A pilot platform for the coal-to-hydrogen generation (COHYGEN) R&D project

Enrico Maggio*, Carlo Amorino, Marcella Fadda,
Francesca Ferrara, Alessandro Orsini, Alberto Pettinau

Sotacarbo S.p.A. – c/o Grande Miniera di Serbariu – 09013 Carbonia, ITALY
*Corresponding author: e.maggio@sotacarbo.it

Abstract

The possibility to have a large scale hydrogen production from coal through "zero emissions" power generation plants is being more and more interesting for its implications from the economic and environmental points of view. However, the application of these technologies is subject to the high capital and operative costs. This need a great scientific and technical effort in order to optimize the processes and the equipments, thus reducing the hydrogen production cost.

In this field, Sotacarbo, together with Ansaldo Ricerche, ENEA (the Italian National Agency for New Technologies, Energy and Environment) and the University of Cagliari (Department of Mechanical Engineering) carried out the COHYGEN (Coal-to-hydrogen generation) research and development project, ended in February 2009 and characterized by a global cost of about 11 M€, partially funded by the Italian Ministry of Education, University and Research.

In order to develop and optimize an integrated process for a combined production of hydrogen and electrical energy through coal gasification, a pilot platform has been built up at the Sotacarbo Research Centre in Carbonia, Italy. The platform includes two different units: a 5 MW_{th} pilot plant (with the main goal to optimize the gasification process) and a 200 kW_{th} laboratory scale plant (designed to develop and optimize the syngas treatment line for hydrogen production and power generation, with CO_2 separation).

This paper reports a detailed description of the whole experimental equipment, together with an analysis of the first experimental results obtained for every plant section. These results allowed to obtain useful indications to improve the plant performances and to optimize each syngas treatment and hydrogen production process.

Keywords: *coal gasification, coal-to-hydrogen, carbon capture, experimental plant*

1 Introduction

Nowadays, coal is characterized by a wide availability in the world and a uniform distribution with respect to other fossil fuels. This involves a relatively stable price and represents a secure source from a strategic point of view [1]. Moreover, the need to an environmental friendly use of coal, in particular for power generation, involves an increasing interest on the development of clean coal technologies, designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use [2].

Among clean coal technologies, gasification is particularly interesting since it allows both power generation (mainly by using integrated gasification combined cycles power plants, IGCC) and clean fuels production, such as methanol, dymethylether (DME), Fisher-Tropsh

liquids and, in particular, hydrogen, which promises to be the most important energy carrier [3-5].
All over the world, gasification processes, due to the low flexibility of synthesis gas (syngas) production, are, so far, mainly used in large scale IGCC power plants in order to supply base energy load. But in a short term future, the possibility to use syngas to co-produce hydrogen and electrical energy [6-7] could make gasification technologies very interesting for medium and small scale industrial application.
In this aim, Sotacarbo, together with Ansaldo Ricerche S.p.A., ENEA (the Italian National Agency for New Technologies, Energy and Environment) and the University of Cagliari (Department of Mechanical Engineering) carried out a R&D project with the aim to develop an integrated process for a combined hydrogen and electrical energy production. The project, called COHYGEN (coal-to-hydrogen generation) has been funded by the Italian Ministry of Education, University and Research.
The developed process regards an integrated gasification and syngas treatment system for combined production of hydrogen and electrical energy, to be used in medium and small scale commercial plants. To this goal, a flexible and fully equipped pilot platform has been recently built up at the Sotacarbo Research Centre in Carbonia, in South-West Sardinia (Italy). The platform includes a pilot (700 kg/h) and a laboratory scale (35 kg/h) coal gasifiers; in particular, the latter is equipped with a syngas treatment process for a combined hydrogen and electrical energy production.
This paper reports a detailed description of the platform and the main experimental results for each plant section. A more detailed analysis of the results obtained in the gasification section and a global plant balance has been presented in an other work [8].

