TECHNICAL COMPARISON BETWEEN IGCC AND NGCC POWER PLANTS

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Abstract. *Among the emerging clean coal technologies for power generation, Integrated Gasification Combined Cycle (IGCC) and Natural Gas Combined Cycle (NGCC) systems are receiving considerable attention as a potentially attractive option to reduce the emissions of greenhouse gases (GHG). The main reason is because these systems has high efficiency and low emissions in comparison with tradicional power generation plants. Currently in IGCC and NGCC systems at demonstration stage is been considered to implement CCS technology. CO_2 emissions can be avoided in a gasification-based power plant because by transferring almost all carbon compounds to CO_2 through the water gas shift (WGS) reaction, then removing the CO_2 before it is diluted in the combustion stage.*
The aim of this study is to compare the technical performance of an IGCC system that uses Brazilian coal and petroleum coke as fuel with a NGCC system, with the same fixed output power of 450 MW. The first section of this paper presents the plant configurations of IGCC systems. The following section presents an analysis of NGCC technology.

Keywords*: Gasification, Integrated Gasification Combined Cycle (IGCC), Natural Gas Combined Cycle (NGCC), Carbon Capture and Storage (CCS); Power plant efficiencies.*

1. INTRODUCTION

Emissions of greenhouse gases to the atmosphere are expected to cause significant global climate change. The most significant greenhouse gas is CO_2, which arises mainly from use of fossil fuels. According to BP Statistical Review of World Energy (2009), fossil fuels currently provide about 85% of the world's commercial energy needs. Government measures, such as improved energy efficiency and use of alternative energy sources, as IGCC and NGCC systems will help to reduce emissions but a rapid move away from fossil fuels may cause serious disruption to the global economy, as energy supply infrastructure has a long lifetime.

The main target of this study is to make a technical assessment of IGCC and NGCC power generation systems from fossil fuel, using coal, petroleum coke (petcoke) and natural gas, respectively. In order to evaluate IGCC technology, in this paper is analysis carried out the combine a coal gasification process with a power plant cycle. The combustion of the syngas from coal gasification with oxygen and steam was simulated using CeSFaMBi^{TM} software. In a following stage, the syngas composition is used in GateCycle^{TM} software to analyze power plant performance. Finally, in this work the NGCC technology was analysis developed a model in GateCycle^{TM} software using as fuel natural gas.

2. CLEAN COAL TECHNOLOGIES FOR POWER GENERATION

Fossil fuels are likely to remain as the dominant mean of producing electricity in 2030, partly because power stations have long lifetimes (Oliver, 2008). Future technologies and fossil-fuelled power plants are focused on the development and implementation of CCS technology to reduce CO_2 emissions and increase plant efficiency that can give significant reductions in generation costs (Kvamsdal, 2010). In this context are described IGCC and NGCC systems. These technologies need to include both coal and gas and also be suitable for new plants and for retrofitting existing ones.

2.1. Integrated gasification combined cycles (IGCC) systems

IGCC technology is based around the gasification of coal. In this process are used modern gasifiers that convert coal into a mixture of hydrogen and carbon monoxide, both of which are combustible. Gasification normally takes place by heating the coal with a mixture of steam or air and oxygen. This can be carried out in a fixed bed, a fluidized bed or an entrained flow gasifier. The synthesis gas (syngas) produced, meanwhile, is cleaned and can be burned in a gas turbine to produce further electricity. Heat from the exhaust of the gas turbine is used to raise additional steam for power generation. IGCC technology has yet to make an impact in the main power generation market. Further development is required to enable gasification to realize its full potential. This will include effective technologies for cleaning the hot exhaust gas before it enters the gas turbine stage of the IGCC plant. Hot gas cleanup will allow an IGCC plant to operate at optimum efficiency (Breeze, 2005).

One aspect of gasification technology which has attracted recent attention is its ability to produce gaseous hydrogen. If an energy economy based on hydrogen ever evolves, then coal gasification could provide one source of the fuel. Another area that could prove attractive is underground gasification, involves the controlled burning of coal in the seams underground where it is found. Air is injected through a borehole into the seam and the gasification product is extracted from a second borehole. Underground gasification avoids many of the pollution problems associated with coal combustion while requiring little advanced technology. However the technique is nowhere near commercial application.

