計測法　詳細

Gravimetric Method 重量法

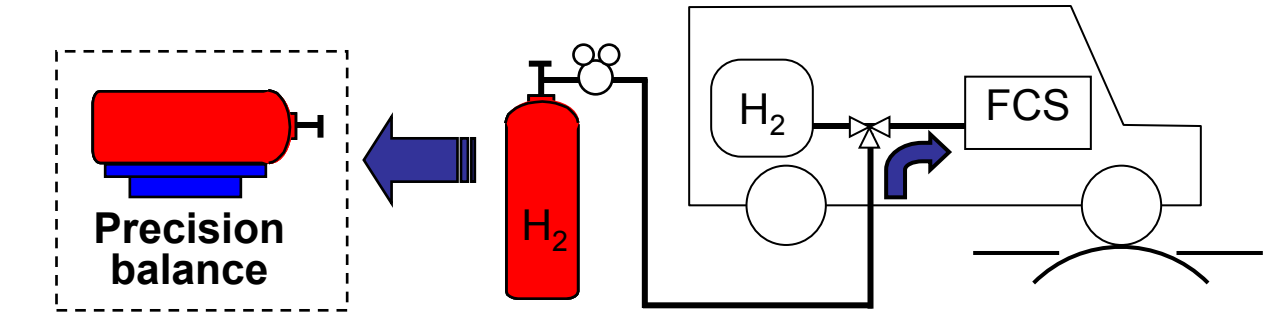
Principle: Weighing the H2 tank before and after the test

$$W = g_1 - g_2$$

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

Here, W = Fuel consumption

$g1$ = Mass of H_2 tank before test , $g2$ = Mass of H_2 tank after test



Before and after the test　　Fuel bypass line

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

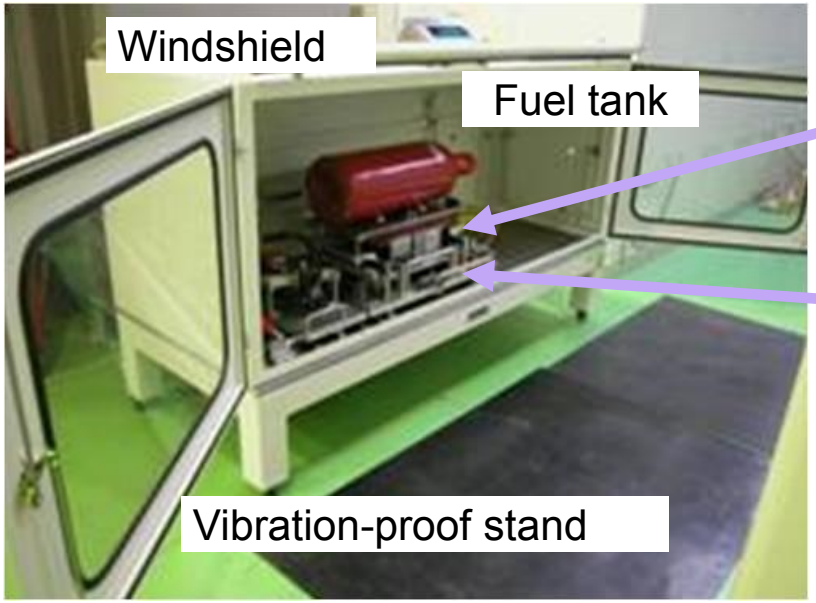
短所：水素タンクの着脱が必要

- Need to disconnect H2 tank from fuel line for weighing

Reference: JARI presentation

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 ｸﾞﾗﾑ)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ﾌｪｰｽﾞの推定水素消費量(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

