Proc. 5th NZ Geothermal Workshop 1983

# BINARY CYCLES IN CHINA

Hong-Yi Zhou

Research Institute of
Electrical Construction,
Peking, P.R. China

## ABSTRACT

Four pilot binary cycle plants have been set up in China since 1970, The material presented here discusses the Progress and problems existed in binary cycle research in China, thermodynamic cycle, selection of working fluid, design of heat exchanger, design of turbine, material and chemical considerations etc. are included. It can be expected that binary cycle will make great contribution to the geothermal cause of China.

## INTRODUCTION

In spite of geothermal water8 have been used in China for over 2,000 years and defining geothermal water as that above 20°C in the north and above 25°C in the south, nearly 2,500 springs have been identified ,covering all of China's provinces , municipalities and autonomous regions, but to research and explore seriously geothermal. resources as a renewable energy was just a thing began in 1970. Up to now the progress is still rather rudimentory and it is hard to estimate how much potential geothermal energy can be exploited in China. In over 30 geothermal anomaly areas covering 14 provinces, municipalities and autonomous regions, over 500 exploration wells whose total depth reaches 80, 000 m were drilled, mostly shallow ones. Downhole geofluid temgeratures of most wells were less than 100 C.The highest temperature encountered was 170°C at depth of 130 m in Yangbajing, Tibet. In Tengchong, Yunnan Province, 145° C was encountered at depth of 12 m. In Fujian and Guangdong Province, temperatures of some wells were just more than 100°C. Primary result of exploration shows that most of geothermal. fields in China are of low-grade energy sources.

China began to research steam flash cycle and binary cycle in 1970 for utilizing these low-grade energy *sources* for generation. Binary cycle has many advantages over steam flash cycle, such as much higher specfic output, good ability to exploit low-grade energy sources, fairly compact turbomachinery, smaller size of pipeline, the whole expansion process of cycle operated in dry condition, no droplet erosion, confining chemical problems to the heat exchanger alone, easy to re-inject·etc. So it can not be denied that the future of binary cycle is more brilliant than steam flash cycle in exploiting low-grade energy sources. This paper mainly introduces binary cycle research in China,

## GENERAL DESCRIPTION

The Huailai Pilot Binary Plant is located in Huailai County, Hobei Province about 92 km N-W of Peking. Early in Feb. 1971, ünder the leadship of China's Ministry of Electric Power, the research Institute of Electric Construction et al. were in charge of setting up the pilot plant. By the time three wells had been drilled with total mass flow rate of 210 t/h, average temperature of 83°C, well casing of 1-10" and 2-12", average depth of 79 m. All equipments were remade of second hand, except deep well pumps and an evaporator. The plant was commissioned in Sep. 1971 and some experiments and redesigning equipments have been done or made since then. The plant is rated at 200 KW, with a maximum output of 285 KW. The sum total of operation hours are up to 30,000 with the longest period of 3,400 h. Waste geofluid was used for multi-purpose utilization such as greenhouse, bathing, sanitorium.

Wentang is located in the west of Jiangxi Province, about 21 km of Yichun City. One 8" well had been drilled with depth of 69 m, temperature of 66°C, mass flow rate of 80-100 t/h before the plant planning. Wentang Pilot Binary Plant rated at 50 KW was completed in Sep. 1971, almost same time as Huailai, by Jiangxi Hydrogeology Team, Tianjin University et al. The interesting thing is that neither deep well pump nor cooling water pump is necessary. Both geothermal water and cooling water flow by themselves. Some experiments and redesigning equipments have been done or made during the last ten years. Waste geofluid was also for multi–purpose utilization.

Fengshun is located in the N–E of Guangdong Province, about 70 km of Shantou City. No 1 of a flash steam turbine had been there. NO 2 unit of fengshun is a binary cycle type rated at 200 KW. It was completed in April 1977 by Kuangdong Renewable Energy Research Institute,the Academy of Sciences of China. Geothermal water from wells is 92°C, Mass flow rate of 240 t/h, without deep well pumps.

Xiongyue Pilot Binary Plant is located in Liaonin Province, about 64 km from Yingkou City. Two wells had been drilled with total flow rate of 120 t/h, temperature of 80°C. The plant was commisioned in May 1978 rated at 100 KW.

The design specifications for four pilot binary plants are given in table 1.

## THERMODYNAMICS CYCLE AND SELECTION OF WORKING FLUID

Since the temperature of geothermal waters were very low, no other cycle could be selected except simple Ranking cycle for these four pilot plants.

