

Operating Instructions

Rxn-45 Raman spectroscopic probe



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1 General notes

1.1 Warnings

Structure of Information	Meaning
<p>⚠ WARNING</p> <p>Causes (/consequences) Consequences of noncompliance (if applicable) ▶ Corrective action</p>	This symbol alerts you to a dangerous situation. Failure to avoid the dangerous situation can result in a fatal or serious injury.
<p>⚠ CAUTION</p> <p>Causes (/consequences) Consequences of noncompliance (if applicable) ▶ Corrective action</p>	This symbol alerts you to a dangerous situation. Failure to avoid this situation can result in minor or more serious injuries.
<p>ℹ NOTICE</p> <p>Cause/situation Consequences of noncompliance (if applicable) ▶ Action/note</p>	This symbol alerts you to situations which may result in damage to property.

1.2 Symbols on the device

Symbol	Description
	The Laser Radiation symbol is used to alert the user to the danger of exposure to hazardous visible laser radiation when using the system.
	The High Voltage symbol that alerts people to the presence of electric potential large enough to cause injury or damage. In certain industries, high voltage refers to voltage above a certain threshold. Equipment and conductors that carry high voltage warrant special safety requirements and procedures.
	The WEEE symbol indicates that the product should not be discarded as unsorted waste but must be sent to separate collection facilities for recovery and recycling.
	The CE Marking indicates conformity with health, safety, and environmental protection standards for products sold within the European Economic Area (EEA).

1.3 U.S. export compliance

The policy of Endress+Hauser is strict compliance with U.S. export control laws as detailed in the website of the [Bureau of Industry and Security](#) at the U.S. Department of Commerce.

1.4 Glossary

Term	Description
ANSI	American National Standards Institute
°C	Celsius
CDRH	Center for Devices and Radiological Health
CIP	clean-in-place
CFR	Code of Federal Regulations
cGMP	current good manufacturing practices
cm	centimeter
CSA	Canadian Standards Association
EO	electro-optical
°F	Fahrenheit
ft	feet
FWHM	full width at half maximum
HCA	Raman Calibration Accessory
IEC	International Electrotechnical Commission
in	inches
kg	kilogram
m	meter
μin	microinches
μm	micrometer
mm	millimeter
MPE	maximum permissible exposure
mW	milliwatt
nm	nanometer
psi	pounds per square inch
SIP	steam-in-place
WEEE	Waste Electrical and Electronic Equipment

2 Basic safety instructions

2.1 Requirements for personnel

- Installation, commissioning, operation, and maintenance of the measuring system may be carried out only by specially trained technical personnel.
- The technical personnel must be authorized by the plant operator to carry out the specified activities.
- The technical personnel must have read and understood these Operating Instructions and must follow the instructions contained herein.
- The facility must designate a laser safety officer who ensures staff are trained on all Class 3B laser operating and safety procedures.
- Faults at the measuring point may only be rectified by properly authorized and trained personnel. Repairs not described in this document must be carried out only directly at the manufacturer's site or by the service organization.

2.2 Designated use

The Rxn-45 Raman spectroscopic probe is designed for the needs of bioprocessing pilot and manufacturing sites.

Recommended applications include:

- **Cell culture:** glucose, lactate, amino acids, cell density, titer, and more
- **Fermentation:** glucose, glycerol, acetate, methanol, ethanol, biomass, and more

Use of the device for any purpose other than that described, poses a threat to the safety of people and of the entire measuring system and invalidates any warranty.

2.3 Workplace safety

As the user, you are responsible for complying with the following safety conditions:

- Installation guidelines
- Local standards and regulations for electromagnetic compatibility

The product has been tested for electromagnetic compatibility in accordance with the applicable international standards for industrial applications.

The electromagnetic compatibility indicated applies only to a product that has been properly connected to the analyzer.

2.4 Operational safety

Before commissioning the entire measuring point:

1. Verify that all connections are correct.
2. Ensure that electro-optical cables are undamaged.
3. Ensure fluid level is sufficient for probe/optics immersion (if applicable).
4. Do not operate damaged products, and protect them against unintentional operation.
5. Label damaged products as defective.

During operation:

1. If faults cannot be rectified, products must be taken out of service and protected against unintentional operation.
2. When working with laser devices, always follow all local laser safety protocols which may include the use of personal protective equipment and limiting device access to authorized users.

