

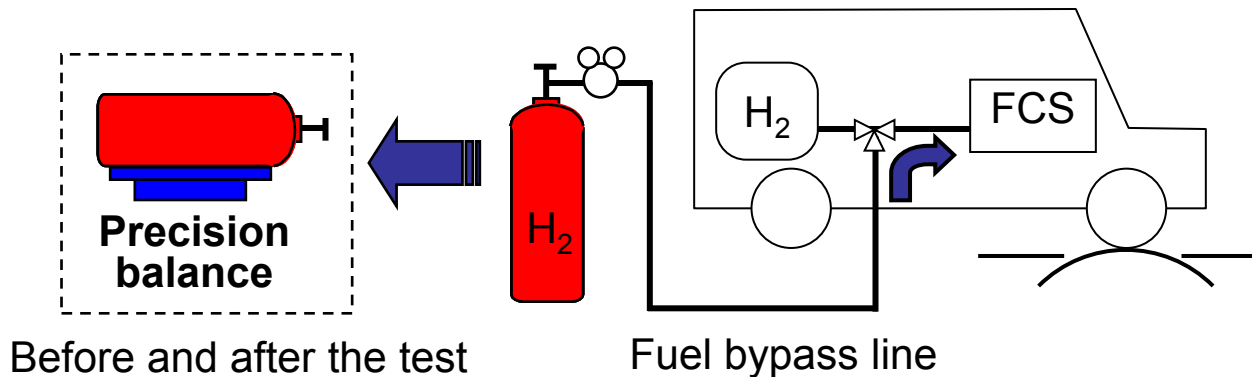
Principle: Weighing the H₂ tank before and after the test

$$W = g_1 - g_2$$

Here, W = Fuel consumption

g_1 = Mass of H₂ tank before test, g_2 = Mass of H₂ tank after test

試験前後に水素タンクの重量を計測
その差から水素燃料の消費量を求める



Advantages

長所: 水素の質量を直接測定 (高い信頼性)

- H₂ mass is directly measured (reliability).

Disadvantages

短所: 水素タンクの着脱が必要

- Need to disconnect H₂ tank from fuel line for weighing

Test Equipment for Gravimetric Method

重量法の試験機器

精密重量計

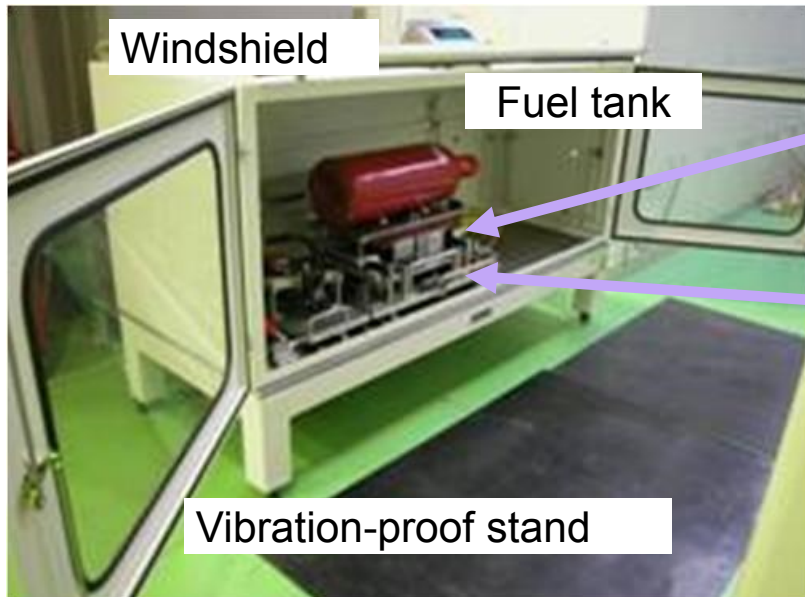
Precision balance

Fuel tank setting device

- setting of a tank on the center of balance
- shock absorber for tank setting

重量計中央への設置、制振、風除け

Picture from JARI presentation



Precision Balance	A	B
Full scale	64100 g	64100 g
Minimum reading	0.1 g (approx. H ₂ 1.0L)	0.01 g (approx. H ₂ 0.1L)
Repeatability	0.1g *	0.025 g
Others	Windshield, Vibration-proof stand, Fuel tank setting device	

Change of H₂ mass(tens g) in H₂ tank(tens kg) can be measured by precision balance. 水素消費量(数十 グラム)の計測可能

Consideration for Gravimetric method 考察 (重量法)

- Principle : Weighing a hydrogen tank before and after a test - Simplest among 3 methods

最も実績のある、信頼できる方法

- Most proven and reliable method

精密重量計が入手可能

- Sufficiently precise balance is available.

Lフェーズの推定水素消費量(RCB=0)に対して精度を規定可能

- Measurement accuracy can be specified for expected H₂ consumption in L-phase of WLTC.



