# Technical Information

TI 11T03E01-01E

## Model GD402
Gas Density Meter

EXAGD

# CONTENTS



YOKOGAWA ◆


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# 1. Overview

The GD402 Gas Density Meter is a process gas analyzer which exploits the principle that the resonant frequency of a thin-walled cylinder will vary according to the density of the gas surrounding it.

The cylindrical resonator is constructed of stainless steel for enhanced corrosion resistance. The outstanding performance, with extremely low drift due to dust accumulation and temperature variations, is achieved through the use of a multi-mode, self-exciting oscillator circuit.

Superior reliability, and ease of maintenance and operability, are obtained by employing a microprocessor-based converter with a large digital display, providing features such as one touch calibration, self-diagnostics, free setting of measurement range and hi/lo alarm points, a variety of contact output functions, and both digital readout and data transmission of measurement and setup parameters.

In addition to gas density, the analyzer can also be used to measure physical quantities which can be computed from density, such as specific gravity, molecular weight, gas concentrations, hydrogen and caloric values.

**GD402G General purpose Converter**

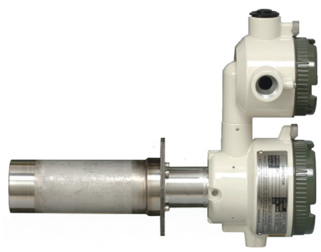
Rainproof for outdoor use

(equivalent to IP65/NEMA4X)

**GD402T, V, R Explosion-proof Converter**

Rainproof for outdoor use

(equivalent to IP65/NEMA4X)



**GD40G, T, V, R Detector**

Rainproof for outdoor use

(equivalent to IP65/NEMA4X)

# 2. Features

## PROVEN DESIGN

Highly responsive and sensitive measurement of density. Specific gravity, molecular weight, gas concentration and hydrogen can also be displayed using Yokogawa's gas density analyzing techniques.

## DETECTOR FEATURES

- Resistant to external vibrations.
- Outstanding stability against sudden changes in gas temperature (within 1 $g/m^3$ (6.2 x $10^{-5}$ $lb/ft^3$)) for sudden changes in gas temperature of 10°C).
- The multi-mode self-oscillation circuit minimizes drift caused by the sensor itself or by oil mist, dust, moisture, etc. sticking to the sensor.
- Easy cleaning and regeneration of sensor.
  Should the sensor be contaminated with dust and/or mist, then it can be easily cleaned and returned to its original condition.
- Only routine maintenance is required.
  (for example, once per 3 months depending on application.)

## SIMPLE, USER-FRIENDLY INTERFACE

Configuration can be performed locally via the front panel or remotely by using the (optional) "Brain" terminal.

## LOW INSTALLATION COST

Both explosion-proof and general purpose converters are designed for easy mounting on a pipe. Wiring between the detector and converter is based on a two-wire system, keeping installation cost to a minimum.

# 3. Specification

**GD402 specification list**

| Item | Density kg/m³ | Density lb/ft³ | Specific Gravity | Molecular Weight | Concentration vol% |
|---|---|---|---|---|---|
| Range | 0 - 6(compensated)<br>0 - 60(physical) | 0 - 0.4(compensated)<br>0 - 4(physical) | 0 - 5 | 0 - 140 | 0 - 100 |
| Minimum range | 0.1 | 0.01 | 0.1 | 4 | Concentration equivalent to 0.1 $kg/m^3$ |
| Response Time 90% | approx. 5 sec | approx. 5 sec | approx. 5 sec | approx. 5 sec | approx. 5 sec |
| Linearity | ±1 % FS | ±1 % FS | ±1 % FS | ±1 % FS | ±1 |
| Repeatability | ± 0.001 or ±0.5%FS * | ± 0.0001 or ±0.5%FS* | ± 0.001 or ±0.5%FS* | ± 0.02 or ±0.5%FS* | ± 0.5% or Concentration equivalent to ±0.001 $kg/m^3$ * |
| Long term stability | ± 0.003/month | ± 0.002/month | ± 0.003/month | ± 0.07/month | Concentration equivalent to ± 0.003 $kg/m^3$/month |

*: Whichever is greater

Density is the basic measurement, the other items are derived from the Density data.

| Item | $H_2$ in Air vol% | $H_2$ in $CO_2$ vol% | Air in $CO_2$ vol% |
|---|---|---|---|
| Range | 85 - 100 | 0 - 100 | 0 - 100 |
| Minimum range | – | – | – |
| Response Time 90% | approx. 5 sec | approx. 5 sec | approx. 5 sec |
| Linearity | ±1 | ±1 | ±1 |
| Repeatability | ±0.5 | ±0.5 | ±0.5 |
| Drift | ± 0.5/month | ± 0.5/month | ± 0.5/month |

| Caloric value $MJ/m^3$ | British Thermal Unit $KBTU/ft^3$ |
|---|---|
| 0 - 130 | 0 - 3.5 |
| Caloric value equivalent to 0.100 $kg/m^3$ | Caloric value equivalent to 0.100 $kg/m^3$ |
| approx. 5 sec | approx. 5 sec |
| ± 1 % FS | ±1 % FS |
| ±0.5%FS or Caloric value equivalent to 0.001 $kg/m^3$* | ±0.5%FS or Caloric value equivalent to 0.001 $kg/m^3$ * |
| Caloric value equivalent to ± 0.003 $kg/m^3$/month | Caloric value equivalent to ± 0.0025/month |

*: Whichever is greater

Caloric Value and BTU are possible representations of the Density.
GD402 does not contain table information, only a single mathematical equation.

# 4. Operating Principle

Figure 1 shows the construction of the density sensor. Two pairs of piezoelectric elements for drive and detection are attached on four points of a thin-wall cylindrical resonator. A platinum temperature sensor is mounted to the density sensor.

The sample gas from inlet passes over the outside of the thin-walled cylindrical resonator and is exhausted at the gas outlet.

