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Identify the Best Hydrogen Flow Measuring System for a Government Subcontractor, Analyse Different Measurement and Automation Technologies, and use them to Make Procurement Decisions to Reach Net Zero Components

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Abstract
Hydrogen is a key component of the global energy transition, with grey hydrogen being the primary source. However, technological advancements are enabling the production of low- or no-carbon hydrogen, such as green hydrogen from renewable electricity or blue hydrogen from fossil fuels. As a flexible energy source, carrier, and storage medium, hydrogen is expected to decrease in price as its applications expand. This study examines the suitability of metering systems and flow measurement standards for three application scenarios: household use as a substitute fuel for cooking and heating, industrialisation as a substitute fuel for industrial use, and transportation as a fuel substitute in the transportation sector. International standardisation of flow measurement is necessary for a viable hydrogen economy.

***Keywords**: hydrogen, a fossil fuel-based fuel, Pressure and Temperature Sensors Forms Ultrasonic Metre Coriolis Flowmeters, flow and control isolation*

Background of research

Hydrogen is becoming more recognised as a crucial element of the world's energy transition, both domestically and abroad. The majority of hydrogen generated today is grey hydrogen, which has a significant carbon footprint because it is made from fossil fuels. But technical developments are expanding the possibilities for low- or no-carbon hydrogen. Whether it is green hydrogen produced through an electrolysis process using renewable electricity or blue hydrogen created from fossil fuels with associated carbon capture and storage,

As a flexible energy source, carrier, and storage medium, hydrogen is expected to decrease in price as its variety of applications expands. Because of its physical and chemical qualities, flow meters may have difficulty reading it. (Rodrigues, E.R.2009)

This study investigates the suitability of metering systems and flow measurement standards for three application scenarios. To enable a viable hydrogen economy, international standardisation of flow measurement is required. (P.A Consulting, 2020)

- Household: as a substitute fuel for cooking and heating. This assumes that it refers to gas consumers who are linked to the current gas grid and consuming a hydrogen methane split.
- Industrialization: as a substitute fuel for industrial uses This should apply to grid-connected consumers, we assume.
- Transportation: Used as a fuel substitute in the transportation sector (mainly for HGVs and forecourt uses). (P.A Consulting, 2020)

Hydrogen flow measurement

In fuel cells, or directly via combustible hydrogen and oxygen, the two can be used as fuel for storing and releasing energy. Hydrogen can be used in either gaseous or liquid form. hydrogen, which is liquid and has a very low boiling point (below -250oC).

Hydrogen is most frequently kept and used as a pressurised gas or liquid because it is incredibly light and has a low energy density (by volume). (Arup., 2019).

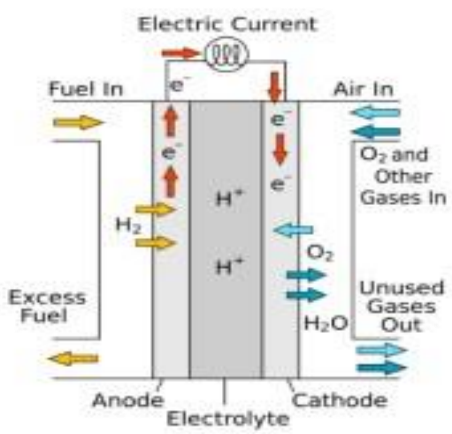

Figure 1:Scheme of a proton conducting fuel cell (Arup., 2019)

Characteristics of measurements

Density of Energy: Atomic hydrogen has about one-third the energy density of natural gas (by volume), so higher flows are required to get the same caloric content.

Leakage: Methane is less likely to leak than hydrogen, which can create gas pockets.

Embrittlement: The materials that have been exposed to hydrogen may become embrittled and brittle.

The odour: In order to help with detection, chemicals can be added, however contaminants can harm the fuel cell's internals. **liquid hydrogen:** The low temperature of liquid hydrogen makes measurements stressful.

Measuring methods

Meter technology can precisely monitor the movement of gases and liquids. (Butler, K.M., 2008.

The following meter kinds are available: Coriolis, Ultrasonic, Differential Pressure, Positive Displacement, Turbine, and Thermal Mass. In the context relating to these studies, two flow measurement types—Coriolis flow measurement devices and Ultrasonic technology flow meters—were taken into consideration and contrasted.

