GAS TURBINE TEST PARAMETERS CORRECTIONS INCLUDING OPERATION WITH WATER INJECTION

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- Introduction: Why Corrections?
- Factors Determining Performance - Correction Curves
- Referring Values To Specific Conditions
- Operation With Water Injection
  - Power, Efficiency, Water Flow
- Summary - Conclusions

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Main Performance Parameters

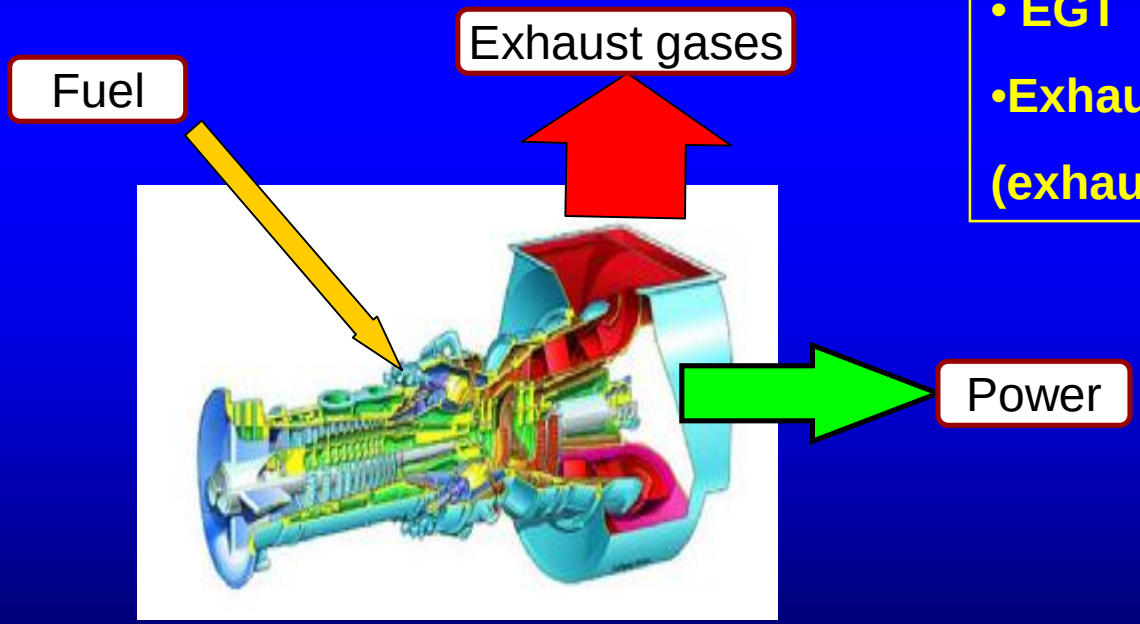
- **Power**
- **Efficiency**

(or equivalently, heat rate)

Other

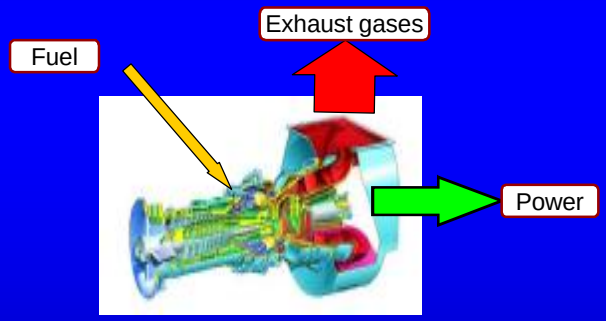
- **EGT**
- **Exhaust Gases Flow Rate**

(exhaust heat exploited)



Why corrections?

Specifications, Guarantees: Standard day Condition



Testing: Site weather conditions

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Factors Determining Performance

$$P = \dot{m}_g c_{pg} T_4 \left(1 - \frac{1}{p_T^{\frac{\gamma_g - 1}{\gamma_g}}}\right) \eta_{Tis} - \dot{m}_a c_{pa} T_2 \frac{1}{\eta_{Cis}} \left(p_c^{\frac{\gamma_a - 1}{\gamma_a}} - 1\right) - P_L$$

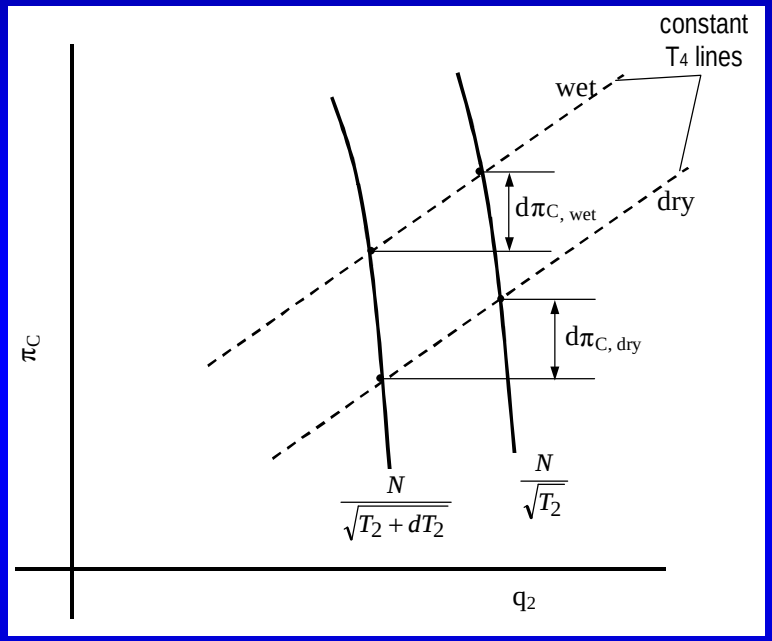
$$\eta_{th} = \frac{P}{Q_{in}}$$

- **Ambient**

  Direct: Ambient pressure, Ambient temperature T2, Humidity.
  Indirect: Change in pressure ratio

- **Fuel ® change Cpg , proportion of m_g to m_a.**
- **Water, steam Injection ® change Cpg the gas mass flow rate mg.**

Movement of Compressor operating point



Dry and wet operation, change in ambient temperature

(constant mechanical speed)