2.5 Laser safety

The Raman Rxn analyzers use Class 3B lasers as defined in the following:

- [American National Standards Institute](#) (ANSI) Z136.1, American National Standard for Safe Use of Lasers
- [International Electrotechnical Commission](#) (IEC) 60825-1, Safety of Laser Products – Part 1

WARNING

Laser radiation

- ▶ Avoid exposure to beam
- ▶ Class 3B laser product

CAUTION

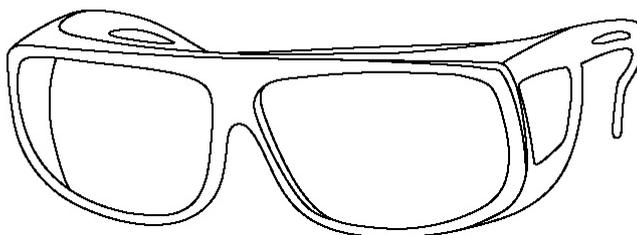
Laser beams can cause ignition of certain substances such as volatile organic compounds.

The two possible mechanisms for ignition are direct heating of the sample to a point causing ignition and the heating of a contaminant (such as dusts) to a critical point leading to ignition of the sample.

The laser configuration presents further safety concerns because the radiation is nearly invisible. Always be aware of the initial direction and possible scattering paths of the laser.

For 532 nm and 785 nm excitation wavelengths, use laser safety glasses with OD3 or greater.

For 993 nm excitation wavelength, use laser safety glasses with OD4 or greater.



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Figure 1. Laser safety glasses

For more assistance with taking appropriate precautions and setting the proper controls when dealing with lasers and their hazards, refer to the most current version of ANSI Z136.1 or IEC 60825-14. See *Function and system design* →  for relevant parameters to calculate maximum permissible exposure (MPE) and nominal ocular hazard distance (NOHD).

2.6 Service safety

Follow your company's safety instructions when removing a process probe from the process interface for service. Always wear proper protective equipment when servicing the equipment.

2.7 Important safeguards

- Do not use the Rxn-45 probe for anything other than its intended use.
- Do not look directly into the laser beam.
- Do not point the laser at a mirrored/shiny surface or a surface that may cause diffuse reflections. The reflected beam is as harmful as the direct beam.
- Do not leave attached and unused probes uncapped or unblocked.
- Always use a laser beam block to avoid inadvertent scatter of laser radiation.

2.8 Product safety

This product is designed to meet all current safety requirements, has been tested, and shipped from the factory in a safe operating condition. The relevant regulations and international standards have been observed. Devices connected to an analyzer must also comply with the applicable analyzer safety standards.

Endress+Hauser Raman spectroscopy systems incorporate the following safety features to conform to the United States Government requirements 21 [Code of Federal Regulations](#) (CFR) Chapter 1, Subchapter J as administered by the [Center for Devices and Radiological Health](#) (CDRH) and IEC-60825-1 as administered by the [International Electrotechnical Commission](#).

2.8.1 CDRH and IEC compliance

Endress+Hauser Raman analyzers are certified by Endress+Hauser to meet CDRH requirements, as well as IEC 60825-1 safety standards for international use.

Endress+Hauser Raman analyzers have been registered with the CDRH. Any unauthorized modifications to an existing Raman Rxn analyzer or accessory may result in hazardous radiation exposure. Such modifications may result in the system being no longer in conformance with Federal requirements as certified by Endress+Hauser.

2.8.2 Laser safety interlock

The Rxn-45 probe, as installed, forms part of the interlock circuit. The interlock circuit is a low-current electrical loop. If the fiber cable is severed, the laser will turn off within milliseconds of the breakage.

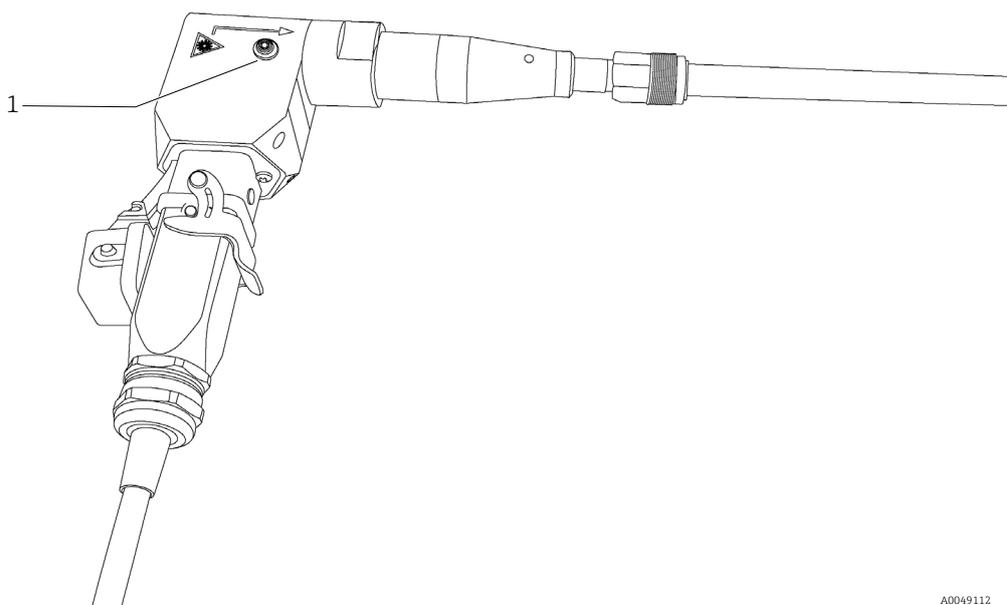
NOTICE

Permanent damage may result if cables are not routed appropriately.

