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RECOMMISSIONING OF NAGQU POWER STATION, TIBET, PRC

Parkin Low[1] and Grant Morris[2]
[1]PB Power, P O Box 3935, Auckland, New Zealand
[2]PB Power, P O Box 668, Wellington, New Zealand

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ABSTRACT

A geothermal power station utilising a low temperature geothermal resource was established with the assistance of the United Nations Development Program (UNDP) in Nagqu Town in the Tibet Autonomous Region of the Peoples' Republic of China in 1993. Due to the need to maintain the geothermal fluid at reservoir pressures in order to prevent calcite scaling, downhole pumps were utilised to pump the well fluids to the binary power plant heat exchangers. However, this proved to be inappropriate technology and by December 1994, both downhole pumps had failed and the plant became idle.

In 1997, the UNDP embarked upon a programme to re-commission the Nagqu Geothermal Power Station. In order to control the calcite scaling, it was proposed that antiscalant injection would be used to replace the downhole pumps. Associated modifications to the steamfield facilities would also be necessary.

The power plant was successfully re-commissioned on 26 August 1998, although not all of the steamfield modifications had been fully implemented by that time. However, the failure of certain vital components has continued to plague the plant, and the difficulty experienced by the plant operating company to procure replacement parts has seriously affected the plant operation since re-commissioning. It is understood that as of August 1999 the plant was idle, waiting on spare parts.

With such a poor operating history, the Nagqu Geothermal Power Station cannot be regarded as a successful project, and this view is shared by the UNDP. However, the fundamental reasons for establishing a geothermal power plant at Nagqu are sound. There was an acute need for energy (electricity and heat) required to advance the development of an isolated region in a rigorous climate, and the desire to utilise an indigenous resource was logical. Unfortunately, in this case, the combination of factors such as a difficult resource, an arduous environment, lack of facilities, trained workforce and technical skills, and geographical isolation have all worked against the project. The challenge for the future is how to turn projects such as this one, with all of its attendant difficulties, into successes, in order that geothermal energy can make significant contributions to the development of economic and human resources by helping to solve energy shortages.

1. PROJECT BACKGROUND

Nagqu County covers an area of 16,000 km^2 at an average altitude of 4500 m on the North Tibetan Plateau. It has a high-altitude sub-frigid semi-arid monsoon climate that is windy, dry and cold, with heavy snowfall in winter and spring. Annual average temperature is –2.1 °C, and snow is usually on the ground from around September until June the following year.

Nagqu Town, with a population of about 20,000, is the political, economic and cultural centre for the region. It is also the transportation hub, since the Qinghai-Xizang highway (north-south) and the Heichang highway (east to Chengdu) both pass through the town, which is 328 km north of Lhasa, the capital of the Tibet Autonomous Region (see Figure 1).

Most of the county is covered in high-altitude grassland, and grazing is the principal occupation of the inhabitants. The yak is the most common livestock, with a small number of sheep, goats and horses. There are schools, a hospital, various government buildings, and shops and other commercial enterprises in Nagqu Town, but it has very little industry.

For centuries, the yak has provided the Tibetan with food, clothing and fuel. The burning of yak butter gives light, and the dried yak dung is burnt as fuel for cooking and heating. However, yak dung needs to be laboriously collected, and the supply can be disrupted during times of heavy snowfall. Furthermore, it has been recognised that over the years the removal of the dung has deprived the grasslands of their natural fertiliser, resulting in the degradation of the pastures.

Tibet does not have an interconnected electrical grid system (outside of Lhasa), and so each locality operates its own decentralised power plants and local power grid. For some time, Nagqu Town was dependent on several small, ageing and unreliable diesel generating sets of 160 kW each for electricity. The price of power was high (around US¢10 per unit), since the diesel fuel had to be trucked in over many hundreds of kilometres, and system undervoltage was common. The development of the region was being stifled.

By 1985, the government had drilled at least a dozen wells in the geothermal field just 2.5 km from the town centre, and a district heating scheme had been developed utilising the fluid from one of the wells. Therefore, it was a natural progression for a proposal to be made to use the geothermal resource for power generation. The United Nations Department of Technical Cooperation for Development (UNDTCD) agreed to provide some financial support to the project in 1988, and a 1 MW binary plant was commissioned in November 1993.

Since 1995, a 10 MW hydro-electric power plant installed within 30 km of Nagqu Town has been adequately supplying the electrical needs of the town during the summer period. However, the capacity of the hydro plant reduces to 1 MW during the winter due to water freezing in the reservoir, and so there is a need to supplement the power supply in the winter months.

