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Kizildere II Multiple-Flash Combined Cycle: A Novel Approach for a Turkish Resource

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ABSTRACT

Kizildere II is the largest geothermal project in Turkey. The project was developed by Zorlu Energy, with engineering service provided by POWER Engineers (POWER), Veizades and Associates and Geologica. POWER was responsible for the overall plant design. Resource engineering was by Geologica and steam field piping engineering by Veizades. A feasibility study reviewing options for geothermal power generation cycle technology was performed at the initial stage of development. Due to the high, non-condensable gas (NCG) content of the geothermal fluid, an advanced and patented triple-flash cycle was selected as the preferred method to harness the Kizildere resource for power generation. The project, commissioned in 2013, consists of a 60 MWe triple-flash plant employing two turbines on a single shaft; the high-pressure turbine exhausting to two 10 MWe binary units and an intermediate/low pressure turbine exhausting to an advanced direct contact condenser. Both the IP/LP turbine's condenser and binary plant are cooled by condensate from a wet cooling tower. This plant configuration was chosen to cost-effectively match the equipment and parasitic load requirements to the distinctive characteristics of the Kizildere hydrothermal resource, and to allow the plant systems to cost-effectively respond to anticipated changes in resource characteristics over the project's life cycle, as resource gas content and enthalpy change over time. In addition to its principal power generation stages, the plant is capable of providing thermal energy in the form of hot water for several nearby greenhouses, as well as for use in district heating to a neighboring community. The purpose of this paper is to describe the design approach, options considered for key plant aspects such as electrical output optimization and direct use applications, and discuss plant layout, features and operations.

1. INTRODUCTION

Zorlu Energy, a large Turkish contractor, is an innovative and forward-thinking firm which is a part of the Zorlu Group of companies, a huge Turkey conglomerate. Zorlu Energy purchased the 15 MW Kizildere I Geothermal Power Plant (the first geothermal power plant in Turkey) in 2008 and thus entered the geothermal arena.

The Kizildere site is located in the Menderes Graben area of Anatolia with geological features known for relatively accessible hydrothermal resources with geothermal potential. Zorlu Energy was not content to simply sit on the existing plant and operate it but chose instead to develop the resource and expand by developing a new, 60 MW (gross) power plant. Towards this end, POWER was hired in 2009 to prepare a feasibility study for the new plant. POWER, in turn, hired a resource specialty firm, Geologica, and a gathering and injection system specialty firm, Veizades and Associates, to assist with their areas of expertise.

Although the Kizildere resource has a high enthalpy, it also presents a considerable challenge with respect to very high concentrations of NCG, chiefly carbon dioxide, in the reservoir. To evaluate an appropriate way of extracting the energy from the resource and converting it to electricity, various power cycles were evaluated. The evaluation considered power output, capital, operating and maintenance costs over the projected thirty year design life. The costs included those from the wells, field facilities and the plant. It was concluded in the initial study that a triple flash plant would provide the best return on investment.

Geologica, after analyzing the data and preparing a resource model, also concluded that the resource was adequate for the new 60 MW as well as the existing 15 MW plant over the 30 year life.

An additional "mini" feasibility study was conducted to ascertain whether additional power generation via the addition of a bottoming cycle to the high pressure steam turbine exhaust would be beneficial. The study indicated that this option would also provide favorable economics, so Zorlu made the decision to include a bottoming cycle.

POWER, again supported by Geologica and Veizades and Associates, was hired to perform engineering, design, procurement, commissioning and startup services for the plant. Zorlu acted as their own general manager and hired local subcontractors to construct the facility.

The plant, now 80 MW with the addition of the 20 MW binary cycle, entered commercial operation on 31, October, 2013, thus becoming the largest geothermal power plant in Turkey. In addition, during the winter the plant can utilize a portion of the geothermal energy supplied to the binary cycle to supply energy to a district heating system. In the geothermal world, this plant has it all: a flash cycle, a binary cycle and district heating capability.

2. RESOURCE CONDITIONS

Many resources in Turkey are characterized by high enthalpy fluids and very high NCG, primarily carbon dioxide. High NCG content adds a level of complexity to the evaluation of cycle selection. This may lead to plant designs specifically targeted to minimize parasitic load and capital cost of NCG removal equipment as well as improve the flexibility of the plant to adapt to inevitable changing resource conditions.

In addition, NCG content is difficult to predict precisely and will change over time. Often, a slow decline in enthalpy of the geofluid, or an increase in NCG content in the geofluid, can result in higher NCG content in the steam. If insufficient NCG system capacity was provided, this can limit plant output.

