the base of the cylinder and is stationary; the piston moves through the seal. This design is known as a "piston metering pump", which is different than a "syringe metering pump", in which the piston seal moves with the piston. Benefits of this design include increased accuracy and elimination of damage to the cylinder wall from abrasives trapped around the moving seal.

From the cylinder internal view, you can also see that there is a small gap ("annulus") between the piston and cylinder wall. As a result, the two valves connected to the cylinder are always in pressure communication. **Because of this, if the pump is connected to a high pressure system, users must avoid having the inlet and outlet valve open at the same time, as pressurized fluid can flow through the cylinder and out the fluid inlet valve. VPware issues a warning message if the user attempts to open both inlet and outlet valves on the same cylinder.**

2.2 Pump Operations Overview

The VP-Series pumps are among the most sophisticated high-pressure metering pumps available. These pumps are capable of being operated continuously in "paired cylinder modes" or "independent modes" where each cylinder acts as an independent single-cylinder pump. As delivered from the factory, a manifold connects the two fluid inlet valves and another manifold connects the two fluid outlet valves so that there so that there is a single "Fluid Inlet" port and "Fluid Outlet" port. In order to use the pump with each piston/cylinder operating independently of the other, it is necessary to replace the Fluid Inlet and Outlet manifolds with two inlet and two fluid outlet connectors to segregate the cylinders. These Independent Fluid Manifolds are available from Vindum Engineering.

2.2.1 Pulse-Free Operation—Paired Cylinder Modes

In the paired cylinder modes, the motion of the two pistons and operation of the valves is coordinated via advanced electronics to deliver continuous, pulse-free fluid flow at either constant-rates or constant-pressure. This is accomplished by the patented, constant-volume fluid inlet/outlet valves that are integrated with each cylinder. Opening or closing these valves does not create a pressure pulse because the internal volume of the valve does not change when opened/closed. These valves are activated by four solenoid valves, located on the rear of the pump. The computer circuit board sends an electrical signal to the individual solenoid valves, causing them to open or close. When the solenoids are activated they direct compressed air to open or close the valve to which the solenoid pilot valve is connected.

In paired operating modes, one piston is actively pumping, while the other refills with fluid. The cylinder that is refilling is called the "passive cylinder" and it's piston is the "passive piston". Once refilled, the valves on the passive cylinder close and the piston pressurizes the fluid inside to match the pressure of the pumping (or "active") cylinder. Right as the active cylinder reaches the end of it's stroke, the deliver valve on the passive cylinder opens to continue pumping. Because the pressure in the two cylinders is the same, no pressure pulse is introduced into the fluid. Thus, in "paired constant-rate mode," the pump can

continuously deliver (or receive) very precise rates of fluid for weeks, months, or even years, if needed. Similarly, in "paired constant-pressure mode" the pump will run continuously and deliver or receive fluid at constant pressure. Note that in constant-rate mode, the pressure is dependent on the rate, while in constant-pressure mode, the set pressure is maintained and the fluid rate may vary. **It is not possible to specify both constant pressure and rate at the same time using the pump controller.**

2.2.2 Independent Cylinder Operation

In the "independent modes" the VP-Series pumps operate as two independent single – cylinder pumps, each cylinder operating independently of the other. The volume delivery in single-cylinder mode is limited to the piston stroke volume, as each cylinder needs to be refilled at the end of the piston stroke before pumping can resume. **In order to operate the two cylinders independently at the same time, it is necessary to replace the Fluid-In and Fluid-Out manifolds with separate fittings for each cylinder. Contact Vindum Engineering (support@vindum.com or +1-281-782-8312) regarding purchase of these optional single-cylinder fluid inlet and outlet ports.**

2.3 Pump Safety Features

WORKING WITH FLUIDS, AND ESPECIALLY GASES, AT HIGH PRESSURE REQUIRES PLANNING AND CAREFUL OPERATION. ENSURE THAT YOU HAVE READ AND FULLY UNDERSTAND ALL THE IMPORTANT SAFETY WARNINGS AT THE FRONT OF THIS MANUAL!

Each VP-Series pump has been designed with user safety in mind and includes a number of features to help protect the user and to prevent damage to the pump and any other equipment connected to your pump. This section describes the pump hardware safety features:

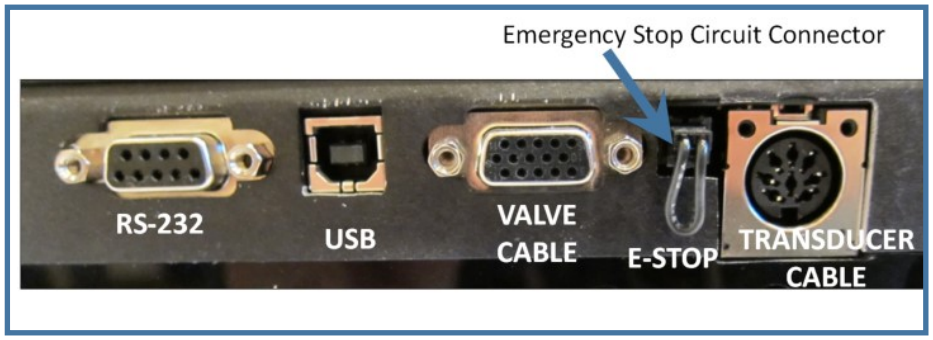
2.3.1 Power Switch

The power cord receptacle and power switch are located on the rear of the pump, on the bottom right side (when viewed from the front). **When power to the pump is turned off or is interrupted, the pump stops pumping and all the four fluid inlet and outlet valves close (assuming that compressed air remains connected to the pump). As a result, the fluid remaining in the pump can still be at high pressure and must be safely relieved, as explained in Section 6.**

2.3.2 Emergency Stop (E-Stop) Circuit

The VP-Series pump has a emergency stop circuit located on the back of the pump between the transducer cable and valve cable, as shown in the figure on the next page. The VP-Series pumps are shipped with a jumper (i.e., continuous wire) across the e-

stop connector, which the user may modify to form a simple circuit interrupt to stop the pump. Breaking this circuit interrupts power to the pumps' motors and valves, thereby stopping the pump and closing all valves. Power is maintained to the pump's circuit board when the E-Stop interrupt is activated so that the user can check the pump status, including cylinder pressures.



The E-Stop circuit should not be used to stop the pump in normal operation. It is intended only for true emergency stop situations. Activating the E-Stop can result in the rotational position of the motor(s) to be out-of-alignment with the position ordered by the motor controller, resulting in a "Motor Stall" event. In most cases the motors' positioning sensor will reset itself without any user action. In some cases, a pump may be unable to reset itself after an emergency stop. If this happens, the user is advised to power down the pump completely via the power switch. After waiting a few seconds, power the pump back on and the motor positioning sensors will re-orient themselves and allow the pump to be started again.

2.3.3 Safety Burst Discs

All VP-Series pumps have a Safety Burst Disc (SBD) Assembly, also called a safety rupture disc, mounted on the back of each cylinder. A metal "tag", from the burst-disc manufacturer, is also included in the spares kit. It lists the burst disc material and the burst pressure rating.

The safety burst discs are designed to relieve excessive pressure from the pump's cylinders in the event that high-pressure fluid accidentally enters the pump. The SBDs also protect the pump's pressure transducers from accidental over-pressure. Transducers will be damaged by exposure to fluid at pressure in excess of 1.5X the transducer maximum operating pressure. This is commonly referred to as the transducer's "Proof Pressure". Exceeding the proof pressure will permanently damage the transducer. **For this reason, it is important to select safety burst discs with a burst pressure that is below the transducer's proof pressure.**

IMPORTANT: SAFETY BURST DISC EXHAUST PORT CONNECTIONS AND ROUTING

The Safety Burst Disc outlet fittings on the back of the pump should be plumbed away from the pump and user in order to prevent bodily harm or damage to the pump or surrounding equipment in the event of a disk bursting. This is especially important if the pump is being used with corrosive fluids or gasses, which could cause bodily harm if vented at high pressure.

The female end of the burst disc assembly for each cylinder is threaded for the user to connect metal tubing to route any released liquid away from the pump. **The connection type for VP-3K, VP-6K, and VP-12K pumps is 1/8" Parker Speed Bite® fitting (or compatible). For VP-20K and VP-25K pumps, the burst disk exhaust port connection is 3/8" NPT.**

The port on the safety burst disc assembly is threaded so that high-pressure tubing can be connected to the port to route any released fluid to a safe area.

Safety Burst Discs are "wear items" and can fail in the course of normal pump use. Repeated pressure cycles in excess of 70-75% of the burst disc rating can fatigue the burst disc and cause it to fail over time. **If the pump is frequently operated at pressures in excess of 70% of the SBD's rated burst pressures, we recommend replacing the safety burst discs every year (or before beginning a long-term experiment). A video with instructions for replacing the safety burst discs is available on the Vindum Engineering channel at www.youtube.com Replacement burst discs are also available from Vindum Engineering (support@vindum.com or +1-281-782-8312).**

2.4 Power and Compressed Air Supply

This section describes the power and compressed air supply requirement for pump operation.

2.4.1 Power Supply

All VP-Series pumps require connection to an AC power source that is within the range of 100 -240 volts and 47—63 Hz. The pump will automatically adapt to the local power supply if within both voltage and frequency ranges. The AC power supply should be "clean", i.e., free of surges, voltage and frequency swings.

2.4.2 Uninterruptable Power Supply Recommended

As VP-Series pumps are capable of being run continuously for extended periods of time, we recommend that your pump and computer controller be protected by an

Uninterruptable Power Supply (UPS). The UPS will ensure that brief power interruptions or power fluctuations will not disrupt the pump's operation. **It is strongly recommended that users working with a VP-Series pump in continuous pulse-free flow mode for an extended runs be connected to a UPS to prevent rate or pressure fluctuations from power supply interruptions or variations.**

2.4.3 Compressed Air Supply

All VP-Series require a source of 70-100 psi (5-7 bar) to open/close the pump's valves. The compressed air line is connected to the pump using 1/4" or 6mm plastic tubing. For using 6mm tubing, the female connector uses M5x0.8 threads to screw into the pump. The photo below shows the quick-connect fitting (middle) and the two air exhaust "mufflers" above and below it that quiet the compressed air that is exhausted when a valve is actuated.

In order to avoid damage to the solenoids or valves of VP-Series pumps, it is very important that the source of compressed air meet the following requirements:

- **Clean (small particles can damage the solenoids and valves)**
- **Dry (moisture will cause the pilot solenoids to malfunction)**
- **Oil-Free**
- **Between 70 and 100 psi (not to exceed 100 psi)**

An inline filter is recommended where there are any concerns about the incoming supply of compressed air to the pump.

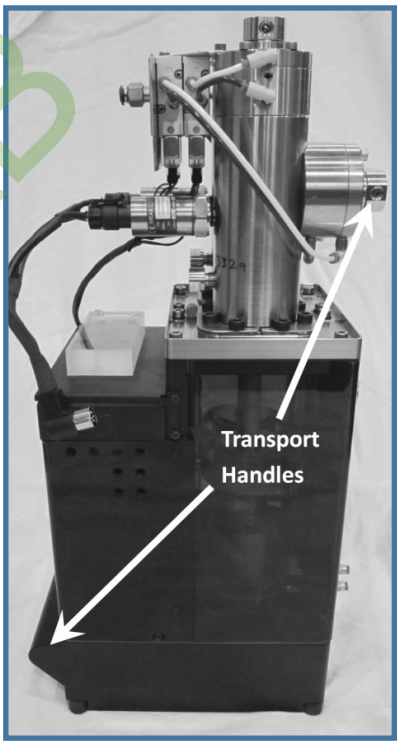
3. Initial Setup and Connections

Vindum Engineering ships each VP-Series pump in a custom-fitted box to protect the pump during shipment. However, in the event that this box shows any damage on arrival, please contact the shipping company immediately and also notify Vindum Engineering.

IT IS THE CUSTOMER'S RESPONSIBILITY TO IMMEDIATELY NOTIFY THE VINDUM ENGINEERING AND THE SHIPPING COMPANY OF ANY SHIPPING DAMAGE. WE ALSO RECOMMENDED TAKING PHOTOS OF THE DAMAGED ITEMS AND SENDING THOSE TO VINDUM ENGINEERING SO THAT WE CAN BE AWARE OF THE PROBLEM AND HELP RESOLVE ANY ISSUES.

3.1 Unpacking and Placement

VP-SERIES PUMPS WEIGHS BETWEEN 54 LBS AND 65 LBS (25-30 kg), DEPENDING ON THE MODEL. LIFT THE PUMP BY THE TWO TRANSPORT HANDLES AND USE CAUTION WHEN LIFTING.



Open the pump shipping box and review the enclosed packing list to ensure that all items are present. Contact Vindum Engineering regarding any missing items.

The CD enclosed with the pump contain a short video showing the basic steps of unpacking and setting up the pump.

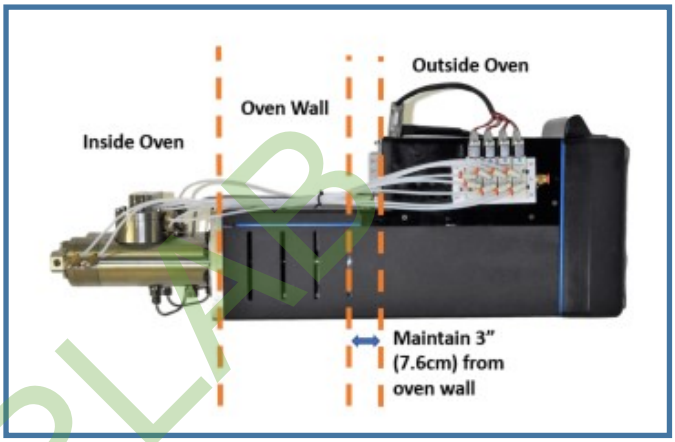
3.1.1 Pump Placement—All Models

VP-Series pumps are designed for laboratory use. **All pumps should be placed in locations that meet all of the criteria listed below. Additional placement criteria specific to High Temperature Pumps are listed in Section 3.1.2.**

- Operating environment complies with specifications of Section 1.2;
- Power supply within specifications of Section 1.3;
- Positioned on a laboratory bench or table that is able to handle the pump's weight;
- Pump is positioned so that the user has ready access to the power supply switch;
- Ventilation holes on the bottom and sides of the pump are not obstructed. If these are blocked the pump could overheat and shut down;

3.1.2 Pump Placement—High Temperature Models

High-Temperature Vindum Pump models are designed to be mounted either horizontally through the wall of a laboratory oven/air bath. An opening in the oven wall of 7" high x 6" wide will allow about 1/2" clearance between the pump and the oven wall (18cm x 15.5cm). As shown in the figure below, insert the pump so that the cylinder barrels extend into the oven but **leave a 3 inch (7.5cm) gap between the exterior oven wall and the top of the motor assembly to insure adequate cooling of the pump's electrical components.** Otherwise the pump could overheat and shut down if its internal components register an over-temperature condition. Fill the gaps between the pump and the oven wall with suitable insulating material rated for temperatures of at least 160°C (320° F). Support the body of the pump that is outside the oven with a sturdy stand capable of supporting the weight of the pump.



High-Temperature pump models may also be operated with the pump in a vertical position, but requires some slight modification. **Please contact Vindum Engineering for instructions on using the pump in the vertical position.**

3.2 Connections and Initializing Your Pump

The initial pump setup procedure for your new pump is explained in this section. There is also a short "Pump Setup" video included on the CD that shipped with your pump, or you can view the video at www.youtube.com. From the Youtube.com website, enter "Vindum Engineering" to find the list of instructional pump videos.

3.2.1 Fluid Lines Connections

All VP-Series pumps have "Fluid In" and "Fluid Out" engraved on the manifolds (see Section 2.1 for location of manifolds). In all cases, the low pressure fluid is connected to the Fluid Inlet manifold and the high pressure fluid is connected to the Fluid Out manifold connection.

The tubing size and connection type varies by model of VP-Series pumps, as shown in the table below. **All part numbers are for Parker Autoclave Engineers (AE) parts, although compatible parts from other manufacturers may also be used (FITOK or BuTech compression fittings are compatible).**

Pump Model	Tubing Size	Connection Type	Gland Nut	Ferrule or Collar	Max Pressure of connection*
VP-3K	1/4”	SW250	SMN40	SSL40	15,000 psi
VP-6K	1/4”	SW250	SMN40	SLL40	15,000 psi
VP-12K	1/8” 1/16”**	W125 W062	SMN20 SMN10	SSL20 SSL10	15,000 psi
VP-20K **VP-25K**	1/4”	F250C	AGL40	ACL40	60,000 psi

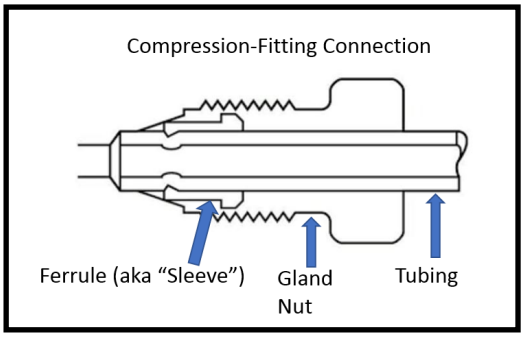
Glands and ferrules to make the tubing connections are included in the pump shipping box. Part numbers refer to Parker-Autoclave Engineer fittings.
*PAWP shown is at ambient temp. and decreases with increasing temperature.
**Special request item: 1/16” gland nut threads to 1/8” female connector on pump.

Ensure that tubing connected to the pump’s fluid-out manifold has a pressure rating that exceeds the maximum pressure capability of the pump and the system to which it is connected. Otherwise the tubing connection could fail or the tubing could burst and cause bodily injury.

<u>Tubing Connections for VP-3k, 6k, and 12k pumps</u>:

The compression-fitting used in the Fluid-In and Fluid-Out connections on the VP-3k, 6k, and 12k model pumps is compatible with Autoclave Engineers Speed Bite® fittings. These fittings have a MAWP (Maximum Allowable Working Pressure) of 15,000 psi at room temperature. Given the high fluid pressures capabilities of VP-Series pumps, it is very important to ensure that these compression-fitting connections are properly assembled (see figure on next page). Failure to sufficiently tighten the connection can result in the tubing being ejected from the connection at high pressure, which can lead to dam-

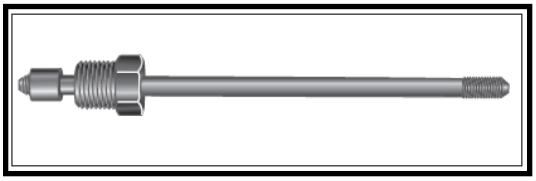
age or injury. On the other hand, over-tightening the gland nut can permanently damage the connection seat. As such, please follow the directions below carefully:



1. Cut tubing to length (add 0.50" for extra engagement allowance for 1/8" tubing and 0.75", per connection, for 1/4" tubing).
2. Deburr and clean the cut end of tubing by placing it in a vice. Use a reamer to deburr the ID and a file for the OD of the tubing-end. Be sure not to scratch the tubing OD when filing.
3. Place the gland nut and ferrule over the end of the tubing, as shown in the drawing above. Ensure that the sleeve is correctly orientated (larger end next to the threaded gland nut) and that the end of the sleeve is in contact with the interior of the gland.
4. **First, hand-tighten the gland nut. Then, using a wrench on the gland nut, tighten an additional 1 to 1-1/4 turn to complete the seal. When correctly sealed, the sleeve will still rotate on the tubing but the tubing cannot be pulled out of the connection by hand.**
5. For reassembly of this type of connection, tighten the gland nut onto the female threads hand-tight, then use a wrench to tighten an additional 1/8-3/8 turn for a gas-tight seal.

<u>Tubing Connections for VP-20k and VP-25k pumps:</u>

The higher pressure capabilities of these pumps requires use of "coned and threaded" connector type, as shown in the image below. After cutting, coning, threading, and deburring the 1/4" tubing, check for proper thread fit and length with a new collar. Next, flush the tubing with a process-compatible fluid prior to installation. The completed tubing connection is shown below for reference:



Assemble and make the high-pressure connection to the pump as follows:

1. Slip the threaded gland nut onto the tubing and thread the collar onto the tubing until one or two threads are visible between the end of the collar and the coned part of the tubing;
2. Lubricate the male threads of the gland nut with a metal-based thread lubricant (e.g., copper anti-seize lubricant);

3. Apply a small amount of process compatible lubricant to the end of the cone, such as silicone grease, to aid the sealing process;
4. Insert the tubing into the connection and thread the gland nut finger-tight;
5. Holding the fitting with a wrench, use a torque wrench to tighten the gland nut to 25ft-lbs (33.9Nm) (for F250C connection).

Tips for Fluid Tubing and Connections:

- Position the fluid reservoir near the pump and at the same level or above to help prevent cavitation or failure to draw fluid into the pump;

- Use of larger ID tubing on the fluid inlet side helps avoid restriction of incoming fluids. Plastic tubing (nylon, Teflon, etc. that is compatible with fluids being pumped) is suitable for use on the low-pressure fluid inlet side;

- Fluid Filter: Use an inline filter to prevent particulates from being drawn into the pump. A 5-micron filter is sufficient for most applications. Periodically check the filter to ensure it is not clogged as this will restrict fluid inlet capacity;

- Follow manufacturer's recommended procedure for preparing metal tubing for connection. Carefully clean the tubing with process-compatible fluid to remove any metal shavings from inside the tubing before first use.

- For corrosive fluids (e.g., brines) use corrosion-resistant tubing and connections, such as Hastelloy C-276. This tubing is available from Vindum Engineering;

- For purging air from the pump's cylinders (Auto-Prime Sequence) , it is advisable to attach a short piece of tubing, not a long one, to the Fluid Out manifold to help ensure that the air displaced from the cylinder is fully expelled from the tubing.

3.2.2 Safety Burst Disc Fluid Routing

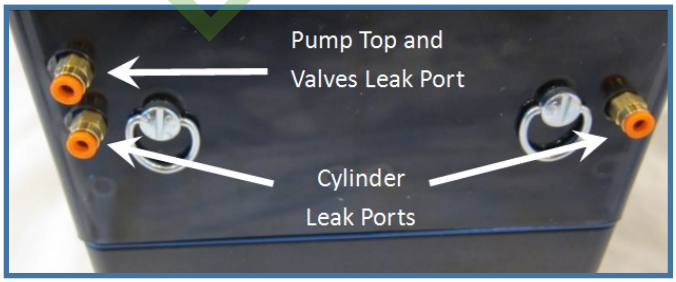
SAFETY BURST DISC EXHAUST PORT CONNECTIONS AND ROUTING

The Safety Burst Disk fittings on the back of each pump cylinder should be plumbed to a safe location in order to prevent bodily harm to personnel in the vicinity of the pump from release of the high pressure fluid due to activation of the safety burst disc.

The female end of the burst disc assembly for each cylinder is threaded for connecting to metal tubing to safely route any liquid expelled by a burst safety disc. The connection type for VP-3K, VP-6K, and VP-12K pumps is 1/8" Autoclave Speed Bite® fitting, or compatible. For VP-20K and VP-25k pumps, the burst disk exhaust port connection is a 3/8" NPT.

3.2.3 Drain Ports for Fluid Leaks

Ambient-Temperature models of VP-Series pumps incorporate internal drain paths to collect and channel **small fluid leaks** from the pistons and cylinder barrels to three drain ports on the front of the pump, as shown in the image below. Quick-connect fittings, like those shown in the image, are included in the shipping box with each new pump. The user may connect any 1/8" plastic tubing (ensure that this tubing is compatible with the fluids being pumped) to route/collect the leaked fluid to a safe location. Since any leaked fluid collected by the drain ports will not be under pressure, it is not necessary to use high-pressure tubing to connect to the drain ports.



HANDLE FLUID LEAKS IMMEDIATELY!: Although the internal drain paths that connect to each piston holder are designed to collect small amounts of fluid leaking from the piston seal at the bottom of each cylinder, **the user should immediately address any fluid leak seen anywhere on the pump**, rather than rely on the leak ports. Some viscous fluids may not flow through the leak port tubing and/or or continued

leaks may overwhelm the small capture basins that are built into the pump and fluid can overflow to other parts of the pump. **If you spot any fluid leak, stop and address the issue immediately!**

3.2.4 Compressed Air Inlet Connector

The figure below shows the 1/4" or 6mm OD quick connector that supplies compressed air to activate the four fluid valves on the pump. It is located on a manifold of four solenoid pilot valves on the backside of ambient-temperature pumps or on the side of high-temperature pump models. Insert the 1/4" / 6mm OD Nylon tubing that is supplied with each pump into this quick-connect air-inlet fitting, until the tubing is firmly seated (about 3/4" of tubing will be inserted into the connector). Attach the other end of the tubing to your source of clean compressed air. This air source can either be from standard laboratory air, from an air compressor, or compressed air tank that meets the requirements listed below. If sourcing the 6mm quick connector, use one with M5x0.8 threads.

In order to avoid damage to the solenoids or valves of VP-Series pumps, it is very important that the source of compressed air meet the following requirements:

- **Clean (small particles can damage the solenoids and valves. Use and in-line air filter to avoid potential damage)**
- **Dry (moisture will cause the pilot solenoids to malfunction)**
- **Oil-Free**
- **Between 70 and 100 psi (not to exceed 100 psi)**

To remove the 1/4" nylon tubing from the pump's air inlet quick-connector , PUSH BOTH the tubing and the outer "release ring" of the quick-connector into the fitting and gently pull the tubing away from the pump (while continuing to push on the "release ring"). **Please note that it may be difficult to release the nylon tubing from the fitting if the tubing is pressurized. To avoid this, release the pressure in the air line before attempting to disconnect the nylon tubing from the pump.**

3.2.5 Valve Actuation Air Lines

The compressed air supply is used to activate each of the four valves (two fluid inlet valves and two fluid out valves) on the pump. Each valve is connected to the solenoid pilot valves by two 1/8" OD Urethane or Teflon tubes. When the solenoid is activated (opened), it directs compressed air into an air chamber in the valve, which moves an internal piston that opens the valve. When the solenoid is closed, the compressed air is directed to the other side of the valve, causing it to close and holding it in the closed position.

The default position for each of the four fluid valves on the pump is "closed", i.e., unless the solenoid is activated, it continually directs the compressed air to the side of the valve that holds the valve closed. In the event of a loss of power to the pump, so long as the supply of compressed air is maintained, the valves will be held closed by the compressed air. Refer to the Safety Warnings section at the front of this manual for important precautions regarding safe operation of the air-activated valves and read Section 6 (Stopping Pumps and Valve Position).

3.2.6 Power Cable and Power Supply (UPS Recommended)

Your pump is supplied with a power cord approved for operation in the domestic market to which the pump was delivered.

Warning: Avoid use of a non-approved power cable with the VP-Series Pumps, as this could increase the risk of an electrical shock or other malfunction which could damage the pump and injure the user.

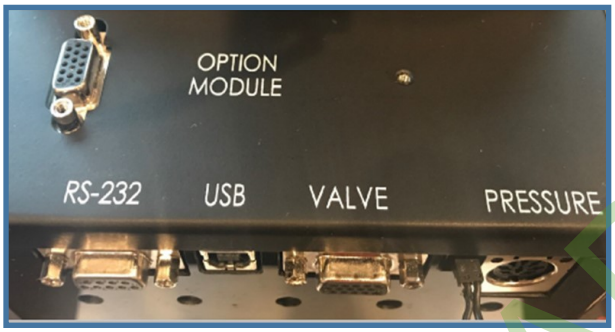
Plug the provided power cord into the pump power receptacle found on the bottom left hand side of the back of the pump (viewed from back of pump). Plug the other end of the power cord into the wall socket power source.

See Section 1.3 of this user guide for complete power specifications and power requirements. The VP-Series pumps are designed to auto-adapt to AC power sources in the range of 110-240 volts (47-63 Hz), as shown in the following below:

As VP-Series pumps are capable of being run continuously for extended periods of time, we recommend that your pump and computer controller be protected by an Uninterruptable Power Supply (UPS). The UPS will ensure that brief power interruptions or power surges will not disrupt the pump's operation.

3.2.7 Computer Cables and Cable Driver Software

For using the VPware pump-control application, the pump may be connected to the computer using a USB-USB cable, a RS232-USB cable, or a RS232-RS232 cable (not supplied). USB-USB and USB-RS232 cables are included with each pump sold by Vindum Engineering. Connect either the male end of the RS232 cable or the USB 2.0 Type B connector to the corresponding female port on the back of the pump, shown in photo below. Plug the other end of the cable into a USB port on your computer (Window 7 or later Operating System is required).



Use USB-USB cables of 10ft (3m) or less to avoid loss of signal. If the distance between the computer and pump is more than this, use a RS232-USB cable or a powered USB-USB cable.

In order for your computer to recognize the communications cable that you just connected to the pump, you may need to install the cable driver software on your computer. Without the driver software for the cable installed, the computer may not recognize or communicate with the Vindum Pump. If the computer has internet access and is authorized for program downloads, the cable drivers may download automatically when you connect the cable from the pump to the computer. If your computer is running an older version of Windows (e.g., Windows 7) or does not have internet access, you will likely need to install the cable driver. Instructions for installing the driver (s) are explained in Section 3.4.3.

If using a RS232-RS232 cable, ensure that it is a male-male DB9 “straight-through” cable (also called “non-null” cable). Pin configuration of this cable is standard: Pin 2 (Receive data from pump), Pin 3 (Transmit data to pump), Pin 5 (Ground).

3.3 Installation of VPware Pump-Control Software

VPware is the Windows-based software application developed by Vindum Engineering for controlling all models of Vindum Pumps. This section of the User Guide describes how to use VPware during initial pump set-up. Section 7 of this User Guide explains the VPware application in detail.

3.3.1 Computer Requirements

VPware pump software is compatible with computers running Microsoft Windows 7, or later, operating systems. VPware is not compatible with Windows operating systems before Windows 7 (e.g., Windows XP). If you do not have access to a computer with a compatible version of the Windows OS, please see Section 9 for other ways of controlling the Vindum Pumps.

3.3.2 VPware Installation and Updates

Your new pump was shipped with a CD containing the VPware pump control software. Insert the CD into the computer drive and install the VPware pump software as follows:

1) Double-click on the "VPwareSetup 1.2.xx.exe" icon to launch the VPware installer;
2) Review the software licensing agreement terms (and check box);
3) Once the program installation is complete, double-click on the VPware shortcut icon on the Windows desktop to launch the VPware app.

Note: If your computer does not have a CD/DVD drive, you can also download the VPware software via the internet, using a link provided by Vindum Engineering. Please contact Vindum Engineering to request the link to the file download website.

Vindum Engineering issues periodic updates to the VPware software and pump firmware with added features, enhancements, and bug fixes. These updates are available, free-of-charge, to all owners of Vindum Pumps. Please contact Vindum Engineering (support@vindum.com or +1-281-782-8312) or the sales agent from whom you purchased the pump to request current updates of the VPware software and pump firmware.

New versions of VPware may be installed the same way as the initial installation. The newer version automatically uninstalls the older version of VPware from the computer when it is installed. However, if any difficulty is encountered during the installation, it's a good idea to uninstall the prior version of VPware from your computer and then install the later version. For instructions on how to uninstall the VPware application, go to Windows "Settings/Applications" or search Windows for "uninstall".

3.4 Computer-To-Pump Communication

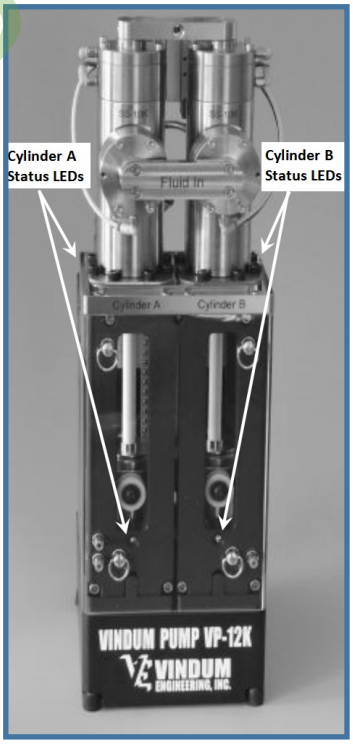
At this point you should have completed the following steps to prepare your VP-Series pump for operation:

- **Fluid connections are made (Section 3.2.1-3.2.3)**
- **Compressed air supply connection is made and activated (Section 3.2.4)**
- **Power cord installed and connected to AC power supply (Section 3.2.6)**
- **Computer cable connected (Section 3.2.7)**
- **VPware is installed on computer and the application is running (Section 3.3.2)**

This section explains how to establish computer-to-pump communication and the meaning of the LED lights that are used to indicate pump status.

3.4.1 LED Status Lights

Before describing the instructions for establishing communication between the computer using VPware and the pump, it is important to understand the meaning of the colored LEDs on the front and sides of the pump. There are four LED status lights on the pump that indicate the status and the activity of each cylinder (see adjacent image showing location of the LEDs). When viewed from the front of the pump, the two LEDs on the left side of the pump correspond to status of Cylinder A, while the two LEDs on the right side of the pump communicate the status of Cylinder B.



When the pump is first powered on, the LEDs blink red alternately left-right-left-right for 5 seconds, then blink blue simultaneously four times before showing solid blue. [This pattern of LED lights presumes that pump firmware version 270 (or later) is installed on your pump. If the LEDs on the left and right sides of the pump blink at the same time during the first 5 seconds of powering-on the pump, you need to upgrade the pump firmware to the latest version, which is available from Vindum Engineering (contact support@vndum.com +1-281-782-8312).]

The color of the LEDs represents the pump status and the activity of each cylinder, as follows:

- **RED LEDs: Indicates that the cylinder is In-Error and a user action is required. Red LEDs during pump operation indicate an error has occurred which has caused the pump to stop.**

- **BLUE LEDs:** Indicates that the piston/cylinder is in "ready/standby mode", i.e., ready to pump. The piston may either be stopped or is waiting for the other piston to finish it's stroke before starting to pump (i.e., in "paired modes"). Blue LEDs that all blink continually at the same time indicates that the safety pressure has not been set.
- **GREEN LEDs:** Indicates that the cylinder is actively moving fluid (i.e., either "pumping" or "receiving" fluid, depending on the pumping mode). Once the piston stroke is completed, the pair of LEDs on that side of the pump will change from green to blue while the piston repositions for the next stroke.
- The four pump LEDs blink together four times whenever the pump receives a command from the computer.

