

PU-2 Pump Unit

for liquid cooling systems with non-conductive coolants such as PFPE, PFC, HFE or low viscose silicone oil.

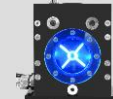
DATA SHEET & INSTRUCTIONS

Left: PU-2 pump unit complete with plastic flange and front cover (removeable for system integration)

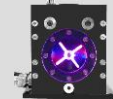
Right up: The electronically commutated pump motor with self-adjusting magnet rotor and coolant lubricated ceramic bearing for an extreme life time

Right middle: The control and safety electronics

Right below: The illuminated viewing window



<50°C (122F)



>50°C (122F)



>65°C (149F)

PU2 - LIQUID COOLING MADE EASY

The cooling of high voltage and high frequency power electronics, such as high-voltage solid-state switches, is a very special challenge. The pursuit of good electrical insulation and low thermal resistance is difficult because the two are diametrically opposite. This is especially true at higher operating frequencies where classical cooling methods quickly reach their limits. Capacitive coupling between grounded heatsinks and the part components to be cooled can cause significant noise currents, which make EMC design of the whole application very difficult or even impossible, not to mention the significant capacitive power losses. To solve this challenge, in 1993 BEHLKE developed a special method of liquid cooling for their high voltage solid-state switches. This "**Direct Liquid Cooling**" (DLC) uses a dielectric liquid to combine excellent cooling efficiency with extremely good insulation even at high operating frequencies. The DLC principle utilizes highly insulating and chemically inert liquids for the heat transfer from the high voltage / high frequency circuit to grounded heat exchangers or active radiators. These liquids can be Perfluorinated Polyethers (PFPE), Perfluorocarbons (PFC), Hydrofluorethers (HFE)¹⁾ or silicone oil as a cost efficient alternative.

Compared to classical cooling methods using grounded heatsinks or ceramic watercoolers, the DLC cooling avoids any stray capacitance between power circuit and ground. Concurrently, the cooling performance is increased dramatically, since there is no heat resistance from insulating material between power part components and the coolant media. DLC cooling reduces also the temperature stress for the entire circuit board and all part components on it, whereby the part components can be operated at a significantly increased power dissipation.

In BEHLKE DLC switching modules the dielectric coolant flows in specially formed cooling channels and comes in direct contact with the non-isolated part components to be cooled. In order to achieve the lowest possible heat resistance through high coolant velocity, the ideal cooling channel is as narrow as possible. Narrow cooling channels simplify also the deaeration at initial use and keep the systems total liquid volume low, which

reduces the heat expansion and the system pressure overall at increased temperature. Last but not least, the fluorinated coolant is a significant cost factor in the cooling system and therefore it makes sense to limit its quantity wherever possible. The limited coolant volume, however, can become a problem if the coolant flow is stopped completely, for any reason whatsoever. In connection with its small heat capacity the coolant can overheat then very rapidly with dramatic consequences for the power electronics to be cooled. Therefore, in DLC cooling systems it is very important, that the coolant flow is never interrupted completely for more than 10 seconds. The coolant flow should be carefully monitored and if it fails, then the heat dissipating power electronics must be turned off immediately. All these requirements are perfectly fulfilled by the PU-2 pump unit with its intelligent control and safety electronics.

The pump unit is milled from a billet aluminum block and allows an absolute leakage free operation even at high temperature and high pressure. The PU-2 pump unit consists of the above mentioned safety and control circuit, an electrical commutated pump motor and a reservoir for the coolant. The motor, its drivers and the entire control electronics are installed in the coolant reservoir and are completely immersed in the coolant. The front side of the unit, which is usually mounted behind the front panel of a system housing (e.g. a 19" housing unit), has an o-ring sealed viewing window for the built-in flow turbine wheel. The flow turbine wheel serves as a visual flow indicator and as digital flow sensor in the same time. Double ball bearing, coolant lubrication and optical scanning guarantees a MTBF of >5x10E5 hours for this safety relevant part component.

The built-in electronics monitors the coolant flow, the tank fill level, the coolant temperature, the motor function and the supply voltage. The speed of the pump motor and the speed of the externally connected radiator fans are regulated proportionally to the coolant temperature. The automatic speed control can be turned-off by a logic signal for full cooling power or for external speed control by means of the supply voltage variation, if demanded. The manual speed control of pump can also be helpful for the deaeration of very large

switching modules and radiators. In case of any fault condition (over temperature, flow disturbance, empty reservoir, missing or incorrect supply voltage etc.) a relay contact is immediately released to protect the connected power electronics in the cooling circle. For BEHLKE HTS high voltage switches, the alarm contact (normally closed contact) will simply be connected between the inhibit and the GND input of the switch control. Any false or critical operating condition will also be indicated by different color illuminations of the coolant, which is visible through the viewing window. During normal cooling operation the color of illumination is blue.

