OMEGA™

HANI™ High Accuracy Non-Invasive Temperature Sensor

WHITEPAPER

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Omega HANI™ Sensor Delivers Accurate, In-Pipe Temperature Measurement Without an Invasive In-Pipe Sensor

PATENT PENDING

Attain quick and accurate in-pipe media temperature measurement with Omega's HANI high accuracy, non-invasive clamp temperature sensor.

The invasiveness of traditional, highly accurate, in-pipe temperature sensors and the inaccuracy of traditional, easy-to-install surface temperature sensors both present unique challenges for process, measurement, and control. This paper will detail how Omega's High Accuracy, Non-Invasive Clamp Temperature Sensor addresses these challenges and delivers highly accurate, non-invasive, in-pipe temperature readings with the quickest and easiest installation process of any sensor on the market today.

While invasive, in-pipe sensors have complicated installation processes that require tools, the HANI High Accuracy, Non-Invasive Clamp Temperature Sensor is easy to install and can be done completely by hand in seconds. Omega's innovative clamp-on design allows for the sensor to be attached directly to the outside of a pipe while measuring the temperature of the media flowing within with comparable accuracy to an in-pipe sensor.

There is no need for pipe cutting, welding, or modifications of any kind, and the ease and simplicity of installation and relocation reduces cost, minimizes downtime, and eliminates all consequences of incorrect placement. Also, because the Omega HANI Clamp Sensor is non-invasive and never comes in contact with the process media flowing through the pipe, there is no risk of contamination from an invasive, in-pipe sensor. Since there is no in-pipe sensor, equipment wear and tear is reduced tremendously.

The HANI Clamp Sensor features an M12 8-pin connection for versatile communication, offering three ways to connect:

- 4 to 20 mA loop powered analog output
- Ad/hoc with direct connection to laptop
- LayerN ecosystem for cloud data monitoring

Omega's patent pending Hybrid Temperature Sensing platform uses multiple sensors and a proprietary algorithm to achieve the same accuracy (±0.50°C) and fast response times (5 sec (t63), 10 sec (t90)) as state-of-the-art invasive sensors.

With lower total ownership cost, quick and easy installation, and reduced contamination risk, Omega's HANI High Accuracy, Non-Invasive Clamp Temperature Sensor is ideal for both newly designed systems and for retrofitting existing systems into industries such as Food and Beverage, Pharmaceutical, Life Sciences, Chemical Processing, Personal Care, Water/Wastewater, Petrochemical, Industrial Coatings, and Automation and Control.

Traditional invasive, in-pipe temperature sensor challenges

Although highly accurate, invasive in-pipe temperature sensors have inherent issues that cause major challenges for process, measurement, and control in a variety of industries. Invasive, in-pipe temperature sensors require a major installation process, in which the pipe must be cut or drilled into so that a process fitting or sensor "T" can be welded on. Downtime is inevitable, and relocating the sensor is a costly and time-consuming process as well. Because the in-pipe sensor is directly in contact with the process media, it is often exposed to such variables as high flow rates, corrosive and/or abrasive media, and wake frequency and/or water hammer. This is especially true for industries processing fluid media with inclusions, such as ice cream, fruit pulp, yogurt, pet food, and personal care products. This direct contact leads to media build up, sensor drift, reduced flow of media, pipe clogging, lack of quality of control, and wasted product. If an invasive, in-pipe sensor is inserted close to a bottling/canning process, for example, it will increase turbulence in the line and will cause unwanted de-carbonation which generates waste and defeats the purpose of ensuring the right temperature during the fill. Also, an invasive, in-pipe temperature sensor must be removed if a pig is used to clean, inspect, or recover process media in production pipping systems, again causing inevitable downtime.