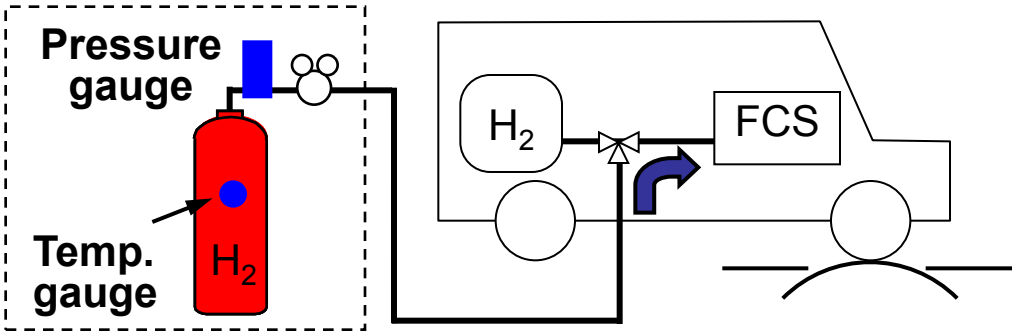
Here, W = Fuel consumption [g], m = Molecular weight of H_2 2.016 [g/mol]
V = Volume of H_2 tank [m3], R = Gas constant 8.314 [J/mol·K]
$P1$ = H_2 pressure before test [Pa], $P2$ = H2 pressure after test [Pa]
$T1$ = H_2 temperature before test [K], $T2$ = H2 temperature after test [K]
$z1$ = Compressibility factor at P1, T1, $z2$ = Compressibility factor at P2, T2

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）



Reference: JARI presentation

Test Equipment for Pressure Method

圧力法の試験機器

Pressure gauge

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

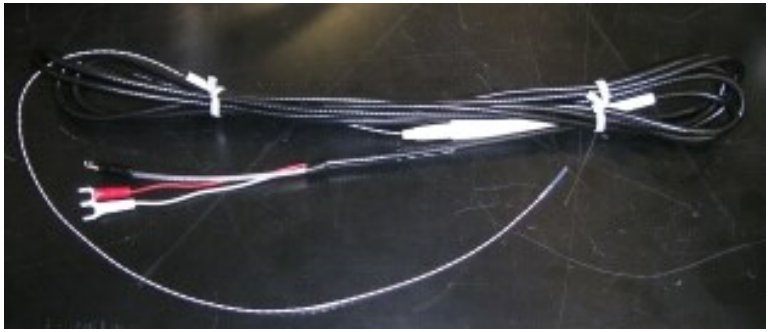
高圧測定可

- Applicable to high pressure

十分な精度

- Sufficient accuracy

Temperature gauge



Range	10 to 30 ℃
Error	0.01 to 0.03 ℃

十分な精度

- Sufficient accuracy

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℃は同0.15%相当

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

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

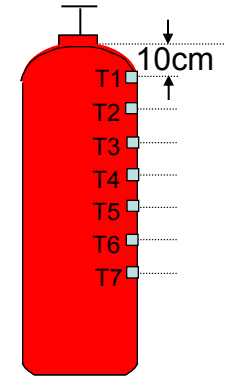
30g of H2 consumption is assumed for phase-L3 of WLTC

Pictures/Tables from JARI presentation

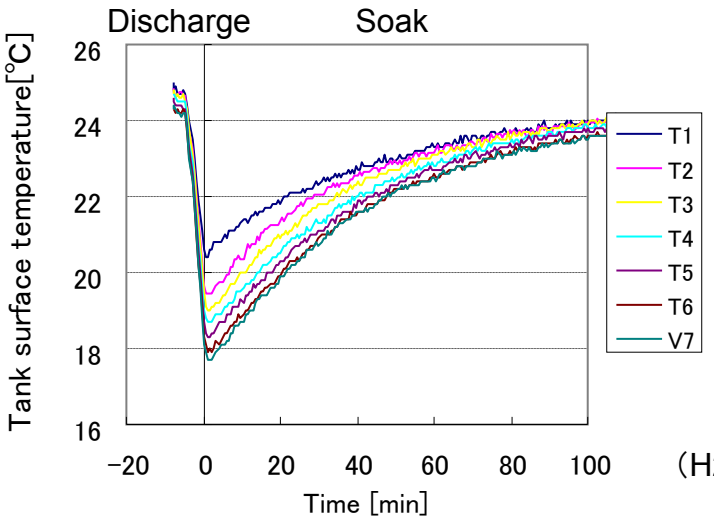
Temperature Trend after Test 試験後のタンク温度

Tank Surface Temperature - during H_2 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)



- Temp. decrease during H_2 discharge
- The lower part reached lower temp. than upper part.
- Temp. increased again during soak.