The maximum cooling capacity with sufficient active radiators (e.g. BEHLKE AR-3000W) or heat exchangers (e.g. BEHLKE HE-10) is approx. 3000 Watt for the standard pump unit and approx. 5000 Watt in connection with the power option 30W. In general, the option 30W is advantageous for larger high voltage switches with increased flow resistance. If ordered with option IHE (internal heat exchanger), the pump block with its plain milled surfaces can also be utilized as a highly efficient heat exchanger / heat sink. With the help of the option IHE, the coolant heat can be easily transferred via the housing block to an existing heatsink. This can be a classical heatsink or any large massive metal housing (e.g. a 19" housing with thick front panel) or a large metal chassis of a machine. A cooling solution with option IHE allows a power dissipation of at least 500 Watt without any radiator or heat exchanger, providing the pump unit is attached to a sufficient heat sink element.

The PU-2 pump unit is designed for system integration. It can easily be attached behind the front panel of a 19" rack housing. In order to align the viewing window with a 19" front panel, the 6 mm (0.24") plastic front cover is replaced by a 3 mm (0.12") plastic spacer (included in supply). Aluminum spacers are available if the front panel is to be utilized as heat sink. A front fill port and a front drain are provided. The option EFSI (extra features for system integration) includes an additional optocoupler output (open collector), a digital flow signal output and an internal temperature sensor according to customers specifications (NTC, PTC, PT100, PT1000, FeCr, KTY etc.)

Features and Technical Data:

- Non-blocking, highly reliable pump motor for industrial purposes with coolant lubricated and self-adjusting ceramic bearing.
- Guaranteed motor life expectancy >50,000 hours (typically >100,000 hours) at maximum temperature / maximum load condition.
- Temperature depending speed control (can be switched off) for low power consumption and maximum motor life expectancy.
- Maximum flow rate > 3l / min (option **30W**: >4l / min with Galden HT-135 @ 25°C and < 30 cm height difference.
- Pump power 8 - 20 Watt (option **30W**: 12 - 30 Watt), 12 VDC, current consumption max. 1.8 A (option **30W**: max. 2.5A).
- Temperature depending speed control for external radiator fans, 6-12 VDC, max. 3 A. Noiseless analog control - no pulse width modulation.
- Illuminated viewing window with turbine wheel for the visualization of coolant flow and control of coolant condition
- Electronic monitoring of coolant flow, temperature, fill level and pump supply voltage. Dry run protection by dual coolant level detector.
- Pre-warning at 50°C (122°F) when normal operating temperature range is exceeded. Window illumination changes from blue to violet.
- Over temperature alarm output signal at 65°C (149°F). Window illumination changes from violet to red flashing.
- Alarm output by a passively closed relay contact (max. 170V, 0.5 A) and optionally by an additional optocoupler (option **EFSI**)
- Overpressure valve (0.5 bar / 7 psi). Fill port on top lid or alternatively on front side, if the **PU-2** is installed in 19" housings.
- Self cleaning filter with particle trap for particles > 500 µm (20 mil). Maintenance free at normal pollution.
- Useful reservoir volume approx. 400 ml (13.5 oz), air buffer volume (volume change compensation) approx. 100 ml (3.4 oz).
- Threated inserts, metric M5 on bottom, right side, rear side and front side for heatsink attachment. Matching M5 screws are included in supply.
- Housing billet aluminum, black anodized, block dimension 120x100x100 mm³ (HxWxD), net weight without coolant 1.95 kg (4.3 lb).
- Operating Temperature Range -25 to 65°C (-13 to 149 °F), Storage Temperature Range -50 to 100°C (-58 to 212 °F) with **Galden HT-135**.

