

Gas Cylinder Meter with Cloud Data Management

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Abstract

A thermal mass flow meter with micromachined sensing elements is designed and manufactured to address the accurate gas consumption, remote data and connectivity of gas cylinders in particular for medical, food and fuel supply industries. The designed flow meter has a rugged and compact enclosure whereas the flow dynamic range is over 100:1 with the mass flow totalizer capability. Verification of the metrology properties of this design was performed with a precise scale which weighted the gas consumption directly from the weight loss of the cylinder during usage, and compared to the totalized mass flow measured by the meter. The data transmission is realized via a Bluetooth and a smart device APP, or with a 3G/4G network or a NB-IoT or similar wireless network. For the grouped gas cylinders, the meter could also register each cylinder before usage or via a programmed consecutive register alert that can be timely sent to the end user. The data relayed to the cloud via the smart device/APP or a concentrator enable the gas cylinder user and suppliers to instantly access the cylinder status. The system enables the effective management of the gas cylinder manufacture, inventory and delivery. It also provides added value services to the end user who shall be timely notified for any programmed gas consumption.

1. Introduction

Gas cylinders have a variety of applications from medical operation to daily clean cooking. Gas cylinders are regulated via a mechanical valve with low accuracy pressure gauges and management of such is largely based on estimation only. Australian gas company El Gas is teaching its domestic customers to use a cup of hot water to alter the surface temperature of a cylinder resulting in a metering of the gas volume remained in a home fuel gas cylinder [1]. Some recommendations in the web-based knowledge even suggest a shaking of the cylinder would give the user a hint for the amount of the gas left inside the cylinder. These approaches are by far the accurate ones but also all have potential safety issues.

The domestic usage of the fuel cylinders would be mostly a matter of convenience, but in other applications instant knowledge of the gas status in a cylinder could be critical and helpful for not only gas consumers but gas cylinder suppliers. For example, medical oxygen cylinders have a large user base in a metropolis where the home care patient who needs oxygen therapy is still relying on the telecommunication with the suppliers. In this application, the suppliers could not manage the delivery of the needed cylinders in advance without

the knowledge of the instant status of the cylinders. In a large city, even the unexpected traffic conditions may prevent a promised delivery leading to customer complains. In addition, the suppliers must also constantly keep excessive inventory at various locations to meet the unexpected demands. In some cases, the failure of the timely supply would have even cost the loss of human life. Therefore, it is desired to develop not only a smart meter but a system that shall facilitate the usage of the cylinders. In a most recent disclosure [2,3], a special device is proposed to monitor the remaining gas volume of a gas container. Inside the special device a flow meter is used to measure a plurality of flowrates that vary when the gas is being consumed. However, the disclosed device for the gas consumption is based on a rolling mean or average of a plurality of non-continuous measured flow rate that may be quite deviated from the actual mass as it also requires the knowledge of the gas density, pressure and temperature. The disclosed device has a capability to be remotely connected to a system for the remote gas data management. This device requires external power sources and additional valves since it is an add-on unit, if direct attached to the high pressurized gas cylinder, it may have some safety risks, and particularly not all locations where a gas cylinder is placed would have an accessible power source, which then eliminates

the claimed application potentials. In another efforts, Linde Gas has developed an EVOS gas valve with electronic data transmission capability [4]. This valve utilizes the pressure sensor to estimate the consumption of gas volume and relay the data to the control centre for cylinder management. Nevertheless, both of the above systems are extremely costly compared to that for the current mechanical regulator and would not be practical for domestic applications.

In this paper, a battery powered device using mass flow sensing technology with micromachined thermal calorimetric sensors and cloud data enabled functions for the gas cylinder management is reported, and the corresponding applications are discussed.

2. Design of the device

2.1 Mass flow meter design

For a typical gas cylinder, a pressure regulator with mechanical pressure gauges is a standard accessory since the pressure inside the cylinder shall be too high to be directly connected to the devices for the end user. The traditional regulator for the cylinder is normally having two mechanical pressure gauges, one gauge is to measure the pressure inside the cylinder and another one to gauge the pressure in the pipeline to the end user. As the meter is designed to precisely measure the gas consumption via the pipeline to the end user, the mechanical pressure gauge at the outlet of the regulator is then not necessary and can be completely replaced by the meter. In order to have an easy adaption, the design of the flow meter is desired to be compact and easy to be connected to the outlet of the traditional pressure cylinder regulators.