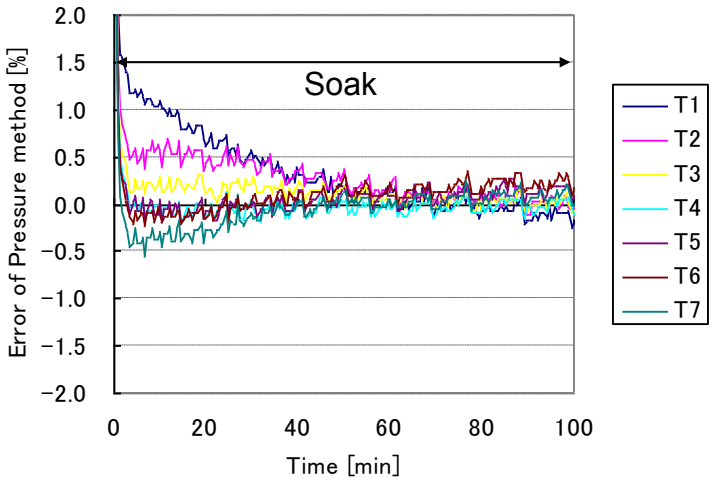
・水素放出時にタンク温度低下
・ソーク時にタンク温度上昇（環境温度に戻る）

（H2 discharge : 30L/min, 5min）

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.

Reference : JARI presentation

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ﾌｪｰｽﾞ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”.

Flow Method 質量法

Principle: Measure H2 flow rate and Integrate during a test

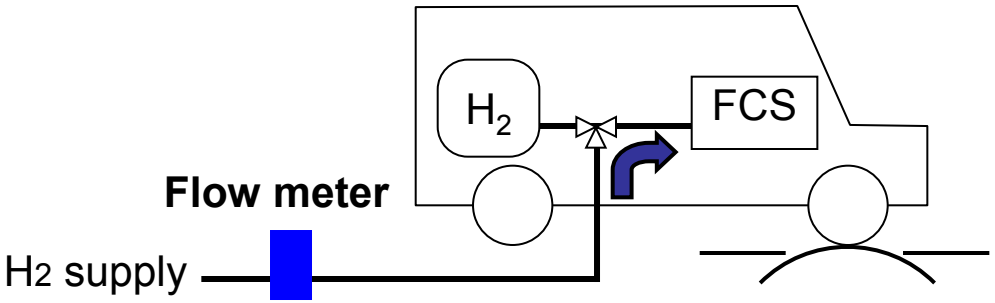
$$W = \int_{test} q(t)dt \times \frac{m}{22.414}$$

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]



フェーズ間を連続して計測可能

Advantages - Continuous measurement for series of phases

流量計、計測系の設定を事前に確認する必要がある

Disadvantages - Need to examine suitable flow meter and settings for FCV test

Reference: JARI presentation

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]