Coriolis Flowmeters

The operation

The U-shaped tube construction of the Coriolis mass flow sensor has fixed ends.

An AC is delivered to the tube in the presence of a magnetic field (B) to cause the tube to vibrate by the Lorentz force. The tube vibrates in its twist mode as a result of the Lorentz forces that result, as shown by the symbol act. Providing an actuating force are

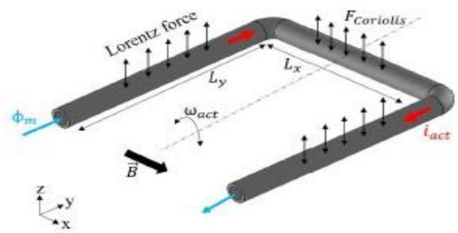

Figure 2: The principle of operation.

Coriolis flow metering directly measures mass flow by utilizing the Coriolis effect. Simply put, the inertial effects produced by a fluid flowing through a tube are inversely proportional to the fluid's mass flow. (P.A Consulting, 2020)

$$\overrightarrow{F_{act}} = L_y(i_{\vec{act}} \times \vec{B})$$

As a result of derivation, tube segments that are parallel to the field's direction produce rotational vibrations. (Schut, R, 2020). They may set the rotation's angle and angular velocity as:

$$\theta_a = \alpha \sin(\omega_a t)$$

$$\frac{d\theta_a}{dt} = \alpha\omega_a \cos(\omega_a t)$$

The use of Coriolis measuring technologies is widespread in business. A Coriolis metre may determine the density of fluid in addition to the mass flow by analysing the resonant frequency of the flow and flow and fluid pollution monitoring, there is a growing curiosity about using this density measurement ability as the key process output. (Lindsay, G 2020 et al)

Figure 3: Coriolis Flowmeters

By determining the difference in vibration phase between two ends of a flow tube, Coriolis flowmeters calculate the mass flow.

*Table 1: **Advantages and Disadvantages (**Bronkhorst, 2020)*

Advantages	**Disadvantages**
• They provide accurate weight measurements. • Measurements are unaffected by pressure, temperature, or density. • In the area of calibration and verification, the high accuracy of Coriolis flowmeters has been demonstrated When measuring the flow of a single phase, such as a liquid, gas, or slurry in suspension, this flow meter provides exceptional precision.	• They offer acceptable accuracy only for liquids. • They are susceptible to fluid densities that are not perfectly consistent with the reference calibration fluid. • They are vulnerable to disturbances from noise, vibration, and pulsing flows. • Research indicates that readings from Coriolis are prone to being inflated by the compressibility effect.

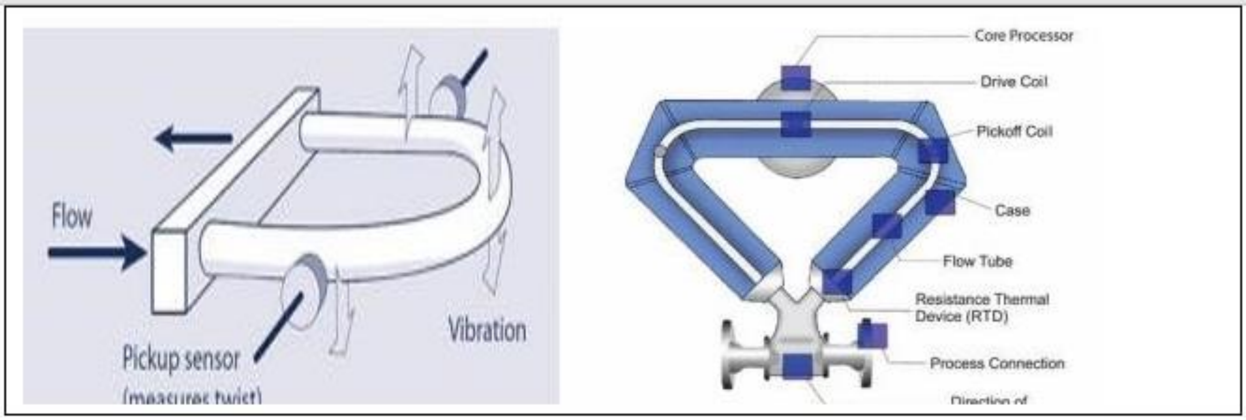

Figure 4: viewing the works of characteristic Coriolis meters (Wang, L et al 2016))

Ultrasonic Metre

Operation

There are many different kinds of ultrasonic metres; however, only transmitting (contrapropagating transit time/time of flight (TOF)) ultrasonic flowing metres are appropriate for clean hydrogen and gas measuring tasks. However, cleaner natural gas mixtures might be used with Doppler metres. The disparity in the time that ultrasonic signals take to propagate upstream and downstream is how TOF metres gauge the amount of flow. Flow and contaminant diagnostics can be provided by many transducer pairings. Fluid compositional analysis can be performed using TOF-based ultrasonic technology.