- ▶ Handle probes and cables with care, ensuring they are not kinked.
- ▶ Install fiber cables with a minimum bend radius according to the *Raman fiber-optic cable Technical Information (TI01641C)*.

The electro-optical (EO) fiber cable with its embedded interlock loop must be plugged into the back of the Raman Rxn analyzer for the appropriate channel. The interlock loop is complete when the probe side of the EO fiber cable is plugged into the Rxn-45 probe.

When there is potential for the laser to be energized, the laser interlock indicator light on the probe body is illuminated.



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Figure 2. Location of laser interlock indicator light (1)

3 Phase of product lifecycle

3.1 Documentation

All documentation is available:

- On the Endress+Hauser mobile app: www.endress.com/supporting-tools
- In the Downloads area of the Endress+Hauser website: www.endress.com/downloads

This document is an integral part of the document package, which includes:

Part number	Document Type	Document Title
KA01549C	Brief Operating Instructions	Rxn-45 Raman spectroscopic probe Brief Operating Instructions
TI01633C	Technical Information	Rxn-45 Raman spectroscopic probe Technical Information
BA02173C	Operating Instructions	Raman calibration accessory Operating Instructions

3.2 Incoming acceptance

3.2.1 Notes on incoming acceptance

1. Verify that the packaging is undamaged. Notify the supplier of any damage to the packaging. Keep the damaged packaging until the issue has been resolved.
2. Verify that the contents are undamaged. Notify the supplier of any damage to the delivery contents. Keep the damaged goods until the issue has been resolved.
3. Check that the delivery is complete and nothing is missing. Compare the shipping documents with your order.
4. Pack the product for storage and transportation in such a way that it is protected against impact and moisture. The original packaging offers the best protection. Make sure to comply with the permitted ambient conditions.

If you have any questions, please contact your supplier or your local sales center.

NOTICE

Probe may be damaged during transport if packaged inadequately.

3.2.2 Product identification

3.2.2.1 Label

At a minimum, the probe/tag is labeled with the following information:

- Endress+Hauser branding
- Product identification (e.g., Rxn-45)
- Serial number

Where size allows, the following information is also included:

- Extended order code
- Manufacturer information
- Key functional aspects of the probe (e.g., material, wavelength, focal depth)
- Safety warnings and certification information, as applicable

Compare the information on the label and tag with the order.

3.2.2.2 Manufacturer address

Endress+Hauser
371 Parkland Plaza
Ann Arbor, MI 48103 USA

3.2.3 Scope of delivery

The scope of delivery comprises:

- Rxn-45 probe in the configuration ordered
- *Rxn-45 Raman spectroscopic probe Operating Instructions* manual
- Certificate of Product Performance
- Local declarations of conformity, if applicable
- Rxn-45 probe optional accessories, if applicable
- Material certificates, if applicable

If you have any questions, please contact your supplier or local sales center.

3.3 Assembly

3.3.1 Installation

During installation, standard eye and skin safety precautions for Class 3B laser products (as per EN 60825/IEC 60825-14) should be observed. Additionally, observe the following:

⚠ WARNING	Standard precautions for laser products should be observed. ▶ Probes should always be capped or pointed away from people toward a diffuse target if not installed in a sample chamber.
⚠ CAUTION	If stray light is allowed to enter an unused probe, it will interfere with data collected from a used probe and may cause calibration failure or measurement errors. ▶ Unused probes should ALWAYS be capped to prevent stray light from entering the probe.
NOTICE	When installing the probe head <i>in situ</i>, the user must ensure that there is strain relief at the installation location which complies with fiber bend radius specifications.

3.3.1.1 Installation process

NOTICE

When installing the probe *in situ*, the user must provide the strain relief to the fiber-optic cable at the probe installation location.

To install an Rxn-45 probe, follow the steps below. Refer to the figure below to disconnect and reconnect the fiber-optic cable from the probe.

