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Invited Review

Geothermal steam-water separators: Design overview

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ABSTRACT

Since the development of the liquid dominated geothermal reservoir at Wairakei, New Zealand in 1950s, various separator designs have been utilised to enable the separation of steam and water from two-phase geothermal fluid. This is to ensure that only dry and clean steam enters the turbine and generates electricity. Information from several existing geothermal fields shows that there are two common separator designs, the vertical cyclone separator and the horizontal separator. Both designs are reported to have high separation efficiency in the order of 99.9% or higher. The vertical cyclone separator is normally found at power stations with strong influence by the technology from New Zealand. The horizontal separator is normally found at power stations with strong influence by technology from Iceland, Japan, Russia and the US.

The vertical cyclone designs are based on the experience in Wairakei and Kawerau in the 1950s and 1960s, and the modelling work by Lazalde-Crabtree's (1984). While the principles of the geothermal horizontal separator design were only reported by Gerunda (1981).

This paper reviews the steam-water separator designs that are commonly used in geothermal steam fields worldwide. The general steps to design the separator for any given geothermal fluid are presented. This is starting from the selection of optimum separation pressure, predicting the separator efficiency and calculating the internal pressure drop.

Recent research that utilises the numerical approach using Computational Fluid Dynamics (CFD) to obtain better understanding of the fluid behaviour within the separator is reported.

Unpublished data from the early 1950s Wairakei trials are presented in this work. They show that the breakdown velocity increases with the reduction in the internal diameter of separator body. The measurement of the separator efficiency is also discussed.

Practical design aspects for the optimum locating of the separator and the main separator design considerations are also given. Recent concepts in separator designs are also presented and discussed.

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Nomenclature

A_o surface area of inlet pipe (m^2) A_e inlet width (m) B_e inlet height (m) B_e inlet height (m) S_n^{Na} concentration of sodium in separated brine (mg/kg) S_n^{Na} mass flow rate of sodium in the separated steam (mg/s) Ddiameter (m) D_t inlet pipe diameter (m) D_e steam outlet pipe diameter (m) D_b water outlet pipe diameter (m) d_w drop diameter (m) f_{av} fractional area f_{hv} fractional heighthenthalpy $(k]/kg)$ jdimensionless parameter given by Eq. (26) K' A coefficient for Eq. (3) (m/s) K_c dimensionless parameter given by Eq. (17)Llength (m) m mass flow rate (kg/s) m_s mass flow rate of steam (kg/s) m_b mass flow rate of fluid (kg/s) m_b mass flow rate of brine carryover (kg/s) m_h mass flow rate of big $(kg/m^2 s)$ m_V_L mass flow rate of gas (kg/s) m_V_L mass flow rate of gas $(kg/m^2 s)$ m_f free vortex coefficient (dimensionless) NH dimensionless parameter given by Eq. (29) P pressure $(Pa, unless specified differently)Q_V_Svolumetric steam flow (m^3/s)Q_Lvolumetric steam flow (m^3/s)Q_Lvolumetric steam flow (m^3/s)Q_Lvolumetric steam flow (m^3/s)ReReynolds number (r$	Α	surface area (m ²)
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$\begin{array}{ll} (mg) \\ D & diameter (m) \\ D_t & inlet pipe diameter (m) \\ D_e & steam outlet pipe diameter (m) \\ d_w & drop diameter (m) \\ f_{av} & fractional area \\ f_{hv} & fractional area \\ f_{hv} & fractional height \\ h & enthalpy (kJ/kg) \\ j & dimensionless parameter given by Eq. (26) \\ K' & A coefficient for Eq. (3) (m/s) \\ K_c & dimensionless parameter given by Eq. (17) \\ L & length (m) \\ \dot{m} & mass flow rate of steam (kg/s) \\ \dot{m}_s & mass flow rate of fluid (kg/s) \\ \dot{m}_k & mass flow rate of fluid (kg/s) \\ \dot{m}_k & mass flow rate of fluid (kg/s) \\ \dot{m}_k & mass flow rate of brine carryover (kg/s) \\ \dot{m}_k & mass flow rate of brine carryover (kg/s) \\ \dot{m}_k & mass flow rate of gas (kg/s) \\ \dot{m}_k & mass flow rate of gas (kg/s) \\ \dot{m}_k & mass flow rate of gas (kg/s) \\ \dot{m}_k & mass flow rate of gas (kg/s) \\ \dot{m}_k & mass flow rate of gas (kg/s) \\ \dot{m}_k & mass flow rate of mass (kg/s) \\ \dot{m}_k & mass flow rate of gas (kg/s) \\ \dot{m}_k & mass flow rate of gas (kg/s) \\ \dot{m}_k & mass velocity of the liquid (kg/m^2 s) \\ \dot{m}_k & mass velocity of the gas (kg/m^2 s) \\ n & free vortex coefficient (dimensionless) \\ NH & dimensionless parameter given by Eq. (29) \\ P & pressure (Pa, unless specified differently) \\ Q_{VS} & volumetric steam flow (m^3/s) \\ Re & Reynolds number (ratio of fluid's inertial force to its viscous forces, dimensionless) \\ Sp & separated water purity \\ T & temperature (°C, unless specified differently) \\ TDS & Total Dissolved Solids in the brine (ppm) \\ t_r & residence time (s) \\ t_{ma} & maximum additional time of steam in cyclone (s) \\ u & tangential inlet velocity (m/s) \\ v_t & terminal velocity (m/s) \\ v_t & terminal velocity (m/s) \\ v_h & velocity in the horizontal direction (m/s) \\ V & volumetric flow rate (m^3/s) \\ V_{AN} & upward annular steam velocity (m/s) \\ \end{array}$	CS	mass now rate of source in the separated steam
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V_{AN} upward annular steam velocity (m/s)	v n V	volumetric flow rate (m^3/s)
	Van	unward annular steam velocity (m/s)
	• AN	apward annular steam velocity (m/s)

