

Simulation of a Gas Power Plant



HYSYS®

Name: José M^a Robles

”My conscience has from all over the world for me more weight than the opinion”

*Marco Tulio Cicerone
106 BC -43 BC*

Preface

This project work has been carried out at the NTNU in Trondheim (Norway), framed by the Socrates-Erasmus exchange program. This has given me the opportunity to study in a different university, in a different country, in a different culture and with different people. It has given me the possibility to learn how to be alone and accompanied, to be sad and I happy... all things are they make that at the end; this project has an incalculable value for me and I don't care the final qualification that has, I am proud of my work and of my effort in a different country.

In Trondheim I have learnt, and I am still learning, much more than chemical engineering and I can say that this is being one of the most enriching experiences in my life. Now, when I am near finishing my studies, it is time to reflect on which I have learned, not only in relation to the studies but also to the life.

Acknowledgments

I would like to thank the department of chemical engineering of the NTNU for welcoming me and helping me whenever I have needed it. I would like to thank especially to Sigurd Skogestad that was the first person that helped me when I arrived here when I felt lost like a stranger in this country. He has made possible that the lectures were given in English.

Also, to Marius Støre Govatsmark for his help and his always kind advice and corrections and their readiness to always help me and at any hour of the day that made I learnt a lot. I would also like to thank the Universitat Rovira i Virgili in Tarragona (Spain) and the NTNU in Trondheim for give me the possibility of working here on this project as a Socrates- Erasmus student.

Especially I would like to thank to my family, to my friends, to Jara for come to visit me when more I needed it. And finally, I would like to thank all the people I have meet here in Trondheim for contributing to this fantastic experience; and especially to my friend Ivan, for his support, and Gerald to be my English teacher.

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Introduction

The basic principle of the Combined Cycle is simple: burning gas in a gas turbine (GT) produces not only power - which can be converted to electric power by a coupled generator but also fairly hot exhaust gases. Routing these gases through a water-cooled heat exchanger produces steam, which can be turned into electric power with a coupled steam turbine and generator.

This set-up of Gas Turbine, waste-heat boiler, steam turbine and generators is called a combined cycle. This type of power plant is being installed in increasing numbers round the world where there is access to substantial quantities of natural gas. This type of power plant produces high power outputs at high efficiencies and with low emissions. It is also possible to use the steam from the boiler for heating purposes so such power plants can operate to deliver electricity alone

Efficiencies are very wide ranging depending on the lay-out and size of the installation and vary from about 40-56% for large new natural gas-fired stations. Developments needed for this type of energy conversion is only for the gas turbine. Both waste heat boilers and steam turbines are in common use and well-developed, without specific needs for further improvement.

The primal objective of this report is to show the efficiency into simulate a Gas Power Plant with Combined Cycle technology with HYSYS® software; and to optimize the process to get the biggest possible economic benefit, making changes in the feed variables of the combined cycle plant. The data of this project are based on the document of the Department of Energy of United States.

1. Theoretical principles

1.1 Gas turbine

The gas turbine (Brayton) cycle is one of the most efficient cycles for the conversion of gas fuels to mechanical power or electricity. The use of distillate liquid fuels, usually diesel, is also common where the cost of a gas pipeline cannot be justified. Gas turbines have long been used in simple cycle mode for peak lopping in the power generation industry, where natural gas or distillate liquid fuels have been used, and where their ability to start and shut down on demand is essential.

Gas turbines have also been used in simple cycle mode for base load mechanical power and electricity generation in the oil and gas industries, where natural gas and process gases have been used as fuel. Gas fuels give reduced maintenance costs compared with liquid fuels, but the cost of natural gas supply pipelines is generally only justified for base load operation.

More recently, as simple cycle efficiencies have improved and as natural gas prices have fallen, gas turbines have been more widely adopted for base load power generation, especially in combined cycle mode, where waste heat is recovered in waste heat boilers, and the steam used to produce additional electricity. The efficiency of operation of a gas turbine depends on the operating mode, with full load operation giving the highest efficiency, with efficiency deteriorating rapidly with declining power output.

