Steam balance optimisation strategies

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Background

Optimising a steam balance in a plant with several steam mains pressures is not always a simple intuitive task. Especially when steam turbines, waste energy and ancillary steam generators, letdown valves and vents to the atmosphere are involved in the process. The aim of this article is to show how to optimise an existing plant and how to design a new one using some innovative technology. Only simple concepts as pressure, temperature etc have been used to explain the key ideas avoiding more technical and rigorous calculations involving enthalpy, entropy, exergy etc. This is to make this article understandable to engineers without a specialised background in utilities management.

Steam balance operation

A Refinery with two or more steam pressure mains may operate in different scenarios: *excess or deficit steam in each main*. When an ancillary steam generator is supplying an unbalanced main, the solution is straight forward: the ancillary steam generator must operate producing more or less steam keeping the pressure constant in the main and consequently keeping the steam main in balance.

When an ancillary steam generator is not supplying an unbalanced main two scenarios are possible : Excess steam or deficit steam.

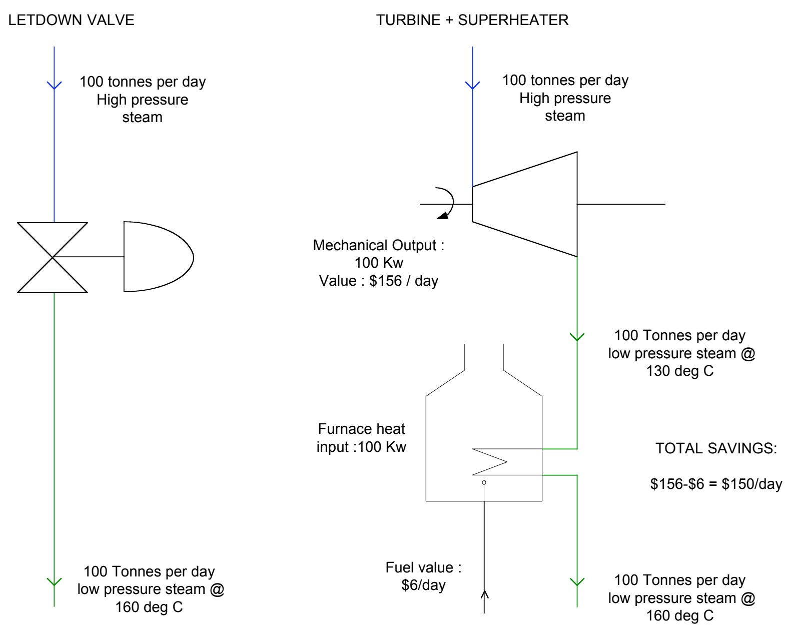
Excess steam is detected by an increase in the main pressure. To fix this problem, a vent to atmosphere is usually installed which controls the pressure (and consequently the balance) in the main by dumping steam to the atmosphere. In an extreme case, the relief valves protecting this main will release to keep the balance, thus avoiding overpressurising the system.

During a deficit steam situation the main pressure drops. To achieve a balance it is necessary to inject steam from an available source of steam which usually is the steam main with immediate higher pressure. The pressure in the unbalanced main is kept constant by injecting steam from a higher pressure steam main utilising a letdown pressure controlled valve.

Although the strategy summarised above fixes the problem *it is not the optimal way to operate the steam balance*. When a Refinery is operating with a steam deficit situation in one of the mains, the balance is made up by letting down from immediate higher pressure steam. Ideally, the inlet steam enthalpy equals the outlet steam enthalpy. No energy is lost across the letdown valve but *the energy value is degraded*.

The letdown valve is converting the energy from steam pressure at the valve inlet to thermal energy by superheating the steam at the valve outlet. High pressure steam is capable of developing more mechanical energy (i.e. in a steam turbine) than the low pressure steam. The mechanical energy can be used to drive pumps or compressors substituting electric motors. Therefore *running a non condensing back pressure steam turbine to expand steam* instead of a letdown valve means *we are utilising part of the high pressure steam energy to decrease electricity consumption in the plant*. This is more advantageous than just superheating the steam using a letdown valve.

The saturated exhaust steam from the turbine will have a lower temperature than the superheated steam in the letdown valve outlet. However, *the cost of the electricity* saved by operating a turbine to drive a pump or a compressor instead of a electric motor *is much higher than the cost of the fuel* that would be required to superheat the turbine steam exhaust to the same temperature as the letdown valve outlet. Electricity is a better quality and consequently more expensive energy than thermal energy. This idea is expressed in the following theoretical comparison (in real applications the furnace is not necessarily required).