2 Overview of the experimental equipments

The pilot platform has been designed considering a very flexible layout, in order to allow experimental tests with different plant solutions and different operating conditions.
Currently, the layout of the Sotacarbo pilot platform (figure 1) includes two fixed-bed up-draft and air-blown Wellman-Galusha gasifiers: a 700 kg/h (corresponding to about 5 MW_{th}) pilot gasifier and a 35 kg/h (200 kW_{th}) laboratory scale gasifier. The choice of this kind of gasification process is a consequence of the particular commercial interest in the field of medium and small scale industrial applications.
Whereas the main goal of the experimental tests on the pilot plant is the optimization of the gasification process and the definition of start-up and shut-down procedures, the laboratory scale plant is used to develop the syngas treatment process for a

Fig. 1. The Sotacarbo pilot platform.

combined power generation and hydrogen production. Therefore, while the pilot plant is only equipped with a wet scrubber (for syngas cooling and tar and dust removal) and the cold syngas is directly sent to a flare, the laboratory scale plant is equipped with a complete and flexible syngas treatment process. In particular, downwards a common system for dust and tar removal, the laboratory scale plant includes two different syngas treatment lines: a power generation line, equipped with a cold gas desulphurization system and an internal combustion engine, and a hydrogen production line, equipped with a hot gas desulphurization process, an integrated CO-shift and CO_2 absorption system and a hydrogen purification section.

Table 1. Sulcis and South African coal ultimate analysis.

	LSC: S.A. coal	HSC: Sulcis coal
Carbon	68.54	53.17
Hydrogen	3.71	3.89
Nitrogen	1.50	1.29
Sulphur	0.55	5.98
Oxygen	5.35	6.75
Chlorine	0.05	0.10
Moisture	8.00	11.51
Ash	15.00	17.31
LHV (MJ/kg)	24.79	20.83

In the first phase of the experimental tests, only coal has been gasified. In particular, a low sulphur South African coal (LSC) has been used in both plants; moreover, being the laboratory scale plant equipped with a highly efficient desulphurization systems, even a high sulphur coal (HSC), from the Sulcis coal basin in South-West Sardinia, has been used. The ultimate analysis of both these coals is shown in table 1.

3 Pilot plant

For the feed of the gasifier, coal (characterized by a granulometry between 5 and 50 mm) is bought in big bags for the experimental tests; every bag, containing about 1 ton of coal, is drown out from the storage area through a heaver and, through a tackle, charged in a particular hopper in order to empty the bag itself. Then, coal is drown out from this hopper and sent to the gasifier through a valve system [9].

The 700 kg/h pilot gasifier (figure 2) is characterized by different operating zones, where the coal drying, devolatilization, pyrolisis, gasification and combustion processes take place [10-11]. As the coal flows downwards, it is heated by the hot raw gas that moves upwards, coming from the gasification and combustion zones [12-13]. The gasification agents (air and steam) are introduced into the reactor near the bottom, so that they are pre-heated by cooling the bottom ash, which are removed through the coal grate [14].

Fig. 2. The pilot gasifier during plant construction.

In order to distribute the fuel as uniformly as possible and optimize the gasification process, coal is sent to the gasifier through four different injection points; moreover, the reactor is equipped with an internally cooled stirrer (in order to keep a low metal temperature), which is characterized by two degrees of freedom: an axial rotation and a

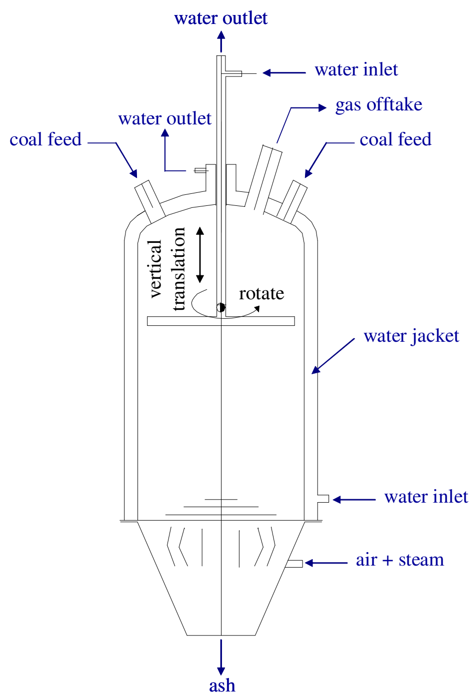

Fig. 3. Simplified scheme of pilot gasifier [14].

