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Perspective

Overview of Control and Monitoring Specification Study to Help Reach Net Zero in the UK for Hydrogen Flow Measurement Network

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ABSTRACT

Currently, environmental damage appears a worldwide issue that affects everyone on the globe. With the goal of a net-zero carbon footprint by the year 2050, many nations have passed legislation, provided aid, and raised both public and private investment to encourage the use of renewable energy sources instead of traditional pathways like fossil fuels. Many other countries have made similar intentions to initiate their journey to an economy with no emissions at all including the UK. The current objective of this study is to review equipment for monitoring techniques and metering which helps to deal with the modern industry to attain net zero emission through the application of hydrogen. Ultrasonic and Coriolis flowmeters have been compared in terms of measurement techniques for hydrogen in the operative system. It has been identified that the petroleum and natural gas industrial sectors are using mass flow monitoring more frequently. Beyond absolute zero and at atmospheric pressures hydrogen becomes liquified. So, it proved essential to have a huge mass flow measuring apparatus having minimal uncertainty and proper and fixed measurement inaccuracy. Moreover, it has been evaluated that Programmable logic controllers are being used to operate the system to create a trustworthy control framework.

Keywords*:* Environmental Damage; Net Zero Emission; Renewable Energy; Flowmeters; Programmable Logic Controllers

1. Introduction

Currently, the degradation of the environment has become a global challenge that affects all mankind on Earth [1]. Consequently, multiple studies have been conducted through various research platforms to mitigate and eventually eliminate this problem, including the goal of reaching the net zero target [2]. Several states, including the UK, have made similar decisions to start the process of switching to a net-zero emissions industry [3]. It is the consequence of environmental studies showing that reducing only carbon emissions could not be sufficient to slow down global warming [4]. A state known as "net zero" occurs when every harmful substance is balanced out with equivalent quantities being taken in from the environment. According to climate science, the quantity of carbon dioxide, that is added to the atmosphere by human actions, ultimately determines how much global warming can possibly occur [5]. In the process, the climate will shift more dramatically the longer it takes to stabilize climate change. Furthermore, there is also a need to limit the emissions of other greenhouse gases, such as methane. The world's climate must be balanced by achieving zero carbon dioxide emissions [6].

Hydrogen is expected to play a key role in lowering carbon emissions across a number of industries [7]. In a fuel cell, electrolysis is a process that splits water that requires power, a conductive liquid, and a metal catalyst that makes hydrogen [8]. Water is broken down by electricity into hydrogen and oxygen. The released hydrogen is capable of being utilized as an application in fuel, in the welding industry, or used as inhalation therapy to treat respiratory conditions such as COVID-19 [9].

Hydrogen has the same potential for energy storage as electricity, however, it requires a power source like renewable energy or fossil fuels in order to be produced [10]. As a result, converting hydrogen into a productive form requires a significant amount of additional energy [11]. The technique and power sources used to manufacture hydrogen give rise to the several color classifications that are commonly associated with it [12]. For instance, coal is used to create black or brown hydrogen, while methane gives grey or blue hydrogen. Both emit greenhouse gases and rely on fossil fuels [13]. While, the majority of the electricity needed to produce green hydrogen must originate from renewable energy sources including solar, wind, and geothermal energy [14].

Figure 1: Measured and Controlled Hydrogen flow across the Pipeline to achieve net zero [7].

One main future advantage is that there is no carbon or other greenhouse gases released by the end product i.e. hydrogen and oxygen. It would help the steel industry become less carbon-intensive by taking the place of fossil fuels in steel manufacturing [15]. It will also be transported to companies and the chemical in- dustry as a source of energy. Additionally, hydrogen could promote the yearly storage of green energy and boost the decarbonization of robust and distant transportation [16]. The need to measure hydro- gen production and transportation is increasing in line with the cost of hydrogen technologies [17].