2.2. Natural Gas-Fired Combined Cycles (NGCC) systems

NGCC systems employ a combination of a gas turbine and a steam turbine, sometimes on a single shaft. In the gas turbine, air, after compression, is heated by combustion of the injected fuel, and the added energy is exploited by expansion of the hot product gases through an expander, turning the rotor. The rotor directly drives the compressor and the generator.

Exhaust gases leaving gas turbines are typically at a temperature of 550-600°C, and are used for the production in a heat recovery boiler of steam at different pressures for expansion through the steam turbine for generation of additional power (IEA, 2007). Reheat may also be used in the steam cycles of combined cycles, depending on cost-effectiveness. Efficiencies are higher than for current coal plants because of the higher working temperature attainable in gas turbines that allow a combined cycle operation and low in-plant power consumption as there is no need for solids handling or SO_2 or particulates emission control systems. NOx is controlled by control of fuel/air mixing and, in some plants, by an SCR unit in the heat recovery boiler.

3. MODELS DEVELOPED FOR THE ANALYSIS OF IGCC AND NGCC SYSTEMS

3.1 - IGCC model

For the IGCC systems was analyzed the gasification process using CeSFaMBi software to determine the composition of synthesis gas (syngas). After that, is using GateCycle software to analyze the power plant cycle. The CeSFaMBi and GateCycle interaction represent appropriate computational tools for simulation of IGCC systems (Silva, 2010). The kind of fuels used in the gasification process simulation was Brazilian coal and petcoke.

3.1.2 - Fuel characterization

Initially it will be presented the main characteristics of the fuels coal, petcoke and a mix (between 50% coal with 50% petcoke) used in this analysis.

Table 1. Candiota coal, Elemental fuel analysis (CIENTEC, 2008)

Ultimate analysis		Proximate analysis (wt. %)	
Carbon (%)	34.0	Moisture (%)	15.0
Hydrogen (%)	2.6	Volatile	16.4
Nitrogen (%)	0.7	Fixed Carbon	24.4
Oxygen (%)	8.5	Ash (%)	44.2
Sulphur (%)	1.2		
Ash (%)	53.0		
HHV (MJ/kg)	13.8		

Table 2. Petcoke, Elemental fuel analysis (Santos, 2007)

Ultimate analysis		Proximate analysis (wt. %)	
Carbon (%)	86.3	Moisture (%)	7.0
Hydrogen (%)	3.5	Volatile	19.2
Nitrogen (%)	1.6	Fixed Carbon	73.5
Oxygen (%)	0.5	Ash (%)	0.3
Sulphur (%)	7.5		
Ash (%)	0.6		
HHV (MJ/kg)	33.6		

Table 3. Candiota Coal / Petcoke Mixture, Elemental fuel analysis

Ultimate analysis		Proximate analysis (wt. %)	
Carbon (%)	62.5	Moisture (%)	9.2
Hydrogen (%)	3.0	Volatile	18.6
Nitrogen (%)	1.1	Fixed Carbon	51.5
Oxygen (%)	4.5	Ash (%)	20.7
Sulphur (%)	3.9		
Ash (%)	25.0		
HHV (MJ/kg)	25.1		

Tables 1, 2 and 3 show the elemental fuel analysis that will be considered in the gasification technologies simulation. This characterization corresponds to samples of Brazilian fuels; including petcoke and Candiota coal, which one of the most important deposits of Brazil coal located in Rio Grande do Sul states. Table 1 shows that Brazilian coal has high ash content, a fact that can influence negatively the performance of a generation system based on its combustion.

Brazilian petcoke is considered as LSC because it is produced during the processing of oil with low sulfur content, while some imported petcoke, which may come from Venezuelan oil refining, presents sulfur content in the order of 3% by weigh (Salvador, 2003), has a low market value and a great chance of becoming an economically viable fuel for thermal generation. According to the World Energy Council, it is for this reason that in many applications it is recommended to mix the coal with petroleum coke (with a content of around 20-50% of coke) to improve fuel properties (WEC Statement, 2007).

