

1. Improvements to fluidic connections

Frequently detected failure modes of the pump were related to the fluidic connections. The N84 is a dual head pump, meaning that fluids are pump into the intake head, then transferred to the exhaust head, and eventually ejected.

The pumps arrived from KNF fitted with incompatible threads, as shown in **Figure S1** and S2. To preserve tightness despite the use of mismatched threads, KNF applies a sealant liquid that seals the gaps once it dries. Leaks due to degradation this sealant were detected in units in service as well in never used spare pumps. An additional point of failure is caused by using a male to female NPT extension to clear the pump body and bridge the offset between the heads.

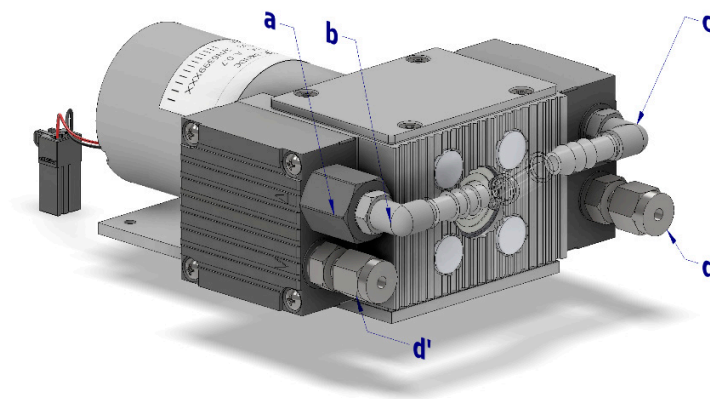


Figure S1: Pump as delivered from suppliers. (a) generic straight thread adapter male 1/8" NPT to female G 1/8" (BSPP), (b) elbow 6mm barbed to male R 1/8" (BSPT), Norma P/N 0730 8910 006, (c) 6mm barbed to male 1/8" NPT, Norma P/N 0730 8917 006, (d)&(d') are added by IBA with PTFE sealant tape, compression tube fitting 1/8" to male 1/8" NPT, Swagelok SS-200-1.

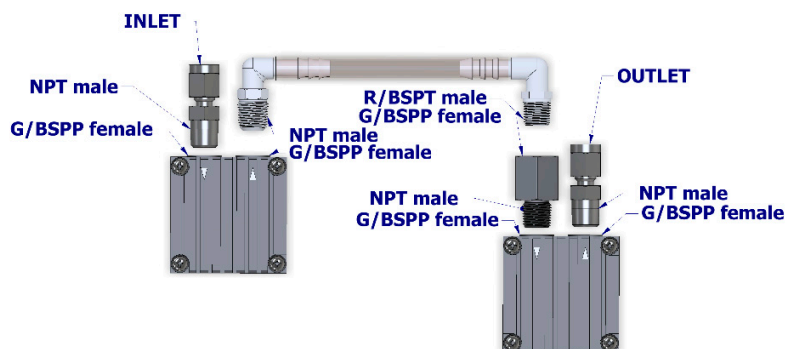


Figure S2: Exploded display using the supplied, incompatible fittings.

Whenever pumps are received or rebuilt, the fittings connecting both heads are replaced with fittings matching the threads of the holes as shown in Figures S3 and S4. The extension normally used on the intake

head was deemed unnecessary by using an extended type (Legris 3129 06 10) The exhaust fitting was the standard variant. (Legris 3129 06 10). The tube connecting both heads was also replaced with one with a larger internal diameter (ATP PU06MA-CB).