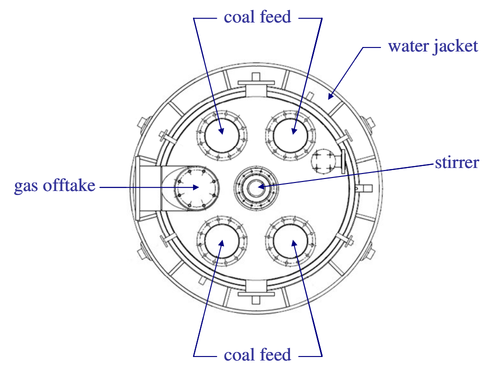

Fig. 4. Coal feed section at the top of the reactor [14].

vertical translation (figure 3 and 4). Furthermore, the gasifier is equipped with a cooling water jacket, in order to operate an accurate temperature control [14].

The start-up of the gasifier is carried out by using a series of ceramic lamps which heat the fuel (initially wood pellets) in a inert atmosphere. When the temperature reaches about 800-850 °C, air is injected in the reactor and the fuel combustion take place. Finally, steam is injected into the reactor (together with the reduction of air injection) and coal can be feed as gasification fuel [9].

The gasifier is equipped by a series of 36 thermocouples (6 sensors, disposed around the circular section of the reactor, in 6 different height levels) in order to have a detailed temperature profile into the reactor.

The pilot plant does not include a syngas desulphurization section (the raw syngas is only sent to a wet scrubber, for tar and dust removal, and then is directly burned in a flare); therefore, pilot gasifier is fed only with coals characterized by a sulphur content lower than 0.5-0.6 % (in weight).

The experimental tests on the pilot plant was under development when this work has been prepared; therefore, the results has been not included in this paper. In any case, a global syngas production of about 2500 Nm^3/h can be estimated, with a gasifier yield of 3.45 Nm^3 of syngas per kilogram of gasified coal; the expected syngas lower heating value is 6.5 MJ/kg, which corresponds to a cold gas efficiency of 93-94%. Finally, the expected H_2 concentration in raw syngas is about 21% [9].

4 Laboratory scale plant

In the Sotacarbo laboratory scale plant (which simplified scheme is shown in figure 5), the raw syngas from the gasification process is sent to a skid which includes a wet scrubber (which reduce syngas temperature from about 300 °C to 50 °C and operates a primary dust and tar separation), a first cold gas desulphurization stage (which currently uses a soda-based solvent) and an electrostatic precipitator (ESP), which allows to achieve a fine particulate and tar removal.

According to the design conditions, downstream the ESP, the syngas is split into two streams: the main stream, about 80% of the produced syngas, is sent to the power generation line,