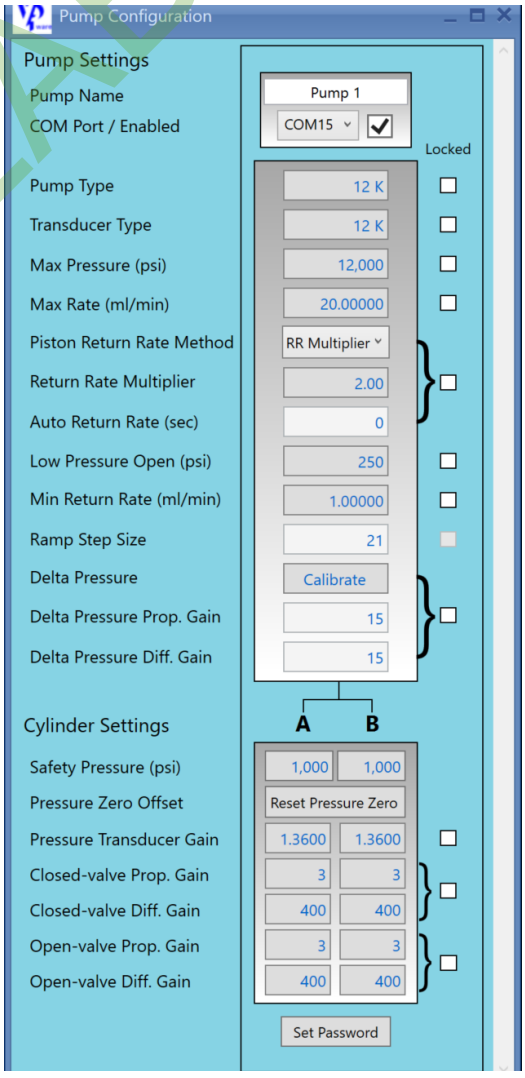
The next section explains how to start the pump and establish computer-pump communication.

3.4.2 Power-On the Pump

Turn on power to the pump by toggling the ON/OFF switch to 'I'. This power switch is located on the bottom back side of the pump, next to the power cable connector.

3.4.3 Establish Computer-to-Pump Communication

At this point, the pump is powered ON, connected to the computer, and the VPware application is running on the computer. From the menu bar at the top of the VPware Main Screen, click "Configure" and select "Pump Configuration" to open the pump configuration window, shown in the figure at right.



At the top of the Pump Configuration window, enter a Pump Name if you desire a different name than the default "Pump #1" name. Next, click on the dialogue box in second line to view a drop-down list of available computer COM Ports. Select the COM Port to which the pump cable is connected and click the "Enabled" check box. If more than one COM port is listed in the drop-down list, you will need to find the

one that corresponds with the pump. To do this, select one of the listed COM ports, then click on the "Enabled" box. If selected COM port is the correct one, communication will be established with the pump and the "Configure" screen will populate with the pump's information.

If, after selecting the COM port and clicking the "Enabled" check-box, a pop-up dialogue box stating that communication has not been established with the pump, first unclick the "Enabled" check-box and try another COM Port from the drop-down list of available COM ports. Repeat this process until you find a COM port that causes the Pump Configuration window be populated with the pump's configuration parameters.

If the COM Port drop-down list is empty (no COM port are listed) or you are unable to establish communication with the pump, check to ensure that the RS232-USB or USB-USB cable is connected and that the pump is powered-on. If there are still no pumps listed in the COM Port drop-down list, close all applications, unplug all peripheral devices, and restart the computer. This will reset the COM ports. Next, connect the cable to the pump and computer, then power-on the pump and start VPware. If there are still no COM devices listed in the VPware pump configuration drop-down list, or none of the listed COM ports will connect to the pump, the next step is to install the driver software for the type of cable you are using. The cable driver files are included on the CD that shipped with the pump and can be found in the folder named "Cable Drivers". Starting with VPware 1.2.42, the driver software for the USB-RS232 and USB-USB cables supplied with the pump are automatically downloaded to the folder "C:\Vindum Pump\Cable Drivers" when you install VPware. **Go to one of these folders and copy both cable driver files to the computer's desktop. Next, follow the instructions below to install the driver for the type of cable being used:**

- **RS232-USB Cable:** Double-click on the file named "CDM21224_Setup.exe" to install this cable driver. Restart the computer after installing this driver, then start VPware and go to the Configure/Pump Configuration screen to select the COM port from the drop-down box. Remember to click on the "Enabled" check-box in VPware Pump Configuration screen;

- **USB-USB Cable:** To find the COM port to which the pump's SB cable is connected, go to computer's Windows Control Panel—Device Manager, and click on "Ports (COM & LPT)" to show the list of COM connections. Look for one with a small yellow "!" exclamation mark (indicating a problem with this COM port). Double-click to open this COM port and check the "Device Status". Next, click on the "Driver/Update Driver" and select "Browse my computer for driver software" and point to the folder that has the file named "**mchpcdc USB to USB driver for pumps.inf**". You will either specify "Desktop" if you copied the file to the computer's Windows Desktop, or folder "C:\Vindum Pump\Cable Drivers" folder. Note that you only need to specify the folder, not the file name. Next. click the box "Include Subfolders", the press "Next" and "Finish" to complete the cable driver installation. When installation of the ca-

ble driver is completed, restart the computer. Start VPware and go to VPware\Configure\Pump Configuration and connect to the pump from the COM port list. Be sure the click the “Enabled” check box that is next to the COM port selector.

If you are still unable to connect to the pump from VPware, restart the computer and try again. Remember that different RS232-USB cables from different manufacturers may use different cable driver software. Make sure that you are using the cable that shipped with the pump. If the problem persists try a different computer or contact Vindum Engineering Support (support@vindum.com or call +1-281-782-8312).

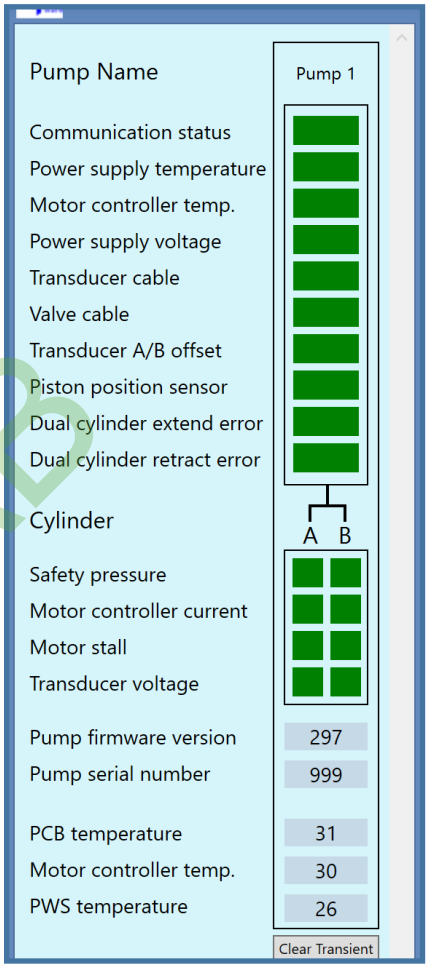
3.5 Initial Pump Check

Your VP-Series pump has been thoroughly checked and tested before it was shipped to you. To ensure that the pump has not been damaged in shipping, we recommend that you perform the simple checks described in this section before operating the pump.

3.5.1 Set Safety Pressure

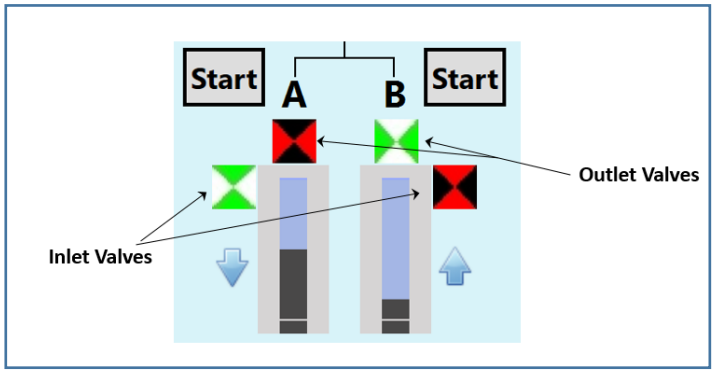
Setting the safety pressure of each cylinder is always the first step after starting a VP-Series pump. The Safety Pressure setting is that pressure which will cause the pump to stop. The safety pressure must be set every time the pump is initialized. The safety pressure values can be input from either the main VPware screen or via the Configure/Pump Configuration window. Click on either of the Safety Pressure boxes and enter a safety pressure value of 100 psi. Note that the "New Set Pressure" box will initially display "-400 psi". The negative pressure is an internal indicator that safety pressure has not been set, so the pump will not start. When a positive value has been entered, the pump is ready to operate.

Next, from the VPware menu bar at the top of the main window, select "Status". This opens the Status window, as shown in the image to the right. This window shows the status of all the pump components, which should be green (i.e., "operational/good").



3.5.2 Valve Operation

To verify that the pump's four air-operated fluid flow control valves are working correctly, follow the instructions in this section. The four valves are integrated with the pump cylinders (refer to Section 2.1 to identify the valves). On the Main VPware window there are icons for these valves, as shown in the figure below.



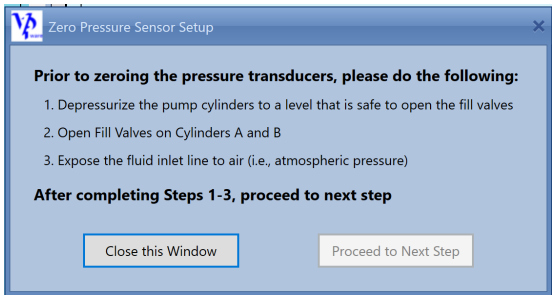
Each of the four valve icons shows the valve either "Closed" (**RED**) or "Open" (**GREEN**). Clicking on the valve icon activates that particular valve (either opens or closes the valve). Select a valve icon from the main VPware screen and click on it. If the valve is operating correctly, you will observe ALL of the following:

1. Valve icon changes color: red-to-green (valve opens) or green-to-red (valve closes);
2. A short audible release of compressed air from the air ports on the solenoid assembly (compressed air exits via the small tapered mufflers attached to the solenoid manifold on the back of the pump), together with an audible "click" as the valve piston changes position inside the valve; and
3. The SMALL LED on the corresponding solenoid body (on the underside of the solenoid assembly that is on the backside of the pump) will either illuminate RED (valve open) or the solenoid LED will go dark (valve closed). Repeat this procedure for each of the four fluid inlet/exit valve icons on the main VPware screen.

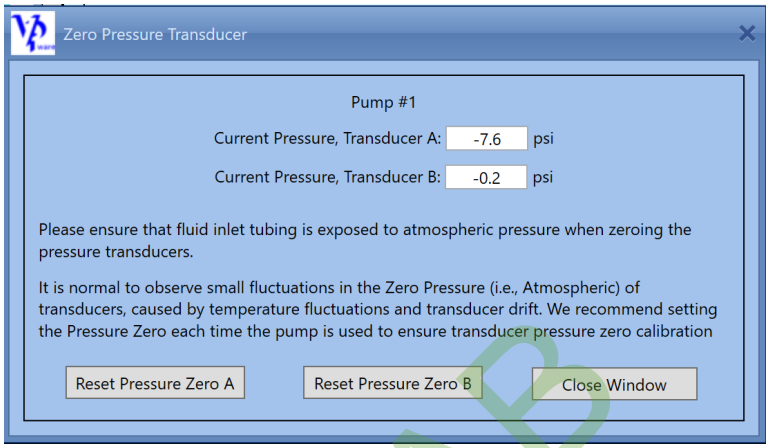
3.5.3 Zero Pressure Transducers

The pressure transducers found on the VP-Series pump are analog-type, in which the strain on a sensor is converted to a voltage that is transmitted to the pump's internal control system. The pressure transducers have two user-adjustable settings: 1) Pressure Zero Offset (i.e., the voltage output corresponding to atmospheric gauge pressure), and 2) Gain Setting (i.e., the voltage output change corresponding to a unit pressure increase).

BEFORE EACH USE (before each experiment or each time the pump is powered on), the Pressure Zero Offset of the transducers should be reset. This ensures that the transducer base voltage is calibrated to atmospheric pressure. It is an essential step to accurate pressure measurements. To zero the transducers, select "Configure" and "Pump Configuration" from the VPware main screen menu bar. On the Pump Configuration window, click on the "**Reset Pressure Zero**" box near the bottom of this window and follow the instructions listed on the window that opens (shown below).



You will need to open the two fluid inlet valves from the VPware main screen (remember that the pump must be connected to compressed air in order to actuate the valves). Once the fluid inlet valves are opened, you will be allowed to proceed to the next step using the "Zero Pressure Transducer" window, shown below:

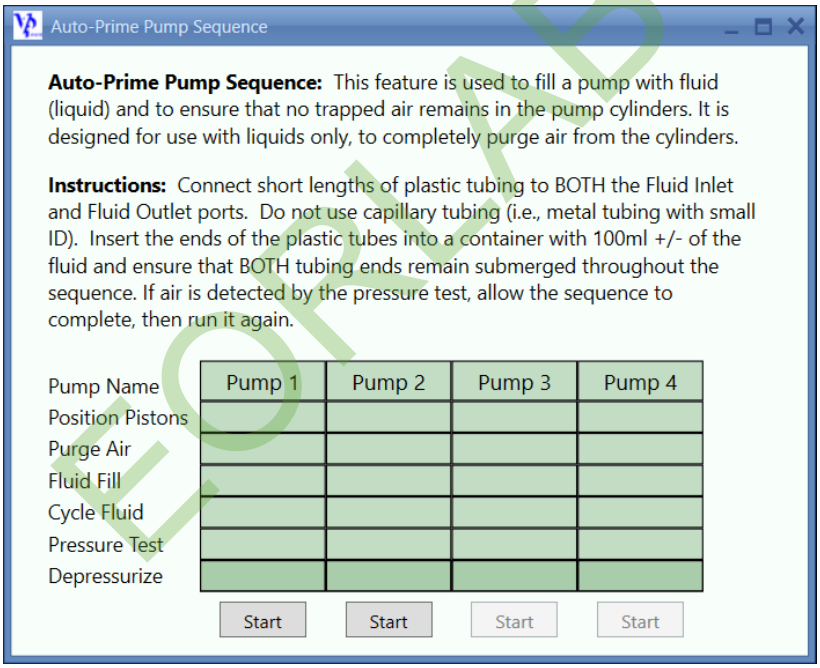


Press the "Reset Pressure Zero A" to reset the transducer on cylinder A to atmospheric pressure (i.e., gauge pressure = 0). Do the same for Cylinder B transducer. You can reset each transducer more than once. The "pressure zero" value of the transducers will fluctuate slightly around a 0 psig when the transducers are exposed to atmospheric pressure. This is due to a number of factors, including temperature variations and very slight fluctuations in the transducer's circuitry. If you notice a persistent drift in the zero-pressure value that is beyond the total error of the transducer (typically +/-0.5% of full-scale) please contact Vindum Engineering to discuss replacing the transducer.

3.6 Priming Pump and Purging Air from Cylinders

The last step of the initial pump check is to fill the cylinders with fluid and ensure that all air has been purged from the cylinders. **Fully purging the air from both pump cylinder is essential for proper operation of the pump. Incomplete purging of air/gas from the cylinders will impede accurate and pulse-free pumping, so it's very important to ensure that all the air is expelled from the pump cylinders before beginning any experiments.**

VPware has an automated air-purge-fluid-fill process. From the menu bar on the VPware main screen, select "Tools" and "Auto-Prime Pump Sequence." This opens the window shown below. Follow the instructions on this window, using the two short lengths of plastic tubing that shipped with the pump (either1/8" OD (3mm OD) or 1/4" OD (or 6mm OD) plastic tubing, depending on pump model) and a container of fluid (distilled water or similar works well). Press "Start" to initiate the 6-8 minute Auto-Prime sequence.



If you receive an error message when running the Auto-Prime Sequence, you can re-run the sequence a second time. If the error persists, it may indicate the presence of a fluid leak somewhere on the pump. Refer to Section 8.4 for procedures on how to diagnose leaks.

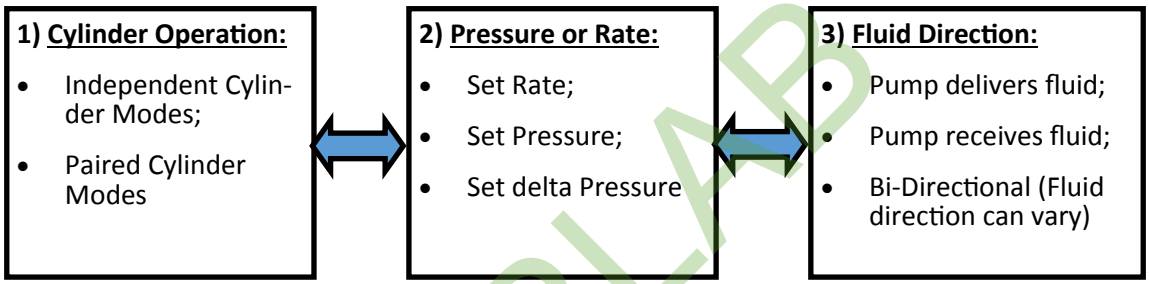
Your new VP-Series pump is now set up and is primed with liquid. Before operating the pump, however, we recommend reading the remainder of this user manual and retain it for future reference. **To ensure your safety, the safety of those in the operating area, and for the protection of the pump, please read this material before operating the pump at pressure.**

4. Pump Operating Modes

This chapter explains the various operating modes of VP-Series pumps, the Start/Stop commands, and best practices. **We encourage the user to gain a thorough understanding of these functions, as they affect nearly all the pump control settings and have implications for proper use of all pump models.**

4.1 Operating Mode Components

VP-Series pumps can operate in 15 distinct modes, listed in Table 4. Each of these modes has three components, as shown in the diagram below. Each of these components is explained in this chapter.



Paired and Independent Cylinder Operation

- **Paired Cylinder Modes:** "Paired" operating modes enable continuous, pulse-free, fluid pumping. While fluid is pumped from one of the cylinders, the other cylinder is filled with fluid, so that when the first piston reaches the end of its stroke, the second piston is ready to continue pumping. In order for pulse-free fluid pumping, the passive cylinder, after filling with fluid, is pressurized to match the pressure of the active cylinder. The "passive" cylinder continues to match the pressure of the "active" cylinder so that, at switchover from one cylinder to the other, the pressures are matched and fluid delivery is continuous and pulse-free. **This pressure-matching between the active and passive cylinders occurs in all Paired Cylinder Modes, i.e., whether the pump is in "pressure" or "rate" modes.**

- **Independent Cylinder Modes:** Each pump cylinder (Cylinder A and Cylinder B) operate independently of each other (optional inlet and outlet manifold, purchased separately from Vindum Engineering, are needed to segregate the fluid inlet and outlet of each cylinder). It's as if the pump is split into two metering pumps that are controlled independently. However, the maximum volume that can be pumped is limited by the piston stroke volume. At the end of the piston stroke pumping is interrupted while the piston retracts to refill the cylinder with fluid.

Constant Rate, Constant Pressure, or Delta Pressure Operation

- **Constant Rate Modes:** The piston delivers (or receives) fluid at a highly accurate rate set by the user (called the "Set Rate"). In this operating mode, rate is controlled while pressure is dependent on downstream conditions. In any of the "Rate Modes", rate is the "independent variable" (i.e., user-selected) and pressure is the "dependent variable".

- **Constant Pressure Modes:** The piston will deliver (or receive) fluid at a pressure specified by the user (the "Set Pressure"). In "Pressure" modes, the pressure transducers that are connected to each of the pump's cylinders read the cylinder pressure and continually output the instantaneous cylinder pressure to the pump's control system. The pump uses the instantaneous pressure readings to vary the pumping rate to whatever is needed to reach and maintain the Set Pressure. Piston speed is adjusted many times per second to control the cylinder pressure to the Set Pressure.

- **Delta Pressure Mode:** An external delta pressure transducer, rather than the integrated pressure transducers, is connected to the pump and the Set Pressure is the delta Pressure target value. Pumping rates are continuously adjusted to reach and maintain the target delta pressure.

Fluid Direction (Deliver, Receive, and Bi-directional)

There are three ways in which fluid can be directed through the pump: Fluid Deliver, Fluid Receive, and Bi-Directional fluid flow. **It is important to remember that high pressure fluid is always connected to the top-most valves (labeled "Fluid Out" on the manifold connecting the valves), while low pressure fluid always moves through the two valves connected to the "Fluid In" manifold, regardless of fluid direction.**

- **Deliver Mode:** This is the most commonly-used mode. Fluid enters the pump via the inlet manifold (labeled "Fluid In") as the piston withdraws to fill each cylinder, and is then pressurized and delivered via the outlet valves mounted on each cylinder through the "Fluid Out" manifold.

- **Receive Mode:** In Receive mode, the pump receives fluid into the Fluid Out manifold at the specified rate or pressure (i.e., fluid flow is opposite of Deliver mode described above.) In this mode, the fluid is discharged from the pump via the "Fluid In" manifold after the piston retracts to fill with the incoming fluid.

-  **Bi-Directional Mode:** In this mode, the pump is able to hold a set pressure by either delivering or receiving fluid. **By positioning the passive piston at mid-stroke, it is ready to move in either direction in order to maintain the set pressure.**

Please keep in-mind that, in bi-direction mode, the pump is limited to about half of it's normal maximum flow rate due to the fact that the piston "starting point" is the middle of the cylinder so that it is ready to move in either direction. One example use of Bi-Directional Mode would be to maintain pressure of a vessel that is heated then cooled. For this application, the pump would "receive" fluid as the vessel heats (due to fluid expansion), and would "deliver" fluid to the vessel as it cools in order to offset decreasing pressure from fluid contraction.

Recirculation Mode

Recirculation is a special type of experiment in which one, two, or three fluids are circulated in a closed system (constant volume). Recirculation experiments are typically used to determine the relative permeabilities of oil and water (or oil, water, and gas) in a reservoir rock as a function of varying fluid saturations. Establishing relative permeability curves is a multi-step process in which a fluids are injected at set rates until an equilibrium is established in the rock core. After passing through the core, fluids are reinjected at the front of the core until the equilibrium is established. During this process, one pump maintains constant pressure at the core outlet by injecting or withdrawing fluid. Fluid injection/withdrawal from the system changes continually, as a function of the piston cycles of the injection pumps, so the "Pressure Compensation Pump" is constantly adjusting to maintain constant pressure at the core outlet. After an equilibrium is established for a particular ratio of fluids, the ratio of injected fluids is changed and the process repeated again. By varying the ratio of injected fluids over several steps, a full set of relative permeability curves can be developed. Table 4 lists the two pump modes that are used for recirculation experiments (RPRD & RIPD), but special Recirculation software and pump cables (from Vindum Engineering, additional cost) are required to conduct recirculation experiments. Otherwise, RPRD and RIPD modes should not be used.

4.2 Multi-Pump Modes

VPware, the pump-control application explained in the next chapter, offers three multi-pump modes which expand the usefulness of Vindum Pumps. In each of the multi-pump modes two or more pumps are "linked" together in different ways, as briefly summarized below and explained in-detail in Section 7.8.3.

- **Pressure/Rate Following:** A "Follower Pump" is linked to a "Master Pump", with the actions of the Follower Pump settable as a fraction or differential of the Master Pump's set pressure or set rate. It's a very flexible tool that the user can use to fit their specific requirements.
- **Pump Group - Rate:** Allows linking multiple pumps to achieve higher total flow rates. The rates of the individual pumps can be set as proportional, fractional, or individually-specified. Once grouped, a single command starts/stops all the pumps in unison.
- **Recirculation Mode:** see explanation above.

Table 4: Pump Operating Modes (page 1/3)

VPware Mode Abbreviation	Mode Name	EventLog Mode Number	Continuous Pulse-Free Flow?	Constant Rate or Pressure?	Fluid Deliver or Fluid Receive?	Comments
PRD	Paired Rate Deliver	17	Yes	Rate	Deliver	Paired cylinder operation to deliver fluid continuously at set rate.
PRR	Paired Rate Receive	19	Yes	Rate	Receive	Paired cylinder operation to receive fluid continuously at set rate. Fluid enters pump via outlet manifold, so flow direction in pump is reversed.
PPD	Paired Pressure Deliver	18	Yes	Pressure	Deliver only. Avoid using when downstream pressure is above pump's set pressure.	Pump delivers fluid continuously at set constant pressure. Fluid flow rate varies to maintain set pressure. Use only to deliver fluid. Use bi-directional mode if switching between delivering and receiving fluid without stopping pump.
PPR	Paired Pressure Receive	20	Yes	Pressure	Receive only. Avoid downstream pressure that is below pump's set pressure.	Pump receives fluid at set pressure (fluid enters via Fluid Out manifold). Use only for receiving fluid. Use bi-directional mode if switching between delivering and receiving fluid without stopping pump.
PRDG	Paired Rate Deliver—Geared	16	Continuous but not pulse-free	Rate	Deliver	Pumping and refilling pistons run at the same rate. Fluid is delivered continuously, but pressure changes at piston switch-over may be evident.
PPBD	Paired Pressure Bi-Directional	21	Yes	Pressure	Deliver or Receive	Used to maintain set pressure at Fluid Out manifold. Pump will deliver fluid to raise downstream pressure to set pressure or will receive fluid to maintain set pressure. In this mode, max flow rate is limited to about one-half of normal delivery rate.
IR	Independent Rate—Manual	1	No	Rate	Deliver or Receive, depending on piston direction and valve open/closed positions.	Completely manual, independent, cylinder operation. Commonly used to depressurize cylinders or reposition pistons. When piston reaches end of stroke, pumping stops. Requires user to manually open/close valves and set piston direction.

Table continued on next page

Table 4, continued: Pump Operating Modes (page 2/3)

VPware Mode Abbreviation	Mode Name	EventLog Mode Number	Continuous Pulse-Free Flow?	Constant Rate or Pressure?	Fluid Delivery or Fluid Receive?	Comments
IPD	Independent Pressure Deliver-Manual	2	No	Pressure	Deliver only. Avoid high external pressure downstream of pump which can drive piston backwards.	Pump cylinders operated independently. Pumping stops when piston reaches end of stroke. Requires user to manually set inlet & outlet valve positions and piston direction. Only used to deliver fluid. Avoid exposing open cylinder to downstream pressure that is in-excess of pumps' set pressure, as this will drive fluid into the pump.
IRDC	Independent Rate Deliver-Cycled	3	No	Rate	Deliver	Independent cylinder operation with fluid delivery at set rate. At end of stroke, piston retracts to refill with fluid (no fluid delivered during piston retract). Valve operation is automatically controlled by pump.
IPDC	Independent Pressure Deliver-Cycled	4	No	Pressure	Deliver only. Avoid exposing pump to external pressure that is higher than pump's set pressure.	Independent cylinder operation with fluid delivery at set pressure. At end of stroke, piston retracts to refill with fluid (no fluid delivered during piston retract). Valve operation is automatically controlled by pump.
IRRC	Independent Rate Receive-Cycled	5	No	Rate	Receive	Selected cylinder retracts at set rate to accept fluid via Fluid Outlet port. At end of piston stroke, piston extends to discharge fluid through inlet valve/ manifold.
IPRC	Independent Pressure Receive - Cycled	7	No	Pressure	Receive	Independent cylinder operation with receipt of fluid (via Fluid Deliver valve) at set pressure. At end of stroke, piston extends to empty fluid. Valve operation is automatically controlled by pump.

Table continued on next page

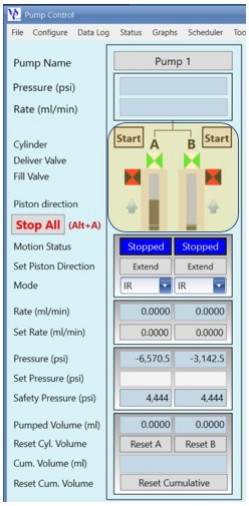
Table 4, continued: Pump Operating Modes (page 3/3)

VPware Mode Abbreviation	Mode Name	EventLog Mode Number	Continuous Pulse-Free Flow?	Constant Rate or Pressure?	Fluid Delivery or Fluid Receive?	Comments
PDPD	Paired delta Pressure Deliver	22	Yes	Pressure	Deliver	Requires compatible delta pressure transducer connected to Option Module port and Option Module Configuration #3 enabled. Pump continuously delivers fluid at set delta pressure.
RIPD	Recirculation - Compensation	6	Yes	Pressure	Bi-directional	Pump maintains constant pressure at fluid outlet during recirculation experiments. Recirculation control software available separately.
RPRD	Recirculation –Flow	23	Yes	Rate	Deliver	Paired cylinder operation to deliver fluid continuously at set rate for recirculation experiments. Recirculation control software available separately.

5. START COMMAND: SETTINGS AND IMPLICATIONS

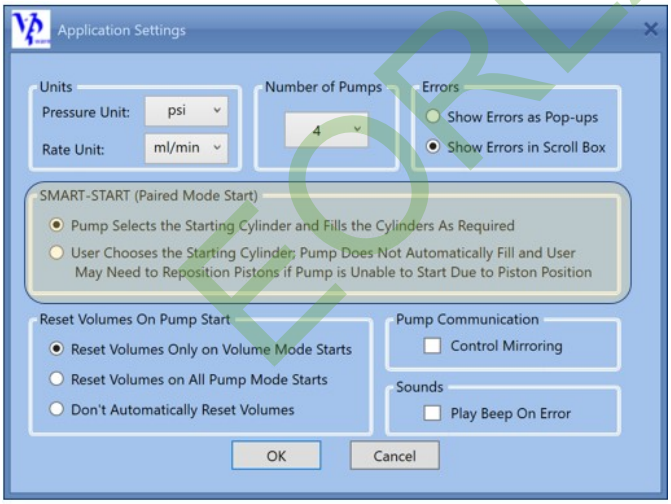
The start logic of VP-Series pumps varies, depending on the start settings and on the pump mode selected. It's important to understand how these settings determine the pump's start-up behavior, as it can impact your experiments.

5.1 Two Start Buttons



You may have noticed that the main screen of VPware has two "Start" button/boxes for each pump, as shown in the highlighted area of the image at the right. When the pump is set to any of the Independent Modes", where each cylinder can be controlled like an independent pump, the left-most Start button starts Piston A (Cylinder A). Likewise, the right-most Start button is used to start Piston/Cylinder B.

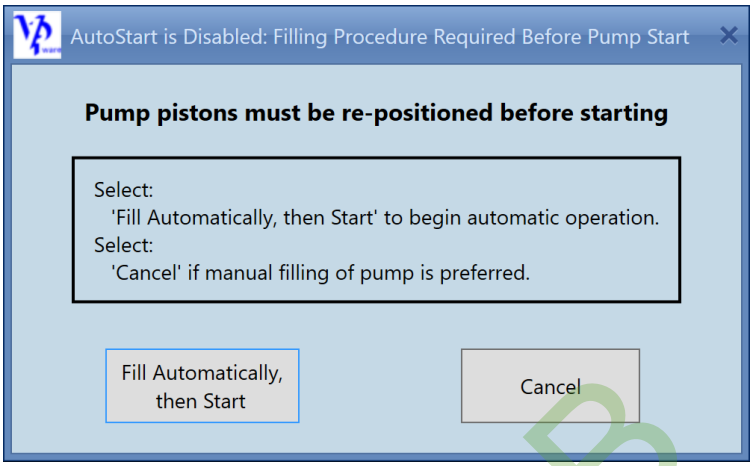
When the pump is operated in any of the Paired modes, the "SMART-START (Paired Mode Start)" setting in the "Configure/Application Settings" window, shown below, determines the outcome of the Start buttons. The SMART-START options are highlighted in the middle of the screen. When



the first of the two SMART-START buttons is selected (i.e., "Pump Selects the Starting Cylinder…."), the pump automatically selects which piston to start pumping first, regardless of which "Start" button is pressed. This determination is made based on the position of the two pistons. The software starts the piston that will allow continuous pumping (i.e., the other piston will have time to refill and repressure). If both pistons are out-of-position, the software automatically repositions one of the pistons before starting so that the pump will operate with continuous, pulse-free flow.

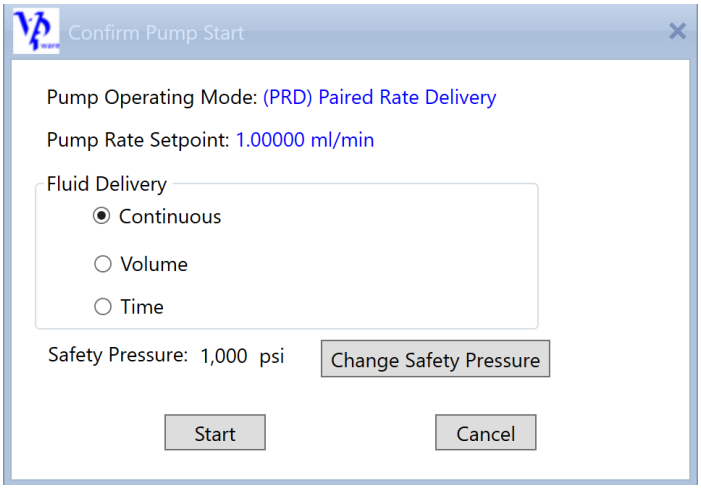
If the user selects the second button of SMART-START area, the pump will start the piston corresponding to the "Start" button pressed by the user. If the user presses the Cylinder A "Start"

button, the pump will start Cylinder A. If the pump software determines that continuous flow will not be possible by starting the selected piston, VPware will issue a warning and offer the user the option to start the other piston first or to reposition the selected position before re-starting the pump again, as shown in the image below.



5.2 Confirm Pump Start Window

Each time the "Start" button is pressed, VPware presents a "Confirm Pump Start" window, like the one shown below. The purpose of this window is three-fold: 1) It prevents an accidental pump start; 2) It allows the user to confirm the mode, the rate or pressure setpoint, and the safety pressure setting; and 3) in most pump modes, the user can choose between having the pump run continuously, dispensing a pre-set volume, or pumping for a preset time. Pressing the "Start" button on this window starts the pump. If volume dispense is selected, the "target volume" is shown on the last line of the Main Screen. Similarly, the remaining time is shown on the VPware Main Screen (at top, by Pump Name) whenever the pump is started in "Time" mode.



5.3 Starting Pump in Pressurized System

In many instances users will pre-pressurize their system, then connect the VP-Series pump to the system to start the experiment. In other cases the VP-Series pump will be used to pressurize the system, starting from a low pressure. **In either case, the pump's starting behavior depends on whether one of the pump's deliver valves is open prior to starting the pump. If the user opens a deliver valve prior to starting the pump, the cylinder becomes pressurized with the system fluid and the pump starts from that pressure so that no pressure pulse is delivered to the system.**

Note that VP-Series pumps are designed to hold piston position when they are powered-on but stopped (not pumping), to allow the user to open a deliver valve and expose a pump cylinder to high downstream pressure without affecting the position of the piston. The user is advised to introduce the pump to high downstream pressure slowly. If a stopped pump is suddenly exposed to very high downstream pressure, the piston might be forced downward (retract) slightly, until the pump's motors can react and hold the piston position.

When the pump is in any of the paired modes and the Configure/Application Settings is set to automatically determine which piston/cylinder to start pumping (see Section 5.1), it's possible that the pump will start the cylinder with the closed deliver valve (rather than starting the cylinder with the open deliver valve). In this event, the pump pre-pressurizes the closed cylinder to the same pressure seen by the open cylinder before opening the deliver valve to start pumping. Equalizing to the system fluid pressure ensures that pressurized fluid does not accidentally flow into the pump as it starts.

If VP-Series pumps are set to any of the pressure modes and started with the deliver valve (independent modes) or valves (paired modes) closed, pressing "Start" directs the pump to pre-pressurize the cylinder to the set pressure before opening the deliver valve to start pumping. This can result in a pressure spike if the system pressure connected to the pump is at a low pressure and the pump is set to a high pressure.