2. THE NAGQU GEOTHERMAL RESOURCE

The geothermal field at Nagqu Town is typical of the 112 known geothermal systems in Tibet (Ren *et al.*, 1995). The wells drilled into the field range in depth from 120 to 700 m, with most between 200 to 400 m depth. They produce alkaline bicarbonate waters from a liquid dominated reservoir with temperatures of 110 – 114 °C. Two aquifers have been inferred, a "shallow" aquifer from 174 to 265 m and a "deep" aquifer below 300 m.

The single-phase reservoir fluids contain dissolved CO_2 gas at a concentration of 5240 ppm (Aquater, 1990). The gas is thought to be of crustal origin. When the fluid is permitted to flash upon a reduction of pressure, calcium carbonate forms and deposits scale at a rapid rate.

It has been concluded from interference testing that the reservoir volume is limited and that rapid drawdown during exploitation is possible. However, the rate of drawdown would be dependent on the rate of aquifer recharge, which is thought to be from the uplift of hot fluids through vertical fractures in the upwelling zone.

3. INITIAL DEVELOPMENT WITH DOWNHOLE PUMPS

3.1 Binary Power Plant & Downhole Pumps

Due to the low temperature of the fluids it was decided, as the first step to producing electricity from the Nagqu geothermal resource, to install a binary cycle power plant. Through an international competitive tender conducted in 1990, the UNDTCD selected and purchased a 1 MW plant from Ormat Industries Ltd. The plant was delivered and installed during the period 1992-93.

In studies undertaken for the UNDTDC in 1989, Aquater recommended that in order to avoid scaling of the wells, pipelines and heat exchangers, either one of two strategies should be adopted for the fluid delivery. These were to

- install downhole pumps to feed the heat exchangers at a pressure above the fluid saturation pressure, or
- produce at the well's natural discharge pressure but inject a chemical inhibitor downhole to control scale formation.

A choice was made at the time for using downhole pumps. However, a consequence of this decision was that two new wells would have to be drilled. The existing wells, although productive, were completed with production casings that were either too narrow for successful pump operation at the required flow rates, or too shallow for successful long term operation because expected drawdown in the shallow reservoir would soon lead to flashing in the well bore. Therefore, new production wells named ZK-1202 and ZK-1102 (also referred to as Wells #1 and #2, respectively) were drilled to the required specifications, including the use of 9 $^5/_8$" production casing. Each well was considered capable of producing the 300 t/h of fluid required to operate the power plant.

The downhole pump specification was produced during a site visit undertaken by GeothermEx, Inc. in 1992. Although the plan was to produce from one well at a time and have the other on standby, concern at uncertainty over the level of drawdown that each well might experience resulted in the simultaneous production of 150 t/h from each well being favoured. The resultant specification was a compromise – variable speed motors would be used, with each pump being designed for the full 300 t/h flow but capable of producing at lower flow rates. The variable speed motors would have the advantage of reducing the parasitic power requirements at the lower flow rates, and also enable the plant to load-follow more effectively.

Centrilift Type 4JB1300 Model JP downhole pumps were procured and installed during the latter part of 1993. The pumps were set at 298 m depth in Well #1 and 264 m depth in Well #2. Transformers to provide the electricity for the motors and buildings to house the pump controls were constructed adjacent to each well. The pump installation and testing was completed on 14 October 1993.

3.2 Operation and Failure of Downhole Pumps and Plant

The Nagqu 1 MW power plant commenced operations on 13 November 1993 with fluid being supplied from Well #2 through the downhole pump. Unfortunately, the collapse of a pump seal caused this pump to fail just 15 days later. Fluid supply was then switched over to the pump at Well #1, but this had to be turned off on 15 December 1993 (after 18 days) when a failure in the plant control computer shut the power plant down.

It took nearly 5 months to repair the plant control computer (in the meantime, no progress was made in repairing the pump seal in Well #2). On 12 May 1994, the power plant was re-started with fluid from Well #1, and was able to run more or less continuously for the next 7 months until 8 December 1994. At this time, the second downhole pump failed due to an electrical fault, and the whole power plant would remain idle for the next 3 ½ years.