The Kizildere geothermal field is located at the eastern end of the Büyük Menderes Graben. The Kizildere field was first investigated in the 1960s, and has been exploited to varying degrees since. It is a good quality geothermal resource, with some well temperatures exceeding 240°C. In 1984, a 15 MW facility was installed, which continues to operate. Well performance gradually declined at Kizildere. Production declines may be attributed to little reinjection relative to production and to calcite scaling in the production wells which was mitigated primarily by periodic mechanical removal from the wellbore. However, ongoing development of injection capacity has begun to rectify this production decline. The removal of calcite scale from wells and surrounding reservoir prevention of new scale formation has improved well productivity. In 1998, a deep high temperature (>240 ^{o}C) resource was discovered. Furthermore, there is geophysical evidence that a deep, high quality reservoir, beyond the perimeter of the drilled resource, is available for exploitation. Kindap et al describe some of the initial efforts to recondition the plant and field after privatization (Kindap, 2010).

The Kizildere resource model includes several distinct reservoirs, though a high level of connectivity is expected. The "intermediate reservoir" from -200m to -600m elevation, has been subject to the most thorough documentation and assessment to date, attributed to its roughly 25 year production history supplying the existing power plant. Fluids in this zone have an average enthalpy of approximately 870 kJ/kg and an average NCG of 1-2% by weight (wt%). Production from the deeper >240 ^{o}C reservoir with a top near -1200m elevation, has been demonstrated by nearly 10 years of production from well R-1, and have NCG concentrations in the 2-3% range (Haizlip and Haklidir, 2011).

3. FEASIBILITY STUDY

POWER was first engaged in 2009 by Zorlu to perform and deliver a feasibility study exploring costs and technology options for developing a large new plant at the Kizildere resource, adjacent to the existing Kizildere I single-flash plant. The study reviewed options for geothermal power generation cycle technology and recommended an advanced (patented by POWER) triple-flash cycle as the optimal method to using the Kizildere resource for power generation. This unique approach was required due to the high NCG content of the geothermal fluid.

Evidence strongly indicated that the Kizildere geothermal field is able to support an additional 60MWe (gross) generating plant for at least 30 years as well as the existing 15MWe plant for a further 30 years. The quality of the resource supports a flash plant which has a higher efficiency and lower specific capital cost (in terms of $/kW installed) than an alternative binary cycle plant.

The nature of the resource, particularly its enthalpy and gas content, suggests that a power plant using a triple pressure steam flash design would be most appropriate. POWER recommended a triple-flash plant to take full advantage of the resource quality and to efficiently deal with the non-condensable gases. The geothermal resource can be reliably produced using conventional technology. The intermediate reservoir produces NCG, mainly CO_2, of 1.5% (wt) and fluids at approximately 190°C to 200°C. The deep resource appears to produce about 3% (wt) of NCG and fluids at approximately 235°C to 240°C. This must be accounted for in the design of the facilities, but it can be handled using conventional methods with well-understood costs.

The Kizildere geothermal resource model includes two developed reservoirs at different depths, enthalpies and chemistry that are most likely inter-connected and are overlain by a shallow reservoir, which is not currently producing. While the reservoir has been explored by drilling of over 20 wells, production from the intermediate depth reservoir has been maintained for over 25 years from approximately seven of those wells. The deeper, hotter reservoir has been produced from a single well for almost 10 years.

The resource gathering system utilizes a mix of centralized and satellite separation. The resource gathering system for the existing plant was recommended to be revised and integrated with the gathering system for the new plant.

The feasibility study considered standard flash plant designs to handle the high NCG's as well as novel approaches tailored to this specific type of resource. In addition to the novel NCG system approach, it was recognized that the addition of a bottoming cycle would allow beneficial use of the low pressure steam/NCG stream that would otherwise be wasted. This steam/NCG stream is also capable of supplying energy to the local district heating system and a local greenhouse and is discussed in greater detail in the follow sections.

3.1 Flash Plant Design and NCG

The discussion which follows addresses the development and reasoning behind the advanced Kizildere design to handle the high NCG content.

In general, geothermal power plants use condensers for condensing the steam exhausted from turbines and electrical power is produced from turbines that drive generators. For the most part, lower condenser operating pressures result in more efficient power generation. This is because the pressure difference between the steam side of the turbine and the condenser side is what moves the steam flow that spins the turbine. Since NCG does not condense, it can be difficult to achieve that desired low operating pressure if relatively high NCG is present in the steam—which results in less efficiency from the turbine generator. In addition, larger condensers and higher-capacity vacuum equipment may be required to handle and remove NCG resulting in increased capital costs and higher parasitic loads for operating vacuum equipment.