重量法を提案

JAMA proposes “Gravimetric method”

Pressure Method

圧力法

Principle: Measure pressure and temperature of H₂ gas and Derive mass of H₂ from equation of state before and after a test

$$W = m \times \frac{V}{R} \times \left(\frac{P_1}{z_1 \times T_1} - \frac{P_2}{z_2 \times T_2} \right)$$

試験前後に水素の圧力と温度を計測
状態方程式により水素重量を計算し
水素消費量を求める

Here, W = Fuel consumption [g], m = Molecular weight of H₂ 2.016 [g/mol]

V = Volume of H₂ tank [m³], R = Gas constant 8.314 [J/mol·K]

P_1 = H₂ pressure before test [Pa], P_2 = H₂ pressure after test [Pa]

T_1 = H₂ temperature before test [K], T_2 = H₂ temperature after test [K]

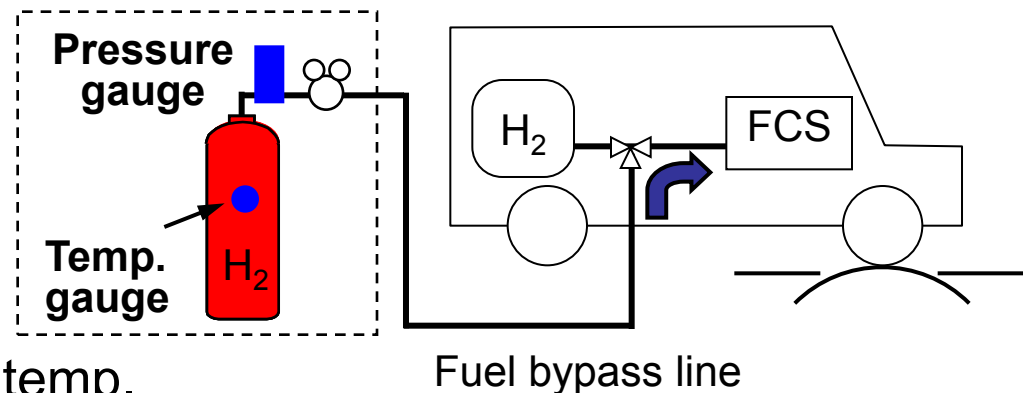
z_1 = Compressibility factor at P_1, T_1 , z_2 = Compressibility factor at P_2, T_2

Advantages

- No need to disconnect H₂ tank 長所: 水素タンクの着脱不要

Disadvantages

- Difficult to measure H₂ gas temp.
(Alternatively tank surface is measured)
短所: 水素ガス温度把握が難しい
(代わりにタンク表面温度計測)



Test Equipment for Pressure Method

Pressure gauge



Range	0 to 16 MPa (abs)
Error	0.05 %F.S.(8kPa)

- Applicable to high pressure 高圧測定可
- Sufficient accuracy 十分な精度

- 8kPa of error is equivalent to approx. 1 % of hydrogen consumption 30g.
- 0.03°C of error is equivalent to approx. 0.15 % of hydrogen consumption 30g.

Condition: Tank Volume :47L, Initial Pressure: 14MPa, Temperature: 23°C

30g of H₂ consumption is assumed for phase-L3 of WLTC

Temperature gauge



Range	10 to 30 °C
Error	0.01 to 0.03 °C

- Sufficient accuracy 十分な精度

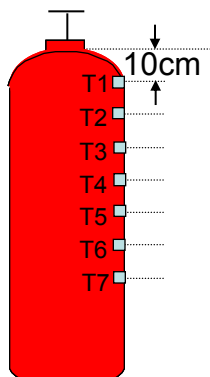
WLTC-L3(約3km)の水素消費を30gと想定すると
誤差8kPaは燃費の1%相当。誤差0.03°Cは同0.15%相当

Temperature Trend after Test

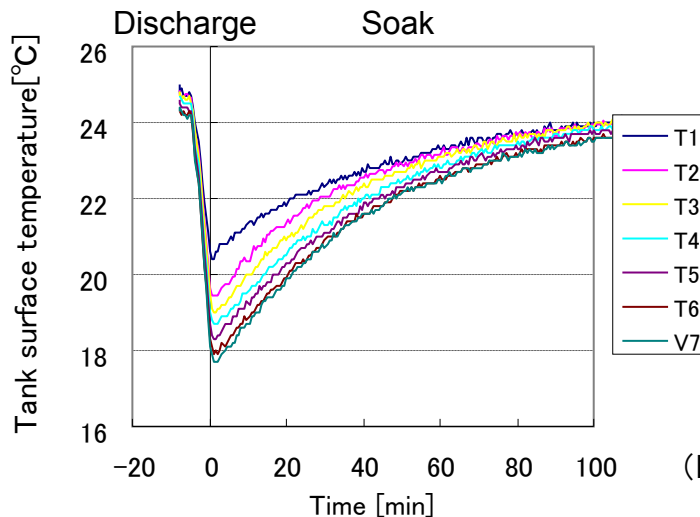
試験後のタンク温度

Tank Surface Temperature - during H₂ gas discharge and soak

タンク表面温度
(ガス放出およびソーク時)