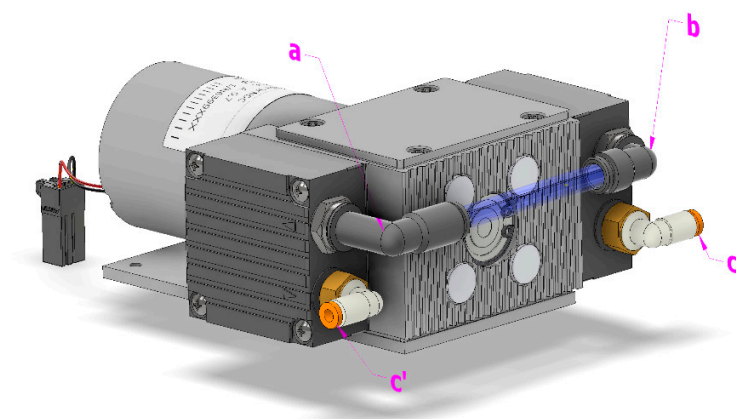


Figure S3: Model of a KNF KNDC85.3 pump featuring upgraded fittings: (a) push-in extended swiveling elbow, 6mm tube OD to 1/8 BSPP, Parker-Legris 3169 06 10, (b) push-in swiveling elbow, 6mm tube OD to 1/8 BSPP, Parker-Legris 3199 06 10 52, (c)&(c') push-in elbow, 1/8" tube OD to 1/8" BSP or NPT, SMC Pneumatics KQ2L01-U01A.

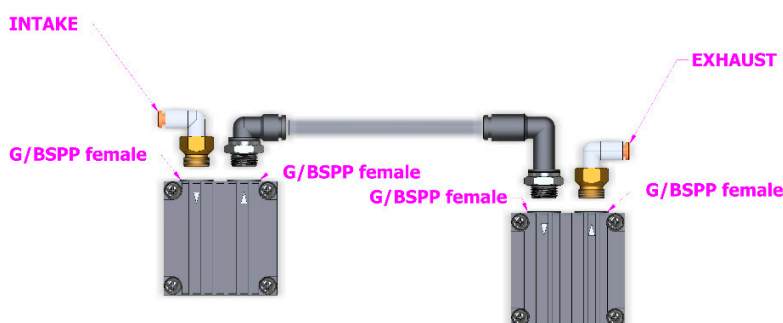


Figure S1: Exploded display using fittings with compatible threads.

The pumps purchased from IBA were also fitted with NPT fittings and sealant connecting its heads but added stainless steel 1/8" NPT to 1/8" Swagelok tube adapters. In this case the thread incompatibility was circumvented with the use of PTFE tape. This combination was difficult to install. Over tightening caused cracks on the pump head plate and the stainless-steel ferrule cut through the 1/8" OD plastic tubing. Intake and exhaust fittings were replaced with 1/8" push-in to 1/8" BSP or NPT elbows (SMC KQ2L01-U01A).

2. Enhanced pump purge procedure

KNF recommends flushing the pump with air or inert gas at atmospheric pressure for five minutes after each use to remove condensation.⁽³⁾ However, we found this method inefficient and implemented our own, that we named Superpurge.

An ideal pressure chart of a Superpurge is shown in **Figure S4**. It starts by establishing a pressure setpoint of 75 kPa maintaining at setpoint constant pumping of dry gas while the pump runs. Five minutes later, the setpoint briefly changes to 150 kPa four times to force liquids out of the pump. Next, once the module is pressurized to a pressure between 205 and 220 kPa, inert gas supply is interrupted, and a tightness test takes place for 10 seconds.

We wrote two versions of the script: one to be used with a bypass tube connecting the inert gas and vacuum LUER connectors on the front of the Synthera®, and another one to be used immediately after a synthesis without having to open the hotcell, with the Integrated Fluidic Processor (IFP™, i.e. radiochemistry cassette) still in place.

