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Operation Experiences of Oxyfuel Power Plant in Callide Oxyfuel Project

Akihiro Komaki[a], Takahiro Gotou[a], Terutoshi Uchida[a], Toshihiko Yamada[a], Takashi Kiga[a] and Chris Spero[b]*

[a]*R&D Department, Energy & Plant Operations, IHI Corporation*
[b]*CS Energy Ltd. / Callide Oxyfuel Services Pty Ltd.*

Abstract

Callide Oxyfuel Project is the only demonstration project for oxyfuel power plant in the world and has been promoted at Callide-A power station in Queensland, Australia. Callide-A power plant, which is a retrofit of an existing power plant with a capacity of 30MWe, is now the largest operating oxyfuel power plant all over the world. Two air separation units (ASU) of 330 TPD and CO_2 compression and purification unit (CPU) of 75 TPD that is about 10% capacity of total flue gas were newly installed. And the existing 30MWe boiler was modified to apply both air and oxufuel combustion. This demonstration is the key and important step for the large-scale oxyfuel power plant in the future and the various tests regarding the oxyfuel boiler and CPU have been performed. Main objectives of this project are to demonstrate the oxyfuel operation with CO_2 capture and storage using the existing power plant and to obtain the design data and operation know-how for the commercialization.

Callide-A oxyfuel boiler with power generation and CO_2 purification unit from oxyfuel flue gas have been demonstrated and have given us the various operation results with some test parameters in the Project. Regarding the oxyfuel boiler, the heat absorbed rate, combustion characteristics, trace elements behaviour and plant operation flexibility have been confirmed at the different coal type and the different boiler inlet O_2 concentration with the various power generation output through the commissioning and demonstration stage.

In this paper, the operational experiences of the oxyfuel power plant in Callide Oxyfuel Project are introduced.

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Keywords: Oxyfuel; Coal; CO_2 capture; CCS; CCUS; Power plant

* Corresponding author. Tel.: +81-3-6204-7506; fax: +81-3-6204-8790.
E-mail address: toshihiko_yamada@ihi.co.jp

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1. Introduction

Interest in global warming is still increasing, and the world is focusing on countermeasures, due to soaring atmospheric CO_2 concentrations accelerating global warming. “Energy Technology Perspectives 2014”(IEA) [1] describe “Continued increase in coal use counteracts emissions reduction from recent progress in the deployment of renewables, underlining the need to improve coal plant efficiency and scale up carbon capture and storage(CCS).” This means that CCS plant itself using coal is very important and is now required to scale up in the near future.

Recently, many CO_2 capturing processes from coal-fired power plants have been under development, such as, post-combustion capture, pre-combustion capture, and chemical looping combustion. Oxyfiring is also a potential candidate for capturing CO_2 from coal-fired power plants.

Oxyfuel technology has been developed within IHI since 1989 [2], and a feasibility study on the demonstration project between Australia and Japan was started in 2004, followed by the Callide Oxyfuel Project which was commenced in 2008.

In this paper, the operation experiences of oxyfuel power plant in Callide Oxyfuel Project and the feasibility study results of future oxyfuel power plant as one of the solution for matching with the regulation of CO_2 emission are introduced.

2. Outline of oxyfuel power plant

Fig.1 shows the overall process of oxyfuel power plant. In oxyfiring, O_2 is separated from the air by ASU (Air Separation Unit) and supplied to the boiler for coal combustion. Accordingly, the flue gas mainly comprises of CO_2 and H_2O, and will theoretically enhance the CO_2 concentration in flue gas up to more than 90 dry%. The method for capturing almost pure CO_2 involves removing H_2O and non-condensable gases from the oxyfuel flue gas via a CO_2 processing unit (CPU).