The background for deriving corrections

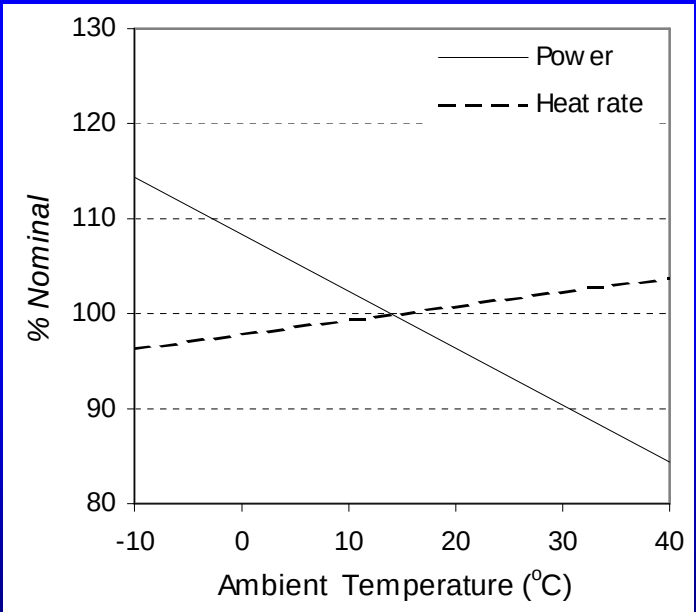
Importance of T4, ® kept it as high as possible.

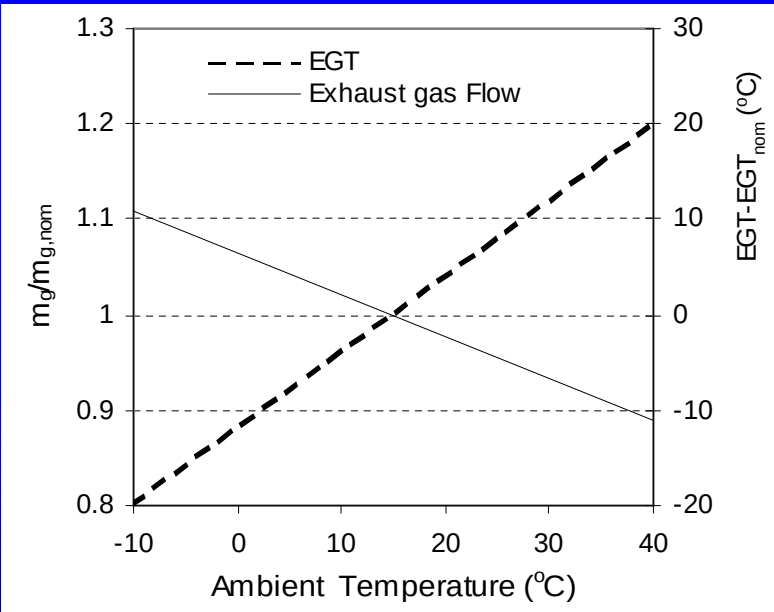
Interesting to know performance for T4 fixed, independently of ambient conditions.

$$Y_{cor} = Y_{test} \cdot K_1 \cdot K_2 \cdots K_n$$

Typical dependence on ambient conditions

Power, Heat Rate, EGT, Exhaust Gases Dependence on ambient temperature

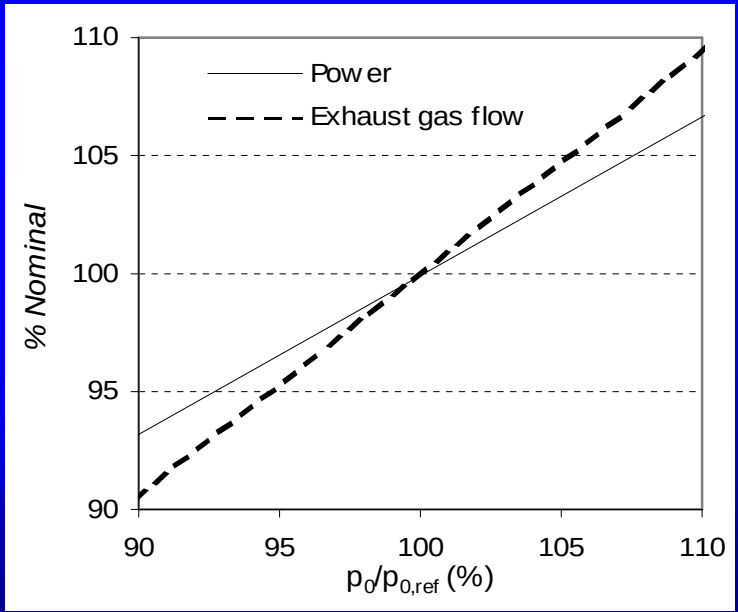




Typical dependence on ambient conditions

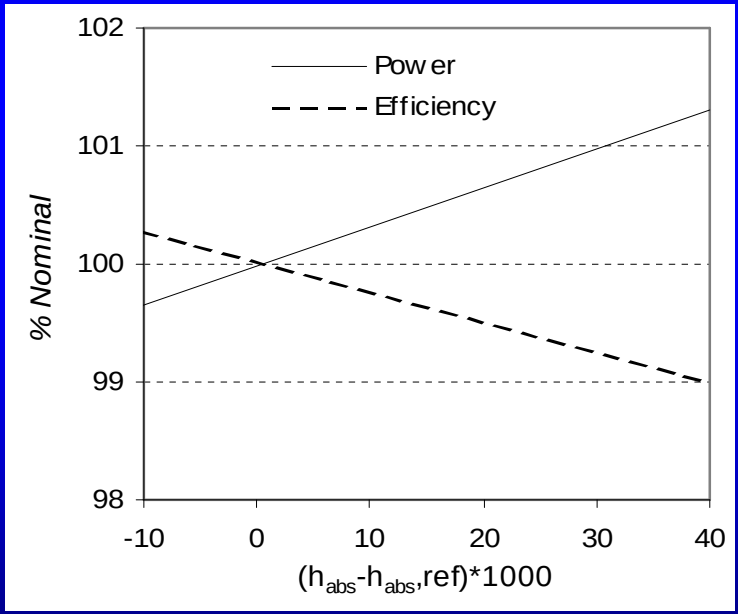
Power and exhaust gases mass flow rate.