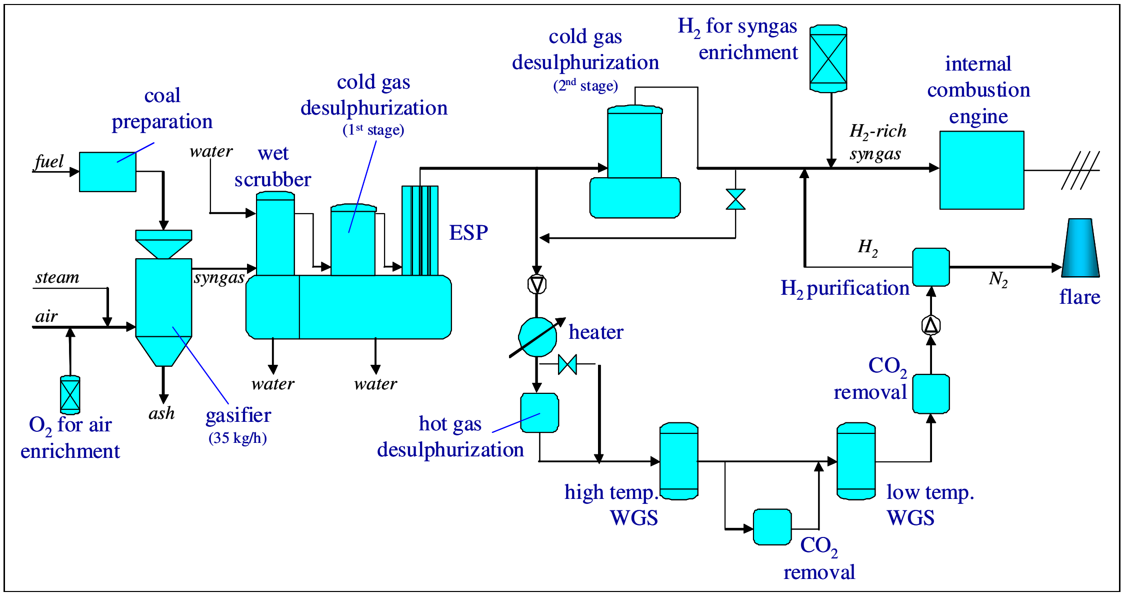

Fig. 5. Laboratory scale plant simplified scheme.

whereas the secondary stream, that is the remaining 20% of the produced syngas, is sent to the hydrogen production line.

In particular, the power generation line is constituted by the second cold gas desulphurization stage, based on a hydrogen sulphide (H_2S) absorption process (which uses a mixture of soda and sodium hypochlorite, diluted in water, as solvent), directly followed by a syngas-feed internal combustion engine.

On the other hand, in the hydrogen production line syngas is pressurized up to about 1.4 bar (in order to win the pressure drops of the treatment line), electrically heated and sent to a two-stages dry hot gas desulphurization process (which employs metal oxide-based sorbents) followed by an integrated CO-shift and CO_2 absorption system; finally, a hydrogen purification system, based on the PSA (pressure swing adsorption) technology, allows a hydrogen purification.

The size of the secondary syngas treatment line, even if much smaller than the size of commercial scale plants, should give reliable experimental data for the scale-up of the future plants [15].

The laboratory scale gasifier is designed to operate with enriched air (simply by using an oxygen bottle) and to allow the co-gasification of coal, wastes and biomass (such as olive bagasse, refuse derived fuel and tyres). Moreover, the possibility to test the internal combustion engine with hydrogen enriched fuels has been considered. In this case, the hydrogen produced by the hot gas treatment line can be mixed with the clean syngas from the cold gas desulphurization process (second stage); otherwise, it is possible to operate the hydrogen enrichment simply by using a hydrogen bottle located upstream the engine.

In order to ensure a full plant flexibility, as well as to simplify the management of the experimental plant, the different cooling and heating devices are not fully integrated. However, the aforementioned layout, if necessary, can be easily modified without significant costs [15].

In order to support the experimental tests, the plant is equipped with a sampling system which allows the monitoring of the process performances, with particular reference to syngas composition. In particular, for the syngas analysis, the plant is equipped with a system for the real-time measurement of oxygen concentration in raw syngas; this measure plays a double role of safety control, in order to avoid the formation of explosive atmosphere (in particular through the electrostatic precipitator), and performance indicator for the gasification process. Moreover, upstream and downstream each plant component, a sampling outlet has been situated in order to operate the syngas analysis through a micro gas chromatograph. This system can be contemporary collected with different sampling points and allows to evaluate the concentration of the main chemical compounds (CO_2, H_2, O_2, CO, CH_4, N_2, H_2S, COS, C_2H_6, C_3H_8) in the selected stream. Even if this system doesn't allow a real-time monitoring of syngas composition, it gives a detailed measure of the concentration of each chemical species every 3 minutes about, which represents a time range negligible with respect to the plant dynamics [16].

5 Experimental tests in the laboratory scale plant

The laboratory scale gasifier has been tested for about 200 hours between June and December 2008. During this first phase of experimental tests carried out for the COHYGEN project, a large amount of data has been collected, in order to evaluate the performances of each section and of the whole plant.

Gasification section

Due to its dimension, the laboratory scale gasifier (figure 6) is slightly different from the pilot unit. In particular, it is not cooled through a water jacket, while its walls are covered with a refractory material; moreover, coal is charged through a single inlet point and the reactor doesn't equipped with the intercooled stirrer. Temperature profile into the reactor can be determined through a series of 11 thermocouples located near the reactor axis.