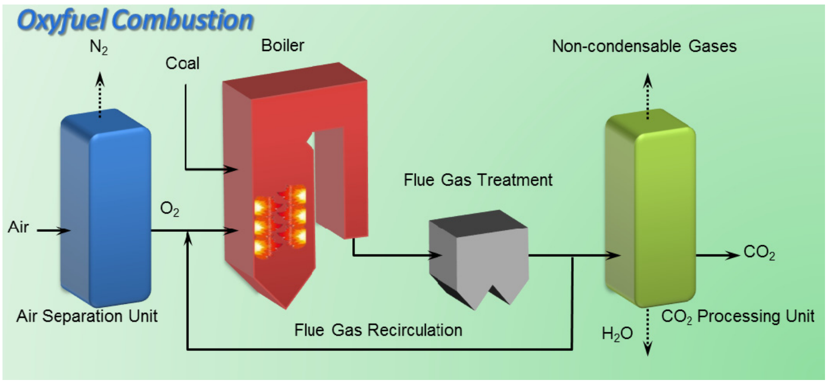

Fig.1 Concept of the oxyfiring system

When applying oxyfiring technology to power generation, in order to use conventional technology for airfiring, the flue gas from the boiler is recirculated and mixed with O_2.

The characteristics of oxyfiring technology are as follows:

- The system can be applied, to existing as well as new construction boiler plants.
- Because N_2 is removed before combustion, highly-concentrated CO_2 can be captured easily from flue gas. Moreover, removed N_2 can be utilized.
- Enriched O_2 is expected to improve combustion efficiency.
- Because the amount of flue gas is decreased (by approximately one-fifth), the efficiency of oxyfuel boiler is far higher than that of an airfired boiler under the same conditions.
- NOx emissions are reduced because recirculation gas is supplied to a furnace and the NOx in the recirculation gas is decomposed. Moreover, NOx can be removed at the CPU.
- Desulfurization equipment can be downsized due to the reduced amount of flue gas.
- The system can be applied, to existing as well as new boiler plants.

The oxyfiring system plays a significant role as an optional technology for capturing CO_2 from coal-fired power plants. This technology is focused by many countries and they have conducted research and demonstration development [3] [4].

Recently, using oxyfiring systems, large-scale demonstration projects applied to more than 250MW power plants with CO_2 capturing ability exceeding 1Mt/yr., are proceeding [4]. They are expected to start operation between 2015 and 2020.

3. Callide Oxyfuel Project

At this moment, Callide Oxyfuel Project in central Queensland, Australia, is the only operating project in oxyfiring and the first and only commercial oxyfiring power plant in the world. This was achieved with funding from the Australian and Japanese governments, and the Queensland state Government, and follows research results from 1989 in Japan [2][5].

3.1. Project Summary

This project is composed of three stages. In stage 1, an existing boiler was modified to oxyfuel boiler, while the ASU and CPU were newly installed. In stage 2, the CO_2 captured by oxyfiring system will be transported by truck and injected underground. In stage 3, the project outcomes will be summarized including the data acquired through the operation. As of the end of August 2014, the cumulative oxyfuel operating of over 7,700 hours and the cumulative CPU operating of over 3,900 hours were achieved. Our target of operation hours are 10,000 hours and 4,000 hours for each.

3.2. Oxyfiring Process in Callide-A

Callide A power station has four 30MWe unit and unit No.4 was modified to oxyfuel one. Fig.2 shows the oxyfiring process applied to the existing process, while Table 1 shows the specification of the boiler. The oxyfiring process is characterized as follows:

- Coal is fed to mill and recirculation gas is used for drying and transporting the coal.
- Three (3) mills and six (6) burners are installed. Namely, each mill has two (2) burners, two (2) mills (four (4) burners) are in service in normal operation. The boiler performances can be confirmed by using different burner patterns.
- The feed-water system is integrated with a flue gas system for heat recovery, which facilitates efficient plant operation in oxyfiring.
- A dehydration system is installed in the primary line to prevent low-temperature corrosion of the mill outlet. It is also possible to operate oxyfuel plants by increasing mill outlet temperature without a dehydration system.
- Air is introduced by the FDF in airfiring. Conversely, gas is recirculated by the same FDF in oxyfiring.
- O_2 from the ASU is mainly mixed with recirculation flue gas. O_2 can also be directly injected into the flame via O_2 lances.
- A part of the flue gas is introduced to the CPU process and purified, compressed