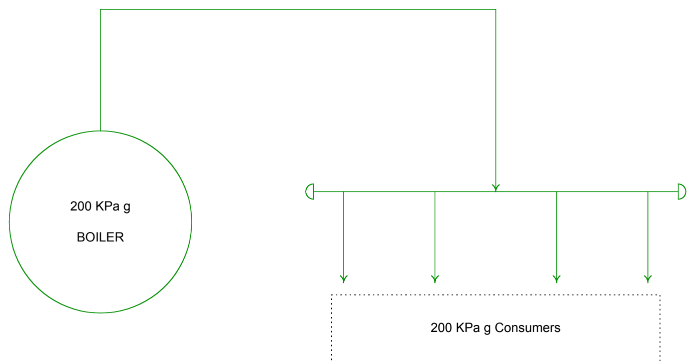


However when the Refinery is in an excess steam scenario in one of the mains *it is usually uneconomic (depending on steam and electricity prices) to keep steam turbines expanding steam from higher pressure to this lower pressure unbalanced main and venting steam from this lower pressure main at the same time* to keep the balance. Therefore *to optimise the balance some turbines have to be shut down* in this excess low pressure steam scenario. Consequently for an good steam balance optimisation it is necessary to continuously monitor letdowns, turbine operation and venting.

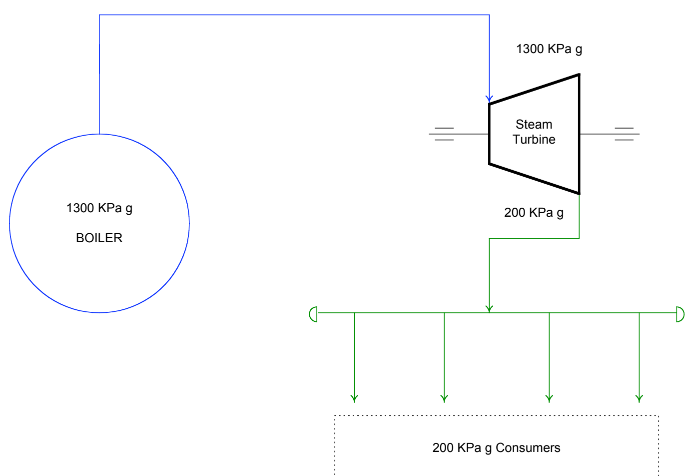
With regards to waste heat steam generator it becomes obvious that the operation should be to maximise production versus ancillary steam generation which consumes valuable fuels.

Steam balance design

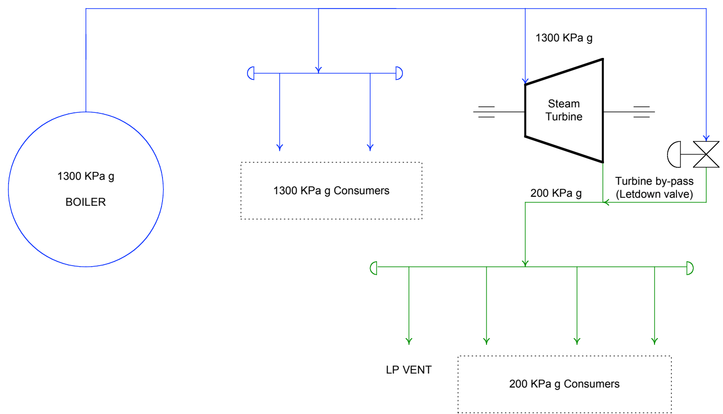
The traditional approach to designing a steam system is to install ancillary steam generators able to generate steam at the maximum pressure and temperature required by the process. Let us consider a simplistic case where the pressure steam requirement is only 200 Kpag maximum. The traditional approach would be as follows:



However for a new investment it usually requires only a relatively small extra investment to rate the steam generators for higher pressure. To meet the lower pressure required by the process *a non condensing backpressure steam turbine can be used to obtain mechanical energy from the high pressure steam* that may be used to run pumps, compressors or to generate electricity.