The fuel feeding system is identical with respect to the pilot gasifier. As for the plant start-up, a series of ceramic lamps allows the heat of the reactor, initially feed with wood pellets and subsequently charged with coke. Only when the gasification reactions are running, coal (with a granulometry between 5 and 50 mm) is fed to the reactor.

As already mentioned, the laboratory scale gasifier has been tested with two different kinds of coal: a low sulphur South African coal (LSC) and a high sulphur coal (HSC) from the Sulcis coal mine.

Table 2 shows the main results of the gasification tests in three different operative conditions: 100% of low sulphur South African coal, 100% of high sulphur Sulcis coal and a mixture (at 50%, in terms of energy contribution) of both low and high sulphur coals.

The experimental tests, which results are synthesized in table 2, have been developed with different load of the gasifier. Therefore, in order to compare the results, all the data have been conventionally reported to the full-load (35 kg/h). For each case, the reported data are medium values calculated during plant steady-state phases of about one hour.

Fig. 6. Laboratory scale gasifier.

Table 2. Main results of the gasification tests.

	LSC	LSC + HSC	HSC
Input data			
Coal feed (kg/h)	35.00	35.00	35.00
Air flow (kg/h)	49.00	49.00	44.35
Steam flow (kg/h)	36.00	37.30	21.00
Air/coal mass ratio	1.40	1.40	1.27
Steam/coal mass ratio	1.03	1.07	0.60
Dry syngas composition (molar fraction)			
CO	0.2241	0.2162	0.1816
CO_2	0.1120	0.1103	0.1316
H_2	0.3721	0.3698	0.3663
N_2	0.2675	0.2815	0.2823
CH_4	0.0201	0.0121	0.0210
H_2S	0.0010	0.0064	0.0126
COS	0.0001	0.0004	0.0013
Ar	0.0031	0.0033	0.0033
Gasifier performances			
Syngas flow (kg/h)	112.88	113.86	92.59
Syngas flow (Nm^3/h)	128.57	129.38	102.04
Syngas LHV (MJ/kg)	7.50	6.65	7.27
Gas outlet temp. (°C)	300	350	270
Maximum temp. (°C)	875	890	850
Cold gas efficiency	97.57%	94.84%	92.33%
Gasifier yield (Nm^3/kg)	3.67	3.70	2.91

For the three gasification conditions, is it possible to notice a syngas flow between 110 and 130 Nm^3/h. Moreover, the high hydrogen and CO_2 concentrations and the relatively low CO content are consequence of the low temperatures into the reactor (typical of the fixed-bed air-blown gasifiers), which increases the effect of the CO-shift reaction [16]. A little amount of the sulphur contained in the primary fuel (in particular for Sulcis coal) is detained by the bottom ash. Finally, the cold gas efficiency has been calculated as a ratio between the chemical power associated with raw syngas and those associated with coal (the other power contributions such as those associated with air and steam injection are not considered in this parameter); therefore, the value of this efficiency is a direct consequence of coal lower heating value and syngas composition. The latter is strongly influenced by the gasification parameters, such as the temperature profile into the reactor, the air/coal and steam/coal mass ratios and the percentage of carbon which remains unreacted (typically between 2 and 5%). This justify the significant variation of the cold gas efficiency in the three considered cases.

A more detailed description of the gasification experimental results, with an evaluation of the effects of the main operating parameters, has been reported in an other work [8].

Dust and tar removal system

As reported above, the raw syngas from the gasifier is sent to a skid (figure 7) in which syngas is washed for the tar and dust removal and, based on the H_2S concentration, is partially desulphurized with a soda-based solvent (with an efficiency up to 99.9%). The system operates with a pH of about 10-11; higher pH values involve a significant CO_2 absorption.

This system is not experimental (even if the integrated and compact configuration is innovative) and only allows to preserve the following equipments by possible damages due to dust and tar content and to the high concentration of sulphur compounds.

Fig. 7. Dust and tar removal system (during the construction phase).

