HOW TO REDUCE CAPITAL COST OF IGCC POWER STATIONS

Paper presented at the 17th EPRI Conference on Gas-Fired Power Plants

San Francisco, October 1998

M.J. van der Burgt

Energy Consultancy B. V., The Netherlands

HOW TO REDUCE CAPITAL COST OF IGCC POWER STATIONS

M.J. van der Burgt

Abstract

Even though various IGCC demonstration projects, featuring commercial size gasifiers and gas turbines, have been successfully operated for some time there remains the problem of the high capital cost. Some process developers maintain that by increasing the size of the power station and marginal improvements the capital cost can be lowered such that coal based IGCC stations will become economically viable. This may be true for the industrialised world where it is realistic to compare IGCC with advanced conventional coal fired power stations featuring supercritical cycles. However, in order to compete with low cost conventional coal fired stations featuring less advanced cycles as built in the developing world where the real growth market is, the gap in capital cost between conventional coal fired stations and IGCC is so large that such measures are not sufficient.

By combining the strong points of the various developments in the field of IGCC a lot can be achieved. Examples are the coal pressurising system, the gasifier proper and the syngas cooler. Other improvements can be found by slightly relaxing the requirements for sulphur removal and by reducing the parasitic power consumption that is caused by the Air Separation Unit and the compressor of the gas turbine.

Introduction

Currently the capital cost of a 250-300 MWe demonstration type coal fired Integrated, Gasification Combined Cycle (IGCC) is about 2000 US$/kW. By marginal improvements and increasing the capacity to 600-700 MWe this figure may drop to about 1500 -1600 US$/kW but further reductions will be difficult. The cost of the Combined Cycle (CC) per se is already 450-500 US$/kW and of the Air Separation Unit (ASU) about 200 US$/kW and these costs will not be reduced much because it are mature technologies. This implies that most cost reductions have to come from the gasification part of the IGCC plant.

From natural gas based power stations it was learned that advanced gas turbines with high inlet temperatures are attractive to use because they result in the highest efficiency provided their hot exhaust gases are used to raise steam for an additional steam cycle in a Heat Recovery Steam Generator (HRSG). Therefore it was logical to use the CC principle also with coal as a feedstock. The coal has of course first to be gasified and the gas freed from its impurities but then nothing is preventing the use of this gas in the efficient CC.

The fact that the sulphur in the coal could be removed as H_2S from the fuel gas rather than as SO_x from the flue gas as in combustion was seen as an additional advantage of gasification. The H_2S is more reactive, available at a higher concentration, is present in a gas that is pressurised and after concentration in a wash system it can be readily converted into elemental sulphur.

Twenty to thirty years ago when IGCC became of interest it was insufficiently realised that apart from sulphur, nitrogen compounds, halogens, carbonyls, toxic metals, arsenic, etc. had to be removed from the gas. Further it was not realised that there would be tremendous progress in both stack gas scrubbing for SOx removal and Selective Catalytic Reduction (SCR) for NO_x removal. Finally the advantage of producing elemental sulphur rather than gypsum may not hold in the future as more and more sulphur will come available from refineries because of more stringent sulphur specifications for liquid fuels and hence sulphur may become a waste product.

Gasification requires high temperatures, which implies that the energy in the coal not only comes available as combustion energy of the syngas but also as sensible heat of the syngas. Unless one is successful in making the maximum amount of this sensible heat available to the combined cycle it is difficult to get a high efficiency for the power plant. In most cases the sensible heat of the gasifier is used to raise additional steam in a syngas cooler that is integrated with the steam raised in the HRSG. The cooling of the gas to essentially ambient temperatures is required., since as yet no good high temperature cleaning processes are available to remove all the impurities.

The steam cycle has an efficiency of about 40% whereas the efficiency of the CC is about 58%. In order to reduce the size of the syngas cooler, which is an expensive piece of equipment, and to make the maximum amount of energy in the coal available to the more efficient CC the coal is preferably gasified with oxygen. This reduces the size of the syngas cooler by 50-60% and makes more heat available to the more efficient CC. Moreover the use of oxygen reduces the amount of gas to be cleaned.