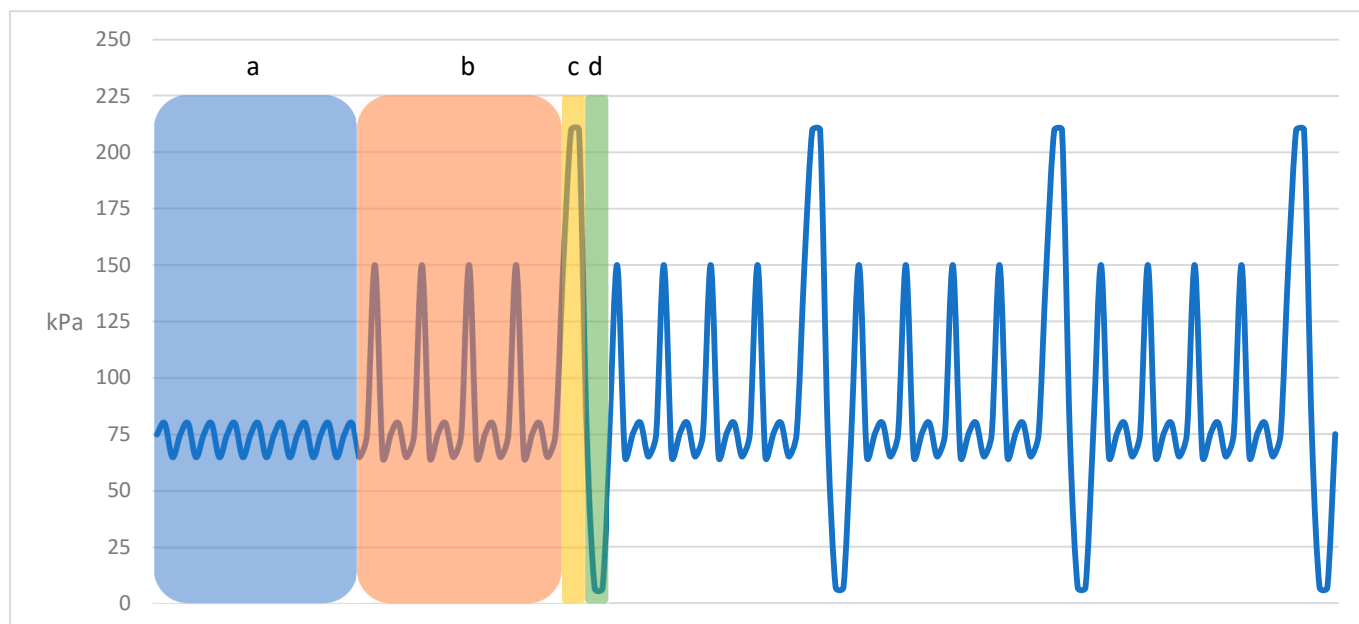


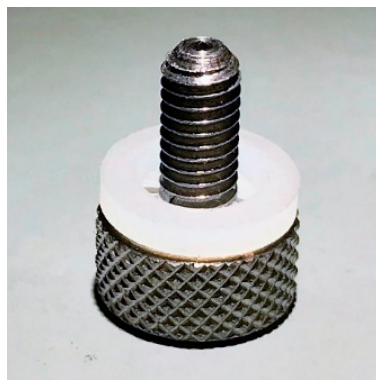
Figure S4: Ideal Superpurge pressure chart. **(a)** Five-minute purge at 75 kPa, **(b)** four short bursts to eject condensate, **(c)** pressure test at 220 kPa , **(d)** vacuum test at 7 to 4 kPa.

3. Reducing Mean Time To Repair (MTTR)

Several modifications were introduced with the goal of shortening the length of time required to remove a defective pump and install a replacement unit. Shorter repair times reduce Synthera® down-time and radiation exposure to the maintenance staff. The following modifications make it possible to exchange the module's vacuum pump without tools.

Shell Removal

Accessing the pump requires removing an external shell held in place by eight Phillips head screws on both sides of the module. These screws are hard to reach if the hotcell is crowded with other instruments, requiring the use of stubby screwdrivers, or ratcheting tools. To ease and speed up repairs, stock fasteners were replaced as shown in **Error! Reference source not found.** Low profile knurled-head thumb screws (McMaster-Carr, 92545A143) and nylon washers (McMaster-Carr, 91755A21). Washers help center the screws in the countersink through the hole of the external shell and protect its paint finish. The washers are self-retaining, meaning that three small prongs keep it conveniently attached to the screw.



(a)



(b)

Figure S5: Example of the fastener modification. (a) thumbscrew and nylon self-retaining washer. (b) Assembled fastener with the nylon washer protecting the paint.

Pump Removal Improvements

The four socket head screws and vibration dampening grommets securing the pump to the base of Synthera® and grommets were also upgraded. The pump was originally attached with socket head screws going through vibration dampers measuring 5.30 mm in height (Keystone 772). This configuration was upgraded by replacing the socket head with knurled-head captive thumb screws, springs and retaining rings (McMaster-Carr 95536A357, 94125K472, and 91065A810, respectively). Vibration dampening grommets were replaced with thicker ones, measuring 7.11 mm in height (McMaster, 9311K64). On top of reducing the pump replacement time and radioactive exposure of service personnel, Synthera® users welcomed the noise reduction, which has the added benefit of making abnormal noises more noticeable.