Cold gas desulphurization

The cold gas desulphurization system (figure 8) has been designed to reduce hydrogen sulphide concentration below the maximum values allowed by the CO-shift process. As a matter of fact, the catalysts commonly used for high and low temperature CO-shift reactors can be poisoned by H_2S concentration above about 50-100 ppm (in any case, when clean syngas is burned, these values involve an SO_2

emission significantly lower than the corresponding emission standards).

The desulphurization system is based on a conventional chemical-physical hydrogen sulphide absorption process carried out by a mixture of sodium hydroxide (NaOH, 40% in volume) and sodium hypochlorite (NaOCl, 13% in volume), diluted in water, according with the following reactions:

$$2\ NaOH + H_2S = Na_2S + 2\ H_2O$$
$$Na_2S + 4\ NaOCl = Na_2SO_4 + 4\ NaCl$$

The liquid solvent is continuously recycled to the absorber and an authomatic control system regulates the acidity of the solvent solution in order to maintain the pH at about 12. In this way, a final H_2S concentration lower than 10 ppm has been measured during the experimental campaigns, with a global efficiency up to 98%.


Fig. 8. Cold gas desulphurization system.

The choice of this kind of solvent, which is not regenerable, is due to the experimental nature of the plant. In any case, the cold gas desulphurization system has been designed in order to allow some experimental tests with other regenerable solvents, such as methyl-diethanolamine (MDEA), which is highly selective for hydrogen sulphide [17].

Internal combustion engine

The laboratory scale plant is equipped with a commercial 25 kW internal combustion engine for power generation. Due to a series of technical problems, this system has been only used in four plant runs and it has never been used with its nominal load; in particular, during different experimental tests, about 50 Nm^3/h of syngas highly diluted in nitrogen (with N_2 and H_2 concentration of about 50 and 20%, respectively, and a lower heating value of about 3.5 MJ/kg) have been sent to the engine. In these conditions, with an electrical load of 12 kW, an electrical efficiency of about 25-26% has been measured, with respect with the nominal efficiency of about 35%.

Hot gas desulphurization

A portion (about 25 Nm^3/h) of syngas from the dust and tar removal system is compressed to 1.4 bar, heated to about 400 °C and sent to the hot gas desulphurization system (figure 9).

Being the metal oxides used for hot gas desulphurization highly selective for hydrogen sulphide but not for COS, the system is equipped with a catalytic reactor which converts COS into H_2S, according with the following reaction:

$$COS + H_2 = H_2S + CO$$

This hydrogenation reactor is followed by two adsorption reactors (in lead-leg configuration)


Fig. 9. Hot gas desulphurization system.

in which H_2S is captured through a zinc oxide-based sorbent, according with the following reaction [18-19]:

$$ZnO + H_2S = ZnS + H_2O$$

The plant has been designed in order to have a final H_2S concentration lower than 10 ppm for 80 hours, considering syngas from Sulcis high sulphur coal. In any case, during the experimental tests, a final H_2S concentration of 1 ppm about has been measured.

Integrated CO-shift and CO_2 adsorption

In order to enrich syngas in hydrogen, the plant is equipped with an integrated CO-shift and CO_2 absorption process. In particular, desulphurized syngas is mixed with steam and sent to the high temperature CO-shift stage (which operates at about 400 °C). A portion of the reacted gas (about 50%, according with the design conditions) is cooled and sent to the first CO_2 absorption stage and subsequently sent to the low temperature CO-shift reactor (operating at about 250 °C), together with the remaining 50% of the reacted gas. Downwards the second CO-shift stage, all reacted syngas is sent to the final CO_2 absorption reactor. This integrated configuration allows to maximize the carbon monoxide conversion with a relatively low steam consumption.

The high and low temperature CO-shift reactors are filled with two different non piroforic platinum-based catalysts. During the experimental tests with low sulphur coal, they operated with a steam/CO molar ratio of about 1.7 (5.0 kg/h of steam) and 11.4 (1.5 kg/h of steam), respectively; in these operative conditions, a CO conversions very closed to those corresponding to the chemical equilibrium (higher than 90% in the first stage and about 85% in the second stage, with a final CO content lower than 3%) has been obtained [16].