In order to reduce the capital cost of the plant and for reasons of efficiency the compressed air required for the ASU is often taken from the air compressor of the gas turbine. This results in a second integration of a main process stream. The nitrogen that is co-produced in the ASU is often used to dilute the (clean) syngas before it is combusted in the gas turbine in order to reduce the thermal NOx production. This comprises a third major integration.

The above measures result in plants that are expected to have efficiencies of 48 to 50% when using the best state of the art gas turbines. This is quite an accomplishment considering the fact that the gases yo-yo in temperature from ambient to minus 200 C (ASU) to 1500 C (gasifier) to ambient (water wash) to 150 C (COS and HCN conversion) to ambient (acid gas removal) to 1300 C (gas turbine) to 100 C (stack). It is not surprising that such plants are very high in capital cost.

Ways to reduce these costs are the subject of the present paper. Improvements that will lead to a reduction in capital cost are divided into three sections: Reduction in equipment costs, simplification in process line-up and gas turbine modifications.

General

An increase in efficiency generally leads to a reduction in equipment cost. An exception is the last 1-2 % points efficiency, which can only be obtained by a disproportionate increase in the cost of equipment.

Another important general point to consider is that an IGCC per se is only efficient in case it is running under essentially base load conditions. This is a result of making the gas turbine the focal point around which the whole IGCC is arranged. By co-producing a peak shaving fuel as methanol or liquid CO this problem can be partly solved as the gasifier part can run at base load. The CC part of the plant has of course always to follow the demand for electricity. Certainly in the case of liquid CO storage the peak shaving facility will largely be paid for by the fact that depending on the conditions the gasifier section of the IGCC can be built for a 15-20 % lower capacity.

All in all it is rather unrealistic to demand other than base load conditions from the first generation IGCC's.

A second solution to cope with the problem of grid following is to make the power plant so low in capital that it is economically feasible to run for say e.g. 16 hours per day. It is unlikely that this requirement can be met. An additional requirement for such a plant would be that it can be started up and shut down in a short time which implies that the gasifier can be started up and shut down in say less than 30 minutes and that the steam cycle will have to be eliminated. The latter means that the CC concept is being abandoned. This may not be a bad idea as also for base load conditions doing away with the steam cycle will result in a lower capital cost as will be discussed below.

Reduction in equipment cost

In the present discussion only oxygen blown pressurised entrained slagging gasifiers will be considered.

For dry coal feed systems the first unit to be discussed is the milling and drying unit. The equipment is standard and in principle little can be done in terms of capital cost reduction. It is possible though to reduce or even eliminate the amount of natural gas used for the drying. One way of doing this is by using low-level heat in the exhaust gases from the gas turbine for drying. Further in case hot fly slag with a suitable content of carbon is produced in the gasifier it is advantageous to recycle this hot material back to the milling and drying unit. The sensible heat in the fly slag reduces the heat required for drying and the carbon in the fly slag is homogeneously mixed with the coal and gets another chance to be gasified.

The next section is the coal pressurising system. The only commercial systems that are applied are lock-hoppering in case a dry coal feed is used or water slurry feeding. The latter option is lower in capital per ton coal feed but results in a 2-3 % drop in process efficiency and, in case a heat recovery is applied, in a substantially larger syngas cooler because of all the steam that is present in the syngas leaving the gasifier. As a result the capital cost per kW is in the latter case not much lower than for dry coal feed systems.

Lock-hoppers are complex and high in both capital and operating cost. The most promising low capital alternative pressurising systems are the Firth pump as e.g. developed by Starmet and the use of very tall feed hoppers. Unfortunately both systems are as yet not commercially available for IGCC. The principle of the tall hopper is that the pressure in the gasifier system is lower than the static pressure of the coal in the hopper and that the upward velocity of the gas through the interstices of the coal is lower than the downward velocity of the coal in the hopper. The solution of a tall hopper will probably only be considered in case a high stack is required as then the hopper can be integrated with the stack structure.