Reference: JARI presentation

Characteristic of Flow Meter

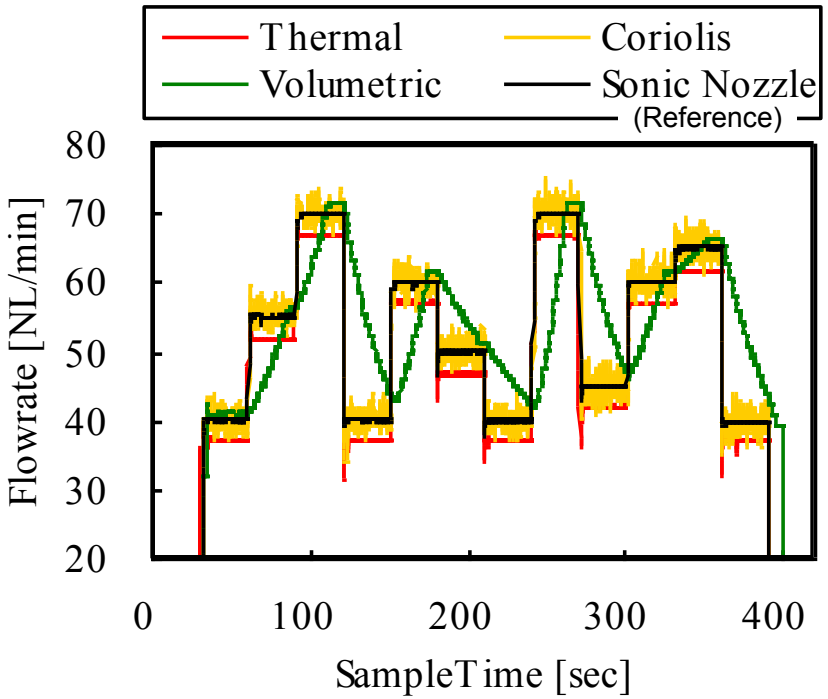
流量計の特徴

精度とレスポンスを評価

- Accuracy and response of flow meters were tested in transient flow.