Traditional surface temperature sensor challenges

While basic surface temperature sensors overcome many of the challenges associated with invasive, in-pipe temperature sensors, they too have inherent issues that present challenges for process measurement, and control. Accuracy can be significantly affected by outside variables if they are not properly accounted for. The golden rule of contact temperature measurement is that a temperature sensor can only measure its own temperature. When a traditional surface sensor is attached to a pipe to measure surface temperature, the pipe is not the only thing in contact with the surface sensor. The ambient air surrounding the sensor and pipe also has a significant effect on both the pipe surface temperature and the sensor reading through the physics of convection heat transfer. For example, if a fluid inside a pipe is 100°C, but the surrounding ambient air temperature around the pipe is 25°C, then we know the pipe surface temperature will be somewhere between the two. Through empirical studies, it has been quite commonly found that even some of the best insulated surface temperature sensors still experience at least 10% accuracy error when compared to the actual temperature of the fluid inside a pipe. So, while conventional pipe surface temperature sensors are much easier to install than invasive in-pipe sensors, their accuracy does not match that of in-pipe sensors.

Omega's HANI high accuracy, non-invasive clamp temperature sensor solves challenges presented by both traditional invasive, in-pipe temperature sensors and traditional surface temperature sensors

As outlined in the previous sections, there are serious challenges presented by both traditional invasive, in-pipe sensors and traditional surface sensors that have costly and time-consuming repercussions. Omega's HANI High Accuracy, Non-Invasive Clamp Temperature Sensor addresses and solves these challenges, providing highly accurate temperature readings with the ease and convenience of low-cost installation that can be completed in seconds. Simply put, the HANI Clamp Sensor mounts to a pipe with the ease of a surface sensor while delivering the high accuracy of an invasive sensor.

Due to its innovative clamp-on design, the HANI High Accuracy, Non-Invasive Clamp Temperature Sensor can literally be installed in seconds. The sensor easily straps on to the outside of a pipe with an innovative clasp and quick-latch cam solution and calculates the temperature of the in-pipe process media without penetrating the pipe. There is no invasive probe of any kind, and, therefore, no need for the drilling or welding associated with traditional invasive, in-pipe temperature sensor installment. With no need for a lengthy installation process, there is, as a result, none of the downtime. And if the HANI Clamp Sensor needs to be relocated, just un-clamp it and re-attach it anywhere in seconds.

Because the HANI Clamp Sensor is non-invasive, it operates without making any contact with the in-pipe process media. This eliminates the risk of media buildup, sensor wear, or sensor breakage – all of which are inherent with traditional invasive, in-pipe sensors. And, because the HANI Clamp Sensor requires no invasive probes, a PIG can be used to clean, retain, and recover a product line without having to uninstall the sensor.

The HANI High Accuracy, Non-Invasive Clamp Temperature Sensor also addresses and eliminates the challenges inherent to traditional surface sensors. To overcome the inaccuracies of surface temperature measurement sensors due to ambient surrounding effects, the HANI Clamp Sensor uses a Heat Flux Sensor in addition to a carefully coupled surface temperature sensor. The Heat Flux Sensor is a flexible, thin film thermopile that measures the amount of heat loss from the pipe surface. If the temperature of the surface is measured and the heat loss from that surface is also taken into consideration, then we can use Fourier's Law of Heat Conduction to determine the temperature on the other side of that surface:

$$q" = -k\frac{dT}{dx}$$

Given a particular time interval, we can simplify this to:

$$q" = -k\frac{T_{out} - T_{in}}{\Delta x}$$

Which can be re-arranged to solve for T_{in}:

$$T_{in} = q"\frac{\Delta x}{k} + T_{out}$$

Where:

- T_{in} = temperature on the inside wall
- T_{out} = temperature on the outside wall that is measured by a surface temperature sensor
- q" = heat transfer per unit area, as measured by a heat flux sensor
- Δx = thickness of the material
- k = thermal conductivity of the material

So, as long as we know the thermal conductivity and the thickness of the object being measured, we can then calculate the temperature on the other side. Of course, this equation is for one dimensional heat transfer; so, for a pipe with thickness t and outer radius r, a shape factor must be applied:

$$\Delta x = r * \ln\left(\frac{r}{r-t}\right)$$

Which can be substituted into our previous equation for one dimensional heat transfer:

$$T_{in} = q''\left[\frac{r\ln\left(\frac{r}{r-t}\right)}{k}\right] + T_{out}$$

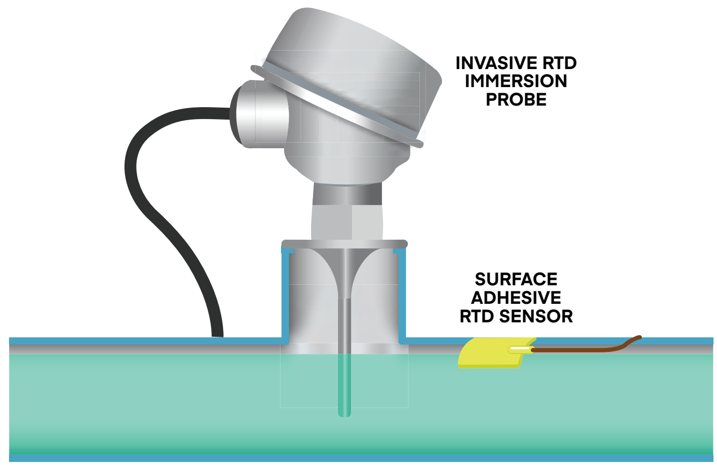
In order to determine the temperature on the inside of the pipe (in addition to measuring the temperature on the outside of the pipe, T_{out}, and the heat flux through the pipe, q") the outside radius, thickness, and thermal conductivity for the pipe must also be known. The thermal conductivity of stainless-steel is around 13 W/mK whereas the thermal conductivity of copper is around 400 W/mK; so, even among different types of metal, thermal conductivity values can vary quite dramatically. Since the thermal conductivity of a particular pipe is not commonly known, Omega has pre-loaded thermal conductivity values for commonly used industrial and sanitary pipes into the Omega SYNC software:

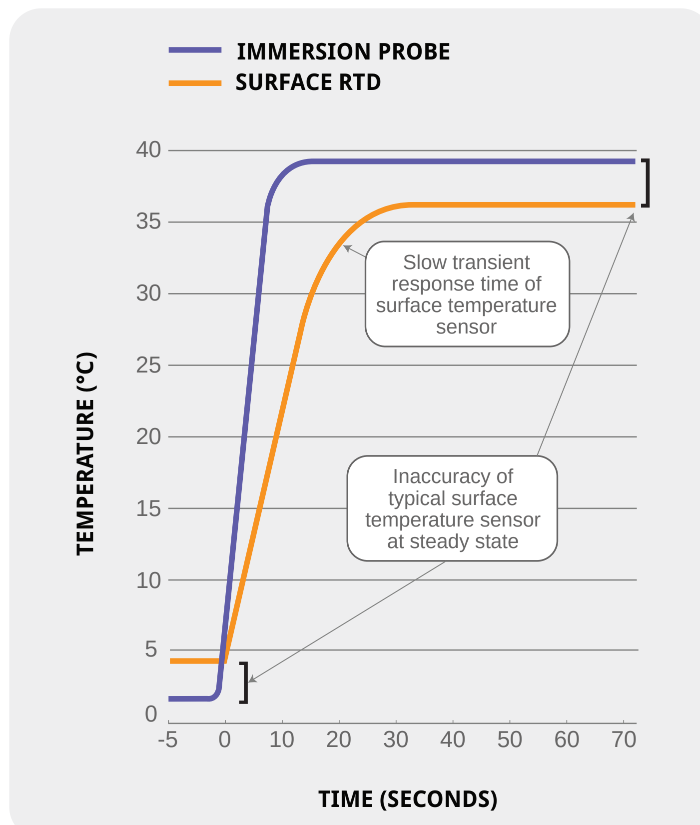
Material	Theoretical Thermal Conductivity (W/mK) @ 0°C
Stainless Steel	13
Carbon Steel	54
Galvanized Steel	54
Copper	401
Brass	111
Aluminum	236
User Specified	—

If the pipe material is something other than the 6 common pipe materials above, then the Operator may select "User Specified" and enter the specific thermal conductivity of the pipe being used, which will either have to be looked up in a materials reference table or measured directly with a thermal conductivity meter.