6. STOPPING PUMP: VALVE POSITION & RELIEVING PRESSURE

6.1 Stopping Pump and Valve Position

In VPware, pressing the "Stop" button stops the single cylinder (Individual pump modes) or both cylinders (Paired modes). The "Stop All" button, located on the left side of the Main Screen, stops all pumps, regardless of operating mode, that are running with a single click. "Alt+A" keystroke will also stop all running pumps. When a pump is stopped in any of these ways, power is maintained to the motors so that the pistons can hold their position. **If pumps are stopped by pressing the "Stop" buttons or "Stop All" button (or Alt-A) the pistons will hold their position, even if exposed to high pressure fluids.**

If a motor stall event occurs, the pump stops. "Motor Stall" means that the rotational position of the motor is out-of-sync with the motor controller. In the event of a motor stall, the pump's valves close, on the cylinder that is in-error, in order to prevent high pressure fluid from flowing back into the stopped pump. Common causes of motor stalls are:

1. **Emergency stop while pump is running at high speeds.** Not every emergency stop will result in a motor stall, but the chances of a motor stall happening increases at higher pumping rates.
2. **E-Stop circuit is interrupted.** Activating the E-Stop circuit interrupts power to the pumps motors. Without power, the motors cannot hold their position, so a motor stall error is guaranteed.
3. **Electrical power is switched off.** Motor position is lost when incoming power is switched off.

TIP: To avoid unnecessary safety pressure stops, which can result in a motor stall event, it's a good idea to set the safety pressure a fair amount over the set pumping pressure, but after ensuring that other system components can safely handle the pressure.

6.2 Relieving Pressure of a Closed Cylinder

If both inlet and outlet valves on a cylinder have closed with the cylinder under pressure, e.g., safety pressure is exceeded while pumping, take the following steps to safely relieve the cylinder pressure:

1) Establish computer-to-pump communication, if not already connected;
2) Check the current cylinder pressures from the VPware Main Screen;
3) Change the pump mode to Independent Rate (IR) and set the piston direction to

"retract" (since increasing the cylinder volume will lower the cylinder pressure) and enter a rate value (e.g., 1-2 ml/min). Click Start to retract the piston to relieve the cylinder pressure to an acceptable level. **Note that only "IR" mode is operable whenever the pump pressure exceeds the safety pressure. The pump will not operate in any other mode as long as the pump pressure is greater than the safety pressure.**

If the piston cannot be retracted to lower the cylinder pressure to an acceptable level, you can resolve the safety over-pressure by changing both cylinders to IR mode, close the fluid inlet valve of both cylinders, and then open the fluid deliver valves of both cylinders. This will allow the high pressure fluid to flow between the cylinders. Retract the piston of the second cylinder to lower the pressure more, if needed.

6.3 Avoid Loss of Compressed Air To Valves

 **The supply of compressed air to the pump's four fluid control valves must be maintained at all times the pump is being used.** Without this compressed air supply, the pump's valves cannot be actuated and the position of the valves cannot be known and the valve position shown on the VPware Main Screen may not be correct. **This is because VPware reports the position of the solenoids that activate the valves but, without compressed air, the valves may not be in the position displayed by VPware.**

 **Stop the pump immediately if you suspect a loss of compressed air supply to the pump or if the air pressure drops below 65 psi (4.5 bar). Additionally, to prevent the possibility of high-pressure fluid flowing into or through the pump in the event of loss of compressed air, we recommend installing a check valve on the Fluid Deliver side of the pump. The check valve will insure that no fluid flows back into/through the pump, even in the event of a loss of compressed air supply.**

7. VPWARE PUMP-CONTROL SOFTWARE

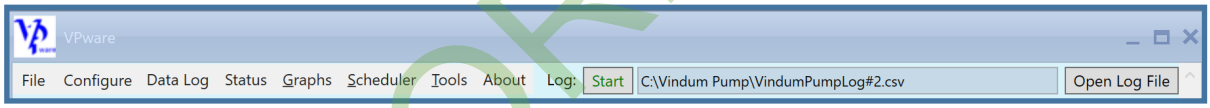
"VPware" is a Windows-based application developed by Vindum Engineering to operate the VP -Series pumps. This section of the pump user guide covers the features and capabilities of VPware. VPware requires connection to a PC/laptop running Microsoft Windows 7 operating system, or higher, with a USB or RS232 COM port.

For instructions for installing or updating VPware, see section 3.3 of this user guide.

FOR YOUR SAFETY AND TO PROTECT YOUR VP-SERIES PUMP, DO NOT OPERATE THE PUMP UNTIL YOU HAVE READ AND UNDERSTOOD THE IMPORTANT SAFETY WARNINGS AT THE FRONT OF THIS USER GUIDE AND HAVE COMPLETED CHAPTERS TWO AND THREE OF THIS USER GUIDE.

7.1 VPware Menu Bar

The VPware menu bar is the gray horizontal bar at the top of the VPware main screen, as shown in the image below. Each of the items of the menu bar is briefly described below and explained in detail in the following sections:



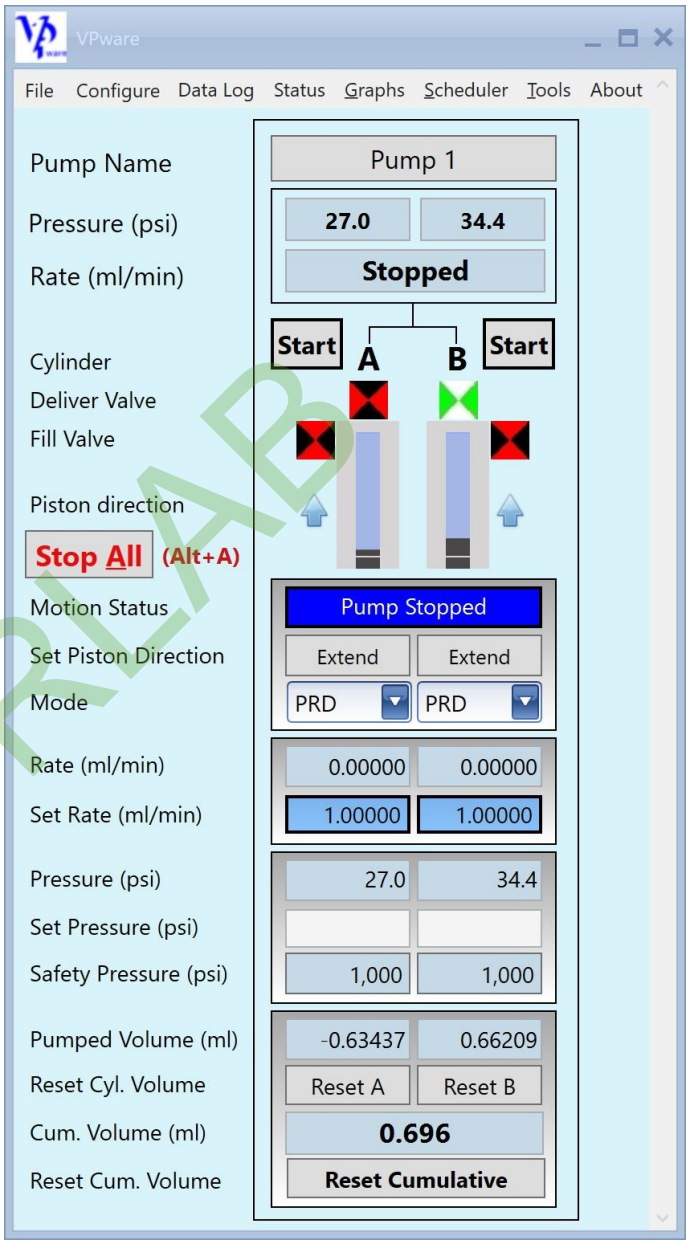
- **File:** clicking "File/Exit" closes VPware application.
- **Configure:** Clicking on this item in the Menu Bar allows the user to access three configuration options for individual pumps:
  1) **Pump Configuration** settings, covered in-detail later in the chapter;
  2) **Application Settings**, which are applied to all pumps connected to the computer. These include selection of units displayed for pump rate and pressure, number of pumps displayed in the VPware app, Error display options, SMART-START pump start options, and when pumped volumes are reset, Pump Control Mirroring (when using external pump control), and Sounds (i.e., beep on error);
  3) **Options Modules Configuration:** used to engage the 15-pin Options Module connection on the back side of the pump for remotely controlling the pump using digital and analog signals. New configurations are created by Vindum Engineering at customers' requests;
- **Data Log:** Records pump parameters (e.g., time, rates, pressures, volume) to a user-specified .csv file.

- **Status:** Displays the status of each pump's components (OK, error, or transient error), as well as the Firmware version installed on each pump and the serial number of the pump. The firmware version and pump serial number are stored in the pump's CPU.
- **Graphs:** Allows the user to easily create any number of graphs showing the pump's performance in real time. Templates of the graphs can be saved for future use.
- **Scheduler:** Allows the user to configure, save, and run multi-step schedules varying rates or pressures. "Schedule Status" bar displays the status of a running Schedule.
- **Tools:** Includes sub-menus with functions to:
    1) **Auto-Prime Pump Sequence** is used to purge air from pump's cylinders and fill with liquid;
    2) **Firmware Update** is used to install new firmware into pump's memory. It is often necessary to update pump firmware when using a new update of the VPware app, since the VPware software and pump firmware work together.
    3) **Multi-Pump Modes**: advanced control capabilities, including Pressure/ Rate Following, Pump Grouping (in Rate Modes), and Recirculation (for 2-phase and 3-phase constant pressure experiments — sold separately);
    4) **Pump Error Analysis:** Enables user to view commands and operating data leading up to a pump error event. Error State Display is an innovative way of recreating pump operations second-by-second for easy error analysis.
- **About:** Shows the version of VPware that is installed on the computer controlling the pump.
- **Data-Log Shortcut:** Start/Stop data log recording to the file shown. Click "Open Log File" to open the data-log file when data-logging is stopped.

7.2 Main Screen

Note: The number of pump displayed on the VPware Main Screen can be changed from the "Configure/Application Settings" menu, from one pump to 16 pumps. Depending on the size of your monitor, you may need to scroll this window horizontally to view "hidden" pumps.

Each of the parameters of the VPware Main Screen has been numbered in the adjacent figure for explanation:



1) **Pump Name:** User-assigned name, helpful to differentiate pumps in multi-pump systems. Go to the "Configure/Pump Configure" screen to enter the pump name.

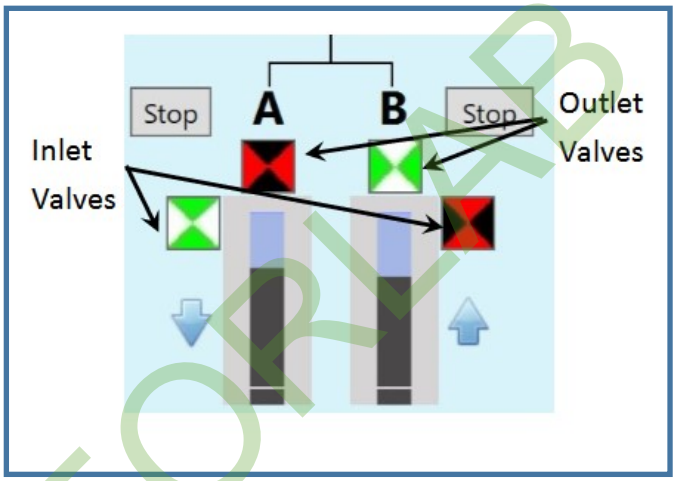
2) **Pressure (psi, bar, kPa, or MPa):** Displays the instantaneous pump pressure, updated every second. When pump is stopped or set in 'independent' modes, pressure for each cylinder is shown. In "paired" mode, when pump is running, the pressure of the active, i.e., pumping cylinder, is shown in this box.

3) **Rate:** In "paired" modes, flow rate of the active cylinder (i.e., cylinder that is delivering or receiving fluid, depending on mode selected) is shown. When pump is operated in "independent" modes, the display is split, to show the rate of each cylinder. If the pump is not running, the rate box shows "Stopped".

4) **Cylinder Start/Stop switch:** Buttons to start or stop Cylinder A or Cylinder B when pump is operated in "independent" modes. The Start/Stop button corresponds to the cylinder beneath it. If the default "SMART-START Paired Mode Start" setting has been selected (see Configure/Application Settings), the pump to automatically select the best piston to start regardless of which Start button is pressed. If SMART-START Paired

Mode Start is disabled, whichever Start button the user presses starts that specific piston. See Section 5 of this User Guide for a detailed explanation.

5) **Fluid Inlet & Outlet Valves:** Each cylinder has an icon for its inlet (fill) and outlet (deliver) valve, as shown in expanded the figure below. In all operating modes, except IR (Independent Rate-Manual) and IPD (Independent Pressure Deliver-Manual), these valves are automatically actuated when the pump is running. However, the valves may also manually opened/closed by clicking on the respective valve icon. Note the color of the valve icons shows the position of each valve, presuming that compressed air supply is connected to the pump. **RED** indicates that the valve is closed, while **GREEN** indicates the valve is open. When you click on the valve icon you will see it change color and simultaneously hear an audible click and a release of compressed air from the valve solenoid as the valve changes position. As mentioned above, when the pump mode is set to IR or IPD, the user must activate each valve by clicking on the respective



valve icon. **The position of valves can only be changed while the pump is stopped.** Attempting to open/close a valve while the pump is running results in a warning that the position of valves cannot be changed while the pump is running.

6) **Piston Direction:** The vertical blue arrow icons in the above figure show the movement direction of each of the pistons. **The direction of the pistons can be changed, only while the pump is stopped, by clicking on these arrow icons.** You can also change the piston direction, when the pump is stopped, by clicking on the "Set Piston Direction" boxes (refer to Item 9 of this list).

When the pump is in paired modes, you may notice the arrow of the standby piston oscillate "up/down" after refilling. This is normal. It's due to the fact that the stand-by piston is adjusting its cylinder pressure to match the pressure of the active cylinder (which may be continually changing) so that there will not be a pressure pulse when the pump switches from one piston to the other.

7) **"Stop All" Button:** Pushing this button instantly stops ALL pumps controlled by the computer running VPware. Using keystrokes "ALT+A" also stops all pumps in the same way.

8) **Motion Status:** These boxes show the status of the each piston.

   When the pump cylinders are operated independently, the following motion status indicators are shown:

   - **Stopped** (**Blue box**): Piston stopped but ready to run
   - **Error** (**Red box**): Piston stopped due to error. An accompanying error message gives possible causes and ways of correct the error.
   - **Running** i.e., delivering or receiving fluid, depending on the mode (**Green box**)

   When the pump is paired modes, a single colored box displays the pump status:

   - **Pump Stopped** (**Blue box**) but ready to resume pumping
   - **Error—Pump Stopped** (**Red box**). A pop-up error message gives possible causes and ways to correct the error.
   - **Pump Running** (**Green box**): pump mode is shown inside the box.
   - **Auto-Filling** (Yellow box): this message is displayed when the Paired Mode Start is enabled (see Configure/Application Setting menu) and pump needs to repositioning one of the pistons prior to starting in order to maintain pulse-free flow.

9) **Set Piston Direction (pump must be stopped):** Each of these buttons is used to manually change the piston direction from "Extend" (move up) to "Retract" (move down) or vice versa when the pump is stopped. You can also change piston direction by clicking on the blue piston direction arrows next to the pump cylinder animation.

10) **Mode:** Pump operating modes are selected by clicking on this drop-down menu. Refer to Section 4 of this user guide for detailed descriptions of the 15 pump modes. Note that when a "paired" mode is selected for one cylinder, the other cylinder is automatically switched to the same "paired" mode. Similarly, if one cylinder is changed to an independent mode (from paired mode), the other cylinder is set to that same independent mode, though the user can change to another independent mode (i.e., both cylinders may be set to different independent modes, if so desired).

11) **Rate (ml/min or ml/hr):** Displays the instantaneous rate of the piston movement for each cylinder. Values are updated every second. Positive numbers represent fluid delivery (piston moving upwards) and negative numbers represent a piston moving downwards i.e. cylinder refilling. The units of rate may be changed from the "Configure / Applications Settings" sub-menu.

12) **Set Rate (ml/min or ml/hr):** The user-entered, or "set" pumping rate, is shown in this box. Click the box to open a "Set Cylinder Rate" window and enter the set rate. Set Rate values are always positive numbers (or zero). Pressing "OK" or "Enter" will input the new set rate and cause the pump LEDS to blink four time, reflecting that a command has been issued to the pump. Note: Set rates can be changed at any time, including when the pump is running. Note that the "Set Rate" box is a darker blue when the pump is set to any of the "rate" modes, and is grayed-out when the pump is set to any of the Pressure pumping modes. This is intended to make it easier to find the appropriate "set" value when the pump is in "rate" modes.

13) **Pressure (psi, bar, kpa, or MPA):** Displays the instantaneous gauge pressure reading of the transducer mounted to each cylinder . Pressures may be positive (above atmospheric) or negative (below atmospheric), as the VP-Series pumps are capable of drawing a slight vacuum (~0.5-0.6 atmosphere) when the cylinder is refilling. Pressures units ("psi", "bar", "kPa", or "MPa") are selectable from the "Configure / Application Settings" menu.

14) **Set Pressure (psi, bar, kPa, MPa):** Pressing the button of this row opens a window for the user to enter a new set pressure when using the pump in any of the "pressure" modes. The set pressure can be changed at any time, including when the pump is running. Different pressures may be set for each cylinder when operating in "Independent" modes, whereas the pressure value entered for either cylinder is applied to both cylinder when the pump is operated in "paired cylinder" modes. Note that the "set pressure" box is a darker blue when pump is in "pressure" modes and is greyed-out when pump is operated in "rate" modes.

15)  **Safety Pressure (psi, bar, kPa, MPa):** Pump makes an emergency stop if this pressure is exceeded. **The recommended safety pressure is one that is low enough to protect any equipment connected to the pump from damage, but high enough above the set pressure so as not be activated in the normal course of operating the pump.** Setting the safety pressure very close to the set pressure can result in unnecessary pump stoppage. Safety pressure values can be input either from this Main Screen (by clicking on the "Safety Pressure" box) or from the "Configure/Pump Configure" screen. **Note: A safety feature of all VP-Series pumps prevents the pump from operating until a safety pressure has been set by the user. When a pump is first started, the Safety Pressure boxes will show the wording "Not Set" in yellow highlight to remind the user to set it. When first setting the safety pressure, you will note a value of –400 psi (or equivalent) which is an internal flag that prevents the pump from operating. Only positive safety pressure values allow the pump to operate.**

16) **Pumped Volume (individual cylinder) and Reset:** VP-Series pumps display delivered volumes (i.e., fluid leaving via the Fluid Out manifold) as positive numbers and received volumes (i.e., fluid coming into the pump via the Fluid Out manifold, when the pump is operated in "Receive" modes) as negative numbers. When operated in "Individual"

modes, the Pumped Volume value increases when the piston is extending and decreases (negative value) when retracting. Because of this, the Pumped Volume value for each cylinder is only meaningful when measuring the volume of one piston stroke. Users can reset the volume of each cylinder at any time by clicking on the "Reset A" and "Reset B" buttons on the Main Screen. In addition, resetting the volumes can be set to occur automatically from the Configure/Application Settings menu.

17) **Cumulative Volume:** When the pump is operated in any of the Paired Cylinder modes, the cumulative volume box displays the volume displaced or received by the pump since it was last reset. Fluid volume delivered by the pump are positive numbers, while fluid volume received are negative numbers. Please keep in-mind that VP-Series pumps measure pumped volume based on the precise movement of the piston, as if the fluid were incompressible. Other factors, such as presence of any gases in the cylinder during pumping and the effect of dissolved gases in the fluid are not considered.

18) **Reset Cum. Volume:** Cumulative pumped volume can be reset at any time by pressing this button. Alternatively, cum volume can be configured to be reset automatically using the setting in the Configure/Application Settings window. When the pump is used in volume dispense mode (set in the Start Confirmation window), the Reset Cum. Volume line displays the set dispense volume.

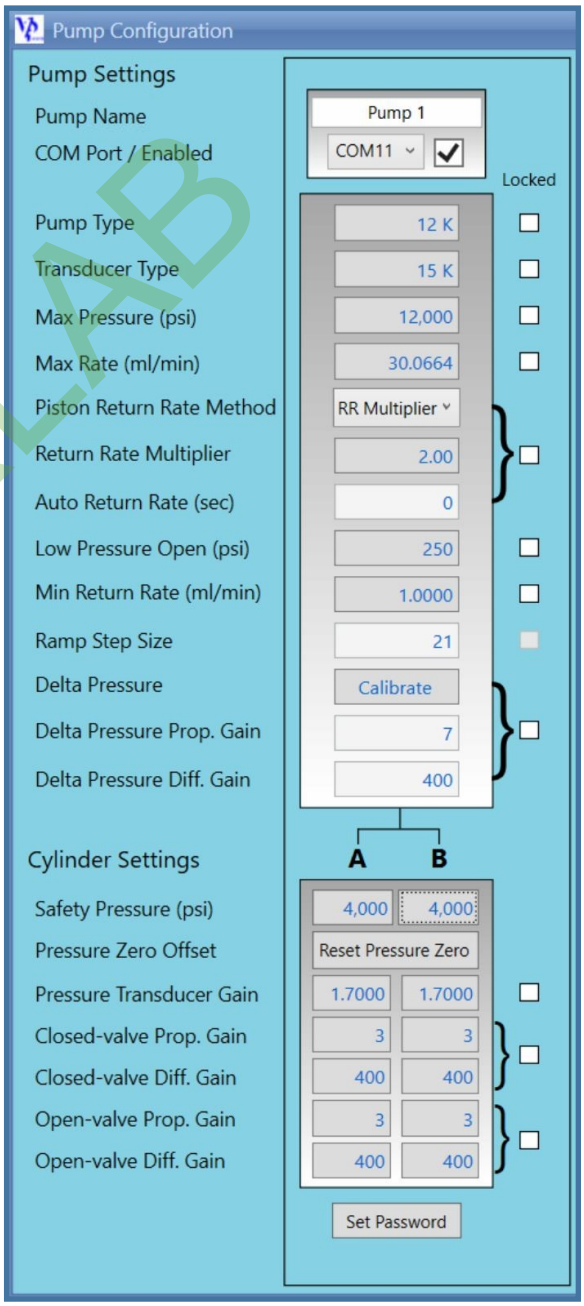
7.3 Configure Menus

Clicking “Configure” on the VPware menu bar accesses three sub-menus, which are explained in this section:

1. **Pump Configuration:** Window showing all settings for each individual pump. Provides ability to specify min/max rates and pressures for each pump, set safety pressure, calibrate pressure transducers, etc.

2. **Application Settings:** Change settings that are applied to all pumps controlled by VPware. Settings include units of pressure and rates, error display options, start options, and control of cumulative volume settings.

3. **Option Modules Configuration:** Select configuration options for using the 15-pin Options Module for remote control of the pump via digital and analog signals.



7.3.1 Pump Configuration

The image at right shows the Pump Configuration screen that is accessed by clicking “Configure / Pump Configuration” from the VPware Menu Bar. This screen is used to establish communication with the pump and to change the main operating parameters of individual pump pumps. Some of the Configure parameters are automatically uploaded from the pump’s firmware; the remaining parameters are user-specified. Each of the Pump Configuration screen parameters is explained in this section:

1) **Pump Name:** The user may enter a unique pump name directly into this box. If not specified, the default names are: Pump 1, Pump 2, Pump 3, and Pump 4, etc.;

2) **Com Port / Enabled: Refer to Section 3.4.3 for detailed instructions on establishing communication between your computer and VP-Series pumps.** After connecting your VP-Series pump

to the computer, powering it on, and starting the VPware app, go to the "Configure/ Pump Configuration" screen. Click on the COM Port / Enabled drop-down box to view the list of available COM ports. Select one of the listed COM ports and click "Enable" to establish pump-to-computer communication. When the correct COM port is selected and "Enabled" check-box is checked, the pump configuration settings will be populated.

If more than one COM port is shown in the drop-down list, you can try the ports one-by-one (be sure to check the "Enabled" box each time you try a different COM port. When you find the COM port connected to the pump, the Pump Configuration window will populate with the pump settings.

If the COM Port drop-down list is empty (no COM port are listed), check to ensure that the communications cable is connected and that the pump is powered-on. If there are still no pumps listed in the COM Port drop-down list, close all applications, unplug all peripheral devices, and restart the computer. This will reset the COM ports. Next, connect the cable to the pump and computer, then power-on the pump and start VPware. If there are still no COM devices listed in the VPware pump configuration drop-down list or none of the listed COM ports will connect to the pump, the next step is to install the driver for the type of cable you are using. Starting with VPware 1.2.42, the driver software for the USB-RS232 and USB-USB cables supplied with the pump are included in the VPware .exe file and are automatically downloaded with VPware. **Go to C:\Vindum Pump\Cable Drivers folder and follow the instructions below for the type of cable you are using:**

- **RS232-USB Cable:** Double-click on CDM21224_Setup.exe to install the cable driver. You may need to restart the computer after downloading. Go to VPware Configure/Pump Configuration to find the COM port and connect to the pump.
- **USB-USB Cable:** Go to Windows Control Panel—Device Manager and click on "Ports (COM & LPT)" to show the list of COM connections. Look for one with a small yellow "!" flag (indicating a problem with this COM port). Double-click to open this COM port and check "Device Status". If the device is not working properly, click on the "Driver/Update Driver" and select "Browse my computer for driver software". Search for drivers in "C:\Vindum Pump\Cable Drivers" folder and click the box "Include Subfolders", the press "Next" and "Finish" to complete the cable driver installation. The computer should now recognize the cable and pump, so you can return to VPware\Configure\Pump Configuration and connect to the pump.

If you are still unable to connect to the pump from VPware, restart the computer and try again to connect to the pump from VPware. If the problem persists try a different computer or contact Vindum Engineering Support (support@vindum.com or call +1-281-782-8312).

3)  **Pump Type:** The pump type/model is stored on the pump's memory and affects other configuration settings (e.g., Max Pressure and Max Rate). **Be sure that you have a good reason for changing the pump type (such as having changed the top section of the pump to a different model). It would also be prudent to "Lock" this setting using the Administrator/password control, as described later in this section.** If the Pump Type setting is changed, the new setting is stored on the pump's internal memory.

4)  **Transducer Type:** Clicking on this setting opens a dialogue box with a drop-down list of the different models of transducers that are available from Vindum Engineering for VP-Series pumps. Because **safe operation of the pump depends on the pressure readings from the transducer, the transducer type should only be changed if a different transducer model is installed. The output voltage range of all the transducer models used on these pumps is 0.5-4.5V, where 0.5V corresponds to atmospheric pressure and 4.5V is the max pressure of each transducer model. Installing a different transducer model without changing the transducer type setting will result in erroneous pressure readings and can lead to serious injury. If in doubt, check max pressure that is printed on the body of the transducer to verify that the max pressure value matches the VPware transducer type. Use only transducers supplied by Vindum Engineering to ensure proper operation of the pump. Use of non-approved transducers can damage the pump and result in injury to personnel.** The transducer type setting is stored on the pump's memory. **If you have any questions regarding substituting transducers, contact Vindum Engineering (support@vindum.com or +1 - 281-782-8312).**

5) **Max Pressure:** The default Max Pressure setting on every pump shipped from the factory, is determined by the pump model or the model of transducer installed, whichever has the lower pressure. If a lower pressure transducer model is installed on the pump (and the transducer type setting is changed to reflect this), the max pressure setting is automatically set to that value. Adding a higher-pressure transducer to the pump, however, does not increase the pressure capability of the pump. Another reason for lowering the max pressure could also be to add a level of protection for inexperienced users, such as in educational settings. The max pressure setting is stored on the pump's memory so the set value will show the same if the pump is connected to a different computer. Note that if a max pressure is entered that is lower than the safety pressure, VPware issues a warning that that the safety pressure values (one for each cylinder) are too high, to advise the user to lower the safety pressure settings. If you see these pair of warnings, reset the safety pressure on each cylinder to a value that is less than the max pressure.

6) **Max Rate:** The default max rate is determined by the pump type. It may be useful to change the max rate to a lower value. For instance, when working in "pressure"

modes, you may want to ensure that the pump does not exceed a certain rate. Like the other pump configuration settings, max pressure is stored in the pump's memory.

7) **Piston Return Rate Method and Return Rate Multiplier: The piston return rate setting is a critical factor to enabling pulse-free flow when the pump is used in any of the "paired" cylinder modes.** When a pumping piston reaches the end of it's stroke, it needs to retract quickly enough so that the cylinder can refill with fluid and repressure to match the pressure of the active/pumping cylinder. If the piston return rate is too slow, fluid flow from the pump will not be pulse-free. In addition, the act of compressing the fluid in the refilled cylinder induces a temperature increase and associated pressure waves inside the cylinder, which need to dissipate before starting to pump fluid from this cylinder. To ensure pulse-free flow, it is best to allow at least 12 seconds, after the passive piston refills, to pressurize the cylinder and dissipate any increase in fluid temperature before starting to pump from this cylinder. In VPware, the refill speed of the piston is controlled by the Return Rate Multiplier.

Starting with VPware v1.2.15, there are two options for setting the piston return rate, selectable from the "Piston Return Rate Method" drop-down box: 1) **Auto Return Rate ("Auto RR");** and 2) **Return Rate Multiplier ("RR Multiplier"):**

1. **Auto RR** sets the time, in seconds, that the passive piston has to repressure the cylinder before it starts pumping. It is applicable to all continuous pumping modes, both pressure and rate. The minimum recommended time for the Auto RR setting is 10 seconds. Recommended Auto RR repressurization times are 12-16 seconds.

2. The **RR Multiplier (RRM)** method of setting the piston return speed uses a single value that is entered in the "Return Rate Multiplier" box. With this method, the return speed of the passive piston equals the rate of the pumping piston multiplied by the RRM. For example, with a RRM=2, if pumping fluid at 10ml/min, the passive piston will retract at 20ml/min. Typically a RRM value of 2 or 3 ensures that the passive piston has time to retract and the cylinder repressure before it needs to start pumping.

Regardless whether piston return rate is set by repressure time (Auto RR) or pumping speed (RRM), there are some important constraints to keep in-mind:

- The maximum return rate for each model of VP-Series pump is 2X the pump's maximum pumping rate capability. For VP-12k pump the max pumping rate is 29 ml/min, so the max return rate is 58 ml/min., regardless of whether the return rate multiplier implies a faster return rate.

- Although it may seem that setting a fast piston return rate is desirable, beware that the possibility of fluid cavitation (as the cylinder refills) increases with faster return rate, especially for high-viscosity fluids;

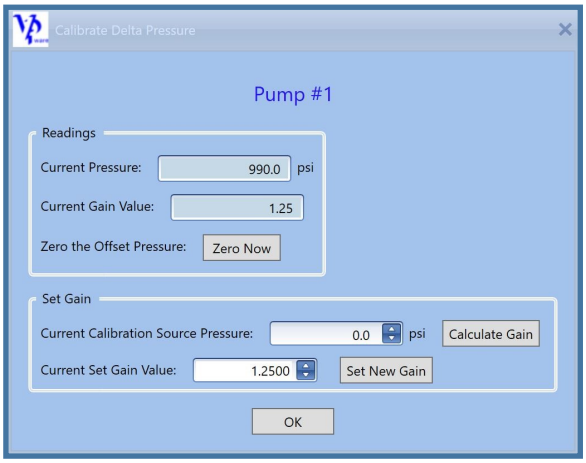
- When pumping at very low rates you want to use the “Min Return Rate” setting on the Configure/Pump Configuration screen to speed up the speed of the returning piston to allow more time for the cylinder to repressure. If the return rate set by the return rate multiplier is less than the minimum return rate setting, the piston retract speed will be the min. return rate value.

8) **Low Pressure Open:** In continuous pumping modes, when a piston reaches the end of it’s stroke the cylinder is still under high pressure. Before the fill valve opens to start refilling the cylinder, the pump automatically lowers the cylinder pressure before opening the fill valve to refill the cylinder. The “Low Pressure Open” sets the cylinder pressure at which the fill valve opens to refill the cylinder. As the piston retracts and the pressure in the cylinder drops, the fluid inlet valve will open when the internal cylinder pressure reaches the Low Pressure Open (LPO) value. **It may be necessary to increase the Low Pressure Open if pumping gases or highly compressible fluids, since gas expansion can keep cylinder pressure above 250 psi even though the piston is retracting. If the cylinder pressure never drops below 250 psi, the fluid inlet valve will not open. If you notice that the fill valve is not opening to refill the cylinder, increase the LPO so that the fluid inlet valve opens soon after the piston starts its refill stroke.**

9) **Minimum Return Rate:** Sets the minimum rate at which the piston moves during the refill stroke. If the refill rate set by the Return Rate Multiplier is less than this Minimum Return Rate, then the Minimum Return Rate value is applied. As previously mentioned, this setting is useful when pumping at very low rates, so that the piston retracts faster to ensure more time for repressuring the cylinder after refilling.

10) **Ramp Step Size:** This parameter sets the rate of motor acceleration. At this time, this parameter is not user-settable. If you require control over the ramp step size, please contact Vindum Engineering.

11) **Delta Pressure Transducer Gain, Prop. Gain, and Diff. Gain: (Refer to Section 9.5 for instructions on using Option Modules Configuration #3 for working with delta Pressure transducers)** These three boxes are used when operating the pump with an external delta pressure (dP) transducer. With an external dP transducer plugged into the pump’s Option Module port, the mode set to PDPD (pressure, delta pressure, deliver) and Option Module #3 is enabled (via Configure/Option Modules menu), the pump will maintain a set delta pressure. Prior to operating in



this mode, the dP transducer gain values need to be entered and the dP offset pressure zeroed. The image above shows the window that opens when the "Calibrate" button is pressed. The dP transducer's gain can be set directly or will be calculated if the dP transducer is connected to a known pressure and the "Calculate Gain" button is pressed. Once the gain is set, the transducer pressure-zero can be reset by exposing the dP transducer to ambient pressure and pressing the "Zero Now" button.

The Delta Pressure Proportional and Differential Gain boxes are used to control the piston attack speed when the pump is operated in PDPD mode. See item 15 of this section for a detailed explanation of Proportional and Differential Gain settings and procedure for adjusting them.