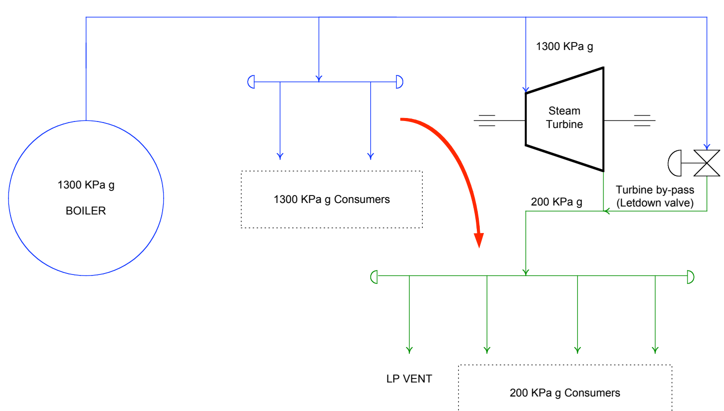
Let us consider a more realistic case where some of the consumers require 1300 Kpa g steam pressure and others require only 200 Kpa g steam pressure.



Clearly *the letdown valve shown in the drawing has to be considered as a turbine by-pass*. Maximising steam through the turbine (or turbines) versus the letdown valve becomes an obvious way to optimise the steam balance. *This strategy will maximise the mechanical energy generation in the steam turbine*. However if more 1300 Kpa g steam is expanded than required by the 200 kPa g steam consumers the system will vent 200 kPa g steam to atmosphere. This situation is usually uneconomical (depending on steam and electricity prices) and the steam flow rate expanded in the turbine should be reduced to avoid venting.

Sometimes is easier to design new systems using higher pressure steam rather than lower pressure steam. Obviously, saturated high pressure steam has higher temperature than saturated lower pressure steam. This means that less exchange surface is required in heat exchangers and reboilers. In addition high pressure steam has higher density and requires less bore in the steam mains. Consequently the usage of high pressure steam represents less capital expenditure.

Although this philosophy represents minimum initial capital investment it can be wrong in a long term basis. In fact, it is, usually, *economically more efficient to use low pressure steam than high pressure steam*. By maximising low pressure steam consumers versus high pressure steam consumers the amount of steam that can be expanded through turbines to drive pumps or compressors or to generate electricity is maximised as well.



The philosophy described above can be summarised by three simple rules :

1. "Produce steam at the highest possible temperature and pressure."

2. "Expand steam from a higher pressure to a lower pressure level through the most efficient means possible."

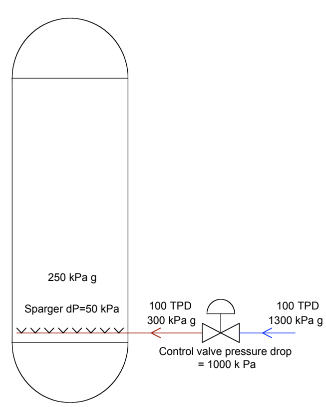
3. "Apply steam to process usage at the lowest economically attractive pressure and temperature. Reboilers and steam preheaters should be designed to use the lowest steam pressure available (extended tube surfaces, lower tower operating pressures, etc)"

To apply these rules, theoretically, a refinery should be designed with as many steam main pressures as there are steam consumers, requiring different pressures, with turbines expanding steam from the maximum pressure to each main pressure to meet each consumer steam demand. Obviously this is not feasible. However, in real life, a compromise is met and refineries are designed typically with two or three steam pressures.

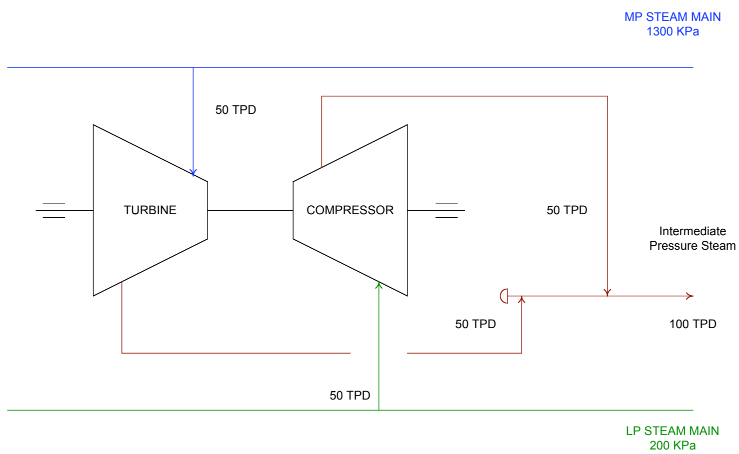
Usually the optimum steam pressure required by a consumer is in between the pressure of two steam mains. Normally in this situation the steam is supplied from the immediate higher pressure steam main as the immediate lower pressure steam main cannot be used. *Then the consumer control valve actuates, in some way, as a let down valve.*

That is the case, for example, in some stripping steam systems. The pressure in a column is higher than the low pressure steam main. Therefore low pressure steam cannot be used. The immediate higher pressure steam main will supply the steam. *Hence the stripping steam control valve (usually set as a flow controller) will work, in reality, as a let down valve.* This flow controller will be effectively letting down the steam from the steam main pressure to the pressure in the column.