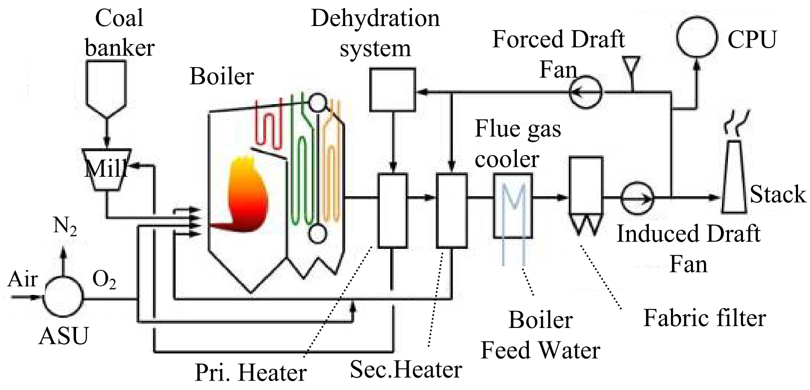

Fig.2 Oxyfiring process in the Callide A boiler

Table 1 Major specifications of the Callide A boiler

Item	Description
Name	Callide-A power station unit No.4 (30MWe)
Coal	Callide coal
Boiler type	2 drum type without re-heater
Main Steam condition	Flow rate:136 ton/h Pressure:4.1 MPa Temperature:460 degC
Combustion Device and other facility	Mill:3 units Burner arrangement: Wall (front) firing Burner type: Original 4 units, IHI-DF burners 2 units (Total 6 units) Incidental facility: Direct O_2 nozzle
Draft system	Balance draft with 1 forced draft fan and 1 induced draft fan

and cooled to capture almost pure CO_2.

3.3. Operation experiences of the oxyfuel boiler

Oxyfiring was started since March 2012 when O_2 was supplied to the boiler and the various basic characteristics of the oxyfuel boiler have been confirmed.

The oxyfiring operation starts after the combustion mode transition from airfiring is completed. Testing has been completed to confirm the characteristics of the various loads and boiler inlet O_2 concentrations and also matters including the influence of the variation in mill patterns to date. The test results achieved from the demonstration operation of the oxyfuel boiler are described as follows.

- When airfiring is compared to oxyfiring, the amount of flue gas out of the boiler process is decreased by around a quarter under oxyfiring. From the result of operation. Heat absorbed in furnace at oxyfiring with 30MWe and the boiler inlet-O2 of 27% is 2 to 3 MW lower than that at airifiring of 30MWe, because heat of flue gas in flue gas cooler is recovered by boiler feed water and this result suggest that plant efficiency in oxyfiring is enhanced. And then, the rate of heat absorbed of the furnace is almost same with airfiring.
- Fig.3 shows the stack inlet NO and NO_2 with correction value to 12% CO_2 in order to compare on the basis of emission amount. The NOcorr, with a 12% CO_2 corrective value, declines around 60% with oxyfiring due to the effect of NO reduction by a large amount of recirculation gas. On the other hand, there is not so much different between airfiring and oxyfiring of NO_2 corr
- The CO_2 concentration in flue gas shows virtually identical characteristics as deigned. Over 70 dry% CO_2 is obtained at 30MW operation as shown in Fig.4.
- Fig.5 shows carbon-in-ash at both conditions. Carbon-in-ash in oxyfiring is almost half of carbon-in-ash in airfiring. Because the residence time in furnace is longer due to the smaller gas volume, and combustion is improved due to the local higher O_2 concentration.
- The various operations at boiler inlet O_2 concentration range between 24 - 30% were tried and confirmed. The operation results with various boiler inlet O_2 are as follows:
  - The boiler performance was maintained during the oxyfiring operation as well as the airfiring operation.
  - NO is slightly higher when the boiler inlet O_2 is 30%.
  - Flame is more stable and plant operation is more flexible when inlet O_2 is less than 27%, due to higher gas volume to the boiler.
  - Brightness of the flame from viewed through the observation window near the burner throat is different depending on the boiler inlet O_2 as shown in Fig.6. Flame location is closer to burner throat due to the

