Energy 138 (2017) 647–658

Contents lists available at ScienceDirect

Energy

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

Landfill gas-powered atmospheric water harvesting for oilfield operations in the United States

Enakshi D. Wikramanayake, Onur Ozkan, Vaibhav Bahadur*

Department of Mechanical Engineering, The University of Texas at Austin, Austin, TX 78712, USA

A R T I C L E I N F O

Article history:
Received 5 January 2017
Received in revised form
27 May 2017
Accepted 10 July 2017
Available online 14 July 2017

Keywords:
Landfill gas
Atmospheric water harvesting
Condensation
Oilfields
Refrigeration cycle
Techno-economic analysis

A B S T R A C T

Landfill gas accounts for 18% of US greenhouse gas emissions. The energy wasted via venting/flaring methane in landfill gas can be valued at 7.5 billion USD (annually). This work presents a novel utilization concept, wherein landfill gas-powered refrigeration enables large-scale atmospheric water harvesting, via dehumidification. This work analyzes the potential of landfill gas-powered atmospheric water harvesting towards meeting the water requirements of oilfields located near landfills. Heat and mass transfer-based analytical modeling is used to estimate the seasonal water harvest, and techno-economic analyses are presented to quantify the benefits for US oilfields. This technology is seen to be attractive for the Barnett Shale (Texas) and Kern County (California), which can be served by 30 landfills each, and are located in hot-humid and water-stressed areas. Results show that landfill gas-powered water harvesting can meet 34% of water requirements (hydraulic fracturing) in the Barnett Shale and 12–26% of water requirements (enhanced oil recovery) in Kern County oilfields, respectively. Landfill gas projects are economically more viable in the Barnett as compared to Kern County. The impact of landfill gas-powered water harvesting on CO_2e emissions from landfills is quantified. Constraints and challenges associated with water harvesting are discussed. Importantly, this waste-to-value concept has worldwide relevance since landfills co-exist with population centers.

1. Introduction

Landfills account for 15% of global anthropogenic methane emissions, and 18% of greenhouse gas emissions from the US [1]. More than half of the 260 million tons of municipal solid waste (MSW) generated annually in the US is landfilled [2]. In developed nations, landfill emissions show a declining trend [3], as recycling increases. However, it is likely that landfilling will increase globally, primarily driven by population and consumption increases in China and India. Importantly, landfill emissions continue steadily for many decades [1] even after a landfill is closed (reaches capacity).

Landfill gas (LFG), produced by anaerobic decomposition of MSW contains [4] methane (50–55%), carbon dioxide (45–50%) and trace amounts of other gases [5]. Along with adverse environmental impacts, LFG emissions constitute a large-scale energy waste. Methane emissions from US landfills equal 14% of US residential natural gas consumption [1,6], and can be valued at 7.5 billion USD. Emphasis on LFG utilization has led to 650 operational LFG projects and 416 candidate projects in US landfills [1]. Of these projects, 71% involve electricity generation [2,4], via gas turbines and engines [7,8], without needing extensive treatment to remove non methane components. However, electricity generation projects are not viable everywhere due to inadequate demand and/or access to the grid.

Other types of LFG-to-energy projects have been implemented. In the US, 25% of LFG projects use LFG for direct heating in boilers, space heating and greenhouses [4]. Less than 5% of projects [9] involve LFG conversion to high Btu natural gas [10] and subsequent injection in pipelines. Some LFG-to-energy projects use LFG as the feedstock to produce synthetic fuels like methanol [9]. Other concepts [1] that have been explored include LFG use for hydroponics, aquaculture and blacksmithing.

LFG utilization for water production has not been considered in any available literature, and is the focus of this work. The concept introduced in this work uses LFG-powered refrigeration cycles for atmospheric water harvesting (AWH). Atmospheric moisture is a large untapped freshwater resource, with 1 square kilometer of land holding between 10,000–30,000 m^3 of moisture above it (excluding moisture in clouds) [11]. However, the energy intensive

---

* Corresponding author.
E-mail address: vb@austin.utexas.edu (V. Bahadur).

http://dx.doi.org/10.1016/j.energy.2017.07.062
0360-5442/

nature of condensation (2260 kJ/kg) has held back industrial scale AWH. Existing electricity-powered AWH systems can produce a few thousand liters of water daily [12], but with high costs exceeding 5 cents/liter. The present group recently published four articles [13–16] to highlight the benefits of using excess natural gas from oilfields (which is typically flared) to power AWH systems for providing onsite water for oilfield operations. *Methane in LFG can also power large scale AWH; this premise is developed and analyzed in this work*.