1.2 Steam turbine

The operation of the turbine of steam is based on the thermodynamic principle that expresses that when the steam expands it diminishes its temperature and it decreases its internal energy

This situation reduction of the energy becomes mechanical energy for the acceleration of the particles of steam, what allows have a great quantity of energy directly. When the steam expands, the reduction of its internal energy can produce an increase of the speed from the particles. To these speeds the available energy is very high, although the particles are very slight.

The action turbine, it is the one that the jets of the turbine are subject of the shell of the turbine and the poles are prepared in the borders of wheels that rotate around a central axis. The steam passes through the mouthpieces and it reaches the shovels. These absorb a part of the kinetic energy of the steam in expansion that it makes rotate the wheel that with her the axis to the one that this united one. The steam enters in an end it expands through a series of mouthpieces until it has lost most of its internal energy. So that the energy of the steam is used efficiently in turbines it is necessary to use several steps in each one of which it becomes kinetic energy a part of the thermal energy of the steam. If the energy conversion was made in a single step the rotational speed of the wheel was very excessive.

1.3 Heat Recovery Steam Generator

In the design of an HRSG, the first step normally is to perform a theoretical heat balance which will give us the relationship between the tube side and shell side process. We must decide the tube side components which will make up our HRSG unit, but only it considers the three primary coil types that may be present, Evaporator, Superheater and Economizer.

1.3.1 Evaporator Section: The most important component would, of course, be the Evaporator Section. So an evaporator section may consist of one or more coils. In these coils, the effluent (water), passing through the tubes is heated to the saturation point for the pressure it is flowing.

1.3.2 Superheater Section: The Superheater Section of the HRSG is used to dry the saturated vapour being separated in the steam drum. In some units it may only be heated to little above the saturation point where in other units it may be superheated to a significant temperature for additional energy storage. The Superheater Section is normally located in the hotter gas stream, in front of the evaporator.

1.3.3 Economizer Section: The Economizer Section, sometimes called a preheater or preheat coil, is used to preheat the feedwater being introduced to the system to replace the steam (vapour) being removed from the system via the superheater or steam outlet and the water loss through blowdown. It is normally located in the colder gas downstream of the evaporator. Since the evaporator inlet and outlet temperatures are both close to the saturation temperature for the system pressure, the amount of heat that may be removed from the flue gas is limited due to the approach to the evaporator, whereas the economizer inlet temperature is low, allowing the flue gas temperature to be taken lower.

1.4 PID Controller

PID stands for Proportional-Integral-Derivative. This is a type of feedback controller whose output, a control variable (CV), is generally based on the error between some user-defined set point (SP) and some measured process variable (PV). Each element of the PID controller refers to a particular action taken on the error:

- Proportional: error multiplied by a gain, K_p . This is an adjustable amplifier. In many systems K_p is responsible for process stability: too low and the PV can drift away; too high and the PV can oscillate.
- Integral: the integral of error multiplied by a gain, K_i . In many systems K_i is responsible for driving error to zero, but to set K_i too high is to invite oscillation or instability or integrator windup or actuator saturation.
- Derivative: the rate of change of error multiplied by a gain, K_d . In many systems K_d is responsible for system response: too low and the PV will oscillate; too high and the PV will respond sluggishly. The designer should also note that derivative action amplifies any noise in the error signal.

Tuning of a PID involves the adjustment of K_p , K_i , and K_d to achieve some user-defined "optimal" character of system response.

1.5 PID Controller in HYSYS®

The Controller operation is the primary means of manipulating the model in dynamic studies. It adjust a stream (OP) flow to maintain a specific flowsheet variable (PV) at a certain value (SP). The controller can cross the boundaries between flowsheets, enabling you sense a process variable in one flowsheet, and control a valve in another.

To **install** the controller operation, choose **Add Operations** from the flowsheet menu, and select **Controller**. Alternatively, select the **Controller** button in the Palette.