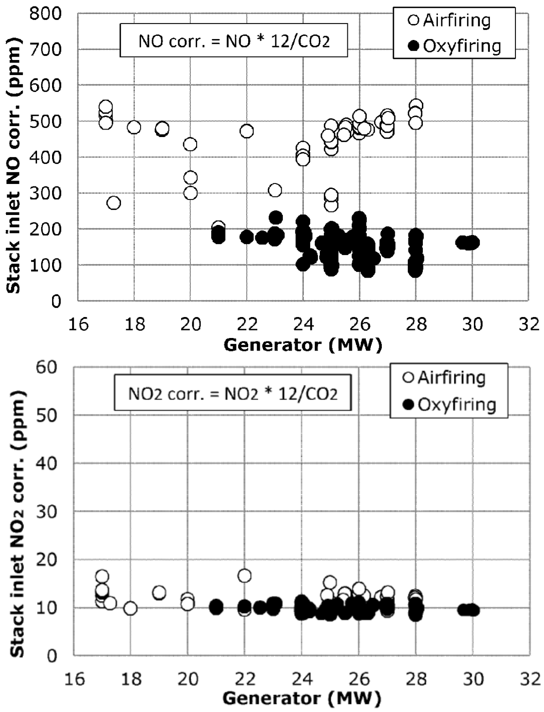

Fig.3 Stack inlet NO and NO_2

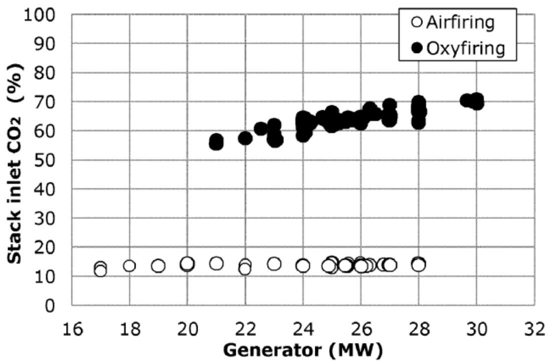

Fig.4 CO_2 concentration at stack inlet

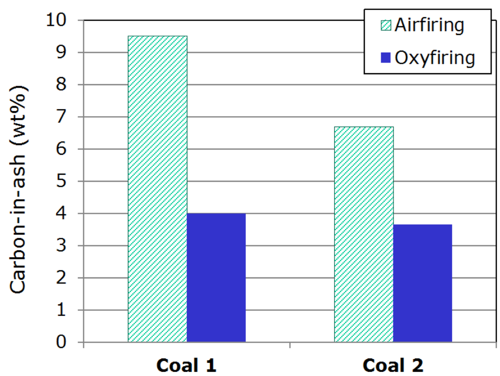

Fig.5 Carbon-in-ash

reduction of gas volume and higher O_2 concentration in combustion gas, when boiler inlet O_2 is 30%.

24.5% 27% 30%

Fig.6 Photos of flame in oxyfiring with various inlet-O_2, 24.5%, 27% and 30%

- SO_3 and mercury contents were measured at boiler outlet, secondary heater outlet, flue gas cooler outlet and IDF outlet in Fig.7. Fig.7 shows SO_3 concentration in the boiler process. At the boiler outet, SO_3 in oxyfiring is almost 2 to 4 times concentration of SO_3 in airfiring, however at IDF outlet after fabric filter passed, SO_3 concentration in both airfiring and oxyfiring was less than detection level that was 0.1 ppm. Fig.8 shows the Hg measurement results by Ontario hydro method at boiler outlet, secondary heater outlet and IDF outlet in oxyfiring. Hg measurement by the continuous monitor was also performed at IDF outlet and the average value of Hg^0 and Hg^{2+} is also shown in Fig.8. Hg concentration was decreased from boiler outlet to IDF outlet, especially Hg^0. This tendency is almost same behaviour with the results at pilot-test facilities. And Hg concentration at IDF outlet by the continuous monitor is the same level with the results by Ontario hydro method.