1. If the Rxn-45 probe is currently attached to a Raman Rxn analyzer, use the laser key on the front of the base unit to turn the laser OFF or power down the analyzer prior to probe installation.
2. Disconnect the fiber-optic cable from the Rxn-45 probe.
 - Unlatch the connector clip. **(A)**
 - Grasp the gray part of the EO connector and, with your other hand, pull straight down to disconnect the fiber-optic cable. **(B)**
3. Screw the appropriate adapter onto the Rxn-45 probe and secure in place using the PG13.5 thread process connector.
4. Insert the Rxn-45 probe into a side-port on the vessel.
5. Screw the adapter that is now attached to the Rxn-45 probe into a side-port on the vessel such that the fiber connector interface remains facing downward.
6. Reconnect the fiber-optic cable to the Rxn-45 probe.
 - Open the spring-loaded fiber connector cap at the base of the Rxn-45 probe. **(C)**
 - Insert the fiber cable EO connector into the base of the probe and push up until secure.
 - Re-latch the connector clip.
7. When ready to use the analyzer and probe, power ON the laser or analyzer.

8. After a minute, verify that the laser interlock indicator on the probe is illuminated.

The Rxn-45 probe is now ready for CIP/SIP using standard bio-process water or steam cleaning processes prior to vessel filling.

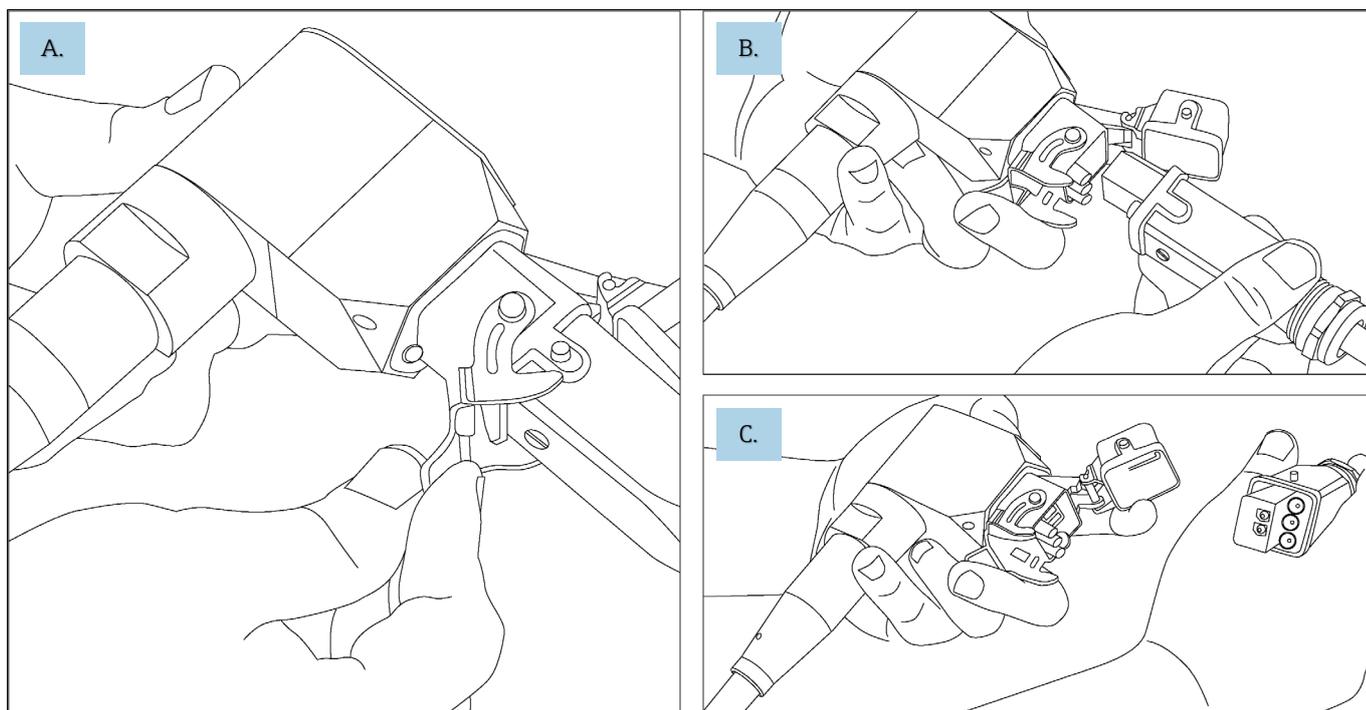


Figure 3. Disconnecting and reconnecting the fiber-optic cable

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3.4 Commissioning

The Rxn-45 probe is delivered ready to connect to the Raman Rxn analyzer. No additional alignment or adjustment to the probe is required. Follow the instructions below to commission the probe for use.

3.4.1 Receipt of probe

Perform the steps for incoming product acceptance described in *Notes on incoming acceptance* → .

3.4.2 Probe calibration and verification

The probe and the analyzer must be calibrated before use. Refer to the applicable Raman Rxn2 or Raman Rxn4 analyzer Operating Instructions for further information on internal instrument calibration.

An intensity calibration must be performed before collecting measurements and after changing optics. Use the Raman calibration accessory (HCA) with an appropriate optic adapter to perform the probe calibration. All accessory information and calibration instructions can be found in the *Raman calibration accessory Operating Instructions (BA02173C)*.