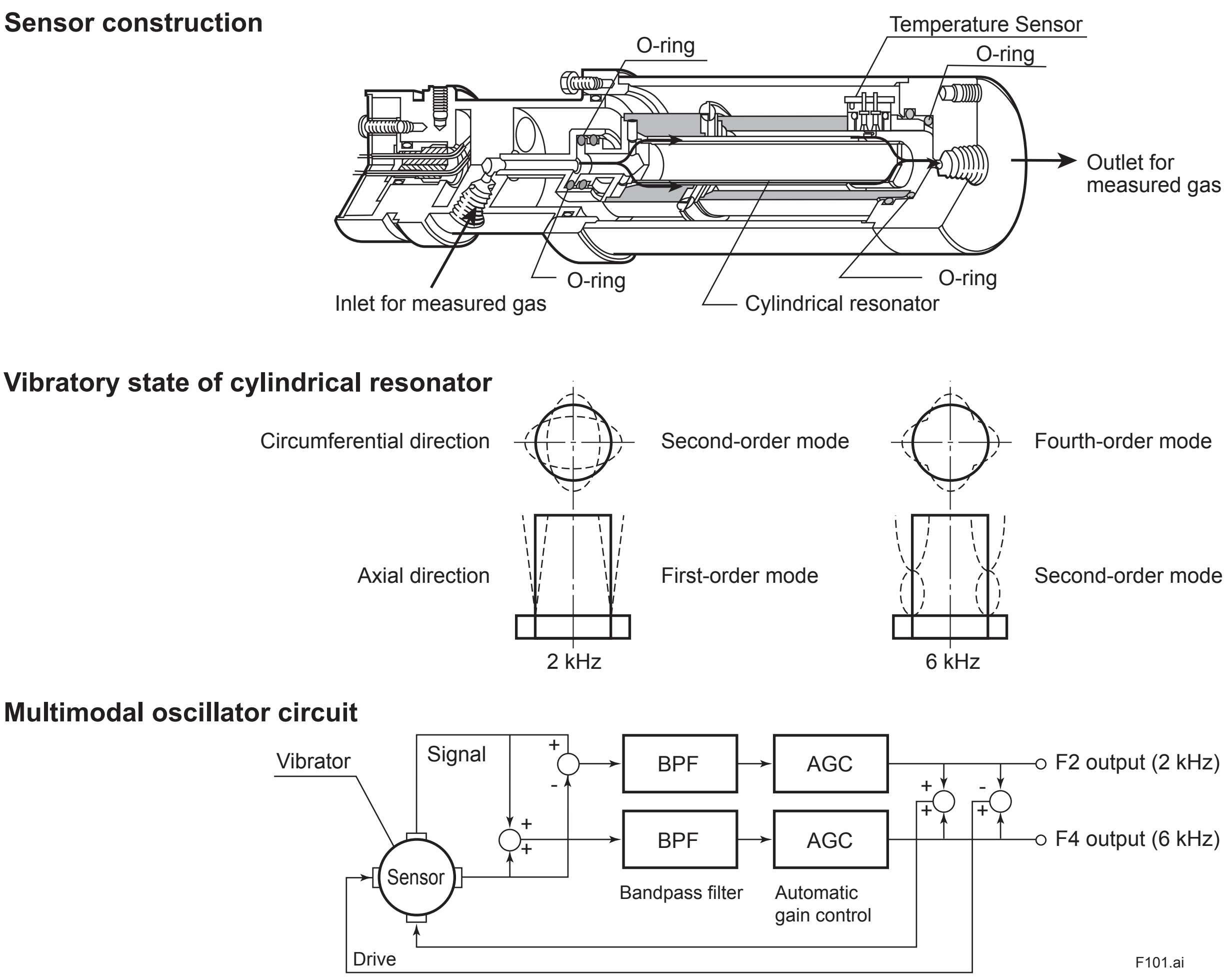



**Figure 1 Operating Principle**

- As its operating principle, the GD402 gas density meter utilizes the phenomenon whereby the resonant frequency of a thin-walled cylinder varies with the density of a given fluid.
- If the cylinder vibrates in a fluid, a mass of the fluid surrounding the cylinder also vibrates together with the cylinder. When viewed from the cylinder, the surrounding mass of fluid serves as an inertial load. This load causes the apparent mass of the cylinder to increase, resulting in a change in the resonant frequency. Since this change is a function of the fluid's density as shown below, the density can be made known by measuring the resonant frequency.

$$f(i, j) = \frac{1}{2\pi r}\left(\frac{Eg\Delta(i, j)}{\rho(i, j)(1 - \sigma^2)}\right)^{1/2} \cdot (1 + \alpha T) \cdot (1 + \gamma \log t / t_0) \quad \text{(1)}$$

$$R = \frac{f\,i}{f\,j} = \left(\frac{\rho\,j}{\rho\,i}\;\frac{\Delta\,i}{\Delta\,j}\right)^{1/2} \quad \text{(2)}$$

Where

$f(i, j)$ : Cylinder's resonant frequency of *i* th- or *j* th-order mode
( i : Order of mode in the axial direction
j : Order of mode in the circumferential direction )

E : Longitudinal elastic modulus

σ : Poisson ratio

ρ (i, j) : Density (resonator's density plus equivalent fluid's density of *i* th- or *j* th-order mode)

α : Temperature coefficient of resonant frequency

γ : Coefficient as the rate of change with time

$T$ : Temperature

$t$ : Elapsed time

$t_0$ : Initial time

$r$ : Radius

$\Delta(i, j)$ : Constant frequency of *i* th- or *j* th-order mode

g : Gravitational acceleration

$R$ : The ratio between the resonant frequencies of the two modes

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- As understood from the equations above, the fluid's density can be known by selecting two modes, by measuring R, and then by calculating the equations.

# 5. Characteristics

## 5.1 Linearity

Linearity has been checked by measuring three types of gas, He, $CH_4$, and $N_2$, with the GD402/GD40 over the range of 0.1 to 1.3 kg/Nm$^3$.

| Standard gas | True value (kg/Nm$^3$) | Measured value (kg/Nm$^3$) | Error (%) |
|---|---|---|---|
| He | 0.179 | 0.1788 | -0.017 |
| $CH_4$ | 0.718 | 0.7139 | -0.342 |
| $N_2$ | 1.259 | 1.2509 | -0.675 |

Error (%)=((Measured value-True value)/Range) x 100

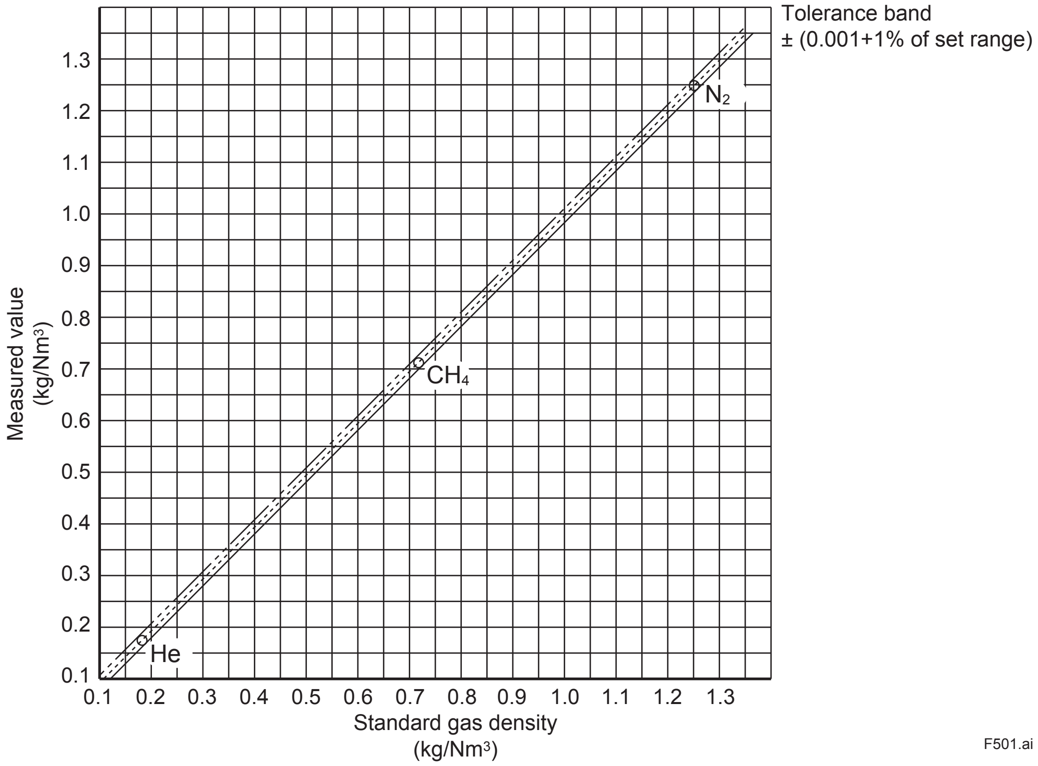



**Figure 2 Linearity**

## 5.2 Repeatability and Reproducibility

The $N_2$ gas was measured repeatedly as much as five times by the GD402/GD40 over the range of 0.1 and 1.3 kg/Nm³, and the repeatability was checked as follows.

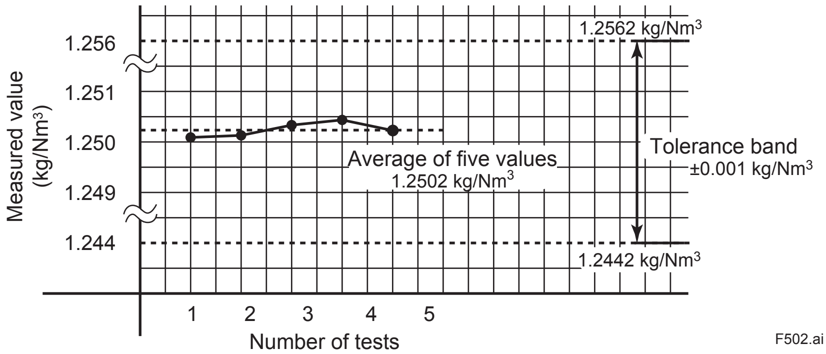



**Figure 3 Repeatability and Reproducibility**

## 5.3 Gas Flow Variation Influences

Output variation was checked by varying $H_2$ gas flow from 300 to 600 to 1000 ml/min.

| Gas flow (ml/min) | Indicated value (kg/Nm³) | Deviation from value at rated flow |
|---|---|---|
| 300 | 1.2502 | -0.0002 |
| 600 (rated flow) | 1.2504 | 0 |
| 1000 | 1.2515 | +0.0011 |

# 5.4 Actual Density and Compensated Density Outputs

Because the GD402/GD40 measures the absolute value of the density (actual density), it compensates the measurement to the density at standard conditions of 0ºC and 1 atmosphere (compensated density).