47L tank
(Length 1350cm)



(H₂ discharge : 30L/min, 5min)

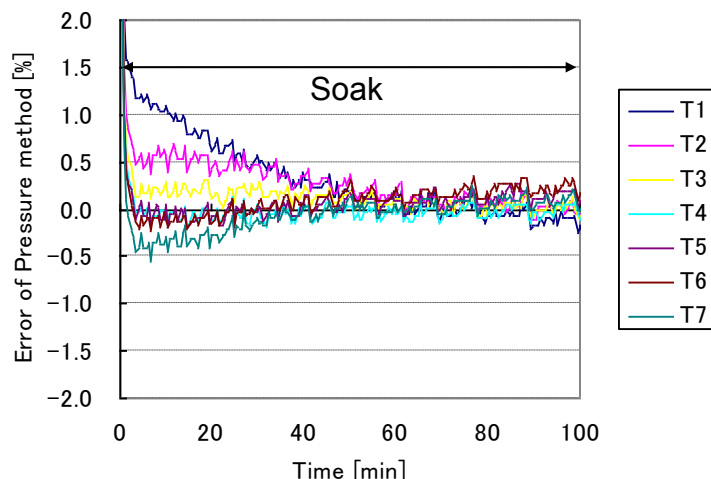
- Temp. decrease during H₂ discharge
- The lower part reached lower temp. than upper part.
- Temp. increased again during soak.

- 水素放出時にタンク温度低下
- ソーク時にタンク温度上昇(環境温度に戻る)

ソーク後の計測誤差(重量法に対する)

Measurement Error after soak

(reference: gravimetric method)



試験後のソークにより誤差が縮小

- Errors were reduced during soak.
- Temp. at T₄, T₅ showed high accuracy even in short soak time.

試験後のソークが必要(温度による誤差解消のため)

Soak after a test is needed to eliminate error due to temperature measurement.

Consideration of Pressure Method 考察(圧力法)

- Principle: Measure pressure and temperature of H₂ tank. Calculate mass of hydrogen by using an equation of state before and after a test.

重量法より容易な計測(適切に設定すれば)

- Easier to measure than gravimetric methods if setting is provided appropriately.

高精度の圧力計が入手可能

- Sufficiently precise pressure gauge is available.

温度による誤差はソークにより解消可能

- Error due to temperature measurement is eliminated by soak(at least 1 hour) after a test.

Lフェーズの想定水素消費量に対して精度を規定可能

- Measurement accuracy can be specified for expected H₂ consumption in phase-L of WLTC.

圧力法を提案



JAMA proposes “Pressure method”.

Principle: Measure H₂ flow rate and Integrate during a test

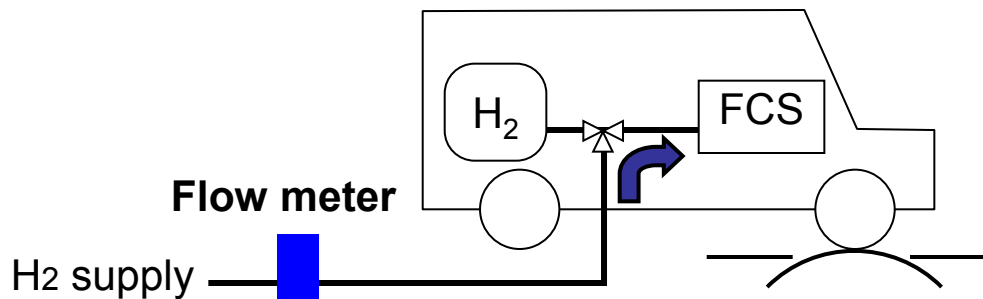
$$W = \int_{test} q(t)dt \times \frac{m}{22.414}$$

水素燃料の流量を計測、積算し、水素消費量を求める

Here, W = Fuel consumption [g]

= Integrated flow of hydrogen at normal conditions (273.15K, 101.3kPa) [L]

m = Molecular weight of hydrogen 2.016 [g/mol]



Advantages

- Continuous measurement for series of phases

フェーズ間を連続して計測可能

Disadvantages





- Need to examine suitable flow meter and settings

流量計、計測系の設定を事前に確認する必要がある

for FCV test

Verification of Flow Meter

流量計の検証

Type	Thermal	Coriolis	Volumetric	Ultrasonic
Range	4~500 [NL/min]	10~750 [NL/min]	1.6~116 [L/min]	9~2000 [NL/min]
Accuracy	±1 [%FS] (~400NL/min) ±2 [%FS] (400~500NL/min)	±0.58 [%RD](500NL/min) ±0.66 [%RD](250NL/min) ±0.87 [%RD](100NL/min) ±4.49 [%RD](10NL/min)	±1.07 [%RD] (±0.2 [%RD]) ^{※1}	±2 [%RD]
Response	10 [ms]	—	—	50 [ms]
Pressure Range	0~0.98 [MPaG]	0~10 [MPaG]	0~0.5 [MPaG]	0~1 [MPaG]
Photo				