12)  **Safety Pressure:** The purpose of the safety pressure setting is to prevent damage to equipment connected to the pump. **To prevent damage to equipment and potential injury, set the Safety Pressure below the pressure at which any equipment connected to the pump would be damaged. The importance of the safety pressure dictates that safety pressure values be entered by the user every time the pump is initialized. See Section 3.5.1 for more information about setting safety pressure.**

If the safety pressure is reached or exceeded at any time, the pump interrupts power to the motor on the cylinder that hit the safety pressure, in order to stop piston movement as quickly as possible. **The pump should be operated so that the safety pressure is only exceeded in exceptional circumstances. Setting the safety pressure very close to the normal operating pressure of your experiment is not recommended, since small fluctuations in pressure can trigger a safety pressure stop. See Section 6 (Stopping Pumps and Valve Position) for implications of stopping VP-Series pumps by exceeding the safety pressure setpoint.**

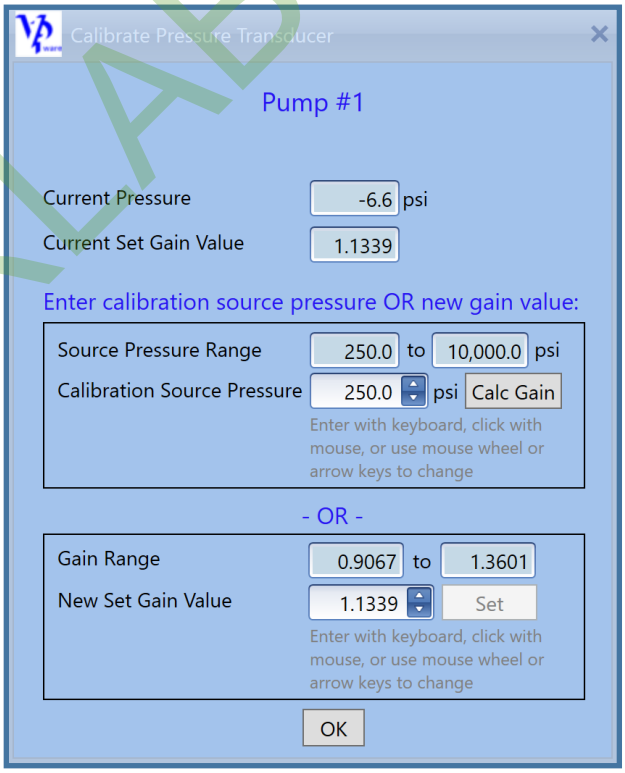
For convenience the safety pressure values can be entered/changed on either the Pump Configuration window or by clicking on the safety pressure boxes on the Main Screen.

There is a safety pressure box for each cylinder because, if the pump is operated in independent cylinder modes, each cylinder may have a different safety pressure requirement. When used in the paired modes, the same safety pressure value is entered for each cylinder.

13)  **Pressure Zero Offset:** The output voltage of the transducers on VP-Series pumps varies from 0.5V (atmospheric pressure) to a max 4.5V (corresponding to transducer's Full Scale Output pressure, printed on the transducer body). The Pressure Zero process calibrates the transducer "resting" output voltage to atmospheric pressure, aka pressure zero. **Since all output voltage is measured as a differential to the resting output voltage it is important to reset the transducers' pressure zero often, prefera-**

bly each time the pump is started. Transducers also have a tendency to "drift" over time and in response to changing ambient temperature. Resetting Pressure Zero aligns the transducer's output voltage to current ambient conditions. Doing this is especially important for pulse-free pump operation because poorly-calibrated transducers will see the same pressure as different values, which can result in pressure pulses when the pump switches from one cylinder to the other in paired modes. See Section 3.5.3 for instructions for the simple procedure to reset pressure zero or click on the "Reset Pressure Zero" box on the Pump Configuration screen and follow the instructions in VPware.

14) **Pressure Transducer Gain:** This parameter, also known as the "span", is used to convert the transducer output voltage to a pressure value, which is essential for proper operation of the pump. All VP-Series pumps use analog transducers with a 0.5V-4.5V range, with 0.5V being atmospheric gauge pressure and 4.5V corresponding to the transducer's maximum pressure (also called Full Scale Output and listed on the transducer body). As such, the Pressure Transducer Gain setting is analogous to the slope of an output voltage vs. pressure line. Gain values for each transducer have been set by Vindum Engineering during pump testing and are stored in the pump's memory. Many organizations periodically check and recalibrate transducers' gain settings to account for device for drift due to aging or environmental effects. VPware facilitates this process. Click on the box with the transducer gain value and a window like the one shown at right. Each transducer can be calibrated using a reference pressure device, such as a deadweight gauge or by using a reference transducer and a pressure source connected to the pump. After entering Calibration Source Pressure value, press the "Calc Gain" box and VPware calculates the new transducer gain value. Alternately, if the transducer gain is calibrated externally, the gain value can be entered directly in "New Set Gain Value" in the lower box of this window. **For best pressure accuracy, it's a good idea to do the span calibration at, or near, the pressure at which you will be using the pump.**



If installing a different model of transducer (sold by Vindum Engineering) on the pump, transducer gain values will be automatically adjusted when the "Transducer Type" setting is changed, as discussed earlier in this section (see item 4 of this section).

15)  **Proportional and Differential Gain Settings:** The Proportional Gain (PG) and Differential Gain (DG) settings are inputs to a Proportional-Integral-Differential algorithm (PID) that is used to guide the pump's motor response as it ramps the cylinder pressure to the target set pressure. Instantaneous pressure reading from the transducers are compared to the set pressure and the PID algorithm determines the instantaneous motor speed. The pump processes this information several times a second and adjusts the motor speed in response to the latest PID calculation. Differences in the size of the system being pressurized and the compressibility of the fluid being pumped have a large effect on the observed pressure response. The goal of the pump operator is to find PG and DG settings that result in the pump reaching and maintaining the set pressure (i.e., target pressure) as quickly as possible. **As such the PG and DG settings are critical to the pump delivering pulse-free performance.** There are two pairs of Proportional Gain and Differential Gain setting in the Pump Configure screen (one pair for each cylinder):

- The "**Closed-Valve Gain**" settings shape the motor response of the passive (refilling) cylinder in re-pressuring to match the pressure of the active (pumping) cylinder's pressure. VP-Series pumps use the Closed Valve Gain settings when operating in all continuous-flow pump modes (both pressure and rate modes).
- The "**Open-Valve Gain**" settings shape the motor response of the active (pumping) cylinder when the pump is used in constant-pressure modes. It is not used in "Paired Rate" pump modes.

In the high-speed PID feedback loop, the difference between current and set pressure is called the "error value". This PID feedback loop uses a **proportional value** that measures the magnitude of the proportional error, while the **differential value** measures the rate-of-change of the proportional error versus time. The **integral** component sums the "error value" term over time and works with the proportional and differential readings to provide a motor response that reaches and holds the set pressure as quickly as possible. Mathematically, **Proportional Gain (PG)** and **Differential Gain (DG)** are "correction constants" (i.e., multipliers) applied to the Proportional and Differential error values of control algorithm to help "tune" the initial pressure response to different system sizes and fluid compressibility.

Proportional and Differential Gain settings have the following impact on pump motor response:

- **Proportional Gain Setting (PG):** Increasing PG increases the motor response, increasing the piston speed in an attempt to reach the set pressure more quickly. **Increasing the PG increases the "attack speed" of the piston, much like the accel-**

erator pedal on a car. However, if PG is set too high, the pump will over-shoot the pressure and "cycle" around the set pressure or even becoming unstable and never reaching the set-pressure.

- **Differential Gain Setting (DG):** Increasing the DG constant has the effect of "dampening" (i.e., slowing) the piston speed as the instantaneous pressure approaches the target set-pressure. **Increasing DG resulting in slower pressure movements, much like the brakes on a car as you approach a stop sign ("the target").** On its own, though, increasing DG is not always a good thing, as it increases the time required to read the set pressure.

Example: Optimizing the OPEN-Valve Proportional and Differential Gain Settings

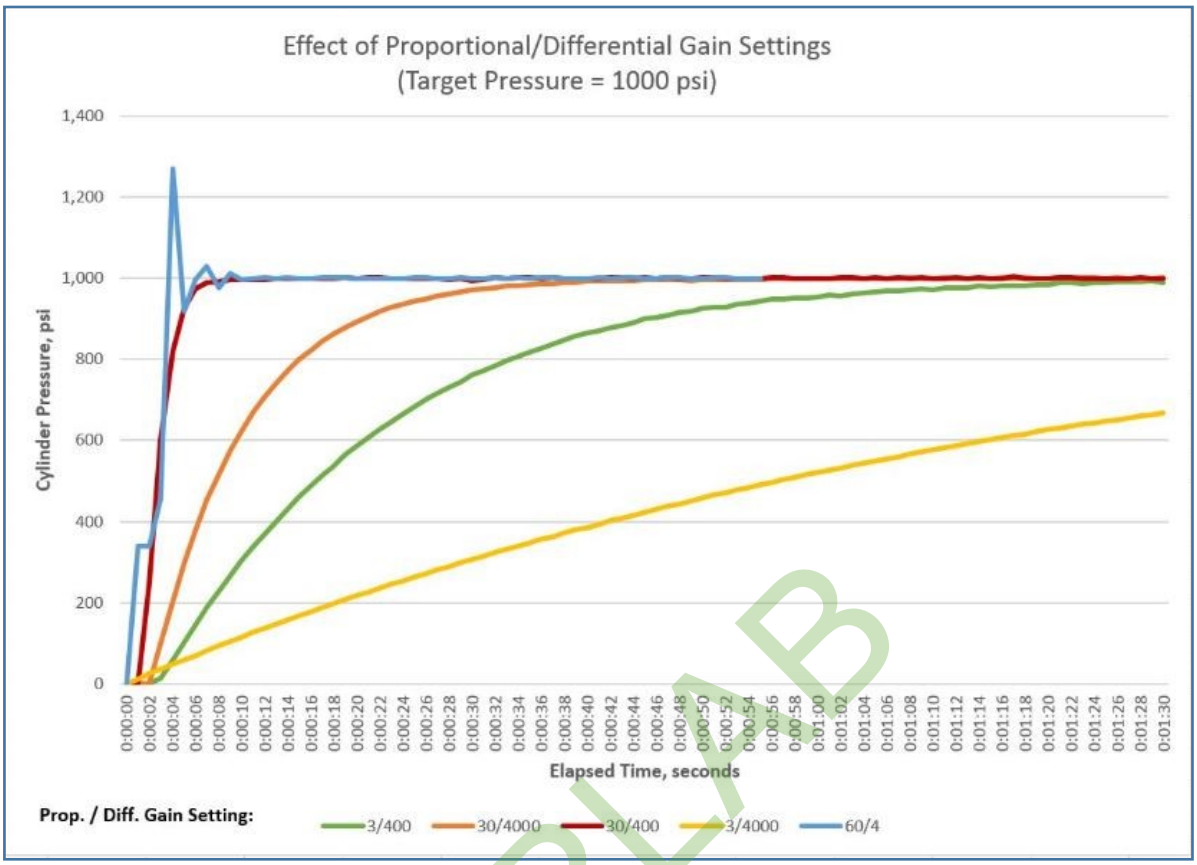
Indicators that you need to adjust the Open-Valve PG and DG settings in the Pump Configure Screen are: 1) Pump is over-shooting the set pressure or taking a long time to reach the set pressure, or 2) The pump is "cycling" around the set pressure or taking a long time to stabilize at the set pressure.

Graphing "Pressure versus Time" is very helpful to visualizing the effects of changing Proportional and Differential Gain settings. The graph on the next page shows the start-up pressure response of a pump connected to a capillary tube with a target pressure of 1000 psi and various iterations of open-valve PG and DG settings.

The first line (green color) shows the pressure response versus time using the factory default settings for Open-Valve Proportional Gain and Differential Gain, (i.e., PG=3, DG=400). The second trace (orange line) shows start-up pressure behavior of the same pump after increasing both the PG and DG settings. Given that the pump was able to reach the target pressure more quickly, the increases represent an improvement. The PG & DG settings used to create the third line (red color) are an even better result than either of the first two runs. Increasing PG to a value of 30 while leaving DG at the initial setting of 400, enabled the pump to reach and maintain the target set pressure very quickly! With PG increased from 3 to 30 and DG left unchanged from the original setting, the pump accelerated towards the set pressure much faster but still had enough "brakes" (DG=400) to stay at 1000 psi once it was reached.

The fourth (yellow) line shows the pressure response that results from a large increase in Differential Gain (i.e., applying more "brakes") with no change the Proportional Gain setting (i.e., same "accelerator"). Increasing the DG results in a very low pressure response, which failed to reach the target pressure and is clearly inferior to the last case (red line).

Finally, large increases in the Proportional Gain setting, with a reduction to the DG setting can cause the pressure response shown by the blue line. In this case, the PG=60 setting (DG=4) resulting in a very rapid pressure response with little ability to



"slow" approaching the set pressure. The pump significantly overshot the 1000 psi target pressure and cycled around it before settling to 1000 psi.

As this example shows, finding suitable PG and DG settings for systems of different sizes and fluid types is a trial-and-error process, but by understanding the impact of each, it is relatively easy to tune the pump to different system conditions.

<u>CLOSED-valve Proportional and Differential Gain Settings</u>

CLOSED-valve Proportional and Differential Gain settings affect the motor response of the cylinder after refilling when the fluid inlet and outlet valves are closed. In all continuous-flow modes (i.e., paired pressure and paired rate modes), the passive cylinder must match the pressure of the active (pumping) cylinder in order to maintain pulse-free flow.

If you notice that the passive cylinder pressure, after refilling, is unable to match the pressure of the active cylinder and is causing a pressure pulse when the pump switches between cylinders, adjusting the Closed-valve PG and DG is advised. This situation most commonly occurs when working with highly compressible fluids or gases. Adjustments are made in the same manner as for OPEN-valve PID settings outlined in the example above. Increase PG and DG to pressurize the passive cylinder more quickly, but watch the passive cylinder's pressure to ensure that it is not over-shooting the pressure of the active cylinder. If this happens, reduce the values of both CLOSED-

valve PG and DG settings until the passive cylinder reaches the pressure of the active cylinder efficiently. **Also note that you may need to increase the Return Rate Multiplier setting in order to give the passive cylinder more time to re-pressurize after filling.**

Additional Tips for Adjusting Proportional and Differential Gain Settings:

1. Start by graphing Pressure Versus Time using the factory default settings for PG and DG. Graph and compare the changes you make each time. Increases to PG and DG should be made slowly and methodically. Use a set pressure similar to that which you expect to use in your experiments.

2. Proportional Gain is analogous to the "accelerator" on a car. Increasing PG resulting in faster pressure increase towards the target pressure. **Differential Gain** is analogous to the "brakes" on a car; increasing DG counteracts the increased speed of a PG increase and slows the pressure response as the pump approaches the target pressure. **As such, it's common to increase both PG and DG in tuning the pump, often by the same multiple (e.g., double PG, double DG), at least initially.**

3. Change PG or DG?: Changing Proportional Gain, all else constant, has a larger impact than changing Differential Gain. If the pump is slow to reach the set-pressure, or is unable to reach the set-pressure within one piston stroke, you will need to increase the Proportional Gain. If the pump significantly overshoots the set-pressure and/or "cycles" above/below the set pressure, it's a sure sign that you need to decrease the PG setting (and/or increase the Differential Gain).

4. If your pump is stopping due to exceeding the safety pressure limit, it might be because your safety pressure is set too close to your working pressure (need to allow some pressure "headroom") or your PG overshoot is close to your safety pressure. To solve this issue, you will need to either increase your safety pressure setting or raise your DG setting to dampen the pressure movements.

The factory default settings for Proportional Gains and Differential Gains are shown below. These are based on pumping water (fairly incompressible fluid) into a moderate-sized system.

- Closed-valve Proportional Gain (**factory setting = 3**)
- Closed-valve Differential Gain (**factory setting = 400**)
- Open-valve Proportional Gain (**factory setting = 3**)
- Open-valve Differential Gain (**factory setting = 400**)

16) **Locking Pump Configuration Settings:** All of the pump configuration settings can be locked to prevent accidental changes or to limit pump capabilities when used by less-experienced users. For instance, should a pump administrator want to limit a pump's max rate or max pressure, she could change those settings in the Pump Configuration menu and then lock those values as follows:

1. Connect the pump to be configured and establish communication with the computer in the normal fashion;
2. Open the Configure/Pump Configuration menu;
3. Enter new values for parameter to be changed, such as Max Pressure;
4. Click on the "Locked" column of boxes next to the parameter that you want to lock. This will cause a "Password" box to open, prompting the user to enter an "Administrator Password". **Every pump has a default four-digit password (numerical) that is linked to the last digit of the pump's serial number. These are listed in the table to the right. The pump's serial number can be found on label on the back of the pump near the on/off switch.** Enter the 4-digit password and press "OK".
5. **A red outlined box and check-box on the Pump Configuration window indicates that the parameter is locked.** Once the password is entered you may lock multiple parameters without having to reenter the password. Once the Pump Configuration window is closed, it will be necessary to reenter the password again to lock/unlock configuration parameters.

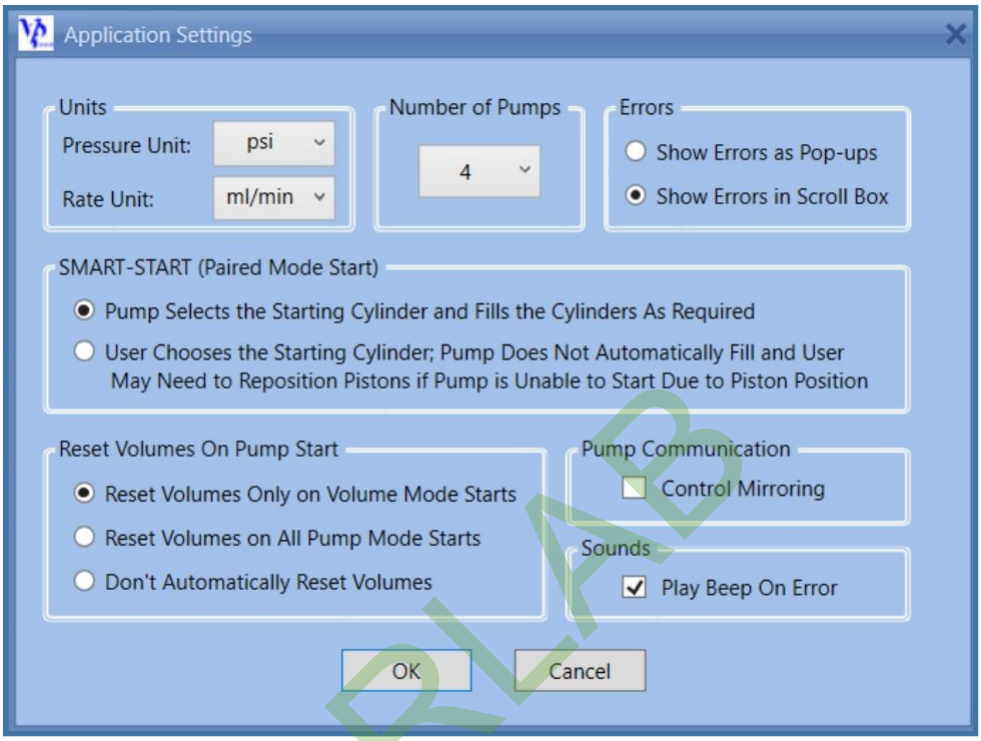
Last digit of Pump Serial #	Default Password to Lock or Unlock Configuration
0	4561
1	9931
2	4935
3	1784
4	3579
5	1463
6	6875
7	5197
8	8462
9	2879

The locked configuration settings are stored in the pump's memory (not on the computer) so that they remain in-effect regardless of the computer that is used with the pump.

To select a different password, click on the "Set Password" box at the bottom of the pump configuration screen. After entering the current password, a screen will prompt for a new Administrator Password. Enter the new four-digit numeric password twice and then press "OK" to save the new password to the pump's memory. **Should you lose the Administrator Password, please contact Vindum Engineering (support@vindum.com) for instructions to reset the password.**

7.3.2 Application Settings

The Application Settings window is the second selection of the "Configure" menu from VPware Main Screen. The Application Settings window, shown below, controls settings that are applied to all pumps. Each of these settings is explained in this section:



1. **Units:** Pressure and Rate Units are set from the drop-down list of options. Choices for pressure units include psi (pounds per sq. inch), bar (equivalent to 14.5038 psi), kPa (kilopascal), and MPa (megapascal; equivalent to 10 bar). Rate units can be set to either ml/min or ml/hour.

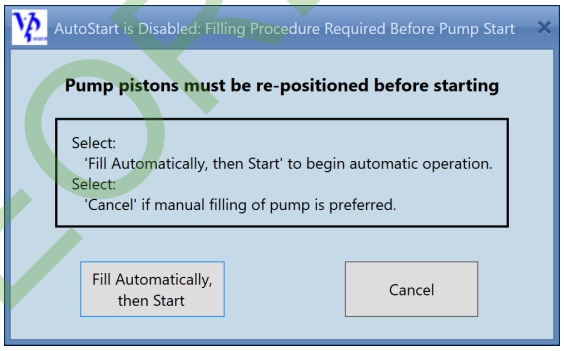
2. **Number of Pumps:** Up to 16 pumps can be shown in VPware. Depending on the computer screen size, it may become necessary to scroll to see all the pumps if a large number of pumps is used. When the number of pumps is changed, it's necessary to restart VPware in order to change the displays.

3. **Errors:** Select to view errors that stop the pump in two formats: 1) As pop-up messages, or 2) As a list that is shown at the bottom of the VPware Main Screen. Pop-up error messages are more readily noticed, but some users prefer errors to be shown in a list, to minimize screen clutter. To make the errors more noticeable, the user can also check the "Play Beep On Error" box at the bottom of the Applications Settings window.

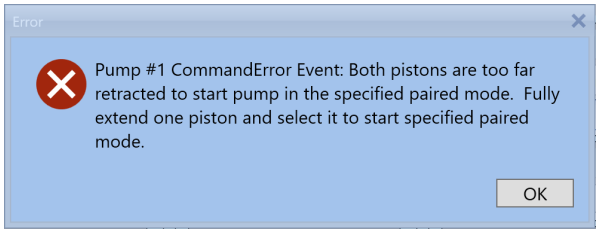
4. **SMART-START (Paired Mode Start):** As the name implies, this setting affects the choice of which pistons starts pumping when in paired pressure or rate modes are used. When the pump starts in paired modes (i.e. set for continuous flow), the refilling piston must retract (in deliver modes) and pressurize to the same pressure as the active cylinder before the pumping piston reaches the end of its stroke. Otherwise, the

pump cannot deliver continuous, pulse-free flow. So, if the pistons are too far extended (deliver modes) or retracted (receive modes), the pump is unable to start in these paired modes. The first of the "SMART-START" buttons automates positioning of the pistons for paired mode starts. When this capability is activated, the pump determines which of its pistons is in the best position to start pumping so that continuous, pulse-free flow will be possible. If the pump determines that both pistons are out of position for the selected pump mode, it will reposition one of the pistons prior to starting. When this happens, the "Motion Status" box on the VPware main screen will display "Auto-Filling" with a yellow background while it repositions one of the pistons to enable pulse-free, continuous flow. After repositioning the piston, the pump starts in the mode selected.

Some users may prefer to dictate which piston initiates pumping in paired modes, rather that having the pump automatically select which piston starts pumping. The second button in the Paired Mode Start box gives this option. When selected, the pump will start with the piston associated with whichever "Start" button is pressed (i.e., the Start button next to piston A will start Piston A when pressed, while pressing the Start button next to piston B starts that piston first). Keep in mind that it may be necessary to reposition the selected piston (or the other piston) prior to starting the pump in order to achieve continuous pulse-free flow. If the pump senses that it needs to reposition the piston(s) prior to starting to pump, the following message will be shown when the "Start" command is given:



The user can then select "Fill Automatically, then Start" and the pump will reposition whichever piston is needed to enable continuous flow. If the user instead presses "Cancel", an error message like the one shown below pops-up with instructions on how to reposition the pistons so that the pump can be started and maintain continuous pulse-free flow for the specified paired mode.



5. **Reset Volumes on Pump Start:** The last application setting gives users the option of when to reset the pumped volume boxes on the VPware Mains Screen. The first radio button (default setting) resets the pumped volumes whenever the pump is started with "Volume Dispense" specified in the Start Confirm window. This way the user can confirm the volume dispensed from the pump each time the dispense setting is used.

6. **Pump Communication/Control Mirroring:** This check-box is designed as a programming aid. It should not be used in normal pump operations. If you plan to control the pump from a system other than VPware/Option Module (e.g., LabVIEW, Anybus Communicator, etc.), you can use Control Mirroring to verify that a command to the pump from the "other" control system is processed correctly by seeing the command "mirrored" in VPware. To use Control Mirroring, connect the pump to computer running VPware with one communications cable (e.g., RS232-USB cable) and use another COM cable (e.g., USB-USB cable) to connect the pump to another computer or control program. When the Control Mirroring box is checked, VPware updates pump Status, ReadInit, ReadLow, and ReadErrors every second. As a result, any actions by the other control system will be reflected in VPware. For example, when a command is given to the pump from the alternate program (e.g., LabVIEW), if the command was correctly processed by the pump, the change will be visible in the VPware displays.

   Control Mirroring is only a programming aid and should not be used to operate the pump via two control systems. Operating the pump with two control systems connected is beyond the design scope of VP-Series pumps and is not recommended for the following reasons: 1) If the pump receives overlapping commands from two systems, both commands will be ignored or may be processed incorrectly. VPware continually sends commands to the pump to update displays, to check pump status, and to check for errors, so the risk of command "overlap" is more likely than it might seem at first; and 2) Commands to the pump from one control system will update the display of that software, but may not update the display of the other control system. If this happens, one of the control systems will not display the correct pump settings/status.

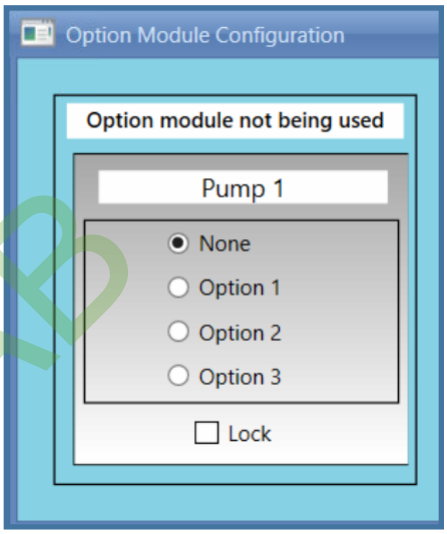
   Use Control Mirroring during programming only, for testing single pump commands. When operating the pump, only have one communication cable connected to the pump.

7. **Sounds/Play Beep On Error:** Computer plays an audible sound if an error occurs. The computer must have speakers and sound enabled. This is an extra means of alerting the user to a issue during pump operation

7.3.3 Option Module Configuration

The third Configure sub-menu is “Option Modules Configuration”. The Option Module is a 15-pin connector on the top-back of the pump which allows limited pump control functionality via this 15-pin port. This connector has pins for Analog In, Digital I/O, power supply for external devices, and ground. These pins can be configured in a number of ways (options) to provide additional pump control capabilities. Currently three different configurations have been programmed (Options 1-3).

Selecting “Option Module” opens the window shown at right. Each of the Options listed in this window enable a pre-configured pump control mode for the pump that is named in the window (Pump 1 in this case).



In the Option Module Configuration window, a short configuration descriptor appears in the white box above the pump name. Hovering your cursor over the “Option” wording also opens a text box with a brief description of the module and pin configuration. Following is a short description of the three option module configurations**.** For documentation of the Options Module, including pin configuration diagrams, go to the Customer Area of the Vindum website or contact Vindum Engineering for a copy.

- **None:** This is the default setting, when the option module is not being used.
- **Option 1:** Designed for basic remote analog/digital control of the pump, Available control items are: start/stop, set rate or pressure, running/stopped status, and cable connection assurance.
- **Option 2:** This pin configuration was designed for an application in which the pump was installed inside a cabinet. The functionality is to “lock out” the pump unless both channels signal that the cabinet door is closed. Without this the pump cannot be started.
- **Option 3:** This module is designed for using the pump with an external delta pressure transducer. The pump will hold a set delta Pressure, using the pressure reading of the dP transducer.

Once the 15-pin plug is connected to the Option Modules port on the back of the pump and the Option button is pressed, the individual controls of the option module become active. For instance, when Option 1 is activated, start/stop control is transferred from VPware to the option module interface. To deactivate the option module, click on the “None” button of the Option Module Configuration screen. To ensure that Option Module

functionality is not accidentally deactivated, click the “Lock” box at the bottom of the Option Module Configuration window. The password is the same four-digit numerical password used for the Pump Configuration screen, if the user has enabled “locking” of input parameters on that screen (see Section 7.3.1).

If you have the need for analog/digital control of Vindum Pumps via the Option Module, please contact Vindum Engineering Support (support@vindum.com). We can help design new configurations to meet your requirements and can supply the connector & cabling for using any of the Option Module configurations.

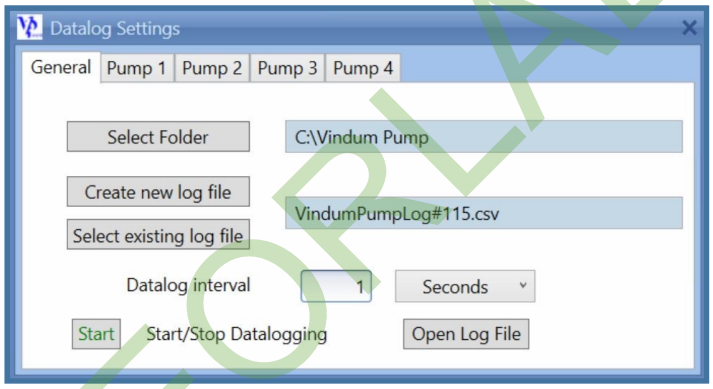
7.4 Data Log Menu

Data Log allows the user to record pump pressure, rate, and volume data versus time to a .csv file (comma separated values) for later analysis using spreadsheet applications such as Microsoft Excel.

The .csv file should not be opened while data logging is underway. If the file is opened, data recording will be interrupted.

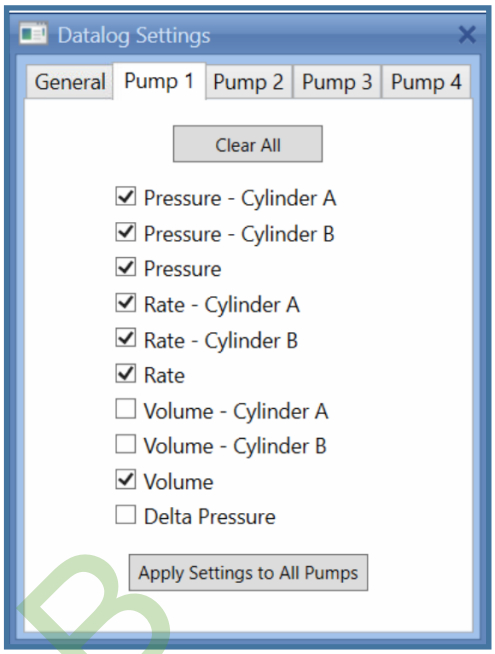
Setting up data logging takes three simple steps:

1. Click "Data Log" from the VPware Main menu to open the Datalog Settings window, as shown in the image below. From the "General" tab, select the folder and file name for the .csv datalog file. The default folder is C:\Vindum Pump. Next, either create a new datalog file or select an existing .csv file. If an existing file is chosen, the new data will be added to the bottom of the pre-existing data in that .csv file.



2. Select the data recording interval from the Datalog Settings/General window shown above. Pump data will be written to the file at the interval selected. Options are minutes, seconds, and milliseconds. Data can be logged at up to 50 milliseconds (i.e., 20X per second), but the standard datalog frequency is 1 second, i.e., data is written to the file each second. **If you select "millisecond" recording frequency, you must use the USB-USB cable to communicate with the pump to ensure consistency of the recording intervals. In addition, it's helpful to close other applications that are running on the computer, to reduce the load on the computer's CPU, so that the computer can write to the datalog file at the chosen interval. If you notice fluctuations in the millisecond datalog recording frequency, ensure that you are using the USB-USB cable and that you have closed other non-essential computer applications. If the recording frequency still varies from the chosen millisecond frequency, consider using a faster computer when datalogging in milliseconds. Remember that short datalog intervals generate very large .csv files that can be cumbersome to work with, especially for long experiments. Be sure to consider whether additional data points are really necessary when setting the datalog interval.**

3. To select the data parameters that you want to record for each pump, click on one of the "Pump" tabs at the top of the Datalog Settings window. This opens a window, like the one shown at right, that allows you to select the parameters that you want to record. You can record individual cylinder pressure, rate, and volume data, as well as pump pressure, rate and volume. When operating in paired pump modes (continuous, pulse-free pumping), selecting the individual cylinder values allows you to see the individual cylinder values during the full cycle of each piston (i.e., pumping and refilling). If you select to record only the "Pressure", "Rate", and "Volume" parameters, you will not have the individual cylinder parameter values (though you may not need or want that extra detail).



4. Once you have selected the parameters that you want to datalog, return to the "General" tab of the Datalog Settings window. From here, datalogging is started by either clicking on the "Start" button within the Data Log dialogue box or from the "Log: Start" button on the Main screen menu bar. Once the "Start" button is pressed, data logging is initiated, regardless of whether the pump is started/running. To stop data logging, click the "Stop" button from either the Main screen menu bar or from the Data Log dialogue window.

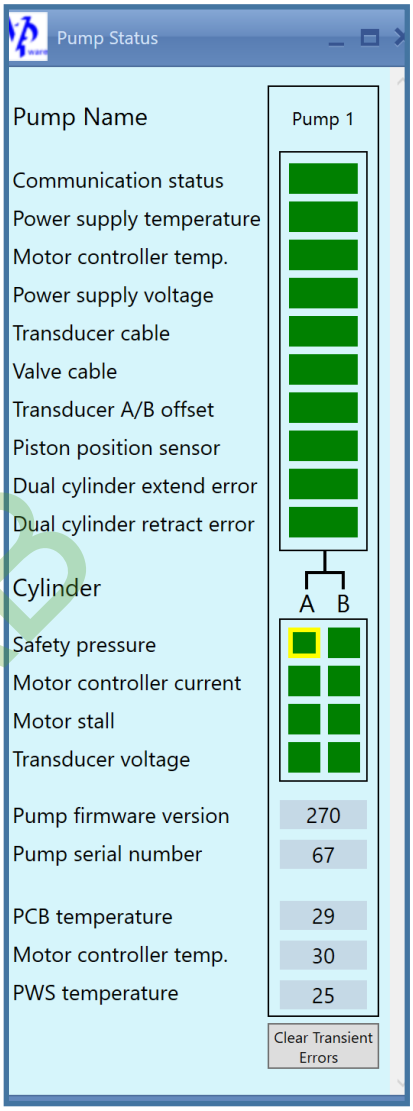
   The data log records information from all pumps connected to the computer unless you "uncheck" all the parameters for pumps that you do not want to include in the datalog.

   As mentioned above, if re-using an existing datalog file, the new pump data is be added from the last row of the existing data in the .csv file. All pre-existing data is retained. If you want to reuse an existing .csv file but do not want to retain any of the prior data, click on the "Create new log file" button and select an existing file name. Windows will advise that this file already exists. Press "Yes" to replace the file and all prior data or "No" to leave the existing file intact.

To view the .csv file data, be sure to first stop data logging. If you try to open the .csv file while VPware is still writing data to it, you will receive a Window file conflict error, meaning that two programs are attempting to access a file simultaneously (i.e., VPware and Excel). Only one application can have access to the .csv data at a time.

7.5 Status Menu

Pump Status is accessed by clicking "Status" from the VPware main menu bar. The Pump Status window, see image at right, shows the state of each of pump's components. **GREEN** boxes indicate components with "OK" status, while a **RED** box indicates an error or issue that is preventing the pump from running. **A yellow-outlined box (see image at right) indicates that a "transient error" has occurred (which stopped the pump) but the issue is no longer present.** Exceeding safety pressure is an example of a transient error. Exceeding the safety pressure will stop the pump and the safety pressure status box will turn red. However, if the cylinder depressurizes so that it's now below the safety pressure value, the error is no longer present. As a result, the safety pressure status will return to **GREEN** (i.e., safety pressure is no longer in-error). To show that the over-pressure error occurred, VPware puts a yellow outline around the safety pressure box. This yellow outline associated with transient errors must be cleared by pressing the "Clear Transient Errors" box at the bottom of the Status screen.