1.5.1 Connections

The connections page allows you to select the PV and OP, as well as providing access to the sizing of the Control Valve.

Process Variable: The Process Variable, or PV, is the variable that must be maintained or controlled at a desired value. To attach the Process Variable Source, choose the **Select PV** button. You then select the appropriate object and variable simultaneously, using the Variable Navigator.

Cascade: In the case of cascade control, the primary (or master) controller checks the primary variable and compares it to the setpoint. The output from the Master controller then becomes the setpoint for the secondary or Slave controller. In this case, the master controller output target is the slave controller. There will be no control valve associated with the master controller. On the slave controller, you will connect the process variable source and output target object as usual, and size the control valve. By selecting the master controller as the cascade SP source, the connection between the two controllers is made.

Output: The output of the controller is the control valve which the controller manipulates in order to reach the setpoint. The output signal, or OP, is the actual percent opening of the control valve, based on the operating range which you define in the **View Control Valve** view.

Control Valve: The information shown on the Control Valve view is specific to the associated valve. For instance, the information for a vapour valve is different than that for a Liquid Valve.

1.5.2 Parameters

The parameters page allows you to set the process variable range, controller, action, operating mode, and depending on the mode, either SP or OP.

PV and SP: The PV or Process variable is the measured variable which the controller is trying to keep at the Set Point. The SP or Set Point is the value of the Process Variable which the controller is trying to meet. Depending on the Mode of the Controller, the SP is either input by user or display only.

OP: The OP or Output is the percent opening of the control valve. The controller manipulates the valve opening for the Output stream in order to reach the set point. HYSYS calculates the necessary OP using the controller logic in all modes with the exception of Manual. In Manual mode, you may input a valve for the Output, and the Set Point will become whatever the PV is at the particular valve opening you specify.

Modes: The controller in HYSYS can operate in different modes. These modes are shown in the next table:

Table 1. Operability modes in HYSYS controller.

Off	- The controller does not manipulate the control valve, although the appropriate is still tracked.
Manual	- Manipulate the controller output manually.
Auto	- The controller reacts to fluctuations in the Process Variable and manipulates the Output according to the logic defined by the tuning parameters.
Ramping	- The Set Point is adjusted gradually to a certain value over a specified period of time.
Cascade	- The master controller determines the Set Point, which is passed to the secondary controller.
Tune	- The ATV method is used to tune the controller.

Action: There are two options for the action of the Controller; these options are shown in the next table:

Table 2. Action modes in HYSYS controller.