※1: In super highly accurate sensor use

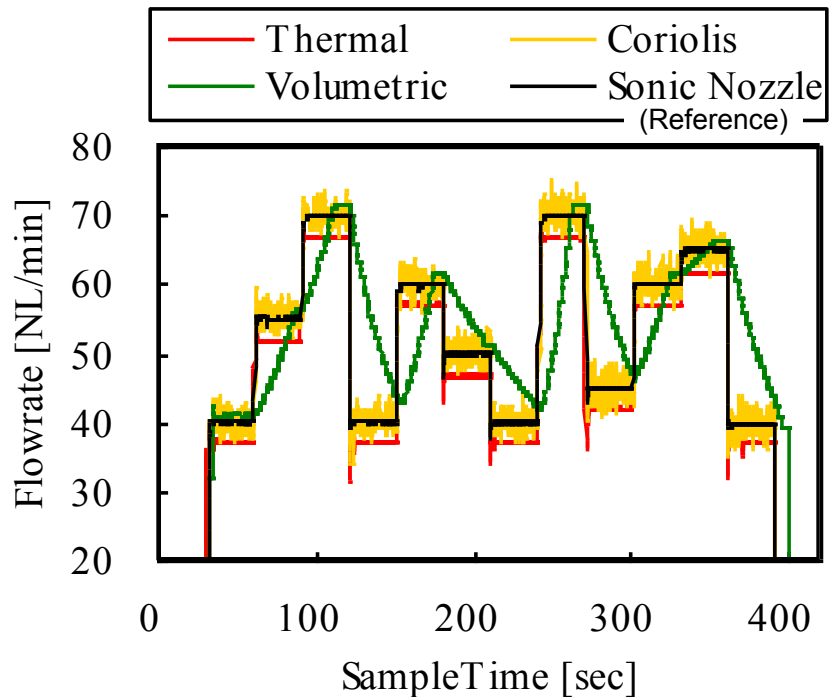
[%FS] : [% of Full Scale], [%RD] : [% of Reading]

Characteristic of Flow Meter

精度とレスポンスを評価

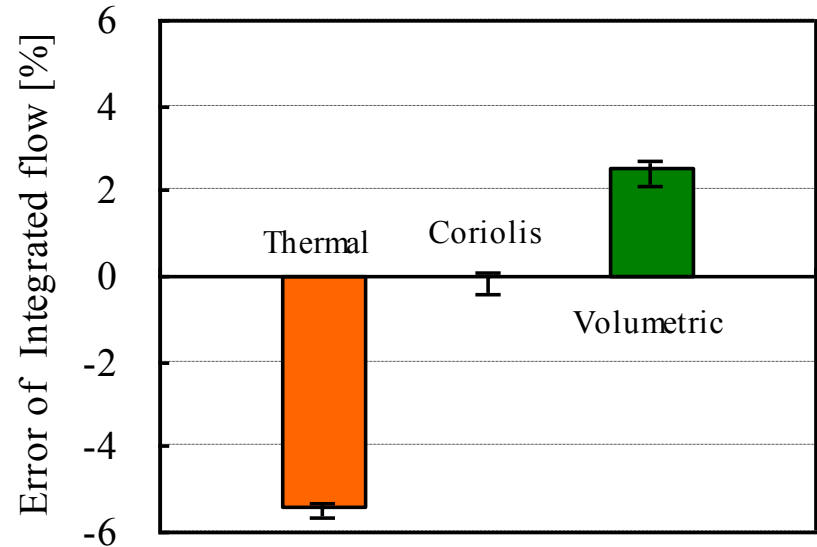
- Accuracy and response of flow meters were tested in transient flow.
- Flow meters showed different trends and different integrated values. Those errors were reduced by re-calibration of flow meters with sonic nozzle (JARI).