Thermophysical, transport and other properties of over ten hydrocarbons or fluorocarbons had been compared. Then ethyl chloride, n–butane, iso–butane, F-11 F-113 were tested.

To select ethyl chloride as a working fluid is due to higher specific output, less power consumption by cooling water pump and working fluid pump. The operation experience in Huailai showed that was really done, but bad corrosion was induced when the water was contained in ethyl chloride fluid. Since no simple and economical way could be found to remove the water effectively from ethyl chloride, ethyl chloride was substituted by n–butane in Huailai. Ethyl chloride corrosion will be mentioned later in detail.

The result tested in Huailai showed n–butane was cheap, non–corrosive, although with less specfic output, higher power consumption of working fluid pump than ethyl chloride. This is why n–butane is in

Table 1. Specifications for four pilot binary plants in China

| Plant name<br>Generating date | Huailai<br>Sep. 1971 | Wentang<br>Sep. 1971 | Fengshun<br>April 1977 | Xiongyue<br>May 1978 |
|---|---|---|---|---|
| Type | Impulse, 3–stage, Axial–flow. | 1–stage, Radial–inflow, geared | Impulse, 2–stage, Axial–flow | Impulse, Axial–flow. |
| Rated capacity | 200 KW | 50 KW | 200 KW | 100 KW |
| Speed, turbine/generator | 1,500 rpm | 4,500/ 1,000 rpm | 3,000 rpm | 1,500 rpm |
| Secondary working fluid | Ethyl chloride /n–butane | Ethyl chloride | Iso–butane | F–11/n–butane |
| W.F. inlet pressure | 4.1 bar | 3.4 bar | 12.2 bar | 3 bar |
| W.F. inlet temperature | 55"C | 48°C | 74°C | 6.3"C |
| W.F. exhaust pressure | 1.7 bar | 1.9 bar | 4.2 bar | 1 bar |
| W.F. exhaust temperature | 25.5°C | 30°C | 45°C | 23°C |
| W.F. mass flow rate | 43.4 t/h | 12 t/h | 26.2 t/h | 43 t/h |
| Geothermal fluid data: | | | | |
| Inlet pressure | 3 bar | N.A. | N.A. | N.A. |
| Inlet temperature | 85°C | 67°C | 91°C | 80"C |
| Outlet temperature | 55°C | 58°C | 52°C | 57°C |
| Mass flow rate | 163 t/h | 120 t/h | 134 t/h | 76 t/h |
| Condenser data: | | | | |
| Type | STST | HFSTST | LGSTST | BPFCST |
| C.W. inlet temperature | 15°C | 20°C | 23°C | 12°C |
| C.W. outlet temperature | 20.5°C | 27°C | 28°C | 17°C |
| C.W. mass flow rate | 890 t/h | 108 t/h | 439 t/h | N.A. |

W.F. = Working fluid; C.W. =Cooling water; N.A. = Not available; STST = Shell–and tube, surface type; HFSTST = Helical–fin shell–and–tube, surface type; LGSTST = Longtitudinal-groove shell–and–tube, surface type; BPFCST = Brazed-plate-fin condenser, surface type.
Two secondary working fluids mean both tested in different time.
The data in Huailai is for ethyl chloride. The data in Xiongyue is for F-11.
An axial–flow impulse turbine and a spiral–plate condenser were initially used in Wentang, they were substituted afterwards.

use in Huailai now.

Iso–butane is used in Fengshun. Its specific output is not as high as n–butane, power consumption of working fluid pump is higher than n–butane.

The advantage of F-11, F-113 as a working fluid is safety. Specific output of F-113 and F-11 are higher than n–butane and roughly same as n–butane respectively. Power consumption of working fluid pump of F-113 and F-11 are less than n–butane. Expensive in China, unstable at temperature much above 120°C, corrosion induced to over 2 ppm water contained in fluid are the disadvantage of F-11 and F–113.

Other cycles such as flash/binary cycle supercritical cycle, direct contact cycle will be studied in the near future in China. To find a more ideal working fluid is still a study task.

## HEAT EXCHANGER AND CONDENSER

Simple shell and tube heat exchangers were used in pilot binary plants in early stage. Because heat exchangers represented about 20 % of the conversion system cost and organic heat transfer coefficients were very low, so that attempts were made to improve heat exchanger.

