Design and Evaluation of Geothermal Steam Separators: A Review of the State of Art

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ABSTRACT

A compilation, review and analysis of the current "state of art" of different theoretical and practical aspects on the design and evaluation of geothermal steam separators, up to 2014, is presented in this paper. In addition, various computational work tools for designing and evaluating the behavior of geothermal steam separators are included. Most of these programs are based on the theory Lazalde-Crabtree to validate its operation, which is fundamental and applicable reference work for this end. The main goal of this work is to review the background for the development of a computational tool which can be used to design of new equipment and to evaluate the current performance of existing steam separators which have been under operation for a long time, particularly in the Cerro Prieto Geothermal Field (CPGF), México.

1. Introduction

Most geothermal fields in the world are liquid-dominated geothermal field, producing liquid and steam. The steam must be removed to feed the turbines in separation equipment that are normally centrifugal or Webre type. The main function of separators is the elimination of the liquid portion the mixture of geothermal fluid, this is achieved by separating the water which carries the salts and dissolved solids which cause scaling and corrosion into the equipment, mainly the turbines.

The purity (percent vapor) of the separated vapor predominantly depends on the input speed of the mixture to the separator, as well the physical characteristics of the equipment. Therefore, it is necessary to analyze the available historical information about the operating conditions (process variables) separators and dryers, in order to verify if this equipment have remained operating within the range for which they were designed.

It has been found that Lazalde-Crabtree methodology is used worldwide for the separation equipment design, and computer programs which also include evaluation of operating equipment.

In this paper a literature review is presented to determinate the current "state of art" of the design and evaluation of geothermal steam/water separators. In addition, the literature reviews was carried out worldwide, in order to know the solutions that have been implemented in other geothermal plants, especially those with similar characteristics of Cerro Prieto.

This review aims to be the fundamental basis for the design of a new computer program to design or evaluate separators and dryers. This software will assess the performance of the separators and dryers of the Cerro Prieto Geothermal Field (Typically Webre-Type).

2. Literature Review

The search was conducted by selecting and analyzing available published literature in the liquid-dominated geothermal field.

The literature review was conducted with special emphasis in cases where the conditions and design recommendations particularly those operating in geothermal fields dominant fluid.

The following summarizes important aspects and / or the conclusions drawn by some research related to the design and evaluation of Webre-type separators and dryers: theories, methods, procedures of the design of separators and dryers, assessment techniques of work efficiency and some cases design computer programs are presented for the equipment evaluation.

Bangma (1961) established that the cyclone separators with vapor discharge at the bottom outlet cyclone (BOC) had a number of advantages compared to those who had the discharge the top, mainly its simplicity (no internal fittings) as corrosion and erosion problems are avoided. Consequently, this simplicity meant a lower cost (see figure 1). After theoretically analyze the variables that would affect the performance of the BOC, Bangma concluded that separate steam quality was a function of the steam-water mixing ratio and the input speed of the separator. One interesting variable is the pressure drop, which increases with the variables mentioned above. A pilot test separator 30 inches was used in the geothermal fields of Wairakei and Kawerau. The purpose of the tests was to obtain design parameters to enable the designs of larger separators. In addition, specific tests were conducted to evaluate the performance of the input geometry to the separator: (a) tangential inlet; and (b) spiral entry. In this series of tests one inlet pipe 10 inches in diameter, was used in each case, and the diameter of the separator and the height of the inner tube steam discharge, which represent the highest separation efficiency, was determined in terms of steam quality. Importantly, in this paper a series of graphs, whose analysis allowed Bangma to propose that the dimensions of a BOC are relative to the inlet diameter as a function of the steam/water ratio the mixture are presented.

The results of the tests in the separator 30 inches in diameter, using water-steam mixture with 3.5% by volume of water indicated that the optimal speed of the inlet to the separator was 220 ft / s, which produce a higher quality of 99.5 %. Recommended for inlet diameter dimensions D are: (1) diameter separator = 3D; (2) diameter of the outlet pipe of water and steam = D; (3) length of the inner tube of the steam discharge = 4L (inlet above the mixing and (4) the location of the discharge water = 3D (below the mixture inlet).