流量計により異なる結果 (誤差は流量計の再補正により低減)



Trend data of instant flow rate

瞬時の流量の誤差

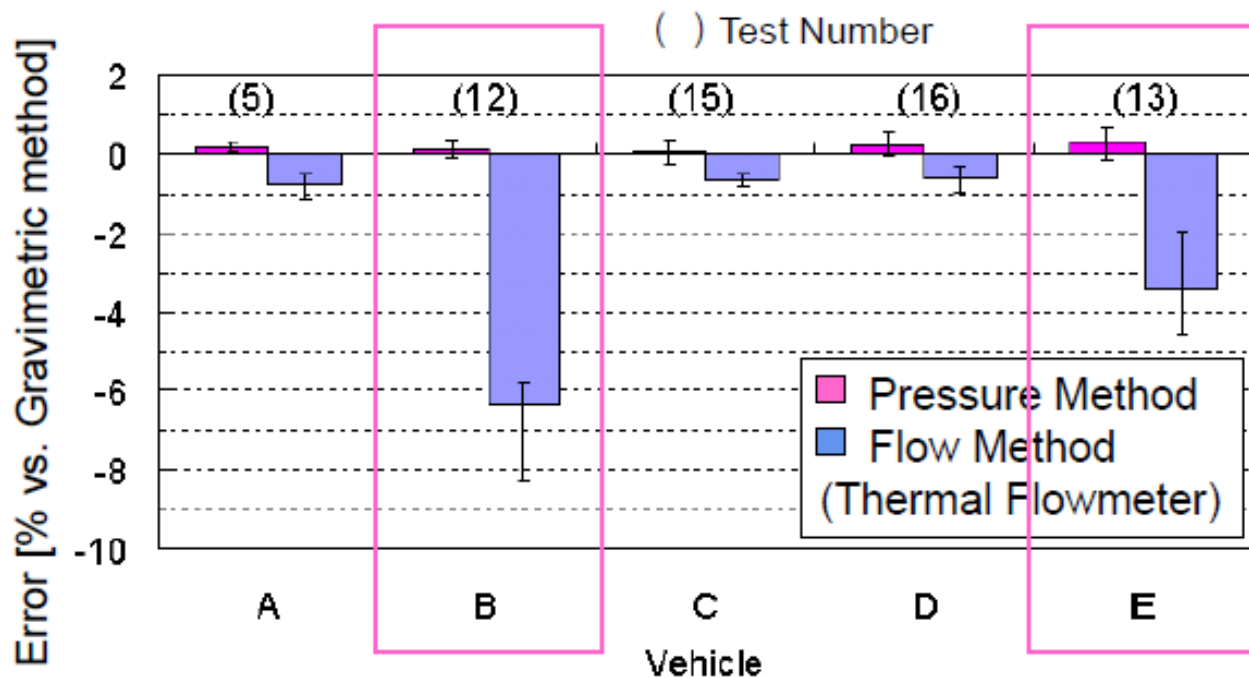


Error of integrated flow vs. gravimetric method

積算流量の誤差 (重量法比)

Issue of Flow Method - FCV test

5車種のFCVの燃費を3つの方法で測定。一部のFCVでは流量法の誤差が大きかった
In 2004, fuel consumption of five FCVs were measured by three methods, "Pressure", "Flow" and "Gravimetric(as reference)".
Flow method showed large error for two FCVs.



Japanese 10·15 mode tested in 2004

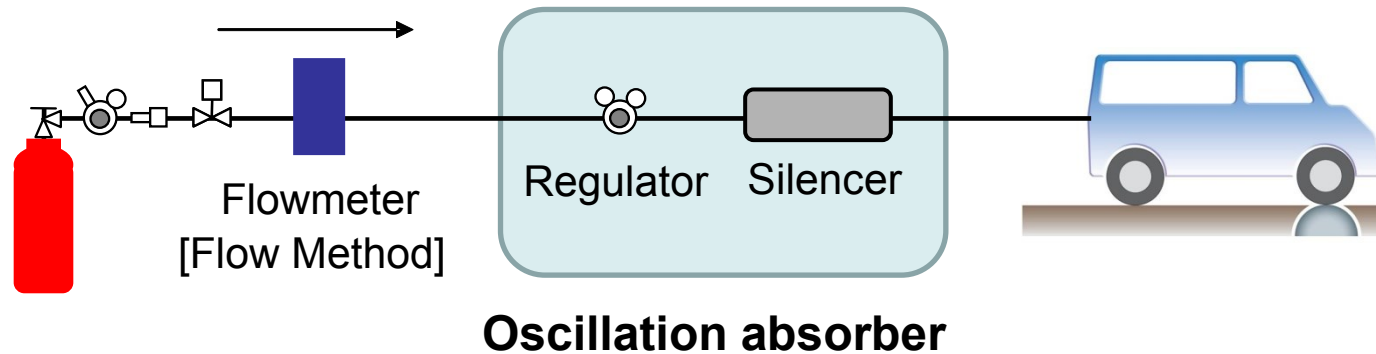
流量法の誤差の大きさは
車両モデルに依存

Error range depends on vehicle model

Application to FCV

車両に由来する誤差を解消するために 流量変動の吸収の効果を評価

- Oscillation absorber was examined to reduce error relating to FCV.