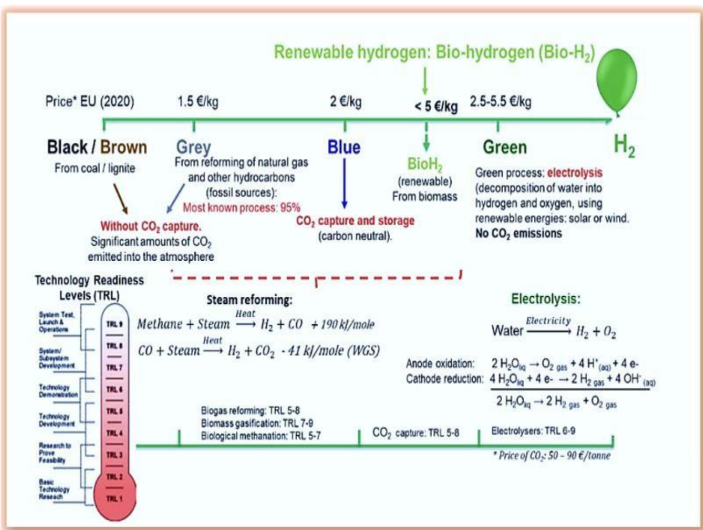

Figure 2: A Summary of Economical, technical and diverse Sources of Hydrogen [18].

The aim of the study is to overview the stability of control parts and satisfy standards that will meet with the current industry as well as overlook the monitoring and managing system of the hydrogen flow through a pipeline to achieve net zero for a better future in the coming era. As flowmeters play a significant role in accurate hydrogen flow metering systems, for this purpose a com- parison has been made between the two flowmeters. The view of the best suitable flowmeter for measuring hydrogen has been examined in this study. Furthermore, we discussed the sensors installed in pipelines for safety to determine the metering of Hydrogen. In the end, the overview of Programmable logic controllers has been studied for control and indication of electrical components.

2. Flow Measurement Methods

2.1. Flowmeters for the Hydrogen Monitoring System

The flow meter is a measurement instrument used to determine the volume of liquid, steam, gas, powdered material, or a mixture of these components that moves through a pipeline or vent in a particular period of time [19]. Various measuring techniques have been employed, depending on the fluid's kind and state, the measurement purpose, and other criteria such as the measurement loca- tion. Usually, mass or volume is used to measure hydrogen flow [20]. There has been a great innovation in the flow measurement technologies involving both Coriolis and ultrasonic flowmeters, this is the reason it is pertinent to compare the two-meter categories [21]. Moreover, Coriolis and ultrasonic flowmeters have the fastest rates of growth for numerous processes, possibly with the addition of multiphase flowmeters [22]. The advantages and disadvantages of each method of detecting hydrogen flow have been discussed in this work. Coriolis and ultrasonic flowmeters have extensive applications in the oil and gas sector for hydrogen custody transfer [23].

2.2. Basic Operating Principle for Coriolis and Ultrasonic Flowmeters

There are several physical, mechanical, and electrical concepts that underpin all types of flowmeters. With an ultrasonic flowmeter, the flow rate through a pipe is measured using sound, a fundamental physical variable [24]. They are employed in the measurement of the volumetric flow of the fluid, or the number of liters per unit time of flow. Temperature, pressure, pipe diameter, and fluid viscosity are some of the factors that affect the velocity of a fluid running through a pipe in a single stream [25]. The rate of flow accelerates when there is a pressure differential across a particular location in the pipe as well as its downstream position. Higher temperatures usually lead to higher flow while other parameters stay the same. Certain fluids are clear, whereas others contain particles or air bubbles. Similar to this, some fluids like heavy oils, move relatively slower compared to others because of their high viscosity [26].

An ultrasonic flowmeter's main operating principle is to measure the time that is necessary for a signal to move with the flow. The Doppler and transit-time ultrasonic flowmeters have been the two primary forms employed in the measurement system [27]. Transit-based ultrasonic flowmeter with a time base: They need a pair of actuators and at least one sensor to function. Any of them might be the transmitter or recipient [28]. A specific angle is ap- plied to transfer the ultrasonic impulses, while the flow gauge measures the duration that it takes for an electrical signal to go through the pipe from one end to another. The time variation across the two pulses is related to flow rate or it is called flow velocity, taking into consideration the medium's sound speed. Doppler meters monitor the flow of unclean fluids; they are not used to measure the flow of gas. Transit-time ultrasonic flowmeters, on the other hand, are mostly used with clean fluids [29].

Coriolis flowmeters are composed of certain vibrating tubes that can be found in straight and frequently curved varieties. The fluid that is being monitored can travel via oscillating tubes [30]. The fluid accelerates as it gets closer to the location of maximum vibration and decelerates as it leaves this point. Pickoff coils traveling through a field of magnets at the inlet and outlet points create a sinusoidal wave. The amount of rotating motion in the tubes on both sides and the phase shift or time difference are directly related to mass flow [31].