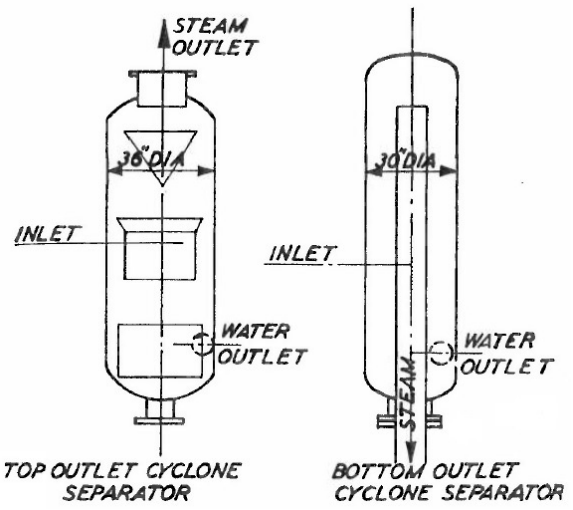

Figure 1. Schematic diagram of top outlet cyclone separator (TOC) and bottom outlet cyclone separator (BOC).

Awerbuch et al. (1982) present a design study of steam separators and analyzing the implementation of the spacers in two cases of plant design 50 MW. The first case, represented by the presence of high salinity and high temperature brine as found near the Niland area of southern California. The second case represented by the presence of moderate-temperature and low-to-intermediate geothermal fluids. Design requirements cyclonic separators steam is exposed: the guide for separation selection and design, test objectives, methodology of calculating the separation efficiency, design of a unit test, chemical analysis exposed and the development of a testing program applied to a well of East Mesa, south of California. This work is based on Bangma (1961).

The design and test result performed to a separator indicates two parameters affect separation efficiency: speed two-phase inlet and the mass fraction of liquid in the incoming mixture. The main recommendation for the design of the separator is to use high-speed input mixture to improve the separation efficiency; this also allows cost savings in the capital. This work concludes that for 12-inch inlet, speeds should be 18 m / s. In the presence of high salinity brine or brine with high silica content, a second separator is required.

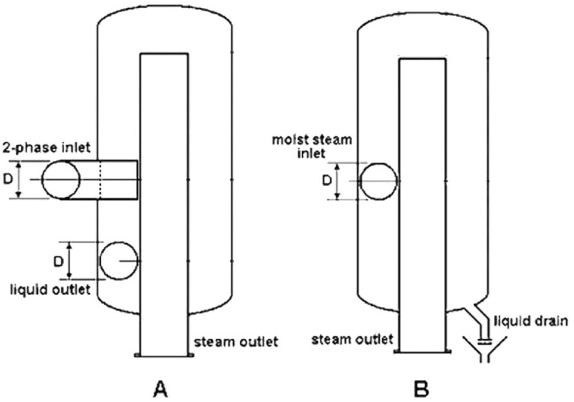

Figure 2. Schematic diagram of steam-water separator (A) and steam dryers (B).

Lazalde-Crabtree (1984) shows in detail the results of the design characteristics of steam-water separators and steam dryers for geothermal applications, see figure 2. This empirical study presents a series of guides, for example: process design, process calculations, the recommended design parameters, mechanical design and / or civil specifically the characteristics of diameter the equipment, methodologies are shown and mechanisms governing the operation of the equipment.

Work of Lazalde-Crabtree aims ensure the quality of separated steam required by the project or up to 99.9 percent. The methodologies developed in this work allow more economical equipment design, considering the lowest possible

pressure drop. An illustrative example is designed for a geothermal secondary separator ensuring quality steam in a 99.95 percent. This example returns the following: design dimensions, calculations centrifuged efficiency, drop particle, flow pattern, efficiency, outlet steam quality, liquid velocities, steam and mixture pressure drop.

Lazalde-Crabtree concluded that Webre-type separator is the best for geothermal applications.

Buendía (1985) conducted a series of studies aimed at determining the behavior of dryers Unit 1 of Cerro Prieto Two (CP2), México, as there have been problems plugging the strainer at the turbine inlet. The activities carried out were of two types: (1) determine the quality of chemical vapor and calorimetrically measuring water content and (2) chemical analysis of the sampled deposits. The tests were conducted at different loads of the turbine 25, 40 and 100 MW.

The test results show a good performance of the dryer, from the viewpoint of the removal of moisture, as measured steam quality was approximately 99.99 %. However, the main problem is to steam purity because the solids separation efficiencies were on the order of 33%, for the above-mentioned quality. Chemical analyzes of the scale indicate various corrosion products, which was considered to have had their origin in the formation of condensate and stagnation. At evaluating method, the chemical method is more suitable for measuring vapor purity, while the calorimeter method is for determining humidity. Buendía recommended avoid ingress of oxygen in pipes and to steam blow the pipe, so there is no risk of ingress of solid to the turbine. It is also convenient to install active drain between dryer and the turbine inlet steam, as well as monitor quality through conductivity.