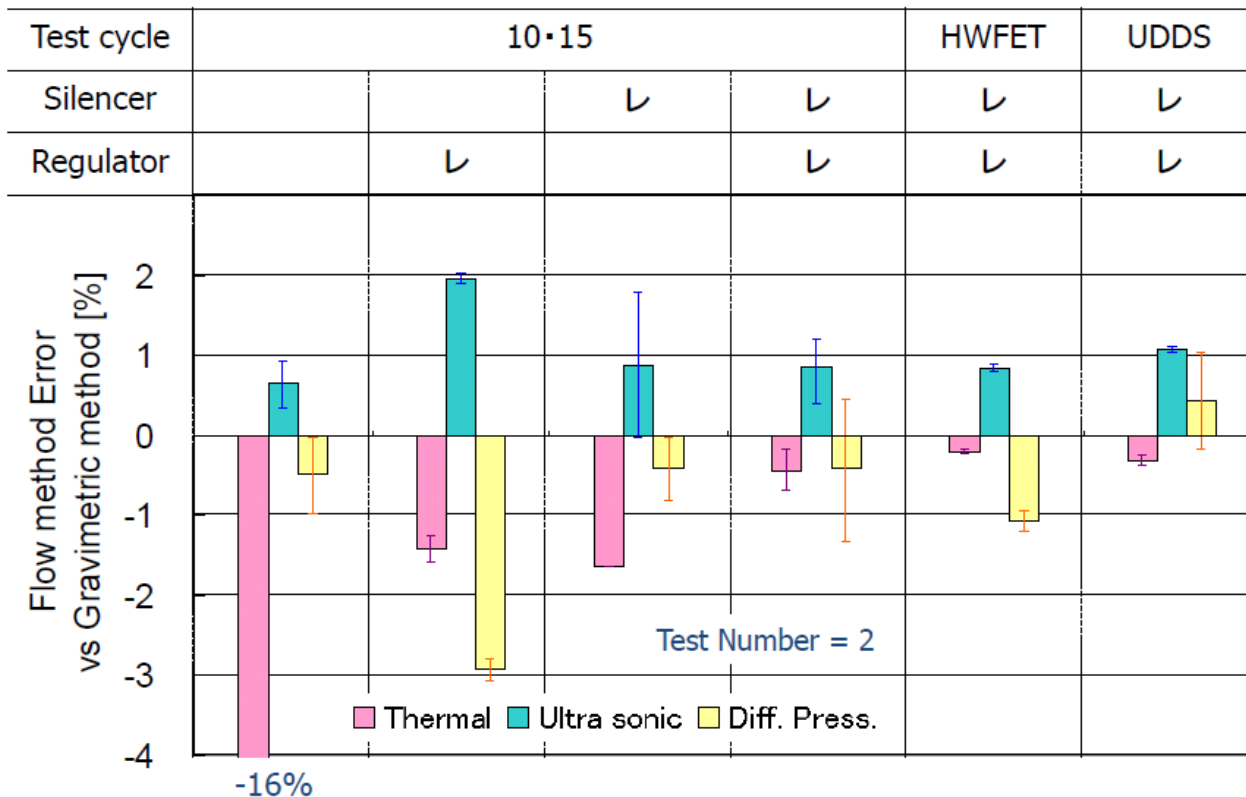


Test cycle	Japanese 10-15mode, US HWFET, UDDS
Test Number	2 in each test cycle
FCV	Vehicle that showed significant oscillations in hydrogen flow
Flow meter	Thermal, Ultrasonic, Diff. pressure.
Pulsation absorber	Silencer (volume 4L), Regulator

Error of Flow Method - FCV Test

流量変動の吸収により誤差は減少

- Errors were reduced by using an oscillation absorber.



但し、流量変動の吸収の効果はWLTCで現在のFCVを用いた確認が必要

The effect of an oscillation absorber needs to be examined with present FCVs in WLTC.

Consideration of Flow method

考察(流量法)

原理: 水素流量を計測し積算

- Principle: Measure H₂ flow rate and Integrate during a test.

計測系を適切に設定すれば、連続的な測定が可能

- If settings are provided appropriately, continuous measurement is possible.

燃費の誤差は流量計、車両の燃料システム、試験サイクルに依存。幾つかの事例で変動吸収が有効

- Error depends on flow meter, FCV fuel system and test cycle. Oscillation absorber was effective to reduce error in some cases.

WLTCで現在のFCVを使った試験なしに、精度に関する規定を作ることは難しい

- Difficult to specify measurement accuracy without testing present FCVs in WLTC.



JAMAはPhase 1bで 流量法を提案しない
(試験データの裏付けある提案あれば反対しない)

JAMA doesn't propose "Flow method" in phase 1b.

(Acceptable if proposed with test data in WLTC.)