Brazed–plate–fin heat exchanger, spiral–plate heat exchanger, helical–fin shell and tube condenser, longitudinal–groove shell and tube condenser and direct heat exchanger were tested. Brazed-aluminum alloy–plate–fin heat exchangers were made up of a stack of layers, with each layer consisting of a straight corrugated fin between flat alloy sheets sealed off on two sides by channels to form one passage for the flow of fluid. The type of heat exchanger used in Huailai as an evaporator is a compact, lightweight reversing unit with up to 1,000-1,500 sq. m of total heat transfer surface per cubic meter of heat exchanger volumn. It could be designed for pressure up to 40 bar. The disadvantages of this unit are big friction, only used in the condition where no scale deposits since it is hard to clean and maintain. Fortunately the geofluid in Huailai is so clean that no scale could be found. The over–all heat transfer coefficient is 1,050 - 1,400 W/m²°k. It is still used in Huailai.

Spiral–plate heat exchangers used in Fengshun and wentang as an evaporator and condenser respectively are made from a pair of mild steel plates rolled to provided two relatively long rectangular passages fro working fluid and brine or cooling water in countercurrent flow. The continous path eliminates reversals and accompanying pressure drop, by-passing and differential–expansion problems. Scale deposit could be removed by chemical process. The design of unit is compact, for example, 166 m of heat transfer surfac was provided in a unit of 1.3 m dia. and 4.6 m height with 39 m long path in the evaporator of Fengshun. It could be designed up to 12 bar abs. for pressure and 1,170 W/m²K for over–all heat transfer coefficient which is similar to the operation datum.

Helical–fin shell and tube condenser and longitudinal-groove shell and tube condenser are used in Wentang and Fengshun respectively. The former over–all heat transfer coefficient is 1,628 –2,617 W/m²K as testing value, the latter is about 1,860 W/m²°K. Direct heat exchanger was tested in Huailai. Bad corrosion happend, water droplet contaminated the working fluid and working fluid loss was made by its partial solubility in geofluid. Soon the unit was dismantled.

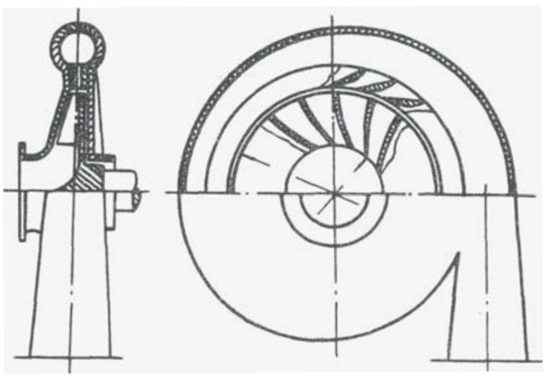
To improve heat exchanger is still a important task in the future.

## TURBINE

Turbine used in Huailai was initially an old, ready to be scrapped, six–stage, impulse steam turbine. It was rated at 750 KW turned 6,500 rpm and geared into generator with 1,500 rpm. for remaking it, the first three stages had to be removed, turbine changed its rotation speed to 1,500 rpm, the diaphragms were redesigned in order to reequip it as an organic turbine. The disadvantage of using reequiped turbine is low internal efficiency, only 65 - 68 %.

Instead of the old axial flow turbine, a single stage, cantiliver shaft

Figure 1. Simplified sectional view of radial–inflow turbine in wentang.



radial-inflqw turbine made by Jiangxi Hydrogeology Team et al. was installed in Wentang in May 1974. It is simple, cheap, 80 % interal efficiency, *mainly* made by mild steel, typical machine of the type used for low grade applications. (Fig 1) Most Chinese specialists think it *may* be better to use radial-inflow turbine than to use axial flow turbine in small capacity, low grade energy applications.

## MATERIAL AND CHEMICAL CONSIDERATION

Chemical analysis of liquids from wells in four plants is *shown* in table 2. Corrosion and scaling can usually be tolerated in these four plants. The material used in equipment is very common, such as mild steel, copper, aluminium etc, This may be just the advantage of using binary cycle. In the condition ethyl chloride as a working fluid, corrosion happend, especially in the brazed-aluminium alloy-plate-fin heat exchanger and hot well of condenser in Huailai. Brass is usually satisfactory, mild steel is worse, aluminium could not be tolerated for corrosion. Two reasons could be found. One was that air leaked in during the unit shut off, the other was that chemical reaction happened between ethyl chloride and remaining water. The chemical equation can be shown as below.

$$C_2H_5Cl + H_2O \rightleftharpoons C_2H_5OH + HCl$$
$$Fe + 2HCl \rightarrow FeCl_2 + H_2$$
$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl$$
$$2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$$
$$AlCl_3 + 3H_2O \rightarrow Al(OH)_3 + 3HCl$$

The use of aluminium should be avoided, and the water content of the ethyl chloride should be confined lower than 10 ppm according to the experience.