The capital cost of the gasifiers currently applied in demonstration unit's show a large variation. It varies from simple one burner top fired cylindrical gasifiers with low cost insulating brick walls and a combined outlet for gas and liquid slag to multiburner designs with more complex tube wall constructions having separate outlets for gas and slag. In the latter case the gasifier not has to act as a reactor but also as a gas-liquid separator, which complicates the design and operation.

The insulating wall increases the process efficiency but makes the gasifier more vulnerable to temperature excursions compared to the more expensive tube wall. In the tube wall saturated steam is produced which contributes to the steam cycle whereas in case of the insulating wall this heat is used to increase the combustion energy of the fuel gas. The tube wall may possibly be simplified by applying a reactor wall with an internal water/steam jacket. This will reduce the capital cost but will not reduce the heat loss.

Apart from the lower capital cost of a single-burner design (fewer control loops!) it has the advantage that the gas composition is a much better indicator for process control as it is only dependent on the flows to one burner.

The slag leaving the gasifier is quenched in a water bath beneath the reactor. It is advantageous to use a boiling water bath as the steam may replace process steam and possibly sour water may be fed to the slag bath, which eliminates the need for a sour water stripper.

In order to eliminate the need for a slag lock-hopper system it is possible to apply a continuous slag/water depressurising system, which is lower in both capital and operating cost.

Before entering the syngas cooler the gas has to be quenched from 1500-1600 C to 900 C in order to solidify liquid slag particles, which are entrained in the gas. The quenching can be accomplished in four different ways: water quench, gas quench, cooling in a radiant boiler and applying a so-called chemical quench. The use of a radiant boiler requires the highest capital cost whereas the water quench is lowest in capital cost. Just as with the water slurry feed the water quench results in a lower process efficiency. The gas quench is more efficient but also more expensive than the water quench because it requires in its presently applied form a recycle gas compressor.

The chemical quench is efficiency wise the most attractive option. It comprises the introduction of a fuel into the hot gases leaving the first slagging stage of the gasifier and requires a second non-slagging gasifier stage. The secondary fuel is converted with steam into syngas and enhances the gasifier efficiency as a higher percentage of the combustion energy of the combined fuel to both stages of the gasifier is recovered as combustion energy of the fuel gas.

A problem with introducing a hydrocarbon fuel in the second stage is the formation of tar, which may interfere with downstream processes such as filtering. This problem can be avoided by feeding all fuel to the first slagging stage of the gasifier together with only oxygen. As there is not sufficient gasifying agent to gasify all coal, carbon is formed which together with the gas is flowing to the second stage where the remaining carbon is gasified with steam and optionally some additional oxygen. In this case no tar is formed and an elegant way has been established to have a low capital two-stage gasifier. No complex two-phase burners are required for the second stage as the carbon coming from the first stage is already homogeneously dispersed in the gas. In fact although the gasifier is still slagging the outlet temperature has been reduced by about 500 C from about 1550 C to 1050 C resulting in a lower oxygen consumption and a smaller syngas cooler. The above proposal will only work with dry coal feed gasifiers as with a water slurry feed a surplus of gasifying agent is already introduced in the first slagging stage and it is not possible to let substantial amounts of carbon slip to the second non-slagging stage.

A high capital item in IGCC plants is the syngas cooler. The most drastic way to eliminate these costs is by (further) water quenching the gas to the desired low temperature. Just as with the water slurry feed and the water quench this results in an appreciable reduction in process efficiency but it does reduce capital costs. An elegant way to reduce the size of the syngas cooler is to introduce a second gasifier stage as described above. Such a secondary stage requires less capital than the corresponding additional capacity of the syngas cooler as it consists of a simple empty cylindrical cold wall pressure vessel with internal insulation.