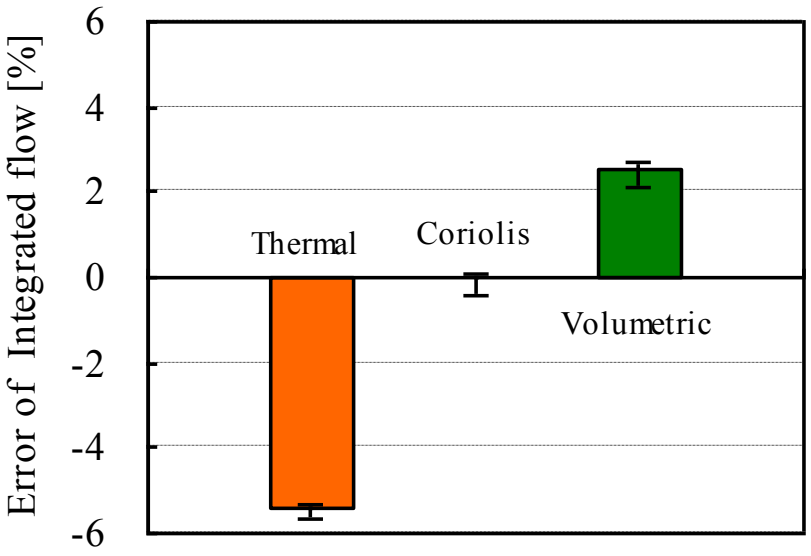
流量計により異なる結果（誤差は流量計の再補正により低減）

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



Trend data of instant flow rate

瞬時の流量の誤差



Error of integrated flow vs. gravimetric method

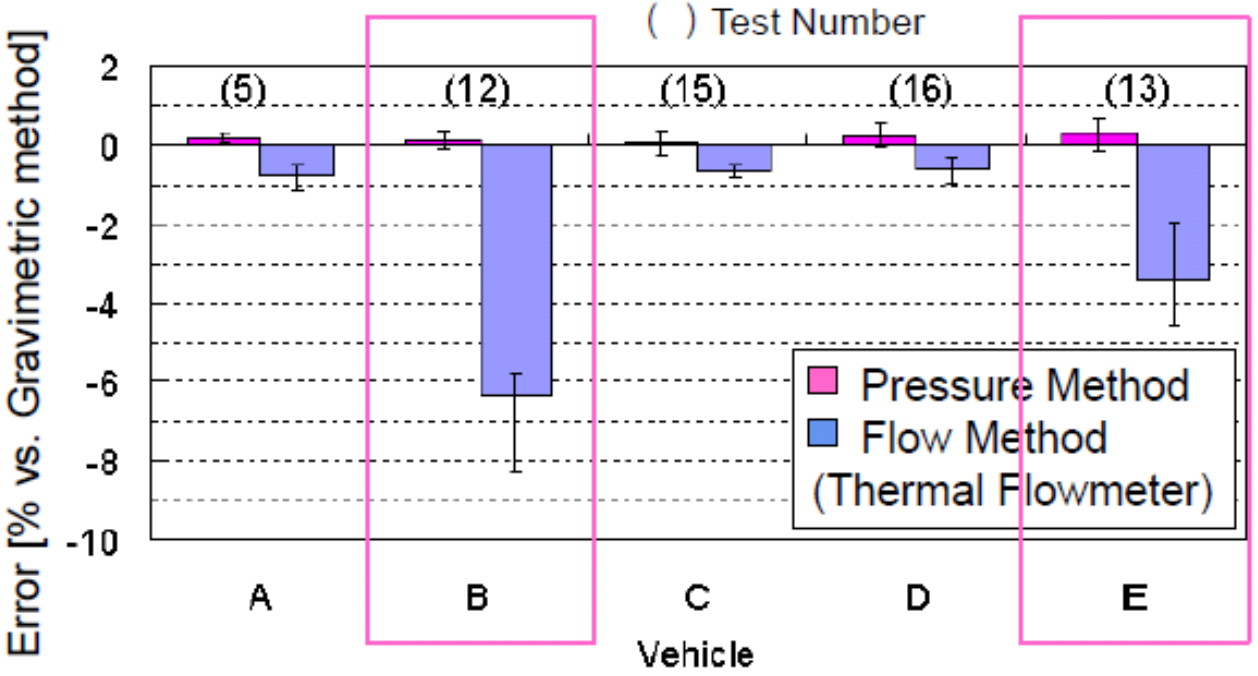
積算流量の誤差（重量法比）

Figures from JARI presentation

Issue of Flow Method - FCV test 流量法の課題

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

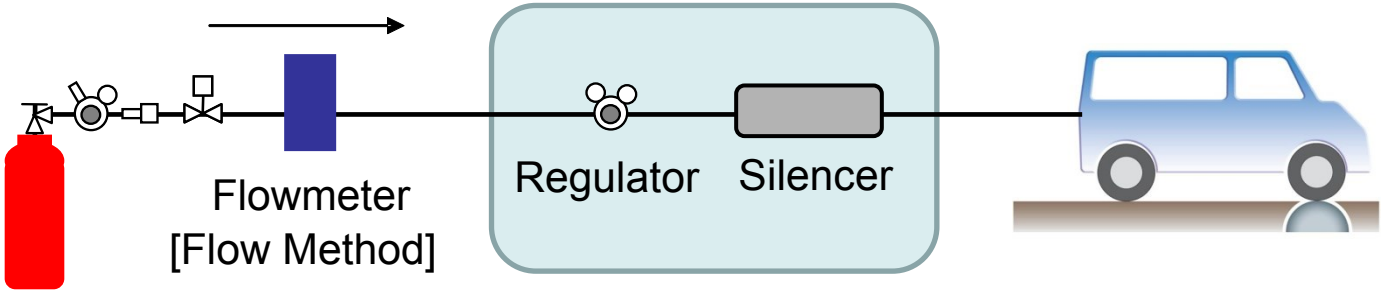
Reference : JARI presentation

Application to FCV

車両への適用

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.