On the other hand, the carbon dioxide capture takes place in two identical bubbling reactors (figure 10), operating at 30 °C by using a 30% monoethanolamine (MEA) solution (diluted in water) as solvent, according with the following reaction [20-21]:

$$CO_2 + 2\ HOCH_2CH_2NH_2 = HOCH_2CH_2NH_3^+ + HOCH_2CH_2NHCOO^-$$

This reaction takes place in two steps:

$$CO_2 + HOCH_2CH_2NH_2 = HOCH_2CH_2NHCOO^- + H^+$$
$$H^+ + HOCH_2CH_2NH_2 = HOCH_2CH_2NH_3^+$$

These reactions are highly influenced by absorption temperature and pressure and by pH value in the solvent solution (which depends by the amine concentration).

The bubbling reactors are characterized by an innovative configuration, developed by Ansaldo Ricerche. In particular, two membranes for gas diffusion in the liquid phase (in order to maximize the liquid-gas contact surface) and for the complete liquid-gas separation downwards the absorption process have been used [14].

Fig. 10. CO_2 capture bubbling reactors.

Hydrogen purification

In order to assess the capabilities to produce hydrogen for fuelling an advanced power generation system as micro gas turbine or fuel cell for distributed power generation [22-24], the experimental plant has been equipped with an hydrogen purification system, based on a PSA (pressure swing adsorption) process. While all the hot gas treatment line operates at about atmospheric pressure, the hydrogen adsorption process operates at about 3 bar by using zeolites as sorbent.

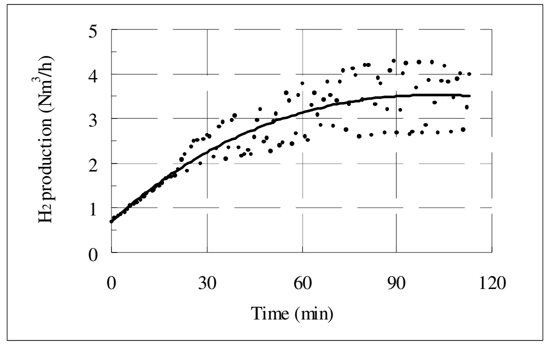

Fig. 11. Behavior of hydrogen production in the PSA.

Figure 11 shows the behaviour of the hydrogen production (in Nm^3/h) through PSA during a two-hours experimental test. This curve shows two different phases of the PSA operation: a first phase (50-60 minutes) in which the system reached the steady state (the increasing of the hydrogen production is a consequence of a linear rising of the syngas mass flow) and a second phase in which the hydrogen production is near constant [16].

The purity of the produced hydrogen has been measured of about 97%. This value is relatively low with respect to the modern PSA systems, which can reach 99.999%, because in the experimental plant there is no need to have a high purity level (hydrogen is used to enrich the syngas sent to the internal combustion engine).

6 Main results and future developments

Globally, the COHYGEN research and development project allowed to demonstrate the possibility to integrate conventional processes in a non conventional configuration. Moreover, some equipments have been optimized, with the result of significant performance improvements.

In particular, the conventional Wellman-Galusha gasification technologies has been improved by using an innovative start-up system, based on ceramic lamps for the heating of fuel bed. The start-up and shut-down procedures have been set up in the laboratory scale reactor and are currently under optimization in the pilot gasifier.

The syngas cleaning system allowed to obtain a fine depulverization and desulphurization, even when high sulphur Sulcis coal has been used for the experimental tests. In particular, the cold gas desulphurization technology allowed to obtain a final H_2S concentration lower than 10 ppm, compatible with the use of clean syngas to feed an internal combustion engine. On the other hand, the hot gas desulphurization system (based on zinc oxides as sorbent) allows to obtain an H_2S concentration lower than 10 ppm (and, in many cases, lower than 1 ppm) in the clean syngas. These concentrations are compatible with some technologies for distributed power generation, like internal combustion engine, micro gas turbines and different kinds of fuel cells.

