Heat Balance & Plant Performance Simulation

Heat Balance

- Energy Balance: based on 1st Law – IN = OUT + ACC or IN + PROD = OUT + ACC
- Balance Types: Energy (economy); Mass (processing); Heat (generation)
- Heat Balance: began in chemical engineering in processing material & use of energy
- Heat balance mechanics: $\mathbf{Q = \Delta(u + {}^1/_2C^2 + gz) + \Delta(p,v) + \omega s}$

Performance Simulation

- Flow simulation: began in chemical engineering process heat & mass balance flow sheet
- Simulation chart: similar to Process Flow Diagram (PFD) in chemical plant design project
- Parameters: heat balance is "sans frontieres" involves many aspects in natural science

Heat Balance & Simulation Soft wares

All major OEMs have their own software to support sales and after sales, offer software in their sales package. EPC contractors and consulting firms also sell soft wares to clients.

There are many soft wares available in the market; the most popular ones are Thermoflow's GTPro series and GE Energy's Gate Cycle series with 2 main types of heat balance and plant simulation programs:

- Application Specified Program
- Flexible (not specified) Program

Application Specified Program:

Plant features are already modeled within software (from outside to inside)

- *Advantage*: All in to prevent errors and crashes within system
- *Disadvantage*: Predefined scope of system features and details (for large and mature models)

Flexible Program

Can model any system as the user wishes to define (from inside to outside)

- *Advantage*: Allow variety component logic, leave system logic to user
- *Disadvantage*: heavy burden on program operator, with numerous program inputs

Thermoflow was found by Dr. Mahar Elmasri professor of MIT with a series of products:

- *GT Pro & Steam Pro* - Preliminary system design in Sizing & Scoping for EPC tender
- *GT Master & Steam Master* - Simulation of the designed system for operation models
- *RE Master* - Configuration of system repowering - bottom-up existing steam plant to GTCC
- *PEACE* – Project evaluation and construction estimate – Plant engineering
- *PDE* – Program for executive level (ass-hole) use of GTPro

Usage

GT Pro is popular for its data bank of gas turbines and its reputation, which has become a "benchmark" in the power industry. Different sectors use it for their own purpose such as:

- *OEMs* - can view competitors' products data to calibrate and guarantee rated output
- *EPCs* - can view project scope of supply and comparative costs in different equipment
- *Developers* - can design new plant at finger tip for project sizing, scoping and budgeting
- *Utilities* - can simulate the performance of plants and bottom up existing for extension

Limitation

As application specified programs have been predefined by OEMs given data or published figures, they may have propensity in "margin of truth" for protection, and may not work well for "outside the list" equipment.

Simulating Existing System

Albeit to the flexibility given in the programs, which allow user to define own system by overriding default data, the user must know all the steps and system configurations in this program and the existing plant, to make sure they are collated, before overriding the program default.

Any existing system has deficiency in flow terminals like gas turbine, boiler, steam turbine, feed-water heater, deaerator, condensers etc. however, guaranteed value or performance record of each terminal in the original system is the basis for performance simulation, which can trace or locate defects by iterations.

Heat Balance Methodology

1. Assess the type of engine or equipment and specified operation cycles
2. Assess the plant system configuration and draw up schematic relationship chart
3. Link up all heat flow process points and draw up single line process flow chart
4. Acquire the heat flow parameters in-and-out each process point in the system loop
5. Acquire the thermal /mechanical efficiency of each point in the system from OEMs
6. Assess the heat exchange cycle / model of each point in the system flow loop
7. Ascertain correct enthalpy and entropy of each point with Gas Table and Steam Stable
8. Heat balance is calculated in series of enthalpy differences in all points in the system

Example of simple heat balance

Given a 6MW condensing type steam power plant with primary data as follows:

- Boiler steam (outlet) - P = 3.92Mpa; T = 440C;
- Turbine steam (inlet) - P = 3.43Mpa; T = 435C; (exhaust) P = 0.005Mpa;
- Efficiency: boiler - 0.88; turbine - 0.86; mechanical - 0.97; generator – 0.98

Find out all steam parameter in all points from the steam table as follows:

- Boiler outlet steam enthalpy H_b = 3309.5 kj/kg
- Turbine inlet steam enthalpy H_0 = 3305 kj/kg
- Turbine exhaust steam enthalpy Hx = 2125.3 kj/kg
- Turbine condense water enthalpy Hc = 137.77 kj/kg

Thus these can be used to calculate the over plant efficiency and economics as follows:

- Actual exhaust steam enthalpy = 3305 – (3305 - 2125.3) * 0.86 = 2290.5 kj/kg
- Actual cycle thermal efficiency = (3305 – 2290.5) / (3305 – 137.77) = 0.3203 (32%)
- Plant piping efficiency = (3305 - 137.77) / (3309.5 - 127.77) = 0.9986 (99.9%)
- Total plant thermal efficiency = 0.88 * 0.86 * 0.97 * 0.98 = 0.2676 (26.8%)

Per kilo-watt-hour of power generation

- Overall power generation heat rate = 3600 / 0.2676 = 13453 kj/kw/h
- Boiler heat loss = 13453 * (1 – 0.88) = 1614 kj/kw.h
- Piping heat loss = 13453 * 0.88 * (1 - 0.9986) = 17 kj/kw/h
- Cold-end heat loss = 13453 * 0.88 * 0.9986 * (1 – 0.3203) = 8035 kj/kw/h
- Mechanical loss = 13453 * 0.88 * 0.9986 * 0.3203 * (1 – 0.97) = 114 kj/kw/h
- Generator loss = 3600 * (1 / 0.98 - 1) = 73 kj/kw/h

Per kilo-gram of steam generation:

- Boiler heat load = 3309.5 – 137.77 = 3172 kj/kg
- Boiler fuel heat input = 3172 / 0.88 = 3605 kj/kg
- Boiler heat loss = 3506 – 3172 = 433 kj/kg
- Piping heat loss = 3172 * (1 – 0.9986) = 4 kj/kg
- Cold-end heat loss = 3172 * 0.9986 * (1 – 0.3203) = 2153 kj/kg
- Mechanical loss = 3172 * 0.88 * 0.9986 * 0.3203 * (1 – 0.97) = 30 kj/kg
- Generator loss = 3172 * 0.88 * 0.9986 * 0.3203 * 0.97 * (1 – 0.98) = 20 kj/kg
- Generator output = 3605 - 443 - 4 -2153 - 30 - 30 = 965 kj/kg

Heat balance table

index	Item	per kw.h power generation		per kg steam generation	
		kj/kw/h	%	kj/kg	%
1	Boiler fuel heat input	13453	100	3605	100
2	Boiler heat loss	1614	12	433	12
3	Piping heat loss	17	0.12	4	0.12
4	Cold end heat loss	8035	59.73	2153	59.72
5	Mechanical loss	114	0.84	30	0.84
6	Generator loss	73	0.54	20	0.54
7	Power output	3600	26.77	965	26.78

Below is another example of energy balance in different form

From: prlang1@gmail.com
To: vincent.m.ma@conocophillips.com
Sent: Wed, January 16, 2008 9:31:21 PM
Subject: LNG price vs CLP tariff

Vincent,

I attach herewith the extracts of CLP's 05-06 annual reports with Scheme of Control (SOC) statement showing certain operation data, together with CLP's quoted fuel mix ratio, power plant efficiency and heat rates as the basis for bold-path calculations without simulation detail per your request.

You need a clear mind to read their energy data and price for mixed fuel, but you can roughly iterate the fuel cost, by focusing in Castle Peak (4108 MW coal plant) and Black Point (2500 MW gas plant), ignore Daya Bay nuclear (1980 MW-70%), Guangzhou pump-storage (2400 MW- 25%) and Penny's Bay backup (300 MW oil GTSC), being outside SOC or insignificant fuel.

The basis of coal price is 5000 kCal/kg (20930 kj/kg) Indonesian steam coal for my calculation. The fuel mix ratio is 0.625 (coal) to 0.37 (gas) in 2005 and 0.632 (coal) to 0.363 (gas) in 2006.

Due to Take-or-Pay in gas, the gas plant was running 5034 / 5019 UTH (full-load utilization hours) in 2005/06 while the coal plants was running only 3883 / 3855 UTH in 2005/06.

The total fuel cost in 2005 was HK$ 4144 mil, of which HK$ 2590 mil for coal and HK$ 1532 mil for gas; the coal price is iterated at US$ 73.7/Mt CIF and the natural gas price at US$ 6.53/mmBtu.

The total fuel cost in 2006 was HK$ 4336 mil, of which HK$ 2741 mil for coal and HK$ 1574 mil for gas; the coal price is iterated at US$ 76.2/Mt CIF and the natural gas price at US$ 6.86/mmBtu.

The 2005 power tariff was HK$ 0.882/kWh + 0.002/kWh in fuel variation that total was HK$ 0.884/kWh; the 2006 tariff was HK$ 0.88/kWh + 0.02 in fuel variation that total was HK$ 0.90/kWh. The tariff includes T&D cost, which is around HK$ 0.12 + 0.1 = 0.22 for network transmission and distribution.

The fuel cost has been around 19.25% to gross sales or 25.5% to net sales (deduct T&D cost). You can see the SOC is a "Cost-Plus-Return" setup, of which fuel cost variation is "passed-on" to consumers.

As per your request for LNG cost effect on CLP, I have done some counts for you based on their 2006 fuel use pattern with "coal price unchanged" as follows:

1/ If LNG cost was US$ 10/mmBtu, the total fuel cost would be increased by 16% to HK$ 5035 mil, the net fuel to sales ratio thus 29.6% > 25.5%, the variation could be increased to HK$ 0.04/kWh (net) or 0.028/kWh (overall).

2/ If LNG cost was US$ 12/mmBtu, the total fuel cost would be increased by 26.7% to HK$ 5493 mil, the net fuel to sales ratio thus 32.3% > 25.5%, the variation could be increased to HK$ 0.06/kWh (net) or 0.046/kWh (overall).

3/ If LNG cost was US$ 14/mmBtu, the total fuel cost would be increased by 37.3% to HK$ 5952 mil, the net fuel to sales ratio thus 35% > 25.5%, the variation could be increased to HK$ 0.1/kWh (net) or 0.065/kWh (overall).

I hope the about bold paths could help you, if you need to go detail, it would take simulation and full audit, anyway, you owe me 3 days of work (US$4.5k) in my book, Ha Ha.

rgds/PR

> From: vincent.m.ma@conocophillips.com
> To: prlang1@gmail.com
> Subject: LNG pricing
> Date: Sun, 13 Jan 2008 20:26:24 +0800
>
> PR, don't forgot my math probelms for CLP most important is that with nuclear, gas, coal and pump storage, and gas price at $7/mmbtu. if they buy LNG what would be the impact on electricity tariff rate in HK$/kwh say $10/mmbtu, $11/mmbtu and $12/mmbtu, $13/mmbtu and $14/mmbtu ? Thanks.
> Vincent