Oscillation absorber

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

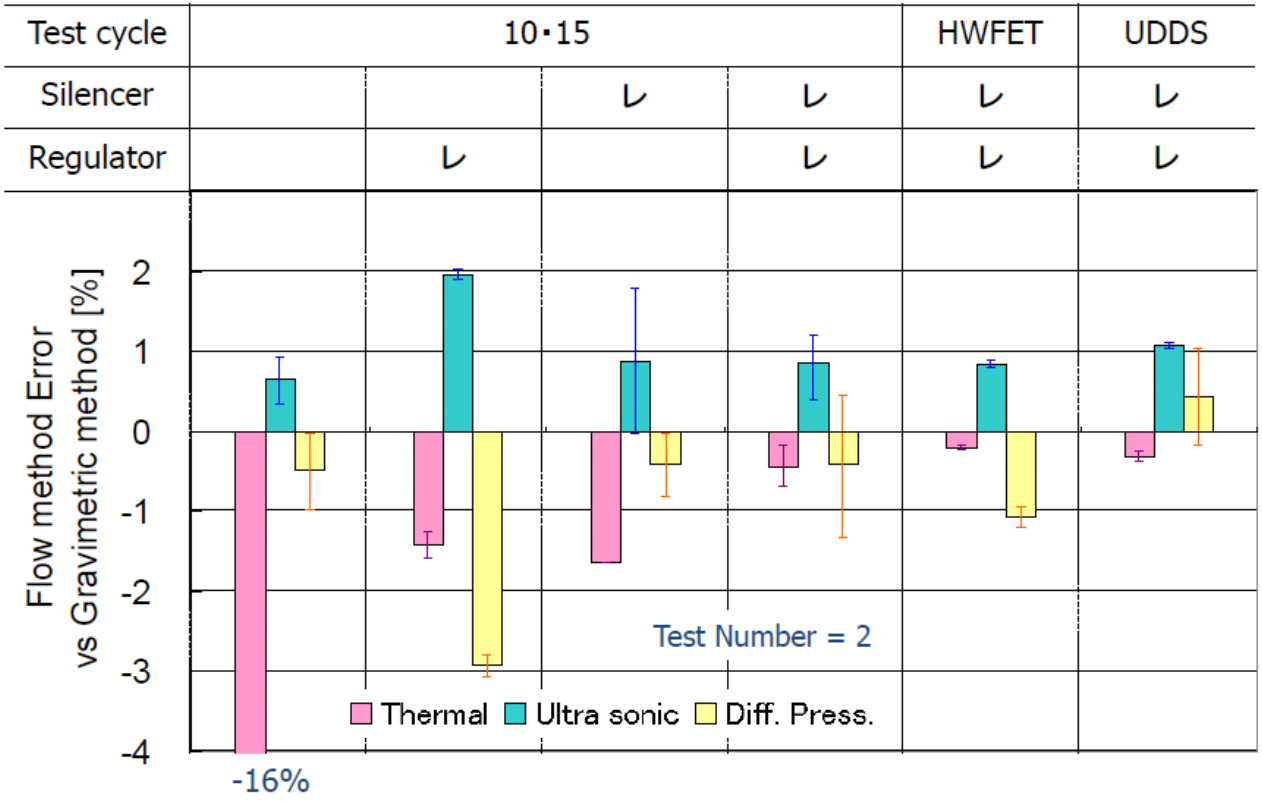
Reference: JARI presentation

Error of Flow Method - FCV Test

流量法の誤差

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.