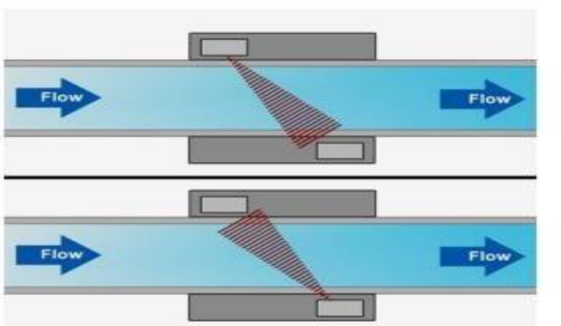

Figure 5: Illustration of a period of flight (Zhu, X., 2023)

Applications

(OIML R137, Class 0.5, MI-002, AGA9) Appropriate for the custody transfer and measuring of natural gas and hydrogen. Gas measuring for use at home

Ultrasonic Flowmeters Operations

Ultrasonic metres come in a variety of forms; however, only transmission (contra-propagating transit time/time of flight (TOF)) is used. Ultrasonic applications using clean hydrogen and gas metering can benefit from the use of flow metres. However, dirtier natural gas mixtures might be used with Doppler metres. The ultrasonic pressure waveform, which is connected to the medium speed by the difference in frequency, is reflected by the bubbles in the medium stream in a Doppler change type. (Mousavi, S.F., 2020)

The figure above, time of flight ultrasonic meter in act, for fluid chemical analysis, which provides data concerning gas mixes, TOF-based ultrasonic technology has the potential to be utilised. The Kfactor is the predicted number of pulses for each volumetric unit of fluid that passes through a specific flow metre.

***Table 2: Advantages and disadvantages**:*

Advantages	**Disadvantages**
• may enable the inference of gas composition from variations in sound speed. • Appropriate for usage with high pressure. • Unaffected by significant changes in either pressure or temperature • It is possible to fit either of the following:	• There are more affordable metres available for residential and commercial applications that are smaller in scope. • Externally, clamp-on metres must also consider how pipework affects the measurement. Challenges with thick, high-pressure gas pipelines

• - External (non-contact, nonwetted, clamp-on) within pipes - In-line, wetted, or a spool part • In line versions may be able to identify very small amounts of fluid, contaminants, or flow disruptions in pipes (deposits, dirt, variations in roughness of the surface, etc.).	Clamp-on metres are only 3–5% of the full scale accurate, which is insufficient for custody transfer purposes. • For best accuracy, flow conditioning is necessary (for example, straight runs into metres).

Figure 6: Ultrasonic Flow Meter for Two-Path Gas (Scelzo, M.J., 2001).

Chosen Flowmeter

Since hydrogen is a volatile and combustible gas, the ultrasonic flowmeter was used for the system design. It is the only kind of flowmeter that can be installed into existing pipelines without requiring draining or piping, which lowers installation costs and prevents pipeline invasion that could cause pressure drops. The metre has clamp-on transducers that produce custody transfer appropriate values after being flow calibrated. (Euramet, 2020.

They have the following advantages over Coriolis flowmeters:

- They are more accurate. 1ms response time.
- Designed for high- or low-pressure air, hydrogen, or natural gas in pipes made of almost any material, including metal.
- Luckily, when precise flow velocity readings at a pipe's cross-section are required, a multipath ultrasonic flowmeter is the way to go.
- The audio component propagation in the fluid can be monitored using single-path and multipath ultrasonic flowmeters (sound speed, attenuation coefficient), from which other parameters can be calculated.