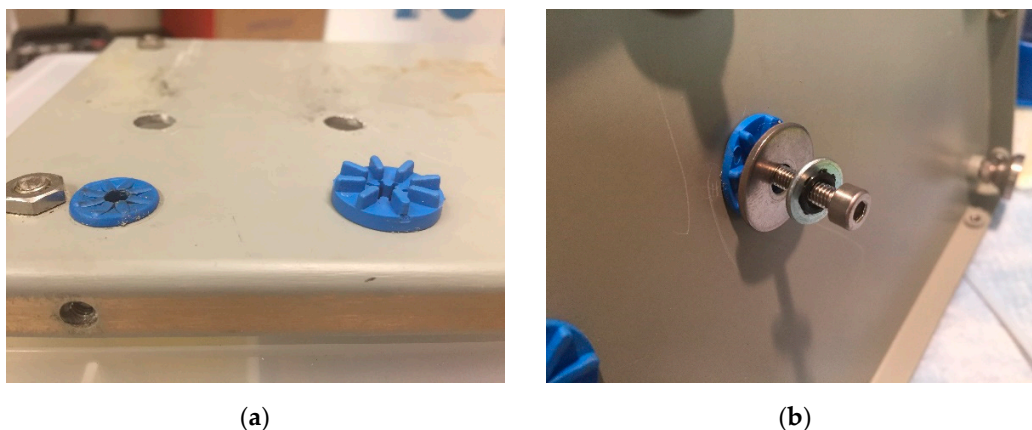


Figure S6: Upgraded pump fasteners. **(a)** comparison between short, worn out dampers on the left and new, thicker ones on the right. **(b)** complete assembly of a revamped pump mount.

4. Tracking Mean Time Between Failure (MTBF)

An inductive hour meter (EMN Company Model MT10105) was added to record how long the pumps run before they need to be replaced. The meter's probe is attached to the pump motor with adhesive tape and the readout is affixed to the back panel of Synthera® with hook-and-loop tape. A notch was cut on the rear panel to feed the cable connecting probe and readout. The running hours are recorded monthly and when the pump is replaced, and it is reset when a new pump is installed.

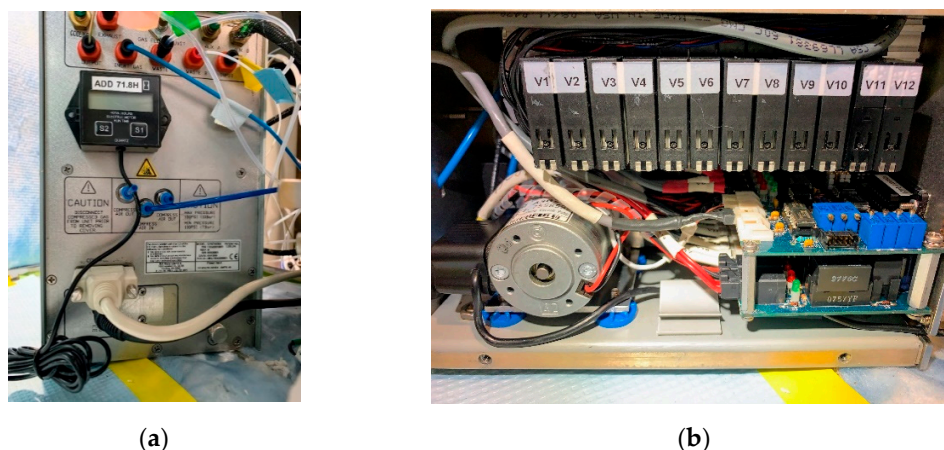


Figure S7: Hour meter installation. **(a)** hour meter mounted on the rear panel of a Synthera® module. **(b)** Inductive sensor mounted on the electric motor of the pump, wire routing and rear panel notch.

Since installing the hour meters, five pumps have been replaced. The average working time was 104 hours. Since our modules are used for research purposes, it is difficult to determine a service interval base of this data. However, laboratories doing routine work could use this approach to schedule pump replacement in anticipation of a drop in performance.