Figure 4 is the data of the actual and compensated density.

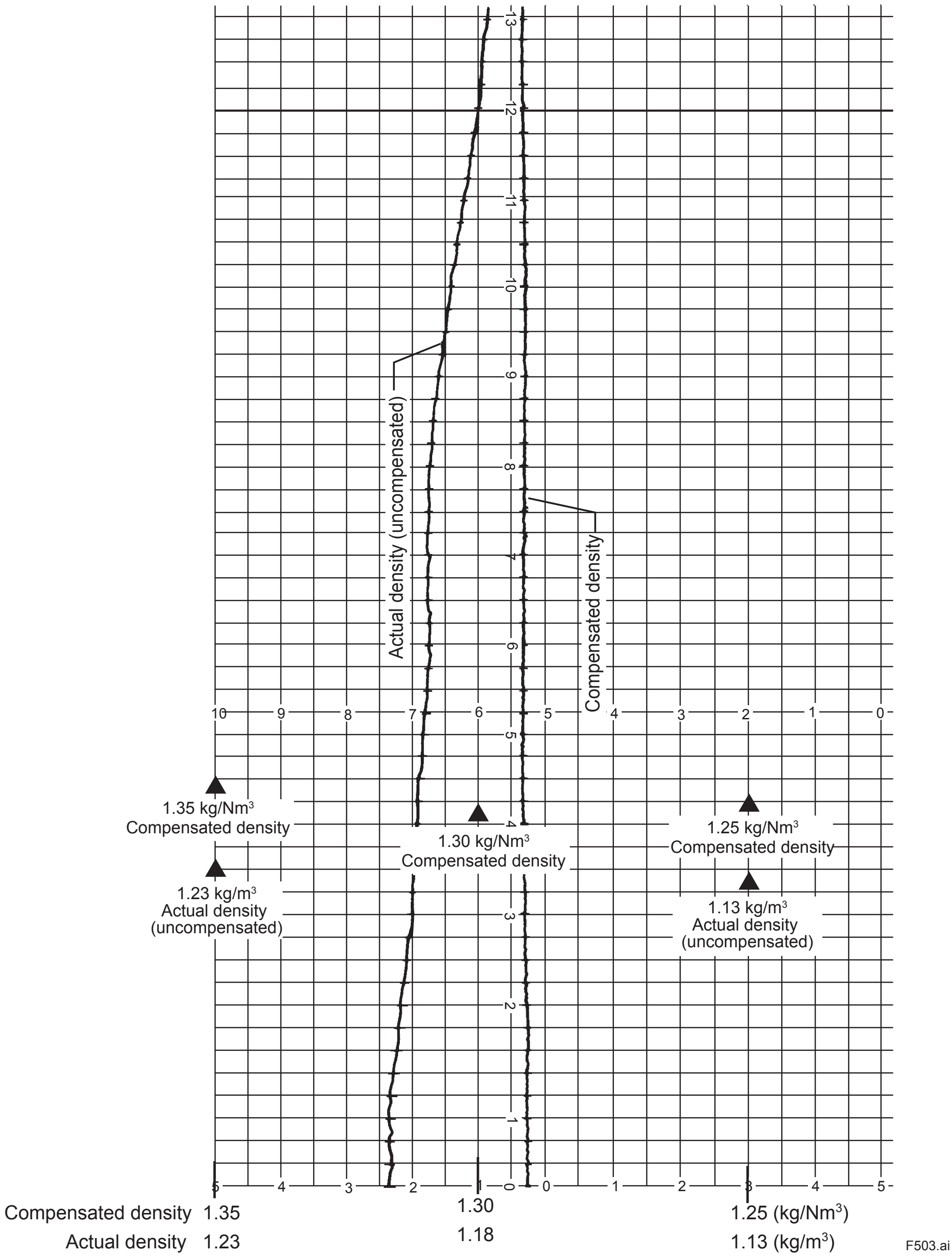



**Figure 4 Actual density and Compensated density**

# 5.5 Errors Due to Dust Accumulation on Resonator

Figure 5 shows the relative effect on density error in single-mode and multi-mode self-exciting oscillator systems when 0.4 mg/cm$^2$ of dust (MgO) has accumulated on the cylindrical resonator.

As is clear from Figure 5, the effect of dust accumulation on indication drift for the multi-mode self-exciting oscillator system is only about 1/10th that for a single-mode self-exciting system.

Multi-mode vs. Single-Mode Self-Exciting Oscillator Systems

The resonant frequency of the cylindrical resonator will vary due to contamination of the vibrating surfaces and to time variations of the coefficient of linear expansion and modulus of elasticity of its material. Thus, if density measurements are made based on single-mode vibration, they must be compensated to correct for these influences.

To eliminate these influences, a multi-mode self-exciting oscillator system can be used. In the multi-mode self-exciting oscillator system, the cylindrical resonator is forced to resonate simultaneously at two different frequencies, its *i* th-mode and its *j* th-mode, and the ratio of those resonant frequencies is taken. By this means the influences mutually cancel and can be ignored, enabling much higher accuracy of measurement.

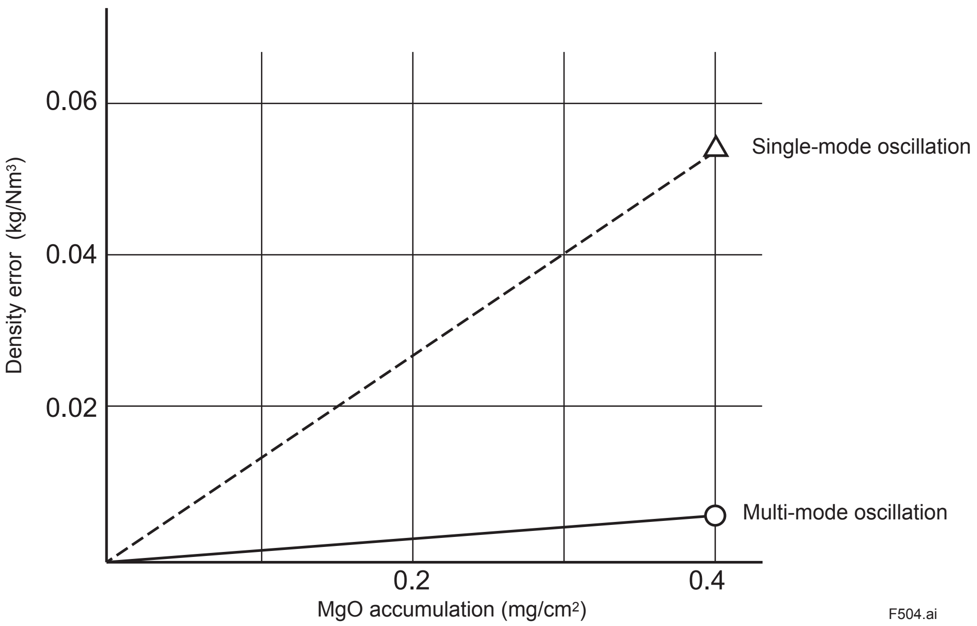
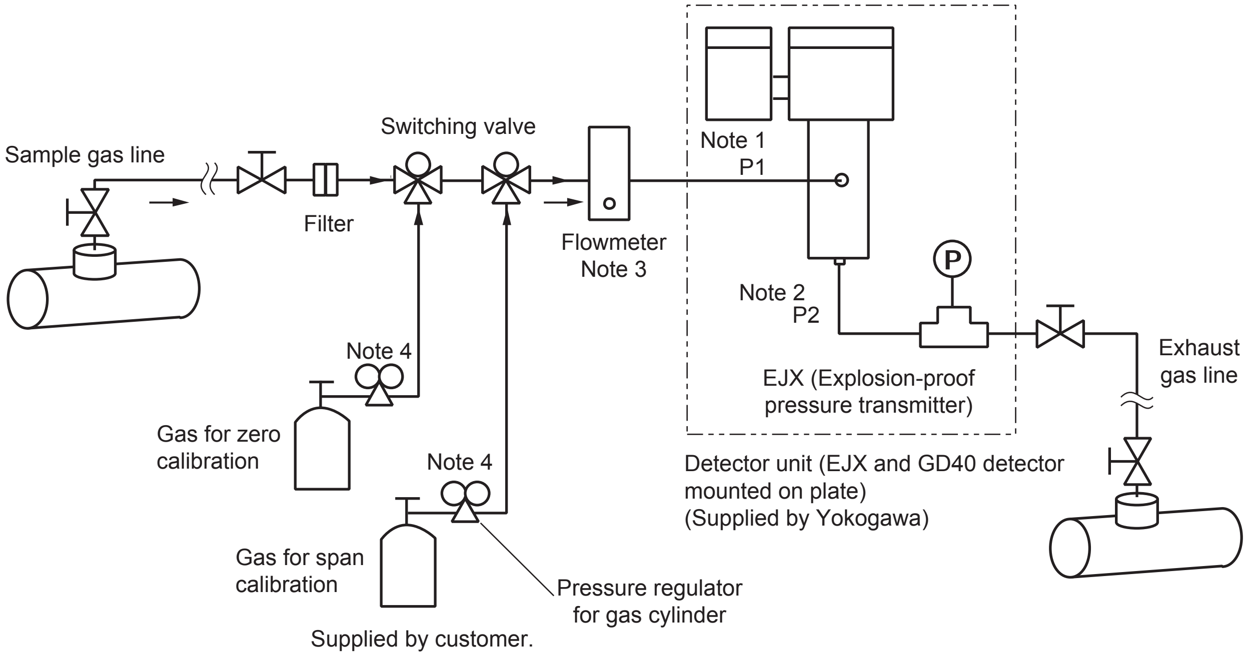