The Raman RunTime software will not allow spectra to be collected without passing internal system calibrations.

After calibration, perform Raman RunTime channel verification using a Raman shift standard. Verification of the calibration results is recommended, but not required. Instructions on verification with Raman shift standards can also be found in the Calibration accessory Operating Instructions.

The recommended calibration and qualification sequence follows this order:

1. Internal analyzer calibration for spectrograph and laser wavelength
2. System intensity calibration using appropriate calibration accessory
3. System function verification using appropriate standard material

Contact your sales associate for specific questions related to your probe, optic, and sampling system.

3.5 Operation

The Endress+Hauser Rxn-45 probe is a compact probe designed for the needs of bioprocessing pilot and manufacturing sites. The probe is compatible with Endress+Hauser Raman Rxn analyzers operating at 785 nm and 993 nm.

CAUTION

Do NOT use the Rxn-45 probe with hydrocarbon solvents, including ketones and aromatics.

These solvents can damage the window material, degrade probe performance, and invalidate the warranty.

Refer to the applicable Raman Rxn analyzer Operating Instructions for additional instructions for use.

3.6 Diagnostics and troubleshooting

Refer to the table below when troubleshooting issues with the Rxn-45 probe. If the probe is damaged, isolate the probe from the process and turn off the laser prior to evaluation. Contact your service representative as needed for assistance.

Symptom		Possible cause	Action
1	Substantial reduction in signal or signal-to-noise ratio	Window fouling	<ol style="list-style-type: none"> Carefully remove probe from the process, decontaminate, and inspect optical window at tip of probe. If necessary, clean the window before returning it to service. Refer to <i>Cleaning the probe window</i> → .
		Cracked but intact fiber	Verify condition of fiber and contact your service representative for replacement.
2	Complete loss of signal while laser is powered and laser interlock indicator is lit	Broken fiber without interlock wire breakage	Ensure all fiber connections are secure. Verify condition of fiber and contact your service representative for replacement.
3	Laser interlock indicator on probe is not lit	Damaged fiber assembly	Look for signs of breakage in fiber. Contact your service representative for replacement.
		Fiber cable EO connector not secured/latched	Ensure EO connector is properly connected and latched to the probe (if applicable) and to the analyzer.
		Remote interlock connector disconnected	Ensure the twist-lock remote interlock connector at the rear of analyzer (next to fiber EO connector) is connected.
4	Unstable signal and contamination visible behind window	Window seal failure	<ol style="list-style-type: none"> Examine the area inside the window for moisture or condensation. Examine the probe for fluid penetration or signs of sample fluid in the probe body (e.g., corrosion, residue). Look for any sign of spectral deviation. If any of the above are noted, contact your service representative to return the probe to the manufacturer.
5	Decreased laser power or collection efficiency	Contaminated fiber connection	Carefully clean the fiber ends at the probe. Refer to the applicable Raman Rxn analyzer Operating Instructions for cleaning instructions and steps for starting up a new probe.
6	Laser interlock on analyzer causes laser to shut down	Laser interlock activated	Check for fiber breakage on all connected fiber-optic cable channels and ensure remote interlock connectors are in place on each channel.
7	Unrecognized bands or patterns in the spectra	Cracked but intact fiber	Verify possible causes and contact your service representative to return the damaged product.
		Contaminated probe tip	

8	Other unexplained negative performance of the probe	Physical damage to probe	Contact your service representative to return the damaged product.
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3.7 Maintenance

3.7.1 Cleaning the Rxn-45 probe *in situ*

There are two aspects to cleaning an installed Rxn-45 probe:

- Cleaning the wetted parts
- Cleaning the non-wetted parts

3.7.1.1 *Cleaning the wetted probe parts*

No special precautions are required to clean the wetted parts of the Rxn-45 probe. The probe may be cleaned in place using bio-processing industry standard SIP and CIP processes.

The Rxn-45 probe is rated for 50 SIP/CIP cycles. After that, the probe must be returned for service. Contact your local Endress+Hauser service provider for additional information

3.7.1.2 *Cleaning the non-wetted probe parts*

To clean the non-wetted parts of the Rxn-45 probe (the components exterior to the bioreactor or fermentor), follow the steps below.

1. Blow off the surface with clean compressed air to remove any loose particles.
2. Wipe the surface using a **lightly** dampened wipe or cloth.
3. Wipe the surface dry with a dry wipe or cloth.
4. Blow with clean compressed air to remove any wipe or cloth remnants.
5. Repeat the previous steps as necessary.

For service other than surface cleaning, return the Rxn-45 probe to the manufacturer or service organization.