5. Bill Of Materials

TYPE	DESCRIPTION	VENDOR	PART NUMBER	QTY
ENCLOSURE	240mm Aluminum T-Slotted Framing Extrusion Rail, Single Profile, 20mm Size, Solid	McMaster-Carr	5537T9	12
	120mm Aluminum T-Slotted Framing Extrusion Rail, Single Profile, 20mm Size, Solid	McMaster-Carr	5537T9	6
	3-Way Corner Bracket for 20 mm High Single Rail	McMaster-Carr	5537T289	8
	Outside Corner Bracket for 20 mm High Single Rail	McMaster-Carr	5537T286	4
	Heavy Duty Hinge for 20mm High Single Profile Aluminum T-Slotted Framing Extrusion	McMaster-Carr	5537T859	2
	Swivel Leveling Mount, Nickel-Plated Steel with 2" Long 10-32 Threaded Stud	McMaster-Carr	6111K45	4
	T-slotted Silver Surface Bracket, 1-1/2" Long for 20 mm High Rail	McMaster-Carr	5537T944	5
	18-8 Stainless Steel Hex Drive Flat Head Screw, M4 x 0.7 mm Thread, 12 mm Long	McMaster-Carr	92125A192	9
	18-8 Stainless Steel Cap Nut, M4 x 0.7 mm Thread	McMaster-Carr	94000A035	3
	Spring-Loaded Ball Fastener, M5 Thread Size for Aluminum T-Slotted Framing Extrusion	McMaster-Carr	5537T75	8
	Turn-to-Open Draw Latch, Stainless Steel, Nonlocking, 3/4" Latch Distance	McMaster-Carr	1406A46	1
	Impact-Resistant Polycarbonate Sheet, 24" x 24" x 1/8"	McMaster-Carr	8574K193	1
	Clear Impact-Resistant Polycarbonate, 12" x 12" x 1/16" Sheet	McMaster-Carr	8574K24	1
	Tie Cable Holder for 20 mm High Single Rail T-Slotted Framing	McMaster-Carr	5537T356	1
	Thumb-Screw-Head Captive Panel Screw, M4 x 0.7mm Thread Size, 22mm Long	McMaster-Carr	95536A357	4
	Vibration Damping Grommets, Ribbed, 0.17" Hole Diameter, 0.39" Overall Thickness	McMaster-Carr	9311K62	4
	Retainers for M4 x 0.7mm Thread Size Captive Panel Screws	McMaster-Carr	91065A850	4
	Compression Springs, Corrosion Resistant, 9.5 mm Long	McMaster-Carr	94125K472	4
	Spring Clip Holder for 7/8" to 1.25" Item Diameter, Nylon-Coated Steel	McMaster-Carr	1722A32	1
	Fastener Caps, Hinged, for 1/4" Thread Diameter - White	McMaster-Carr	91620A300	2
	Gas Spring, Miniature, stroke: 3.54in, compression force: 6lbs	McMaster-Carr	9417K6	1
	Heavy Duty 0.16" ID Eyelet Mounting Bracket for Gas Spring	McMaster-Carr	9417K92	1
	Nylon Plastic Washer for M3 Screw Size, 3.2 mm ID, 8 mm OD, Off-White	McMaster-Carr	95610A130	4