While there are many uses for this high quality freshwater [17], this work analyzes the benefits of this water for oilfield operations. *LFG from landfills in proximity to oil-gas production sites can power AWH for oilfield utilization*. The water requirements of the oil-gas industry have increased substantially [18] with the advent of hydraulic fracturing to extract Shale oil-gas. On average, a hydraulic fracturing operation requires 9500 m^3 water [19–21]; this is enough to fill four Olympic sized swimming pools. Drilling is less water intensive with 950 m^3 required per well [20]. However, thousands of wells are drilled [18], and the cumulative water requirements are significant. Sourcing water is challenging since many Shale plays are located in acute water stress regions. 50% of US Shale wells are in extreme stress regions [19], where freshwater procurement and transportation costs can reach 3.75 cents/liter [13]. Currently oil producers meet their water requirements from various sources including drilling water wells, trucking in water and treating produced water for reuse. However, water issues will persist and water is becoming an increasingly important consideration for Shale oil production. *LFG-based AWH can enable landfills to serve as local water sources for oil producers*, who often have to rely on faraway freshwater depots or surface water access points.

The above concept is analyzed for major US oilfields and is seen to be attractive for the Barnett Shale in Texas and oil fields in Kern County in California. The Barnett Shale is located near the Dallas-Fort Worth area, and can rely upon LFG-based AWH from 30 nearby landfills for its water intensive hydraulic fracturing operations. California is the fourth largest oil producing region in the US [22,23], after Texas, Gulf of Mexico and North Dakota. More than 70% of the state's production [23] occurs in Kern County (around Bakersfield) via conventional enhanced oil recovery techniques. The top five oilfields in California are located in western Kern County [24,25]. This region also overlaps with the vast Monterey Shale, which has been explored recently via hydraulic fracturing [19]. LFG-based AWH from 30 landfills in this region can supply water to support conventional oil production as well as any future hydraulic fracturing operations.

The novelty of this work lies in the conceptualization, and the technical and techno-economic analysis of LFG-powered AWH. A framework for quantifying the benefits of LFG is established, and is used to assess the benefits of this technology. It is stressed that the methodology developed in this work can be applied globally.

2. Description and modeling of LFG-powered atmospheric water harvesting

Various refrigeration pathways can generate the cooling capacity to enable AWH. Fig. 1 shows an AWH system based on a gas engine-powered vapor compression refrigeration cycle. LFG is fed to a gas engine after cleanup, and runs the compressor. The cooling capacity generated by refrigerant (R134a) evaporation in the evaporator produces chilled water, which is used to condense moisture from ambient air in a humid air condenser (a fin and tube heat exchanger). The refrigerant vapor leaving the evaporator is compressed and then liquefied in the air-cooled condenser (ACC). The dehumidified and cold air exiting the humid air condenser is routed to the ACC to sustain the performance of the refrigeration cycle in high ambient temperatures. It is noted that other refrigeration cycles like vapor absorption and desiccant dehumidification can also be used. The vapor compression cycle provides higher

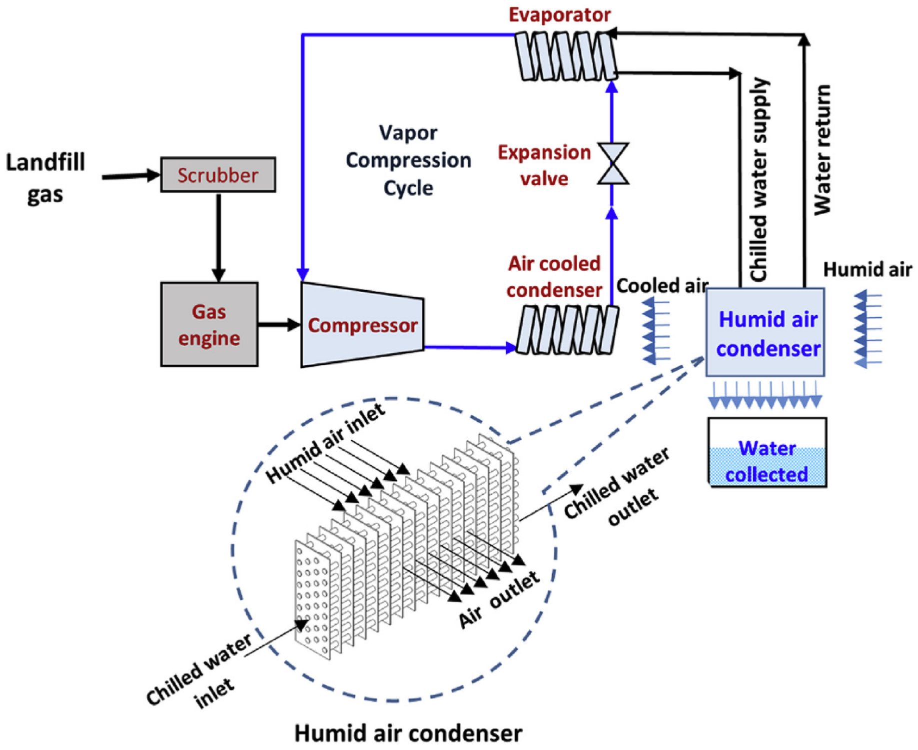

Fig. 1. Landfill gas-powered vapor compression system for AWH. A landfill gas-powered engine runs the compressor of the refrigeration cycle, which provides chilled water to a humid air condenser. The humid air condenser is a fin and tube heat exchanger with water condensing on the outside of tubes.