The Status Screen works in conjunction with VPware Error & Warning Message Boxes to help the user identify and fix causes of pump errors. Whenever an error occurs, the issue is shown on the Status window and also with error message will be displayed with information to help assess and resolve the issue. A list of error and warning messages, including explanations can be found in Section 7.8.4.

Individual elements of the Pump Status window are explained next:

1) **Communication Status**: Shows status of the computer-to-pump communications. If this box is blank, it indicates no communication with the pump; either the COM Port has not been selected or is not enabled. If this is **RED**, the cable to the pump is loose or has disconnected.

2) **Power Supply Temperature:** **RED** indicates over-heating of the pump's power supply, that is located in the base of the pump. To correct, clear any of the pump's air vents (including under the pump) that may be blocked and/or re-locate the pump from proximate heat sources, and turn off power to the pump to let it cool.

3) **Motor Controller Temp.:** **RED** indicates high temperature for the pump's motor-driver

circuitry. To correct, clear any blocked vents (including under the pump), and/or remove from proximate heat sources, and turn off power to the pump to let it cool.

4) **Power Supply Voltage:** **RED** indicates that the pump's circuitry is not detect 56V or 12V from the pump's power supply. This may be due to interruption in external power supply, activation of the emergency stop circuit ("E-Stop"), problem with pump's power supply unit or other internal circuitry. Ensure that the pump is receiving power, i.e., that the power cord is firmly connected and that the E-Stop connector on the back of the pump is firmly inserted and that it's short jumper cables are not loose.

5) **Transducer cable:** Should the transducer cable become loose or disconnected from the pump, this status box will turn **RED** and the four LED lights on the pump will shift to **RED** as well. Reattaching the pressure transducer cable should return this status box to **GREEN** and the pump LEDs to **BLUE** (assuming there are no other issues with the pump).

6) **Valve cable:** A loose or disconnected cable to the valves will cause this status box to change from **GREEN** to **RED** and the four pump LEDs to glow **RED**. When the valve cable is disconnected, the solenoid pilot valves that actuate the pump's inlet and outlet valves lose power, which causes any open inlet/outlet valve(s) to close.

7) **Transducer A/B offset:** This warning indicates that there is a >250 psi difference between the pressures readings of the transducers at switch-over (pump operating in paired modes). The pump will continue to operate, but flow will likely not be pulse-free.

8) **Piston Position Sensor:** This error indicates a problem with the piston position sensor board, which is visible between the ball screw drives inside the front plexiglass cover. Stop the pump and power it off, then check that the cable connected to the position sensor circuit board (inside the clear plexiglass cover) is firmly engaged.

9) **Dual Cylinder Extend Error:** This error is caused by a piston return rate multiplier being set too low, so that the pump is unable to maintain continuous fluid delivery when operated in paired fluid delivery modes.

10) **Dual Cylinder Retract Error:** This error is caused by a piston return rate multiplier being set too low, so pump is unable to maintain continuous receipt of fluid when in paired fluid receive pump modes.

11) **Safety pressure:** The two status boxes show if the pressure in Cylinder A or Cylinder B is CURRENTLY in excess of the set safety pressure value (see Configure screen to change safety pressure settings). If either of the safety pressure limit status boxes is **RED**, it could be caused by a number of possible situations, such as the piston extending with the Cylinder's inlet and outlet valves both closed, or a safety pressure set too close to the working pressure. When the pump stops due to a safety pressure limit error, the pressure may drop slightly, causing the cylinder pressure to drop below the safety pressure setting and the safety pressure status box will turn **GREEN** with a yellow

outline to the status box. As previously mentioned, the yellow outline indicates a "transient error". To clear transient errors (yellow outlines), click the "Clear Transient Error" box at the bottom of the Status window.

12) **Motor Controller Current:** This error indicates that the power required to keep the motor's position is more than allowed for the given pumping speed. This can be due to a few factors, of which the most common is that the pump was stopped rapidly due to exceeding the safety pressure and the motor has lost it's position. To remedy this, power the pump off/on to reset it. If this does not resolve this error, look for anything that might have obstructed the piston/ball screw movement and remove it. Lastly, the error could be due to a fault in the wiring to the motors. If you found nothing obstructing piston movement and powering the pump off/on does not resolve the error, please report the problem to Vindum Engineering support.

13) **Motor Stall:** The motor stall error indicates that that the motor is not in the precise rotational position ordered by the control system. The most common cause of this error is the pump executing a safety stop, such as when the safety pressure is exceeded. Most of the time this error will correct itself and the pump can be immediately restarted. If not, try powering the pump OFF/ON to allow the motor sensors reposition themselves.

14) **Transducer Voltage:** This error indicates either a loose connection of the cable to the transducer or a malfunction of the transducer. The error is triggered by the output voltage of the transducer being below the minimum transducer output voltage (0.5V).

15) **Pump Firmware Version:** Indicates the version of firmware code that is installed on the pump. The firmware works with the VPware pump-control software so when new features are added to VPware it is often necessary to install updated firmware on the pump.

16) **Pump serial number:** Manufacturer's serial number. It is helpful to supply the serial number when requesting support from Vindum Engineering.

17) **PCB Temperature:** Printed Circuit Board temperature, in degrees Celsius. In some early VP-Series pumps, this capability was not enabled, so a value of zero is displayed.

18) **Motor Controller Temp.:** Shows the temperature of the Field Effect Transistors (in degrees Celsius), a key component of the pump's motor control system.

19) **PWS Temperature:** This is the Power Supply Temperature, in degrees Celsius. You may observe the PWS temperature rise and the internal fan run faster when the pump is operated at high speeds.

20) **Clear Transient Errors:** This button is used to clear transient error display (yellow box outline) from the Pump Status window. As mentioned previously, transient errors are those that stop pumping, but later resolve themselves. Examples include power supply temperature or safety pressure being exceeded.

7.6 Graphs Menu

It's easy to create real-time graphs of pump parameters with VPware. Click on "Graphs" on the VPware menu bar to open the Graphs Manager window, shown below.

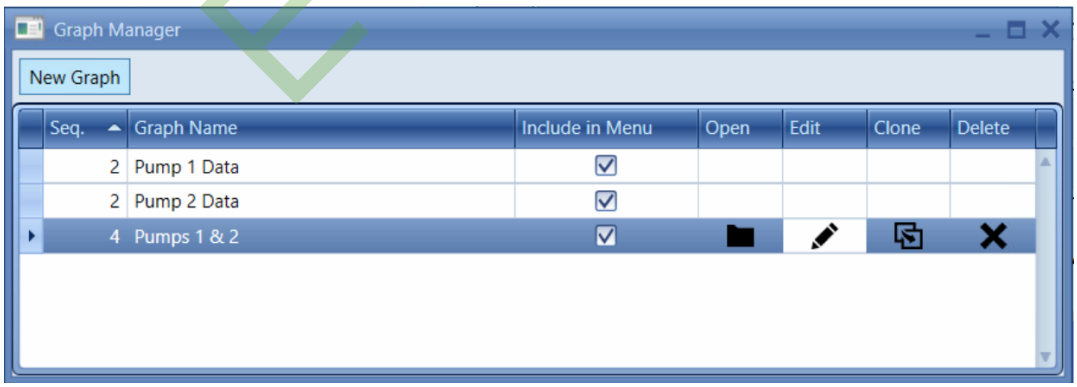
Using Graph Manager, you can create graphs of the following pump parameters:

- Pump pressure (for pulse-free continuous-flow modes)
- Pump rate (for pulse-free continuous-flow modes)
- Cumulative pumped volume (for pulse-free continuous-flow modes)
- Delta Pressure (using external pressure transducer)
- Individual Cylinder Parameters (Cylinder A or B):
    - Pressure
    - Rate
    - Pumped Volume

These graphs do not record or save the pump data. In order to keep a permanent record of pump operating data, use the Data Log functionality described in Section 7.4.

7.6.1 Define a New Graph

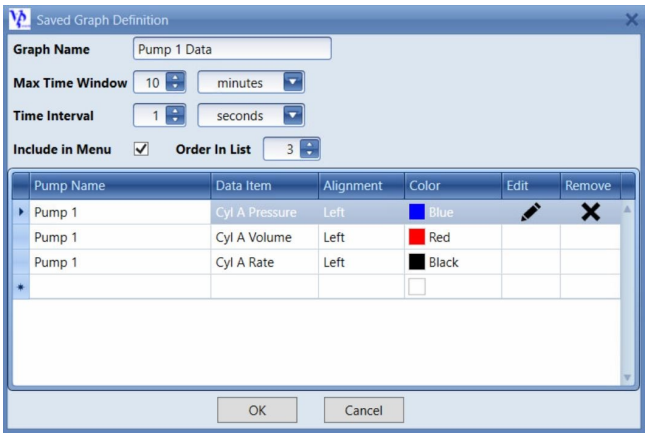
To create a new graph, click on "Graphs" from the VPware menu bar, then select "Graph Manager". As shown in the image below, the Graph Manager window contains a list of



previously-saved graphs and has a box labelled "New Graph". Clicking the "New Graph" button opens another window, like the one shown on the next page, in which the user sets the parameters:

- **Graph Name**: user-specified.
- **Max Time Window:** this is the time limit after which the graph will begin to over-write itself (i.e., replace the datapoints at the start of the graph).

- **Time Interval:** A new datapoint will be graphed each second (the default).
- **Include in Menu:** makes the graph appear in a drop-down list under "Graphs" on the VPware main menu bar.
- **Order in List:** this is the order in which the graph appears in the graph library list when the Scheduler menu is pressed on the VPware home page.



Next, select the pump and parameters you want to graph by clicking in the boxes below the title row and select from the drop-down list. You can graph up to nine parameters on a single graph, although it might become cluttered and confusing to read. When done adding data items, click "OK" to save the graph.

If you decide to delete a graph, simply open the Graph Manager, click the Delete "X" to remove the graph and confirm that you want to remove it.

Important Notes About Graphing:

- **The Max Time Window and Time Interval affect the amount of computer memory required for the graph. If your computer has very limited memory, it may be necessary to reduce either the Max Time Window or the Time Interval, or both, in order not to overload the computer's memory.**

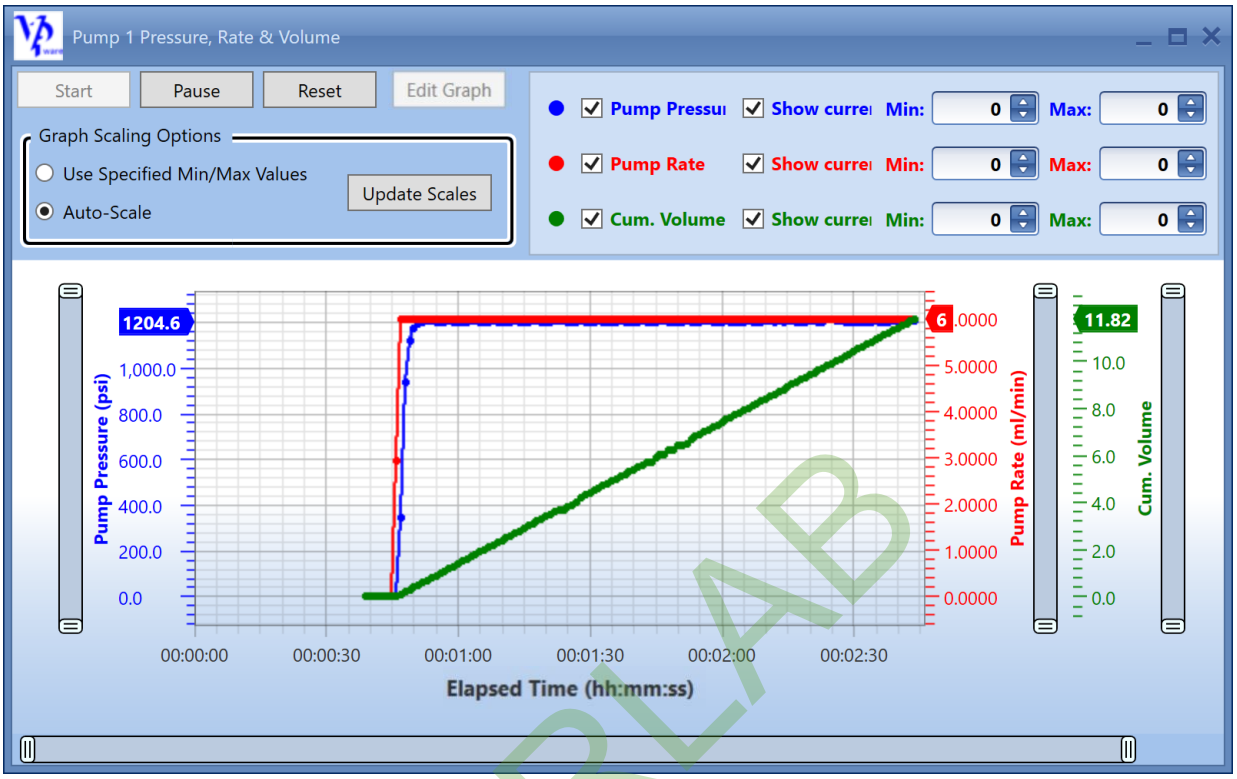
- **VPware has the capability to graph data at speeds up to 50 milliseconds (i.e., data is plotted 20X per second). Using millisecond graphing speed requires a lot of computer CPU time to continually update the graph and can slow datalogging if logging in milliseconds. If you notice inconsistent datalog intervals, consider graphing in "seconds" rather than "milliseconds" to free up the computer CPU and Windows response time.**

7.6.2 Using Graphs

Once a graph is created, there are two ways to open/view it: 1) If you selected "Include in Menu" when you created the new graph, it will show in the drop-down list of graphs when you select "Graphs" from the VPware menu bar; and 2) Click on "Graphs", "Graph Manager" from the VPware menu bar to see the list of graphs created previously. Click "Open" (folder icon) to view the graph.

The figure below shows an example graph in which three variables are plotted: Pump Pres-

sure (blue), Pump Rate (red), and Cumulative Volume (green). There are many useful features available to use with the graphs:



- **Graph Scaling Options:** The Y-axis range for each variable is automatically scaled ("Auto-Scale" is selected in the "Graph Scaling Options" sub-window). Alternatively, the user can enter different min/max values of the graph for each variable, select "Use Specified Min/Max Values", and then press the "Update Scales" button to re-scale the graph as needed.
- **Show/Hide Parameters:** The check-box above the graph allows you to show/hide individual variables. This is useful if you have a large number of parameters on a single graph and want to highlight one or two for more careful inspection. The graph's data for the variables that you have 'hidden' is not lost; clicking the check-box restores the line history of that variable;
- **Current Value:** The check-box above the graph also gives you the option to see the current instantaneous value of the each variable next to its respective axis;
- **Start/Pause/Reset Buttons:**
  - **Start:** Press Start to begin graphing or to restart graphing if paused. You can start graphing at any time; the pump does not need to be running.
  - **Pause:** Pause stops the graphing function only; the pump will continue to run.

- **Reset:** Pressing this button stops the graph and erases the prior data from the graph area. Press "Start" to start graphing.
- **Restart All:** Simultaneously resets & restarts all graphs that are open.
- **Edit Graph:** Once a graph is stopped, the graph can be edited by pressing the "Edit Graph" button.

7.7 Scheduler Menu

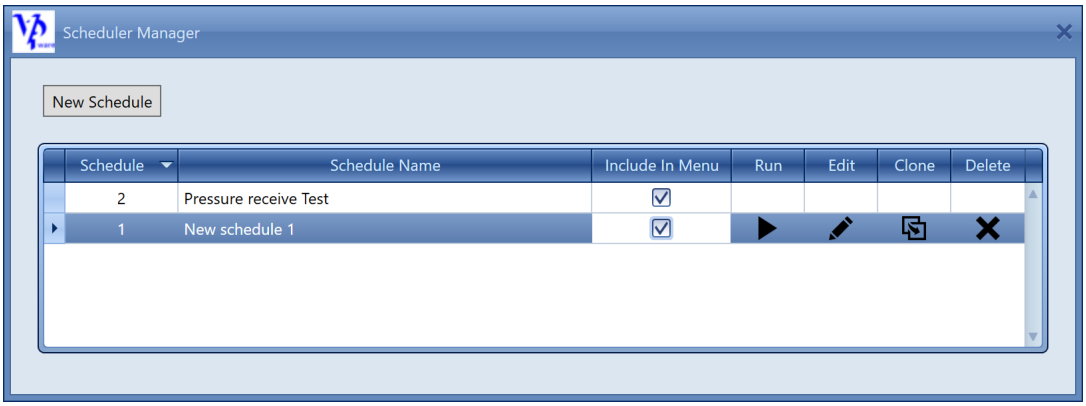
A VPware Schedule is a preset sequence of "steps" (pressure or rates) set by the user. Once a schedule is created and saved, it is available for future use on any Vindum pump. The Scheduler feature makes it easy to quickly create a sequence of rates or pressure versus time (or volume).

Any of the "Paired" pump operating modes can be used in a schedule. "Independent" cylinder operating modes are not available for use with the Scheduler.

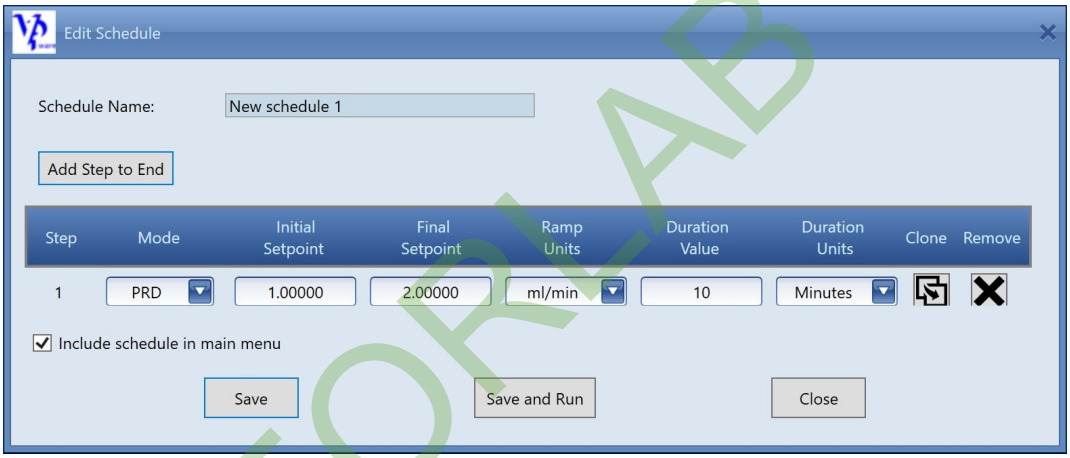
Following are a few examples of Schedules that can be created and saved for future use. There are a multitude of combinations that can be created; these are just a few examples:

- **Rate-Time Schedule:** Increase/decrease from one rate to another in a specified amount of time, or hold a constant rate for a specified time;
- **Rate-Volume Schedule:** Increase/decrease/hold a set rate until a specified volume is delivered, then move to another rate until a second volume is dispensed;
- **Rate-Volume-Time:** Run pump at set rate for period of time, then ramp from that rate to a higher rate until a specified volume is delivered;
- **Pressure-Time:** Ramp from starting pressure to another pressure in a specified amount of time. Additional pressure-time steps can be added to the schedule.
- **Rate-Pressure-Time:** Since the pump mode can be changed inside a schedule, the user can create a schedule that starts the pump in PRD mode (Paired Rate Deliver), pump a set volume, then move to another step that used PPD mode (Paired Pressure Deliver) to continue pumping to a set pressure or pressure ramp.

To create or edit a Schedule, from the Main Screen, select **Schedule/Scheduler Manager** and a screen like the one at the top of the next page will open. Press the **"New Schedule"** button and a new schedule is added to the Scheduler Manager window.



Next, click the **"Edit"** box (pencil icon) on the "New Schedule" line to open the "Edit Schedule" dialog box to begin building the schedule by specifying the steps of the schedule (see image below).



The steps to building a schedule are:

1. Name the schedule. The default name is New schedule "X", but this can be changed by editing the box at the top of the "Edit Schedule" window.

2. Step 1 of the schedule is shown. Use the arrow in each box to access the drop-down menu of options. Any of the "Paired" pump modes are available. Specify the initial and final setpoints for the step, select the setpoint units, and the duration.

3. Add the next step by clicking on the "Add Step to End" button and enter the parameters for this step.

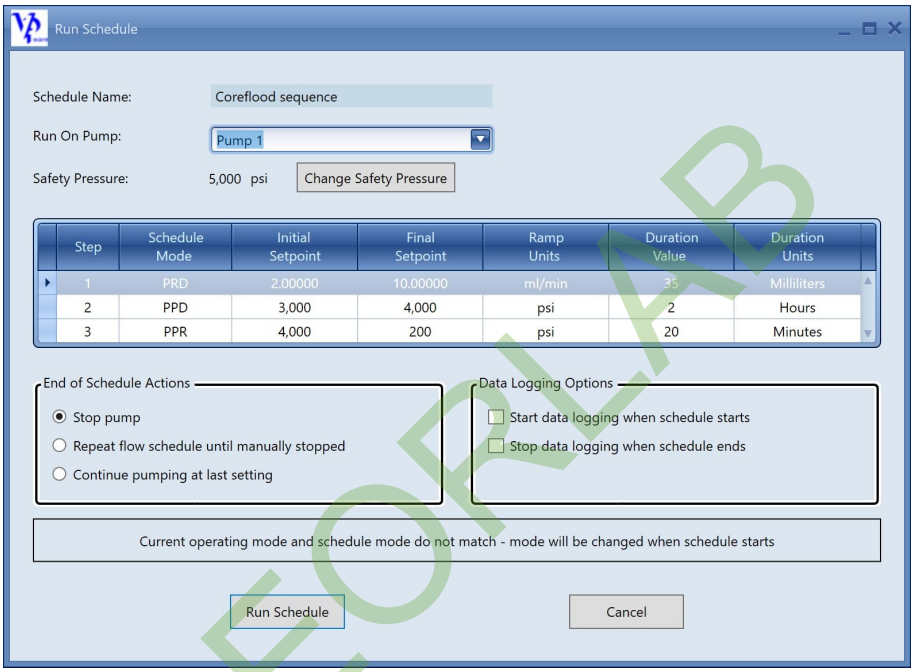
4. Continue "Adding Steps to End" to build the Schedule;

5. Check "Include schedule in main menu" if you want this schedule to be accessible from the Scheduler tab of the VPware Main Screen Menu Bar;

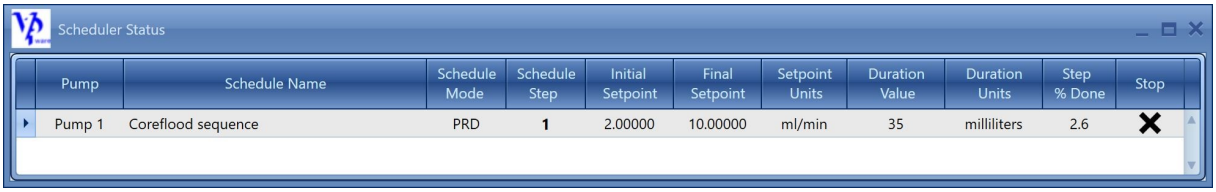
6. When you have finished entering all the steps, press "Save" and "Close" or "Save and Run". Schedules are saved to the computer connected to the pump.

To Run a Schedule, you can either press "Save and Run" after building the schedule or you can open the "Scheduler/Scheduler Manager" window and press the "Run" icon for the desired schedule. This opens a "Run Schedule" window like the one shown below. Choose the pump that you will use to run the schedule and select or change the safety pressure. At the end of the schedule the pump will stop, unless you select one of the other "End of Schedule Actions." You also have options to activate data logging when the schedule begins and stop data logging when the schedule is finished. Press the "Run Schedule" button to start the Schedule.

Alternatively, if you elected to include the schedule in the main menu, simply click "Scheduler" from the VPware menu bar and select the schedule you wish to run. Select the pump you want to use and press the "Run Schedule" button to start the schedule.



When a schedule starts, a blue outline appears around the pump in the VPware main screen. In addition, the "Scheduler Status" box pops-up, like the one shown below. The Schedule Status window displays all the information about the schedule, including the active "Step" and the "Step % Done" (0-100%). A "Stop" button is available on this window, in case the user decides to interrupt the schedule. **All other "Stop" buttons can also be used to stop the pump while a schedule is underway.**



It's easy to modify an existing schedule. Go to the Scheduler Manager and click the "Edit" box for the schedule you wish to modify. You can then change any of the setpoint values, add additional steps to the schedule, delete steps from the schedule, etc.

Scheduler Suggestions:

- If you make a schedule that contains changes to pump modes for different steps, ensure that the selected modes are compatible. For instance, if you use the pump to pressurize a system to 500 bar using PPD mode (Paired Pressure Deliver) and then want to decrease the system pressure to 400 bar, you must use PPR mode (Paired Pressure Receive) mode (or PPBD mode). You should also check the feasibility of your schedules. For instance, the pump may not be able to execute very rapid changes of rate or pressure in short periods of time. You may need to increase the time interval to allow the pump more time to reach the target pressure.
- If using a schedule to apply hydrostatic pressure to a closed vessel or system to which you will raise and lower the pressure during the schedule, use the "Bi-directional" pressure mode. When the pump mode is set to "Paired Pressure Deliver", the pump will retract the active piston if the schedule calls for a pressure decrease. This can result in an error that will stop the pump (if the active piston runs out of room to retract). As such, we do not recommend using "PPD" with schedules that have steps where pressure is decrease;. Use PPBD mode instead.
- When using "paired rate" pump modes, you can use a rate of zero ml/min to pause the pump or to delay and start of the schedule. The pump will show as "running", but at a rate of 0 ml/min.
- Within a step, the same starting and ending rate or pressure can be used. This will give pumping at constant rate or pressure during this step;
- A discontinuous rate or pressure step will introduce a pressure pulse (i.e., if the initial rate of Step 2 is not equal to the ending rate of Step 1), since the pump cannot instantaneously change pressure or rates without creating a pressure pulse in the fluid being pumped.

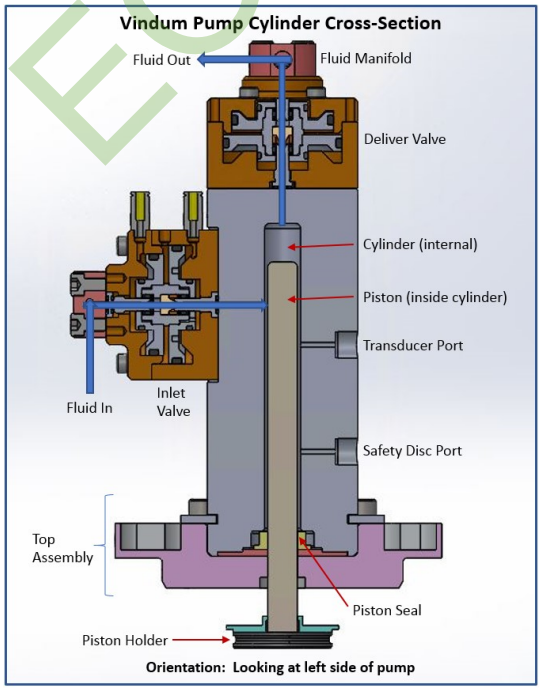
7.8 Tools Menu

There are several useful features in the “Tools” tab on the VPware main screen. Pressing “Tools” opens a drop-down list of four sub-menus which are explained in this section:

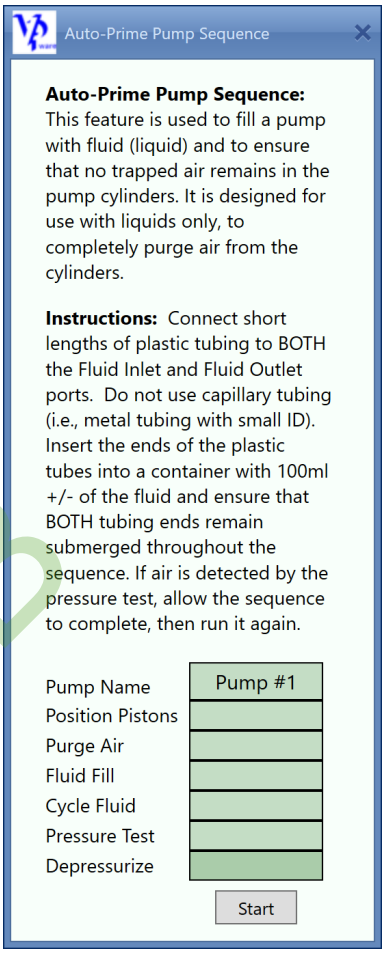
1. **Auto-Prime Pump Sequence:** This feature automates filling the pump with fluid and ensures that all residual air is removed from the cylinders. We strongly recommend running the Auto-Prime before starting any experiment and whenever the pump is filled with fluid after maintenance.
2. **Firmware Update:** Guides the user through process of updating the pump’s firmware;
3. **Multi-Pump Modes:** This section has the settings for linking multiple pumps in various configurations, such as Pressure/Rate Following, Rate Grouping, and Recirculation.
4. **Pump Error Analysis:** This feature is used to diagnose pump error events.

7.8.1 Auto-Prime Pump Sequence

When filling a pump with liquids for the first time, after cleaning, or after changing fluids, it’s very important to purge all the air from the cylinders. The illustration below shows the internal configuration of a VP-Series pump’s cylinder. As this illustration shows, there is a small annulus between the piston and the inner cylinder wall, which can hold residual air even after cycling the piston through its full stroke. The “Auto-Prime Pump Sequence” was developed to purge this residual air from the cylinder.



To run the Auto-Prime Pump Sequence, first establish communication between the computer and pump in the normal fashion. Then, from the main menu select "Tools/ Auto-Prime Pump Sequence" to open the window shown at right. Follow the written instructions in the window, ensuring that you use large-diameter tubing to so that there are no flow-path restrictions for fluid to enter or leave the pump. **Capillary tubing is not recommended for Auto-Prime, as it's too restrictive.** Two short pieces of plastic tubing work very well. With the tubing connected to the fluid inlet and outlet ports on the pump, press "Start" to initiate the Auto-Prime. It takes 6-8 minutes to complete the sequence, including a pressure test at the end to check for residual air/gas in the cylinders. If residual air is detected by the pressure test, repeat the Auto-Prime sequence. Typically one Auto-Prime Sequence will remove the residual air from the cylinders. If, after running the Auto-Prime twice, the pressure test still detects air in the cylinders, inspect the pump for loose connections or fittings for evidence of a leak.



Note: Auto-Prime is intended for use with liquids only. Highly-compressible fluids (like gases) will fail the pressure test at the end of the Auto-Prime sequence.

7.8.2 Firmware Update

Vindum Engineering periodically releases updates to the VPware pump-control software with new features and bug corrections. In order to have the full functionality of the VPware features it's also necessary to update the firmware on the pump itself. The firmware "Version xxx.hex" file is available from Vindum Engineering. Download this "Version xxx.hex" file and follow the firmware update instructions in VPware. Before beginning the firmware update, open the VPware "Status" window to check the firmware version currently installed on the pump.

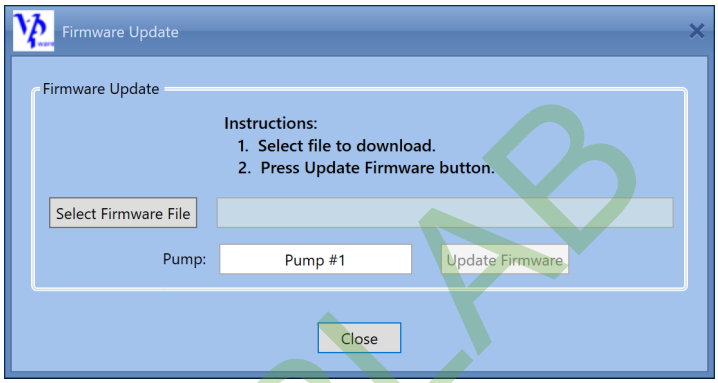
From the "Tools" menu, select "Firmware Update" from the dropdown list and follow the instructions in the pop-up windows that guide you through the installation:

1. Following the instructions of the first pop-up window, connect a USB-USB cable from your computer to the USB port on the backside of the pump. The USB-RS232 cable also remains connected to the pump (if you were using this cable). Press the "USB-USB

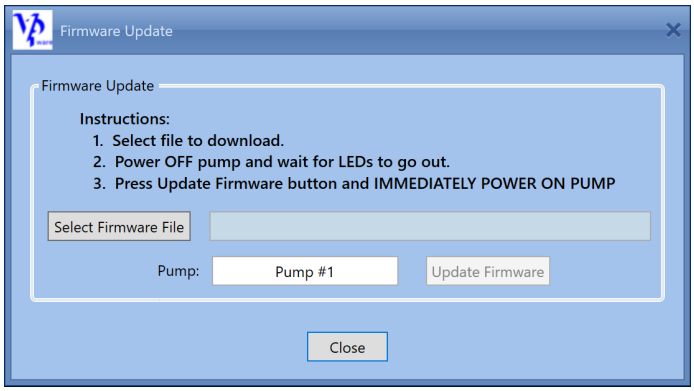
Cable Is Connected" button to continue;

2. Depending on the current firmware version installed on the pump, the instructions will vary:

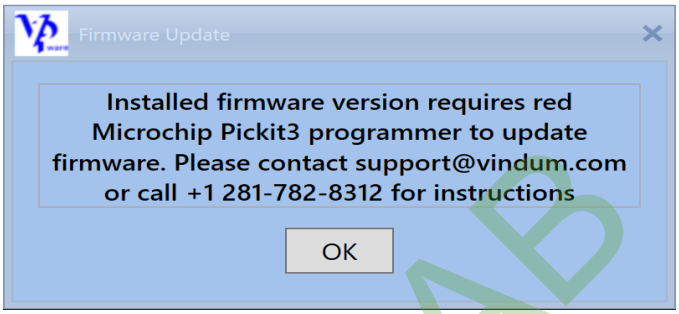
   a. Most pumps upgrade firmware in a single step. After establishing communication with the computer and connecting the USB-USB cable, a window like the one shown below opens to complete the firmware update. Simply select the new firmware ".hex" file, specify the pump to update, and press the "Update Firmware" button. After installing the firmware, re-establish COM communication with the pump from the "Configure/Pump Configuration" window. Then, open the "Status" window to verify that the new firmware version is listed.



   b. Pumps with early firmware versions will cause a slightly different window, like the one shown below, to open when upgrading firmware. Follow the instructions in the window to download/install the latest firmware version: 1) Select the firmware file; 2) Specify the pump on which it will be installed; 3) Power-off the pump from the power switch on the back of the pump and wait for the pump's LEDs to go dark; and 4) Press the "Update Firmware" button and promptly power-on the pump. After the new firmware is installed, re-establish COM communication with the pump from the "Configure/Pump Configuration" window. Lastly, open the "Status" window to verify that the new firmware version is listed.



c. A few early pumps will require the red Microchip Pickit3 programmer to bring their firmware up-to-date. This "red programmer", shown at right, was included with the pump. **This is a one-time requirement to use this programmer; once updated this way, future firmware updates will use the process described in method "a." above.**

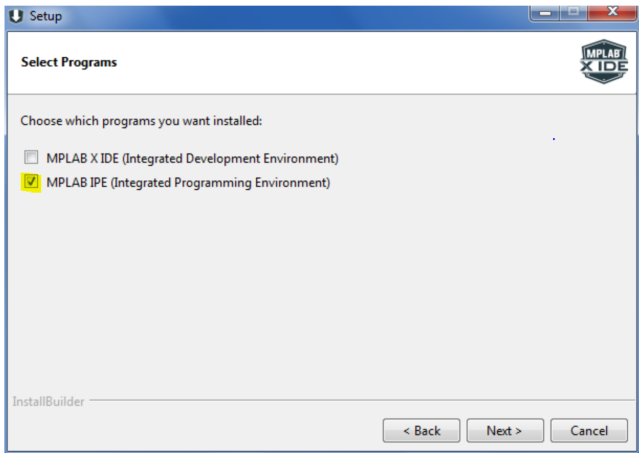


If you initiate a firmware update from VPware and the window shown above appears, locate the red Pickit3 programmer that shipped with your pump and contact Vindum Engineering support to access the files needed to perform the firmware update.