Illustration of Performance Superiority

To illustrate the performance advantages of the HANI High Accuracy, Non-Invasive Clamp Temperature Sensor, an experiment is carried out on a stainless-steel pipe with flowing water. The pipe has been fitted with a sensor "T" section, in which a 3" long, ¼" diameter immersion RTD probe is inserted into the middle of the pipe fluid flow. On the outside of the pipe, a thin film surface RTD sensor has been fitted to the pipe surface with a pressure sensitive adhesive. The temperature of the water flowing through the pipe is held at a steady 1.5°C until time 0, when the cold circuit valve is closed and the hot circuit valve is opened to allow 39°C water to flow through the pipe test piece. The data for this experiment can be seen to the right. The experiment shows that at the steady state conditions (before the valve is opened at time 0 as well as sufficiently after allowing the system to settle for 2 minutes), the surface temperature sensor is a few degrees lower than the water temperature at 39°C. Note that the surface temperature sensor will always bias inaccuracy towards the ambient temperature of the surroundings (i.e. it will read "low" when the ambient temperature is lower than the process temperature and it will read "high" when the ambient temperature is higher than the process temperature). This experiment also illustrates how, during the short time after the temperature change known as the transient state, the surface temperature sensor takes a lot longer to react to the change of the fluid temperature. This is due to the golden rule of contact temperature measurement: a temperature sensor can only measure its own temperature. Since it is mounted to the pipe surface, it needs to wait for the pipe to heat up. The latency of this sensor will largely depend on many of the factors mentioned above, such as pipe thermal conductivity, thickness, and even water flow rate.