3.7.2 Cleaning the probe window

This process is performed when the Rxn-45 probe is removed from the vessel. Note the following:

- The probe should be cleaned after immersion in phosphate buffer solutions to avoid particle deposit contamination.
- Extra care must be taken to ensure that the window surface is not further contaminated during the cleaning process.
- If the window is damaged, discontinue probe use and contact your local Endress+Hauser service provider for additional information.

To clean the probe window:

1. Ensure that the laser is turned **OFF** or the probe is disconnected from the analyzer.
2. Blow off the surface with clean compressed air to remove any loose particles.
3. Wipe the surface using a swab **lightly** dampened with a solvent appropriate for the substance to be cleaned.
 - Do not clean the Rxn-45 probe window with hydrocarbon solvents (including ketones and aromatics) as these can damage the window material, degrade probe performance and invalidate the warranty.
 - Do not allow the solvent to drip behind the retaining components.
4. Wipe the surface dry with a dry swab.
5. Repeat the cleaning with an additional solvent, if needed, and wipe the surface dry with a dry swab.
6. Blow with clean compressed air to remove any swab remnants.
7. Inspect the surface to verify the effectiveness of the cleaning.

Verification with an inspection microscope in the cleaning process is highly recommended to look for smeared contaminants, swab remnants, etc., that may cause increased spectrum background.

8. Repeat the previous steps as necessary.

NOTICE

Only 70 % IPA should be used for optical verification.

- ▶ Only 70 percent by volume (%v/v) will work. Endress+Hauser recommends using CiDehol 70 by Decon Laboratories.
- ▶ Use of any other liquid for verification will result in a failed verification and may result in damage to both the verification cell and the Raman probe.

3.7.3 Inspecting and cleaning the optical fibers

The optical fiber connectors in the cable must be clean and free of debris and oil to achieve optimal performance. If cleaning is required, refer to the applicable Raman Rxn analyzer Operating Instructions or fiber-optic cables Operating Instructions.

3.8 Repair

Repairs not described in this document must be carried out only directly at the manufacturer's site or by the service organization. For Technical Service, refer to our website (<https://endress.com/contact>) for the list of local sales channels in your area.

If a product must be returned for repair or replacement, follow all decontamination procedures indicated by your service provider.

⚠ WARNING

Failure to properly decontaminate wetted parts before return can result in a fatal or serious injury.

To ensure swift, safe and professional product returns, please contact your service organization.

For additional product return information, refer to the following site and select the applicable market/region:
<https://www.endress.com/en/instrumentation-services/instrumentation-repair>

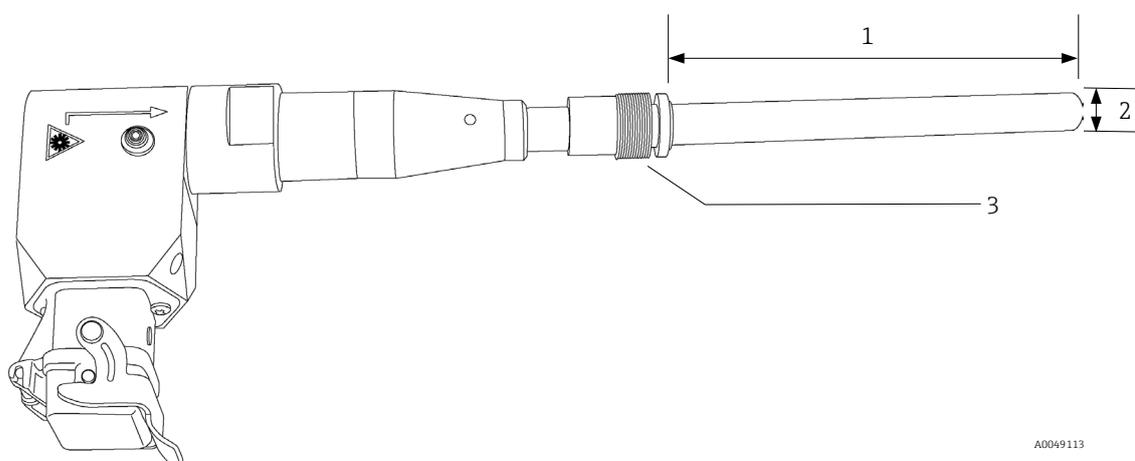
4 Function and system design

4.1 Product description

4.1.1 Rxn-45 probe

The Rxn-45 Raman spectroscopic probe, powered by Kaiser Raman technology, is a clean-in-place (CIP)/steam-in-place (SIP) compatible probe designed for *in situ* monitoring and control of bioprocess applications in development and manufacturing settings. This probe is ideally suited for side-port entry into a bioreactor or fermenter, and is compatible with Endress+Hauser Raman Rxn analyzers operating at 785 nm and 993 nm.