Before it was shut down on 8 December 1994, the power plant had managed to operate for 6158 hours and generated 2,230,000 kWh of electricity. A plant output of 1,000 kW or more was achieved during the colder periods, but this fell to as low as 500 kW during the warmer months (June to September) when daytime temperatures sometimes rose to 20°C (well above the design ambient temperature of the binary plant of -1.9 °C). However, the net electricity output was a mere 879,000 kWh, due principally to the large parasitic power consumption of the downhole pumps.

During 1995, the Tibet Geological and Geothermal Team (TG&GT) which is based in Lhasa removed the two downhole pumps from the wells. The two pumps are presently lying abandoned outside the power plant.

While they were operating, the downhole pumps performed as expected, delivering the required quantity of fluid to the power plant heat exchangers while preventing scaling within the fluid system. However, the problems that were subsequently experienced at Nagqu clearly illustrate that even though a solution might be *technically* suitable, it might not necessarily be the most appropriate for the situation. In other words, it is often necessary to look *beyond* the technical solution only.

In the case of the downhole pumps at Nagqu, it is believed that they did not succeed because the technology offered was inappropriate. Because of the complexity of the equipment (real or otherwise) local personnel were not able to troubleshoot and maintain it for themselves, and so immediately looked for assistance from the supplier or manufacturer. However, because the equipment was imported, it was consequently difficult for the Nagqu power plant authorities to obtain service or spare parts. Furthermore, the pumps had to be removed from the wells before they could be examined.

In addition to the aforementioned problems, the downhole pumps had one more drawback – each had a parasitic power consumption of about 300 kW (at full output) which is significant when compared with the total gross output of around 1,000 kW from the power plant. With power plant auxiliaries taking about another 200 kW, the maximum net output from the plant could never be much more than around 500 kW.

4. RE-COMMISSIONING PLAN

4.1 Antiscalant Injection

Antiscalant dosing of the production wells had been considered as an alternative to downhole pumps for the original development. Therefore, when it was realised that the downhole pumps were not well suited to the conditions at Nagqu, the dosing option was revived.

Work on an antiscalant dosing option had started in 1995 with the Thermal Power Research Institute (TPRI) of Xian conducting tests of several antiscalants in surface pipework supplying hot water to a glasshouse. These preliminary tests demonstrated the technical feasibility of the antiscalant dosing alternative. Funding was advanced by the New Zealand Ministry of Foreign Affairs and Trade to enable specialists from Industrial Research Limited (IRL) to coordinate the chemical dosing strategy in association with TPRI. The focus of this specialist input was to promote a local solution to the scaling problem and to assist in the transfer of technology in this and related areas, covering:

- Control of scaling
- Wellhead maintenance and reservoir monitoring
- Reservoir modelling
- Corrosion and materials.

4.2 Plant Inspection and Work Planning

With initial trials of antiscalant injection offering a workable alternative to the downhole pumps, there was a real prospect of re-commissioning the binary power plant. But before proceeding further, an initial inspection was necessary to ascertain the condition of the power plant and ancillary equipment, and to identify any parts required for rehabilitation after three years of inactivity. This inspection took place in August/September 1997 and, in addition to United Nations Development Programme (UNDP) personnel, included a representative of the plant manufacturer plus other technical specialists. The primary objective of the visit was to gather sufficient cost and technical information to enable a decision to be made on whether the rehabilitation project should proceed or not. The following matters were identified as being particularly relevant:

- Condition of the binary power plant
- Condition of electrical cabling and other electrical items
- The ability to electrically integrate the binary plant with the local grid (especially with the presence of the hydro plant)
- Identification of contracts and potential contractors for the rehabilitation site works
- Availability of suitable personnel for training as plant operators.

Based on a range of inspections and tests and a simulated start-up test, it was confirmed that the plant was still in running condition and had not deteriorated to any significant extent. The operations staff had drained the plant of brine when it was originally shut down, and this in conjunction with the low humidity and rarefied air no doubt contributed to the good overall condition of the plant. The estimated cost to recommission the plant fell within earlier budget values and the recommendation was made to proceed with the rehabilitation of the project. A checklist of maintenance activities was left with the operating staff to assist in their preparation for re-commissioning.

In order to avoid repeating the earlier mistakes, it was intended that as much use as possible would be made of local resources. While re-commissioning of the binary power plant was to be directed by the manufacturer (Ormat), the major modifications to the fluid delivery system were contracted to:

TPRI:

- Manufacture and supply of antiscalant chemical
- Supply and installation of dosing system (pumps, tanks control)
- Installation of downhole antiscalant injection tubing.