**Figure 5 Density Error Due to Dust Accumulation**

# 6. System Composition




Note 1: P1 (Inlet pressure) ≦ Max. 0.5 MPa (71 psi)
Note 2: P1 (Inlet pressure) - P2 (Outlet pressure) ≧ 0.5 kPa (0.071 psi)
(depending on the size and length of the pipe)
Note 3: Flowrate = 0.1 to 1 l/min
Note 4: The cylinder pressure must be reduced to P1 (Inlet pressure).

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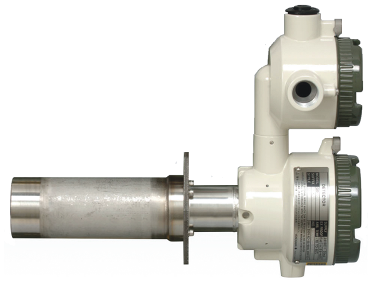
**Figure 6 System Composition (for wiring, see Instruction Manual IM 11T3E1-01E)**

The GD402 Gas Density Meter consists of the sensor, converter, and EJX pressure transmitter. The measured gas can be either exhausted to the atmosphere or recycled. After preprocessing, the sample gas is introduced into the sensor at a constant flow rate. The signal proportional to the gas density is sent to the converter along with the temperature and pressure signals (from the EJX pressure transmitter) required to compute the density at standard conditions. The output from the converter is a signal proportional to a density variable computed according to the application objective.

Note If the measured gas contains dust and/or mist, filtering and/or moisture removal devices must be used. If the measured gas will not flow at the specified rate under its own pressure, a pump must be used.

# 7. Features of Individual Devices

## 7.1 GD40G, T, V, R Detector



GD40G, T, V, R Detector

**Features**

1) Resistant to external vibrations.
2) Outstanding stability against sudden changes in gas temperature (within 1 g/m3 for sudden changes in gas temperature of 10ºC).
3) The multi-mode self-oscillation circuit minimizes drift caused by the sensor itself or by oil mist, dust, moisture, etc. sticking to the sensor.
4) Easy cleaning and regeneration of sensor. Should the sensor be contaminated with dust and/or mist, then it can be easily cleaned and returned to its original condition.
5) Only routine maintenance is required. (for example, once per 3 months depending on application.)
6) Detector

GD40G: General purpose detector (Non-Explosion-proof)

GD40T: FM Explosion-proof and Intrinsically safe Approval.

Explosion-proof for Class I, Division 1, Groups B, C and D;
Dust Ignition-proof for Class II, III, Division 1, Groups E, F and G with Intrinsically Safe sensor for Class I, II, III, Division 1, Groups B, C, D, E, F and G.

Enclosure : NEMA Type 4X

Temperature Code : T5

GD40V: CSA Explosion-proof and Intrinsically safe Approval.

Explosion-proof for Class I, Division 1, Groups B, C and D;
Dust Ignition-proof for Class II, III, Division 1, Groups E, F and G with Intrinsically Safe sensor for Class I, II, III, Division 1, Groups B, C, D, E, F and G.

Enclosure : Type 4X

Temperature Code : T5

GD40R: TIIS Explosion-proof and Intrinsically safe Approval.

Explosion-proof code : Exd [ia] IIB+$H_2$T5

Temperature Code : T5

# 7.2 GD402G, T, V, R Converter

GD402G General purpose Converter

GD402T, V, R Explosion-proof Converter

**Features**

1) Large digital display.
2) Self-diagnostic error detection with contact output and error message display.
3) "One-touch" calibration.
4) Rich set of display functions (numeric display, status indications, error indications).
5) Able to measure actual density, compensated density, caloric value, British Thermal Unit specific gravity, molecular weight, gas concentration, $H_2$ in Air, $H_2$ in $CO_2$, or Air in $CO_2$.
6) Rainproof for outdoor use (equivalent to IP65/NEMA 4X)

GD402G: General purpose converter (Non-Explosion-proof)

GD402T: FM Explosion-proof Approval.

Explosion-proof for Class I, Division 1, Groups B, C and D;
Dust Ignition-proof for Class II, III, Division 1, Groups E, F and G.

Enclosure : NEMA Type 4X

Temperature Code : T6

GD402V: CSA Explosion-proof Approval.

Explosion-proof for Class I, Division 1, Groups B, C and D;
Dust Ignition-proof for Class II, III, Division 1, Groups E, F and G.

Enclosure : Type 4X

Temperature Code : T6

GD402R: TIIS Explosion-proof Approval.

Explosion-proof code : Exd IIB+$H_2$T6

Temperature Code : T6

# 8. Applications

## 8.1 Hydrogen-Cooled Turbine Generator

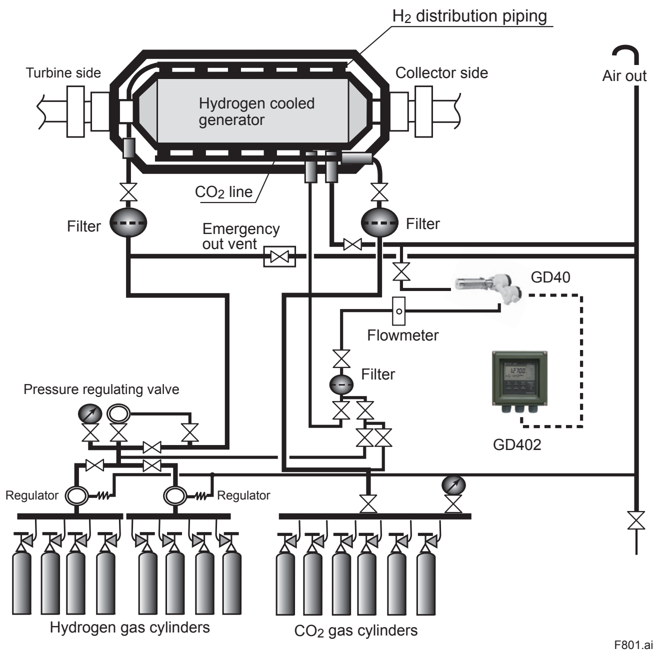



**Figure 7 Hydrogen-Cooled Turbine Generator**

The high rate of rotation of modern turbine generators requires that hydrogen gas be used for cooling. In this application GD402 can be used for several purposes.