In principle further cooling the gas leaving a two-stage gasifier from about 1000 C to 500 C with nitrogen from the ASU complemented with some water injection can also completely eliminate the need for a syngas cooler: The 500 C gas can be filtered in order to remove solids including alkali metal compounds. The hot gas can then be directly combusted in the gas turbine.

Using nitrogen for cooling instead of only as dilution gas as is now common practice in many demonstration plants has the advantage that no additional recycle gas compressor is required which reduces capital cost. The option is only attractive in case flue gas treating is applied as in the case of fuel gas treating the nitrogen about doubles the amount of gas to be treated and halves the concentrations of the compounds to be removed.

In the case described above the efficiency of the process increases dramatically. However, there is no free lunch as now flue gas scrubbing and possibly NOx removal are required to comply with environmental legislation. In order to limit the amount of flue gas to be treated and to increase the concentration of the components to be removed in most cases flue gas recycle to the gas turbine compressor has to be applied. It could well be though that this solution is less capital intensive than the alternative of fuel gas treating at low temperatures as is currently applied in all demonstration units.

Further flue gas treating has the advantage over fuel gas treating that it is an end pipe treating which does not interfere with the main process.

The main reason why flue gas treating could be more advantageous for reasons of efficiency is that the sensible heat in the fuel gas is also being used in the more efficient CC and not only in the steam cycle as is the case when a syngas cooler is applied. Further the amount of different compounds to be removed is substantially smaller in case of flue gas treating. Carbonyls, HCN, NH3, COS, fluorides, etc. have not to be removed separately and most toxic elements are removed as a purge from the fly slag removed in the filter system. All gas and water treating will be same as required for conventional coal fired power stations equipped with stack gas scrubbing facilities.

All in all the complex chemical plants which are so scary for power station operators will essentially be reduced to what they are now used to in conventional coal fired power stations.

Finally as few words on hot gas treating. In case all contaminants in the fuel gas could be removed at a temperature of 400-500 C there was no need for flue gas treating and still all the advantages of making both the chemical heat and sensible heat available to the CC would be conserved. There is no doubt that this solution would be the most elegant. Whether it would also be the lowest cost option is not so certain. So far the only success in hot gas treating is the removal of solids (and alkali provided the temperature is below 500 C) in candle filters. Expensive but it works. However, apart from particulates and alkali compounds, H2S, COS, NH3, HCN, toxic elements, carbonyls, halogens, etc. have to be removed at the same high temperature and there are no processes available which do all this. Sulphur can e.g. be removed in high capital cost equipment requiring high temperature lock-hoppers in which the solid acceptors used are poisoned by trace elements in the fuel gas and/or disintegrates because of mechanical handling, but a comprehensive and economically viable solution is not available.

Many improvements have been made in the past decades in the Air Separation Unit (ASU). However, all the industrial size units are still based on cryogenic separation and apart from the gas turbine compressor the ASU remains the major parasitic power consumer in an IGCC. Promising developments are taking place in the field of air separation based on membranes and adsorption technologies.. It could well be that these technologies will develop such that they become an attractive alternative for cryogenic units. Membrane technology is especially promising for IGCC because oxygen with a purity of 80% is already acceptable. This is contrary to gasification for syngas production in which high purity oxygen is required.

Simplification in process line-up

All process developers are currently essentially using the same process line-up comprising: coal milling, coal pressurising, gasification, syngas cooling, solids removal, catalytic COS/HCN removal, amine scrubbing, the combined cycle proper and further the ASU and water treating plant. In most processes the pressurised air for the ASU is taken from the gas turbine compressor, steam systems from the gasifier and the HRSG are integrated and nitrogen from the ASU is used as dilution gas for the fuel gas.

The above line-up makes good sense in case a reasonable efficiency is to be obtained. It does also result though in a very high capital cost. The main reasons for these high costs are that:

- All gasifiers currently employed where in the first instance designed for making synthesis gas rather than making fuel gas.
- The gas treating is mainly based on the treating of refinery gases.
- The gas turbines used are built for firing natural gas in a CC mode.
- Another problem with the above line-up is that the IGCC plants are very complex and difficult to operate because of the high degree of integration.