South West Electric Power Design Institute (SWEPDI), of Chengdu:

- Design of the Fluid Gathering System piping and separator vessel modifications
- Specification of surface brine pumps.

TG&GT:

- Well workover and master valve overhaul
- Piping modifications
- Separator vessel modifications and erection
- Pump installation.

See Figure 2 for a schematic of the new Fluid Gathering System. The prime purpose of the separation vessels was to separate and discharge the non-condensable gases at a safe location, and to prevent cavitation problems with the brine pumps.

It had been planned to initiate the rehabilitation work shortly after this plant inspection visit had established that it was feasible. However, with the onset of winter less than 3 months away, the work was delayed until the following summer.

4.3 Plant Rehabilitation

The rehabilitation work at site commenced in June 1998 with civil work for the separator and pumpset foundations.

Specialists from IRL supervised installation of the antiscalant system and assisted with the initial monitoring and training of local staff to sample and measure key chemical indicators such as calcium levels at the power plant. The antiscalant is injected via a stainless steel line assembled from lengths of tube and compression fittings. The combined efforts of TPRI, TG&GT and the IRL team from New Zealand saw the tubing installed without major difficulty. It is vital that the dosing chemical is delivered to the correct point in the well, below the water level. Therefore, once installed, the integrity of the jointed tubing was confirmed by the injection of dye into the tubing and timing its return to the surface at a convenient tapping point adjacent to the well.

All of the dosing equipment as well as the dosing chemical was sourced locally from within China, and was performing reliably during commissioning and operation of the power plant.

Co-ordination of the power plant re-commissioning was closely linked to the installation of the antiscalant injection system. This system was installed on schedule allowing geothermal brine to be produced and the plant commissioned on 26 August 1998. The Ormat commissioning engineer had arrived 5 days' earlier and had attended to outstanding plant maintenance items and pre-commissioning checks in conjunction with Nagqu operations staff. No major problems were encountered leading up to and during the plant commissioning. Because the separation and pumping system had not been completed at this stage, the plant had to rely on the natural output capability of the two production wells. Gross generation ranged from 550 kW to 700 kW depending on ambient temperature. A number of outages occurred in the initial days of operation due to heat exchanger blockage and incorrect (unfamiliar) plant operation, but these outages were soon overcome and plant availability steadily improved past 85% in the first few weeks of operation.

The Fluid Gathering System was completed on 15 September 1998, allowing the power plant to be fully loaded and generate at or above its design capacity. A total output of 1029 kW was recorded at an ambient temperature of 1 °C.

Key plant design parameters are

• Brine inlet temperature	110 °C
• Brine discharge temperature	80 °C
• Brine flow	300 t/h
• Design ambient air temperature	-1.9 °C
• Gross plant output.	1010 kW

However, the power plant ceased operation in late October 1998 due to a reported governor amplifier failure. Difficulties experienced by the site staff in trouble shooting and sourcing the spare parts to effect a repair saw the plant remain idle for the rest of the winter. With the assistance of technicians from the Jingmen Thermal Power Plant, the Nagqu plant was restarted on 12 April 1999, only to be shutdown 4 days later due to a mechanical seal failure on the binary fluid cycle pump. It is understood that the plant has not operated since.

5. WHY THE PROJECT STILL FAILED

So, despite the earlier setbacks and lessons learned, why has the project still failed to deliver?

Granted, equipment problems and failures have contributed to many of the project's woes, but these can never be totally avoided, and they can be caused or influenced by many factors. Therefore, there is no attempt here to suggest that the project failed due to poor quality machinery or equipment. Nor is it believed that the project failed because those involved in its planning and implementation did not put in sufficient effort.

Rather, it is probably a combination of the following factors:

- The location of Nagqu – its remoteness means long travel times and high cost of access and transportation.
- The harsh climatic conditions - seem to affect the well-being and attitude of the workforce.
- Inexperienced staff – intensive training is required in order that national staff can take responsibility for operating and maintaining all the plant. Unfortunately, personnel who undergo training often move on to other positions outside of the project. This is a matter for the local authorities to address. Exchange of operating and maintenance personnel between the Nagqu geothermal plant and other thermal plant in China would aid the process of knowledge transfer (and this has been proposed to the Nagqu authorities by the UNDP).
- Lack of ready access to spare parts – procurement can be delayed by complex procedures, availability of funds, communications difficulties or indistinct lines of authority.
- Language difficulties – the English language is required for understanding and operating the foreign plant and equipment, but the number of national staff proficient in the language is few.
- Limited organisation and infrastructure - leads to a lack of support for plant management and operation, affecting procedures such as foreign procurement.
- Integration with power distribution system - in addition to technical matters, consideration must also be given to commercial and political factors to ensure the successful operation of a "new" plant as part of an existing electricity distribution system.
- Imported vs local supplies – while it is clearly unavoidable for some plant and equipment to be imported, the use of locally available materials and expertise can ensure that things can be repaired and remain functioning.
- High technology – unless the level of local knowledge and support is high, simple is often best.

However, in spite of the failures, it should be recognised that there were a number of successes during the project such as

- The successful installation of an operational antiscalant dosing system using local equipment and antiscalant chemical.
- The re-commissioning of the binary cycle power plant confirming the earlier assessment that the plant was in good condition.
- The integration of expertise from within China and elsewhere (Israel, New Zealand) to successfully modify and re-commission the overall plant.

6. THE CHALLENGE

The Nagqu experience has identified a number of challenges for the geothermal community to rise up and meet. Some of these are considered to be:

- To find innovative and cost effective ways of dealing with “problematic” geothermal fluids such as those at Nagqu.
- To design and build power plants, using appropriate technology that can utilise the more marginal geothermal resources (lower temperature, more aggressive fluids) as the “easy” ones run out.
- To design and construct power plants to suit not only the resource conditions but also the socio-economic conditions. This means simplicity, durability, and ease of maintenance, replaceable “consumable” parts that are readily obtainable, and a commitment to providing prompt and affordable “after sales service”.
- To design and construct power plants that are environmentally friendly and can be seen to be good neighbours when in the vicinity of National parks or other environmentally sensitive areas.
- To deliver quality technical transfer and training that is effectively matched to local requirements.

It is fully recognised that businesses need to make money in order to survive, and that no-one would be willing to commit money to something that is not going to produce an acceptable return on investment. However, if the geothermal industry is willing to invest in solving problems such as those outlined above, it will be the whole industry that benefits, not just the “development” type projects. After all, the main challenge facing the geothermal community as it heads into the 21st century is how to keep the cost of power generation from geothermal resources competitive. This is particularly relevant as the industry faces intense competition from other cheaper and more efficient power plants such as combined cycle gas turbine plants. Therefore, a commitment to solving the above problems will provide the competitiveness required.

In conclusion, it should be possible for us to help ourselves and our businesses while improving the standard of living of people in less developed countries, and at the same time reducing the adverse effects on our planet.

7. ACKNOWLEDGEMENTS

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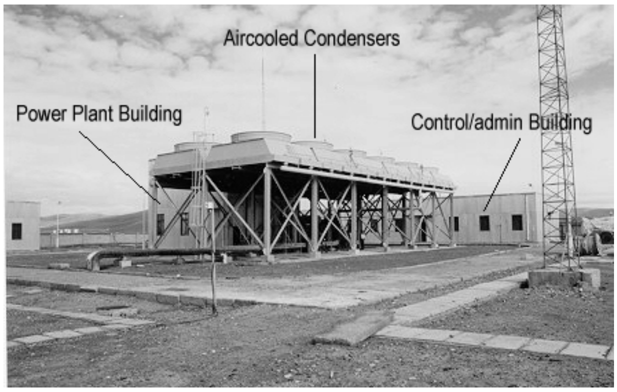

The Nagqu Power Plant

The Nagqu Steamfield. The production pipeline runs from Well #2 to Well #1, then into the power plant at bottom left of photo. The two existing horizontal separators (in middle of photo) were modified into vertical separators for the new Fluid Gathering System.