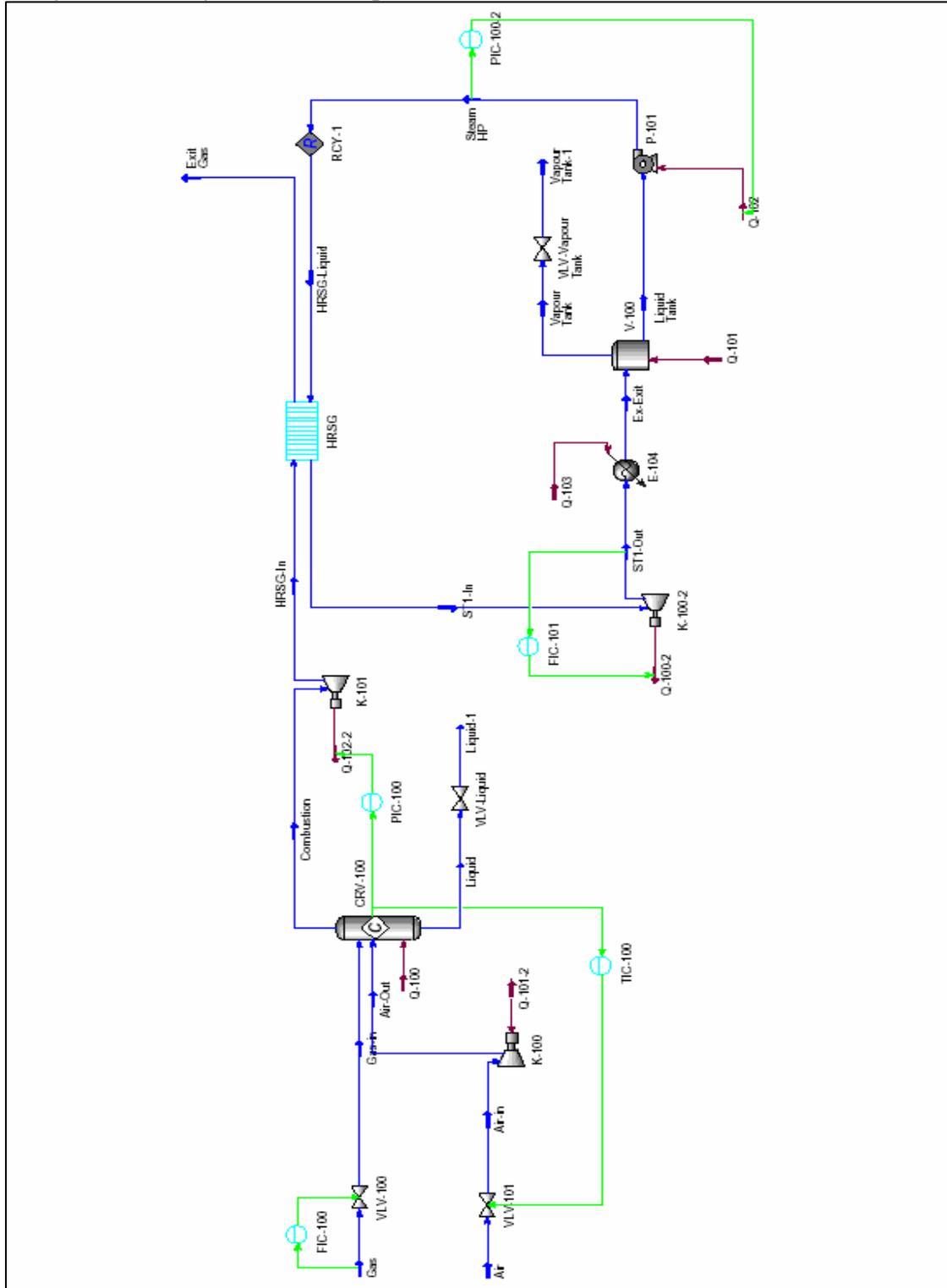
Direct	- When the PV rises above the SP, the OP increases. When the PV falls below the SP, the OP decreases.
Reverse	- When the PV rises above the SP, the OP decreases. When the PV falls below the SP, the OP increases.

1.5.3 Tuning

The controller tuning page allows you to define the constants associated with the PID control equation, as well as the Ramping parameters. In addition, the Operating Parameters, displayed on the Parameters page, are shown here as well. The Tuning Page contains all of the essential information required to operate the Controller once the initial set up is completed.

2. Process Description

2.1 Figure 1. PFD of the simulated process.



2.2 Units Operations

The unitary operations in that the process is based are:

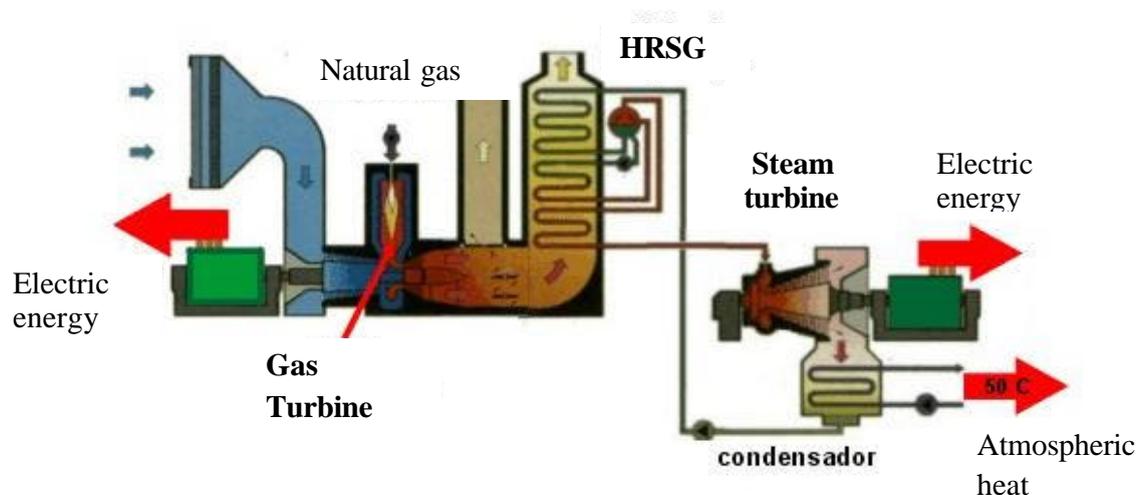
- 1 Compressor
- 1 Gas turbine
- 1 Steam turbine
- HRSG (Heat Recovery Steam Generator)
- 1 Condensation stage (exchanger and a tank)
- Energy generator.

2.3 Process Description

In general terms, a plant of combined cycle is integrated by two or more thermodynamic cycles of energy to transform the feed energy more efficiently into work or power. With the advances in the dependability and readiness of the gas turbines, the term plants in combined cycle it refers to a compound system of a gas turbine, a heat recovery steam generator (HRSG) and steam turbines. Thermodynamically, this implies to equal a high temperature Brayton cycle of the gas turbine with a low temperature moderate Rankine cycle, the heat of waste of the exit of the Brayton cycle it serves as entrance of heat to the Rankine cycle. The gas turbine (Brayton) cycle is one of the most efficient cycles for the conversion of gas fuels to mechanical power or electricity. The challenge in these systems is to obtain an integration degree that maximizes the efficiency at an economic cost.

Two big parts can differ; a first one, referred to the gas cycle, where energy will be liberated that will serve to be able to carry out the second part, the steam cycle. The air enters in the plant coming from the atmosphere goes by a compressor, which the pressure increases from the atmospheric one up to 23 bars. The compressed air passes to a combustion camera that blended with natural gas, the combustion takes place.

Figure 2. Representative outline of the operation of a combined cycle.



The generated hot gases of combustion go by the gas turbine, where they expand, arriving another time to the atmospheric pressure. These go toward to the HRSG, which recovers the great quantity of thermal energy that subtracts in them to produce steam. This is distributed among the circuit of high pressure to 160 bars.

The steam flow of high pressure will be good to feed the steam turbine. The steam expands from 160 up to 1 bar of exit.

The final stage of this process concerns to the condensation and recirculation of the steam water. In the first condensation stage, the steam that LP has left the turbine passes to a condenser, where it goes to a tank to assure that the bomb always enters liquid. The pump increases the pressure until the 160 bars. This flow of water passes in to the HRSG. The closed steam cycle is completed this way.

With respect to the cycle of gas, the remaining gases that have been good to generate vapour of water when going by the HRSG, have cooled down until the temperature of 500°C, that later they can use them to sell to others industries.

2.4 Manipulated variables (Degrees of freedom)

In a process that is desired to regulate some condition, a quantity or a condition that is altered by the control in order to initiate a change in the value of the regulated condition.

In the next, is shown a table with the list of the Manipulated variables of the simulation of this gas power plant.

Table 3. Manipulated Variables and degrees of freedom.

Manipulated variables	Quantity
Fuel Valve	1
Air valve	1
Air compressor work	1
Gas turbine work	1
Steam turbine work	1
Cooling water flowrate	1
Pump	1
TOTAL MANIPULATED	7
Mass balance air feed flowrate	-1
TOTAL Degrees of freedom	6

2.5 Disturbances & Constraints

A **Disturbance** upsets the process system and causes the output variables to move from their desire setpoint. Disturbances variables cannot be controlled or manipulated by the process engineer. The control structure should account for all disturbances that can significantly affect a process. The disturbances to a process can either be measured or unmeasured. The disturbances of the process are shown on the next table:

Table 4. Disturbances and their expected values and variations values.