Since hydrogen is highly combustible and dangerous, especially when mixed with air, the hydrogen purity must be measured during normal operation of the turbine generator. Ideally the concentration must be 100%, but the actual concentration will be slightly lower due to leakage of air. This measurement of the hydrogen purity can be done by the GD402.

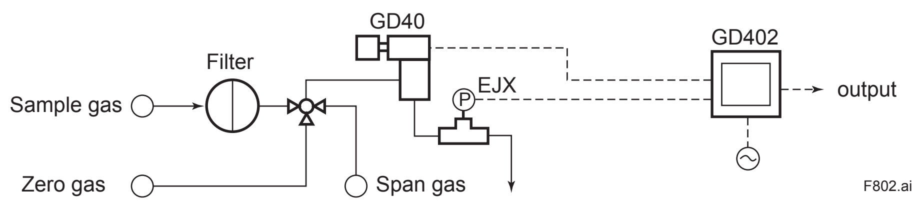
When the turbine generator must be maintained or repaired, the interior must first be purged with $CO_2$ before exposing the interior to Air. The degree of $H_2$ replacement by $CO_2$ can be measured by the GD402. Then when there is almost 100% $CO_2$ it is safe to open the turbine and expose the interior to air.

When going back into operation the same process takes place in reverse order. Now the GD402 is used to measure if all of the air is replaced by $CO_2$. Only when all of the air is replaced by $CO_2$ it is safe to start replacing the $CO_2$ by $H_2$. The degree of air replacement by $CO_2$ can be measured by the GD402. After a $CO_2$ concentration of almost 100% is reached the turbine can be purged with $H_2$ again.

Finally when the turbine is back at about 100% $H_2$ purging the $H_2$ purity can be measured with the GD402.

| | | | |
|---|---|---|---|
| Temperature : | Ambient temperature | Composition: | $CO_2 \rightarrow H_2$ |
| Dust : | None | | |

**System Configuration**



# 8.2 Natural Gas Calorie Control

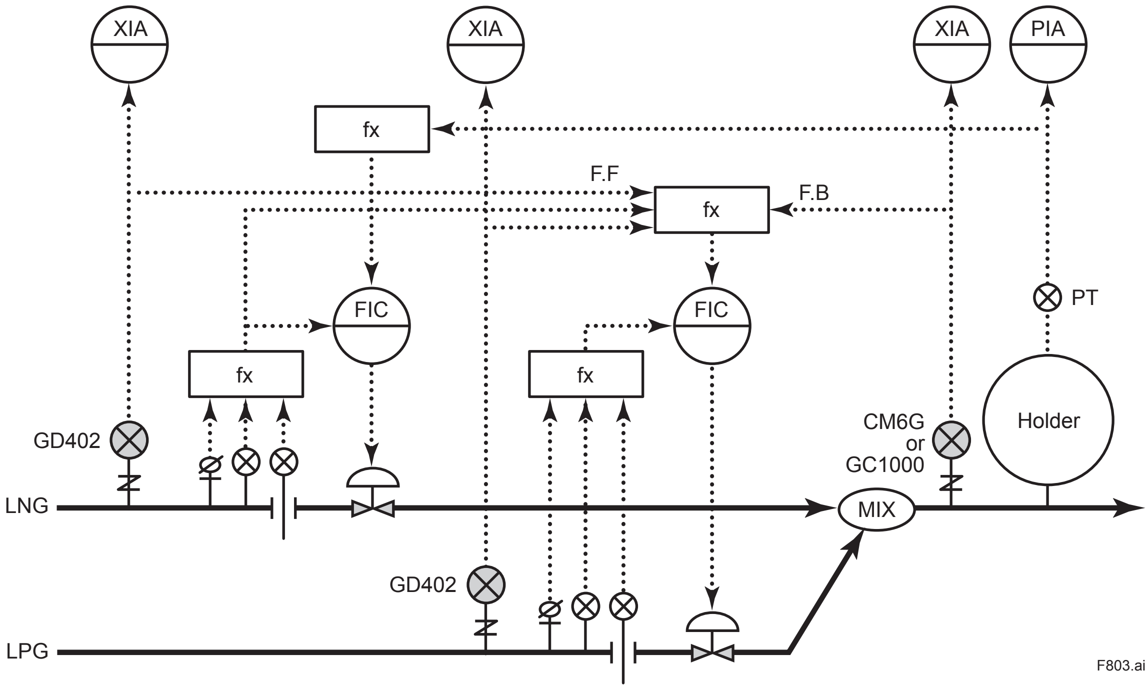
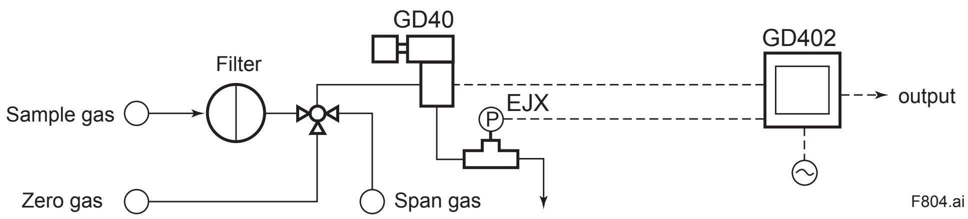



**Figure 8 Natural Gas Calorie Control**

This plant produces a gas having a specified heating value by mixing liquid natural gas (LNG) with LPG and air. Since the liquid natural gas composition will vary according to the location at which it was extracted, the liquid natural gas density (heating value) is premeasured with the GD402 and used for feedforward control. This type of plant is used by most city gas companies.

| | |
|---|---|
| Composition : | $CH_4$, $C_2H_6$, $C_3H_8$, $C_4H_{10}$ |
| Specific gravity : | 0.65 |
| Heating value : | Approx. 46.2 MJ/m$^3$ (1.16 KBTU/ft$^3$) |