Figure from JARI presentation

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

温度 － ソーク時間

- Temperature / Soak time

誤差 － ソーク時間

- Error / Soak time

Temp./ Soak time

タンク温度／ソーク時間

Pressure before discharge　タンク初期圧

14MPaG　8MPaG　5MPaG

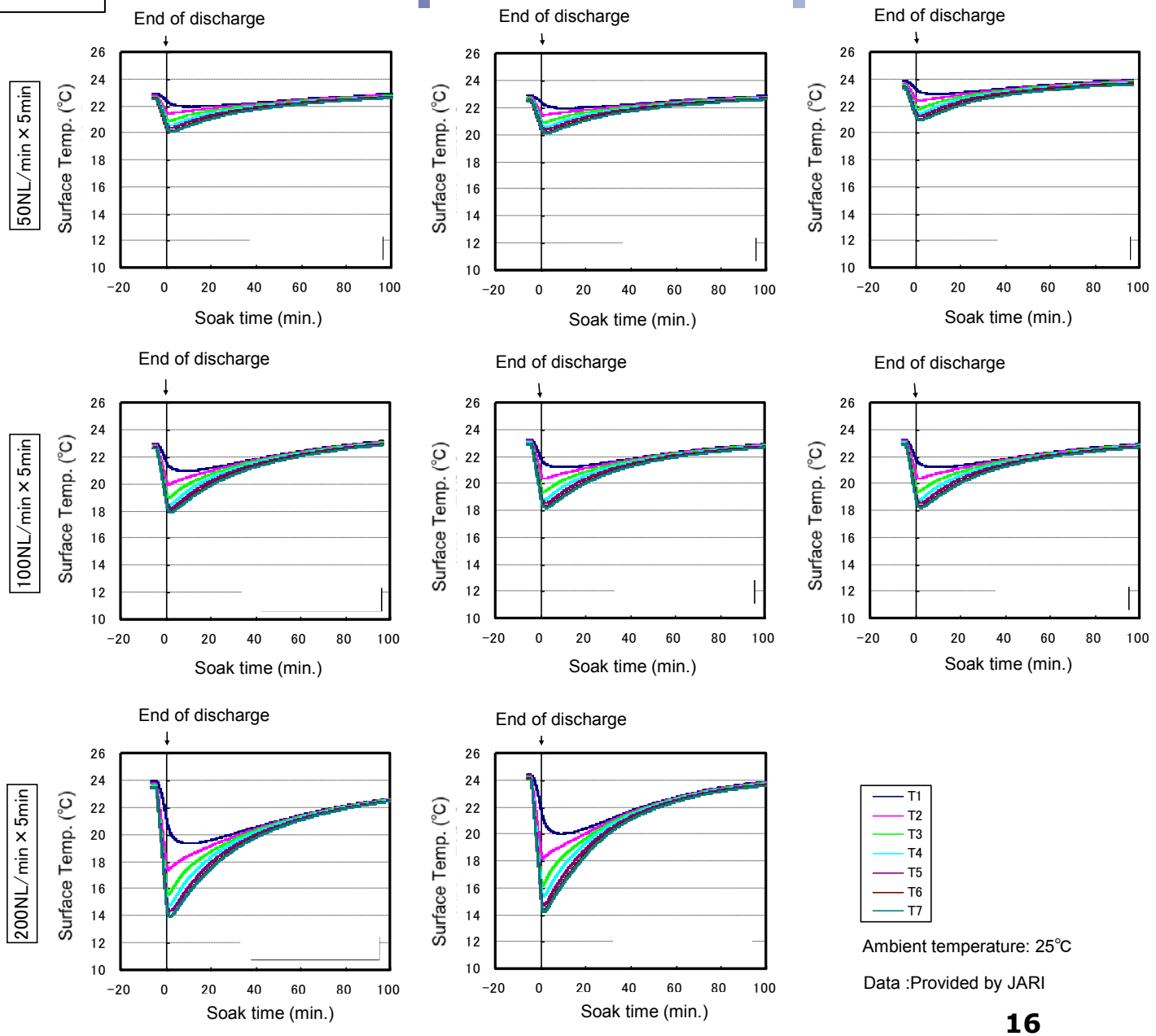
Discharge rate and time

タンクからの水素放出量（流量×時間）