TRADITIONAL APPROACH

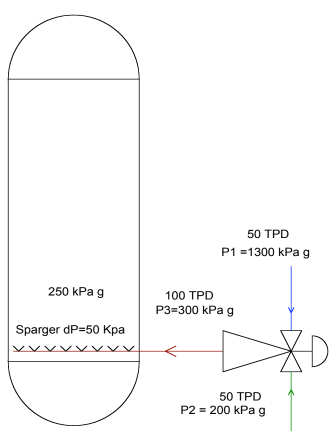


However we know that letting down steam is not the best way to use the steam. *An opportunity to generate mechanical energy is lost.* Complicated arrangements using traditional technology could be developed to meet the required intermediate pressure using a mixture of low pressure and high pressure steam generating useable mechanical energy . But although they would be technically feasible they would become *economically unacceptable* based on the capital required.



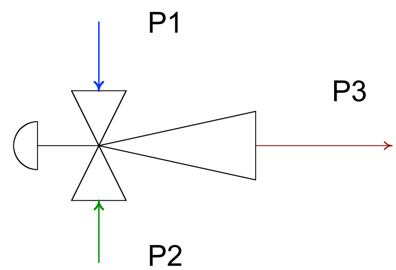
However a *thermocompressor is an economically feasible technology* that takes advantage of this opportunity with very low capital investment.

THERMOCOMPRESSOR
APPROACH



Thermocompressors

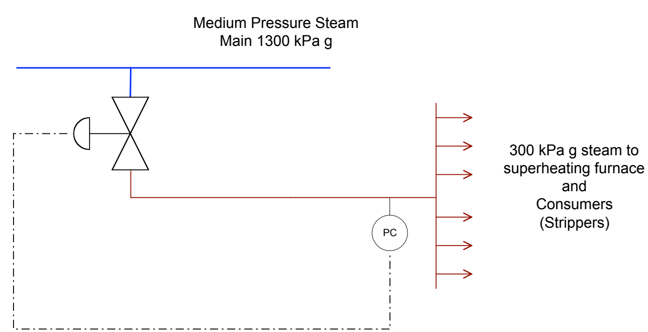
A thermocompressor (or controlled ejector) is a piece of static equipment capable of compressing a fluid from a low pressure (P2) up to a greater pressure (P3) using a stream with higher pressure (P1) as motive energy. The thermocompressor uses the energy of the motive stream expanding from P1 to P3 to compress a fluid from P2 to P3. (P1>P3>P2).



The flow ratio "suction flow/motive flow" depends on the pressures utilised. *The thermocompressor is a control valve* and can control pressures, flow rates etc as a normal control valve. The thercompressors achieve this by changing the internal nozzle pass section changing the motive stream flow rate and, consequently, the suction stream flow rate. The flow ratio varies for different valve positions.

Example:
A crude distillation unit in a refinery needs approximately 250 tpd of steam with a minimum pressure of 300 kPa g for stripping in distillation towers. This required minimum pressure is approximately 100 kPa higher than the refinery Low Pressure (LP) steam main (200 kPa g). Therefore Low Pressure steam cannot be directly used for this duty. Currently the steam pressure requirement for these consumers is met by letting down Medium Pressure (MP) steam (1300 kPa g).

Current Operation



A thermocompressor can be used to withdraw some LP steam to supply these consumers. The motive stream for the thermocompressor will be MP steam. In this way the MP steam demand will be decreased.

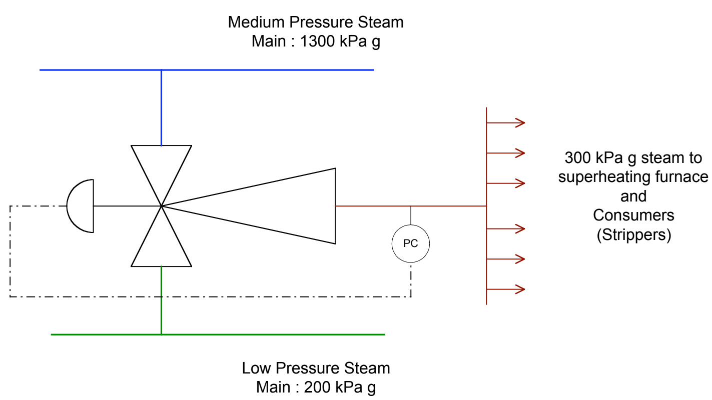
The steam demand for these consumers can oscillate between 170 tpd and 250 tpd of steam. The thermocompressor will work by controlling the steam pressure discharge to 300 kPa g.