The Rxn-45 probe has a 120 mm (4.73 in) immersion length with a 12 mm (0.48 in) outer diameter and a surface finish of Ra 0.38 μm (Ra 15 μin) or better. The PG13.5 connector allows for installation with multiple port types, using industry standard sensor housings for 25 mm (0.98 in) side ports. Welded port connectors and flanges are also available in multiple brands and sizes.



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Figure 4. Rxn-45 probe

#	Description
1	120mm (4.73 in) immersion length
2	Ø12mm (0.48 in)
3	Captive nut PG13.5 thread

4.1.2 Benefits of the probe design

The Rxn-45 probe offers the following benefits:

- Measures multiple components in real-time for automated 24/7 process feedback
- Provides long-term measurement stability
- Offers a suitable surface finish for cGMP manufacturing
- Provides compatibility with industry standard bioreactor side ports and sensor housings
- Offers the flexibility of being installed in development and production reactors
- Compatible with CIP/SIP standards for reduced sterilization and cleaning burdens

4.1.3 Short data collection zone

All versions of the Rxn-45 probe utilize short data collection zones. The short data collection zone maximizes spectral reproducibility by minimizing the impact of sample opacity, sample color, and transient particulates on the measured Raman spectrum.

4.2 Probe and fiber optic connection

The Rxn-45 probe is compatible with Endress+Hauser Raman Rxn analyzers operating at 785 nm and 993 nm. The probe connects to the Raman Rxn analyzer via a user-removable electro-optical (EO) fiber cable. The EO fiber cable connects the Rxn-45 probe to the analyzer with a single, robust connector that contains the excitation and collection fiber optics as well as an electrical laser interlock. The fiber cable is sold separately.

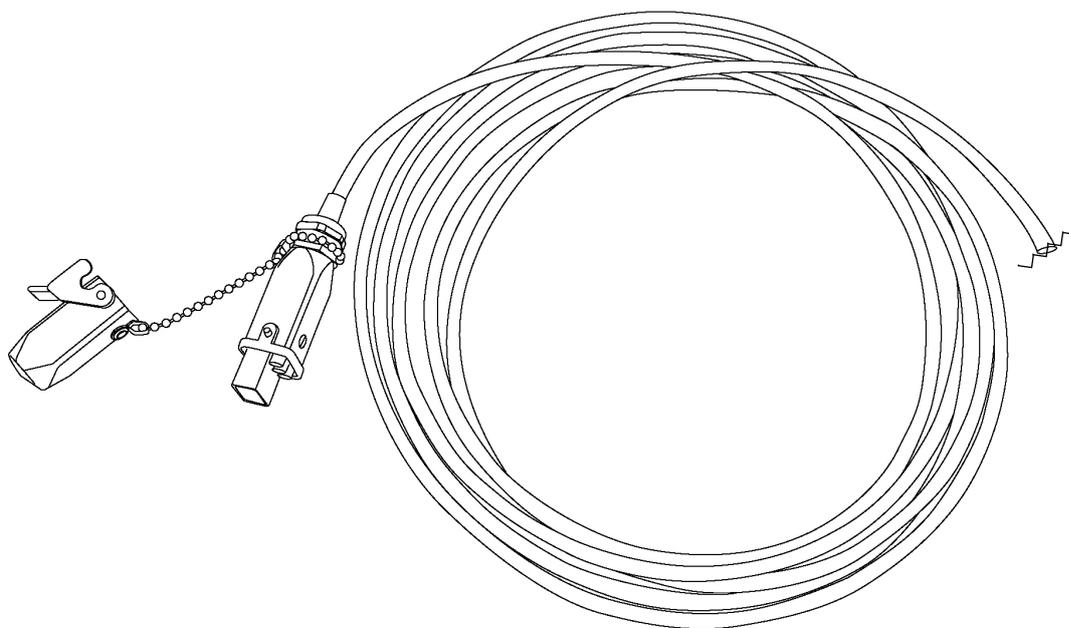
Endress + Hauser recommends using the KFOC1B Raman Fiber-Optic Cable with Raman Rxn analyzers and probes. Refer to the applicable Raman Rxn analyzer Operating Instructions for analyzer connection details.

NOTICE

Connection of the probe to the fiber-optic cable must be conducted by a qualified Endress+Hauser engineer or specially trained technical personnel.

- ▶ Unless trained by qualified personnel, customer attempts to connect the probe to the fiber-optic cable can result in damage and may void the warranty.
- ▶ Contact your local Endress+Hauser service representative for additional support regarding the probe and fiber cable connection.

Fiber-optic cable is available in 5 m (16.4 ft) increments up to 200 m (656.2 ft), with the length limited by the application.



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Figure 5. EO fiber cable showing connector for analyzer

5 Technical data

5.1 General specifications

Note: Maximum service pressure ratings do not include the ratings of any fittings or flanges used to mount the probe into the process system. These items need to be independently evaluated and may lower the maximum service pressure of the probe.