2.3. Coriolis Vs. Ultrasonic Flowmeter

Ultrasonic flowmeters had very little pressure drop and full-throttle operation, so they could support very large pipe sizes without any limitations. Ultrasonic flowmeters have many benefits, including backup features, low maintenance requirements, cost-effectiveness, relevant testing, high stability, high turn-down percentages, extended longevity, and a lack of moving parts that make them immune to oscillating flow [20]. Ultrasonic flowmeters are used in upstream applications such as placement metering, test measurement, and measuring oil and gas from production units. They are usually used for custody transfer in the intermediate sec- tion of the natural gas pipeline. The ultrasonic flowmeter's Multi- path design provides incredibly accurate measurements of gases and liquids [32].

For the application of hydrogen flow, it is necessary to take into account a greater speed of sound and less density. The lower density of hydrogen has resulted in a decrease in sound resonance be- tween a transducer and the hydrogen gas, making it more difficult for the ultrasonic signal to travel between the transducer's producing and receiving ends. Consequently, the signal-to-noise ratio for hydrogen is lower than for natural gas. Since the signal-to-noise ratio increases as pressure increases, ultrasonic flow measurements of hydrogen gas are still conducted at atmospheric pressure. The rapid sound speed of hydrogen allows the ultrasonic signal to move swiftly between the transducers [33].

Because of the short transit time, the receiving transducer must be ready in advance to receive the signal from the sending transducer [27]. The large opening angle can cause crosstalk, especially in pipes with tiny diameters. Using transducers with higher frequencies can help reduce interference. Flowmeters are often checked using natural gas, water, or air since there are not any large-scale hydrogen flow calibration facilities currently authorized by ISO 17025. Depending on the flow distribution inside the meter, ultrasonic flowmeters can be calibrated using a Reynolds number [34]. For example, one can use natural gas at an eight-fold lower flow rate or pressure to calibrate a flowmeter to obtain the Reynolds figures shown on a hydrogen application. By taking into con- sideration a few more elements, natural gas calibration can be ap- plied to hydrogen applications [35].

Early Coriolis flowmeters were not widely accepted due to technological difficulties. Resonance problems made zero-point consistency difficult to maintain in bent tubes. A large number of commonly used Coriolis flowmeters have an accuracy of 0.1 to 0.05 percent and require very little maintenance. Coriolis flowmeters are useful in chemical reactions where mass vs volume is important since they can also be used to quantify mass flow. Because mass flow may be exposed to temperature as well as pressure significantly much faster as compared to liquids, it has proven particularly helpful for measuring gases. As a result, mass flow monitoring is used extensively in the natural gas and petrochemical industries [36].

When measuring mass, density, and volume movement over long distances, Coriolis meters provide incredibly precise results. The meters are still capable of measuring multiphase flow and pro- vide a precise mass measurement that is not reliant on flow parameters. It is crucial to ensure that the flowmeter satisfies the minimum density requirement for measuring gases, especially low-density hydrogen, in order to ensure the flowmeter's operation [38]. This essentially indicates that there should be little pressure on custody transfer applications.

Figure 3: The combined flow mass analyzing equipment at KROHNE Coriolis's production site, Welling Borough, UK [37].

Since Coriolis meters measure mass by vibrating one or more tubes, its maximum pressure of operation is dependent upon these relatively thin-walled tubes. Hilko den Hollander, KROHNE, et al. also confirmed that thicker, more difficult-to-vibrate tubes are re- quired for higher pressures (often above 200 bar), which may result in some accuracy loss for the Coriolis meter [39]. Coriolis meters are not greatly affected by flow profiles. To guarantee optimum performance and accuracy, meters have been tested frequently using water over an accurate calibration testing workplace equipped with a highly precision measuring balance. It is possible to perform calibrations without using the same fluid that will be used in the final product [22].

3. Instrumentation for Flow Measurement

3.1. Pressure and temperature sensors

Pressure sensors help service providers take preventative action by warning them of possible issues before they get out of line. The seven main types of pressure sensors are aneroid barometers, piezoelectric, bourdon tubes, sealed, aneroid barometers, and vacuum (Pirani) sensors. The most often used types of pressure sensors are transducers, including strain gauges and piezoelectric sensors. In industrial applications, these are used to monitor airspeed, flow, high levels, and pump mechanics.

