

APPENDIX 3

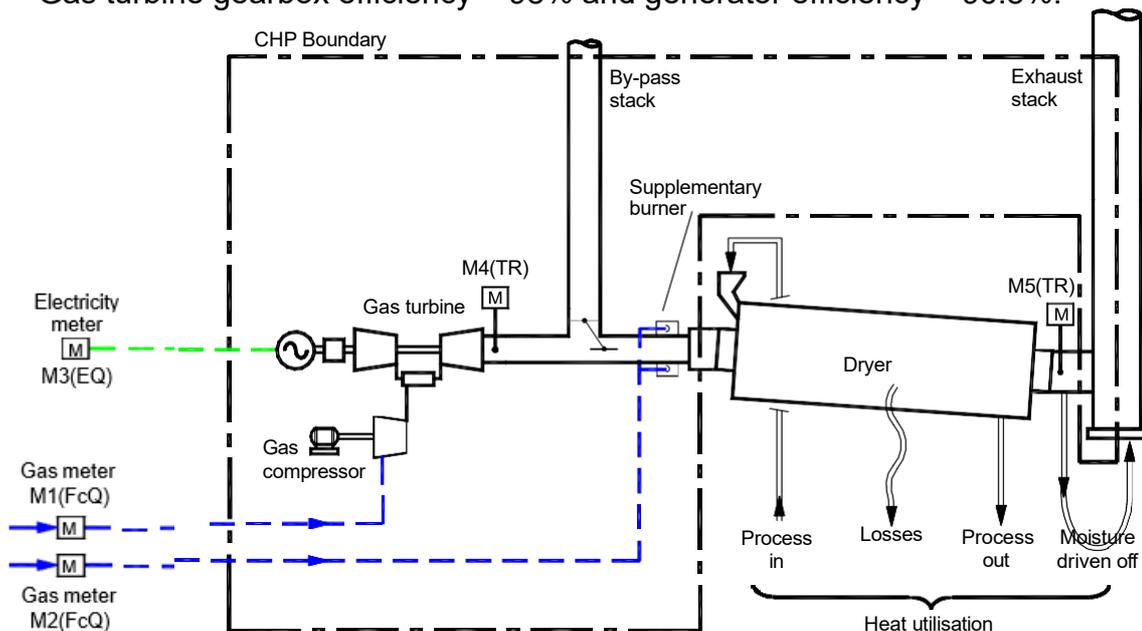
EXAMPLE 3 - DETERMINATION OF USEFUL HEAT OUTPUT BY DIRECT USE OF GAS TURBINE (OR ENGINE) EXHAUST GASES

This example considers a CHP Scheme with direct use of the exhaust from the gas turbine for a process drying duty. All of the gas turbine (GT) exhaust gases are required for the operation of the dryer and some supplementary fuel is burnt in the gas duct before the dryer to achieve the desired process exit condition (moisture content).

As a minimum the assessment of this scheme requires measurement of gas turbine and supplementary burner fuel (preferably separately), electricity generation, and exhaust gas temperatures leaving the gas turbine (or before the supplementary burner) and after leaving the dryer.

Additional information required to complete the analysis in this case is:

- Gas turbine cooling losses (from manufacturer or by measurement) = 0.1 MW
- Exhaust gas temperature drop in ducting from GT to supplementary burner = 5°C
- Gas turbine gearbox efficiency = 98% and generator efficiency = 96.8%.



Data

Annual energy data:

Gas turbine fuel energy input	M1(FcQ)	=243,684 MWh (GCV)
Supplementary burner fuel energy input	M2(FcQ)	=27,502 MWh (GCV)
Electricity generated	M3(EQ)	=60,144 MWh

Other annual data:

Mean turbine exhaust gas temperature	M4(TR)	=560°C
Mean dryer exhaust gas temperature	M5(TR)	=120°C
Mean ambient temperature		=10°C
Gas turbine and dryer operating hours		=8,400 h

Method

As the energy inputs to the Scheme must balance the energy outputs, the useful heat supplied to the dryer can be determined since all of the other energy flows are either measured or estimated. The useful heat output from the Scheme is determined by carrying out a series of energy balances, first to determine the energy content of the turbine exhaust gases and finally to determine the energy supplied to the dryer after allowing for ducting heat losses.

Analysis

Gas turbine energy balance to determine energy in exhaust gases

	MWh (gross)	MWh (net)	MWh (latent)
Inputs: GT fuel	243,684	219,705	23,979
Outputs:			
Electricity	60,144	60,144	
Gearbox and generator losses	3,256	3,256	
Gas turbine cooling loss	840	840	
Energy in exhaust gas (to balance)	179,444	155,465	23,979
	243,684	219,705	23,979

Notes:

Natural gas:	MWh (net)	= heat input on net calorific value basis
		= MWh (gross) x 0.9016
	MWh (latent)	= MWh (gross) x 0.0984