3.1.3 - Gasification process simulation with the CeSFaMBi software

The proposed model for the gasification process uses CeSFaMBi software, which is a comprehensive mathematical model and simulation program for bubbling and circulating fluidized-bed, as well as downdraft and updraft moving-bed equipment. Among these equipments, there are furnaces, boilers, gasifiers, dryers, and reactors (De Souza, 2007). Table 4 shows different types of gasifier used in gasification process to IGCC systems.

Table 4. Characteristics of different categories of gasification process (adapted from Higman, 2008)

Category	**Moving-bed**		**Fluid-bed**		**Entrained-flow**
Ash conditions	Dry bottom	Slagging	Dry ash	Agglomerating	Slagging
Typical processes	Lurgi	BGL	Winkler, HTW, KBR, CFB, HRL	KRW, U-Gas	KT, Shell, GEE, E-Gas, Siemens, MHI, PWR
Feed characteristic					
Size	6–50 mm	6–50 mm	6–10 mm	6–10 mm	< 100 μm
Acceptability of caking coal	Yes (with stirrer)	Yes (with stirrer)	Possibly	Yes	Yes
Preferred coal rank	Any	High	Low	Any	Any
Operating characteristics					
Outlet gas temperature	Low (425–650°C)	Low (425–650°C)	Moderate (900–1050°C)	Moderate (900–1050°C)	High (1250–1600°C)
Oxidant demand	Low	Low	Moderate	Moderate	High
Steam demand	High	Low	Moderate	Moderate	Low
Other characteristics	Hydrocarbons in gas	Hydrocarbons in gas	Lower carbon conversion	Lower carbon conversion	Pure gas, high carbon conversion
Power	20 kW to 2 MWth		5 to 100 MWth		>100 MWth

In the gasification process simulation it was selected a circulating fluidized bed as gasifier, this technology has been successfully used in many fields, including combustion, biomass/coal gasification and oil catalytic cracking, which is the type that best fits within the possibilities of simulation gasifiers in the CeSFaMBi program, taking into account the power ranges that they can achieve.

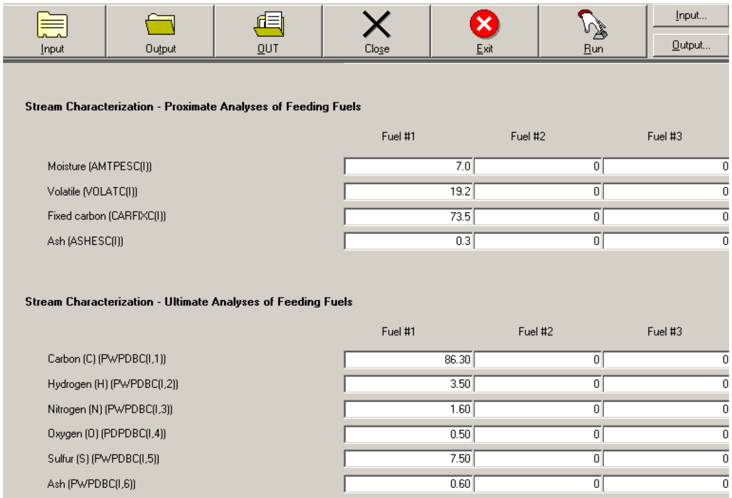

Figure 1. CeSFaMBi interface

Figure 1 shows the CeSFaMBi interface, where is introduced the stream characterization and fuel composition, in wet basis, for proximate analysis, and in dry basis, for ultimate analysis. The data shown is this figure refers to used in Paraná coal.

3.1.4 - Results and analysis of gasification process simulation

Gasification process simulation was carried out using different types of fuels (Tables 1 – 3) and a circulating fluid bed as gasifier. Table 5 lists the main parameters required by CeSFaMBi software for the gasifier simulation using coke as fuel. In the tests carried out, the feed mass flow rates, the feed gas though distributor (Gasification agent) and the granulometry of the fuel fed to the gasifier were modified in order to achieve the conditions above the second turbulence limit, allowing for increased contact between particles and gases.