**System Configuration**



# 8.3 LPG Calorie Control

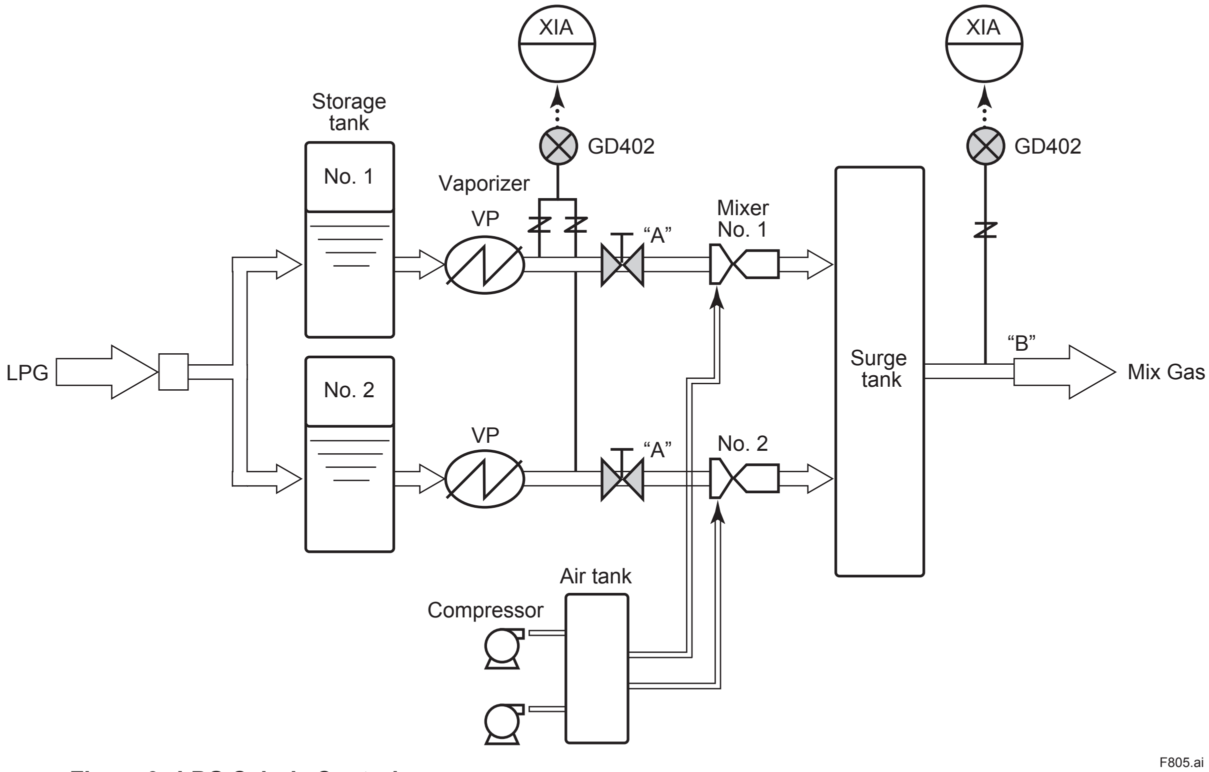


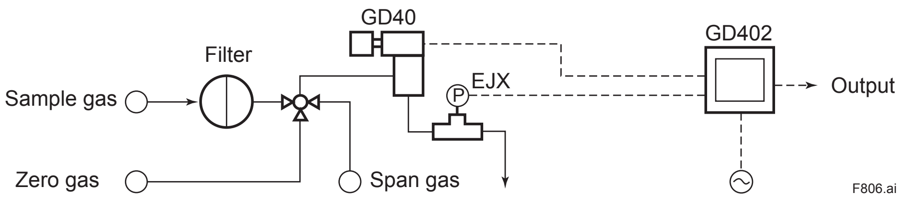

**Figure 9 LPG Calorie Control**

LPG heating value control involves vaporizing LPG and mixing it with air so as to obtain a gas having the desired heating value. The GD402 can be used to measure the heating value indirectly through its correlation with the density of the mixed gas. Since there will be some variation in the composition of the LP gas from lot to lot, the LP gas density is premeasured and the computational parameter data of the analyzer is set based on that so as to minimize the error due to the composition variation.

| **LP Gas "A"** | | **Mixed Gas "B"** | |
|---|---|---|---|
| Pressure : | 100 to 300 kPa (14 to 42.6 psi) | Pressure : | 10 to 33 kPa (1.4 to 4.7 psi) |
| Temperature : | 30 to 50 °C (86 to 122°F) | Temperature: | 20 to 35 °C (68 to 95 °F) |
| Dust : | None | Dust : | None |
| Composition : | Propane : 15 to 35 vol%<br>Butane : 85 to 65 vol% | Composition : | LPG + air |

Heating value : Approx. 117.6 MJ/m³ (2.9 KBTU/ft³)

### System Configuration



# 8.4 Substitute Natural Gas Unit

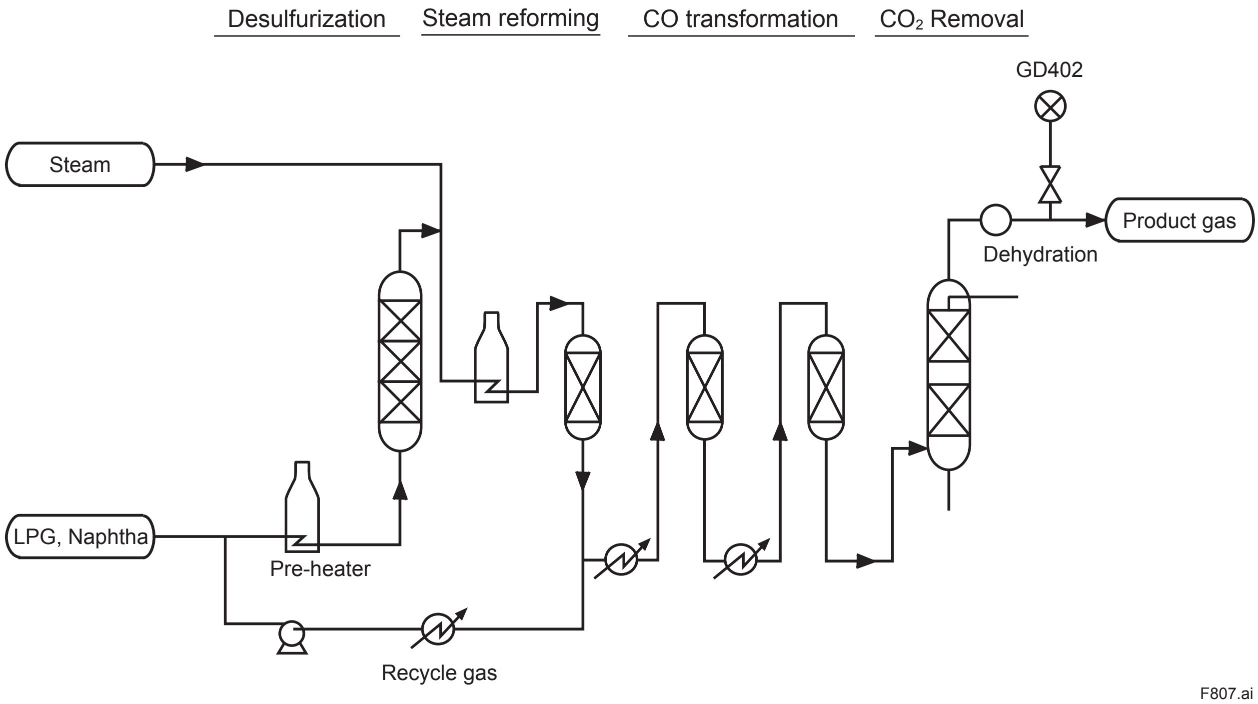
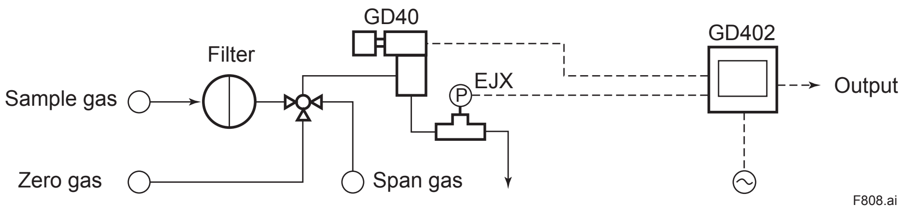



**Figure 10 Substitute natural gas Unit**

This plant reforms a feedstock such as natural gas, off-gas, propane, butane, or naphtha, etc., into a 13A gas Substitute natural gas consisting mainly of methane.

| | | | |
|---|---|---|---|
| Pressure : | 200 to 300 kPa | Composition : | $CH_4$ ($H_2$, $CO_2$) |
| Temperature : | Ambient temperature | Gravity : | 0.42 to 0.44 |
| Dust : | Small amount | Heating value : | 11.80 to 11.39 MJ/$m^3$ |