2. Pressure and Temperature Sensors Forms

Dynamic temperature and pressure measurements are critical for manufacturing, process control, safety testing, and research improvement. Nonetheless, advancement is limited by a scarcity of accurate sensors and traceable calibration. (Saxholm, S et al, 2018)

Because temperature changes are sudden and difficult to observe systematically, quick and accurate measurements are critical for improving pressure sensor reliability. In industrial contexts such as internal combustion engines and nuclear power reactors, dynamic temperature measurements are critical. Current methods and technologies for sensing dynamic temperature changes must be evaluated. (Saxholm, S et al, 2018)

Thermocouple

A thermocouple is constructed from two distinct conducting materials that are linked at one point to form a closed circuit. The unit of measurement at the junction is one connection, while the reference point is the opposite connection. (Root, W., Bechtold, T. and Pham, T., 2020).

Ultrasonic Thermocouples Solidification on alloy

The solidification behaviour of the Al7SiMg alloy is affected by ultrasonic melt treatment. The TNTDCP is improved by ultrasonic melt processing by 10°C at 700°C, 14°C at 640°C, and 27% and 51% at 700°C and 640°C melt the temperature, accordingly. At a lower point, ultrasonic melt processing enhances the microstructure of aluminium-silicon-magnesium alloys. (Grilo, J., et al, 2023)

Table 3: Thermocouples Advantages and disadvantages (Priecel, P., 2018)

Advantages	**Disadvantages**

• It is a non-contact temperature sensor device that transfers heat via infrared radiation. • In situations when contact-based sensors are impractical, • It is used to measure the temperature of moving objects. • There are smaller sizes available. • Using numerous thermocouple devices results in a higher output voltage. • It is reasonably priced and accessible	• Handle the sensor device with care; avoid oily, dirty, or dusty fingers; and clean the thermopile sensor with alcohol and a cotton swab for optimal performance. • To avoid damage, keep thermopile sensors away from direct sunlight and dampness. • To protect against static fields, keep unused thermopile sensors in conductive storage. • Monitor manual stress and polarity to prevent thermopile sensor damage caused by absolute maximum ratings. • The entire field of view of the thermopile sensor device must be used for accurate measurement of temperature.

Figure 7: Fiber Insulated Thermocouples

Platinum Resistance Thermometers (PRTs)

Platinum resistance thermometers are vital for accurate temperature measurements in process industries and labs, with IPRTs delivering tens of millikelvin sensitivity over a large temperature span.

Table 4: PRTs Advantages and disadvantages (Fernicola, V.C., 2008).

Advantages	**Disadvantages**

• This technique was largely justified by the lesser accuracy required by IPRT applications, as well as the advantage of sensor interchangeability provided by standard-compliant IPRTs. • They maintain a high level of stability across time • They provide good temperature sensitivity over a wide temperature span.	• They have a poor response time and are unable to manage abrupt shifts in temperature. • Because of the flow of energy going through them, they are prone to self-heating. • They are seldom offered with small diameters
• They have a higher resolution. • It is relatively simple to measure and calibrate.	

Figure 8: A Pt100 PRT (Fernicola, V.C., 2008).

Capacitance Diaphragm Transmitter (CDT)

A capacitance diaphragm gauge measures vacuum gas pressure by exerting energy on a thin diaphragm, whereas a standard capacitance vacuum transducer monitors absolute pressure. (Han, X. et al, 2021)

Table 5: CDG Advantages and Disadvantages (Han, X. et al, 2021)

Advantages	**Disadvantages**

• It can detect non-metallic compounds. • It can also be identified using certain materials. • It is simple to construct and customizable. • It is capable of detecting both thick targets and liquids. • It is less costly. • It has a higher sensitivity and can work with less force.	• It is particularly sensitive to environmental changes such as temperature and humidity. This will have an impact on the final result. • Measuring capacitance is more complicated than measuring resistance. • Capacitive proximity sensors are less accurate than inductive proximity sensors. • They aren't particularly sensitive to temperature variations. • Capacitive sensors have non-linear performance. • They are troubled by wandering capacitance.