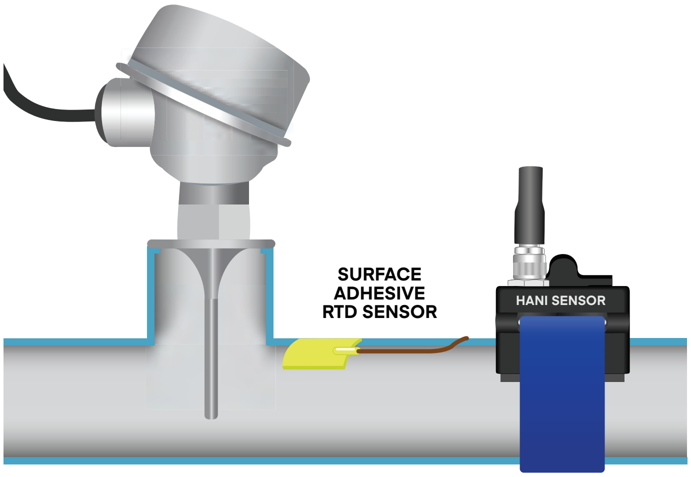


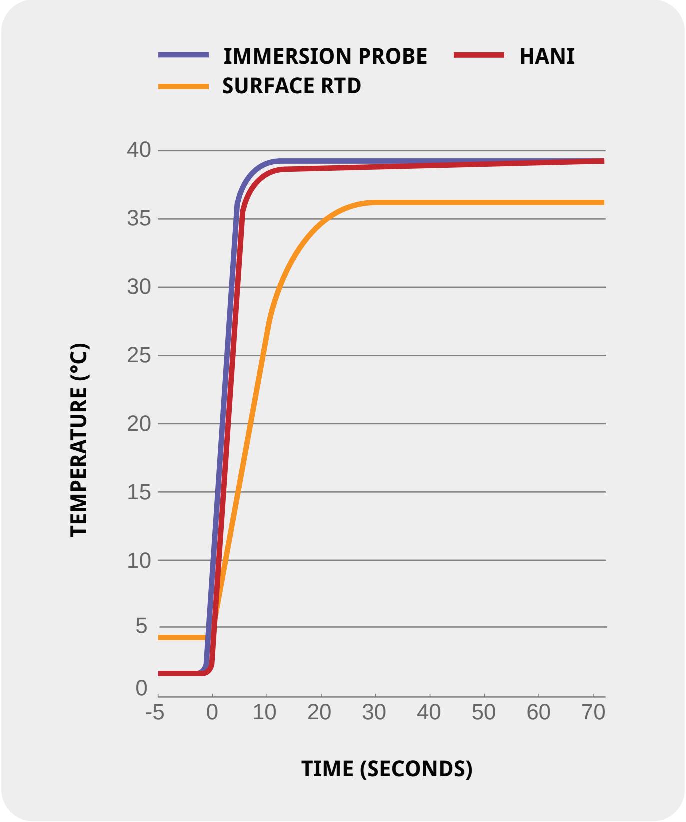


Now, the same experiment can be run again, but this time with the HANI High Accuracy, Non-Invasive Clamp Temperature Sensor on the outside of the pipe, next to the surface temperature sensor used in the previous experiment. The HANI temperature sensor utilizes a surface RTD temperature sensor (much like the surface sensor mounted to the outside of the pipe), but it also utilizes a thin film heat flux sensor and the heat conduction algorithm developed in the section above:

$$T_{HANI} = q'' \left[\frac{r \ln\left(\frac{r}{r-t}\right)}{k} \right] + T_{out}$$

T_{out} is the temperature measured by the surface RTD temperature sensor in the HANI Clamp Temperature Sensor. q" is the heat flux per unit area, as measured by the Heat Flux Sensor in the HANI. The HANI is also configured for the radius (r), thickness (t), and thermal conductivity (k) of the pipe. The resulting calculated temperature measurement of the HANI, T_{HANI}, is shown in the figure below, next to the graphs of the same immersion temperature sensor and surface temperature sensor from experiment 1:



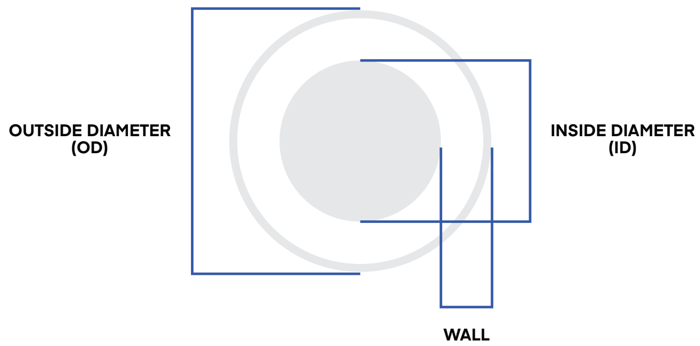


Note that at steady state conditions, the HANI High Accuracy, Non-Invasive Clamp Temperature Sensor has much improved accuracy over the surface temperature sensor. The HANI very closely approximates the actual temperature of the water flowing through the pipe. Also, during the transient state, the HANI Clamp Temperature sensor is very fast to react. As demonstrated by this experiment, the HANI High Accuracy, Non-Invasive Clamp Temperature Sensor compensates for the errors inherent in traditional surface sensors while providing highly accurate temperature readings with a response time equivalent to that of an invasive, in-pipe sensor.

Performance Considerations / Things to Know

General Overview

Metal process piping is supplied in various materials, inner diameters (ID), and outer diameters (OD). There are two types of pipes often used: Industrial and Sanitary. Commonly used metal material for both types is stainless-steel, but industrial pipes are also available in carbon steel, galvanized steel, copper, brass, and aluminum. The actual sizes of the inside and outside diameters vary depending on the nominal pipe size and must be considered when choosing piping for process systems as well as when choosing the appropriate HANI Clamp Sensor.



Industrial Metal Pipes

The nominal pipe size for industrial pipes is different from the outer diameter; please refer to table for actual pipe dimensions. Industrial pipes have different ID's based on their "Schedule". The pipe schedule identifies the pipe thickness based on the pipe's nominal size. The higher the schedule the thicker the pipe; standard thickness is schedule 40. Schedules 40 and 80 are the most commonly used, but 10, 120, 160, and thicker schedules are also available.