Gearbox and generator losses

$$\begin{aligned}
 &= \text{Generator output} \times \left[\left(\frac{100\%}{\text{Gearbox Eff. \%}} \right) \times \left(\frac{100\%}{\text{Generator Eff. \%}} \right) - 1 \right] \\
 &= 60,144 \text{ MWh} \times \left[\left(\frac{100\%}{98.0\%} \right) \times \left(\frac{100\%}{96.8\%} \right) - 1 \right] \\
 &= 3,256 \text{ MWh}
 \end{aligned}$$

$$\begin{aligned}
 &= \text{Gas turbine cooling loss (MWh)} = \text{rate of heat loss (MW)} \times \text{annual operating hours} \\
 &= \text{Gas turbine cooling loss (MWh)} = 0.1 \text{ MW} \times 8,400 \text{ hours} \\
 &= 840 \text{ MWh}
 \end{aligned}$$

Gas Turbine Exhaust (GTE) energy content to supplementary burner

$$\text{Ducting Energy Loss} = \text{GTE MWh (net)} \times \left[\frac{\text{temp drop}}{\text{GTE exhaust temp.} - \text{Ambient temp.}} \right]$$

$$\begin{aligned}
 \text{Ducting Energy Loss} &= 155,465 \text{ MWh (net)} \times \left[\frac{5^\circ\text{C}}{560^\circ\text{C} - 10^\circ\text{C.}} \right] \\
 &= 1,413 \text{ MWh}
 \end{aligned}$$

$$\text{Energy remaining in GTE (net)} = 155,465 \text{ MWh} - 1,413 \text{ MWh} = 154,052 \text{ MWh}$$

$$\text{Energy remaining in GTE (latent)} = 23,979 \text{ MWh (i. e. unchanged)}$$

$$\text{Energy remaining in GTE (gross)} = 154,052 \text{ MWh} + 23,979 \text{ MWh} = 178,031 \text{ MWh}$$

Therefore,

	MWh (gross)	MWh (net)	MWh (latent)
Remaining energy in exhaust gas	178,031	154,052	23,979

Energy added by combustion of supplementary fuel

	MWh (gross)	MWh (net)	MWh (latent)
Supplementary fuel	27,502	24,796	2,706

Total energy content after supplementary burner

	MWh (gross)	MWh (net)	MWh (latent)
GTE at burner	178,031	154,052	23,979
Supplementary fuel	<u>27,502</u>	<u>24,796</u>	<u>2,706</u>
Total	205,533	178,848	26,685

Total energy content of exhaust gases leaving dryer

a). Gas turbine exhaust (GTE) energy content leaving dryer

$$\text{Heat content (net)} = \text{GTE MWh (net)} \times \left[\frac{\text{GTE temp dryer exhaust} - \text{ambient temp.}}{\text{GTE temp. at burner} - \text{ambient temp.}} \right] \times [0.95]$$

$$\begin{aligned} \text{Heat content (net)} &= 154,052 \text{ MWh (net)} \times \left[\frac{120^{\circ}\text{C} - 10^{\circ}\text{C}}{555^{\circ}\text{C} - 10^{\circ}\text{C}} \right] \times [0.95] \\ &= 29,538 \text{ MWh} \end{aligned}$$

Note: 0.95 is a factor to correct for the increase in gas specific heat with temperature - it may be applied with acceptable accuracy for typical GTE and flue gas temperatures. An exact calculation requires a combustion calculation to determine the GTE composition and mass flow and the calculation of energy content at the two temperatures using specific heat data for each component of the GTE (oxygen, nitrogen, carbon dioxide and water vapour).

Heat content ex-dryer (gross) = heat content ex-dryer (net) + latent heat

	MWh (gross)	MWh (net)	MWh (latent)
Energy in exhaust gas	53,517	29,538	23,979

b). Additional energy losses due to supplementary firing

	MWh (gross)	MWh (net)	MWh (latent)
Losses from supplementary fuel *	3,202	496	2,706

* Losses from supplementary fuel = 100% of latent heat (no condensation), plus 2% (approx) of net heat input (allows for some burner stabilisation air and the added mass of supplementary fuel).

Dryer energy balance to determine CHP useful heat outputs

	MWh (gross)	MWh (net)	MWh (latent)
Inputs:			
GTE at burner	178,031	154,052	23,979
Supplementary fuel	<u>27,502</u>	<u>24,796</u>	<u>2,706</u>
	205,533	178,848	26,685
Outputs:			
GTE ex dryer	53,517	29,538	23,979
Losses from supplementary fuel	3,202	496	2,706
CHP heat outputs (to balance)	<u>148,814</u>	<u>148,814</u>	<u>0</u>
	205,533	178,848	26,685

Total energy inputs (gross)

Gas turbine fuel energy input	= 243,684 MWh
Supplementary burner fuel energy input	= <u>27,502</u> MWh
Total energy inputs	= 271,186 MWh

Efficiencies and QI

Electrical efficiency = $100 \times 60,144 / 271,186 = 22.18 \%$

Heat efficiency = $100 \times 148,814 / 271,186 = 54.88 \%$

QI calculation: X coefficient = 220 Y coefficient = 125

Quality Index = $220 \times 0.2218 + 125 \times 0.5488$
= 117.4