Table 5. Key input parameters of the gasifier design

Parameter	**Variable**	**Value**	**Units**
STREAM CHARACTERIZATION SOLIDS AND FUEL FEEDING			
Apparent density, Carbonaceous	ROPESC	750	kg/m^3
True density, Carbonaceous	RORESC	1650	kg/m^3
Inlet mass flow rate, Carbonaceous	FMTESC	28.5	kg/s
Inlet temperature, Carbonaceous	TPESA	298	K
EQUIPMENT DATA - BASIC GEOMETRY ***Gasifier***			
Bed - equivalent hydraulic internal diameter	DD	3.0	m
Freeboard - equivalent hydraulic internal diameter	DF	3.0	m
Position of main gas withdrawal	ZF	10.0	m
Position of carbonaceous fuel feeding	ZFEEDA	2.5	m
Distributor			
Number of orifices for gas/steam injection (0=porous plate)	NOD	3300	-
Diameter of orifices for gas/steam injection through distributor	DOD	0.005	m

Table 5. Key input parameters of the gasifier design (continue)

Parameter	Variable	Value	Units
EQUIPMENT DATA - CYCLONES AND RECYCLING			
Ciclone			
Internal diameter of cyclones	DCY	0.8	m
Height of the cylindrical part of cyclones	HCY	1.5	m
Height of the conical part of cyclones	HCYC	1.5	m
Position of recycling injection	ZRCY	2.0	m
STREAM CHARACTERIZATION GASES THROUGH DISTRIBUTOR			
Gasification agent	Mixture Oxygen (85%) + Steam (15%)		
Inlet gas through distributor, Temperature	TEGID	495	K
Inlet gas through distributor, Pressure	PEGID	170	kPa (abs.)
ADDITIONAL OPERATIONAL CHARACTERISTICS			
Local Ambient Conditions			
Average pressure in the bed	POPER	155	kPa (abs.)
AVG surrounding air temperature	TAMB	298	K
Wind velocity	VV	2.0	m/s

Table 6 describes the gasifier efficiency and the main compounds in volumetric percentage of the synthesis gas produced from coal, pet coke and a mixture or both, using the CeSFaMBi software without taking into account the low percentage of H_2, H_2S, NH_3 and SO_2 compounds.

Table 6. Synthesis gas composition (dry basis) and gasifier efficiency

	COAL	PETCOKE	MIXTURE (50:50w)
CO_2	13,95	14,05	14,92
CO	43,19	41,06	40,87
CH_4	0,05	0,07	0,04
H_2	41,46	43,57	42,98
N_2	0,81	0,59	0,94
H_2O	43,85	45,73	47,48
HHV (MJ/kg)	11,15	13,03	12,68
Cold efficiency 58%		Hot efficiency 82%	

3.1.5 - Combined cycle simulation using GateCycle software

Currently there are several commercial software that can be used for modeling thermal cycles, which can be used for the simulation purposes or for other applications (design, teaching, research, etc.). These software are characterized by simulating projects searching optimal graphically and analytically settings, fact that represents its main advantage.

GateCycle software developed by GE Enter Software, available in the version 5.51 as a commercial product was used as a tool for thermal simulation studies. GateCycle also provides a user configurable optimizer and an MS-Excel™ based interface called CycleLink (GateCycle, 2003). In addition to these tools, SteamTable has been widely used to determine steam and water properties.

3.1.6 - Assumptions on plant configuration

In this paper, the IGCC system simulation was conduct using a model developed in GateCycle version 5.51 (see Figure 2) and syngas composition presented in Table 6. The simulation considered the ISO standard conditions (1 atm, 15 °C and 60 % HR) and GateCycle's model was developed with the information presented in Table 7.

This model is characterized by the integration of thermodynamic cycles, Brayton and Rankine, the first of them describes the workings of the gas turbine engine (power cycle) and the second describes a model of steam operated forward heat engine which converts heat into work (steam cycle). The simulations were performed considering Siemens V94.3A (1999 GTW) gas turbines.