Common industrial pipe sizes can be found in the chart below. For more information on industrial pipe sizes available for the HANI Sensor, visit **www.jakar.cz/en/hani** (HANI-I)

Nominal Pipe Size	Outside Diameter (in)	Schedule 10		Schedule 40		Schedule 80		Schedule 120		Schedule 160	
		Inner Diameter (in)	Wall Thickness (in)	Inner Diameter (in)	Wall Thickness (in)	Inner Diameter (in)	Wall Thickness (in)	Inner Diameter (in)	Wall Thickness (in)	Inner Diameter (in)	Wall Thickness (in)
1/8"	0.405	0.307	0.049	0.269	0.068	0.215	0.095	-	-	-	-
1/4"	0.540	0.410	0.065	0.364	0.088	0.302	0.119	-	-	-	-
3/8"	0.675	0.545	0.065	0.493	0.091	0.423	0.126	-	-	-	-
1/2"	0.840	0.674	0.083	0.622	0.109	0.546	0.147	0.480	0.170	0.464	0.188
3/4"	1.050	0.884	0.083	0.824	0.113	0.742	0.154	0.690	0.170	0.612	0.219
1"	1.315	1.097	0.109	1.049	0.133	0.957	0.179	0.891	0.200	0.815	0.250
1 ¼"	1.660	1.442	0.109	1.380	0.140	1.278	0.191	1.204	0.215	1.160	0.250
1 ½"	1.900	1.682	0.109	1.610	0.145	1.500	0.200	1.423	0.225	1.338	0.281
2"	2.375	2.157	0.109	2.067	0.154	1.939	0.218	1.845	0.250	1.687	0.344
2 ½"	2.875	2.635	0.120	2.469	0.203	2.325	0.275	2.239	0.300	2.125	0.375
3"	3.500	3.260	0.120	3.068	0.216	2.900	0.300	2.758	0.350	2.624	0.438
3 ½"	4.000	3.760	0.120	3.548	0.226	3.364	0.318	-	-	-	-
4"	4.500	4.260	0.120	4.026	0.237	3.826	0.337	3.574	0.473	3.438	0.531
5"	5.563	5.295	0.134	5.047	0.258	4.813	0.375	-	-	4.313	0.625
6"	6.625	6.357	0.134	6.065	0.280	5.761	0.432	-	-	5.187	0.719
8"	8.625	8.329	0.148	7.981	0.322	7.625	0.500	-	-	6.813	0.906

Sanitary Metal Pipes

Sanitary pipes (also known as sanitary or hygienic tubing) do not have varying wall thickness. The thickness of the wall is defined in the table below. Sanitary pipes are usually supplied in different grades of polish on the exterior and interior. Polish grade is sometimes referred to as Ra or Rz finish, but this can vary. Sanitary pipes have smoother/higher polish surface finishes when compared to industrial pipes. Please note, unlike industrial pipes, sanitary pipes have a nominal size equal to the outside diameter.

Common sanitary pipe sizes can be found in the chart to the right. For more information on sanitary pipe sizes available for the HANI Sensor, visit **www.jakar.cz/en/hani** (HANI-S)

Nominal Pipe Size	Outside Diameter (in)	Inner Diameter (in)	Wall Thickness (in)
1/2"	0.5	0.37	0.065
3/4"	.75	0.62	0.065
1"	1.0	0.87	0.065
1 ½"	1.5	1.37	0.065
2"	2.0	1.87	0.065
2 ½"	2.5	2.37	0.065
3"	3.0	2.87	0.065
4"	4.0	3.83	0.083
6"	6.0	5.78	0.109
8"	8.0	7.78	0.109

Fluid Types

The process media/fluid is an important consideration when choosing a HANI clamp temperature sensor. Process fluids with a higher thermal conductivity will transfer heat to the pipe much better than fluids with lower thermal conductivity. Below is a table with some common process fluids and their approximate thermal conductivities at room temperature.

Fluid	Thermal Conductivity (W/mK)
Alcohol, ethyl	0.17
Ammonia	0.51
Engine Oil	0.15
Ethylene Glycol	0.26
Milk	0.56-0.65
Petroleum	0.16
Propylene Glycol	0.15
Sulfuric Acid	0.5
Tomato Paste	0.46-0.66
Water	0.61
Yogurt	0.45-0.55

The HANI comes pre-calibrated for applications with water-based media, so the published factory accuracy (±0.5°C for Hygienic pipes & ±1.0°C for Industrial pipes) can be considered for fluids with similar (or higher) thermal conductivities compared to water (i.e. beer, milk, tomato paste, etc.). For applications using fluids with lower thermal conductivities (i.e. oil, propylene glycol, etc.), the expected accuracy without a user calibration will be closer to ±1°C for sanitary pipes and ±1.5°C for Industrial pipes. If an improved accuracy is desired for a specific application that has a fluid with lower thermal conductivity, then a 1 or 2-point in-situation User Calibration can be performed on the HANI Clamp Temperature Sensor with the free Omega Sync Software and an in place immersion temperature sensor for reference. See the user manual for details on performing 1 or 2-point User Calibrations.