The steps to the firmware update using the Pickit3 programmer are as follows:

1. **Download and install the MPLABX Windows Installer program, which is available from Vindum Engineering:**

   a. From the Setup Wizard "Welcome" window, select "Next", and accept the Microchip license terms. Press "Next" to select the default Installation Directory (or specify another install location), and press "Next" to continue;



b. From the "Select Programs" window (shown here) select ONLY the MPLAB IPE (Integrated Programming Environment) and press "Next";

c. At the "Ready to Install" window, select "Next" to begin the installation. When the installation is complete, a shortcut to MPLAB IPE will be installed on the desktop of your computer. Press "Finish" to close the MPLABX Installer program.

2. Connect the Pickit3 programmer to pump and computer:

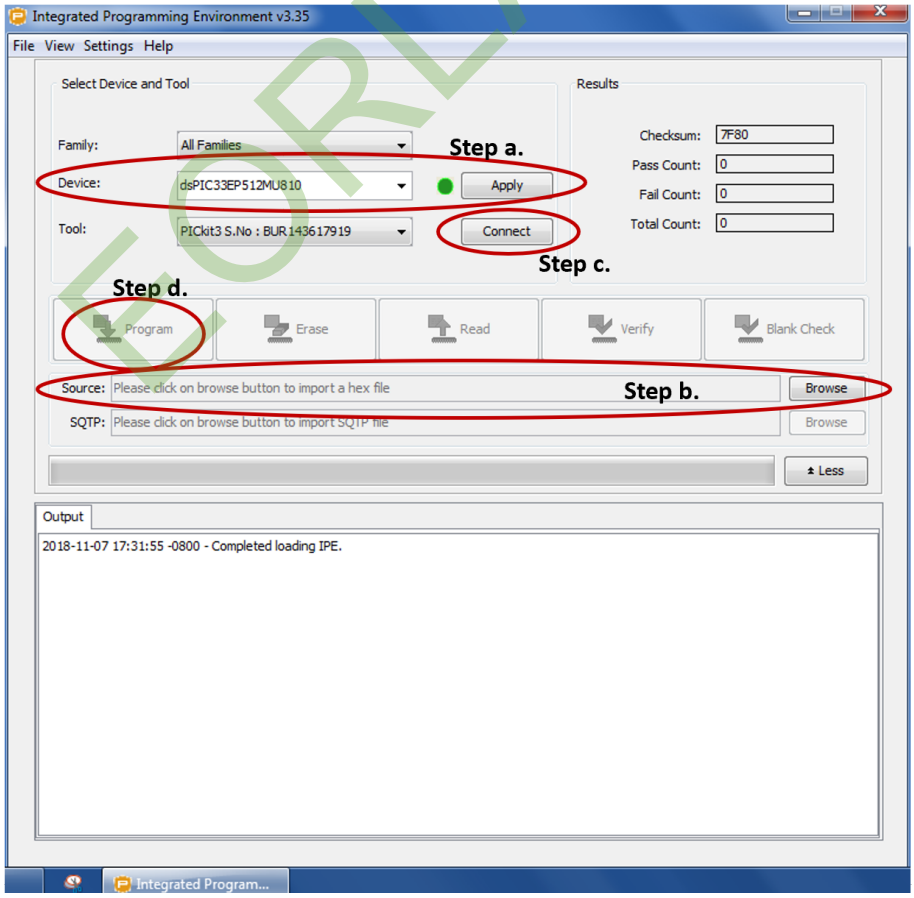
a. Detach the Valve cable from the port labeled "Valve" on the back of the pump;

b. Plug the Pickit3 programmer into the Valve port on the back of the pump and plug the USB end of the red cable into the computer.

c. Turn on the pump (power switch on back of pump).

3. Launch the "MPLAB IPE" application on the computer:

4. **Select the "device" and load the bootloader file: refer to image below and the instruction that follow:**



a. From the “Device” drop-down list, select “dsPIC33EP512MU810”. You will find this device near the bottom of the long drop-down list. Then press “Apply”.

b. In the “Source” line, browse to locate the file named “Vindum_Bootloader_1_2.hex”. This is the bootloader file that you want to install via the red Pickit3 programmer. Once this file is selected, MPLAB IPE will respond with “Hex file loaded successfully.”

c. Press the “Connect” button to connect to the Pickit3 programmer;

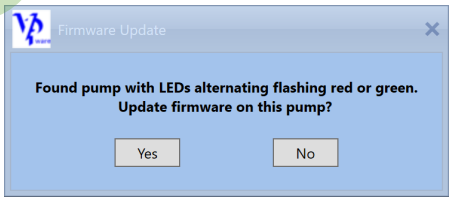
d. Press “Program” to load the bootloader file onto the pump. The dialog box will display a message that the program is complete.

5. **Disconnect the Pickit 3 programmer from the pump and plug the Valve cable back in.** At this point the pump’s LED lights should be alternating red, left-right-left-right. The pump is ready for the firmware update.

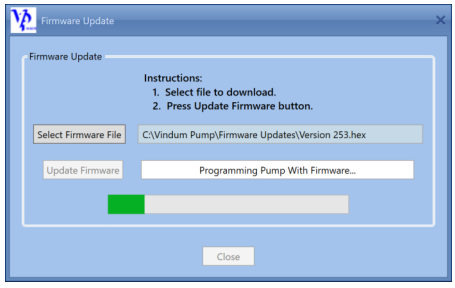
6. Connect a USB-USB cable from the pump to the computer. Leave the USB-RS232 cable connected if it is already connected to the pump.

7. **Install latest firmware on pump:** Launch VPware and open the “Tools/ Firmware Update. Confirm that the USB-USB cable is connected to the pump.

a. A “Firmware Update” window, like the one shown below pops up. Press the “Yes” button to proceed.



b. On the next window (shown below), press the “Select Firmware File” button, locate the latest firmware file (e.g., Version 270.hex), and press the “Update Firmware” button. The green “progress” bar shows the status of the installation. When the firmware pro-

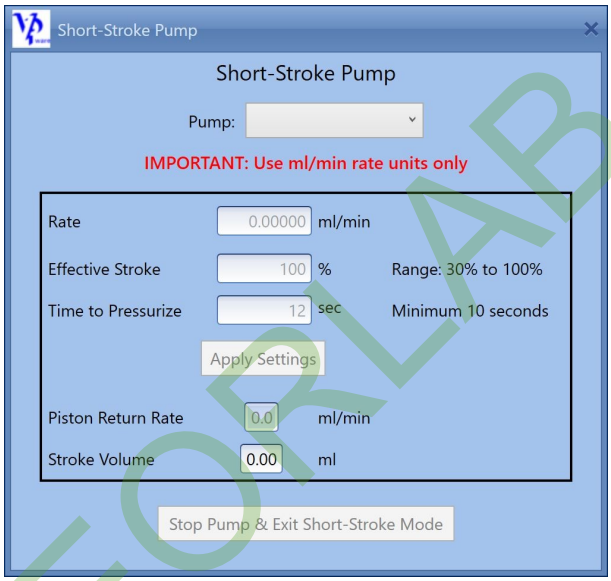


gramming is finished, close the Firmware Update window.

8. Reset the safety pressure from the main VPware window. Verify the firmware version on the VPware Status window. The firmware update is complete.

7.8.3 Short-Stroke Pump

The "short-stroke" feature reduces the pump's piston stroke **[PRD mode (Paired Rate Deliver) ONLY].** The shorter pump stroke reduces the time that fluid is inside the pump. Short-stroke is accessed from the "Tools" tab of the main VPware menu. A screen like the one below appears when prompted.

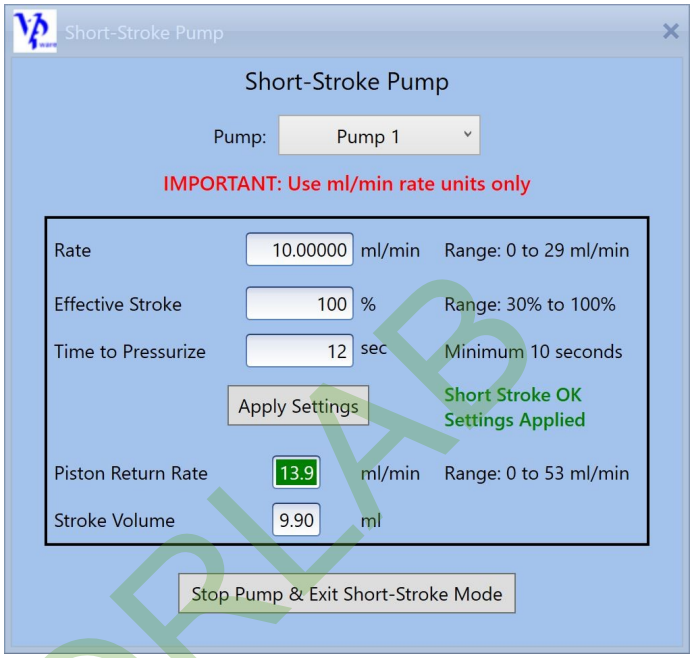


Follow the steps below to use Short Stroke:

1. Set the pump mode to "PRD" from the main VPware screen;
2. Go to Tools/Short-Stroke Pump to open the dialog box of the short stroke settings;
3. Select the pump using the drop-down list at the top of the window. When activated, a light blue outline will appear around the selected pump on the main VPware screen. Remember, the pump must be set to "PRD" mode before activating the short-stroke feature. A warning will appear if the pump is not set to PRD mode when the pump is selected. If this happens, close the Short-Stroke Pump window and change the pump mode to "PRD", then reopen the short-stroke window and select the pump;
4. Enter the desired pumping rate in the Short-Stroke window — only "ml/min" units are allowed;
5. Enter the effective stroke in the next box. This is the percentage of full stroke, so "70%" equates to 70% of the pump's full stroke volume.

6. “Time to Pressurize”: This sets the time for the pump to repressurize, after the cylinder completes it’s stroke and refills. The minimum time allowed for this is 10 seconds and the recommended repressure time is 12 seconds.

7. Once the rate, effective stroke, and pressurize time values are entered, press the yellow “Apply Settings”. If the values are feasible, a green message appears as shown in the image below:



If the values are not feasible, i.e., not enough time for the piston to retract and repressurize, a read message, “Stroke Too Short, Settings NOT Applied”, appears on the screen. If this happens, you can search for a feasible solution by either slowing the pumping rate or increasing the Effective Stroke value, then pressing the “Apply Settings” button to see if a feasible solution is found. Repeat the process, if needed;

8. To start pumping, press either of the “Start” buttons on the main VPware screen. The pump will position the pistons for the shorter stroke and begin pumping. The pump will remain in Short-Stroke mode until the user presses the “Stop Pump & Exit Short-Stroke Mode” at the bottom of the Short-Stroke window. When Short-Stroke mode is deactivated, the light-blue outline around the pump (in VPware main screen) will disappear. If you want to stop the pump, but keep Short-Stroke mode active, stop the pump using the “Start/Stop” buttons on the VPware main screen.

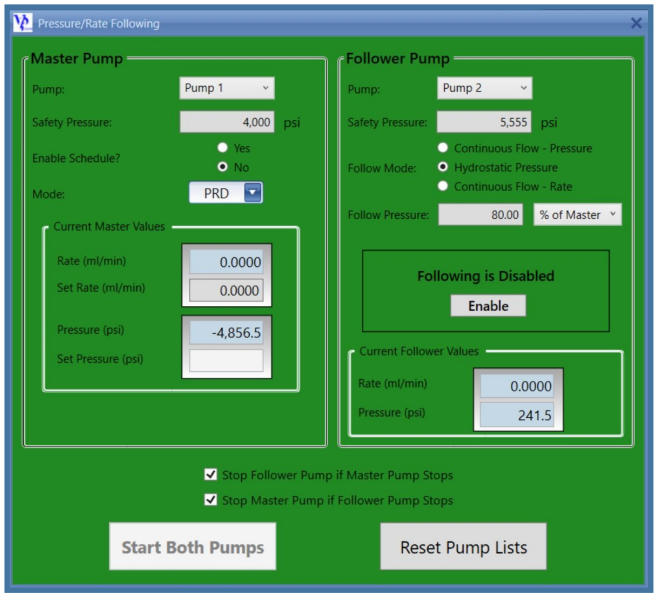
7.8.4 Multi-pump Modes Menu

VPware offers capabilities for linking pumps in unique and useful configurations, which are explained in this section. Access Multi-Pump Modes by selecting "Tools/Multi-Pump Modes" from the VPware menu bar. The multi-pump mode options are summarized below and explained in-detail in this section:

- **Pressure/Rate Following Mode:** Enables two pumps to be operated in "Master/ Follower" configuration in which the Follower Pump's rate or pressure is a function of the Master Pump's rate or pressure. The Follower Pump's pressure or rate can be set as either a percentage of the Master Pump's value or as a fixed differential to the Master Pump's rate or pressure. The pumps can be operated in different pump modes. For instance, the Master Pump can be operated in "paired-rate delivery" while the Follower Pump can operate in "paired-pressure delivery". This setup is very useful for coreflood experiments in which the Master Pump is used to inject fluid through a core as a set rate or pressure while the Follower Pump maintains hydrostatic pressure of the core holder as a function of the pore injection rate or pressure.
- **Pump Group - Rate Mode:** This mode allows multiple pumps to be grouped and operated together via single start/stop command. The physical pump connection can be a manifold to which all pump's are connected. This mode works for Paired Rate Deliver or Rated Receive pump modes only. Individual pump rates can be specified, or each pump's rate can be set as percentage or proportion of each pump's capacity. This mode is useful for experiments where a higher total rate is needed or for experiments that require precise mixing of fluids.
- **Recirculation Mode:** This is a specialized mode designed for coreflood experiments in which one or more pumps inject fluid phases at a constant rate while a separate pump maintains constant pressure at the coreholder outlet. Vindum Engineering sells the Recirculation capability as a separate module.

Pressure/Rate Following Mode

This mode allows one pump ("Follower Pump") to track the rate or pressure of a "Master Pump". When this mode is selected, a green screen like the one shown at right opens. Select the Master Pump and enter the required parameters on the left of this screen, including the Safety Pressure, Mode, and Target Rate or Pressure. Next, on the right side of the green screen, select the Follower Pump and set it's Safety Pressure and the Follower Mode.



For an explanation of each of the Follower Mode options, hover your mouse for guidance on each of the three modes.

Lastly, decide if you want the pumps to stop in the event of an error stopping one of the pumps during the experiment. The two check-boxes near the bottom of the green screen allow you to choose how you want the pumps to behave in the event of an error.

There are a few important pointers regarding the functionality of the Follower Modes:

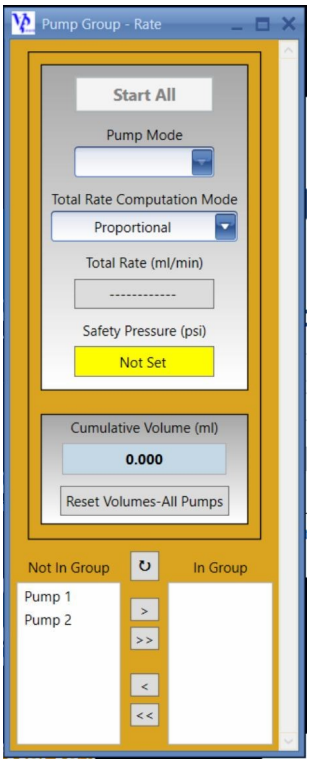
- In the Continuous Flow - Pressure and Continuous Rate - Rate settings, the Follower Pump always delivers fluid. Even if the Master Pump is operated in "Fluid Receive" modes, the direction of Continuous Flow from the Follower Pump is always "Fluid Deliver".
- When the Follower Pump is set to "Hydrostatic Pressure" it is operated in PPBD mode (Paired Pressure Bi-Directional). It is designed to maintain hydrostatic pressure by delivering or receiving fluid to maintain the set pressure. Recall that in PPBD mode, the maximum flow rate of the pump is 50% of the normal max flow rate for that pump model due to the fact that the pistons are positioned at 50% of the stroke length in order to be able to receive or deliver fluid to maintain the set pressure.
- Regardless of whether the Master Pump is operated in "rate" or "pressure" mode, the Follower Pump can be set to pump at either the "pressure" or "rate".
- **IF THE MASTER PUMP AND THE FOLLOWER PUMP ARE BOTH OPERATED IN "PRESSURE" MODES, THEY *MUST NOT* BE CONNECTED TO THE SAME SYSTEM.** If the two pumps are in pressure communication, they will be unable to reach the set pressure due to the pressure interference that is created between the pumps.

Once you have set all the parameters for the Master and Follower Pumps, the "Enable" box on the right of the window can be selected. This engages the two pumps in the Master/Follower relationship. The "Enabled" box is grayed out until all the required settings have been entered. When the "Enable" button is pressed the VPware Main Screen will display green outlines around the two pumps, to show that they are in engaged in the Master/Follower role. Press the "Start Both Pumps" button on the green screen to begin pumping.

Stop Pressure/Rate Following by pressing the "Stop Both Pumps" button at the bottom of the green window. Note that when you stop either pump, Following Mode is disabled and the green boxes on the Main Window disappear. To use Following mode again, both pumps must be stopped. Then press the "Enable" button on the green screen.

The "Reset Pump Lists" button at the bottom of the green Pressure/Rate Following window clears all values from the green screen so that the user can start a fresh Follower configuration.

Pump Group - Rate



Access this mode from the VPware Main Screen. Click on Tools/ Multi-pump Modes/Pump Group - Rate. Activating this mode opens the tan-colored window show at right. To operate this mode, enter the following parameters:

1. **Select Pumps:** Available pumps are shown under the "Not In Group" list at the bottom of the screen. Note that if a pump is already being used in another pump group it will not be in this list. In this example, Pump 1 and Pump 2 are available. Using the arrows (> or >>), move pumps to the "In Group" area. To move a single pump, click on it and press the "right arrow" to put it in the group. To move all pumps to the group, click on the "double arrow" icon. If you connect another pump to the computer after the tan Pump Group window is opened, click on the box with the circular arrow to view the new pump in the list. Note that when pumps are grouped, a tan outline box appears around each grouped pump in the VPware Main Window.
2. **Pump Mode:** At the top of the window, select the pumping mode to be used, either PRD or PRR.
3. **Total Rate Computation Mode:** This selection defines how the flow rates are divided among the pumps in the group. Hover your mouse over the box to view an explanation of each mode. Options are: 1) Proportional, 2) Percentage, or 3) Individual. Due to the fact that different models of pumps can be grouped (e.g., VP-6k, ,VP-12k, etc.), the Proportional and Percentage settings are based on the maximum flowrate capacity of each pump. If two pumps of the same model are grouped and "Proportional" is selected, each pump will be allocated 50% of the total flow rate. Depending on the mode selected, another button will appear below the "Total Rate" box. Click it to input the individual rates or percentages. Once the split between pumps is entered, you can view the individual pump rates on the VPware Main Window. Note the orange outline around pumps in the group.
4. **Safety Pressure:** The value entered is applied to all pumps in the group. Keep in-mind that the combined flow rate of the pumps, if connected to a common manifold, can result in a higher fluid outlet pressure at each pump.
5. **Start/Stop All:** Located at the top of the window, press this button to start or stop all grouped pumps simultaneously. You can also stop all pumps by pressing any of the individual pump Start/Stop on the Main Window.
6. **Ungroup Pumps:** To terminate the Pump Group operation, use the "left arrows" buttons (< or <<) at the bottom of the window to send all pumps back to the "Not in Group" box. Note that the tan box that was around each pump (Main Window) is now

gone.

Recirculation Mode

Recirculation mode uses multiple pumps to perform a coreflood experiment in which two or three fluid phases are continually pumped through the core at an overall constant rate while another pump maintains the outlet pressure of the core constant. During recirculation experiments, the fluid leaving the core is separated at high pressure and re-injected into the core in a pulse-free manner.

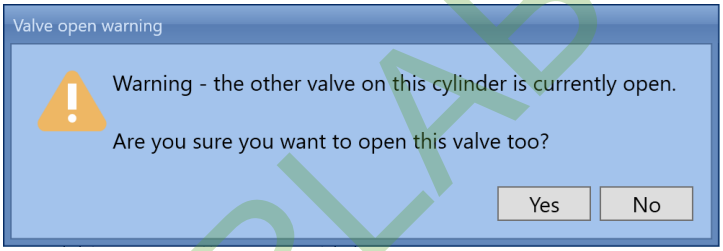
Vindum Engineering offers recirculation software and pump connectors for purchase separately. If interested, please contact Vindum Engineering Support at: support@vindum.com or at +1-281-782-8312.

7.8.5 Error & Warning Messages

In the event of pump errors, VPware uses pop-up windows and dialogue boxes to provide useful information and explanations to the user. In addition, VPware has a unique capability, called "Error State Capture" and "Error State Display", to help users replay and diagnose pump operations leading up to an error event. This section explains the error/warning messaging and the VPware tools for performing in-depth error analysis.

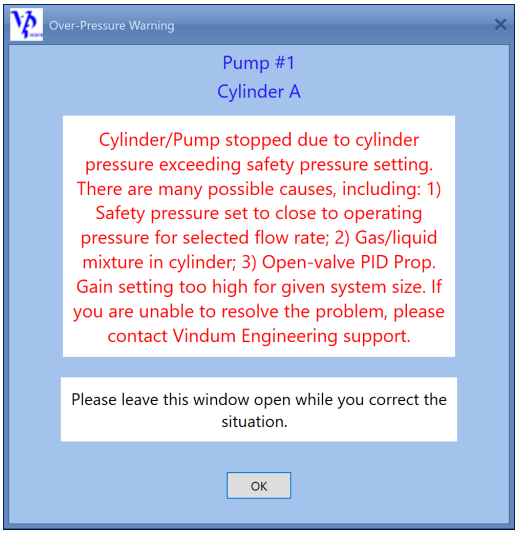
Previous sections of the user guide covered the VPware pump Status window and the meaning of pump LED colors. This section explains two other types of error & warning messaging used by VPware:

1. **Command Errors and Warnings (See Table 7.1 for the full list of Command Errors/Warnings, causes, and suggested solutions):** Before the VP-Series pumps process a command, they check for any issues or problems that need to be corrected. If an issue is identified, the pump displays either a Command Error or Warning. Command Errors & Warnings are displayed as Pop-Up windows in VPware. An example is shown below.

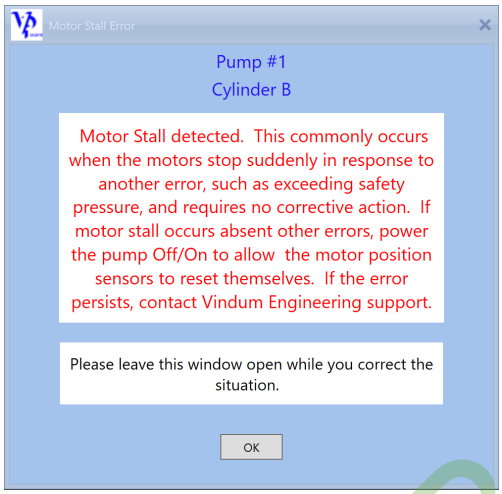


In this case the user issued the command to open a valve when the other valve on the cylinder was already open. This warning was issued because having both valves on a cylinder open simultaneously creates a flow path through the cylinder which can allow high pressure fluid connected to the pump to flow back through the pump very quickly.

2. **Operational Errors and Warnings:** When the pump is running, VPware issues operational errors and warning whenever a problem (or potential problem) is encountered. **The list of these errors/warnings, together with suggested solutions, is shown in Table 7.2.** An example of a this type of error is shown at right. In this case, the pump exceeded the safety pressure, which caused it to execute an emergency stop. The emergency stop also resulted in a Motor Stall Error message, shown on the next page. As discussed in Section 6, power to the pump's motors is interrupted by the emergency stoppage, which can cause a motor stall and associated motor stall error box to be dis-



played in VPware. In this example, VPware displayed two error boxes; one for the Safety Pressure Error and another for the Motor Stall Error.



Operational Error/Warning Display Options: Starting with VPware 1.2.42, the user has the option of displaying pump Operation Errors in pop-up boxes or in a scrolling box at the bottom of the VPware Main Screen. See "Configure/Application Settings" window to make this selection. VPware also gives the option of adding a "Beep" sound whenever an Operational Error occurs. This is set on the same Applications Settings window of VPware.

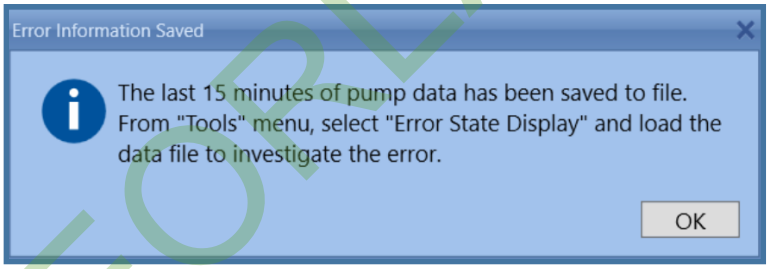
7.8.6 Pump Error Analysis

Pump errors may occur when the pump operator is not present in the laboratory. With this in mind, an "Error State Capture" system has been designed into VPware, which automatically saves 15 minutes of second-by-second pump history leading up to any error event that stops the pump. Users can analyze this history to quickly recreate and analyze pump events leading up to the error event. **There are three parts to the pump error analysis system, which are found on the "Tools/Pump Error Analysis" menu of VPware:**

- **Capture Error State:** As mentioned above, VPware automatically saves 15 minutes of pump data leading up to any error that stops the pump. This file is called the "Error State" file and is saved to folder: "C:\Vindum Pump\ErrorState". Error State files use the following naming format: "ErrorState_Pump_year month day T(24hr time).xml". The time stamp in the file name is the time at which the file was saved.

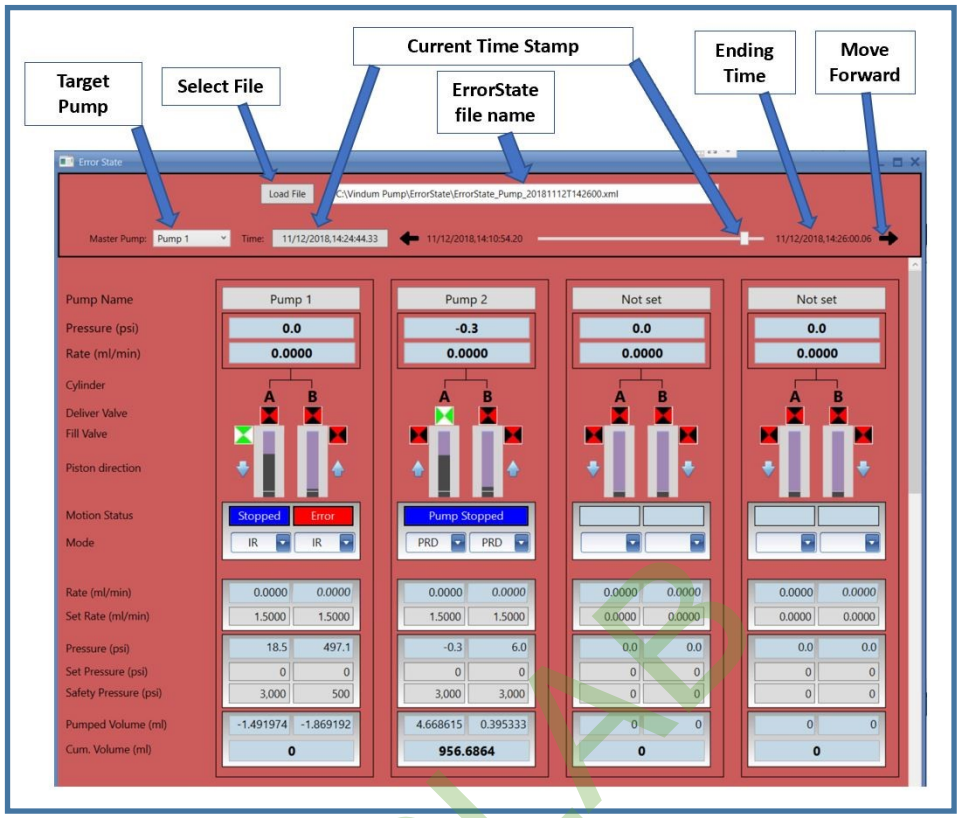
  It's also possible to create an error state capture file at any time you like, such as when you see a pump event that you want to analyze later. To create the file, simply go to "Tools/Pump Error Analysis/Capture Error State". VPware will respond with a pop-up message like the one shown here

- **Error State Display:** To view and analyze the error state capture file information, select **"Tools/Pump Error Analysis/Error State Display",** and a screen like the image on



  the next page opens. To replay the 15-minute history of the error state capture file, first select the file by pressing the "Load File" button at the top of this screen and select the Error State file. Next, select the "Master Pump", which is the pump that you are most interested in reviewing. Use the slider bar to move along the timeline, or move second-by-second using the → or ← to advance or go back one second at a time. These controls make it easy to find the point at which the error occurred and the pump's performance (pressure, rate, etc.) leading up to the error.

  You can scroll down the Error State Display window to view the pump configuration settings and watch the pump Status window second-by-second to see what triggered the pump error. Note that the Error State Display does not contain the operational error messages that VPware displays via pop-ups or in the scroll-box at the bottom of the VPware Main Screen. However, this information is saved in a separate file called the "Event Log", which is explained next.



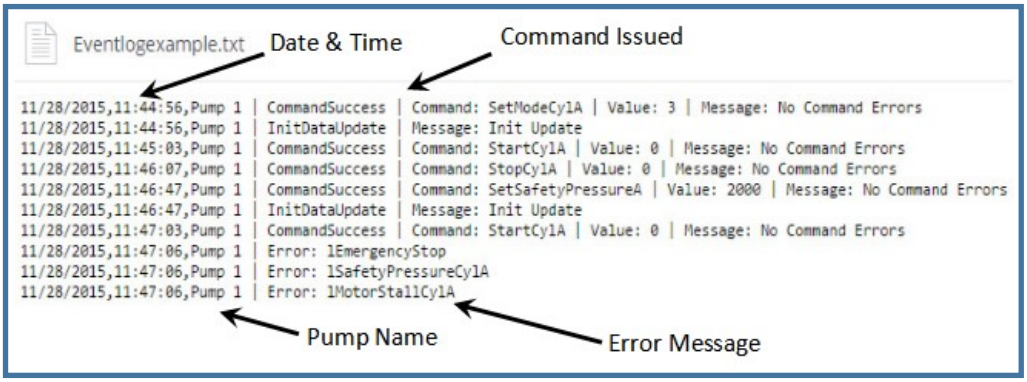
- **Open Event Log:** The Event Log file is a ".txt" file that records all the commands to the pump and all pump events, including warnings and errors. An example of the Event-Log.txt file is shown on the next page. Using the EventLog.txt file, together with the Error State Display system, makes it very easy to recreate and analyze events that resulted in a pump error.

When reading the EventLog.txt file, please remember the following:

1. In the Event Log file pump modes are listed by numerical code, rather than by name. See Table 4 to cross-reference the operating mode number to the name of the pump mode. For instance, in the first line of the Event Log below, "SetModeCylA | Value: 3 |" means that the Command was given to set Cylinder A to IRDC mode (Independent Rate Deliver—Cycled).

2. In the Event Log, pressure units are always shown in "psi", regardless of the pressure units you have selected in "Configure/Application Settings". For example, if you enter a safety pressure of 13.7895 MPa, for Cylinder A, the Event Log will show the following:

| Command: SetSafetyPressureA | Value: 2000 |



Managing the size of the Event Log file: The EventLog.txt file grows very quickly, as each command, command response, and pump update adds a line to the end of the file. It's recommended practice to periodically save this file under a different name (if you want to save the historical data) and then clear the data from the file named "Eventlog.txt". This way, the EventLog.txt (the computer only uses this file name) will not become so long as to be unmanageable.

Table 7.1: Command Response Errors and Warnings Page 1/3

Command Error Message	Explanation	Corrective Action
Cannot change piston direction when pump is running.	User attempted to reverse piston direction with pump running.	Pump must be stopped to change piston direction.
Both pistons are too far extended to start pump in the specified paired mode. Fully retract one piston and select it to start specified paired mode.	Paired mode start requires one piston to be retracted (fluid deliver modes) or extended (fluid receive modes) in order to start.	Use Configure/Application Settings menu, "SMART START" option for pump to automatically reposition piston(s) for all paired mode starts. If needed, pump will refill before starting.
Both pistons are too far retracted to start pump in the specified paired mode. Fully extend one piston and select it to start specified paired mode.	Paired mode start requires one piston to be retracted (fluid deliver modes) or extended (fluid receive modes) in order to start.	Use Configure/Application Settings menu, "SMART START" option for pump to reposition piston(s) for all paired mode starts. Pump will refill before starting, if needed.
Cylinder A (or B) is currently in-error and cannot start. Check Cylinder A (or B) settings in Configure Screen to identify and correct error before restarting.	Pump will not start until any errors that are present have been corrected.	Identify & correct errors. See VPware Status Screen, error messages, or check Pump Configuration settings. Contact VEI support if unable to identify the source of the problem.
Cylinder A (or B) is currently running and cannot start.	User pressed pump "Start" with pump already running.	Avoid pressing "Start" buttons when pump is already running.
Cannot set mode while pump is running. Stop cylinders(s) prior to changing pump mode.	Pump must be stopped in order change the pump mode in VPware.	Stop pump to change operating mode.
Piston A (or B) is too far extended for it to start in selected paired mode. Fully retract Piston A (or B) and then start selected paired mode with Piston A (or B).	If started, the selected piston (A or B) will reach the end of its stroke before the other piston can refill and pressurize, so pump will not allow start using selected piston.	1) Reposition the piston you want to start with, then restart; or, 2) Change Paired Mode Start Setting to SMART START on Configure/Application Settings window.