Dependence on ambient pressure

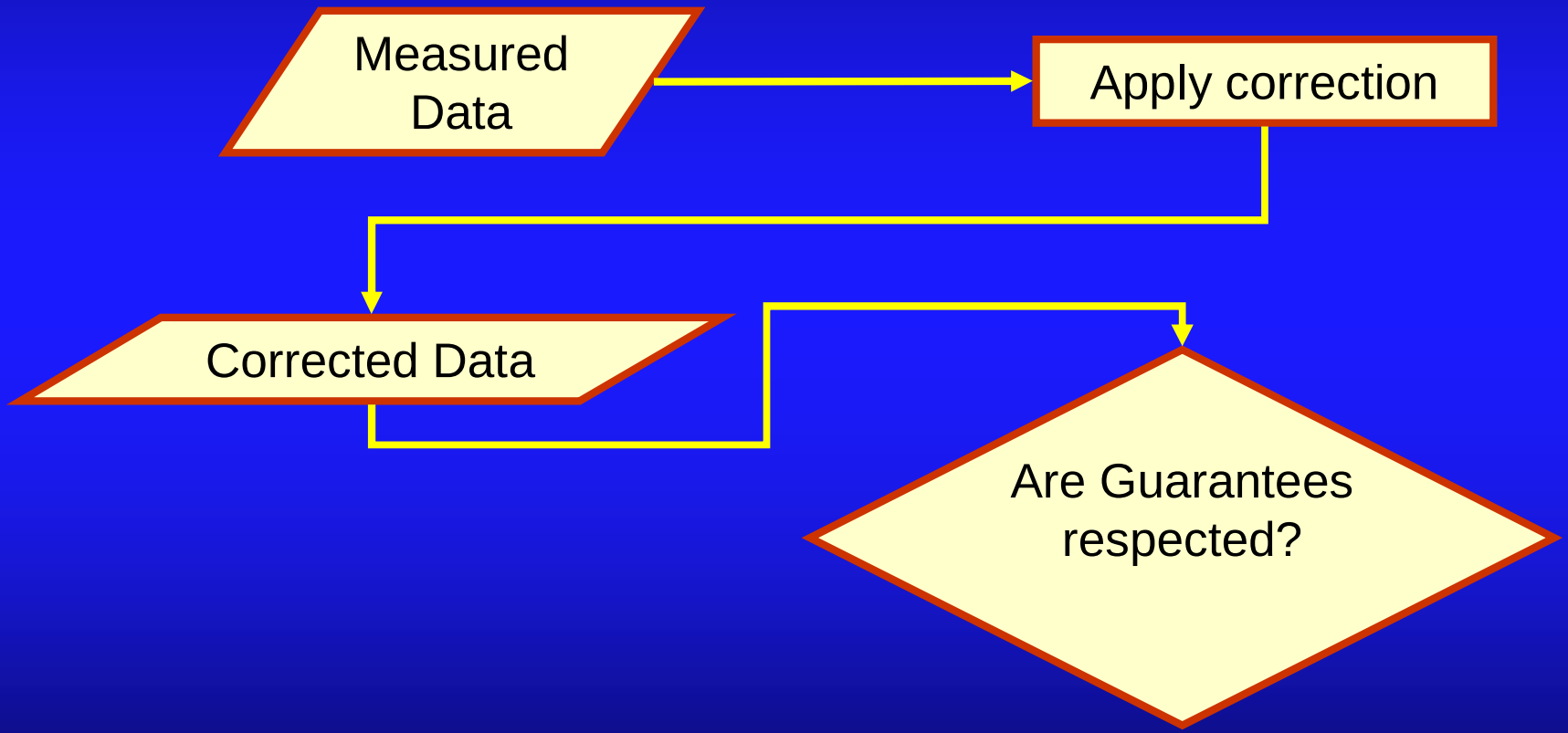


Typical dependence on ambient conditions

Dependence of power and efficiency on ambient humidity.