Unpacking

Unpack the pump unit and make sure the set is complete. The set consists of:

- | | |
|---|--|
| 1x Pump unit PU-2. Options are marked on the left side of the unit. | 2x AMP-Modu socket for PCB's. One socket comes attached to the plug. |
| 1x Plastic front spacer. A metal spacer is available on request. | 16x Metric screws M 5 x 12. Longer screws are available on request. |
| 2x Cap nuts for tubing with 1 mm (0.04") wall diameter. | 1x Set of metric allen wrenches (US market only) |
| 2x Cap nuts for tubing with 1.5 mm (0.06") wall dia. (already installed). | |

Mechanical Installation

The pump unit must be installed in up-right position (fill port up). An angle of inclination of up to 45° is allowed for short time. A larger inclination requires the option **IIO** (Inclination independent operation). Whenever possible, the pump unit should not be installed below the devices to be cooled and also not below the radiator or heat exchanger, otherwise the filling port could overflow, when opened. The ideal pump position is always in the same level of the other cooling components or slightly above them. The **PU-2** can be inserted prior or after the radiator or heat exchanger, but it is often more advantageous to insert the pump unit after the radiator, since the average operating temperature of the pump is then decreased by approx. 5 to 20 Kelvin. The pump unit can simply be fixed through the holes in the plastic flange. A mechanical decoupling for vibration damping is normal not necessary, since the pump is nearly vibration free due to its heavy weight. If it is planned to utilize the milled pump housing as a heat transfer element in the cooling circle, (e.g. in combination with an externally attached heat-sink or in combination with a 19 inch system housing), then the plastic flange and / or the plastic front cover can be removed for lower thermal resistance. It is recommended to treat the relevant contact surfaces with silver compound grease for a better heat transfer. The pure pump housing without flange can be attached by metrical screws only. 16 metrical screws (5x12mm) are included in supply. Screws of any other length are available on request. Please consult BEHLKE.


Please Note: If the housing of the PU-2 is to be used as a heat transfer element, then the option **IHE** (internal heat exchanger) is highly recommended. The option **IHE** reduces the heat resistance between coolant and pump by approx. 70 to 80 %.

The tubing must have an inner diameter of 8 mm (0.32"). There are two sizes of cap nuts. The nuts with the smaller hole are for tubing with 1 mm (0.04") wall diameter and the nuts with bigger hole are for tubing with 1.5 mm (0.06") wall diameter. Any flexible or semi rigid plastic tubing can be used. Flexible PVC tubing is a very cost efficient material and very practical for laboratory purposes. PVC tubing is easy to bend and easy to push on the fittings. Unfortunately the plasticizers may be leached out by the fluorinated coolants and therefore the PVC hose may lose its flexibility over the years, especially at higher temperature. Therefore, it is recommended to re-tighten the nuts after a certain time of operation. Professional cooling systems with extreme demands on long-term reliability should only be realized with semi rigid tubing made of Polyethylene, Polyurethane or Teflon (PTFE / PFA). Those hoses have no plasticizers which can be leached and do not show any embrittlement even after many years. Only Teflon hoses may become a little bit softer over the years when in contact with fluorinated coolants. But this is usually acceptable. To avoid coolant losses by vaporization, the DLC cooling system must always be hermetically sealed. Please make sure, that all hoses are in good condition and that all nuts are well tightened in order to avoid any leakage. **A carefully sealed DLC cooling system is completely maintenance free and does not need refill with coolant even after many years of operational time.**

Electrical Installation

The standard pump unit has a 7 pole and the optional **EFSI** version has a 12 pole self latching AMP-Modu plug for the electrical connection. The device requires a regulated +12 VDC power supply. The current consumption at maximum pump power is approx. 1.8 Amps for the standard model and approx. 2.5 Amps for the model with option **30W**. Additional current is required if external radiator fans are connected. The +12 VDC supply is connected to pin 1 and 2 (2 wires in parallel connection for current sharing). External radiator fans are connected via pin 3. This output provides a maximum current of 3 Amperes. Pin 4 is the common return and ground for the **PU-2** unit and all externally connected radiator fans. Pin 5 and 6 are for the safety relay contact, which can be directly connected to the inhibit input of any BEHLKE high voltage switch. Pin 7 is used to turn-off the temperature depending speed controller for the pump and for the eventually connected radiator fans. All motors will run at full speed, if pin 7 is grounded. The optional **EFSI** features offer an extra optocoupler signal output, a customized temperature sensor and a digital signal from the flow sensor turbine. Please note, that the optocoupler output will not work if the PU-2 unit is not powered. Therefore the optional optocoupler output should not be used to protect BEHLKE switching modules via their inhibit input. Please refer to the table on the next page for the pin assignment.