Disturbance	Expected	Variation
Fuel Concentration (%Methane)	0,96	0,92 – 1
Fuel Temperature (°C)	25	20 – 30
Fuel Pressure (kPa)	2300	2250 – 2350
Air Concentration (%O₂)	0,210	0,205 – 0,215
Air Pressure (kPa)	101,3	100,3 – 102,3
Air Temperature (°C)	20	10 – 30
Exit Pressure (kPa)	101,3	100,3 – 102,3

The **Constraints** are the restrictions or limitations that placed on requirements or design of your process. The constraints of the process are shown in the table 5:

Table 5. Constraints values.

Constraints	Value
Temperature combustion	≤ 1500°C
Temperature steam turbine	≤ 600°C
Pressure cycle steam	≤ 170 bars

2.6 Real data of the DOE process

Next it is shown different tables of data of the process which my project is based. The real data is extract of the combined cycle of the DOE process, so much the produced total energy, as the auxiliary one used, and the total efficiency of the cycle.

Table 6. Energy produced by the DOE process

Generated energy (kW)	
Gas Turbine	275800
Steam Turbine	127537
TOTAL	403337

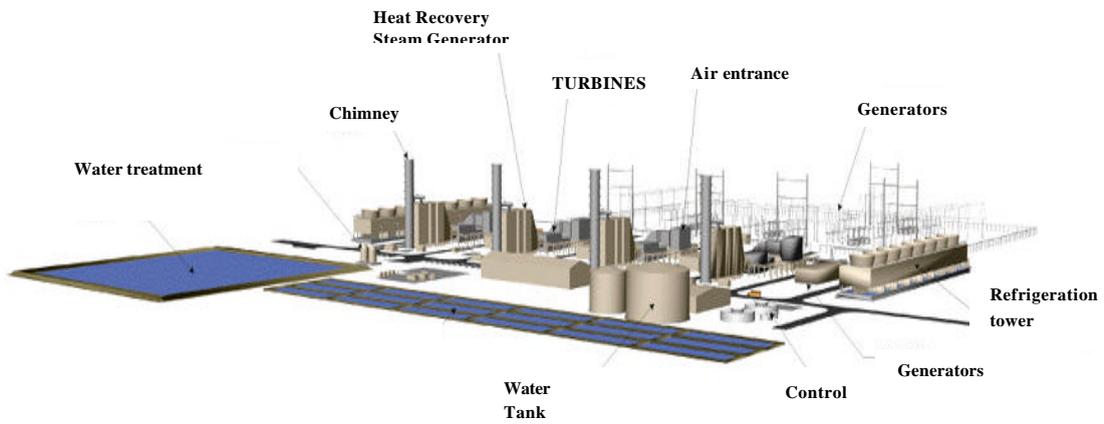
Table 7. Auxiliary energy by the DOE process

Auxiliar energy (kWe)	
Compressor	1680
Recycle HP pump	1630
Control system, lighting...	900
Steam recycling pump	1240
Refrigeration tower	700
Transformation losses	1370
Others...	670
TOTAL	8310

Table 8. Net energies and efficiency.

Net energies (kWe)	
Net energy	395027
Plant efficiency	53,4
Generated net heat	6396
GAS NATURAL consumption (kg/h)	524891

Figure 3. Virtual scheme of a combined cycle plant.



3. Steady-State modelling

3.1 Introduction

The steady-state is a characteristic of a condition, such as value, rate, periodicity, or amplitude, exhibiting only negligible change over an arbitrary long period of time (infinite).