### System Configuration



# 8.5 Combined Cycle Generator

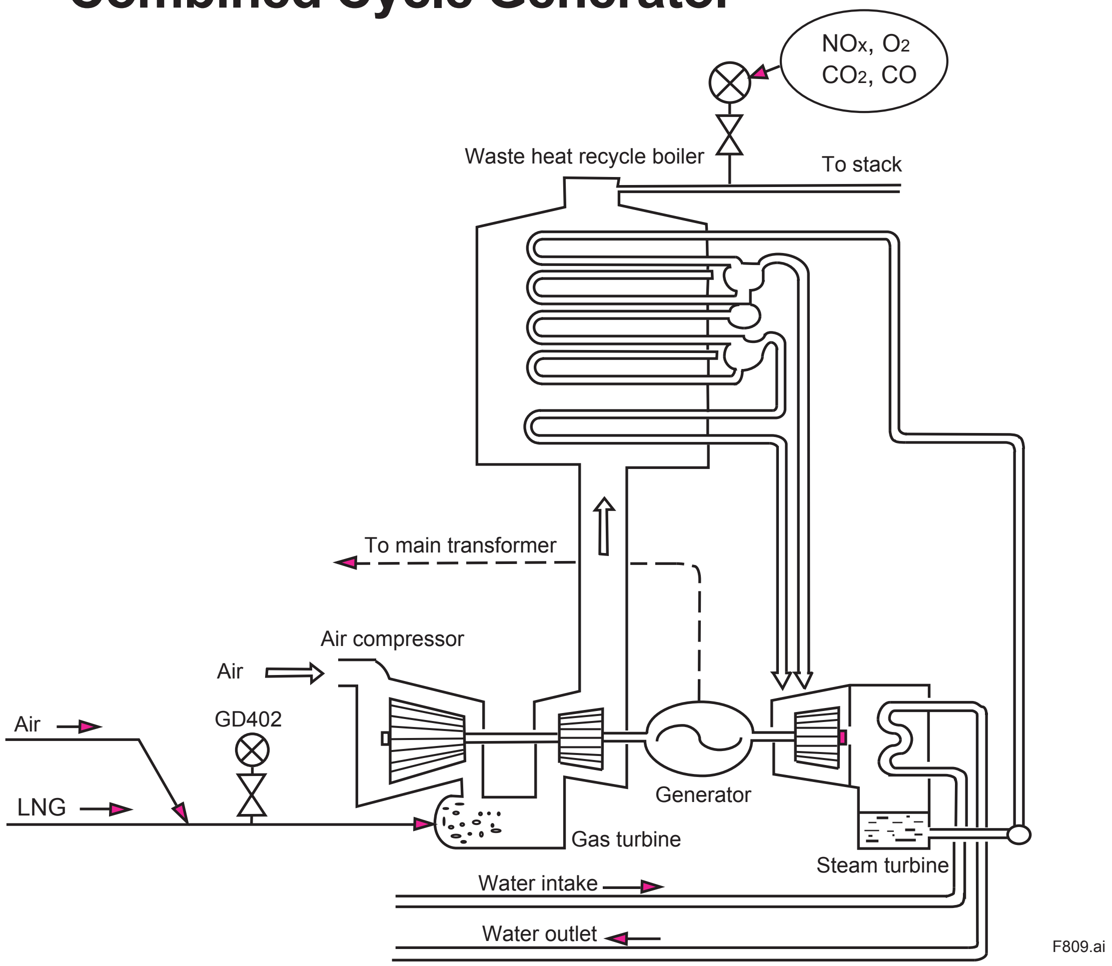



**Figure 11 Combined Cycle Generator**

Combined cycle electrical generation employs a gas turbine and steam turbine in combination to increase efficiency. Since the gas turbine is driven by high-temperature combustion exhaust gas, there is a possibility of NOx generation due to combustion with excess air.

The GD402 is used to measure the calorific value of the fuel gas (generally LNG). The measurement signal is then used to control the air supply ratio so as to minimize the amount of NOx generated. Measurement of the NOx+$O_2$, $CO_2$ and CO in the flue gas is also required for environmental protection.

Pressure: 2.5 to 3.2 MPa (355 to 454 psi)

Temperature : Ambient temperature

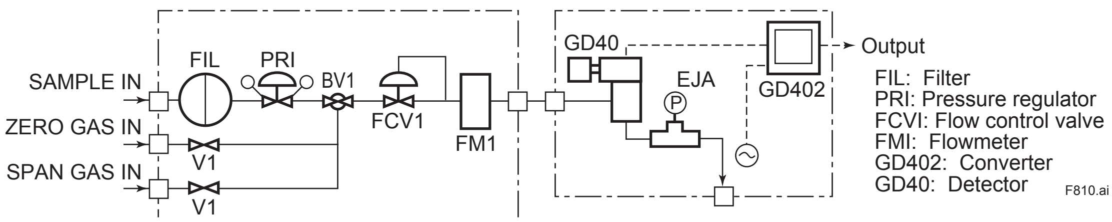
Dust : None

Composition : LNG ($CH_4$: 87.5 vol%, $C_2H_6$:7.9 vol%, $C_3H_8$: 3.1 vol%, $C_4H_{10}$:1.4 vol%, $N_2$: 0.1 vol%)

Density : 0.837 kg/m$^3$ (52.3 lb/ft$^3$)

Heating value: 45.3 MJ/m$^3$ (1.1 KBTU/ft$^3$)

### System Configuration



# 8.6 Refinery Configuration and Refining Process

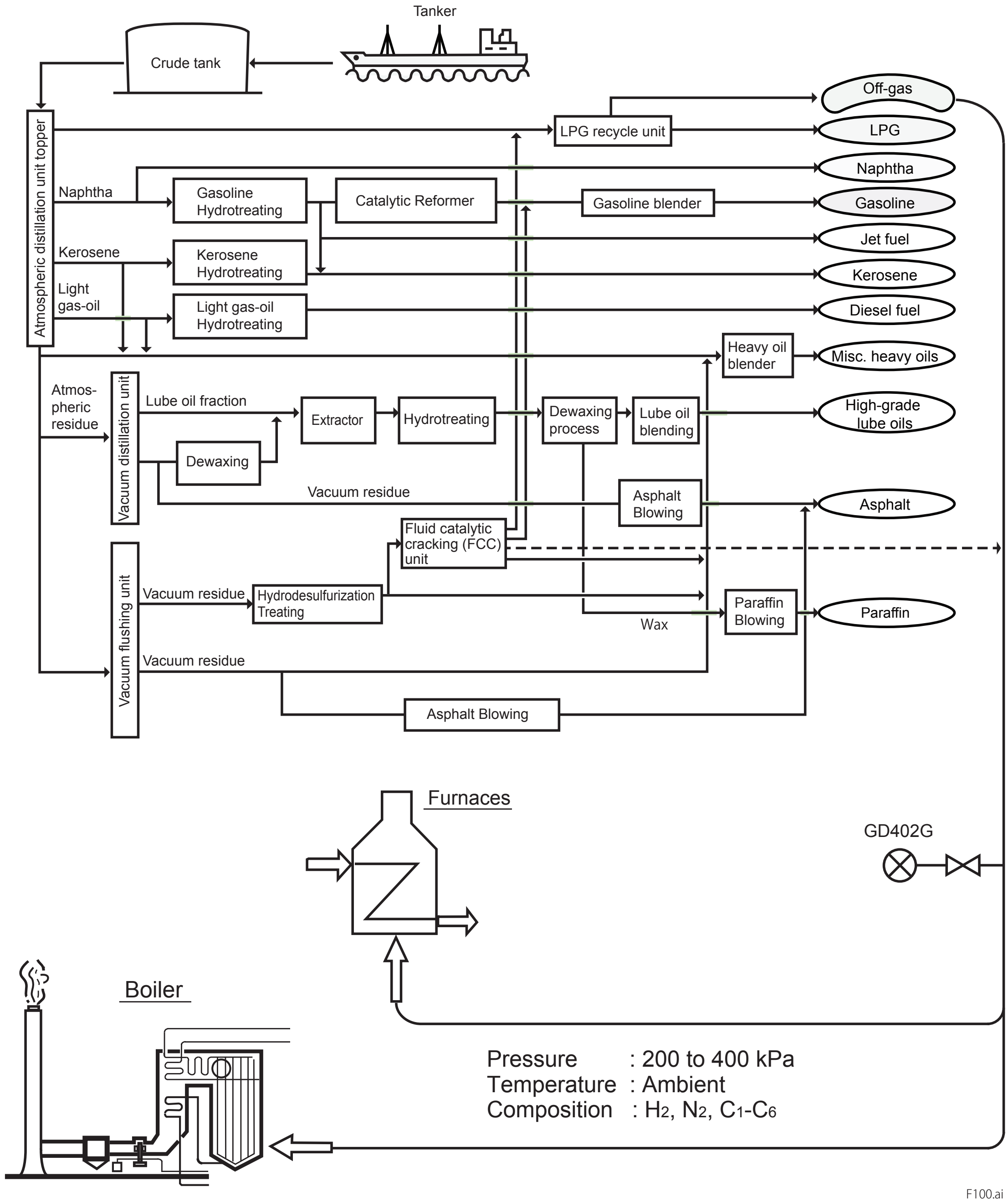
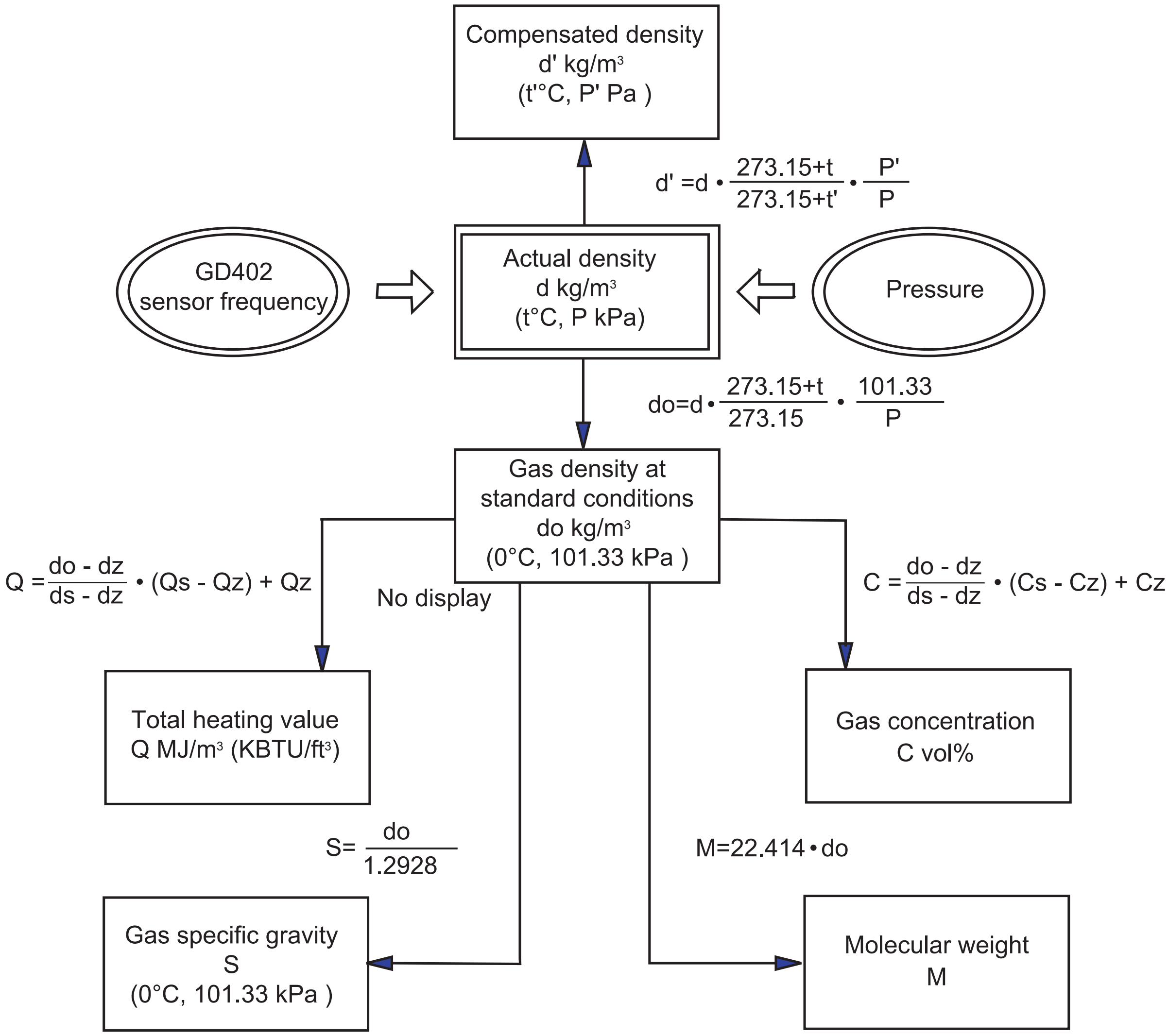