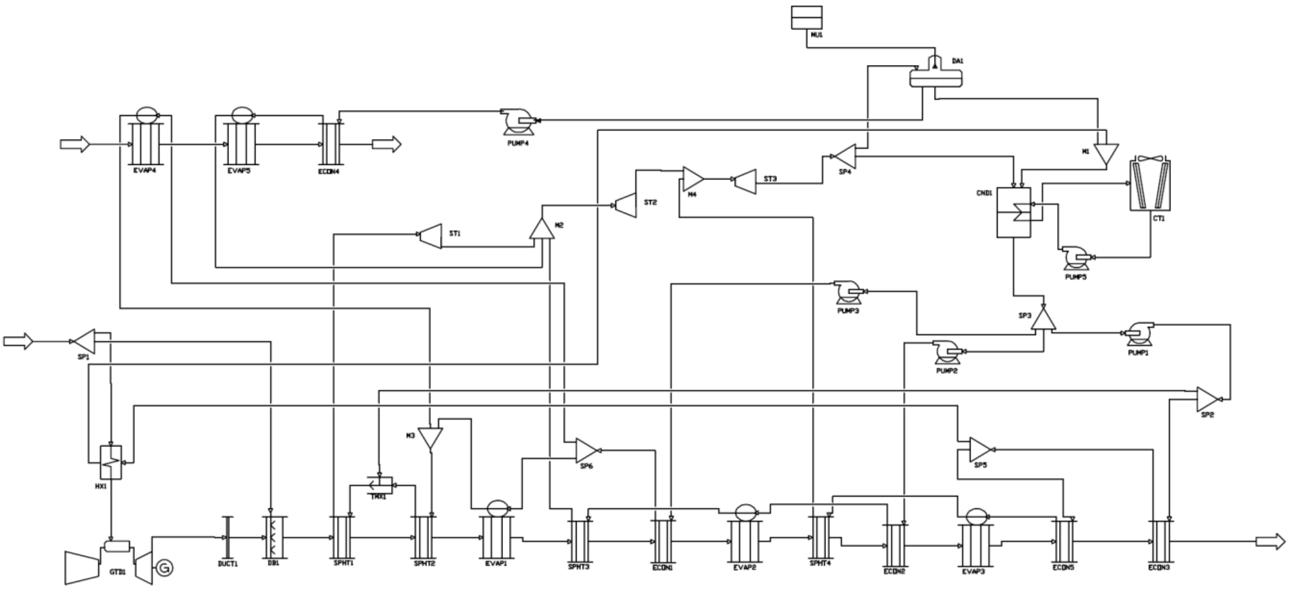

Figure 2. IGCC power plant scheme modeled on GateCycle software

Table 7. Technical description IGCC plant

System	Variable		Value
Environmental conditions	Temperature [°C]		15
	Humidity [%]		0.6
	Pressure		1
HRSG	Steam	High pressure [bar]	135
		Middle pressure [bar]	45
		Low pressure [bar]	8.5
	Combusted gas temperature [°C]	In	545
		Out	105
Gas turbine	Power [MW]		200
	Mass flow air [kg/s]		550
	Compression		15:1
	Thermal efficiency [%]		35
Steam turbine	Power [MW]		150
	High pressure superheated steam	Pressure [bar]	130
		Temp. [°C]	510
	Reheated steam	Pressure [bar]	35
		Temp. [°C]	525
Air splitter unit	Air flow [kg/s]		90
Combined cycle	Net power output [MW]		450

3.1.7 - Analysis and results of IGCC model

GateCycle's model applied used two syngas streams, which are used in the syngas heat recovery block and to consider the feed up gas turbine. In the first one, pressure, temperature and mass flow information is provide for estimation of heat recovery and steam production from the gasification island. The second stream is feed with information associated to clean syngas composition as well as pressure, temperature and mass flow. Moreover, the power cycle using 3 pressure levels, for determining heat rate and efficiency of combined cycle were used to validate the thermodynamics simulations. Figure 3 shows the results obtained for simulations of IGCC power plant using syngas resultant for different types of fossil fuels.