3.2 Standard Steam Flash Design

A standard steam flash plant receives two-phase fluid from the geothermal wellfield. The steam and brine phases are separated and the steam with its NCG component goes to the turbine while the brine goes to a second separator. There, it is flashed to supply steam to the turbine's low-pressure section. Any remaining brine is then injected back into the reservoir.

Steam that emerges from the turbine is condensed in the condenser—which has a back-end NCG removal system whose devices extract these gases from the condenser vessel and compress them to slightly over atmospheric pressure for venting or treatment. A back-end NCG system, usually consisting of steam jet ejectors and/or vacuum pumps, is typical for reservoirs with low NCG content. As discussed earlier, the resource at Kizildere does not have low NCG content. If this typical approach were to be applied there, a large amount of steam would be consumed from the steam jet ejectors and the vacuum pumps would use a lot of power to extract the large amounts of NCG. High capital costs would be the end result.

3.3 Modified Steam Flash Design

By modifying a conventional steam flash approach, high NCG levels like those seen at Kizildere can be more effectively handled. First, the two-phase fluid from the geothermal wellfield is taken at a higher supply pressure and accomplishes the initial two-phase separation at a higher steam pressure than seen in the standard approach. By doing this, the brine phase retains more energy and the mass of steam, along with the NCG in the high-pressure flash fraction, is lower. This high pressure (HP) gas stream (which is steam and almost all of the NCG found in the resource fluid) goes into a separate backpressure turbine. From there, it will exhaust to a separate condenser, a binary cycle or directly into the atmosphere. The NCG can be vented directly into the atmosphere or a treatment system because the exhaust pressure is slightly above atmospheric pressure.

In the meantime, the brine from the initial separator is dispatched in series to two more separators. It is flashed into intermediate pressure (IP) and low pressure (LP) streams, which drive a second, dual-pressure turbine. The IP/LP turbine exhaust contains very little NCG and is discharged into a separate condenser, where it is readily condensed to a low pressure. The lower pressure flashed steam also contains very little NCG, so the gas removal system can be much smaller than a standard design.

3.4 Advantage of the Modified Design Compared to the Standard Design

A modified flash design has several, distinct advantages over a standard flash design. The primary advantage of a modified design is its ability to handle high levels of NCG. This is particularly important for resources like Kizildere. A standard design requires a reasonable understanding of the actual gas concentrations in the steam so that the gas removal system can handle all of the gas. If the actual field conditions reveal NCG levels higher than anticipated, then turbine performance may be reduced. So most standard approaches are designed with additional margin for gas extraction capacity—potentially creating a gas removal system that is formidable in both size and capital costs. In addition, steam consumption could be higher due to steam ejector requirements. This will affect the plant's heat rate. And higher parasite loads for vacuum pumps will reduce the overall net output.

With a modified design, the separate HP turbine/condenser or vent allows for more flexibility with NCG in the steam and the turbine is designed to discharge to atmospheric pressure rather than depending on a low condenser pressure for effective performance. In this case, if actual field conditions reveal NCG levels higher than anticipated, the increased gas flow is handled through the HP turbine for venting or treatment. And the very low level of residual NCG surviving in the IP/LP steam allows the condenser for that turbine to operate at a low pressure, readily providing a pressure that this turbine can efficiently operate under.

Another distinct advantage of a modified design is that it requires a lower wellfield resource demand. This is because plant efficiency is higher than the standard design.

3.5 Addition of a Binary Cycle

After due consideration, the HP turbine NCG-steam exhaust was evaluated as a potential heat source for a binary cycle plant. There was sufficient residual energy in this stream to power a 20 MW binary plant. The addition of the binary unit allowed for the HP condenser of the steam plant only version to be eliminated and provided significant additional generation. The disadvantage is that the overall plant has more complexity and cost. Also, the HP condenser is essentially replaced by the binary plant condenser. However, the advantages outweigh the disadvantages in this case.

4. PLANT DESIGN

In 2011, Zorlu decided to develop the new plant as recommended and engaged POWER and its team to continue with detailed design and equipment specification for the new wellfield and power plant. As recommended in the feasibility study, the new plant consisted of a 60 MWe triple-flash plant employing two turbines—a high-pressure turbine and a separate condensing IP/LP turbine—with the condensing turbine served by a wet cooling tower.

This plant configuration was chosen to match the equipment and parasitic load requirements to the distinctive characteristics of the Kizildere hydrothermal resource, and to allow the plant system to cost-effectively respond to anticipated changes in resource characteristics over the project's life cycle, as resource gas content and enthalpy change over time.