Pin Assignment:

Standard devices: (7 pole plug)	1	Red	+12 VDC power supply	} internally linked	△ Both pins must be connected in parallel for a low terminal resistance. Note: The current rating for a single pin is 3 A.	
	2	Red	+12 VDC power supply			
	3	Yellow	+12 VDC output for ext. radiator fans (max. 3A)			① Output voltage is temperature depending (6...12 V)
	4	Black	Return / Ground			① Return of ext. radiator fans is also connected to pin 4
	5	Green	Safety relay contact	MEDER CRR05-1B max.170V / 0.5A / 10W		① The relay contact is passively closed in case of any fault or if the PU-2 pump unit is not powered with 12V.
	6	Green	Safety relay contact			
	7	Violet	Speed control off (pump and fan motor)			① Motors run at full speed if pin 7 is grounded
Option EFSI: (12 pole plug)	8	Orange	Opto coupler collector	EVERLIGHT EL817 max. 35V / 150 mW	① Open collector. A pull-up resistor (1-10 kΩ) is required. Output is L in case of fault. Not for protection purposes!	
	9	Orange	Opto coupler emitter			
	10	Green	Customized temperature sensor		① The temperature sensor is placed at the pump inlet. Sensor type must be specified by customer.	
	11	Green	Customized temperature sensor			
	12	Grey	Digital turbine flow signal (open collector)		① Calibration is available on request.	
All Models:		Housing	Earthing. Protection against uncontrolled ESD.		① Dielectrical fluids may cause electrostatic charges!	

Options List: internally linked

Option 30W	Pump power 30 Watt instead of 20 Watt	Option H-CF	Housing with cooling fins (in connection with option IHE)
Option IIO	Inclination independent operation	Option H-DIM	Housing dimensions according to customers requirements
Option IHE	Internal heat exchanger (for heat sink coupling)	Option EFSI	Extra features for system integration (see above)

First Time Use and Deaeration

- 1) Make sure that all tubings are connected and all cap nuts are properly tightened. Turn-on the 12 V power supply. The blue flashing illumination indicates, that the reservoir is empty. Open the screw cap on the top of the **PU-2** unit. Fill the coolant carefully in, preferably by means of a laboratory wash bottle or a little funnel. The reservoir should always be filled until overflow, also again after the pump motor has been startet. Please make sure, that the coolant is clean and that no larger particles can fall into the reservoir.
- 2) When the minimum fill level is reached (this is slightly above the viewing window), then the illumination turns from blue flashing to red. A few seconds later, the pump motor starts with full speed. The illumination turns then from red to blue. After short time the pump motor runs slower, since the motor speed is then temperature controlled. Do not stop the filling procedure while the pump is running. The air in the cooling circle must be replaced completely and therefore it is necessary to fill in the coolant continuously, always until overflow. If the deaeration process is faster than the refill of coolant, then the pump motor stops automatically and the blue flashing window illumination indicates an empty reservoir again. This means, that the reservoir has to be filled again until overflow.
- 3) The time of deaeration depends on the size of the switching modules and the size of radiators. To support the deaeration process, it is often helpful to turn off the automatic speed control by grounding pin 7. In some cases the deaeration can also be accelerated if the power supply is turned on and off for several times. Larger switching modules should also be rotated over all axes if they are deaerated the first time. The deaeration process can be monitored through the illuminated viewing window. After a certain time there should be no air bubbles visible anymore, especially not, if the power supply of the **PU-2** unit is turned on and off one time.
- 4) If the deaeration process is completed, please check the coolant level again. Refill until overflow, if necessary. Close the screw cap tightly. The cooling system works with light overpressure (up to 0.5 bar / 7 PSI) at max. operating temperature. Therefore the system must be always hermetically sealed, otherwise the coolant will vaporize over the time.

Note: Never use conductive or chemically aggressive substances as coolant. The pump unit can be damaged irreparably. The **PU-2** unit is designed for these non-conductive coolants: **GALDEN HT135 or HT170** (Solvay Solexis), **FC 3280** (3M), **HFE 7500** (3M)¹⁾ or silicone oil **AK-10** (WACKER).

Operation

After deaeration, the cooling system is ready for operation. When turned on, the pump and the fan motors start at full speed. A few seconds later, the motor speed is controlled by the coolant temperature. The speed is then regulated between 25°C (77°F) to 38°C (100°F) from the minimum to the maximum. This feature helps to increase the life time of the entire cooling system, especially if the full cooling power is not constantly needed. Please note, that the external fan motors will not be activated below 20 °C (68°F). The automatic speed control can be turned off by the grounding of pin 7. The deactivation of the automatic speed control allows a manual variation of the pump motor speed by adjusting the supply voltage between 7.5 and 12 VDC. Lower voltages than 7.5 VDC will release a safety stop. In the same time the blue illumination will flash and the safety relay contact will close. The optically scanned turbine wheel monitors the coolant flow. If the turbine stops to rotate, e.g. due to a broken or bended hose, then the window illumination turns from blue to red and the safety relay is released.