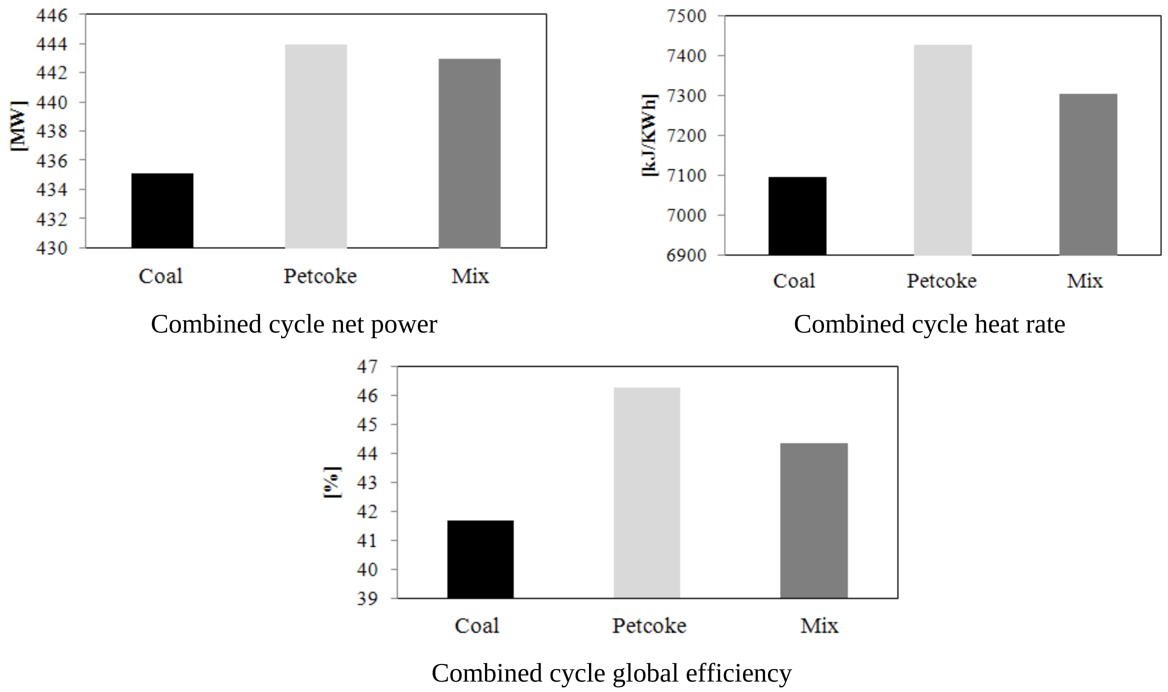

Figure 3. Results for parameters IGCC power plant

3.2 - NGCC MODEL

In this work, the NGCC system simulation was conduct using a model developed in GateCycle version 5.51 and natural gas as fuel. GateCycle's model was developed with the information presented in Table 8.

3.2.1 - Assumptions on plant configuration

Figure 4 shows a diagram of HRSG with three levels: high, medium and low pressure. The set superheater, evaporator and economizer low pressure also provides steam to the deaerator. A HRSG with three pressure levels has a level of utilization of hot gases from the turbine even better than the HRSG of one and two levels of pressure, but their levels of complexity of construction and operation are also higher. The simulations were performed considering Siemens V94.3A (1999 GTW) gas turbines.