Data Correction Procedure



Usual Guarantee Specification

For X= *(VALUE)* , Y no less than *(VALUE)*

Or

X < or > *(VALUE)* ,
with Z remaining < than *LIMIT*

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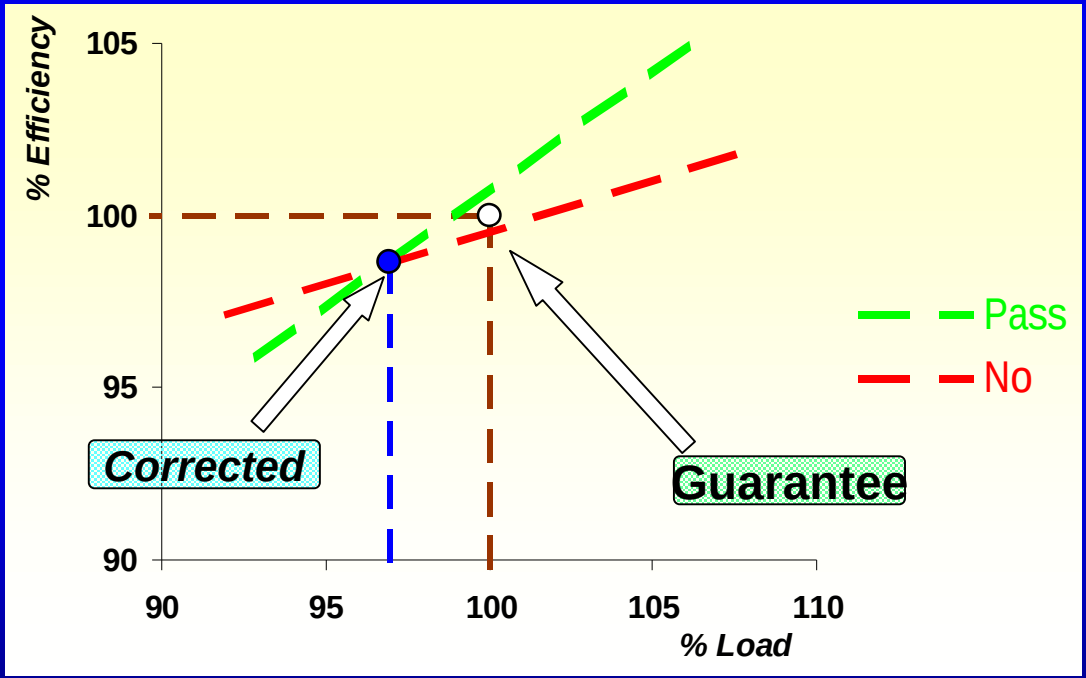
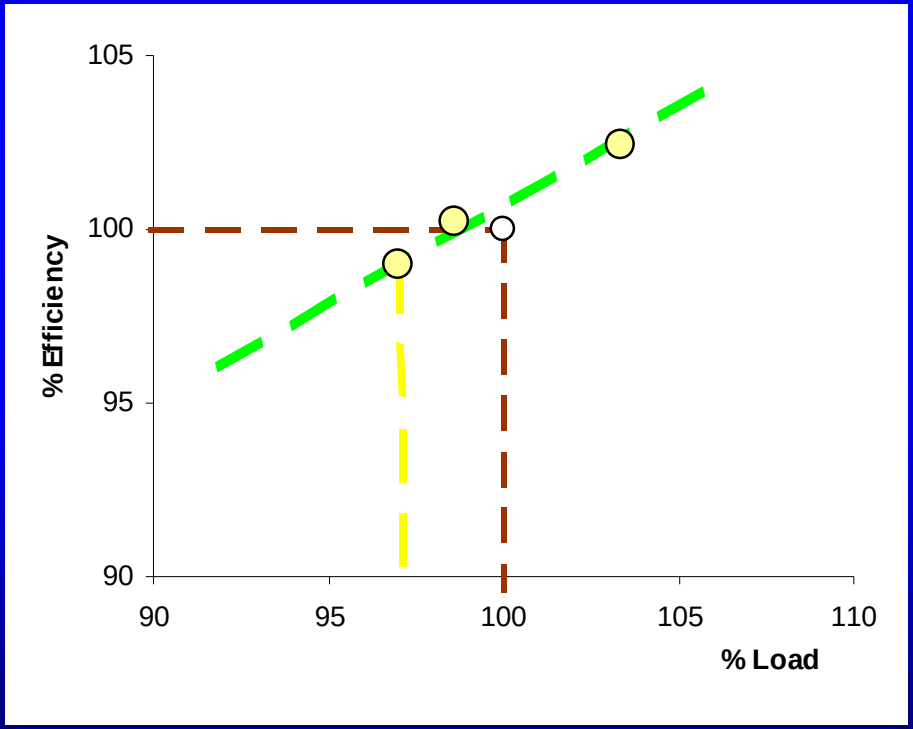
Referring values to specific conditions

Possible Ambiguity for single test point data



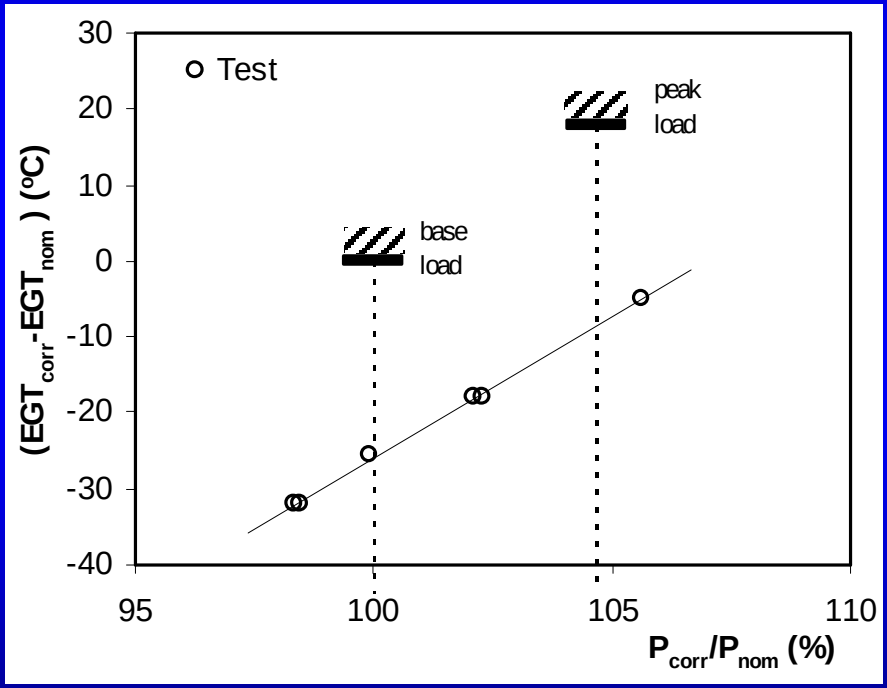
Referring values to specific conditions

Resolve ambiguity by using more test points



Example data referred to standard day

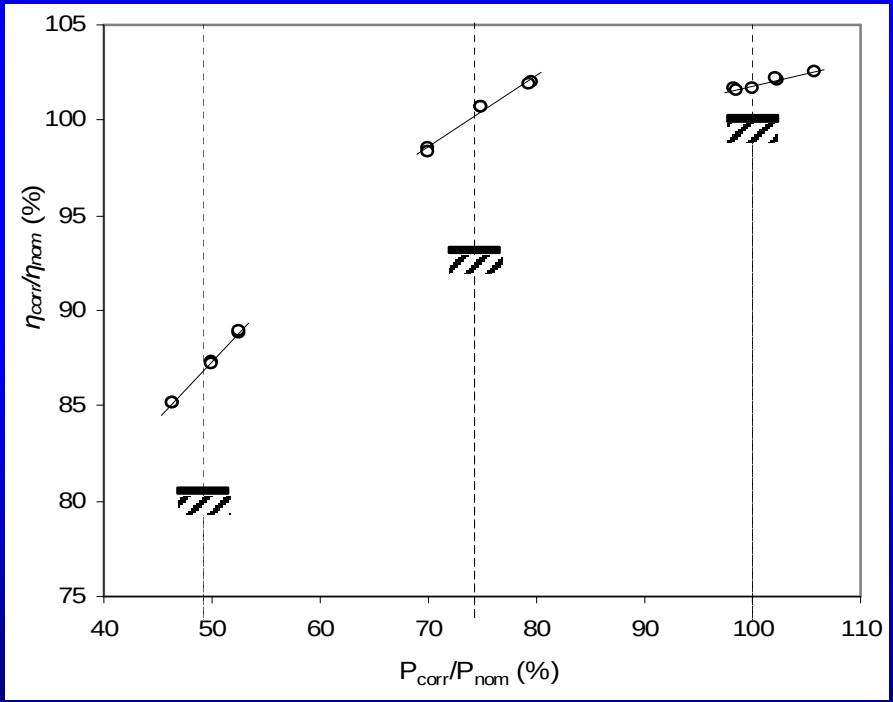
Verify base load and peak load conditions.