3.2 Assumptions

- I have supposed the camera of combustion of the process from the DOE as a conversion reactor in the HYSYS®.
- The conversion is 100% in the reactor.
- In the compressor and the turbines the efficiencies are adiabatic.
- The components of the natural gas are: methane, ethane and nitrogen.
- The natural gas in the feed comes directly at the pressure of 23 bars.
- It's supposed worthless the mechanical losses.
- I supposed that isn't losses on the conversion energy.
- The losses of heat have been rejected in each unit (turbine, compressor, boiler and HRSG adiabatic).

3.3 Fluid Packages

In HYSYS®, all necessary information pertaining to pure component flash and physical property calculations is contained within the Fluid Package. This approach allows you to define all the required information inside a single entity. There are four key advantages to this approach and are listed below:

- All associated information is defined in a single location, allowing for easy creation and modification of the information.
- Fluid packages can be exported and imported as completely defined packages for use in any simulation.
- Fluid packages can be cloned, which simplifies the task of making small changes to a complex Fluid package.
- Multiple Fluid Packages can be used in the same simulation; however; they are all defined inside the common Simulation Basis Manager.

Before beginning the simulation, I have made a study on which it was the best fluid package to simulate a Gas Power Plant. To decide with which fluid package I should catch, I have proven the package that treat hydrocarbons flow (natural gas), and the results of each fluid package, I have compared them with the data of the DOE process.

I have compared the results of temperature, pressure and work in the most important unitary operations. Next a table is shown with the different data for each fluid package.

Table 9. Temperature and Pressure data for each fluid package tested.

	UNIQUAC	SRK	Wilson	PRSV	DOE
T(°C) exit compressor	494,2	494,5	494,2	494,7	481,9
kW compressor	2,76x10 ⁵	2,88x10 ⁵	2,77x10 ⁵	2,77x10 ⁵	2,69x10⁵
T(°C) combustion	1517	1516	1517	1515	1471
kW turbine HP	4,39x10 ⁵	7,74x10 ⁵	5,67x10 ⁵	7,73x10 ⁵	5,54x10⁵
T(°C) exit turbine HP	1240	849,7	720,6	894,4	594,6
T(°C) exit gases HRSG	1059	653,7	322,6	656,1	100,9
T(°C) exit steam turbine	212,4	183,2	166,4	182,5	332
kW steam turbine	9,09x10 ⁴	9,11x10 ⁴	9,02x10 ⁴	9,44x10 ⁴	6,49x10⁴
T(°C) exit pump HP	31,58	31,03	31,58	31,53	44

According to the results of temperatures, pressures and works, I have chosen the thermodynamic model **SRK**, since it is the one that more it resembles the results of the DOE process. For similarity of results I had to have caught **WILSON**, but this fluid package, it is not correct, since liquid is obtained in the exit of the combustion camera. That is unthinkable in a combustion camera to a temperature of 1500°C and a pressure of 23 bars.

During the simulation of HYSYS in stationary state mode, I have had many problems to choose the fluid package, since none of the thermodynamic models resembled the results of the process of the DOE. Most of them had the problem that we obtained liquid in the exit of the reactor, when this occurred, discarded the thermodynamic package.

3.4 Components of the Fluid Package

The components that I have used for the simulation of Gas Power Plant in HYSYS® software are the following ones:

- Methane
- Ethane
- Nitrogen
- CO₂
- Oxygen
- H₂O

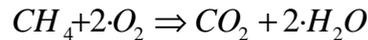
Next is shown a table with the composition of the natural gas that feeds the power plant.

Table 10. Composition of the natural gas.