The normal operating temperature should not exceed 50°C (122°F), otherwise there is no safety margin at increased ambient temperatures. In case the normal temperature range is exceeded, the window illumination turns from blue to violet as a pre-warning for a possible overheating. The maximum operating temperature is 65°C (149°F). If that limit is reached, the window illumination is flashing red. Of course the safety relay will release then to protect the power electronics to be cooled. Please note, that all BEHLKE high voltage switches have an internal thermotrigger, which can shut down the switching module independently from the **PU-2** electronics. In the most cases the HV switch thermotrigger will release earlier. The bubbles which can be seen during operation do not indicate necessarily a possible leak. Those bubbles are formed by evaporation processes due to the temperature differences and are very normal. The coolant gas bubbles are normally condensing within the reservoir of the **PU-2** unit.

Safety

- △ Do not exceed the max. power density for PFPE, PFC & HFE coolants, which is 4W / cm² (26W / sq in), otherwise it can be chemically cracked and Hydrofluoric Acid can be generated. **DANGER: Hydrofluoric Acid is harmful!**
In case of fire or any overheat accident, do not touch the coolant or inhale the vapor if there is a **pungent odor!**
- △ Do not use conductive coolants such as water. The pump unit and the entire electronics to be cooled will be damaged! Conductive liquids must be completely removed from the cooling circle. **DANGER: High Voltage!**

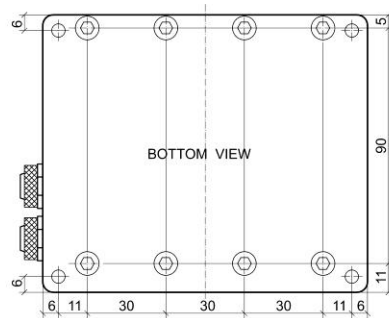
Trouble Shooting

Effect	Possible cause of trouble	Counter Measures
Pump motor does not start or starts only periodically. Illumination is blue flashing or changes periodically between blue and red.	1. Reservoir is empty or not full enough. 2. The system is not deaerated completely.	1. Refill coolant until overflow. 2. Connect pin 7 to ground and deaerate the system with full pump power.
Pump motor does not start. Reservoir is filled until overflow. Illumination is blue flashing.	Supply voltage is less than 7.5 VDC.	Check power supply voltage.
Pump motor starts only periodically. Reservoir is filled completely and supply voltage is $>7.5V$.	The power supply delivers not enough current due to a current limiter or poor wiring.	Check possible current limiters for false adjustment. Improve wiring if necessary.
Pump power is too low after an unwanted pollution.	Internal particle filter is dirty.	Reflush the PU-2 unit via the inlet.
External radiator fans does not run.	Coolant temperature is below 20°C (68°F).	None. Fans turn on if coolant warms up.
Cooling system is fully deaerated but in the viewing window is a heavy blistering visible.	The system is operated pressure-less. The bubbles result from vaporized coolant.	Close the fill port screw cap tightly and check the cooling circle for leakages.
Cooling system is fully deaerated and hermetically sealed but there is still a heavy blistering visible if the electronics to be cooled is operated under full load conditions. The system pressure does not return to zero after cooling down and turning off. There is a pungent odor when the screw cap is opened. DANGER: HF gas. Do not inhale the emitted vapor!	The power density in the electronics to be cooled is higher than 4 W / cm ² (26 W / sq in). If it is a BEHLKE switch, then the capacity of the internal DLC heat exchanger is exceeded significantly. The coolant is then chemically cracked and Hydrofluoric Acid respectively Hydrogen Fluoride Gas (HF) is produced.	Reduce the power input of the electronics to be cooled. Do not exceed the rated P _{d(max)} . Replace the cracked coolant by fresh one. DANGER: Hydrofluoric Acid and Hydrogen Fluoride Gas is harmful. In case of any accident with extreme over temperature do not touch the damaged coolants or inhale the HF gas!