**Figure 12 Refinery Configuration and Refining Process**

In order to obtain gasoline, kerosene, and various heavier oils such as lubricating oils from the crude oil, refineries refine crude oil through a combination of atmospheric-pressure distillation, vacuum distillation, and catalytic cracking processes. The various process units generate not only liquid products, but also gases containing propane and butane.

In the past, most of these off-gases generated in the refining process were burned in a flare stack unit, but today they are recycled either as fuel for the furnaces and boiler, or even sold as product. When they are used as fuels, density or molecular weight measurement is used for combustion air ratio control, since the composition of the gases will vary depending on the crude composition and on the operating conditions in the process units.

# 9. Gas Density Meter Computations




Where,

| | | | |
|---|---|---|---|
| ds: span point density | $kg/m^3$ | Qz: zero point calories | $MJ/m^3$ ($KBTU/ft^3$) |
| dz: zero point density | $kg/m^3$ | Cs: span point concentration | vol% |
| Qs: span point calories | $MJ/m^3$ | Cz: zero point concentration | vol% |

Basically, the sensor measures the actual density, based on the frequencies.
By entering the measured gas conditions for that actual density, you can obtain the measurements in terms of the correlated variables in the single-line boxes.

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# 10. Appendix

**Table 1 Pure Gas Specific Gravities, Gloss Calorific Values, Densities and Net Calorific Values (0ºC, 1 atm)**

| No. | Gas | Chemical formula | Specific gravity (Air=1.0000) | Gloss Calorific value (kJ/m³) | Gas Density (*) (kg/m³) | Net Calorific Values (KJ/m³) |
|---|---|---|---|---|---|---|
| 1 | Carbon monoxide | $CO$ | 0.967 | 12610 | 1.2504 | 12610 |
| 2 | Hydrogen | $H_2$ | 0.0696 | 12780 | 0.08988 | 10830 |
| 3 | Methane | $CH_4$ | 0.554 | 39940 | 0.7175 | 36020 |
| 4 | Ethane | $C_2H_6$ | 1.038 | 70470 | 1.3552 | 64550 |
| 5 | Ethylene | $C_2H_4$ | 0.968 | 63560 | 1.2612 | 59620 |
| 6 | Propane | $C_3H_8$ | 1.522 | 101400 | 2.0102 | 93390 |
| 7 | Propylene | $C_3H_6$ | 1.452 | 93730 | 1.9122 | 87760 |
| 8 | n-Butane | n-$C_4H_{10}$ | 2.006 | 134300 | 2.7024 | 124100 |
| 9 | i-Butane | i-$C_4H_{10}$ | 2.006 | 133100 | 2.6897 | 122900 |
| 10 | 1-Butene | 1-$C_4H_8$ | 1.936 | 126300 | 2.5956 | 118100 |
| 11 | cis-2 Butene | cis-2-$C_4H_8$ | 1.936 | 126600 | 2.6042 | 118400 |
| 12 | trans-2 Butene | trans-2-$C_4H_8$ | 1.936 | 126300 | 2.6042 | 118100 |
| 13 | i-Butene | i-$C_4H_8$ | 1.936 | 125500 | 2.5953 | 117400 |
| 14 | n-Pentane | n-$C_5H_{12}$ | 2.490 | 171400 | 3.4542 | 158700 |
| 15 | i-Pentane | i-$C_5H_{12}$ | 2.490 | 169300 | 3.4266 | 156800 |
| 16 | n-Hexane | n-$C_6H_{14}$ | 2.974 | 215700 | 4.3205 | 199900 |
| 17 | Benzene | $C_6H_6$ | 2.695 | 163300 | 3.8343 | 156800 |
| 18 | Toluene | $C_6H_5CH_3$ | 3.179 | 227700 | 4.8495 | 217600 |
| 19 | Carbon dioxide | $CO_2$ | 1.519 | — | 1.9771 | — |
| 20 | Oxygen | $O_2$ | 1.104 | — | 1.4289 | — |
| 21 | Nitrogen | $N_2$ | 0.967 | — | 1.2504 | — |

Source : JIS K2301-1992
(*) Gas density is only reference data.

# Revision Information

Title : GD402 Gas Density Meter
Manual number : TI 11T03E01-01E

**Mar. 2017/5th Edition**
EJA to EJX changed (Pages 10, 13 to 17)
Revised (Pages 3, 14, 16, 18, 19)

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Revised and Corrected over all

**June 2008/3rd Edition**

**Mar. 2005/2nd Edition**

**Feb. 1998/1st Edition**
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