Component	% (molar)
Methane	0,96
Ethane	0,02
Nitrogen	0,02

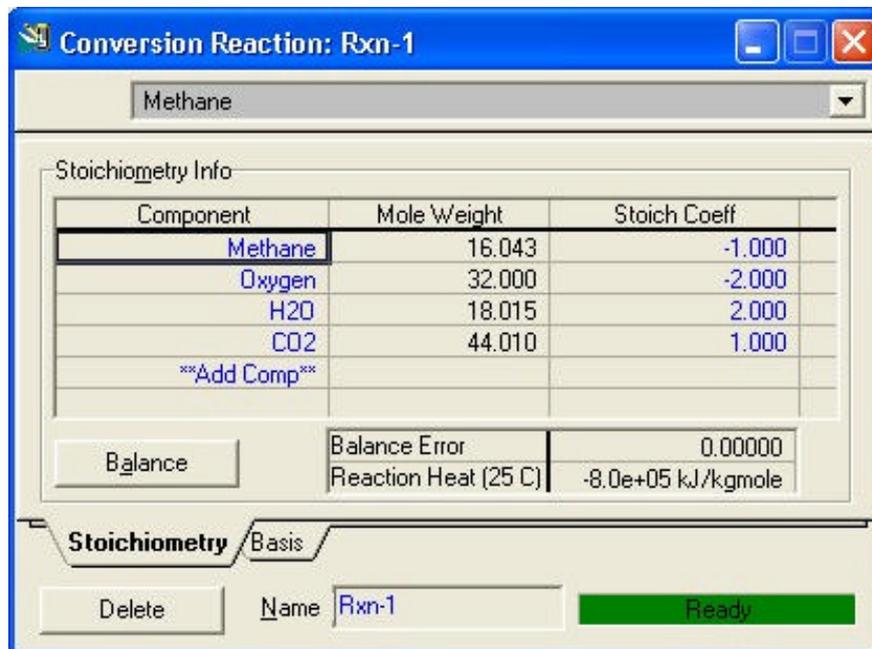
3.5 Combustion Reaction

During the definition of the fluid package, I have also defined the reaction that takes place in the combustion camera, where it mixes the natural gas with the air that it comes from the compressor. The reaction in the reactor is the following one:



In the HYSYS® software, the combustion reaction between the natural gas and air is defined like the next figure:

Figure 4. Definition of the combustion reaction in HYSYS®.



3.6 Results of the Steady-State

For the calculate of the efficiency of the combined cycle are needed the net work produced by the cycle. Net work: The net work corresponds the one generated by the turbines less the one consumed by the bomb and the compressor.

The results of the simulated cycle are shown in the following tables, where the efficiencies of compressors, turbines and bomb are included; the produced energy and the one consumed for the total calculation of combined cycle. The global efficiency of the plant is obtained relating the W_{net} obtained with the heat that we put in the system through the combustion camera.

Table 11. Efficiencies of turbines, compressors and the pump.

Efficiency (%)	
Compressor	83,0
Gas Turbine	84,0
Steam Turbine	83,0
Pump	77,0

Table 12. Net work of the combined cycle.

Works (MW)	
Compressor	287,8
Gas Turbine	778,5
Steam Turbine	91,1
Pump	1,51
TOTAL	580,3

Table 13. Global efficiency of the simulated plant.

Global efficiency (%)	
Net Work (MW)	580,3
Heat (combustion) (MW)	970
Combined Cycle efficiency	59,8 %

3.7 The Profit (expected disturbances)

The Profit is the positive gain from a business, investment or process operation after subtracting for all expenses in the process. In our case, the profit is defined:

$$-J = P_{elect} (W_{gt} + W_{st} - W_c - W_p) - P_{fuel} F_{fuel} - P_{air} F_{air} - P_{water} F_{water}$$

Where:

J =profit

P_{elect} = electricity price

W_{gt} = gas turbine work

W_{st} = steam turbine work

W_c = compressor work

W_p = pump work

$P_{fuel, air, water}$ = price of the fuel, air and water

$F_{fuel, air, water}$ = flowrate of the fuel, air and water

In our case, we have to despise the water price, because in the Norway there isn't problem with water supply; and we have to despise the price of the air, because our plant takes the air directly from the atmosphere and we don't have any cost of water and air.

Next a study of the profit is shown. All the possibilities have been simulated with their respective disturbances. Starting from there, it has been calculated the values of the profit and the disturbances has been determined that have more effect on the profit: