San Jacinto—The First Five Years

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ABSTRACT

The first 10 MW plant entered production service at San Jacinto in Nicaragua in July 2005. This plant, comprising 2 x 5 MW back pressure steam turbines, was installed as a commercial demonstration plant, and in that role has been a resounding success. Because of caution on the part of investors regarding progressive capital investment in the project and in Nicaragua, a number of features of a long term optimized project were purposely omitted from the initial construction. This paper will discuss the rationale behind the initial development decisions and the subsequent operation of the plant and the reservoir, including improvements that were made to ensure that the plant is now fully capable of delivering its rated capacity, plus a little higher. Some interesting experiences were encountered and some important lessons learned.

1. Development Strategy

The San Jacinto – Tizate geothermal resource has been known for many years, since initial drilling activities were undertaken by McBirney, a geologist working under the auspices of Noranda Mines in 1953. Following various studies by such entities as Texas Instruments, UNDP, OLADE and DAL SpA, exploration drilling was undertaken by Intergeoterm between 1993 and 1995. 7 wells were drilled, of which 3 were identified as commercial producers.

San Jacinto Power S.A. (SJPSA - subsequently Polaris Energy Nicaragua S.A. – PENSA – a subsidiary of Polaris Geothermal Inc and now of Ram Power Inc) took over the development of the project in 1998. In considering the development strategy to be applied to the project, Polaris determined that raising commercial debt finance for a project in Nicaragua would be potentially difficult. The decision was therefore made to undertake the development entirely with equity, which in turn meant that initial development costs needed to be minimized. In the event, some debt finance was obtained from Standard Bank of London, supported by Central American Bank of Economic Integration, however this was a relatively small amount, less than 10% of the initial capital, so restrictions to minimize development still applied.

The decision was made to undertake a development based on the existing wells which had been drilled by SJPSA's predecessor, Intergeoterm (JV between the Government and a Russian company.) Furthermore, the plant to be used would be 2 x 5 MW back pressure, to be purchased second hand from GESAL (now LaGeo) of El Salvador.

The Intergeoterm wells which were available for use were SJ1, SJ4, SJ5 and SJ6. SJ1 has good permeability but is cool and had been identified as a potential injection well. SJ4 had a reported productivity in excess of 20 MW (when used with a condensing turbine), which it was considered would provide sufficient steam for 2 x 5 MW i.e. 10 MW when passed through the proposed back pressure units. SJ5 and SJ6 are smaller capacity production wells (5.0 MW and 2.4 MW respectively), which it was assumed would not necessarily be required for initial operation.

2. Steamfield Configuration

Between the time that PENSA took over the development of the project and the start of construction the project experienced some delays. During this period, it was noted that the cost of steel piping was rising significantly and the details of the planned development were reviewed to identify means of further reducing the capital cost. Given that it was believed that SJ4 would have sufficient production capacity to supply, it was decided that a considerable cost could be saved by not constructing the long (3.1 km) injection line to SJ1 and to instead use SJ5 and SJ6 for hot injection.

One consequence of this decision was that the injection pressure would need to be higher than originally planned, which was just sufficient push to prevent the brine from flashing at the high point in the injection line. The pump configuration was therefore changed from having 4 x 33% pumps in parallel, to having two trains in parallel, each with two pumps running in series. This has resulted in a reduced reliability of the injection pumping system as a single pump problem results in a 50% reduction in available pumping capacity.

When the plant was commissioned in July 2005, it was quickly noted that with the well configuration proposed, the production and injection capacity were not capable of supporting 2 x 5 MW generation from the back pressure units. Partially this was as a result of apparently less steam production than anticipated from well SJ4.

2.1 Initial Production Capacity

Logging of the well produced some conflicting results which were interpreted initially as being the result of a casing leak close to the production casing shoe. Enquiries through channels that had maintained contact with the Intergeoterm team indicated that there had been problems in cementing the casing (it was found that the casing had been dropped part way through the cementing process, an incident that was not noted in the drilling records available on site, but was found from personal records then held in Moscow) and it was suspected that this might have been the problem. However, further analysis suggested that in fact the production enthalpy was lower than reported from the initial well testing and it appears that the test discharge pipe had been too small a diameter, with the result that the discharge may have been choked within the discharge pipe, resulting in a misleading lip pressure reading that was outside the applicability of the James correlation being used to estimate output.

It was therefore decided to change SJ5 from injection back to production duty. SJ5 had an estimated production capacity of 5.0 MW (with condensing turbines) and was therefore expected to provide sufficient additional steam to bring the plant up to its nominal 10 MW gross output.

Figure 1. Flash tank and improvised cooling system for cold brine injection.

2.2 Partial Cold Injection

It was recognized that taking SJ5 out of injection duty would result in insufficient injection capacity using SJ6 alone and the decision was made to commence injection to SJ1. However, the cost of constructing a high pressure steel injection line all the way out to SJ1 was still considered prohibitive for the project as it then stood, and so it was decided to temporarily construct the high pressure line only as far as the highest point along the pipeline route and at that point to flash the brine to atmospheric pressure and rely on low pressure, gravity flow from that point.

A simple flash tank was designed and fabricated locally. It was decided, again as a cost saving measure, to use low pressure 18 inch HDPE culvert pipe to transport the atmospheric brine from the flash tank to the injection well, a distance of about 1.3 km. It was recognized that the brine would need to be cooled from 100°C, as the HDPE culvert was not rated to handle that temperature, although tests had indicated that the material would be unlikely to fail by simple softening and collapse. A simple cooling arrangement was fabricated using old mud tanks with overhead distribution pipes made out of irrigation pipe. This system was quite effective in cooling the water from 100°C down to about 80°C.

It was also recognized that the culvert pipe would not be suitable for any significant over-pressure resulting from ground undulation, and so a number of break tanks were constructed using concrete culvert pipes set on end.

Acid dosing was used to control silica deposition after the brine had been flashed to atmospheric pressure. It was decided to dose the acid between the separator and the brine injection pumps, so that the acid would be thoroughly mixed with the brine before being flashed and so that the acid injection equipment would be located in a relatively secure area for safety reasons. Initial trials with concentrated hydrochloric acid were unsuccessful in lowering the Ph sufficiently and the system was changed over to using concentrated sulfuric acid, which is relatively easy to obtain in Nicaragua. A modest dosing rate was found to maintain a fairly stable Ph of the brine in the range of 4.5 to 5.0, with 4.5 being the lowest Ph considered suitable for use with carbon steel brine piping. Visual inspection of the brine in the cooling tank and the various pressure break tanks showed no indications of silica deposition; the brine flow was clear with no hint of milky-blue coloring.

Unfortunately, the HDPE culvert pipe was found to be unsuitable for the duty. A series of small cracks started to appear quite quickly, which were eventually determined to be due to fatigue failure under a combination of temperature and pressure. Initially, individual sections of pipe were replaced, but in the areas of highest over-pressure these were found to fail again quite quickly. An alternative piping material was obviously required very quickly.

Investigations located a quantity of 16 inch fiber cement pipe, which was immediately available for a very competitive price. This pipe was purchased and laid to replace the HDPE pipe. This material proved to be much more robust and suitable for the duty, and the system continued to operate successfully for a considerable time, despite occasional problems with the acid dosing system.

As soon as timing and funding permitted, by mid 2006, a steel pressure pipe was laid in parallel to the fiber cement line and the system switched over to full temperature, pumped injection. The experience was, however, very useful in indicating the suitability of the brine for cold injection with Ph control to prevent silica deposition – a matter of considerable interest as a means of extending the project generating capacity, without additional drilling, by means of a brine based binary plant.

3. Plant Operation

3.1 Initial Performance

The power plant comprises 2 x 5 MW (gross) back pressure turbine generators manufactured by ACEC of Belgium in 1989. They had been previously installed and operated in the Berlin geothermal field in El Salvador from 1992 until being retired from service in 1998, when GESAL (now LaGeo) had installed 56 MW of new condensing plant. As part of the performance guarantee provided by GESAL, one of the units was tested in place in the presence of lenders and investors at the Berlin field. Separate contracts were established with GESAL for the removal of the units from Berlin and re-assembly in San Jacinto, and also for the operation and maintenance of the plant for the first three years. The O&M contract provided for GESAL to wheel make-up power down from El Salvador in the event of a plant did not achieve agreed performance levels. This provision was seen by investors and lenders alike as providing an excellent alternative to a more conventional performance guarantee from a vendor.

The steamfield plant was all new construction, with a very high performance separator and variable speed electric motor drive brine pumps.

The commissioning and initial operation of the power plant was very smooth and successful given the restrictions in steam supply because of limited production and injection capacity. The commissioning of the separator and brine pumps was rather more complicated because of the requirement to correctly tune the interconnected separator water level control system, the brine pump controls and the brine dumping system. The use of a Rotork type valve actuator for brine dumping was not a good selection, as the valve is too slow to open when required to dump and does not appear to have a sufficiently responsive operation when in a modulating mode. Subsequently it was found that there was a logic error in the configuration and operation of the separator high water level controls and since this was corrected the system has performed better. The variable speed motor drives have had some problems with overheating of components, partly due to dust building up inside the electronic cubicles (which are installed under a weather shelter, but not in an enclosed space).

It had originally been planned that the power plant would be shut down for internal inspection and maintenance within three years from commissioning. The O&M contractor undertook a boroscope inspection of the turbines after about 18 months of operation and reported no apparent evidence of silica or other deposits. The plant was kept operating for almost 4 years before it was decided to take an outage (generation shortages and very high oil prices in the country had made outage prior to this point undesirable). It was very gratifying to note that even after 4 years of operation, there was no evidence of any deposition within the inlet area, the first stage nozzles or elsewhere within the turbine. This is seen as evidence of the value of good process design aimed at providing very clean steam to the turbine, starting with an excellent separator design, and supported by pipeline steam scrubbing and good separation pressure control.

3.2 Blade Cracking

Two problems were however found with the turbines. One unit (Unit #2) was found to have cracking in the fifth row rotor blades. The cracks were all in the same place, a short distance up the blade from the root and running into the body of the blade from the trailing edge. The initial assumption was that this was a blade vibration problem, possibly due to operation close to a resonant frequency.

Figure 2. Cracked fifth row blades from Unit #2.

The entire fifth moving blade row was removed, the rotor re-balanced and the unit brought back into service while a new set of blades could be manufactured and the failure analyzed in more detail. The work was undertaken by Elliott, through their establishment in Guatemala City. Further analysis indicated that the problem was probably due to the unit having been held close to a critical speed during the warm-up process. The plant has suffered from numerous trips due to trips of the Nicaraguan national grid (very seasonal, due to lightening strikes during the rainy season and sometimes to other flash-overs during cane cutting season), during which the unit governors and overspeed protection have been unable to handle a full load rejection. The operators were in the habit of adopting a normal, cold restart procedure even when restarting following a very brief grid outage, and as such the unit had spent more time than would normally have been expected close to the critical speed (Unit #1 sits at a slightly different speed when warming up, the hold point being established by the manufacturer by the degree of opening of the start-up valve, not the actual rotor speed). The fifth row blades have recently been replaced, a hot restart procedure has been developed to remove the requirement for holding the unit at a lower than normal speed, the normal start procedure has been modified to take the holding point away from the critical point and the unit is now operating well.

3.3 Internal Erosion

The second problem identified was with erosion in the diaphragm seating area. The diaphragms sit loosely in a groove in the casing and are held in place by the steam pressure across the diaphragm, which presses the diaphragm against a plain metal seating. At some time in the past, someone had tried to adjust the axial position of some of the diaphragms and had done this by building small patches of weld metal on the downstream diaphragm face. Unfortunately, this was on the supposed sealing face of the diaphragm and had the effect of preventing the diaphragm from seating fully and hence from sealing the steam across the diaphragm.

Figure 3. Diaphragm showing weld metal on the sealing face used to reposition the diaphragm axially.