	Plastic Narrow Cheese Head Slotted Screws Off-White Plastic, M3 X 0.5 mm Thread, 6 mm Long	McMaster-Carr	95280A116	12
	Nylon 6/6 Male-Female Threaded Hex Standoff, 4.5mm Hex, 10mm Long, M3 x 0.50 mm Thread	McMaster-Carr	95783A057	12
FLUIDIC CONNECTIONS	Elbow 1/8" push-in to male #10-32	Clippard Minimatic	PQ-ME04N	3
	Brass Pipe Fitting with Sealant, Plug with Hex Drive, 1/8 NPT	McMaster-Carr	50785K918	2
	EV, ET, EC Series Accessories - Multi-Valve Manifold - 2 Stations	Clippard Minimatic	15481-2	2
	2-Way Normally-Closed Valves, Manifold Mount - Standard - Terminal Spades - Vac. to 105 psig+ - 24 VDC	Clippard Minimatic	ET-2M-24	4
	Flow Control Valve, Meter Out from #10-32 Male Thread to 1/8" OD Tubing	Clippard Minimatic	PQ-CV04N	1
	30 PSI Fixed-Pressure Compressed Air Regulator, Zinc Housing 300 Maximum PSI, 1/8 NPT Female	Parker	14R011FCL030	1
	Mounting Bracket Kit for Parker 10F, 14F, P3AR, 14R, 14E and 15R Series Filter/Regulator	Parker	PS417BP	1
	Push-to-Connect Tube Fitting for Air, Thru-Wall 90 Degree Elbow Connector, for 1/8" Tube OD	McMaster-Carr	5779K275	1
	Identification Ring for 1/8" Tube OD Push-to-Connect Tube Fitting for Air - Green	McMaster-Carr	5779K791	1
	Identification Ring for 1/8" Tube OD Push-to-Connect Tube Fitting for Air - Red	McMaster-Carr	5779K791	1
	Muffler, 1/8 NPT Male, Copper, 18 scfm @ 100 PSI Flow Rate	McMaster-Carr	4450K17	1
	Push-to-Connect Tube Fitting for Air, Long 90 Degree Elbow, for 1/8" Tube OD x 1/8 NPT Male	McMaster-Carr	5779K148	2
	Push-to-Connect Tube Fitting for Air, Thru-Wall Adapter, for 1/8" Tube OD x 1/8 NPT Female	McMaster-Carr	5779K267	1
	Push-to-Connect Tube Fitting for Air, Through-Wall Connector for 1/8" Tube OD	McMaster-Carr	5779K675	1
	Push-to-Connect Tube Fitting for Air, Inline Tee Adapter, for 1/8" Tube OD x 1/8 NPT Female	McMaster-Carr	5779K226	1
	Push-to-Connect Tube Fitting for Air, Wye Connector, for 1/8" Tube OD	McMaster-Carr	5779K41	1
	Firm Polyurethane Tubing for Air and Water, 1/16" ID, 1/8" OD, Clear	McMaster-Carr	5648K67	1
	Firm Polyurethane Tubing for Air and Water, 1/16" ID, 1/8" OD, Clear Green	McMaster-Carr	5648K67	1

ELECTRONICS AND POWER DISTRIBUTION	Power Supply Dual Voltage DC 24V/12V	CUI	VF-D250-D1224A-CF	1
	50 psi absolute pressure range, cable connection	Omega	PX309-050A5V	1
	Arduino MEGA 2560 Rev3	Arduino	A000067	1
	Mega protoshield for Arduino	Adafruit	192	1
	8 Channel DC 5V Relay Module	Sainsmart	20-018-102-CMS	1
	power entry module without fuse IEC320-C14	Schurter Inc.	DC11.0031.001	1
	terminal block 4pos/2cir blue miniDIN	Phoenix Contact	3000926	3
	miniDIN rail 15x5.5mm	Weidmuller	117510000	1
	terminal block 4pos/2cir grey miniDIN	Phoenix Contact	1414129	5
	terminal block fixed bridge 10 positions	Phoenix Contact	3001608	1
	terminal block end cover for 4pos grey miniDIN	Phoenix Contact	3002665	1
	terminal block 2pos/1cir grey miniDIN	Phoenix Contact	3100305	1
	Pushbutton Switch SPST-NO Anti-Vandal, Illuminated Panel Mount, Front	E-Switch	PV0H240SS-331	5
	LCD i2c alphanumeric 16x2 grey on white	Matrix Orbital	LK-162-12-GW	1
	Illuminated Toggle Switch DPDT Panel Mount - AMBER	NKK switches	TL22SDAG015D	1
	Illuminated Toggle Switch DPDT Panel Mount - AMBER	NKK switches	TL22SNAG016G	1
	USB 2.0 B Female Socket Printer Panel Mount to Right angle USB 2.0 Type-B Male Adapter Cable	Amazon	B01LRZ8GK2	1
	Rectangular Connectors - Housings Plug Black 0.098" (2.50mm), X-key, 3 positions, panel mount	TE Connectivity	1-1318116-3	1
	Connector Housing, 16 positions Black 0.100" (2.54mm)	TE Connectivity	102387-3	1
	Connector Header Through Hole 16 position 0.100" (2.54mm)	TE Connectivity	5104338-3	1