Buendía and Gutierrez (1986) conducted a study to determine the criteria for the design of dehumidifiers for geothermal use. They did a review of the equipment used in geothermal plants installed in various countries such as Japan, Italy, USA, New Zealand, El Salvador and Mexico. For equipment installed in Mexico, was reviewed in detail in installed geothermal fields of Cerro Prieto and Los Azufres. The case study discusses some of the variables that differentiate each use such as the characteristics of the brine and operating conditions. The criteria for the design of dehumidifiers take into account the following parameters: (1) degree of maintenance; (2) pressure drop; (3) number of accessories; (4) separation efficiency; (5) a separate particle size; (6) operating expenses; (7) limitations on pressure; (8) steam inlet velocity; (9) possible causes of failure; (10) effects of flow fluctuations (pressure output); (11) moving parts; (12) operating techniques; and (12) life team. Four types of analysis equipment subjected: (a) gravitational; (b) inertial impaction; (c) centrifugal; and (c) steam washing.

The result was that Webre type separators were best suited for its simplicity, high separation efficiency, low cost of operation and maintenance. One drawback of these separators is their low efficiency in the separation of solid particles less than 10 microns. This report presents a detailed methodology for the design of dehumidifiers, which includes the criteria (wet steam inlet tangential circular section out of water in the lower head, etc.). Furthermore the design parameters (steam input rate must not exceed 60 m / s , are set preferably to be between 35 and 50 m / s , rate of rise of the steam should not exceed 6 m / s , 1.25 to recommending 4 m / s); geometric relationships of the dryer parts are also established in terms of the diameter of the mixer input.

Caceres (1988) presents the data analysis (10 years) of the variation in the quality of steam separated in Ahuachapán Geothermal Field, Salvador. Since the launch field, types Webre separators were designed for an input stream. Over time, the output characteristics wells vapor has changed, so that the performance of the separator well. Variations in performance are analyzed to verify the design or redesign of separators based on the basic methodology: Bangma (1961), Awerbuch et al. (1982) and Lazalde - Crabtree (1984). Its main conclusion is based on the design methodology Lazalde-Crabtree (1984).

Ayodo (1992) designed a center efficient separation system. For the design of separator, the best options are Webre separators type, since the vapor rate is 20 to 40 m / s in Northest Olkara Geothermal Field. It takes a detailed description of the geological structure, the distribution of pressure and temperature field, geochemical analysis and steam flow, hydrology, field characteristics (lithology and aquifers), the discharge characteristics of wells, the reservoir model, the design of piping system, the physical characteristics of pipe, calculating the pressure drop to two-phase flow and the costs are calculated is described. In this paper the design and construction of Webre separators type based on the calculation procedures specified Lazalde-Crabtree. This methodology is recommended in this work to ensure the best conditions for equipment operation.

Henríquez (1997) determined the optimum pressure for the technical operation of Power Station the Berlin Geothermal Field, El Salvador. Guide calculations and optimization are performed to select the first plant condensate field. A detailed description of the following: geothermal field, design plant (single flash), the optimal pressure input to the turbine, design and characteristics of the steam turbine, the efficiency of energy conversion cooling system design, cooling towers, condensers and calculations of energy consumption. One of the most important design considerations is the purity of steam, so in this work the cyclonic separators type is used. The reference design of such equipment is based on information separator installed in Svartsengi, Iceland. The operating pressure in the separator should be 11 bar.

McKibbin (1998) describes the steam flow patterns and pressure distribution within a typical cyclone separator which is operating at saturation (boiling or flashing) conditions. The mass and volume fractions of the gas (steam) and liquid phases to be separated are for a typical two-phase flow example. The steam fraction occupies most of the separator vessel

volume. The analysis of the motion of this steam phase allows the depiction of the stream surfaces within the flow and an estimate of the pressure drop across the separator. The solution of a set of simplified conservation equations are found by analytical and numerical methods. This numerical analysis is applied to typical separator vessel dimensions at Wairakei.