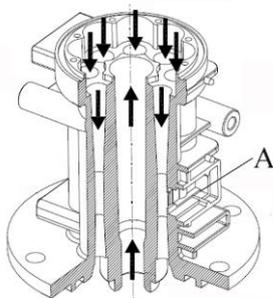


Figure 1: The flow metrology module mechanical design for the smart cylinder mass flow meter. A - is the location where the flow sensing elements are placed.

For the most of the industrial and medical gas cylinder applications, the end user pipeline pressure is within 10 bar and the mass flow rate is within 50

SLPM. In order to have the flow meter's mechanical dimension compatible to the most of the pressure regulator while the performance of the meter should meet these requirements, the conventional straight or bypass flow channel design would then not be feasible, and alternative design approach was considered. Figure 1 shows the designed flow metrology module with split flow channels, where the flow inlet is at the bottom central position and then the flow path splits into eight channels after it entered into a small buffer chamber at the top of the flow metrology mechanical module and the gas is further released from the bottom of the module. The channels are identical in its mechanical dimensions and distributed symmetrically with respect to the central flow inlet channel. The micromachined flow sensing element chip (indicated by letter A in Figure 1) is placed at the wall of one of these eight channels which have the configuration of the Venturi structure. The sensing elements are at the throat of the Venturi flow channel which helps for maintaining a better measurement stability.

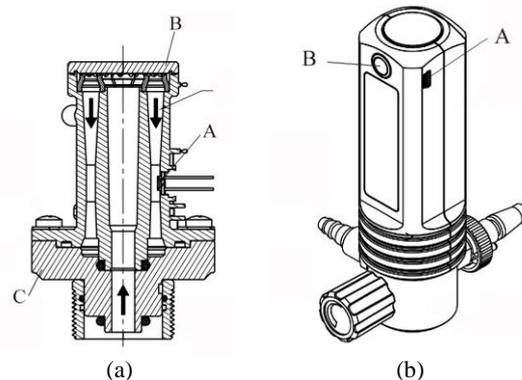


Figure 2: (a) the cross-section of the complete flow metrology module assembly where B is the top buffer chamber cap and A is where the flow sensing elements are located; and (b) the fully assembled smart flow meter for gas cylinders. The wired data port and external power socket is indicated by A, while B is the reset and functional selection button.

Figure 2 shows the assembly of the meter design. Figure 2(a) is the cross-section of the metrology module assembly. The flow metrology module shown in Figure 1 is made of polycarbonate inject mould and is installed onto a metal base C where the flow inlet and outlet are respectively at the central and outer circular path such that the base can also accommodate a manual control valve (Figure 2(b)) providing the capability of precisely adjusting and control of the gas supply, which is particularly important for medical applications. The capability of addition or removal of the mechanical connection ports from the meter base also provides the full spectrum of compatibility for different gas cylinder applications. For industrial applications, the manual valve would not be required, while for

medical applications such as oxygen delivery the adjust valve will be mandatory and this configuration also made the connection to a humidifier water cup much easier. The flow conditioners can be added to the buffer chamber B at the flow module to ensure the flow measurement stability. The reset and menu button B shown in Figure 2(b) provides the easy access to the meter for setting the password, switching the display from totalized readings to instant flow readings and resetting the totalizer. The completed assembled meter as shown in Figure 2(b) also has the battery chamber that accommodates two AA-size batteries or the same sized rechargeable batteries. For continuous measurement, the battery could work up to 90 days. A new sensor chip is being designed with a target for 180-day continuous measurement. The meter is incorporated with a wireless module that can be interchangeable depending on the application requirements. The available modules include a low energy Bluetooth (BLE), a 2G/3G/4G, a LoRa or a NB-IoT module. The APP is downloadable directly from Apple Store or Google Play Store under the name of *SmartCylinder* by Siargo. For gas cylinders delivered in a rack, the meter could also register each cylinder before usage or via a programmed consecutive register alert that can be timely sent to the end user as well as to the cloud server. The data relayed to the cloud via the smart device/APP enable the gas cylinder supplier as well as end user to instantly access the gas consumption information at each gas cylinder installed with the smart meter. A wired data port A shown in Figure 2(b) is also made available for wired data transmission or download the stored data in the meter in case the data transmission failure or power failure. The meter together with the cloud platform forms a system that allows the effective management of the gas cylinders for gas cylinder supplier for its management system for manufacture, inventory and delivery. It also provides added value services to the end user who could gain the accurate gas consumption and be alerted for the usage instantly.