Exhaust gas Temperature must remain below limits

Example data referred to standard day

Verify that efficiency is above guarantee values



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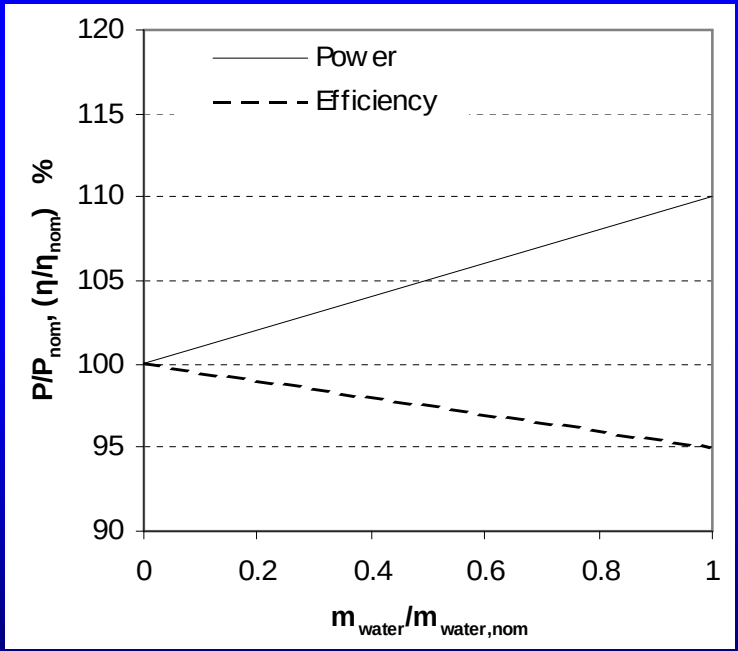
Operation with water injection

Typical Power and Efficiency Variations

For varying Amount of Injected Water.



Operation with water injection

Questions :

- How is the water amount corrected?
- How are performance parameters corrected in this case?

Operation with water injection

Background for corrections

Water flow rate

Water to fuel ratio ***W*** should be kept the same, in order to have the same effect on emissions.

Performance parameters

The 'dry' correction curves for ambient conditions can be applied

Operation with water injection

Reasoning for applying 'dry' corrections (I)

$$\frac{dP}{P} = \left(l\,B - \left(l-1\right)A + 1\right)\frac{dp_c}{p_c} - \left(l-1\right)\frac{dT_2}{T_2}$$

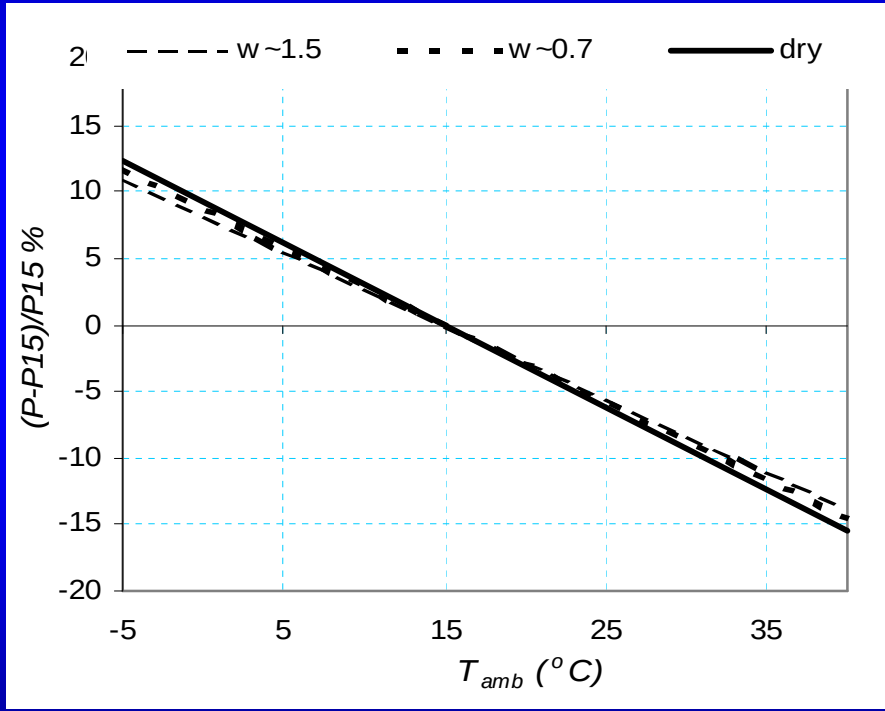
$$l = \frac{P_T}{P}$$

$$A = \frac{g_{a-1}}{g_a} \cdot \frac{p_c^{\frac{g_a - 1}{g_a}}}{p_c^{\frac{g_a - 1}{g_a}} - 1}$$