Table 7.1 is continued on next page

Table 7.1: Command Response Errors and Warnings Page 2/3

Command Error Message	Explanation	Corrective Action
Contact Vindum Engineering for Firmware upgrade to use this option.	Need to install updated firmware on pump to access the selected control feature.	Install latest firmware and VPware software onto pump in order to use all VPware capabilities.
Piston A (or B) is too far retracted for it to start in selected paired mode. Fully retract Piston A (or B) and then start selected paired mode with Piston A (or B).	User has chosen to specify piston for paired receive mode, but the selected piston is too far retracted and will not allow enough time for the other piston to discharge before reaching end of stroke.	1) Extend the piston you want to start with, then restart pump; or, 2) Change the SMART START setting on the Configure/Application Settings to "Pump Selects the Starting Cylinder…."
Pistons are out of position to start pump in bi-directional paired mode. Position both pistons to the center of their stroke before starting pump in this mode.	Bi-directional pressure mode requires pistons to be positioned at approximately the middle of their stroke before starting so that they can respond to pressure increase and decreases.	Reposition pistons to center of stroke manually, or, Use Configure/Application Settings menu, "SMART START" option for pump to automatically reposition cylinder(s) for all paired mode starts. Pump will position pistons before starting, if needed.
Pressure zero offset is out of range. Value will be accepted. Check the transducer calibration before continuing.	The zero pressure (atmospheric pressure) voltage of the transducer appears to be out of acceptable range for this transducer type. This will likely prevent the pump from running pulse-free and needs user attention.	Check the transducer cable connections and the RS232 cable connector. Perform a zero-pressure offset recalibration. If necessary, turn off/on the pump. If problem persists, transducer needs to be replaced.
Warning—the other valve on this cylinder is currently open. Are you sure that you want to open this valve too?	Having both valves on a cylinder open at the same time creates a fluid flow path through the cylinder which can lead to high-pressure fluid flowing back through the pump.	Avoid having both valves on a cylinder open at the same time if the pump is connected to any source of high pressure, as fluid flow through the open cylinder will result. Check your system and proceed with caution.

Table 7.1 is continued on next page

Table 7.1: Command Response Errors and Warnings Page 3/3

Command Error Message	Explanation	Corrective Action
Cannot open/close valve while pump is running. Must stop pump prior to issuing valve open/close command.	The pump's four fluid control valves can only be opened/closed when the pump is stopped.	Stop the pump to change valve position. Manual valve control is only required for "IR" and "IPD"
Warning—the cylinder pressure is over 1,000 psi! Are you sure you want to open this valve?	Opening a cylinder that is highly pressurized is a potential danger, particularly with compressible fluids or gas in the pump.	Ensure that it is safe to open the valves of a cylinder under high pressure. Reduce the pressure before opening by setting the mode to "IR" and retracting the piston to lower the pressure to a safe level before opening the valve.
User Option Module "X" is active and start commands have been locked out	15-pin (DE-15) Option Module connection is controlling the pump, so VPware Start command is disabled.	Use Option Module command to issue Start command to pump. To use VPware, go to VPware Configure / Option Module Configuration screen and change setting to "None" in order to de-activate Option Module control.

Table 7.2: Operational Errors & Warnings Page 1/5

Event Log Error/ Warning	VPware Error/Warning Dialog Box	Error/Warning Description	Corrective Action
DualCylinderExtendError	Pump stopped due to both pistons extending to their maximum extension set-point. Increase the Return Rate Multiplier setting (Configure Screen) so that non-active piston can retract more quickly to get in position to maintain constant flow operation.	Pump is unable to retract the passive piston fast enough to get into correct position to maintain pulse-free continuous flow.	Increase the Return Rate Multiplier so that non-pumping piston has more time refill and repressure the passive cylinder in order to maintain pulse-free flow.
DualCylinderRetractError	Pump stopped due to both pistons retracting to their maximum retraction set-point. Increase the Return Rate Multiplier setting (Configure Screen) so that non-active piston can extend more quickly to get in position to maintain constant flow operation.	Pump is unable to extend the passive piston fast enough to get into correct position to maintain pulse-free continuous flow.	Increase the Return Rate Multiplier so that non-pumping piston has more time refill and repressure the passive cylinder in order to maintain pulse-free flow.
FetCurrent	Cylinder/Pump stopped after detecting excessive motor power draw. Ensure that there is nothing impeding movement of pump's drive mechanism. If problem persists, contact Vindum Engineering support.	Pumps motor(s) are drawing excessive current, so pump stopped.	Look for anything impeding movement of the ball screws. Turn off pump and let it cool. Ensure that you have the latest pump firmware installed on your pump. Install updated firmware. Email support@vindum.com or call +1 281-782-8312 if you cannot resolve.
FetTemperature	Pump stopped due to excessive motor controller temperature. Possible causes: 1) Air vents on bottom and sides of pump are obstructed; 2) Nearby heat source or high ambient temperature; 3) Excessive oven temperature or insufficient heat shielding from oven (High Temp Pumps).	One or both of the FETs (motor drivers) have over-heated. This could indicate a problem with one of the motors or with the pump's internal circuitry.	Power-Off the pump and let it cool. Ensure that air vents on sides and bottom of pump are not blocked. Move pump away from nearby heat sources and/or lower the ambient temperature and increase cool air circulation.

Table 7.2: Operational Errors & Warnings Page 2/5

Event Log Error/ Warning	VPware Error/Warning Dialog Box	Error/Warning Description	Corrective Action
FlashError	Pump Flash Memory Error Detected, either reading from or writing to pump's memory. This is an unusual event; please contact Vindum Engineering for help.	Error detected in pump's flash memory. This is a very unusual event.	Try powering pump off & on and check pump configuration window for abnormal values that could be causing this issue. If problem persists, email support@vindum.com or call +1 281-782-8312.
GetToPessureVol	WARNING! Standby cylinder failed to match pressure of active cylinder within preset range of piston travel (typically 1/4 to 1/3 of total piston stroke). Failure to match active cylinder pressure will result in a pressure pulse when pump switches between cylinders. Possible causes include highly compressible gas/fluid or a fluid leak in the pump. The pump will continue to operate but will not be pulse-free until standby cylinder is able to match pressure of the active cylinder. You may need to pre-pressurize highly compressible gases or fluids in order for pump to operate pulse-free.	Warning message that standby cylinder (non pumping cylinder) failed to reach the pressure of the active (pumping) cylinder within a reasonable portion of it's available stroke. The pump will continue to operate but flow will not be pulse-free.	This situation most often arises when pumping highly compressible fluids or gases. Pre-pressuring the inlet fluid/gas can help the stand-by cylinder pressurize using less of its stroke to match the pumping pressure of the other cylinder, thereby reducing any pressure pulse at cylinder switch-over.
MotorStallCylA (B)	Motor Stall detected. This commonly occurs when the motors stop suddenly in response to another error, such as exceeding safety pressure, and requires no corrective action. If motor stall occurs absent other errors, power the pump Off/On to allow the motor position sensors to reset themselves. If the error persists, contact Vindum Engineering support.	The motor position sensor has detected that the motor position (i.e., rotation) is not where the encoder expects it to be. This is often an outcome of another issue, rather than the cause of the error. Motor stalls can also occur due to foreign objects impeding movement of the ball screw.	Motor stalls error often occur due to the pump rapidly stopping due to such factors as exceeding the safety pressure limit or activation of the emergency stop circuit. Motor stalls often correct themselves once the pump stops, so no corrective action is required. Also check for any foreign object blocking movement of the ball screws or pistons. If the problem persists, try turning the power off/on a few times. If the error persists, contact Vindum Engineering.
OptionModuleAnalog	WARNING! Option Module is in control of the pump. Analog input to the option module is greater than 3.3 Volts. Pump will set the rate or pressure to maximum, based on mode selected.	This is a warning that the Options Module has detected an input voltage greater than it's maximum of 3.3V.	Ensure that external voltage to the Options Module does not exceed 3.3V. Voltage in excess of 3.3V is read by the pump as a "max pressure" or "max rate" command (depending on the pump mode being used).

Table 7.2: Operational Errors & Warnings Page 3/5

Event Log Error/ Warning	VPware Error/Warning Dialog Box	Error/Warning Description	Corrective Action
OptionModuleinControl	WARNING! Option Module is in control of the pump. Go to the configure screen and change the option module selection to none.	User has attempted to send a command via VPware while pump is being controlled via the Option Module.	Set Options Module Configuration to "none" to activate VPware pump control, if so desired.
PowerSupplyTemperature	Pump stopped due to excessive power supply temperature. Possible causes: 1) Air vents on bottom and sides of pump are obstructed; 2) Nearby heat source or high ambient temperature; 3) Excessive oven temperature or insufficient heat shielding from oven (High Temp Pumps).	Temperature of power supply unit has exceeded maximum operating temperature.	Ensure that air vents on sides and bottom of pump are not blocked. Move pump away from nearby heat sources and/or lower the ambient temperature and increase cool air circulation. If necessary, turn off pump and let it cool.
PowerSupplyVoltage	12V/56-Volt power supply interruption. Possible causes: 1) Power switch turned off; 2) E-Stop circuit interruption; 3) internal circuitry (e.g., FET failure), or 4) Problem with pump's power supply unit (e.g., excessive temperature or component failure). Check power supply switch, E-Stop circuit connector (back of pump), and power supply temperature. If error re-	Pump has detected a low-voltage issue with power supply from 56V or 12V elements of internal power supply unit.	Ensure that power supply cord is firmly connected and that E-Stop connector and jumper wires are not loose. If problem remains, power pump off/on. Is the green LED inside plexiglass near top between pump cylinders lit? Are other pump LEDs lit? Open/close a valve and listen for release of compressed air. Report answers to these questions to Vindum Engineering to
PressureCable	Pump stopped due to a problem with the pressure transducer cable. Ensure that transducer cable connections are fully engaged (to individual transducers and to circuit board on back of pump).	Problem with pressure transducer cable or signal from pressure transducer(s).	Ensure pressure transducer cable is connected, then check Status screen for pressure transducer status. If "Pressure cable attached" box is RED and transducer cable is attached, do not use pump; contact Vindum Engineering.
PumpConfigureError	Pump and/or Transducer type do not match available options. Contact Vindum Engineering support.	Pump or transducer type stored in pump's RAM does not match any valid type. Indicates a potential error in pump memory where these values are stored.	Open Pump Configure screen and ensure that the values for pump type and transducer type are correct. If this problem repeats, contact Vindum Engineering support.

Table 7.2: Operational Errors & Warnings Page 4/5

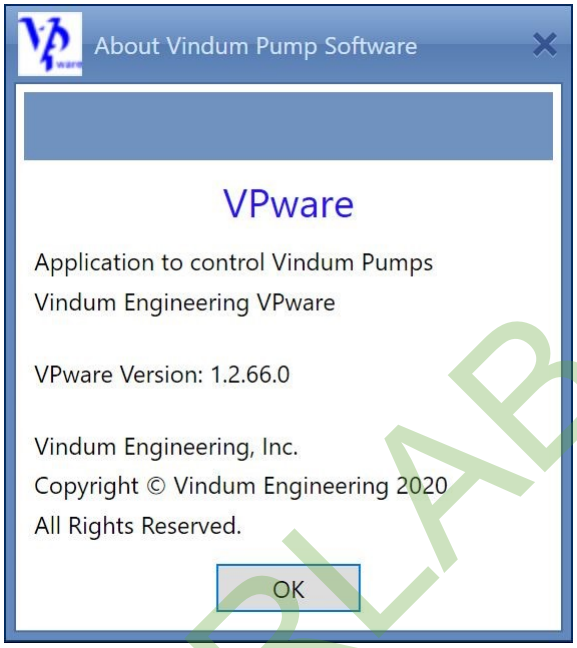
Event Log Error/ Warning	VPware Error/Warning Dialog Box	Error/Warning Description	Corrective Action
SafetyPressureCylA (B)	Cylinder/Pump stopped due to cylinder pressure exceeding safety pressure setting. There are many possible causes, including: 1) Safety pressure set to close to operating pressure for selected flow rate; 2) Gas/ liquid mixture in cylinder; 3) Open-valve PID Prop. Gain setting too high for given system size. If you are unable to resolve the problem, please contact Vindum Engineering support.	Cylinder pressure has exceeded the Safety Pressure setting, so pump has stopped. This is a very common error that can have serval causes.	A common cause of this error is presence of air or gas mixed with liquid phase in the cylinder. Ensure you have fully purged air from the cylinders—use Auto-Prime Sequence. If using the pump in pressure modes with a very small system, you may need to adjusted the Open Valve Prop. gain lower to prevent over-shooting the target pressure. Refer to Pump Configuration Section, Proportional & Differential Gain Settings.
ServoLimitReached	WARNING! Piston travel limit reached and piston movement stopped to prevent damage to pump. Check & reset transducers' "zero-pressure offset", as this is a common cause of this error. This error can also occur if external high-pressure fluid has driven the pump piston(s) opposite of the intended flow direction of the pump operating mode. Use \"Bi-Directional Pressure Mode\" to allow for receiving or delivering fluid without stopping pump.	This is a warning that the stand-by (non active) piston has reached it's maximum travel point so that further movement is not possible. Typically, this means that the stand -by piston is fully retracted (pump in deliver mode). The pump will continue to operate but pulse-free flow is likely compromised.	The most probable causes of this warning are: 1) When operating at very low pressure with transducers that are out-of-calibration on the Pressure Zero Offset. Stop and reset the Zero-Pressure Offset on the Pump Configuration window. 2) High pressure outside the pump is driving the piston opposite of the intended direction. Check the system pressures upstream and downstream of the pump and correct the pump's set pressure or switch to Bi-Directional mode if direction of flow can change with system pressure.
TransducerABoffset	WARNING! Possible transducer issue detected, which is preventing pulse-free operation. Check transducer gain settings in VPware and/or recalibrate the pressure transducers (see User Manual) before using pump.	This warning indicates that there is a significant discrepancy between pressure transducer A and B with the pump operating in paired modes. The pump will continue to operate, but flow will likely not be pulse-free.	Recalibrate both pressure transducers. Run pump in paired-pressure-delivery mode and graph the pump pressure to check for pressure spikes during piston switch-over, which is evidence of excessive transducer offset.

Table 7.2: Operational Errors & Warnings Page 5/5

Event Log Error/Warning	VPware Error/Warning Dialog Box	Error/Warning Description	Corrective Action
TransducerLowVoltage	Error, Transducer reading is below .35 volts. Transducer is not connected or has failed.	Low transducer output voltage suggests that the transducer is not connected or has failed. This is a serious problem, as continued use of pump can lead to damage and/or personal injury.	Stop the pump immediately. Check for loose cable connection to the transducers. If this does not correct the problem, contact Vindum Engineering.
ValveCable	Valve cable error detected. Possible causes: 1) Interruption of power supply to pump; or 2) Loose valve cable connection. Check valve cable connector on back of pump and individual cables connecting to solenoid pilot valve assembly on backside of cylinders. If error remains, contact Vindum Engineering Support.	Often this error is displayed as the result of an interruption of the 56V power supply in the pump. This loss of power is detected by the valve cable and reported as a valve cable error. However, it can also be due to a problem with electrical connection between pump circuitry and solenoid pilot valves.	First check to see if an event has caused an interruption to the 56V power supply, such as exceeding the Safety Pressure. Any loss of power to the pump will generate this valve cable error. If no power supply interruption is present, ensure that 15-pin valve connector on back of pump is securely connected. Check Pump Status screen, "Valve cable" indicator; if box is RED, there is a persistent problem with electrical connection to the solenoid pilot valves. Contact Vindum Engineering support.

7.9 About Menu—VPware Version

Clicking “About” from the VPware menu bar opens a dialog box that shows the version of VPware software installed on the computer, as shown in the image below. After installing a new version of the VPware software, you can verify the installation by checking the VPware Version in this window.



8. PUMP CLEANING, MAINTENANCE, REPAIR, AND TESTING

FOR YOUR PERSONAL SAFETY, ENSURE THAT YOU HAVE READ AND UNDERSTOOD ALL OF THE IMPORTANT SAFETY WARNINGS AT THE START OF THIS USER MANUAL BEFORE STARTING ANY OF THE PROCEDURES IN THIS SECTION.

PREVENT RISK OF PERSONAL INJURY BY PROPERLY RELIEVING ANY PRESSURE IN THE PUMP'S CYLINDERS AND WEARING PROPER PROTECTIVE EQUIPMENT WHEN HANDLING ANY UNKNOWN FLUIDS LEFT INSIDE THE PUMP FROM PRIOR USE.

IF YOU HAVE ANY QUESTIONS, PLEASE CONTACT VINDUM ENGINEERING BEFORE BEGINNING ANY OF THE PROCEDURES DESCRIBED HERE.

8.1 Cleaning Cylinders and Wetted Parts

Cleaning the pump's cylinder barrels and wetted parts (pistons, flow path in valves and manifolds) is recommended when changing the type of fluid being pumped, or to wash dissolved solids or particles from the cylinders, or before storing the pump. The procedure described in this section is recommended to fully evacuate fluids, especially fluids with dissolved salts such as brines, from the pump. **A video showing the cleaning steps is also available in the "Customer Area" at https://vindum.com, which can be accessed by all pump owners. Please go onto the website to register or contact Vindum Engineering (support@vindum.com) to request access.**

Simply pumping a new liquid, such as distilled water, through the pump will not entirely purge the prior liquid from the pump. This is due to small dead fluid volume inside the cylinders and internal fluid paths.

8.1.1 Cleaning Standard & EXT Pumps

Procedure for cleaning cylinders and fluid flow path of standard-sized pumps, including those with heating jacket accessory:

1. Expose the fluid inlet tubing to air and operate the pump in "Paired Rate Deliver" mode until no liquid is seen coming from the fluid delivery tubing, then follow steps a.-c. below:
   a. Connect or insert a compressed air nozzle to the pump's Fluid In manifold port.
   b. Connect a low-pressure tube to the Fluid Out manifold of sufficient length to reach a vessel for capturing the fluid that will be discharged from this manifold.
   c. If you have a helper available, turn the pump upside-down, so that it's resting on the Fluid Out manifold, supported by the helper. Ensure that your helper can hold

the pump and prevent it from falling over. If you are working alone, carefully lay the pump onto its front surface, so that it is resting on the "Fluid In" manifold.

2. Connect compressed lab air tubing to the ¼" or 6mm compressed air fitting on the back of the pump. Using VPware, open the pump's fluid inlet and fluid outlet valves (all four must be open). Once the valves are open, you can disconnect the compressed air line from the back of the pump.

3. Gently introduce compressed air into the Fluid In manifold to displace the residual fluid from inside the pump's cylinders. When no more fluid is seen leaving the pump, you can stop injecting compressed air into the cylinders. Carefully return the pump to its normal, upright position.

4. Using the "Auto-Prime" feature of VPware ("Tools/Auto-Prime Pump Sequence"), fill the pump with distilled water to wash the internal cylinder surfaces and fluid paths. For extra assurance you can repeat the "Auto-Prime" sequence. At this point, the pump's cylinders will contain distilled water. If the pump will not be used again within the next couple weeks or so, repeat steps 1-3 to evacuate all the water from the cylinders.

5. Optional— Brush cylinder walls and/or dry wetted parts: In the case that you want to use a brush to clean the pump's cylinders and/or you want to dry all fluid from the cylinders, you can remove the pump's top assembly and pistons to access the cylinders. For instructions on removing the top assembly , see the video titled "Pump Seal Replacement" on www.Youtube.com (search YouTube for "Vindum Engineering" to locate this video). The first part of this video shows how to remove the top assembly. Once the top section is removed, extract the pistons and drain any residual fluid inside, and use a bottle brush to clean the cylinder walls. Lastly, insert the top assembly into an oven/ air bath and soak at 100F (37C) to evaporate any water residue from inside the cylinders. Reassemble the pump in the reverse order.

8.1.2 Cleaning High - Temperature Pumps

Procedure for cleaning cylinders and fluid flow path for High Temperature Pump models that are designed for inserting into oven/air bath:

1. With the pump in the horizontal position, expose the Fluid In tubing to air and operate the pump in "Paired Rate Receive" mode until no liquid is seen coming from the Fluid In tubing, then follow steps a.-b.:

    a. Connect or insert a compressed air nozzle to the pump's Fluid In manifold port.
    b. Connect a low-pressure tube to the Fluid In manifold of sufficient length to reach a vessel for capturing the fluid that will be discharged from this manifold.

2. Connect compressed lab air tubing to the ¼" or 6mm compressed air fitting on the side of the pump. Using VPware, open the pump's fluid inlet and fluid outlet valves (all four must be open). Once the valves are open, you can disconnect the compressed air sup-

ply line from the side of the pump.

3. Carefully introduce low-pressure compressed air into the pump's "Fluid Out" manifold port to displace the residual fluid from the pump's cylinders. When no more fluid is seen leaving the port on the pump's "Fluid In" manifold, you can stop injecting compressed air into the cylinders.

4. Using the "Auto-Prime" feature of VPware ("Tools/Auto-Prime Pump Sequence"), fill the pump with distilled water to wash the internal cylinder surfaces and fluid paths. For extra assurance you can repeat the "Auto-Prime" sequence.

5. Optional— Brush cylinder walls and/or dry wetted parts: In the case that you want to use a brush to clean the pump's cylinders and/or you want to dry all fluid from the cylinders, you can remove the pump's top assembly and pistons to access the cylinders. For instructions on removing the top assembly , see the video titled "Pump Seal Replacement" on www.Youtube.com (search YouTube for "Vindum Engineering" to locate this video). The first part of this video shows how to remove the top assembly. Once the top section is removed, extract the pistons and drain any residual fluid inside, and use a bottle brush to clean the cylinder walls. Lastly, insert the top assembly into an oven/ air bath and soak at 100F (37C) to evaporate any water residue from inside the cylinders. Reassemble the pump in the reverse order.

8.2 Pump Maintenance & Instructional Videos

Refer to Table 8.2, at the end of this section, for a list of the seal materials used in VP-Series Pumps. The table shows the available seal material options for each fitting.

Refer to Section 8.3 for the torque settings for any parts disassembled during maintenance.

VP-Series pumps are designed to be serviced using the tools that were included in the pump shipment box and other readily-available tools. This section describes recommended frequency and procedures for these routine-service items. **Instructional videos covering most maintenance and repair procedures are available in Customer Area of Vindum Engineering Website. All pump owners may have access to the Customer Area by requesting a new account registration on the Customer Login page of the website or by contacting Vindum Engineering (support@vindum.com).**

To access the Customer Area, go to https://vindum.com and select "Customer Login" at the top -right of this web page. Register as a new user or contact Vindum Engineering (support@vindum.com) to request a access to the Customer Area. The customer area contains a number of instructional videos, access to the latest pump user guide, and latest VPware & firmware downloads.

Instructional videos on the Vindum website include:

Pump Features and Setup Videos:	**Pump Maintenance & Repairs Videos:**
• Features of VP-Series Pumps • Features of VPware Pump Software • Vindum Pump Initial Setup • Making a Speedbite-type Connection • PID Gain Tuning for VP-Series Pumps • Using VPware Scheduler • Updating VPware & Pump Firmware	• Flushing Vindum VP-Series Pumps • Vindum Pump Ball Screw Lubrication • Vindum Pump Piston Seal Replacement • Vindum Pump Safety Burst Disc Replacement • Vindum Pump Transducer Replacement & Calibration • Vindum Pump Valve Refurbishment (VP-12K/6K/3K Models) • Vindum Pump Power Supply Unit Replacement
Pump Accessories Videos:	**Pump Diagnostics Videos:**
• Wash Kit Setup for VP-Series Pumps • Option Module for VP-Series Pumps • MC USB-2408 Device Setup	• Error Analysis - VP-Series Pumps

A few preventative maintenance practices can significantly extend the life of your pump and pump seals:

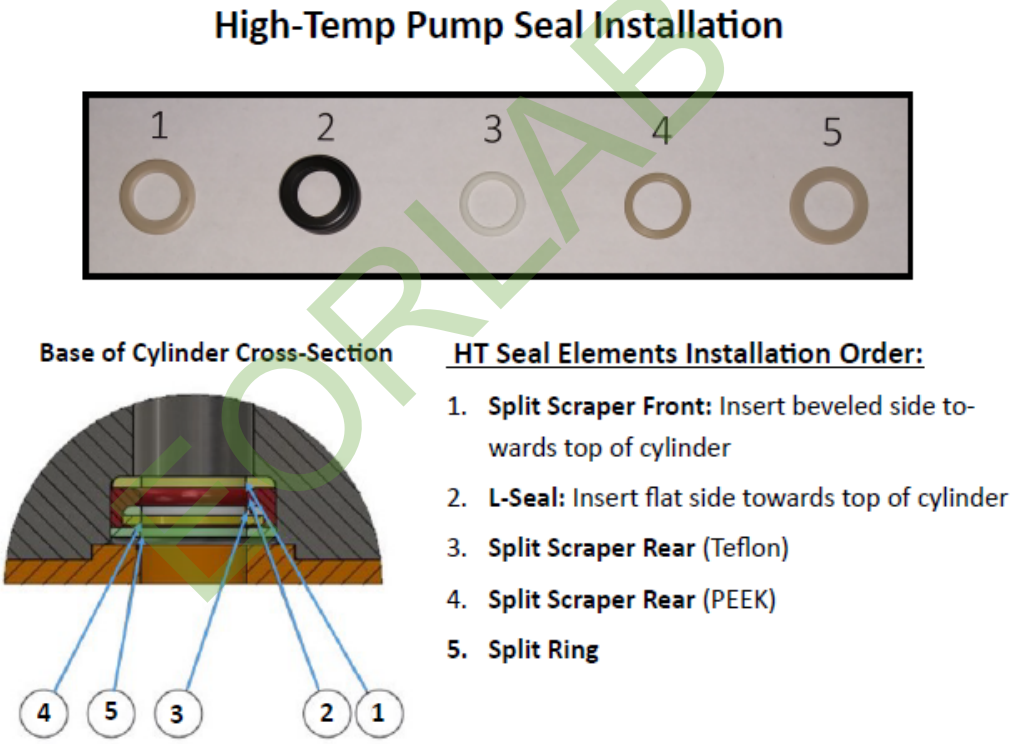
1. Never leave corrosive fluids in the pump. Always flush the pump with distilled water after use. Refer to Section 8.1 or see the "Flushing Pump" instructional video in the Customer Area of https://vindum.com;
2. Use clean, particle-free fluids whenever possible. Filter incoming fluids to avoid particles which can damage pump seals;
3. Ensure the fluids being pumped are compatible with the various pump seals. Incompatible fluids can damage pump seals, leading to leaks and further damage;
4. Frequently inspect the pump for visible fluid leaks. Repair leaky seals as soon as possible. For Hastelloy pumps, remember that the fluid paths are made of Hastelloy, but other metals will corrode when exposed to corrosive fluids;
5. Establish seal replacement intervals and follow them. Keep maintenance records (see sample maintenance form at the end of this Section).
6. Periodically perform the "Static Pressure Test" listed in Section 8.4.1 to check for leaks.

BEFORE PERFORMING ANY MAINTENANCE ON YOUR VP-SERIES PUMP, ENSURE THAT YOU RELIEVE ANY PRESSURE IN THE PUMP'S CYLINDERS. UNPLUG THE POWER CABLE AND WEAR PROPER PROTECTIVE EQUIPMENT WHEN HANDLING ANY UNKNOWN FLUIDS LEFT INSIDE THE PUMP FROM PRIOR USE. FOR YOUR SAFETY, PLEASE ENSURE THAT YOU UNDERSTAND THE SAFETY SYMBOLS AND WARNINGS AT THE BEGINNING OF THIS MANUAL BEFORE UNDERTAKING ANY PUMP MAINTENANCE.

1. **Ball screw Assembly Lubrication (1-2 times/year):** Remove pump's clear plexiglass front cover and fully extend both pistons completely into the cylinders. With a clean towel, wipe clean both ball screws to remove any old grease or other buildup. Once the screw is clean, lightly apply lubricant (available from Vindum Engineering) to each of the two screws and cycle each piston through its complete length a few times. Wipe clean any excess grease accumulation, so that the resulting screw assembly is lightly greased.
2. **Calibrate Pressure Transducers (at least annually):** Refer to Section 7.3.1 of this manual for instructions on calibrating the gain setting of the pressure transducers. Resetting the zero-pressure of the transducers is recommended each time the pump is used.
3. **Replace Piston Seals (at least annually or whenever a leak is detected):** If you see sign of fluid on a piston on, a piston holder, or fluid around the screw that mount each cylinder to the pump top, it likely indicates a leaking piston seal and should be investigated further. Piston seals are durable, but they do wear and require periodic replacement. There isn't a "standard' frequency for replacing piston seals, as wear depends on many factors, including frequency of pump use, fluid type, fluid compatibility, etc. Factors that

can shorten piston seal life include: fast cycling of pistons without fluid in the pump; presence of particles in the fluid being pumped; and pumping fluids that are incompatible with the piston seal material [There are several online sources that list fluid compatibility of UHMW-PE (the seal used in standard VP-Series pumps) and Fluoraz/AFLAS (the piston seal used in high-temperature pumps)]. The key to preventing damage from leaking seals is to inspect the pump for any signs of fluid leaks and to fix them promptly.

To determine if the piston seal is leaking, first conduct the static pressure test described in Section 8.4.1 to confirm that a leak exists. For seal replacement on ambient-temperature or extended-temperature pumps, see the instructional video on Vindum website (Customer Area) or www.youtube.com. For high-temperature pump models (Intended for oven/air bath), the pump disassembly instructions are the same as shown in the video, but the multi-part piston seal should be reassembled in the order shown in the drawing on the next page:



4. **Replace Valve Seals:** Each pump cylinder has a Fluid Inlet valve and a Fluid Outlet valve attached to it. Each of these four valves contain a seal and O-ring/backup rings that wear with use and may eventually need to be replaced. Typical signs of valve needing maintenance are failure to open/close due to blockage of the internal flow path, or a leak from the center port that is located in the middle of the valve, between the two compressed air fittings (see figure below). Should you notice any fluid leaking from the valve leak port or that the pump fails the pressure test described in Section 8.4.1, the valves should be

disassembled and inspected. If significant wear or any damage is observed with the O-ring seal, backup rings, or the valve stem & seat, the parts should be replaced. Extra seals are included with each pump shipment and replacement parts are available from Vindum Engineering (email support@vindum.com). **Table 8.2 at the end of this section lists seal material options and O-ring sizes.**

4. **Replace Safety Burst Disc (if burst disc is activated):** Each cylinder has a safety burst disc assembly on the back of the cylinder barrel. If either of the two safety burst discs fail, the burst disk assembly will need to be unscrewed from the back of the pump cylinder in order to replace the SBD. Extract the burst disk spacer and the dome-shaped burst disk. Replace the burst disk with a certified disk with the same pressure rating and re-install the assembly. Use a torque wrench to tighten the burst disk assembly on the back of the pump cylinder to the torque setting shown in Section 8.3. Next, attach the burst disk certification to the pump for future reference. Replacement safety burst disks are available from Vindum Engineering for each model of VP-Series pump. **Ensure that the replacement burst discs are rated to less than "proof pressure" of the transducer. Pressure transducers can be permanently damaged by exposure to pressures in excess of proof pressure. The safety burst disc should be rated to somewhat less than this pressure.**

6. **Replace Face Seals (whenever leak is detected):** Small elastomer face seals provide sealing of the cylinders and valves, and of the valves and the fluid-in and fluid-out manifolds. If you suspect that one of these seals is leaking, perform the "Static Pressure Test" instructions in Section 8.4.1.

   If this test reveals fluid leaks at any of the pump parts, the pump should be disassembled an the seal(s) replaced. To replace face seals, unscrew the bolts holding the manifold to the valve and then the bolts holding the valve to the cylinder body. Clean the seat where the face seal sits and then carefully place the seal into the seat. To ensure that the seal is properly seated, it's helpful to carefully lay the pump down so that the face seal is facing upwards during assembly. Once the seal is properly seated, carefully mate the other metal part and hand-tighten the first bolt. Install the remaining bolts and hand-tighten each one while ensuring that the parts do not move and dislodge the face seal. Tighten the bolts to the torque settings listed in Section 8.3, using a "crisscross" pattern to ensure that even pressure is applied to the seal.

It's a good idea to keep track of all pump maintenance, repairs, and part changes, especially where the pump is shared among researchers. The table on the next page is designed for this purpose.

PUMP MAINTENANCE AND SERVICE LOG

Serial Number:

Pump Model:

In-Service Date:

Date	Technician	Maintenance Performed	Notes

Table 8.2: Pump Seals—Sizes and Material Options

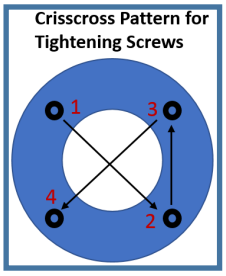
Pump Model	Piston Seal		Valve O-Ring		Face Seals		Rupture Disc Port	Fluid-In/Fluid-Out		Manifold Set Screw
	Size	Material	Size	Material	Size	Material		Connection Type	Material	
VP-3K	Proprietary	UHMWPE	2-010	Options 1	2-006	Options 1	Metal-to-Metal Seal	1/4" AE Speed-Bite	SS or HC	Metal-to-Metal Seal
VP-3K-HT	Proprietary	Fluoraz	2-010	Options 2	2-006	Options 2	Metal-to-Metal Seal	1/4" AE Speed-Bite	SS or HC	Metal-to-Metal Seal
VP-6K	Proprietary	UHMWPE	2-010	Options 1	2-006	Options 1	Metal-to-Metal Seal	1/4" AE Speed-Bite	SS or HC	Metal-to-Metal Seal
VP-6K-HT	Proprietary	Fluoraz	2-010	Options 2	2-006	Options 2	Metal-to-Metal Seal	1/4" AE Speed-Bite	SS or HC	Metal-to-Metal Seal
VP-12K, New	Proprietary	UHMWPE	2-010	Options 1	2-006	Options 1	Metal-to-Metal Seal	1/8" AE Speed-Bite	SS or HC	Metal-to-Metal Seal
VP-12k-HT, New	Proprietary	Fluoraz	2-010	Options 2	2-006	Options 2	Metal-to-Metal Seal	1/8" AE Speed-Bite	SS or HC	Metal-to-Metal Seal
VP-12K, Old	Proprietary	UHMWPE	2-008	Options 1	Dowty or 2-006	Viton or UHMW	Metal-to-Metal Seal	1/8" AE Speed-Bite	SS or HC	Metal-to-Metal Seal
VP-12k-HT, Old	Proprietary	Fluoraz	2-008	Options 2	Dowty	Viton	Metal-to-Metal Seal	1/8" AE Speed-Bite	SS or HC	Metal-to-Metal Seal
VP-20K	Proprietary	UHMWPE	2-010	Options 1	2-006	Options 2	Metal-to-Metal Seal	1/4" AE F250C or HiP HF4	SS or HC	Metal-to-Metal Seal
VP-25K	Proprietary	UHMWPE	1x5mm	Viton	1x2mm	Viton	Metal-to-Metal Seal	1/4" AE F250C or HiP HF4	SS or HC	Metal-to-Metal Seal

Transducer Manufacturer	Transducer Seal Size	Material
Measurement Specialties	Dowty Seal or 2-006 O-ring	Viton (Dowty) or Options 1
ESI-Transducer	2-010	Options 1
Gems Sensors	2-010	Options 2

Seals Material Choices	
Options 1	Options 2
Viton, Aflas, Buna, UHMW	Viton, Aflas, Buna

8.3 Torque Settings and Reassembly

Table 8.3, on the next page, lists the torque settings for screws and parts on the top assembly of VP-Series pumps. The location of each fastener is shown in the figure at the bottom of this page.