DiPippo (1999) describes the design conditions, the thermodynamic efficiency and the economics of construction and operation of the various geothermal plants: dry steam, single flash, and double flash and binary cycle. A description of the equipment typically used in each the four geothermal plants is performed. Webre type dryers are used in the first three geothermal plants. Webre separators type deal in plant single and double flash. Part of the conclusion of this work is based on the Geothermal Energy, is now an alternative energy source and tested for power generation. Due to its economic competitiveness, security of operation of plants and nature with the environment, geothermal energy will continue to serve these countries endowed with natural energy resources.

Sánchez et al. (2002) present a study the importance of separators, steam dryers and steam pipelines in Geothermal Fiel ds in Mexico, in order to improve the purity of the separation of water - vapor and efficiently, increase vapor a supply geothermal units. An analysis of the transient effect on separation equipment Los Azufres Geothermal Field, Mexico, corrosion presented on the surface of equipment and chemical analysis in the purges located along the pipes is carried out.

Foong (2005) presents the conceptual design and operation of water-steam separators type Webre, which proposes a new equation to calculate and improve the separation efficiency. The designs of the separators are applied to Wairakei Geothermal Field, New Zealand. Separation efficiency of 99.97 %, which is 0.03% brine for a 100 MW plant is affirmed. The design also reduces the pressure drop through the separator and improves access to the internal inspection of the separator. It indicates that the use of separators type Webre started from the 50's. In this paper the development of a separator is specified using the methodology Bangma (1961).

To calculate the efficiency of the separator Lazalde-Crabtree (1984) methodology is used. This paper specifies the separator efficiency is a product of mechanical efficiency and void represented as an expansion of the initial equation Lazalde-Crabtree, valid only if, separation mechanisms occur in "parallel" after the initial separation. The modification presented here to the Webre separator type is performed by installing a plate or below the ceiling plate separator and draining fluid collected in the center of the steam pipe to the main stream of brine. Using an inverted cone could also improve the dynamic input and possibly improve the pressure drop.

Pointon et al. (2009) show the development of a computer program CFD "Computational Fluid Dynamic" for the design and optimization of geothermal cyclone separators. This software is used the work of Bangma (1961) and the traditional design Lazalde-Crabtree (1984) as the basis for developing an inhouse separator design methodology, and this has been applied over many years to many projects. CFD has been used to provide for the structural loads of the finite element analysis (FEA) of a separator. Design calculations work Lazalde-Crabtree predicts a separation of 99.955 percent. This information is the main base of the computer program with the CFD results very favorable returns.

Horie et al. (2010) describe the main features of separation, steam wash system, the brine reinjection system, power generation and steam control field applied to the Kawerau Geothermal Power Station, New Zealand. The work indicates that Webre type separators are the teams currently used in the geothermal industry to remove as much of brine and impurities such as silica. The correct separation of these impurities prevents turbine maintenance out over short periods of time and that their costs are lower.

Glassley (2010) mentions in his book that one of the important factors in the performance of generation systems is the quality of steam inlet the turbine, also makes a brief description the operation of centrifugal separators and mentions some design features recommended by Lazalde-Crabtree (1984).

Barrantes (2012) in his thesis mentioned methodology, the geometric relationships and considerations that must be taken into account to design a Webre-type separator and dryer. The reference is a course taught by Electrical Research Institute "Design of the Main Training Components of a Steam Cycle Power plant", held at the Miravalles Geothermal Plant, Guacanaste, Costa Rica.

DiPippo (2012) mentioned in one chapter of this book, the emphasis of importance of water-vapor mixture separation since the liquid entrained in the vapor causes fouling and / or erosion in pipeline and components turbine. Steam quality should be at least 99.995%, also refers to the design parameters of Webre-type drying and separators of Lazalde-Crabtree methodology.

Purnanto et al. (2013) presents the development of software to simulate two-phase fluid movement inside a geothermal cyclone separator. The software is called "Fluent CFD", which has the characteristics of the input flow, verifies the enthalpy flow rate, the performance of the separator and the effect of performance the separator with different inputs. In order to model the flow turbulence as in the interior of the separator, the turbulence model Renormalization Group (RNG) k - ε is implemented. Performance Simulation CFD (Computational Fluid Dynamics) is validated with the Lazalde-Crabtree (1984) empirical approach. The turbulence model (RNG k- ε Fluent) is suitable for use as a first attempt in the CFD analysis. In the CFD analysis, they conclude that he was able to visualize the behavior of the two phases within the separator, a feature that you cannot take with an empirical approach. The patterns of pressure distribution and velocity

profiles according to the existing methodology and results presented indicate that the CFD is a promising tool that can be used to optimize the design of the separator.