The Kizildere plant is considered a "hybrid" or combined cycle geothermal plant consisting of both a flash and binary plant. In additional to its principal flash stages, it provides for a 20 MWe bottoming cycle to recover additional energy from the flash plant's HP turbine exhaust. This HP heat recovery also incorporates the ability to generate hot water to several nearby greenhouses as well district heating to a neighboring community.

This combined cycle relies on a bottoming IP/LP flash plant instead of a bottoming brine binary plantSince the binary unit is driven by condensed steam, this relatively clean water isavailable for makeup water use, allowing wet cooling to be used also for the binary units; this may not have been possible with a brine bottoming binary cycle. The HP and LP turbines may be housed in separate casings driving a single generator—or may be two separate turbo generator units. Figure 1 below shows the indicative cycle schematic.

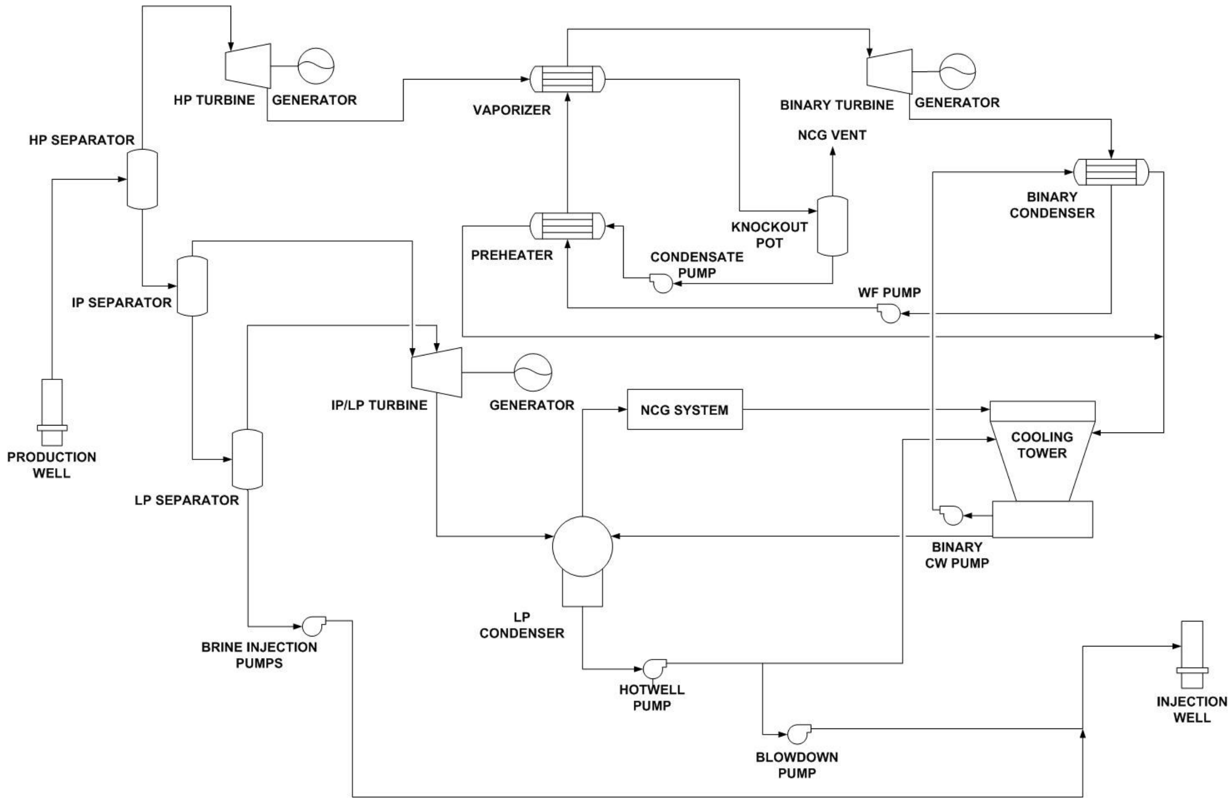

Figure 1: Indicative schematic.

The plant demonstrates a good tolerance for varying NCG content in the HP steam without undue investment in NCG removal equipment. NCG content is simply passed through the HP turbine and binary units and exhausted at atmospheric pressure at the cooling tower fan stacks. The plant design also allows for shifting of steam between pressure levels in the steam turbine or to the binary unit, providing flexibility in the event of resource condition changes. Exhaust steam from the HP turbine can be sent to heat exchangers to supply district heating water to nearby greenhouses and villages.