Finally, produced hydrogen has been characterized by a low purity only due to the kind of PSA system. But hydrogen-rich stream is characterized by a unsignificant pollutants content and a very low carbon monoxide concentration, due to the efficiency of the integrated CO-shift and CO_2 absorption system. For the same reason, the carbon dioxide emissions can be strongly reduced (a separation efficiency up to 85-90% has been obtained without solvent recirculation) through the capture plant, which currently doesn't include a solvent regeneration system; with reference to an industrial application of the technology, a capture system equipped with a solvent regeneration section and a carbon sequestration plant will

allow to separate and store more than 90% of the global carbon content, with some economical advantages related with the International Emissions Trading.
The studies and experimentations on the Sotacarbo pilot platform, carried out for the COHYGEN project represent only the first phase of a large series of experimental campaigns which has been planned in order to optimize the gasification process and the syngas treatment line.
The experimental tests on the pilot gasifier will allow to evaluate the gasification performances with different operating conditions and to define and optimize the start-up and shut-down procedures. Moreover, the possibility to integrate the pilot gasifier with a syngas desulphurization system is currently under evaluation, in order to allow gasification tests with different primary fuels such as high sulphur Sulcis coal.
Due to its flexibility, the laboratory scale plant will be tested in different operating conditions. First of all, some experimental tests will be carry out in order to evaluate the performances of the gasifier with air enrichment in oxygen. As a matter of fact, a rising of the oxygen purity in the gasification agent involves a reduction of syngas dilution with nitrogen and, as a consequence, a decreasing of the syngas flow, with a contemporary rising of its lower heating value. In this case, with reference to the industrial application of the technology, the syngas treatment line can be designed for a lower syngas flow, with a subsequently reduction of the capital and operating costs. Moreover, the possibility to operate the gasification with mixtures of oxygen and CO_2 as a gasification agent will be tested. According with the preliminary theoretical analysis, both this conditions will allow an increasing of the syngas quality, with a significant reduction of nitrogen content.
The possibility to operate a co-gasification of coal with biomass or wastes [25-26] (for example pelletized refuse derived fuels) will be also investigated.
Finally, as for the syngas treatment line, the possibility to test different sorbents and catalysts (in particular for the hot gas desulphurization and for the CO-shift process) will be soon investigated, together with the use of produced hydrogen to feed advanced power generation systems like fuel cell and micro gas turbines [23-24].

7 Conclusions

The experimental tests carried out in the Sotacarbo coal-to-hydrogen pilot platform during the COHYGEN project (ended in February 2009) allowed both to obtain some data and to evaluate the performances of the gasification processes and of each syngas treatment section.
The experimental tests on the pilot plant was under development when this work has been prepared; therefore, the results has been not included in this paper. A preliminary evaluation allows to estimate a syngas production of about 2500 Nm^3/h, with a lower heating value of about 6.5 MJ/kg.
As for the laboratory scale gasifier, about 200 operating hours allow to collect some experimental data and to evaluate the performances of the gasifier. In particular, a yield between 3.0 and 3.7 Nm^3/kg has been measured, depending on the operating parameters, while hydrogen concentration in raw syngas varies, in general, between 30 and 40% (about 37% in the reference conditions).
The syngas treatment lines are based on conventional processes (wet scrubber, electrostatic precipitator, cold and hot gas desulphurization, CO-shift, CO_2 absorption and PSA), integrated in a non conventional configuration. The integration between the different equipments is the main goal of the experimentation in the laboratory scale plant. The process allow the production of an hydrogen stream with a purity of about 97%, suitable for the use in the internal combustion engine. In particular, during the experimental tests, an hydrogen flow

about 1.3-1.6 kg/h (depending on the plant feed and to the operative condition) have been produced. With reference to 7 kg/h of gasified coal (20% of the nominal load, being the hydrogen production line fed with about 20% of produced syngas), for every kW entering into the gasifier, a production of about 0.75 kW of hydrogen has been obtained.
It is important to notice that in this study has not developed a global energy balance of the plant. As a matter of facts, the plant layout, being experimental, has been studied to have a strongly flexible configuration, and has not been optimized from the energetic efficiency point of view. For the same reason, the hydrogen production has not been optimized.

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