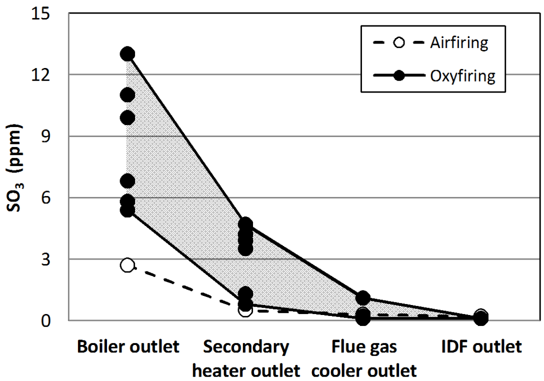

Fig.7 SO3 in boiler process

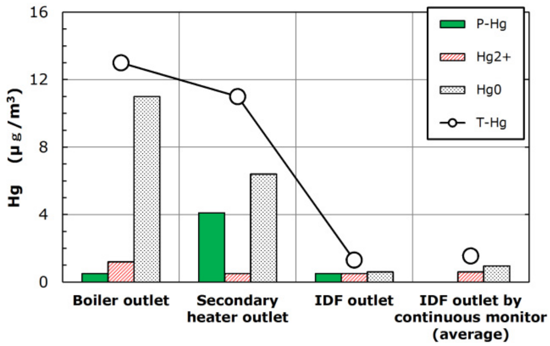

Fig.8 Hg behaviour in oxyfiring

- At the design stage, the existing airfiring burners were reused, 30MWe operation was required at both airfiring and oxyfiring condition and the minimum load in oxyfiring was set to be 24MWe with inlet O_2 of between 24 and 30%, because flame stability and heat balance of flue gas and recirculation gas were concerned. However, it had been found that the flame was stable at 24MWe and there was a possibility to reduce the load at the demonstration stage. Therefore, it is very important to enlarge the operation load range and the confirmation of the turn-down of the oxyfuel boiler is tried with the appropriate operation condition. Test was conducted monitoring the flame shape and stability in visual and the level of flame detection.
  As the results, operation range down to 15MW is achieved that is equivalent with airfiring operation. Test results are summarized as follows.
  - Minimum load is 21MW (70%L) while the boiler inlet O_2 is controlled at 27%.
  - Minimum load is 15MW (50%L) while the boiler inlet O_2 is controlled at 24%.
  - Burner flames look stable and the boiler performance is also stable during the test.

3.4. Future works

To commercialize and realize this technology in the future, further various examinations must be performed in this project. The main contents are shown as follows:

- Various coal combustion tests and load ramp tests to confirm the operation flexibility.
- O_2 injection test to the flame directly to confirm the boiler performance
- Mode transition tests to optimize and confirm the shorter period of mode transition.
- A durable (long term) test to confirm the proper operation of each facility.
- A corrosion probe test to confirm the corrosion of boiler tube materials under oxyfiring atmosphere.

4. Feasibility study in Australia

On the other hand, feasibility study of 500MW oxyfuel power plant in Australia was performed on the basis of the outcome from Callide Oxyfuel Project. From this study results, the utilization of by-products such as N_2 as well as CO_2 from the oxyfuel power plant is very important in order to achieve the lower cost of electricity. If CO_2 and N_2 can be utilized effectively, the cost of electricity for oxyfuel plants can be lower than that for conventional plants and the oxyfuel power plant will be easy to be applied for the market of power plant.

Feasibility study of 500MW oxyfuel power plant in Queensland, Australia was performed in 2012 & 2013 [7] on the basis of outcome from Callide Oxyfuel Project. Table 2 shows the main specifications of oxyfuel power plant including ASU and CPU. Dry cooling system for the condenser and the compressors in ASU and CPU was selected due to dry area in Australia. The boiler process was considered to minimize the air ingress amount to the process and also 600 degree C class steam condition for the boiler was applied in order to minimize the coal and O_2 consumption in this study. Each two (2) trains for ASU and CPU would be necessary for 500MW oxyfuel power plant.

Table 2 Main specifications of Oxyfuel power plant for CO_2 capture

Area	Queensland, Australia
Power Plant	
Gross output	500 MW at each condition of air and oxy
Coal	Bituminous coal
Cooling system	Dry cooling
Steam condition	Main steam pressure : 25.0 MPa Main steam temperature : 600 degree C class
ASU	
Type	Cryogenic
Capacity	200 t-O_2/h x Two (2) trains
O_2 purity	96.5 % or more
CPU	
Capacity	270 t-CO_2/h x Two (2) trains
Main gas composition	H_2O 8.1 mol% / CO_2 72.8 mol% wet
Main product	CO_2 liquid at 16 MPa(abs) & 45 degree C Purity 99.9% or more
Capture rate	98% or more

Fig.9 shows the layout of 500MW oxyfuel power plant in the power station and Fig.10 shows the study results of LCOE (Levelized Cost Of Electricity) based on the plant lifetime of 30 years after starting the commercial operation and plant availability of 85% and so on. Total LCOE is approximately AUD127 per a MWh, and CAPEX occupy over 60% of total LCOE including CCS facility of ASU, CPU and so on that occupy almost 20% (AUD26 per a MWh) of total LCOE.

