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Sustainability of Geothermal Systems

Geothermal energy is classified as a renewable resource, where "renewable"describes a characteristic of the resource: the energy removed from the underground resource is continuously replaced by more energy on time scales similar to those required for energy removal and those typical of technological/societal systems. Consequently, geothermal exploitation is not a "mining"process. The production of geothermal fluid/heat continuously creates a hydraulic/heat sink in the reservoir. This leads to pressure and temperature gradients, which in turn generate fluid/heat inflow to reestablish the pre-production state. The regeneration of geothermal resources is a process, which occurs over various time scales, depending on the type and size of the production system, the rate of extraction, and on the attributes of the resource.

Time scales for re-establishing the pre-production state following the cessation of production have been examined using numerical model simulations for the main geothermal technologies: 1) Heat extraction by geothermal heat pumps, 2) The use of a doublet system on a hydrothermal aquifer for space heating, 3) The generation of electricity on a high enthalpy, two-phase reservoir and 4) EGS: enhanced geothermal system for co-generation. The results show that during production intermissions or after production stops, recovery driven by natural forces like pressure and temperature gradients take place. The recovery typically shows asymptotic behavior, being strong at the start, and then slowing down subsequently, and theoretically taking an infinite amount of time to reach its original state.

However, practical replenishment (up to 95%) will occur much earlier, generally on time scales of the same order as the lifetime of the geothermal production systems. In more detail: 1) Any "balanced"fluid/heat production that does not exceed the natural recharge can be considered fully sustainable, 2) Production rates that exceed the rate of recharge will eventually lead to reservoir depletion, thus stopping economic production. 3) Geothermal resources will attempt to reestablish their pre-production states following termination of production, 4) The post exploitation recovery exhibits an asymptotic behavior reaching a "practical"replenishment on time scales of the same order as the lifetime of the geothermal production system, 5) Geothermal resources are renewable on timescales of technological/societal systems (~30-300 years), 6) Sustainable production secures the longevity of the resource at a lower production levels, 7) The level of sustainable production depends on the utilization technology as well as on the geothermal resource characteristics and 8) Production from geothermal resources should be limited to sustainable levels.

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