$$B = \frac{g_g - 1}{g_g} \cdot \frac{1}{p_T^{\frac{g_g - 1}{g_g}} - 1}$$

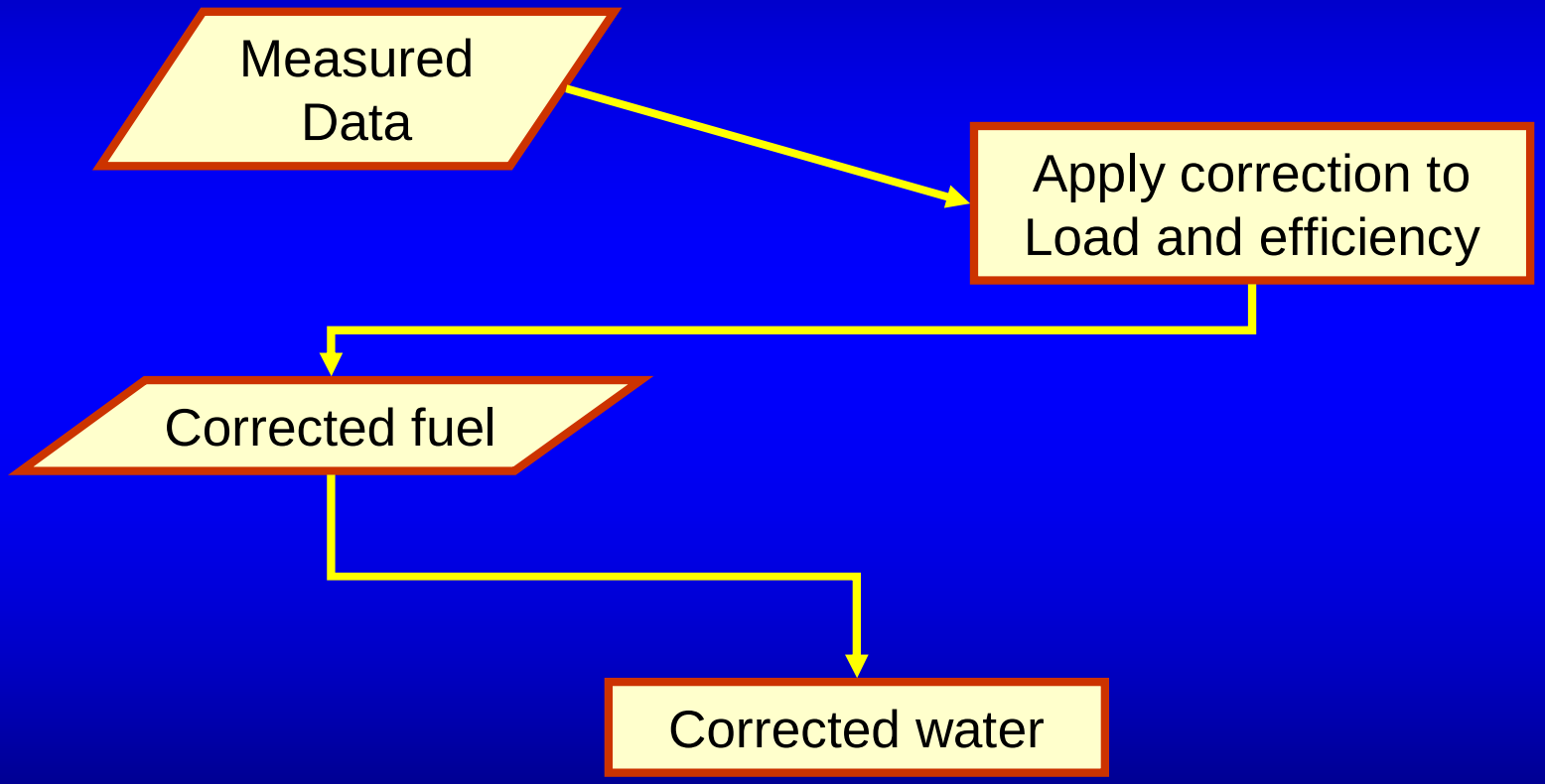
Operation with water injection

Reasoning for applying 'dry' corrections (II)



Example Calculated Fractional change of power for dry and wet operation

Data Correction Procedure



Operation with water injection

Relations for corrections

Corrected fuel flow rate:

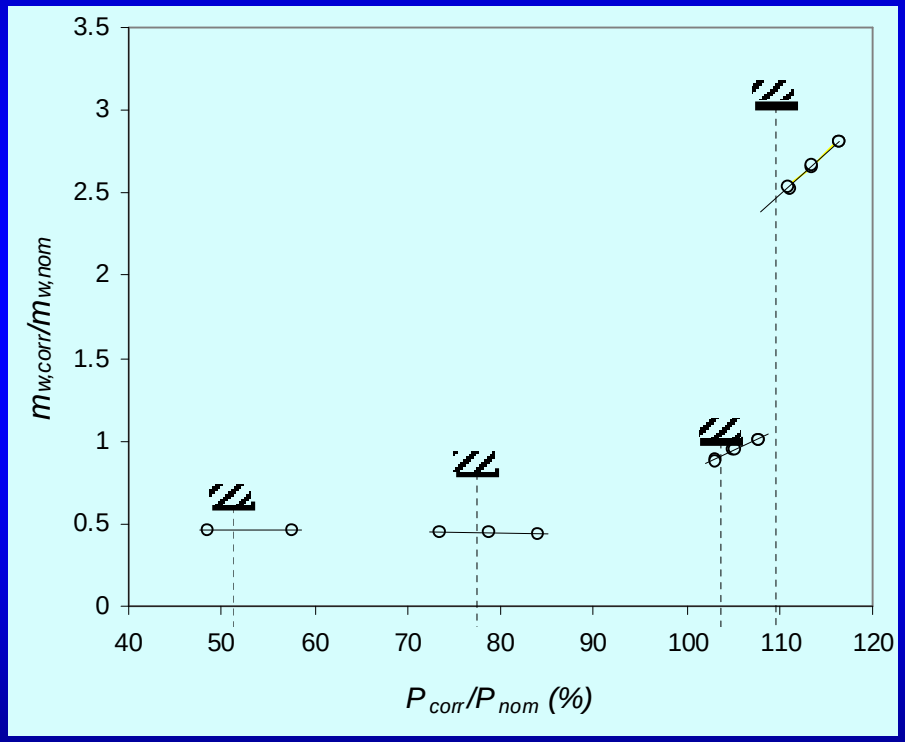
$$\dot{m}_{f,corr} = \frac{P_{corr}}{h_{corr}\, LHV}$$

Corrected water flow rate:

$$\dot{m}_{w,corr} = \dot{m}_{w,meas} \frac{\dot{m}_{f,corr}}{\dot{m}_{f,meas}}$$