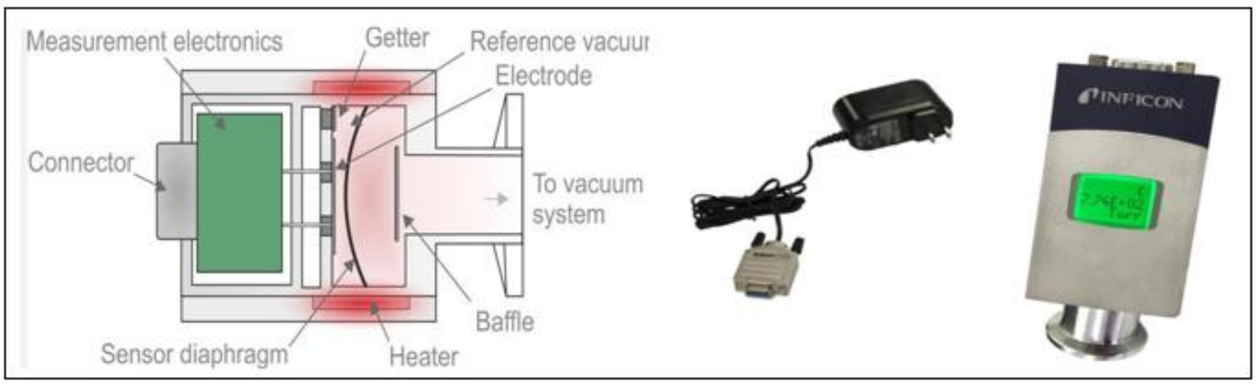

Figure 9: A CDG (Han, X. et al, 2021)

Silicon Diaphragm Transmitters (SDT)

There are numerous silicon transmitters available for various purposes, necessitating system developers' understanding of their purpose and suitability for tackling specific challenges in order to make the optimal decision.

Table 6: SDGTs Advantages and disadvantages (Blazquez, G., 1989)

Advantages	Disadvantages

• Because they use no DC current and measure capacitance via a signal, passive sensors are suited for low-power applications such as remote or IoT sensors. • Simple mechanical sensors provide durable, steady output in difficult situations and are resistant to overpressure. • temperature-sensitive with low hysteresis.	• They are prone to chemical damage. • They are not durable and are not intended for use in extremely high-pressure settings. • They do not work well at extremely low pressures.
• Capacitive sensors provide non-linear output, which is decreased in touch-mode devices, although they may produce hysteresis.	

Figure 10: An SDT (Fuentes-Pérez, et al 2018)

Chosen Sensors

Some essential parameters must be addressed while selecting the pressure and temperature sensors for the fuel cell flow metering system:

Safety: Both sensors are required to be able to react quickly to changes in the system and provide alerts when temperature fluctuations or pressure approaches dangerous levels, and they must be highly reliable.

Given this requirement and the qualities of gaseous hydrogen, the thermocouple was selected as an appropriate temperature sensor. Because their wires are physically exposed to the surroundings and places where temperature changes occur, exposed junction thermocouples have the best dynamic reaction time to rapid temperature changes when compared with PRT sensors, because their wires are immediately susceptible to temperature variations.

The sort of pressure gauge selected is the Silicon Diaphragm Transmitter. About the Capacitive form, they manage sudden variations in pressure quickly and have great reproducibility of recorded pressure points over many pressure cycles.

Metrology: Because both sensors will be placed adjacent to the flowmeters in the system to correct and compensate for their flow measurements, they ought to be as exact as attainable and mounted so that they do not change the flow measurement.

The PRT sensors were selected based on this need and the qualities of the hydrogen gas. They offer more exact readings for temperatures than thermocouples situated quite close to a flow of water, which allows for inaccurate measurement of temperature.

Because of its reliability and capacity to withstand pressure overload, a pressure gauge is a capacitance diaphragm transmitter, which provides superior accuracy. It also enhances the response time of the temperature sensors.

Temperature is a slow-moving variable in intricate loops that is normally heated in a tank with batch or constant flow components and just one direction regulated by outside forces.

Without cooling systems, process fluid heat can build up and overheat. Slow readings of temperature can lead to overheating; as a response, the process controller may turn off the heat when the sensor is close to the setpoint. However, as the method heats up, the actual temperature of the product may rise.

3. Flow Isolation

A valve in fluid handling systems controls the flow of process media, provides flow logic, and connects peripheral components by emptying or releasing fluids. Isolation valves in pressure measurement instruments prevent maintenance labour.

Valves manage fluid flow and halt it in specified instances; they are normally open for normal operation and shut down for maintenance or safety issues.