The complete connected smart mass flow meter design utilizes an integrated control electronics with the micromachined sensing element targeting at a cost comparable to the quality mechanical pressure regulator for the gas cylinders, and can be massive manufactured and deployed.

2.2 Cloud data and system

Figure 3 shows the sketch of the smart gas cylinder system. The smart gas cylinder mass flow meter shall replace the outlet mechanical pressure gauge of the gas regulator. Depending on the specific applications, the mass flow meter shall opt one of

the wireless or even wired communication protocols to transmit the data to the cloud server. For example, if both local wireless and remote data are required, and a local smart device is readily available, then the mass flow meter with a BLE module shall be preferred, and the data can be relayed to the local smart device such as a smart phone with the designated APP. The local user with the smart phone will have direct access to the connected cylinder status while the data shall be simultaneously logged and transmitted to the cloud server via the data connected smart phone. In this example, the smart phone could also interact with the mass flow meter to reset the initial gas volume, timer, and perform other user defined functions, such as set the alarm level of the gas volume in the cylinder. Additionally, any relevant and authorized party can access the data anywhere via the cloud server to interact with the meter via the smart phone. This will be particularly helpful in case of a safety alarm or tariff related issue for the remote service providers. In case that a local smart device is unavailable or local data is not desired or required, the mass flow meter with a 2G/3G/4G wireless module can be selected. The data acquired from the mass flow meter can then directly be relayed to the cloud server for the authorized party to process. Per the common data safety practice, the acquired gas cylinder data by the mass flow meter shall also be stored into the plural number of memories in the control electronics inside the mass flow meter. These data can be readily downloaded to the authorized devices via the USB data port on the mass flow meter.

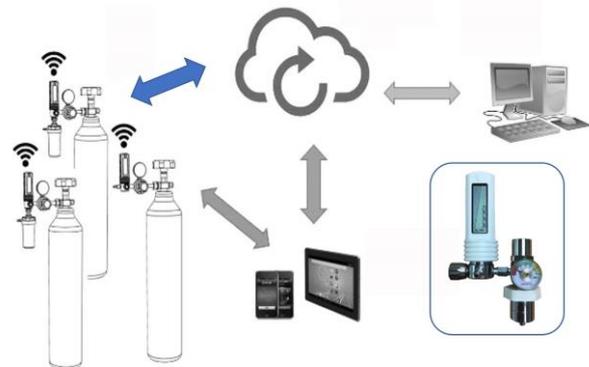


Figure 3: Schematic presentation of the smart gas cylinder management system where the smart gas cylinder meter is installed at each of the cylinder in the loop and the data are relayed to the cloud server directly or indirectly. Authorized users can interact with the gas cylinder via the cloud server. The insert shows an actual meter with a pressure regulator for medical gas cylinder

The complete meter-cloud server system discussed above can be fully customizable and the instant

data will make the close loop beneficial for both end users as well as the gas cylinder suppliers when the manufacture and inventory as well as delivery could be fully controlled.

3. Flow meter metrology verifications

Verification of the metrology properties of the designed mass flow meter was performed with a precise scale with an accuracy of $\pm 1\%$ which weighted the cylinder before and after gas consumption and compared to the mass flow totalization measured by the meter installed on the same gas cylinder. For the cases of interests, a 12 kg capacity LPG gas cylinder connected to the LPG cooking appliance is used for this purpose. By adjusting the difference burning/cooking conditions, the different gas consumption can be obtained, then the data from each measurement were recorded and the comparison can be then corresponded. Another verification was done with an oxygen gas cylinder for home care, and similar procedure for comparison of the scale measured weight loss and flow meter obtained totalized mass flowrate were performed.