A typical requirement for measuring the heat or coolness of liquids, solids, and air is temperature sensors. The device's electrical signal delivers readable temperature readout. While there are many different types of temperature sensors available on the market, thermocouples, thermistors, and resistance temperature detectors (RTDs) are the most well-known types. In conclusion, Resistance Temperature Detector (RTD) temperature sensors are used in manufacturing processes that require high-accuracy measurements because they are incredibly reliable and exact temperature sensors. However, depending on the sector or application of your service, the kind of temperature sensor you need will vary [40].

3.2 Suitable Temperature and Pressure for Hydrogen metering system

As a result of a molecular weight of 2 g/mol, hydrogen is regarded as the lightest element in the periodic table. Consequently, its density is eight times lower than that of natural gas. Despite this, hydrogen has a sound speed that is around three times faster than that of natural gas. In contrast to natural gas, hydrogen contains a higher ratio of energy per unit mass and a lower ratio of energy per unit volume. For the effective usage of hydrogen for transit applications, there is a requirement of high gauge pressures of roughly 350-700 barg, whereas manufacturing processes and pipeline transmission use medium gauge pressures of 30-60 barg. On cooling hydrogen becomes liquified below atmospheric pressure of about -423 °F (-253 °C) and its boiling point of approximately 20

K. A huge flow mass assessment device with a reported estimation error of ±0.05% as well as below 0.017% ambiguity would have been required.

	Technology	Detection/ device type	Concentration range (H_2)	Accuracy for H_2	Temperature range	Pressure range	Response time	Moisture admitted
Intrusive methods	μGC	TCD	>0.3 ppmv	0.8–10 ppm (< ppm μTCD)	Ambient T	<2 bar	<3 min	no
		FID	>0.3 ppmv	low ppb to high ppt				yes
		PDD/PDHID		100 ppb				yes
	GC	FID, MS	50 %vol	low ppb to high ppt			1–10 min	yes
	MS	QMS	100 ppm-100 vol% (>0.1 wt%)	low ppb			10 ms	yes
		ITMS						yes
	Electrochemical techniques		>0.3 ml (H_2)/min in 100 ml (H_2 flow)/min [90]					
Non-intrusive methods	Mass flowmeters/ flowcontrollers	Thermal	0–1000 l/min	1–3%		<35/70 bar	2 s	
		Coriolis	1 g/min to 30 tons/min	0.1–0.15% of Qmax or Qmin	−253 °C–350 °C	<1400 bar	10 ms	yes
	Sensors	Direct sensors	0.1 to 100 %vol	0.1–10% vol	−20 to 50 °C	Atm P	<30s (T50) 2–90 s (T90)	Limited (15–90% relative moisture)
		Indirect sensors (O_2)					<1 s	

Figure 4: Operation of the primary analytical technique for monitor- ing, assessing, and identifying hydrogen [38].

Noble metals, such as platinum, have the ability to absorb hy- drogen, which can alter their physical properties and serve as the foundation for hydrogen sensors. The sensitivity of the hydrogen sensor or its broad applicability to a range of dangerous gases de- termines the reaction time [40].

3.3 Pipeline Installation System for Hydrogen Metering System

Manufacturers can fulfill any installation requirement by offering a variety of transmitters, stainless steel, two-wire, and direct-connect options. By evaluating the dependability of the system through Smart Meter Verification, uptime can be increased without stopping the meter's operation. Minimize maintenance and improve continuous reliability without wearing down moving parts or requiring replacement [7].

While transporting hydrogen, the pipeline must be checked for rust because any weak spots could explode and result in cata- strophic explosions. It is recommended to make use of non- intrusive degradation measurement devices and to ensure that the instruments are connected digitally to the main site of sample col- lection. The Coriolis meters do not need much maintenance and are incredibly dependable. The meter also has an automatic inspection device and a smart verification meter, allowing users to check flowmeter efficiency in real-time without interfering with the flow [41].