It's important to follow the torque setting in the table. To ensure that the fastening forces are spread evenly across the contact surfaces of the joined parts, it's also important to tighten the screws in a "crisscross" pattern, as shown in the diagram at right.

When reassembling any of the parts on the pump, such as the manifolds or cylinder barrels, hand-tighten all the parts, to ensure that all parts are aligned, before tightening them to the torque settings in the table on the next page. If any parts seem hard to reassemble, don't force them. For example, if you have removed the cylinder barrels and manifolds to replace the piston seals, loosely reattach the cylinder bodies to the top assembly of the pump, then loosely mount the manifolds to the valve/cylinder bodies. You should have enough "wiggle room" in the cylinder bodies so that you can slightly move them to align with each manifold. Hand-tighten the manifold screws to hold the manifold in-place and recheck the alignment of all the parts, then proceed to tighten all screws to the recommended torque settings. If you find that you have leaks from the manifold-valve connection, it is likely due to misalignment of the parts or of the cylinders themselves. Loosen the cylinder barrel screws and the manifold screws, and follow the procedure described above to align and re-tighten them. For confirmation that there are no leaks following reassembly, conduct the static pressure test described in Section 8.4.1.

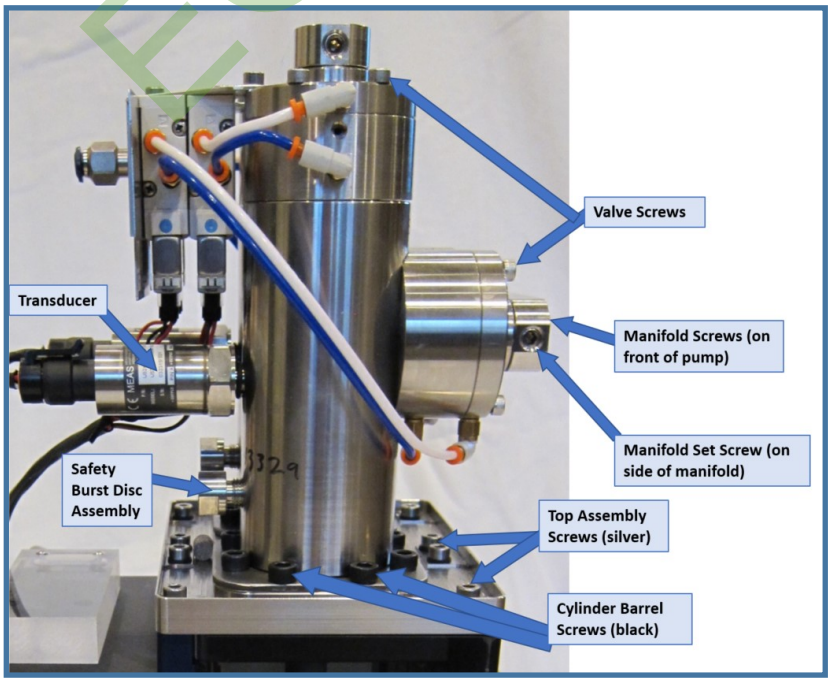


Table 8.3: Torque Settings for VP-Series Pumps See the figure on the prior page for location of screws and connection procedures			
Screw/Part	Torque Setting	Hex Driver Size	Comments
Cylinder Barrel Screws (black colored heads)	15 Nm (133 lbfs.in)	5 mm	Tighten using crisscross pattern, alternating sides to evenly tighten cylinder to top assembly.
Top Assembly Screws (silver colored heads)	4.5 Nm (40 lbsf.in)	4 mm	8 top screws have washers, 2 front & 2 back screws do not. Tighten screws in crisscross pattern.
Manifold Screws	4.5 Nm (40 lbsf.in)	3 mm	Loosely insert all screws and hand-tighten to ensure alignment of cylinder barrels with manifold and ensure that face-seal O-ring is properly positioned.
Manifold Set Screw	16.5 Nm (146 lbsf.in)	4 mm	Insert the metal plug ahead of the set screw and center over the hole. Optional Dowty seal also needs to be centered over the inside hole and is installed before the metal plug.
Valve Screws (fastens valves to cylinder barrel)	4.5 Nm (40 lbsf.in)	3 mm	Ensure O-ring face seal position does not slip during install. Tighten four screws to hand-tight, then do final torqueing in crisscross pattern.
Transducer	Hand-tighten + 1/4 turn with wrench		Ensure O-ring is inserted & properly seated before screwing in transducer. Do not over-tighten transducer!
Safety Burst Disc (all VP-3k, VP-6k, VP-12k pumps)	45 Nm (400 lbsf.in)		See Youtube.com video (search "Vindum Engineering") for procedure.
Safety Burst Disc (VP-20k & VP-25k pumps)	81 Nm (720 lbsf.in) for rupture disc mount 4.5 Nm (40 lbsf.in) for attaching rupture disc assembly to pump cylinder		Ensure that rupture disc is centered in the housing and tighten to recommended torque before screwing the large rupture disc assembly into the cylinder body.

8.4 Pump Tests: Verifying Pump Performance

This section has instructions for running two tests for users to verify that a Vindum Pump is working properly. Test #1 is a static pressure test, to ensure that the pump is holding pressure and has no leaks. Test #2 is to verify operation of the pump electronics components and electrical systems.

The tests procedures described in this section require that the user understands how to set up the Vindum Pump and that they have a good understanding of the VPware pump-control software. Do not perform the tests described in this section unless you are well-versed in both these areas.

8.4.1 Static Pressure Test

The purpose of this test is to determine if the pump has any fluid leaks. This is done by filling the pump with distilled water and letting both cylinders run in IPD mode at elevated pressure, with valves closed, for a period of time. The amount of fluid "pumped" from each cylinder over the course of the test is measured. While changes in ambient temperature can lead to a small volume changes over the course of the test, the volume fluctuations of each cylinder should be small and should closely track each other.

Follow the steps listed here to test for leaks:

a) Fill the pump with distilled water and purge all air from the cylinders using the "Auto-Prime Sequence" in VPware (See Section 7.8.1 for instructions on using the Auto-Prime Sequence). If the pump fails to complete the Auto-Prime Sequence successfully, look for visible leaks and repair them per the instructions in Section 8.2;

b) Retract both pistons using "IR" mode (ensure that both inlet valves are open when you do this);

c) Set the pump mode to "IP", close all four valves (compressed air must be connected to the pump), and set a target pressure of 2000 psi for each cylinder (set the safety pressure to 2500 psi).

d) Reset the cumulative volume of each cylinder to zero;

e) Set both pistons to "extend";

f) Start the datalog, recording the cumulative pumped volume for each cylinder;

g) Start the pump. The pump will pressurize to the target pressure and hold that pressure;

h) Inspect all the connection point around the cylinder for any signs of leaks. If you do not observe any leaks, you may leave the pump running in "IP" mode for several hours, or more.

i) After inspecting for leaked fluid, stop the pump. Depressurize both cylinders by reversing the piston direction, setting the pump mode to "IR" with a set rate of 1 ml/min, and press start. Stop the pump when the cylinder pressure is relieved.

j) Be sure to look for leaks at all seal points: piston seals, transducer ports, safety burst disc ports, valve leak ports, all face seals, and the set screws on the sides of the Fluid In and Fluid Out manifolds.

You can further analyze the test results, open the datalog .csv file in Microsoft Excel and graph the pumped volume of both Cylinder A and Cylinder B over the test duration. This graph will show you the volume change of each cylinder. The volume changes seen in the cylinders should look the same. In a perfect test environment, with completely static ambient temperature, there would be no volume change over the course of the test. If the ambient temperature does change over the course of the test, the volume change the cylinders should track each other fairly closely if there are no leaks. Significant deviation of cumulative volume between the cylinders indicates a probable fluid leak somewhere on the pump.

In order to check for possible leaks from the Fluid In and Fluid Out manifolds, repeat the pressure test described in the steps above, but insert plugs into the Fluid In and Fluid Out manifolds and open the inlet and outlet valves so that fluid fills the manifolds. This way, with all pump valves open, fluid will fill and pressurize the manifolds too. Inspect the fluid connections and set screws (on the sides of the manifolds) for any signs of leaks.

8.4.2 Rate Calibration Test

This test is designed to confirm the accuracy of the pump's fluid delivery. Run this test with distilled water and perform an Auto-Prime Sequence (see Section 7.8.1) to ensure that residual air has been purged from the cylinders.

Start by putting the pump in PRD (Paired Rate Deliver) mode. Set rate to 2 ml/min. Start a new data log. Press the start button. On the Start Confirmation Window, select "Volume" under "Fluid Delivery" and enter 10 ml. Press the Start button. This test should take exactly 5 minutes. When completed, stop the data log and open the data log Excel file. Check the elapsed time between when the rate went to 2ml/min and when the pump stopped. The elapsed time (difference between the starting and stopping time stamps should be within 1 second of 5 minutes. This confirms that the electronics and electrical systems of the pump are operating correctly. Repeating this test can be done to ensure the repeatability of the pump's performance.

8.4.3 Improving Pumping Precision

For users wanting to ensure highest accuracy of their experiments, it is important to minimize variability of the following factors:

1. Constant external temperature: air circulation from HVAC systems should be avoided, or the pump isolated from HVAC system;
2. De-gas the fluid to be pumped, in order to eliminate dissolved gases from the fluid;
3. Use a calibrated, high quality scale for very accurate measurement of pumped fluid;
4. Use tight-fitting lids on fluid collection vessels and avoid exposure to direct sunlight or high temperatures;
5. Ensure pulse free flow: It's very important that the stand-by cylinder reaches pressure equilibrium with the active cylinder and also that the servo rate of the stand-by cylinder is zero or near-zero before cylinder switch-over (i.e., the stand-by cylinder must match the pressure of the active cylinder and be holding that pressure with minimal movement prior to switch-over).

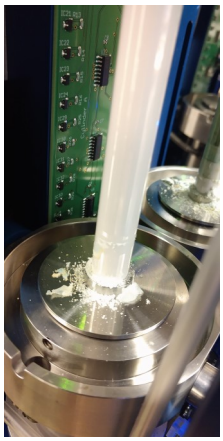
Please keep in-mind that as pumping rates get smaller, the importance of each of these factors increases and that even very small variations or measurement inaccuracies can materially affect the test results. The simplest test method to demonstrate a pump's accuracy is to test the repeatability of pumped volumes, using the method described in Section 8.4.2.

9. SPECIAL CASES— BRINES, GASES, SUPERCRITICAL CO_2, LOW PRESSURE PUMPING, AND HIGH-VISCOSITY FLUIDS

9.1 Pumping Brine or Dissolved Salts

Pumping brine or fluids with dissolved salts can increase the wear on the pump's dynamic seals (i.e., piston seals and fluid seals inside the four pump valves), which can cause them to leak prematurely. We recommend that users frequently inspect these locations for signs of leaks and that users keep spare seals on hand to replace any worn/damaged seals.

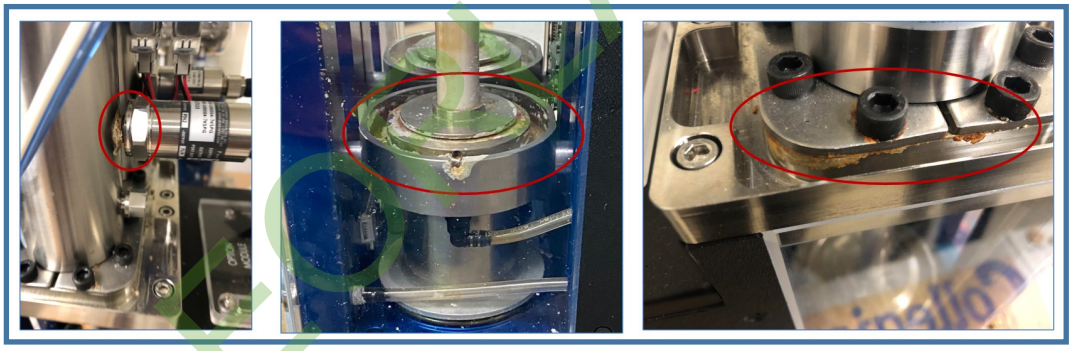
For users who routinely pump dissolved salts or other solids, we recommend fitting Vindum Engineering's piston wash kit to their pump. This kit, shown below, can be fitted to any of the pump models, excluding the high temperature pump models (for insertion into oven/air bath). The piston wash kit circulates distilled water around the pump pistons as they retract from the pump cylinders, thereby preventing salts from hardening on the pistons and causing premature piston seal failures. Contact Vindum Engineering for more information & availability of the piston wash kit for your pump model.



Following is a lists of maintenance suggestions when working with aqueous solutions of dissolved salts, including brine:

- A very thin film of fluid is present on the pistons when they retract from the cylinder. At slow pumping rates, the aqueous portion of this fluid evaporates, leaving a fine build-up of salt on the piston (see photo at right). As the piston moves back into the cylinder, the back up ring scrapes this film off the piston and it accumulates on the piston holder. This salt should be cleaned regularly using a damp cloth.
- Always flush the cylinders and valves with clean distilled water immediately after pumping brine. Do not leave brines in the pump when it's not in use. Ensure that cylinders are fully flushed so that no brine remains inside the cylinders. Refer to Section 8 of this User Guide for complete pump cleaning & fluid flushing instructions.

- Brines and other dissolved salts should only be used in pumps with Hastelloy wetted parts. It's also important that the tubing and fittings in the system also be corrosion-resistant (e.g., Hastelloy, Inconel, Ferralium). This is to prevent rust particles from entering the pump, as rust is highly abrasive and can cause leaks to develop in the dynamic pump seals (i.e., piston seal and valve seals).
- Establish a schedule for inspecting and replacing piston seals and the wetted O-rings in pump valves. Due to the increased wear on these parts from brines or other corrosive fluids, we recommend monthly replacement of piston seals until a wear pattern can be established. Keep spares seals available.
- Only the wetted parts of "HC" model pumps are made of Hastelloy. Other parts of these pump are made of aluminum and stainless steel, which will corrode when exposed to brine. To prevent corrosion damage to these parts, it's important to inspect the pump often and to repair leaks as soon as they are discovered.
- The images below show salt build up from small leaks which has not been addressed in a timely manner. These photos are intended to help users spot fluid leaks and prevent damage to the pump by prompt corrective action. The first one shows a leak at a transducer seal. The second shows damage to the piston holder from a leaky piston seal. The rightmost photo shows salt buildup under the piston holder due to a leaky piston seal.



9.2 Pumping Gases

Working with compressed gases requires special care and safety precautions, due to the energy that can be released from even a small volume of highly compressed gas. Do not use Vindum pumps with gases unless you are an experienced pump user and have the necessary approvals and have taken appropriate safety precautions!

Vindum pumps are not explosion-proof! They should not be used to pump combustible gases due to the risk of electrical sparks causing an explosion. Any user who uses the pumps with combustible gases does so at their own risk.

Gas must be supplied to VP-Series pumps at very near the intended pumping pressure in order for the pump to deliver the gas continuously without a pressure pulse. This is due to high gas compressibility and the pump's small cylinder volume. The compression ratio of VP-Series pumps is about 3:1. To achieve pulse-free flow it's recommended that the incoming gas be kept supercritical or at 85-90% of the target pumping pressure in in gaseous phase.

Other considerations for pumping gases with VP-Series pumps:

- Seal Compatibility: ensure that the gas is compatible with the various pump seal materials. These are listed in Table 8.2. Many online sources list the compatibility of various fluids with the elastomers (and UHMW-PE) used in VP-Series pumps. Contact Vindum Engineering to check availability of other O-ring elastomer compounds.
- Helium and hydrogen gases are inherently difficult to seal. They are sometimes able to leak around fluid seals and even through many seal materials. As such, small leaks may be unavoidable.
- Temperature stability is important when pumping gases at very low rates, as small changes in ambient temperature can affect the pressure. It helps to install an insulating cover over the pump cylinders to improve temperature stability. The "shelf plate", shown in the image below, is available for this purpose.

- Some pump configuration settings must be changed when working with gases:
    1. **Low Pressure Open:** This setting controls the cylinder at which the fluid inlet valve opens to refill. This should be set at a pressure slightly below that of the incoming gas.
    2. **Closed Valve Proportional and Differential Gains:** In order to pressurize the gas

quickly after the passive cylinder is filled with incoming gas, increase both by several multiples. You might try increasing the Proportional Gain and Differential Gain values by a factor of "1000" (compared to respective settings for liquids), then test to see if the passive cylinder matches the pressure of the active, pumping cylinder before it reaches the end of its stroke. In order for flow to be pulse-free, the gas in the passive cylinder must be at the same pressure of the active cylinder before it reaches the end of its stroke. Refer to Section 7.3.1 (#15) for instructions on fine-tuning these PID settings.

3. **Open Valve Proportional & Differential Gains:** These must also be increased, for the same reason as item 2.

4. **Return-Rate Multiplier:** Increase this parameter so that the pistons retract more quickly and allow more time for the passive cylinder to pressurize. This will help ensure that the passive cylinder is able to match the pressure of the active cylinder before that piston reaches the end of its stroke.

-  If you notice that the passive cylinder is not able to match the pressure of the active (pumping) cylinder before the pumping piston completes its stroke, then pumping is not pulse-free, i.e., there will be a pressure change when pumping switches from one cylinder to the other. This is an indication of the following factors: 1) the incoming gas pressure is too low; 2) The selected pumping rate is too fast; 3) The return rate multiplier is set too low; and/or 4) The Closed Valve Proportional Gain is too low.

9.3 Pumping Supercritical CO_2

Supercritical fluids, particularly CO_2, have special pumping requirements. Under pressure, CO_2 is absorbed by many elastomer seals (like those in the valves and face seals of VP-Series pumps). In the course of decompressing, the absorbed CO_2 expands and damages the elastomer seal, resulting in premature seal failure. Specialty elastomers, like TFE/P (i.e., AFLAS) and FFKM (e.g., Chemraz) offer better durability for work with CO_2 and are highly recommended.

In order to keep the CO_2 in supercritical phase while pumping, we recommend using a CO_2 cylinder has a "dip tube" to draw liquid CO_2 from the bottom of the cylinder and into the Fluid In port on the pump.

Supercritical CO_2 has higher compressibility than liquids, so you will likely need to increase the PID gain settings (both the Open Valve PIDs and Closed Valve PIDs). In addition, the Low Pressure Open settings (see VPware Configure/Pump Configuration) can be increased so that the inlet valves open as soon as the pistons begin to retract. This will minimize the cylinder volume when the CO_2 starts to enter the pump and help keep it supercritical.

Due to similarities between supercritical fluids and gases, please read Section 9.2 (Pumping Gases) for more information and suggestions.

9.4 Low Pressure Pumping

Pumping liquids continuously at low pressure, whether in "pressure" or "rate" modes merits some special considerations:

1. **Transducer calibration:** In order for pumping to be pulse-free, the "pressure-zero" of the transducers must be reset before any experiments. In addition, it is advisable to calibrate the "gain value" of the transducers at the experiment pressure to optimize the accuracy of the transducers. Both of these settings are found in VPware Configuration/Pump Configuration menu.

2. **Transducer Error:** Transducer accuracy is often expressed as "percent error". The transducers used with VP-Series pumps are either 0.1% error or 0.25% error. This means that over the pressure range of the transducer, the reported transducer pressure will be within 0.1% or 0.25% of the transducer's maximum value. For instance, the pressure reported by a 0-15,000 psi transducer with 0.25% error is deemed to within +/- 37.5 psi of the actual pressure (i.e., error = 15,000 psi * 0.0025 = 37.5 psi). Minimizing this error is especially important for low-pressure work and can be achieved by: 1) using transducers with lower error; and 2) using transducers that are rated for lower pressure. Vindum Engineering offers transducers with 0-1725 psi range, which can be fitting to any pump model, as well as other transducers for higher-pressure work.

3. **PID Settings:** Fluid compressibility is highest when working at low pressure. As such, it often takes more time for the piston of the passive cylinder to match the pressure of the active, pumping cylinder compared to high-pressure pumping. In order to ensure that the pumping is pulse-free when working at low pressure, you may need to increase the Open Valve Proportional Gain and Open Valve Differential Gain settings of both cylinders, as well as increase the Return Rate Multiplier (to allow more time for the passive cylinder to pressurize). To see if this is necessary, first calibrate the transducers as described above. Next, operate the pump and watch how long it takes the passive cylinder to match the pressure of the active cylinder. If the pumping rate is low, there may be plenty of time to match the pressure. However, if you notice that the passive cylinder does not match the pressure of the active cylinder before switchover occurs, you can adjust the PID settings and/or slow the pumping rate to allow more time for pressure-matching at switchover.

9.5 High-Viscosity Fluids

It may be difficult to draw high-viscosity fluids into the pump without creating a void in the pump cylinders. To help prevent cavitation, reduce the Return Rate Multiplier setting (see Configure/Pump Configuration screen) while still ensuring that the passive cylinder still has 10-12 seconds to repressurize after filling with fluid. If the fluid is not too viscous, shortening the feed line to the pump and placing the fluid above the pump may be sufficient to avoid cavitation during filling. If the fluid is very viscous, you may need to use a pressurized fluid transfer

vessel to feed the pump or pump the fluid using a floating piston accumulator.

10. PUMP CONTROL OPTIONS

The native, machine-level command language used by VP-Series pumps is a "Hexadecimal + CRC" (non-ASCII) control language, selected for it's speed and security. To aid in programming, a .NET assembly DLL (Dynamically-Linked Library) is wrapped over the hex code to provide a user-friendly API (application programming interface). VPware then uses the DLL to provide the user with comprehensive pump control and communications interface that is intuitive and which has several safeguards and error/warning messaging built in.

For customers needing pump control options beyond VPware, Vindum Engineering offers several other pump control interfaces. These control options are described in this section and are summarized in Table 10.1 at the end of the section. These control options are free for Vindum pump customers with the exception of the HMS Anybus® Communicator™ device, which can be purchased from HMS. **Documentation and software downloads for each of the control options in this section are available in the Customer Area of the Vindum Engineering website. If you have questions regarding particular options, or to help evaluate pump control options, please contact Vindum Engineering (support@vindum.com or +1 281-782-8312, ext. 1).**

10.1 LABVIEW© VI DRIVER

The VPware LabVIEW driver package contains two examples, including a "Complete Pump Example", that has many of the features of VPware already built. The driver also includes individual pump VIs, for use by more experienced LabVIEW programmers. Requires LabVIEW 15 or later, PC version, either 32-bit or 64-bit. LabVIEW also has DDE Client and OPC UA Client capabilities, which can control pumps via VPware (see more below).

10.2 OPC UA Server

We offer a version of VPware that has built-in OPC UA Server capability. This allows any Microsoft Windows application with OPC UA Client capability (e.g., LabVIEW) to communicate and control VP-Series pumps. VPware does not have OPC UA Client capability, so it cannot be used to control other OPC UA devices.

10.3 DDE Server

VPware provides the capability for bi-directional communication with other applications that support Dynamic Data Exchange (DDE), such as LabVIEW. VPware has DDE Server capability, for accepting commands and update requests from the DDE Client application. A PC with Windows 7, or later is required. DDE provides a convenient interface for using VP-Series pumps with LabVIEW (for Windows), with the full suite of pump commands and data available. **Note: VPware has DDE "Server" capabilities only. It does not have DDE "Client" capability. As such, VPware cannot control other devices using DDE.**

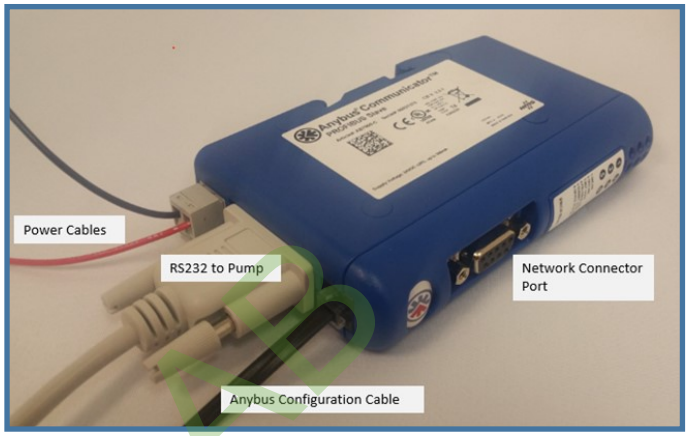
10.4 Option Modules (Analog/Digital Control)

VP-series pumps have a female 15-pin connector (type DE-15) on the back of the pump (under the clear plexiglass cover) that can be used to operate the pump remotely by means of digital input/outputs and a 0-3.3V analog input that can be used for sending pressure or rate set-

points to the pump. When used in combination with the MC USB-2408-2AO device (purchased separately), pump pressure and rate data can also be sent via the device's two analog out channels. The digital and analog channels of the Option Module connector can be configured in different ways to meet varying customer requirements. Please contact Vindum Engineering Support to discuss your control and data requirements using the Option Module interface.

10.5 HMS Anybus® Communicator™ (for Fieldbus / Industrial Ethernet)

The Anybus Communicator device (shown at right) provides a gateway for interfacing VP-Series pumps with many types of fieldbus/ PLC control systems without need for a dedicated computer for the pump. Although PCL programming is required, using the Anybus will speed integration of the pump with PLC control systems. Vindum Engineering has programmed the device so that pump commands and pump data are saved in specific byte registers on the Anybus. A single cyclic "ReadAll" command is used to pass all pump data back to the device. The input and output data from the Anybus is in hexadecimal format, but the CRC (confirmation of commands) is not required. There are several model of Anybus, for use with the following system types: PROFINET-IRT, Modbus, PROFIBUS, EtherCat, and several others. If you want to use VP-Series pumps without a Windows PC, the Anybus Communicator is worth considering.



10.6 .NET DLL

The .NET Dynamically Linked Library (DLL) provides a convenient way for a custom control application to interface to Vindum pumps. The application programming interface (API) to the DLL provides a full set of pump commands, pump status information, and pump events, including error conditions. This .NET assembly DLL handles the low-level communication to the Vindum Pump hardware, providing the developer with a simple API for pump control and monitoring using applications such as PYTHON and MATLAB that can interact with Windows .NET applications. Requires Microsoft .NET framework 4.0 or later.

10.7 Serial RS-232 (Hexadecimal)

Programming-savvy pump customers working with pumps in non-Windows environments, can control the pump via Hexadecimal code (non-ASCII format) that also includes a cyclic redundancy check (CRC). This is the low-level source code for pump control and is arranged into three sections:

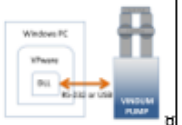
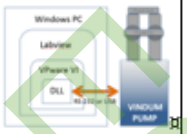
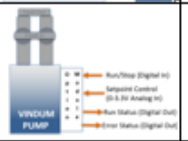
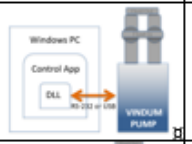
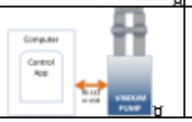
1. **Operational Commands** sent to the pump (all are 8 byte strings);
2. **Command Response:** returned by the pump with every command issued to it, either confirming "no errors" or returning the error code and verbiage indicating the type of error. All communication from the pump is in the form of responses to commands -

the pump does not send any unsolicited messages.;

3. **Data request commands:** consists of four types: Readstatus, ReadInit, ReadErrors, and ReadLow. Each is returned in a byte-string format of different lengths which must be parsed.

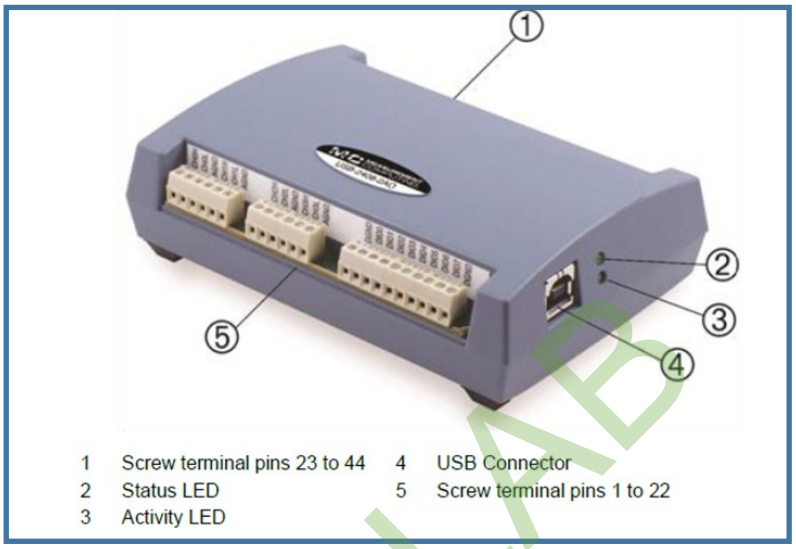
Developing a robust pump control system using the native hexadecimal commands a significant undertaking, even for experienced programmers. Before undertaking this option, consider using the Anybus Communicator if possible.

Table 10.1: Vindum Pump Control Options

Pump Control System	Description	Control Platform	Pump Control Capabilities	Access to Pump Data	Example Applications	Connection Type
VPware	Proprietary pump control application developed by Vindum and included in pump pricing.		Full Pump Control, graphing, advanced features, and error/warning notices	Real-time graphing and/or save to CSV file for later analysis.	VPware is capable of controlling 16 pumps from one computer.	•→RS232–USB •→USB-USB •→RS232-RS232 •→RS232-Ethernet
LabVIEW VI	Driver includes example pump user interface to speed implementation.		LabVIEW driver access full functionality of .NET DLL	Pump events are registered directly in LabVIEW Event Structure. Full pump data.	LabVIEW 2013+	•→same as above
OPC UA	VPware acts as an OPC UA server that allows industrial systems (client) to access pump data and send pump commands.		Full library of pump commands	Client can request full pump data.	Any OPC UA client application	•→same as above
DDE	VPware acts as "server" to a DDE "client" application.		Full library of pump commands	Full pump data is available.	LabVIEW or other applications with DDE client capability	•→same as above
Pump Option Module Port	15-pin connector on pump uses digital signals for Run/Stop and status & analog voltage input to set pressure/rate.		Wiring can be configured to meet various control requirements.	VPware can be used to capture pump data (pressure, rate, etc.).	Remote control of pump requiring limited control functionality.	DBHD15 port for Option Module.
HMS Anybus® Communicator™	Protocol converter gateway enables Vindum Pumps to interface with major fieldbus or Industrial Ethernet networks.	All major Fieldbus/IE systems: Profibus, Profinet, Modbus Ethernet/IP, etc.	Pump commands and status are translated by the Anybus® Configuration Manager for access by the PLC.	Pump data stored in device memory buffer then intelligently uploaded to network.	All major fieldbus or Industrial Ethernet networks.	RS232 connection to HMS Anybus® Communicator™
.NET DLL	.NET assembly DLL, handles low level COM to Vindum Pump. The API to the DLL provides simple interface with custom control apps.		Full library of pump commands, status & errors, communication status, etc.	Full pump data is available.	Python MATLAB	•→same as above
Binary	Direct binary interface with CRC (cyclic redundancy error check)		All pump functions are available in binary code.	Full pump data is available.	LabVIEW Real-Time	•→same as above

11. CONTROLLING EXTERNAL DEVICES - MC USB-2408/2408-2AO

For pump users who want to record data from external analog devices (voltage or temperature), or who want to control digital devices (e.g., Vindum CV automatic valves) together with VP-Series pumps, we recommend using the USB-2408 DAQ device, made by Measurement Computing. This device, shown below, is available from Vindum Engineering or other suppliers.



The MCC USB-2408 device is designed to accurately record data from external analog devices (i.e., voltage or temperature) via 16 single-ended/8 differential analog inputs The device also has eight digital I/O channels that can be used to open/close Vindum CV valves (requires separate 12VDC power source). The USB-2408-2AO model also includes two 16-bit analog outputs, which can be configured to send pump pressure and rate data to the controlling computer.

A separate version of VPware is required to use the USB-2408 or USB-2408-2AO devices. This VPware version, with detailed instructions, is available to download from the Customer Area of the Vindum website or you may request a free copy from Vindum Engineering. Input data from the USB-2408 is automatically data-logged in VPware when datalogging is enabled. Graphs of the input channels can also be graphed via the USB-2408 Graphs menu in VPware.

12. CE DECLARATION OF CONFORMITY

VINDUM ENGINEERING, INC.

CE

EC DECLARATION OF CONFORMITY

Manufacturer's Name:	Vindum Engineering, Inc.
Manufacturer's Address:	369 Syringa Ridge Sandpoint, ID 83864
Equipment Product/Model:	Vindum VP-xxK family of piston metering pumps
Application of Directives:	European ElectroMagnetic Compatibility Directive (EMC) 2004/108/EC European Low Voltage Directive (LVD) 2014/35/EU
Conforms to Standards:	EN 61000-6-4:2007/A1:2011 Radiated Emissions, Technology Equipment EN 61000-6-2:2005/AC:2005 Radiated Immunity Technology Equipment EN/EIC/UL/CSA 61010-1:2010 - Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use

Standard	Description	Severity Level	Criteria/Result
EN 61000-6-4:2007/A1:2011	Radiated Emissions	Class A 30 MHz – 6 GHz	Complies
EN 61000-6-4:2007/A1:2011	Conducted Emissions	Class A 150 kHz–30 MHz	Complies
EN 61000-4-2:2009	Electrostatic Discharge	±8 kV Air Discharge ±4 kV Contact Discharge, VCP, HCP	B Complies
EN 61000-4-3:2006/A2:2010	Radiated Electromagnetic Field Immunity	10 V/m, 80 - 1000 MHz 80%, 1 kHz, AM 3 V/m, 1.4 - 6 GHz 80%, 1 kHz, AM	A Complies
EN 61000-4-4:2004+A1:2010 Basic test standard	Electrical Fast Transient /Burst Immunity	±2 kV on AC Mains ±1 kV on I/O Ports	B Complies
EN 61000-4-5:2006	Surge Immunity	±2 kV CM Line-Gnd ±1 kV, DM Line-Line ±1 kV on I/O Ports	B Complies
EN 61000-4-6:2009	Conducted Immunity	10 Vrms, 0.15 - 80 MHz, AC Mains 10 Vrms, 0.15 - 80 MHz, I/O Ports	A Complies
EN 61000-4-8:2010	Power Frequency Magnetic Field Immunity Test.	30 A/m@ 50 Hz 3 Orthogonal Orientations	A Complies
EN 61000-4-11:2004	Voltage Dips	0%, 1 cycle 40%, 10 cycles 70%, 25 cycles	B/B Complies
EN 61000-4-11:2004	Voltage Interruptions	0%, 250 Periods	C Complies

I, the undersigned, hereby declare that the design of the specified equipment conforms with the Directives and Standards listed herein as of July 21, 2017.

Christa Vindum, President Vindum Engineering