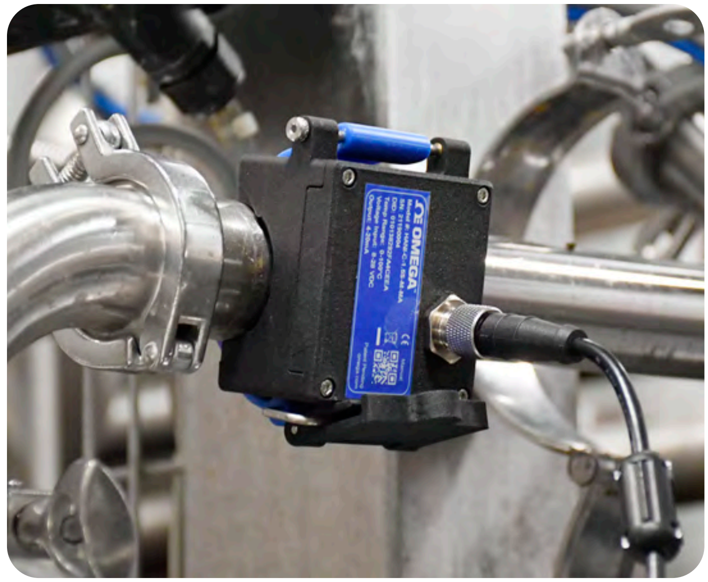
Suitable Process Applications & Industries

Omega's HANI High Accuracy, Non-Invasive Clamp Temperature Sensor is suitable for any application where there is fluid transport inside pipes, including:

- Pipelines
- Small Line Sizes
- High Velocity Flows
- Slurries
- Heavy Particle Fluids
- Fluids with Inclusions
- Processes where Sanitization is Key
- Wellheads
- CIP Processes
- High Viscosity Fluids
- Harsh Processes

The HANI High Accuracy, Non-Invasive Clamp Temperature Sensor is ideal for use in the following industries:

- Food and Beverage
- Pharmaceutical
- Life Sciences
- Chemical Processing
- Personal Care
- Water/Wastewater
- Petrochemical
- Industrial Coatings
- Automation and Control



Placement of Installation

The HANI is designed so that installation is quick and simple. As long as it is mounted on a part of a pipe that is in contact with the fluid media flowing within, the HANI Clamp Sensor can accurately calculate the temperature. However, because the flow of fluid media is not always consistent, the HANI should be placed on the bottom of a horizontal section of the pipe to ensure it will be in contact with fluid media even if the pipe is not 100% full.

Summary

As presented in this paper, Omega's HANI High Accuracy, Non-Invasive Clamp Temperature Sensor directly addresses and solves some of the major challenges that exist in temperature processing, measuring, and controlling of media that is flowing through pipes. It has the temperature measurement accuracy of an invasive, in-pipe sensor without the hassle and cost of installation. The HANI Clamp Sensor features Omega's innovative clamp-on design, which allows the sensor to be mounted directly to the exterior of a pipe. No tools are required, and installation is virtually instantaneous; the HANI Clamp Sensor can be attached to a pipe by hand in seconds. This quick and easy installation process, unique to the HANI High Accuracy, Non-Invasive Clamp Temperature Sensor, eliminates the downtime that is inherent with other sensors of this caliber, which almost always require an invasive and time-consuming installation process. Since the HANI Clamp Sensor is non-invasive and requires no in-pipe probe of any kind, all risk of media build up, sensor drift, reduced flow of media, pipe clogging, lack of quality of control, and wasted product is eliminated. In addition, since the HANI Clamp Sensor can accurately calculate the temperature of in-pipe media from entirely outside of the pipe, it in no way hinders internal pipe cleaning.

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