Apart from new coal pressurising systems, gasifiers and relatively small equipment modifications all substantial improvements will depend on whether the change is made from fuel gas treating to flue gas treating. In that case the syngas cooler becomes superfluous, the "chemical treating plant" is eliminated and flue gas treating processes can be applied which ar.e familiar to modem power station operators. Moreover the steam integration between the syngas cooler/gasifier and the HRSG can be eliminated. Last but not least it results in a 3-5 percentage points increase in efficiency which translates into a substantial reduction in capital cost. The major hurdle may be the flue gas recycle that will be required for the gas turbine, which is being dealt with below.

Gas turbine modifications

It was already mentioned above that the gas turbine is the focal point of an IGCC. In fact it is not only the focal point it is also a dominant lord ruling without a constitution. After many difficulties it is now possible to bum medium- and even low Btu gas in most industrial turbines but more modifications are required in order to make these machines an integral part of an economically viable coal fired power station.

The most important modification is not required for the gas turbine per se but for the compressor. In case this could be made to operate under (quasi-) isothermal conditions the parasitic power consumption, which now amounts to about 60% of the gas turbine output, can be reduced to about 40%. This implies that when the sensible heat in the exhaust gases from the gas turbine is used to heat the combustion air leaving the (quasi-)isothermal compressor the gas turbine cycle will increase its efficiency from about 40 to 60%.

In such a scheme a recuperator will replace the HRSG. Because the hot flue gas side mainly dictates the surface area of both heat exchangers, temperatures are about equal and pressures are lower in case of a recuperator, the cost of both pieces of equipment are about equal. However, the whole steam cycle can be eliminated which results in a major cost reduction and reduces the time required for start-up of the unit. It is estimated that whereas the cost of a CC is about 450 US$/kW the cost of a recuperator based system of equal capacity is only 350 US$/kW. The recuperator-based system has also great potential in natural gas fired applications.

An elegant and low cost way to achieve quasi-isothermal compression in a low cost way is to load the air to the compressor with 10-15% weight of water droplets of a size $<5\mu$. These droplets, which are so small that they easily evaporate and follow the gas flow in the compressor dramatically, reduce the outlet temperature of the compressor. For more information on this so-called Tophat cycle see ref. 1 and 2.

To ensure that the Tophat cycle results in the same high efficiency as a CC it is advantageous to condense the water from tile flue gas. The best part of the condensate is then used as water, which is evaporated in the compressor. As for the condensation low temperatures are required the dry, cold and particulate free gas leaving the condenser is very suitable for flue gas recycling.

Conclusions

Marginal equipment modifications and scale-up will probably not be sufficient to make IGCC plants which are now in the demonstration phase competitive with modem conventional coal fired power stations. Combining the best equipment from the various developments can result in a further cost reduction but whether this is sufficient to make IGCC competitive is still uncertain. A simple slagging gasifier complemented with a low cost non-slagging stage is a key item in this respect.

Changing from fuel gas treatment to conventional flue gas treatment could result in a major cost reduction of IGCC plants. In this way both the syngas cooler and the "chemical plant" become superfluous. This would require flue gas recycle over the gas turbine in order to make it competitive.

There can be little doubt that gasification based power stations can be made very competitive. Rethinking of the process line-up and major modifications of gas turbine compressor principles will be required to obtain this goal.

A major break-through would imply the change to a recuperative gas turbine preferably based on the Tophat concept. This would eliminate the steam cycle and would result in major (additional) cost reductions.

References

1. van der Burgt, MJ. and van Liere, 1. "Tophat and REX turbines", 13th EPRI Conference on Gasification Power Plants, San Francisco, 1994.
2. van der Burgt, MJ and van Liere, J. "Applications of the Tophat cycle in power generation", EPRI Gasification Technologies Conference, San Francisco, 1996.