## OPERATION EXPERIENCE

Noncondensable gases existed in ethyl chloride cycle. It raised the exhaust pressure and decreased the output. Chromatography showed some impurities existed in ethyl chloride fluid, mainly methyl chloride, methyene-bis-chloride, chloroform. In order to keep the operation data, removing the noncondensable gases was necessary. Some minor improvements solved this problem.

## ECONOMIC FACTOR3

Average cost of the four pilot plants was $ 3,000 -4,000/Kw, two to three times figure for a same capacity of a thermal power station per KW. High cost resulted from added research expenses and bad management. The average cost of electricity was about 66 mills/KWH, roughly equivalent *to* the cost of same capacity thermal power station. Specialists estimated that the capital cost could be decreased to 8 1,500/KW and the cost of electricity to 40 mills/KWH, if no research expenses added and management improved. Moreover waste geofluid could be used for multi purpose utilization. The cost of electricity from binary cycle plants is clearly much less than 40 mills/KWH.

## CONCLUSION

Since 1970, in the condition no international interchange, Chinese specialists independetly *engaged* binary cycle experiments. Either in design and manufacture of turbine and heat exchanger or in selection of material and working fluid certain progress has been gained. Although compared with advanced countries certain gap still exists. In spite of it is not satisfied in economical due to low temperature of geothermal water, The author thinks that binary cycles not can be done technically but also can be satisfied in economical if temperature of geofluid is over 120 -130°C. It may be better to use binary cycle in Yangbajing geothermal field, Tibet. The specific out put of 17.2 KWH/Ton for brine at 137°C, dryness of 10.9 % can be done, roughly double over the single flash cycle used in Yangbajing now. Moreover, some tecnical troubles such

Table 2:
Chemical analysis of liquid from wells at Huailai, Wentang, Fengshun and Xiongyue

| Location<br>Well Number | Huailai<br>No. 2 | Wentang<br>ZK-33 | Fengshun<br>No. 11 | Xiongyue<br>SK-1 |
|---|---|---|---|---|
| | | | .2 | |
| PH | 8 | 7.5 | 7.1 | 8.4 |

as scaling, corrosion can be expected to improve. This will be discussed in other paper.

The research progress of binary cycle gained in the past ten years in China is bound to make great contributions to the geothermal and waste heat utilization cause of China, along with improvement of economical management, going a step further in raising the level of geothermal exploration, evaluation, exploitation, promoting international interchange.

## ACKNOWLEGMENTS

The author wishes to express his appreciation to Mr. Lu Guang-Chao, Senior engineer, the Research Institute of Electrical. Construction, China's Ministry of Electric Power for his encouragement and assistance in writing this paper. The author is indebted to Mr. Liu Jin-Sheng for providing valuable informations and data.

## REFERENCES

1. 怀来地热发电组。氯乙烷工质地热发电总结。1975年7月，未发表。

(Huailai Geothermal Generation Group, "Summary on Geothermal Binary Cycle Using Ethyl Chloride as Working Fluid." July 1975, Unpublished.)

2. 刘金声等。关于低温地热水发电技术经济性的探讨。1980年，未发表。

(Liu Jin-Sheng et al. "Evaluation on Economics and Technology of Low-grade Geothermal Generation." 1979, Unpublished.)

3. 江西省地质局水文地质大队等。温汤地热电站试验研究报告。1978年8月。未发表。

(Hydrogeology Team of Jiangxi Geology Breau, et al. "Research Report on Wentang Geothermal Pilot Plant." Aug. 1978, Unpublished.)

4. 胡亮光等。双流体双循环地热发电幅流式汽轮机的研究。1978年10月，未发表。

(Hu Liang-Guang et al. "Research on Radial-inflow Turbine in Binary Geothermal Generation." Oct. 1978, Unpublished.)

5. 中国科学院广州能源研究所等。丰顺邓屋异丁烷"双流系统地热试验电站"，初步运行经验。1978年11月，未发表。

(Kuangdong Renewable Energy Research Institute, Academy of Sciences of Chins et al. "Primary Operation Experience in Fengshun Pilot Binary Cycle Plant." Nov. 1978, Unpublished)

6. 营口市地热利用试验站等。熊岳地热电站用氟利昂11为工质发电试验。1978年6月，未发表。

(Xiongyue Pilot Binary Plant, et al. "Generation Experiment Using F-11 as Working fluid in Xiongyue Pilot Plant." June 1978, Unpublished.)