Example Application

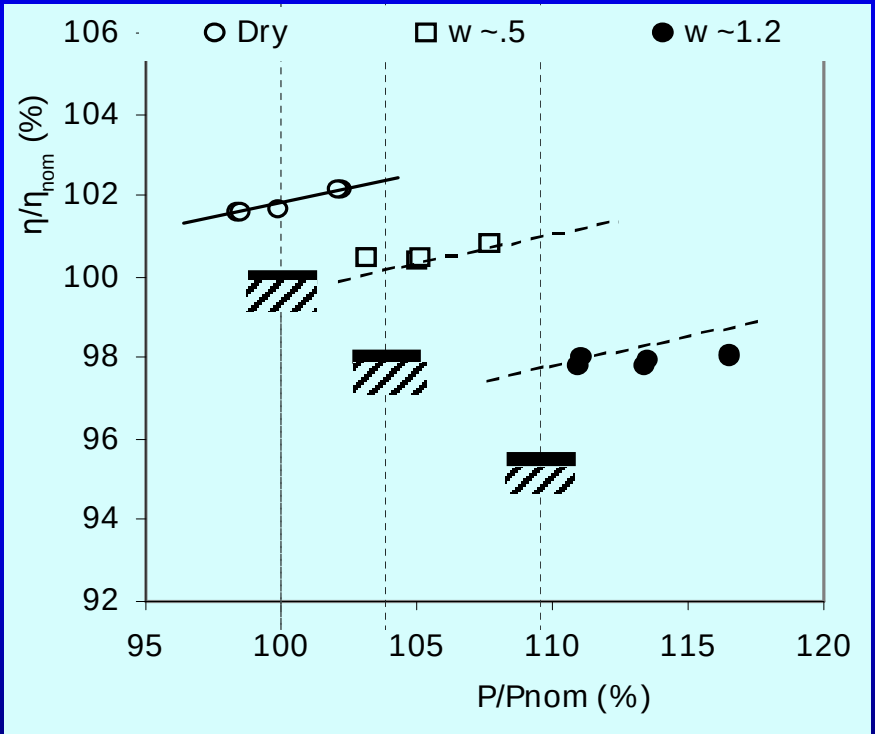
Comparing water flow rates to guarantee values.



Load points A-50%, B-75%, C-100%(1), D-100%(2).

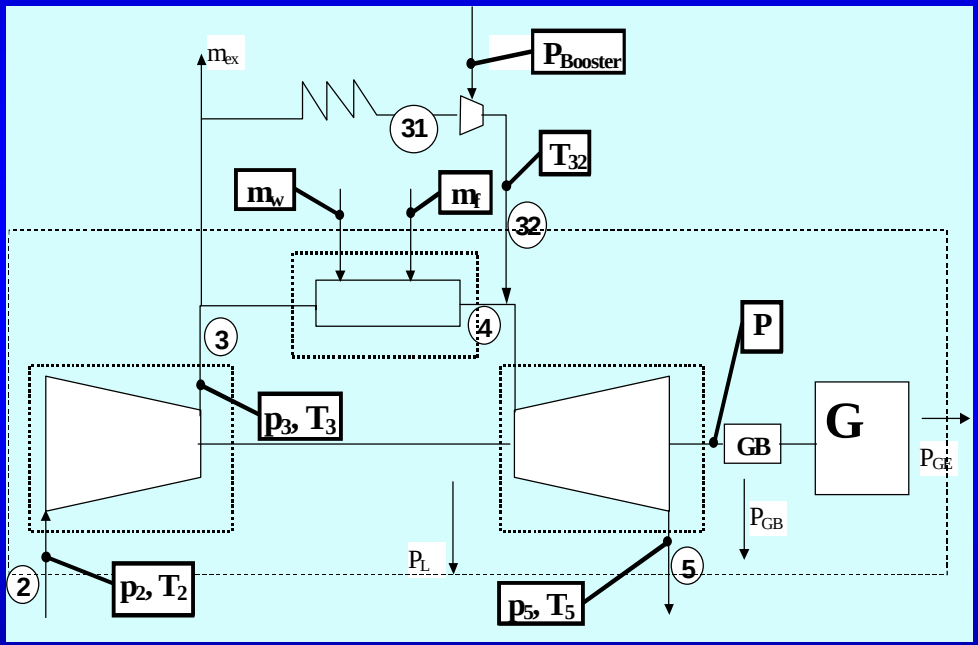
Example Application

Efficiency versus power for different amounts of injected water



Evaluate Dependences on TIT

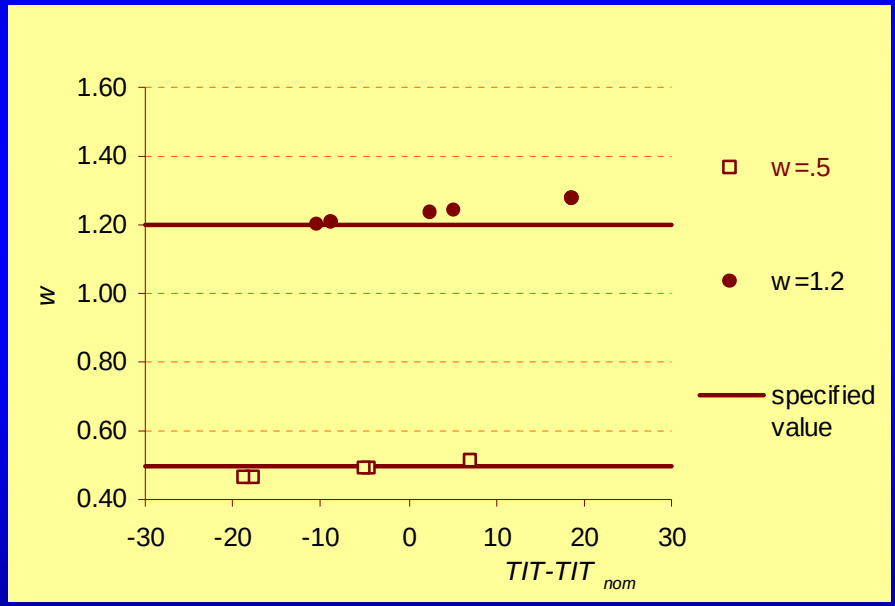
TIT calculation from heat balance



$$m_f\left(h_f - h_{f0}\right) + m_f LHV + \left(m_{a3} - m_{ex} - m_{a31}\right)\left(h_{a3} - h_{a0}\right) = m_{g4}\left(h_{g4} - h_{g0}\right) + m_w\left(h_{s4} - h_w\right)$$