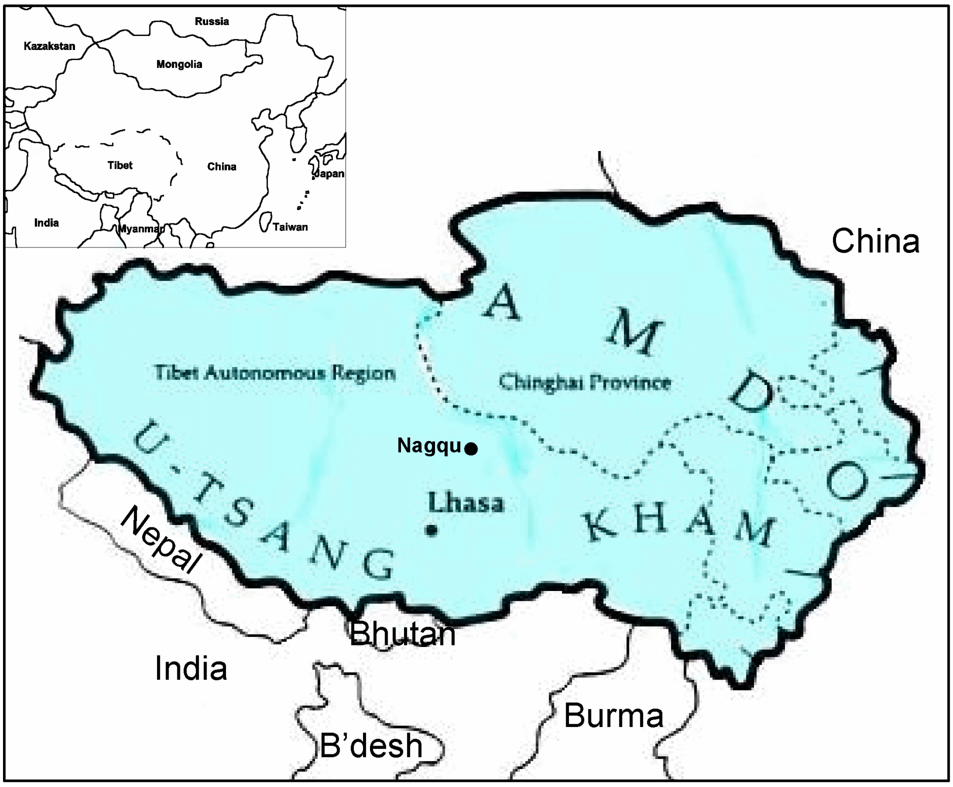

Figure 1. Location of Nagqu in the Tibet Autonomous Region

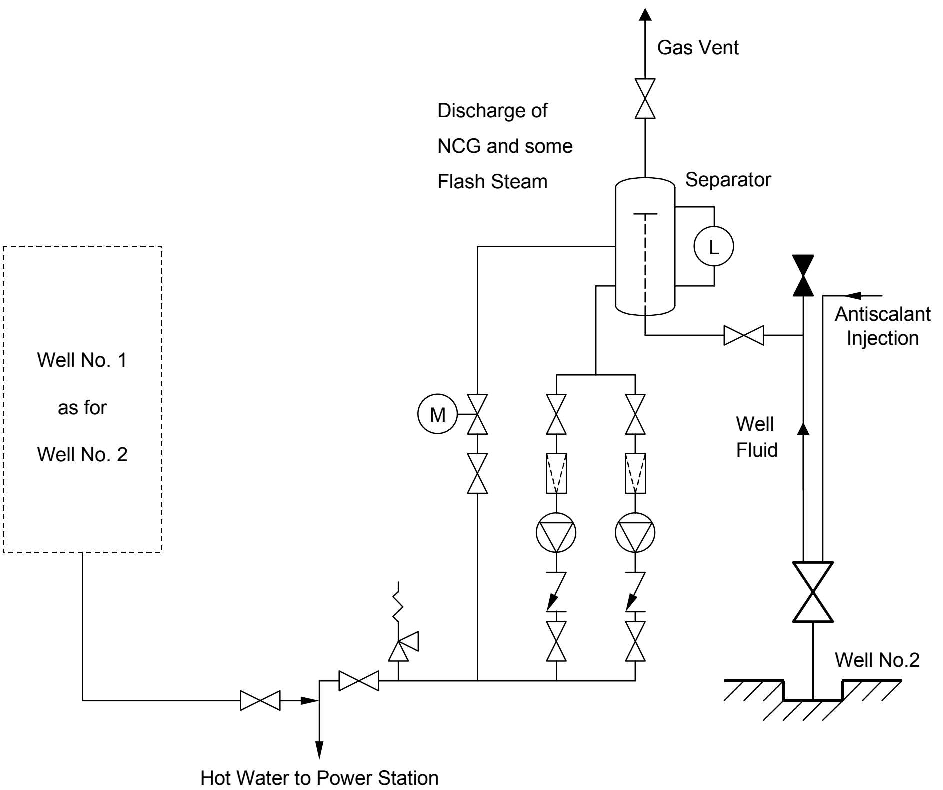

Figure 2. Schematic of the Fluid Gathering System