V _{OS}	volume defined in Fig. 11 (m ³)
V _{OH}	volume defined in Fig. 11 (m ³)
We	Weber number (ratio of fluid's inertia and its surface
	tension, dimensionless)
X_i	steam dryness (dimensionless)
$ ho_L$	density of liquid (kg/m ³)
$ ho_G$	density of gas (kg/m ³)
$ ho_v$	density of vapor (kg/m ³)
$ ho_{air}$	density of air (kg/m ³)
$ ho_{water}$	density of water (kg/m ³)
σ	surface tension (N/m)
σ_{water}	surface tension water (N/m)
ψ'	centrifugal inertia impaction parameter
η	efficiency (%)
η_{eff}	effective efficiency (%)
η_s	actual efficiency (%)
η_m	centrifugal efficiency (%)
η_A	entrainment efficiency (%)
μ_L	dynamic viscosity of water (poise)
μ_v	dynamic viscosity of vapour (kg/m s)

1. Introduction

The energy from geothermal fluid can be converted into electricity by utilising the geothermal steam as the working fluid to rotate the turbine which is coupled with the generator. Since turbine design usually requires a high steam quality at the inlet, i.e. the geothermal steam should be as dry as possible or slightly superheated. A small quantity of water carried over can cause major problems due to the fact that geothermal water contains dissolved minerals (solids) that may form scale deposition on the turbine blades, casing and nozzles reducing the turbine's conversion efficiency (Zarrouk and Moon, 2014). Water entrainment in the inlet steam on the other hand can cause erosion damage to the turbine rotor, blades and nozzles (communications with Mr. Chris Morris, Contact Energy Ltd.).

In dry geothermal fields, separators are not required. However, dry steam reservoirs are rare and only found in few fields around the world: Lardarello (Italy), the Geysers (USA), as well as limited dry steam areas in Matsukawa (Japan), Darajat and Kamojang (Indonesia), and Cove Fort Utah (USA) (Di Pippo, 2012). Most of the remaining conventional geothermal fields worldwide are liquid-dominated reservoirs producing a mixture of steam and water therefore separators are required (Zarrouk and Moon, 2014).

Challenges to develop wet fields for power generation had resulted in the development of steam-water separators. The separator enables the separation of steam and water from two-phase geothermal mixtures so that only steam is sent to run the turbine. Wairakei geothermal power station, New Zealand, was the first Download English Version:

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