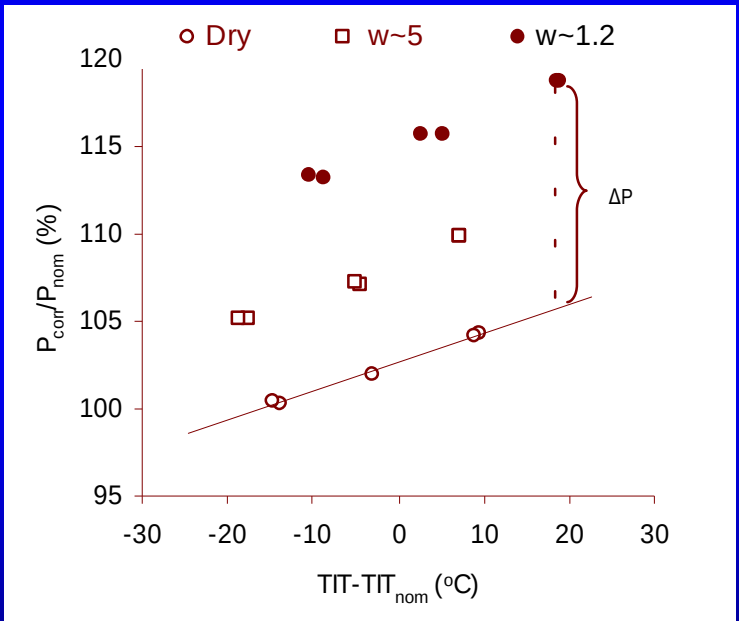
Example Application

Water to fuel ratio for variation of TIT



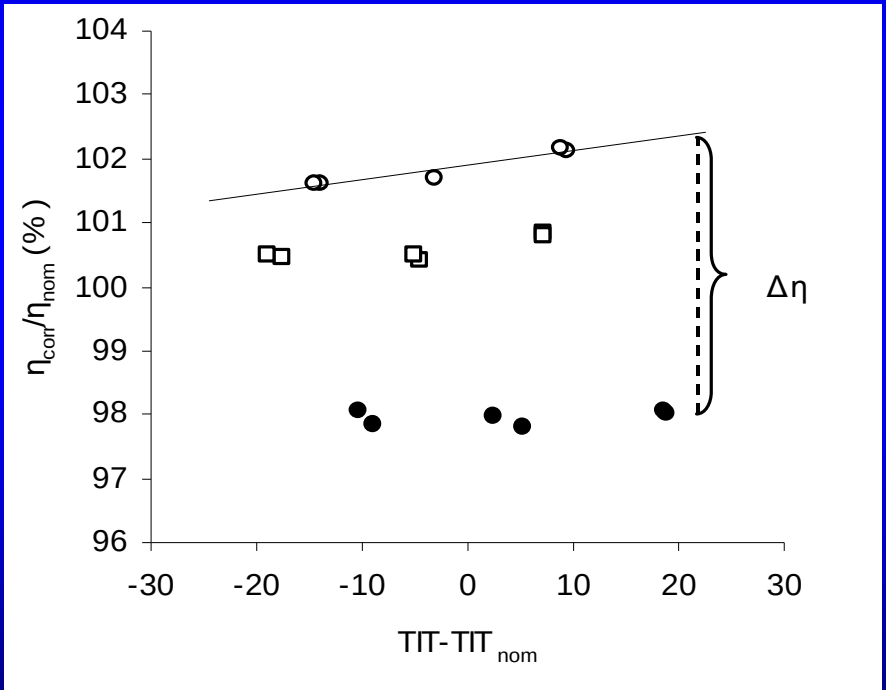
Example Application

Evaluate Power deviations for constant TIT



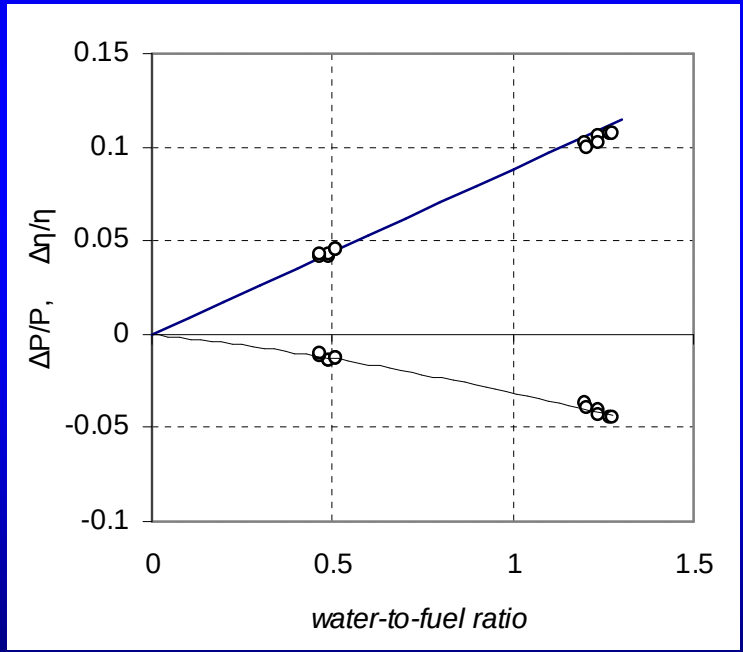
Example Application

Evaluate Efficiency deviations for constant TIT



Example Application

Power , efficiency variation in function of water-to-fuel ratio



CONCLUSIONS

- Correction of test data to refer them to standard day conditions discussed.
- For comparisons at specific values, data at different operating points. Þ Interdependence of parameters Þ Precise information for comparisons.
- A method of correcting performance parameters presented, for operation with water injection.
- Small deviation analysis used to provide a theoretical basis for proposed corrections.
- Evaluation of TIT and air mass flow rate supports wet operation analysis