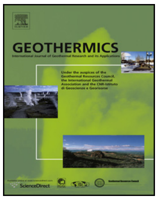
Geothermics 53 (2015) 236–254

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics



Invited Review

Geothermal steam-water separators: Design overview

Sadiq J. Zarrouk[a,*], Munggang H. Purnanto[b]

[a] Department of Engineering Science, The University of Auckland, New Zealand
[b] Facilities Department, Star Energy Geothermal (Wayang Windu) Ltd., Indonesia

ARTICLE INFO

Article history:
Received 26 February 2014
Accepted 29 May 2014
Available online 11 July 2014

Keywords:
Geothermal separator
Cyclone
Separator efficiency
Vertical separator
Horizontal separator
CFD modelling

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Unpublished data from the early 1950s Wairakei trials are presented in this work.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.

Contents

---

* Corresponding author at: Department of Engineering Science, The University of Auckland, Private Bag 92019, Auckland, New Zealand. Tel.: +64 9 373 7599x85542; fax: +64 9 373 7468.

E-mail addresses: s.zarrouk@auckland.ac.nz, sadiqzarrouk@gmail.com (S.J. Zarrouk).

http://dx.doi.org/10.1016/j.geothermics.2014.05.009
0375-6505/

Nomenclature

A	surface area (m^2)
A_o	surface area of inlet pipe (m^2)
A_e	inlet width (m)
B_e	inlet height (m)
C_{sb}^{Na}	concentration of sodium in separated brine (mg/kg)
$\dot{C}_S^{Na}$	mass flow rate of sodium in the separated steam (mg/s)
D	diameter (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 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 (kg/s)
$\dot{m}_s$	mass flow rate of steam (kg/s)
$\dot{m}_f$	mass flow rate of fluid (kg/s)
$\dot{m}_w$	mass flow rate of water (kg/s)
$\dot{m}_b$	mass flow rate of brine carryover (kg/s)
$\dot{m}_L$	mass flow rate of liquid (kg/s)
$\dot{m}_G$	mass flow rate of gas (kg/s)
$\dot{m}_{VL}$	mass velocity of the liquid (kg/m^2 s)
$\dot{m}_{VG}$	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)
Q_L	volumetric water 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)
t_{mi}	average minimum residence time of steam in cyclone (s)
u	tangential inlet 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)
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)
ρ_L	density of liquid (kg/m^3)
ρ_G	density of gas (kg/m^3)
ρ_v	density of vapor (kg/m^3)
ρ_{air}	density of air (kg/m^3)
ρ_{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