The result was excessive erosion of the seating and sealing face, both of the diaphragm itself and also of the casing. The diaphragms could be welded and machined locally to restore the sealing face, but it was not possible to do this with the casing. A temporary repair has been carried out using Belzona to smooth out the seating in the casing – an inspection is planned for later this year to assess how this repair is surviving.

It is intended that both of the back pressure units will be withdrawn from service following the completion of the current project expansion program in December 2011 (installation of 2 x 38.5 MW condensing units) and so the current repair of the diaphragm erosion problem is only required to provide a temporary solution. Once the units are withdrawn from service, if they are required to be relocated to another project then it will be necessary to return the casings to a service shop that has the facilities to weld repair and re-machine the diaphragm seating grooves.

4. Reservoir Performance

The decision to change the reservoir production strategy from production from SJ4 and SJ5 with injection into SJ1 to production from SJ4 only with injection into SJ5 and SJ6 served the overall objective of commercially demonstrating that the project was viable in terms of revenue realization and functioning of the PPA and concession contracts with the government. However, there was an obvious impact on wells SJ5 and SJ6 in terms of their future use as production wells. Experience at other projects worldwide has shown that potential production wells that have been used for injection purposes can quite readily be converted back to production duty if the well is allowed to re-heat.

4.1 Injection

Some interesting debates arose with the Nicaraguan regulator over the use of SJ5 and SJ6 for injection purposes. SJ5 was converted back to production use at a fairly early stage and in fact recovered for that duty quite quickly. SJ6 was retained on injection duty even after SJ1 was initially connected for cold injection. The regulator did in fact instruct that SJ6 should be taken off injection duty, but the subsequent loss of productivity at a time when Nicaragua was suffering from a shortage of electricity was used as part of an argument to return the well to injection duty, which was agreed to by the newly formed Ministry of Energy, which had then taken over regulation of geothermal operations. SJ6 remained on injection duty until a new injection well (SJ10) was drilled and brought into injection duty. PT measurements showed that SJ6 was much slower to recover than SJ5 had done, and this is probably due to lower permeability in that area of the reservoir. SJ6 remains available for production duty as the project is expanded.

SJ1 injectivity was noted as declining over time and logging of the well indicated a problem with increasing blockage in the well. It is believed that the blockage is caused mostly by silica scale debris from upstream parts of the pipeline that have been periodically cooled, especially when the cold injection system was in use and the HDPE pipeline required frequent repair, in turn requiring the injection line to be shut down temporarily. There may also have been some additional material introduced when pumping the brine dump pond back into the reinjection system, a requirements that has been exacerbated by the frequent plant trips (resulting in brine pump trips) caused by national grid instability problems. The well has recently had a mechanical clean (work-over), which produced a large volume of coarse material which is currently being analyzed, but is believed to be mostly silica, and appears to have largely recovered its former capacity. It is planned to add a strainer into the injection line upstream of SJ1.

4.2 Production

Overall, the reservoir has performed generally as would be expected for a liquid dominated reservoir in this geological setting. There has been some decline in the production wells, and a well drilled in 2007 at SJ9 has been connected to compensate for the reduction in capacity. The SJ9 well has similarly shown an initial production decline, but in line with SJ4 and SJ5. Interestingly, although the total mass flow production from SJ4 and SJ5 has reduced, the steam production from those wells has remained relatively constant, indicating an increase in enthalpy associated with boiling in the reservoir, which phenomenon has been seen in a number of similar reservoirs elsewhere.

5. Conclusions

Overall the project has achieved its primary purpose in demonstrating the commercial viability of a geothermal project in Nicaragua and in particular the monetization of earned revenue. As would be expected, the construction of a project with minimized capital expenditure involved some "short cuts", which in the longer term ended up costing more than if the design could have been implemented in a more optimal manner. The main aspect here has been with the injection system, which over the first 5 years has actually cost somewhat more than would have been initially spent had it been constructed as originally planned. The decision to minimize expenditure at the beginning was the right one at the time but the consequence led to some interesting challenges for the operational team to face and overcome.