Item		Description
Laser wavelength		785 nm or 993 nm
Spectral coverage		probe spectral coverage is limited by the coverage of the analyzer being used
Maximum laser power into probe		< 499 mW
Relative humidity		Up to 95 %, non-condensing
Maximum service pressure (at tip)		13.8 barg (200 psig)
Process connection		PG13.5 thread for industry standard sensor housings; welded port connectors available
IEC 60529 for (EO) right angle connector		IP65
North American TYPE rating for (EO) right angle connector		TYPE 13 ¹
Depth of field		0.33 mm (0.013 in) FWHM
Chemical resistance		limited by materials of construction
Sterilization protocol compatibility		SIP/CIP
Probe temperature	window, at tip	-30 to 150 °C (-22 to 302 °F)
	probe body	up to 150 °C (302 °F)
	temperature ramp	≤ 30 °C/min (≤ 54 °F/min)
Probe measurements	immersion length	120 mm (4.73 in)
	diameter	12 mm (0.48 in)
	dimensions (with EO connector cap open)	306 x 127 x 34 mm (12.05 x 5.0 x 1.34 in)
Materials of construction (wetted, in contact with sample)	probe body	316L stainless steel
	window	proprietary material, optimized for bioprocesses
	adhesive	USP Class VI and ISO993 compatible
	surface finish	Ra 0.38 μm (Ra 15 μin) with electropolish
	fiber-optic cable	design: PVC jacketed, proprietary construction connections: proprietary electro-optical (EO) or FC to EO fiber converter(s) for non-embedded systems

¹ This is a self-declaration of conformance to UL 50E TYPE 13 requirements. It does not constitute UL certification or authorization to use the UL mark.

All fiber-optic cable specifications can be found in the *Raman fiber-optic cables KFOC1 and KFOC1B Technical Information (TIO1641C)*.

5.2 Maximum permissible exposure

The maximum permissible exposure (MPE) is the maximum level of laser radiation exposure that can occur before causing ocular or skin damage. The MPE is calculated using the laser wavelength (λ) in nanometers, the duration of the exposure in seconds (t), and the energy involved ($J\cdot\text{cm}^{-2}$ or $W\cdot\text{cm}^{-2}$).

A correction factor (C_A) may also be required and can be determined below.

Wavelength λ (nm)	Correction Factor C_A
400 to 700	1
700 to 1050	$10^{0.002(\lambda-700)}$
1050 to 1400	5

5.2.1 MPE for ocular exposure

The ANSI Z136.1 standard provides means to perform MPE for ocular exposure. Please refer to the standard to calculate the relevant MPE levels for the case of laser exposure from the Rxn-45 probe and from the unlikely occurrence of laser exposure from a broken optical fiber.

MPE for point source ocular exposure to a laser beam				
Wavelength λ (nm)	Exposure duration t (s)	MPE calculation		MPE where $C_A = 1.4791$
		($J\cdot\text{cm}^{-2}$)	($W\cdot\text{cm}^{-2}$)	
785 and 993	10^{-13} to 10^{-11}	$1.5 C_A \times 10^{-8}$	-	2.2×10^{-8} ($J\cdot\text{cm}^{-2}$)
	10^{-11} to 10^{-9}	$2.7 C_A t^{0.75}$	-	Insert time (t) and calculate
	10^{-9} to 18×10^{-6}	$5.0 C_A \times 10^{-7}$	-	7.40×10^{-7} ($J\cdot\text{cm}^{-2}$)
	18×10^{-6} to 10	$1.8 C_A t^{0.75} \times 10^{-3}$	-	Insert time (t) and calculate
	10 to 3×10^4	-	$C_A \times 10^{-3}$	1.4971×10^{-3} ($W\cdot\text{cm}^{-2}$)

5.2.2 MPE for skin exposure

The ANSI Z136.1 standard provides means to perform MPE for skin exposure. Please refer to the standard to calculate the relevant MPE levels for the case of laser exposure from the Rxn-45 probe and from the unlikely occurrence of laser exposure from a broken optical fiber.

MPE for skin exposure to a laser beam				
Wavelength λ (nm)	Exposure duration t (s)	MPE calculation		MPE where $C_A = 1.4791$
		($J\cdot\text{cm}^{-2}$)	($W\cdot\text{cm}^{-2}$)	
785 and 993	10^{-9} to 10^{-7}	$2 C_A \times 10^{-2}$	-	2.9582×10^{-2} ($J\cdot\text{cm}^{-2}$)
	10^{-7} to 10	$1.1 C_A t^{0.25}$	-	Insert time (t) and calculate
	10 to 3×10^4	-	$0.2 C_A$	2.9582×10^{-1} ($W\cdot\text{cm}^{-2}$)

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