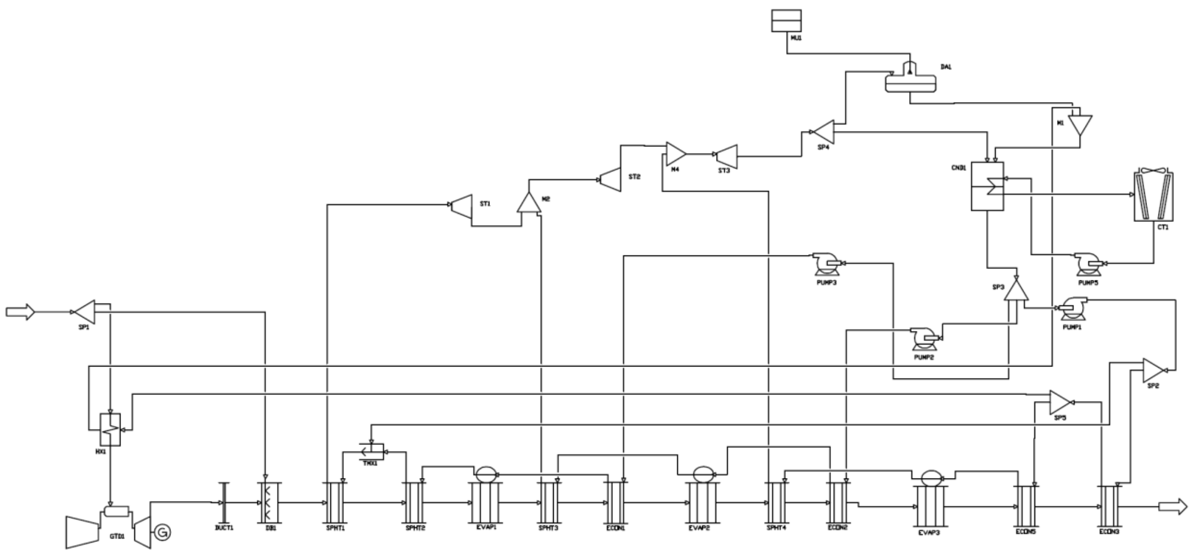

Figure 4. NGCC power plant scheme modeled on GateCycle software

In this cycle, steam is available at three different levels of superheat. The simulation was performed by varying the temperature of one of the levels whilst keeping the other two constant. Varying the temperature of steam within the high pressure section has a more significant effect than in sections of intermediate and low pressure, while the variation of the steam temperature at the entrance of the sections produces a very low variation in the output power, there is a little advantage raising the temperature at the intermediate pressure entrance.

Table 8. Simulation conditions for the NGCC plant

System	**Variable**	**Value**
Environmental conditions	Temperature [°C]	15
	Humidity [%]	0.6
	Pressure [atm]	1
Natural gas fuel	LHV [kJ/kg]	47000
Gases temperature (Gas turbine outlet)	Temperature [°C]	500
Steam temperature (Superheater outlet)	Temperature [°C]	480
Gas outlet temperature	Temperature [°C]	130
Steam turbine		
High pressure steam	Pressure [bar]	90
Intermediate pressure steam	Pressure [bar]	20
Low pressure steam	Pressure [bar]	2
Pressure condenser	Pressure [bar]	0,15
Exhaust gases flow	Flow [kg/s]	400

3.2.2 - Analysis and results of NGCC model

The proposed model for the NGCC system applied in GateCycle uses a natural gas stream, which represents the fuel supply to the gas turbine. Pressure, temperature and mass flow information is provide for estimation of heat recovery and steam production from the combined cycle. As a final point, the power cycle using 3-level pressure for determining heat rate and efficiency of cycle were used to validate our thermodynamics simulations. Table 8 shows the results obtained for simulations of NGCC power plant using natural gas as fuel.

Table 8. Results for parameters NGCC power plant

Parameters	**Units**	**Value**
Combined cycle net power	[MW]	450
Combined cycle heat rate	[kJ/kg]	6550
Combined cycle global efficiency	[%]	51

4. CONCLUSIONS

This paper showed that incorporation of advanced oxygen production and GT technologies holds promise to significantly improve the performance efficient of IGCC systems. The size of the models propuse was determined by the output of the commercially available combustion turbine. A analysis of the economic uncertainties and financial assessment associated with IGCC and NGCC models remains for future research.

In the IGCC model, gasifier circulating fluid bed using oxygen as gasification agent was an adequate type to gasifier for gasification process to achieve the power required by the combined cycle. It makes possible to estimate the syngas composition of the fuels characterized. Moreover, the main difference found in the analyzed parameters of IGCC and NGCC systems for a fixed output power of 450MW is showed in fuel consumption; this is reflected in the calorific value of fuels used and in the heat rate calculated for both cases.

Simulation results showed that these two advanced technologies can yield a system that is more efficient than a current power generation plants. This study also highlighted and characterized the magnitude of the specific fuel requirements. Key parameters for the implementation and deployment on the IGCC or NGCC systems depend largely on the cost and availability of fuel used in these systems, carbon-petcoke and natural gas, respectively.

In the future power generation systems that in their supply chain production to achieve deploy CCS technology, will be competitive systems within the various systems for power generation, accounting for these more opportunities for their implementation, because these advanced power generation systems with CCS technologies offering improved efficiency and lower energy requirements.

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