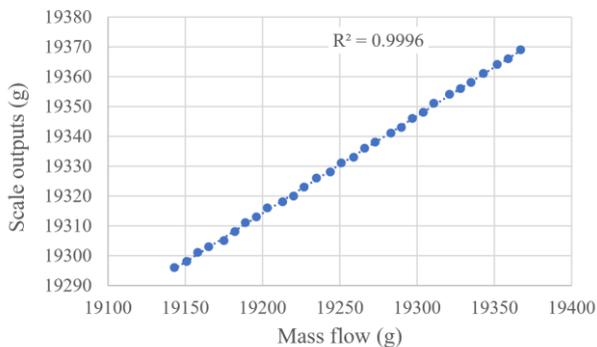


Figure 4: Mass flow meter readings against the scale outputs for a 12 kg LPG gas cylinder.

Figure 4 showed the measurement results from the comparison of the scale readings and the mass flow meter totalizer data from a 12 kg LPG gas cylinder connected to a cooking appliance. The mass flow meter was calibrated by air and converted to the LPG with a LPG gas conversion factor that was previously determined. The meter was reset to synchronize the readings by the scale before starting the verification measurement. The set of the measured data was acquired in a thirty-minute time period and each increment was one minute. It can be seen clearly a linearity of these two readings was well demonstrated which led to a narrow error band within about $\pm 1\%$ that was beyond the accuracy attested.

Further verification measurements were performed with the same sized LPG cylinders having the scale as the reference as well but the data were collected at a random time period. Figure 5 shows the data collected from 10 such measurements. The verification measurement exhibited an $\pm 2\%$ uncertainty, which is well within the design target.

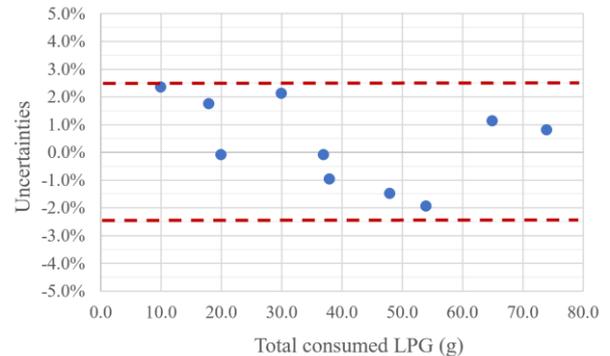


Figure 5: LPG gas consumption test data.

4. Application examples

There are vast numbers of gas cylinders on market. Some applications obviously may not require the connectivity and remote data, but the connectivity and cloud data can certainly provide critical benefits to a number of applications. These applications include:

- Medical gas cylinders, in particular for home care oxygen therapy supplied with cylinders. Currently the oxygen cylinder status is reported by the users and suppliers do not have any remote access to the status. There were reports of life lost due to the failure of timely delivery of the oxygen cylinders. On the other hands, the remote data access helps the manufacturer significantly in inventory and delivery management. Other than the home care oxygen cylinders, the connectivity can also effectively assist the management of the anesthesia gas cylinders used inside the ambulance or oxygen cylinders in hospitals.
- For clean energy gas home applications, LPG or LNG cylinders are main sources in many countries where energy gas pipeline sources are not available or too costly, for example, in many African countries, India, Australia etc. The connectivity and remote data shall help the energy saving, tariff management and a better lifestyle.
- For food industry, to preserve the freshness of the sea food, oxygen supply in vehicle via gas cylinders would be necessary during long

distance transportation. Management of these cylinders are very labor costly as each cylinder is required to be checked for its remaining volume before a new load of transportation. In some countries, food truck serving lunches or hot fast food often has its cooking energy supplied by the gas cylinders, status of those would certainly ease the efficiency of the performance.

- Other demanded applications include the industrial processing gases supplied by gas cylinders such as welding gases. Some special and expensive gas cylinders shall also appreciate the remote data for the management and cost saving.

5. Concluding remarks

The paper presents a design of a precise mass flow meter powered by batteries with wireless or wired connectivity for gas cylinders. The design is with a cost-effective approach targeted to replace one of the mechanical pressure gauge on the standard gas cylinder pressure regulator. The cost for the final product including the pressure regulator is comparable to that for current high-end mechanical pressure regulators. The connectivity and remote data from a cloud server significantly boost the gas cylinder management, cost saving, process control, user experience as well as safety. The connectivity may also reduce the loss of cylinder or facilitate to cylinder cycling. It benefits both the gas cylinder suppliers and end users.

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