Appendix

圧力法の補足データ

Supplement data for Pressure method

- Temperature / Soak time 温度 — ソーク時間
- Error / Soak time 誤差 — ソーク時間

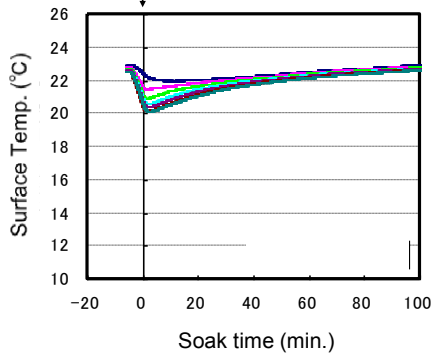
Temp./ Soak time

タンク温度／ソーク時間

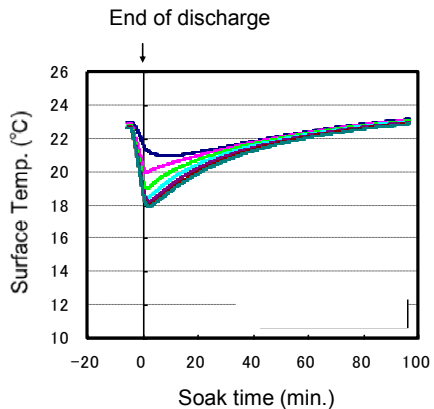
タンクからの水素放出量
(流量 × 時間)

Discharge rate and time

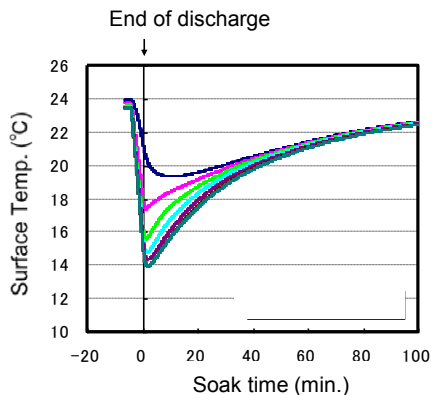
50NL/min × 5min



100NL/min × 5min



200NL/min × 5min



14MPaG

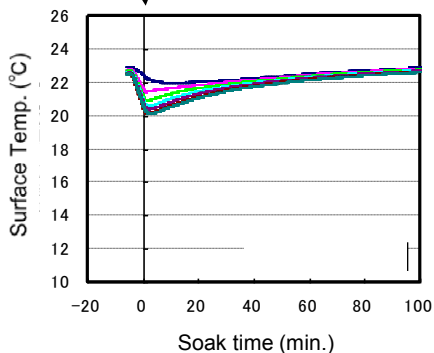
End of discharge

Pressure before discharge

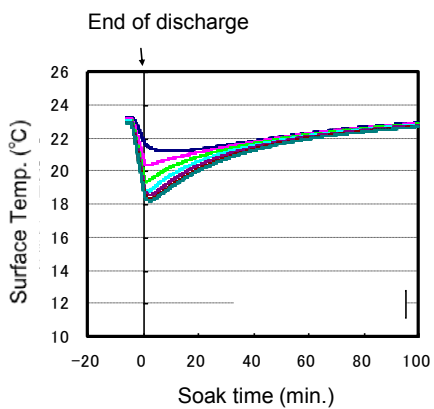
タンク初期圧

8MPaG

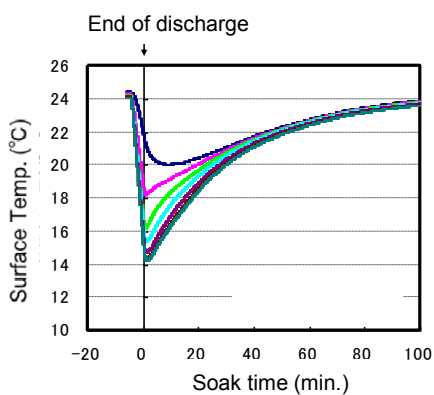
End of discharge



100NL/min × 5min

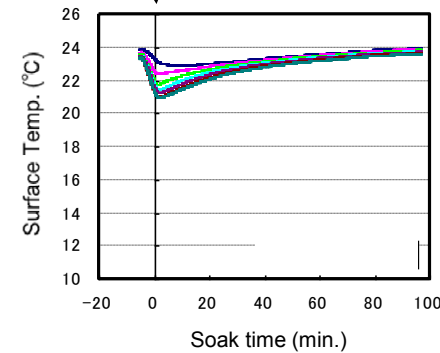


200NL/min × 5min

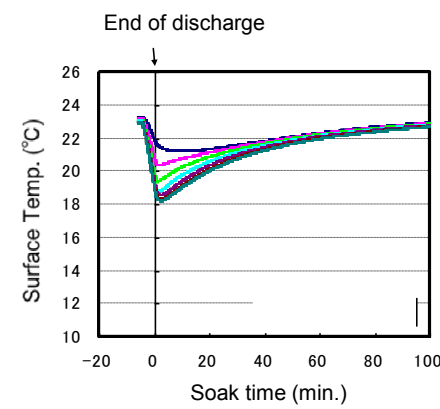


5MPaG

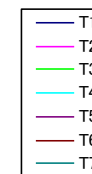
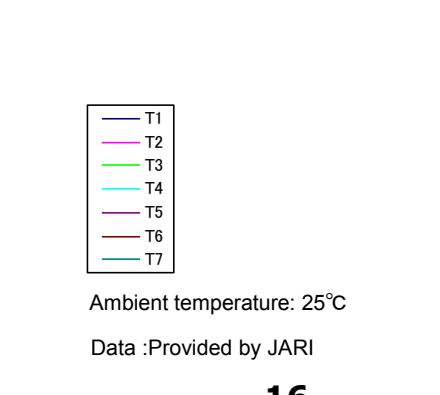
End of discharge