Zarrouk and Purnanto (2014) pointed out that several existing geothermal fields show two common separator designs, the vertical cyclone separator (also known as Webre separator) and the horizontal separator. Both designs are reported to have high separation efficiency in the order of 99.9% or higher. Vertical cyclone designs are based on the experience at Wairakei and Kawerau (New Zeland) in the 1950s and 1960s, and the modeling work by Lazalde-Crabtree (1984), while the principles of the geothermal horizontal separator design were only reported by Gerunda (1981). Horizontal separators are normally found at power stations from Iceland, Japan, Russia and USA. Based on the reported data, about 70% of power plants use vertical separators while 30% have horizontal separators. At present, the vertical separator with spiral inlet and bottom outlet cyclone (BOC) is the most common design used by the industry, while tangential inlet and top outlet cyclone (TOC) are no longer being used.

Practical aspects on the optimum location of the separator, the main separator design considerations, as well as recent concepts in separators design are presented and discussed in this paper. Their main conclusions are that the design and construction of cyclone type separators worldwide are based on the procedures specified by Bangma (1961) and Lazalde-Crabtree (1984). In addition, for a better understanding of the fluid behavior within the separator, Computational Fluid Dynamics (CFD) should be used.

Odhiambo (2015), in his BSc Thesis, developed a model that can be used to optimize the steam gathering and the re-injection systems in Menengai Geothermal Field (MGF), Kenia. This work includes the capital investment and the operational cost. The constraints are the steam and water velocity and the upward slope of the two phase flow pipelines. To test the model, different scenarios are analyzed considering different location of the power plants, the separators and the re-injection system. For each scenario the variable topography distance transform is used to locate the separators and find the pipeline route. Also, he mentions the methodology, the geometric relationships and considerations that must be taken into account for the design a Webre-type separator. The developed model is used to size basic components of steam gathering system using MGF data.

Table 1 shows a comparison matrix of the main features of the references discussed above. In the first column the name of paper used, second column to the four column describes separator type, in column five indicates whether an assessment is made to the separator, in column six indicated if a computer program used and finally the methodology with which the research is based is indicated.

Table 1. Matrix comparing the references.

Work	Webre	Design	Evaluation	Software	Methodology Used
Bangma (1961)	*	*			
Awerbuch et al. (1982)	*	*	*		
Lazalde-Crabtree (1984)	*	*	*	*	Lazalde-Crabtree and Buendía (1982)
Buendía (1985)	*		*		Lazalde-Crabtree (1984)
Buendía y Gutiérrez (1986)	*		*		Lazalde-Crabtree (1984)
Caceres (1988)	*	*	*		Lazalde-Crabtree (1984)
Ayodo (1992)	*	*	*		Lazalde-Crabtree (1984)
Henríquez (1997)	*	*			
McKibbin (1998)	*	*	*		
DiPippo (1999)	*	*			Lazalde-Crabtree (1984)
Sanchez et al. (2002)	*		*		
Foong (2005)	*	*	*		Lazalde-Crabtree (1984)
Pointon et al. (2009)	*	*	*	*	Bangma(1961) and Lazalde-Crabtree (1984)
Horie et al. (2010)	*				
Glassley (2010)	*	*			Lazalde-Crabtree (1984)
Barrantes (2012)	*	*	*		Lazalde-Crabtree (1984)
DiPippo (2012)	*	*			Lazalde-Crabtree (1984)
Purnanto et al (2013)	*		*	*	Lazalde-Crabtree (1984)
Zarrout and Purnanto (2014)	*	*	*	*	Bangma (1961) and Lazalde-Crabtree (1984)
Odhiambo (2015)	*	*			Lazalde-Crabtree (1984)

3. Conclusion

It was concluded that currently, the Webre-type separator and dryers are the most commonly used in different Geothermal Plants worldwide and the Lazalde-Crabtree (1984) methodology is the most popular empirical approach to estimate the efficiency of a Webre-type separator, as well as for the design and evaluation of these equipment's.

The separators and dryers which are designed with the Lazalde-Crabtree methodology, operate with such efficiency that it allows steam quality greater than 99.95% to be achieve which is are required for the operations of Geothermal Power Plants. Furthermore, thus type of separators and dehumidifiers are more economical when compared to horizontal equipment.

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