Flow Control

In control loops, nonlinearity in the process or control valve may exist. In this analysis, we assume negligible process nonlinearity around the data collection site. Under normal operating conditions, linear regulators can usually control facilities well, allowing for linear performance. It is a typical activity that can be accomplished by employing valves to improve or regulate flow rate and avoid fluid overflow.

Valve Types

Ball Valves

A ball valve regulates liquid or gas flow by employing a rotatable ball with a bore. It has a longer service life and more reliable sealing than gate valves, making it more popular as a shut-off valve. Ball valves withstand contaminated media better than other varieties. (Chern, M.J., 2007)

Figure 11: View our online selection of ball valves

They are often thought by users to be faster and easier to use than gate valves. (Chern, M.J., 2007). and can be utilized for both flow control and resolution. They were chosen to be employed for Flow Isolation in this system's layout. (Sotoodeh, K., 2019)

Valves for Needle Valves

Needle Valve for instrumentation and hydraulic uses, offering reliable and secure gas separation. Needle valves use conical discs to control flow in small pipes. (Sotoodeh, K., 2019)

The conical disc allows for highly precise flow management by allowing for a very progressive increase or decrease in the size of the hole; it is commonly employed in industries where precision fluid control is important. They were chosen to be employed for Fluid Control in this system design.

The signal of electricity

- A ball valve's lack of electrical components simplifies maintenance and lowers the need for specific technical expertise. This not only saves time and resources but also assures that the valve can be readily repaired or replaced in the event of a problem, reducing downtime in important systems.
- Actuators are used in ball valves for flow isolation, turning electrical impulses into mechanical movement and digital control, allowing full-on or full-off positions.
- Needle valve actuators use analogue electrical signals (0.00420 Amps or 0–10 volts DC) to control various positions, converting control signals into rotational degrees for efficient flow control within a range of settings.
  (Lee, D.E.,2008)

Signals PLC Modules

The isolation valve is controlled by the PLC module utilizing Digital Output (DO) for on or off and open or close position. Discrete signals 0- or 0-volts DC will cause the valve to be in the off or closed position as well, whereas a discrete signal of 1/12 volts DC will shift the valve to the ON or OPEN position. It will adjust itself to the proper position after receiving those instructions.

The PLC module for reading feedback signals that indicate valve position is called the Digital Input (DI). The Digital Input (DI) PLC modules are necessary for performing the On or Off, Open or Closed control signals (for example, discrete signal 0 or 0 Volts indicates the valve's status is at the Off or Closed position, while discrete signal 1 or 24 volts of DC indicates the valve is at the On or Open position).

The PLC module Analogue Output (AO) transmits instructions for the automatic position adjustment of the needle valve. The Analogue Output (AO) PLC modules are needed for controlling and moving the control valve (Needle Valve) to the appropriate locations. It will automatically relocate to the proper location after receiving directions to do so.

Using feedback signals, the PLC module Analogue Input (AI) determines the valve position and indicates valve acceptance at 50% open with 6 volts of DC from 12 Volts. (For instance, 6 volts of DC rather than 12 volts can alter the valve's opening state to 50% open from full). Analogue Input (AI) is a PLC module needed for reading valve position and transmitting signals for feedback (e.g., 6 volts of DC out of 12 Volts signifies the valve has achieved 50% open).

Conclusions.

The research investigates the significance of flow meters in industrial environments for accurate hydrogen flow measurement.

After comparing the two flowmeters, the ultrasonic flowmeter was selected due to its advantages in the gas flow measuring system and its simple installation.
The **Ultrasonic Flowmeter** was chosen for the flow of gas system's measurement due to its non-invasive setup function, among other advantages, after two flowmeters were studied and evaluated.
Based on their unique advantages, both pressure and temperature sensors were selected for gas flow measurement system safety and metrology needs.
Additionally, the best pressure and temperature sensors for use in a flow of gas measuring device were chosen, considering their advantages over other sensor types covered in this course of study for safety and metrology applications.
Valve types for flow isolation and control were investigated, and a Programmable Logic Controller was fitted to optimize observation, resulting in the development of reliable hydrogen flow measurement systems. A PLC was implemented to enable optimum monitoring and control of the valves after evaluating acceptable valve types for flow isolation and flow rate controls. The criteria described in this category will help in the creation of trustworthy and risk-free hydrogen flow measurement systems.

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