50NL/min × 5min

100NL/min × 5min

200NL/min × 5min



Ambient temperature: 25℃

Data :Provided by JARI

Error / Soak time

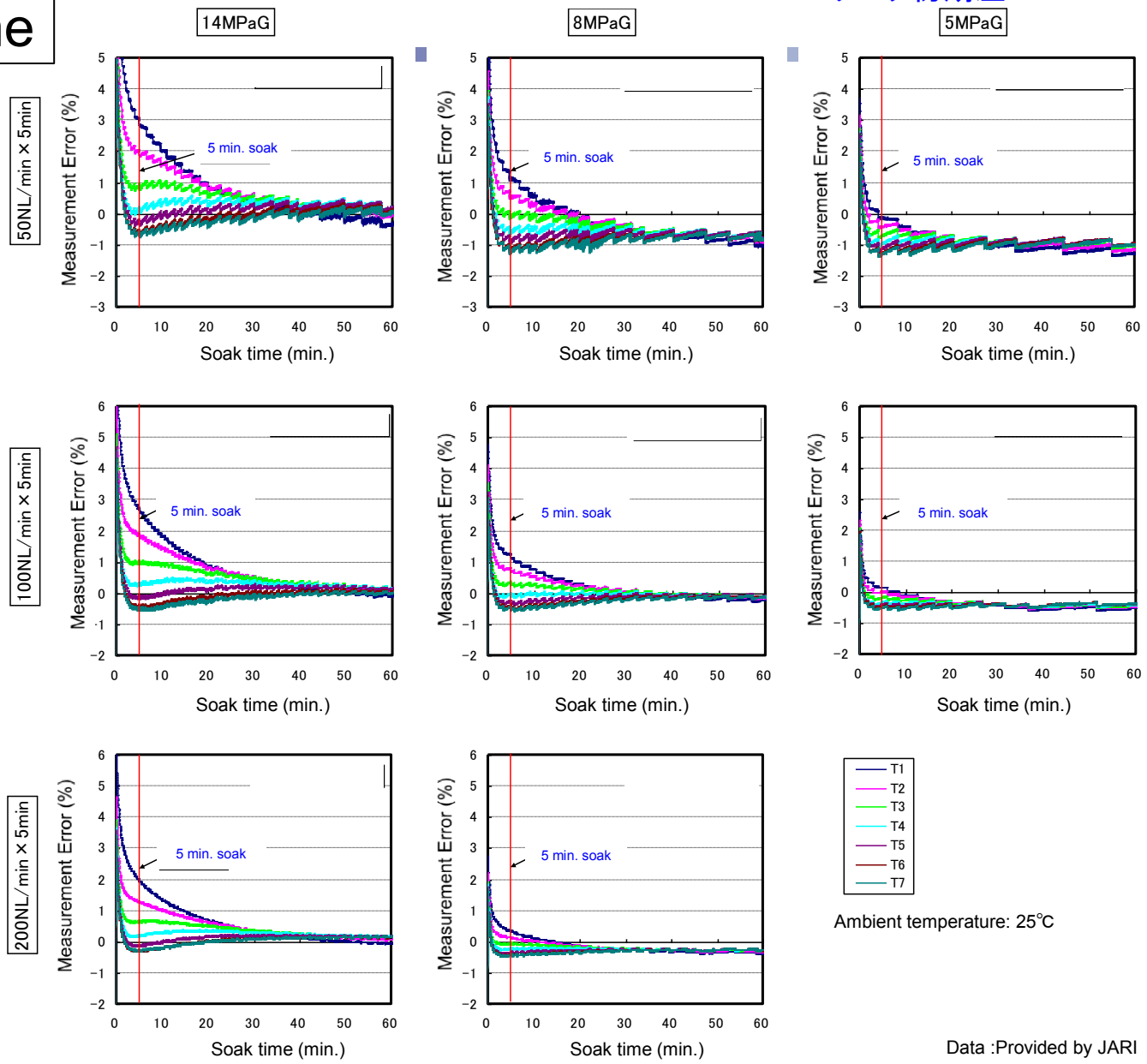
燃費の誤差／ソーク時間

Pressure before discharge

タンク初期圧

Discharge rate and time

タンクからの水素放出量
（流量 × 時間）



Ambient temperature: 25℃

Data :Provided by JARI