On the other hand, the utilization of by-products such as N_2 from ASU as well as CO_2 from the oxyfuel power plant is very important in order to improve the LCOE. If N_2 as well as CO_2 can be utilized effectively, the LCOE for oxyfuel power plant can be lower than market price and this means that oxyfuel power plant would be easy to be applied commercially as compared with conventional power plant in Australia from Fig.10.

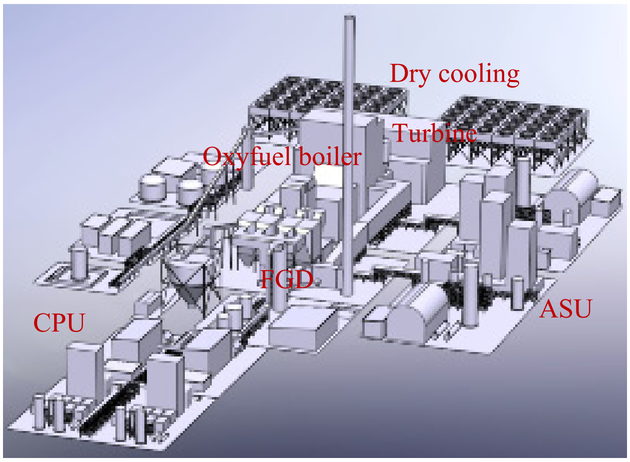

Fig.9 Layout of 500MW oxyfuel power plant

Table 3 shows the plant performance of both oxyfiring and airfiring in this oxyfuel power plant. Oxyfiring condition needs to have the large amount of in-house power consumption for ASU and CPU and net plant efficiency decrease down to around 31.5% as compared with 39.9% in airfiring. However, net CO_2 emission is dramatically decreased down to 20 g/kWh. Regarding the water and steam process, operation results of Callide Oxyfuel Project were reflected and fuel consumption and gross plant efficiency in oxyfiring were improved.

Lastly, in recent days, it is said that CO_2 emission [kg/MWh] from coal fired power plant will be regulated of less than some level, for example 420 g/kWh in Canada. To cope with this kind of the regulation, oxyfuel power plant can be expected to keep with more economical manner than other CO_2 capture process.

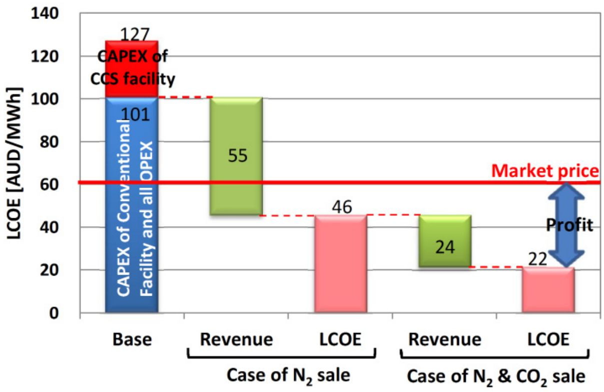

Fig.10 Cost study results of oxyfuel power plant

Table 3 Performance of Power Plant

Combustion mode		Oxyfiring	Airfiring
Gross / Net output	[MW]	500 / 345	500 / 473
Gross / Net plant efficiency	[%]	45.7 / 31.5	42.1 / 39.9
Auxiliary power consumption	[MW]	155	27
CO_2 emission (net)	[g/kWh]	20	740
Fuel consumption	[t/h]	196	212

5. Summary

This paper introduced the Callide Oxyfuel Project and operation experiences of boiler as of now. The demonstration operation will be continued until March 2015 and the operation data will be continued to obtain towards the commercialization of this technology.

And feasibility study results of 500MW oxyfuel power plant were also introduced. It is highly possible for oxyfiring to provide more economical CO_2 capture process as the solution of coal fired power plant to CO_2 regulation. To realize this oxyfiring system as a highly-efficient CCS system, we push forward research, development and demonstration further.

Acknowledgment

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