100NL/min × 5min



200NL/min × 5min



Ambient temperature: 25°C

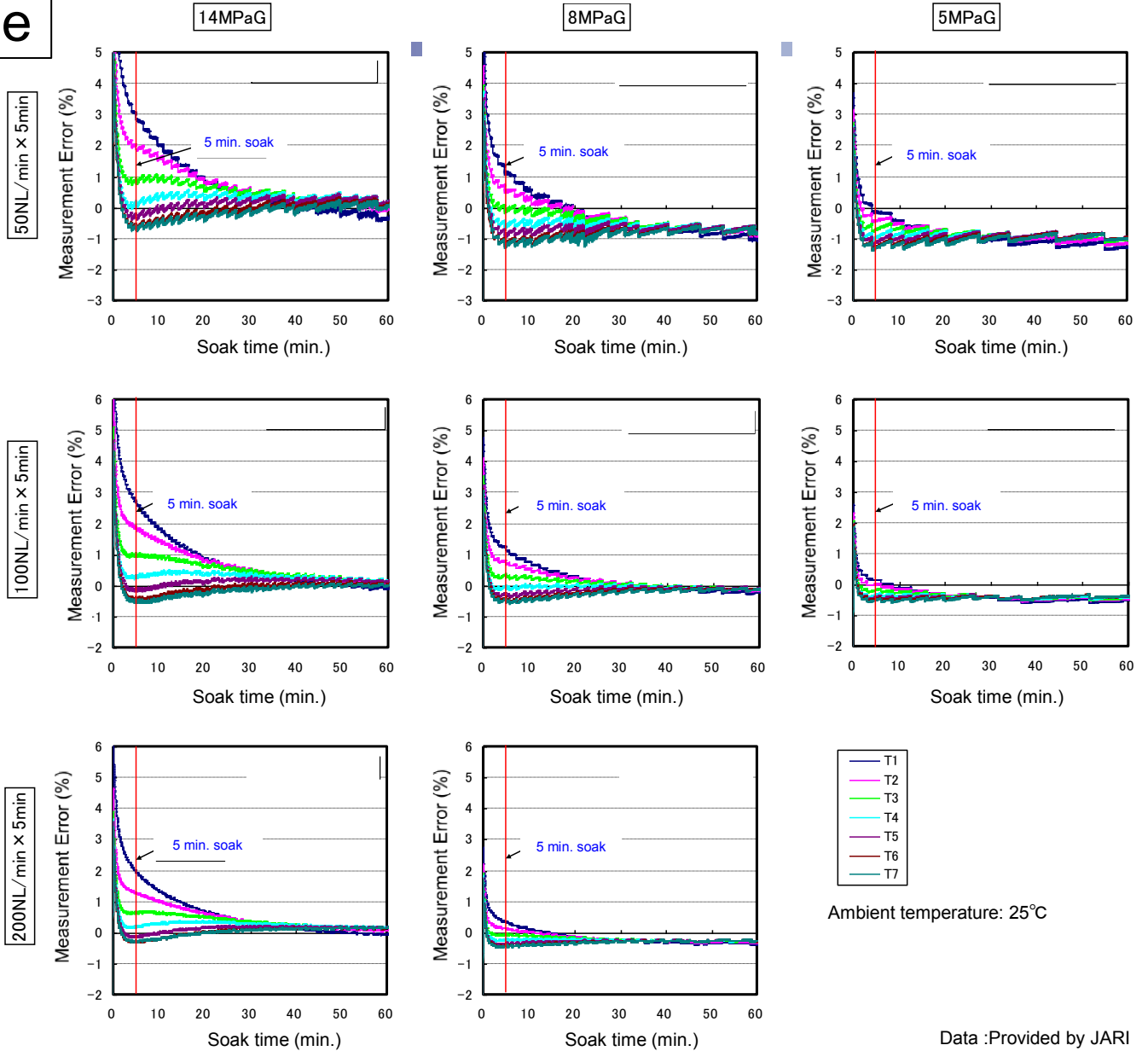
Data : Provided by JARI

Error / Soak time

燃費の誤差 / ソーク時間

タンクからの水素放出量
(流量 × 時間)

Discharge rate and time



Pressure before discharge

タンク初期圧

5MPaG

Data : Provided by JARI