3.4. Techniques for Control and Valve

Operation various types of Valves for flow Isolation and Control

For diverse applications in diverse industries, three types of pressure relief valves are commonly used: Relief valves, Safety valves, and Safety Relief Valves. There are several classifications for the safety relief valve: standard, pilot, pressure & temperature, power, and stable loaded-spring pressure valve. The sharp screech will diminish once switch to a pilot-operated relief valve. The hy- draulic circuit must be understood in order to determine whether the pilot-handled relief valve remains adequate to prevent harm to the system. If you're not sure your pilot-driven relief valve can manage the task, your best option may be to pair it with a small direct-acting relief to minimize the damage caused by pressure spikes. Our broad range of designs, with a current maximum pres- sure of 10,000 psig, provides a range of pressure relief valves that are appropriate for hydrogen applications involving cold to high- temperature hydrogen, based on our significant expertise and cur- rent knowledge of hydrogen. It may be possible to achieve higher pressures depending on the application [41].

3.5. Anderson Greenwood and Crosby pressure relief valves

Applications for gaseous and liquid hydrogen have been met by Anderson Greenwood and Crosby pressure relief valves for more than 60 years. Hydrogen measurement systems have made use of direct spring and pilot pressure relief valves. The advertised performance of a product is unaffected when used in hydrogen service, and each actuator needs to be defined and calibrated according to its intended use. For hydrogen applications, some aspects like hydrogen blending scale, appropriate temperature, and partial or total pressure for suitable material have been significant considerations [42].

Table 1:
Precise Set of Process Constraints and Demands for Pressure Relief Valves by Emerson Integrated Solution Company [42].

Pilot Operated Pressure Relief Valves	Direct Spring Pressure Relief Valves
Anderson Greenwood 200 Series, 1”x2” to 10”x14”	Crosby J-Series 1”x2” to 12”x16”
Anderson Greenwood 400 and 800 Series, 1”x2” to 10”x14”	Crosby OMNI, ½”x1” to 2”x2”
Anderson Greenwood 90 and 9000 Series, 2”x3” to 14”x18”	Anderson Greenwood 80s Series. ½”x¾” to 2”x3”

3.6. PLC Module type

PLC A programmable logic controller (PLC) is being implemented to function the system to develop an accurate management structure. Because of their relatively basic design and easily available programs, PLCs are more useful for engineers and scientists. Experts can diagnose and repair them with more ease. For the cen- tral processing unit to function and provide output, input devices are required. Sensors and transducers, which convert physical ob- servations into electrical impulses, are used to accomplish this pur- pose. Digital sensors give a single on/off pulse. Mechanical switch- es emit an on/off signal based on location. The circuitry of a volt- age transducer establishes a direct connection with the line it is measuring, in contrast to a current transducer [43]. For data collection, MATLAB software is installed on a different PC.

The emergency shutoff buttons are conveniently located throughout the two structures. The entire system is turned off when the emergency shutdown buttons are hit, which sends an electrical signal to the controller (PLCs). Similar to smoke sensors, hydrogen sensors will be installed in the ceilings of every structure. Because hydrogen is so powerful and flammable, it's crucial to maintain its airborne concentration below 4%. The digital signal has been sent to PLCs by hydrogen sensors if the air contains three percentage points of hydrogen. Reducing the number of controllers needed while maintaining autonomous functioning is the aim of automation system design. The different control forms were categorized to generate the following sections: switches and valves for gas [16].

4. Conclusion

The worldwide decrease in greenhouse gas emissions and sustainable growth have been identified as key subjects for study in order to assure future prosperity and energy stability. In the future, some hydrogen colors might become less important whereas several others might flare strongly. It has been observed that hydrogen categories play a necessary role in achieving net zero by developing powered transport and industries instead of traditional dependency on fossil fuels. It has been concluded that when it comes to measurement techniques, Coriolis flowmeters prove more beneficial in operating systems for hydrogen rather than ultrasonic meters. Since hydrogen has a lower speed of sound and less density. So, the adoption of mass flow monitoring growing increasingly in the petroleum and natural gas sectors. The result has reviewed that higher pressures of approximately 350-700 barg have been required for hydrogen transportation and moderate pressures of about 30-60 barg have been utilized in industrial and pipeline transmission systems. A massive mass flow measurement device with a reported uncertainty of lower than 0.017% and about 0.05% estimation error would be mandatory. Programmable logic controllers have become more approachable to researchers and engineers due to their relatively simple architecture and simple-to- operate programs. This also makes it simpler for professionals to diagnose and repair them. It has been reviewed that some parameters like partial pressure and temperature have to be known for pressure relief valves for the next suitability for hydrogen application in net zero journey.

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Data Availability: The data is given in the paper.

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