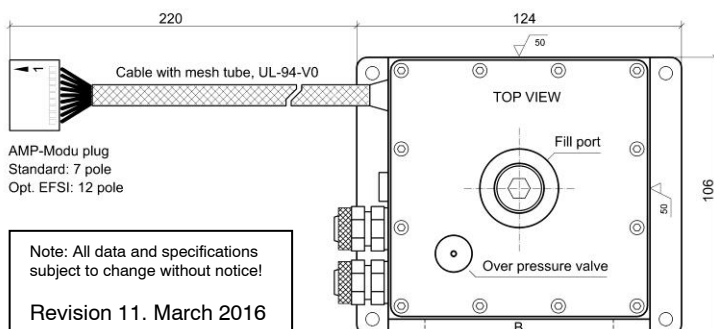
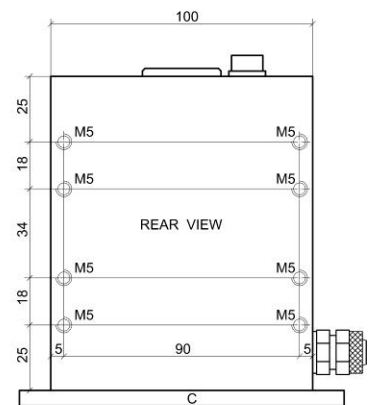
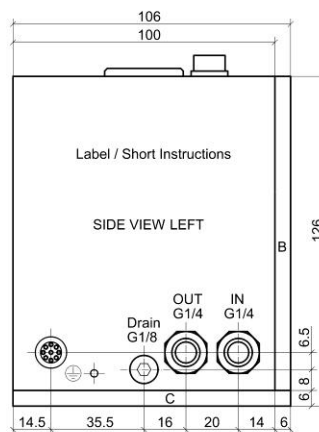
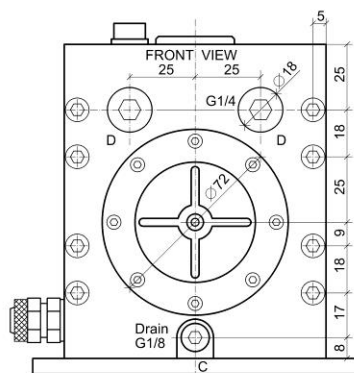
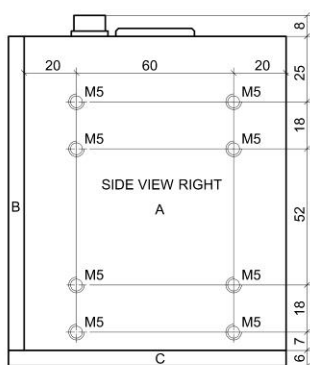
1) **Note:** PFPE, PFC and HFE coolants are all chemical inert, nonflammable and widely un toxic. The coolants differ only in some electrical properties and in the so-called Global Warming Potential (GWP). The advantage of the newly developed HFE coolants is their neglectable low GWP. But this must be relativated, since fluorinated liquids for professional heat transfer purposes are not really relevant for the global warming, because they are used only in extremely small quantities and only in hermetically sealed systems with almost no emission. On the other hand, the dielectrical constant for the classical PFPE's and PFC's is with $\epsilon_r \approx 2$ much better than that of the alternative HFE's ($\epsilon_r \approx 6$). A good dielectrical constant keeps the stray capacitances low and can save substantial amounts of electrical energy, especially in high-voltage high-frequency applications. This must be also taken into account, when the ecological balance is considered.

PU-2 Pump Unit

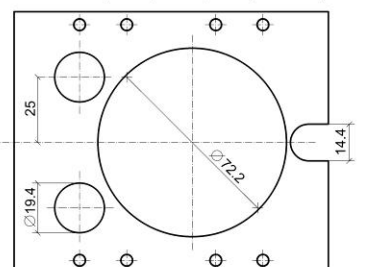
Shown with removeable plastic flange plate and plastic front cover plate



- A: Aluminum pump housing. Can be directly attached by metric M5 screws at the bottom side, front side, rear side and / or right side.
- B: Plastic front cover. Can be removed for a direct front side attachment. The front cover (h=6mm) can also be replaced by a spacer plate (part E, h=3mm) in order to align the viewing window (h=6mm) with the front panel (h=3mm) of a 19 inch system housing. Screw caps D must not be necessarily accessible through front panel.
- C: Plastic flange plate. Can be removed for a direct bottom attachment.
- D: G1/4 threads for alternative fill port and over pressure valve at front side.



Accessory E: Spacer plate (h=3mm)



All plastic part components are flame retardant according to UL-94-V0, except viewing window. Glass viewing windows are available on request.

All dimensions in mm
1 mm = 0.03937 inch

Note: All data and specifications subject to change without notice!

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