The expected flow ratio for this set of pressures is approximately one. It means that for each tonne of LP steam withdrawn, one tonne of MP will be needed as a motive stream. Therefore the steam demand for this duty can change from 250 tpd of MP steam (current operation) to 125 tpd of withdrawn LP steam plus 125 tpd of motive MP steam. The extra 125 tpd LP steam demand created by the thermocompressor will be met by expanding 125 tpd more of MP steam through the Refinery MP-LP steam turbines.

The discharge steam will be less superheated than the steam currently obtained from the letdown valve. However this is not an issue because this steam is already superheated in the crude furnace before being used as stripping steam. The steam will absorb the extra thermal energy required from the furnace flue gas waste heat. Therefore the furnace flue gas will be cooled down slightly more and no extra fuel gas consumption will be required in the furnace.

The existing letdown valve can be left on site available in case of a thermocompressor malfunction or during maintenance.

Proposed operation



Conclusions

Any steam control valve in a refinery could be replaced by a thermocompressor. The thermocompressor will actuate controlling pressure, flow or temperature as the normal control valve currently does while meeting the consumer steam demand by mixing steam with two different pressures. It will enable the generation of additional low pressure steam demand created by the thermocompressor, by expanding steam in a turbine from higher pressure to this lower pressure and then extracting mechanical energy from the turbine and backing out the Refinery electricity demand. Of course to take this opportunity it is necessary to have *spare steam turbine capacity available* in the refinery. Otherwise the additional low pressure steam demand created by the thermocompressor will be met by expanding high pressure steam to low pressure steam through a letdown valve without any benefit.

If there is not spare turbine capacity available in the Refinery and, consequently, the additional low pressure steam demand created by the thermocompressor is met by a letdown valve, the decision of installing a new turbine to drive a spare pump or compressor in a unit rather than using another electric motor should *be based on the electricity savings obtained by running the turbine*. However turbines have higher maintenance costs that should be evaluated as well. A turbine can also be used to directly generate electricity. This option is more flexible in terms of operation but will require an extra investment in the electricity generator connected to the turbine.

It is, probably, uneconomic to replace existing steam control valves with thermocompressors as a general rule. However it may be interesting in new projects. *The price of a thermocompressor is not much higher than the price of a normal control valve* and it becomes an attractive option.

The concept of using turbines to letdown steam instead of a letdown valve is valid regardless the efficiency of the turbines installed. Inefficient turbines will produce less valuable mechanical energy but the exhaust steam with higher temperature. Therefore no energy is lost although the benefits are, of course, lower than operating high efficiency turbines. In fact a simple way to check turbines performance is by monitoring the exhaust temperature. Obviously then, *the benefits of operating a turbine will be always higher than using a letdown valve*. Conceptually a turbine with zero efficiency will not produce any mechanical energy becoming just a simple letdown valve.

Consequently the marginal price per mass unit of low pressure steam (used to evaluate projects saving low pressure steam, utilities cost profiles, etc) should be quantified as follows:

a) If the Refinery has spare steam turbine availability:

> Low pressure steam price = Price of one unit of high pressure steam minus the electricity cost saved by letting down one extra unit of high pressure steam through a theoretical turbine with the Refinery average turbine efficiency.

b) If the Refinery has not spare steam turbine availability:

> Low pressure steam price = High pressure steam price.

c) If the Refinery is venting low pressure steam to atmosphere :

> Low pressure steam price = 0 (there would not be any point in saving low pressure steam if the Refinery is already venting it).

In refineries where low pressure steam is usually vented to atmosphere and *it cannot be avoided by using the techniques explained at the beginning (i.e. shutting down non condensing turbines)* every tonne of low pressure steam withdrawn by a thermocompressor will represent one less tonne of steam vented to atmosphere and one less tonne of high pressure steam demand. This high pressure steam demand is usually met by operating ancillary boilers consuming valuable fuel and boiler feed water. In this situation *the pay back of a new thermocompressor may be in the order of only few months*.