Figure 2 shows a screenshot of the model POWER prepared during the design of the plant.

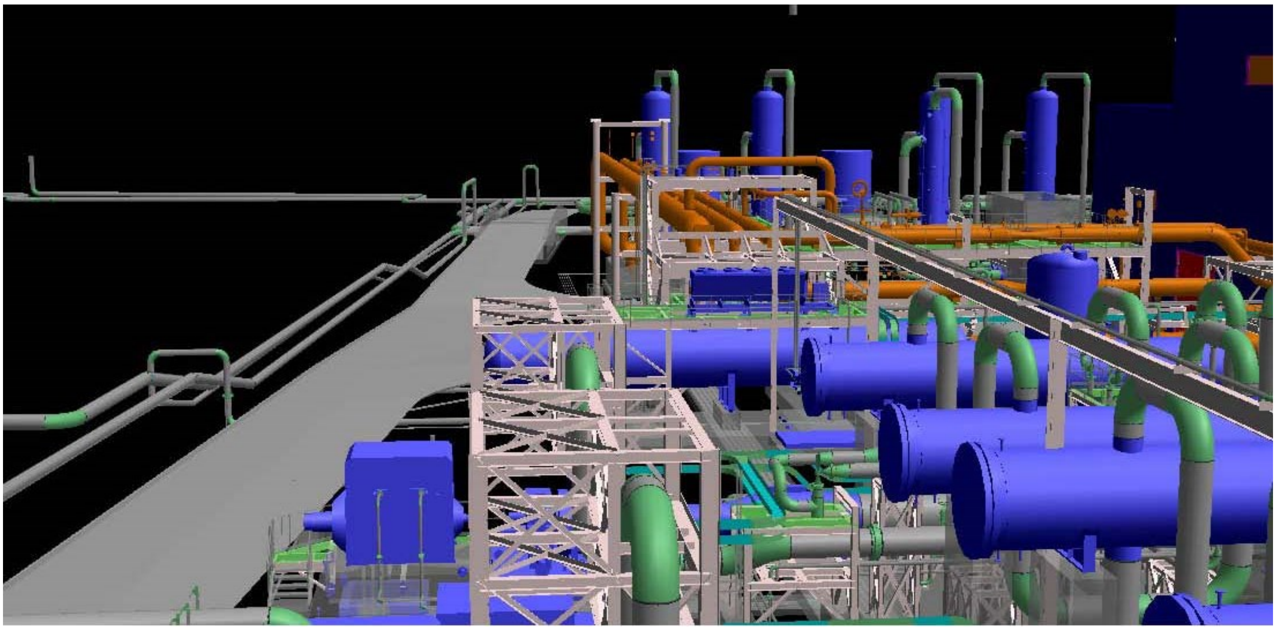

Figure 2: Plant 3-D model.

Figure 3 shows a picture, taken from the same angle, of the power plant in operation. The binary plant is in the foreground, the powerhouse is to the right and the separator station is in the background.

Figure 3: View looking south, binary units in foreground, powerhouse and separation station in background.

5. OPERATION

Now the big question: after all the engineering cleverness and hard work, the procurement, the construction and the startup, how did it work? On October 31, 2013, after passing all performance tests, the 80 MW Kizildere II Geothermal Power Plant was accepted by the Turkish Energy Ministry. The plant has run well since commissioning and has had an availability over 99.75% in 2014 to date. There were some early shakedown issues with the binary bottoming cycle portion of the plant, but it is performing reliably at this time. The overall capacity factor to date is over 96%. It should be noted that the final production well is being completed and will be tied into the plant in June of 2014—so the capacity factor is anticipated to be even higher after that point in time.

6. SUMMARY

The 80 MW Kizildere II is Zorlu's flagship plant and a conspicuous landmark in the rapidly developing Turkish geothermal plant fleet. It is a prime example of how a combined cycle configuration is able to overcome some of the limitations that accompany a typical flash or binary cycle. With a resource high in enthalpy and NCG content, the Kizildere II plant sets a new standard for innovative and ambitious heat recovery from a renewable energy resource.

REFERENCES

Haizlip, J., and Haklidir, F.: High Noncondensible Gas Liquid Dominated Geothermal Reservoir, Kizildere, Turkey, *GRC Transactions*, Vol. 35, (2011).

Kindap, A., Kaya, T., Haklidir, F., and Bukulmez, A.: Privatization of Kizildere Geothermal Power Plant and New Approaches for Field and Plant, *World Geothermal Congress Proceedings*, Bali, Indonesia, April 25-29, (2010).