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Dust and soiling issues and impacts relating to solar energy systems: Literature review update for 2012–2015

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ABSTRACT

The purpose of this review survey is to provide a literature compilation, updating materials reported in several review papers on solar-device soiling and mitigation approaches published over the past 5 years. The focus is on the period 2013–2015, but an updated listing is also provided for the year 2012 for completeness. This literature review also provides the first update for a periodic, single collation report on such publications proposed in this journal two years ago. This review presents a listing of the publications, their publication source, and some brief tabulated information to help guide the reader into the focus of each of the works.

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1. Introduction and background

Soiling of solar collector surfaces ranks with climate conditions (temperature, humidity) and irradiance (spectrum, uniformity, intensity) as the major concerns for component and system reliability. Though R&D on soiling or dust accumulation has now spanned into its 8th decade, many mechanisms remain to be understood and problems to be solved. These needs are intensified by the growing markets in the solar-rich areas of the northern Africa, the Middle East, India, as well as the desert areas of China, Australia, and the United States. Coincidently, these areas are also characterized by high airborne-particle environments, intense dust storms, and water-availability concerns.

The interests and critical nature of these soiling issues are reflected by the publication history, represented in the histogram of Fig. 1. The initial period includes contributions from the solar pioneers (Hottel, Woertz, Tomlinson, Garg – are among the leaders) who envisioned that avoiding soiling would be important for the future adoption and use of collectors for their solar-thermal applications. The coming of the oil embargo in the early- to mid-1970s brought a focus on solar energy and expanded terrestrial applications—with the rise in publications during this period primarily on the effects on heliostats and mirrors used with

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concentrating solar-thermal power (CSP). Political changes at the start of the 1980s (and the diminishing of energy costs/crises) resulted in a loss of funding and related publications in solar and dust issues. The 1990s heralded some shifts. First, the rise of market experiments (e.g., "1000-, 10,000-, 100,000-, million-roof programs" worldwide), large central-station CSP, and then the successes of space exploration, and some limited renewed funding for solutions to soiling reliability issues. There was, for example, a major rise in investments coming from the PV-powered NASA Mars rover ("Sojourner")—which experienced extreme dust conditions with a remoteness that would not allow firsthand manual cleaning! This invigorated research into prevention approaches (coatings, vibration/ultrasonics, electrostatics, and especially electrodynamic screens) that would, in turn, reignite such high-tech remedies for earth-based systems as well.

The new century was marked by a growth in PV, both research and market expansions. This is attributed primarily *to incentive programs* such as the *feed-in tariffs* in Germany and Europe, and *system buy-down subsidies* in Japan and the U.S. Soiling research and product developments shifted as well toward PV because of the rise in applications and country programs. With the China dominance of manufacturing (and accompanying beneficial collapse in PV prices) starting in 2009/2010—as well as the rise in interest in new markets and investments in the desert locations (Saudi Arabia, Qatar, U.A.E. and other Gulf countries, Egypt, India, as well as the U.S., Australia, and China), the publications addressing dust and soiling issues rose to their highest annual levels; levels that can be expected to grow further because of the economic and energy benefits of dust mitigation for these solar-electric generators.

This survey follows on reference databases provided in several reviews that have been published on dust/soiling since 2010 (Table 1, discussed in the next section). It also builds on a commitment in a 2013 publication in this journal [see Tarver et al. 2013 in Table 1] to provide a periodic update to the publication reference base, as a "living document" to afford readers, researchers, developers, and system deployers with a literature base of research investments, product advancements, and latest research/advancements addressing of critical issues relating to this dust/soiling reliability area. This document covers the period 2013 through what has transpired through 2015. However, we have included a compilation, a more complete single listing for 2012—contained in the first section of the Literature Summary (References Section). The majority of these 2012-papers continue to cover the effect of soiling and dust accumulation on the performance of various solar technologies in various locations in the world. However, the focus of this literature review is on 2013–2015. In this period, we emphasize journal and conference publications that can be found through their "DOI" or web identifications—though some open-literature articles are also listed because of their content and interest.

2. Review papers (2010–2015)

Several key review papers covering PV, CPV, and CSP dust and soiling have been published over the past few years, and all have fairly high citation indices indicative of their coverage, interest, and significance. These papers are summarized in Table 1, which provides the source authors, the publication year, a summary of the review contribution and focus, and the solar technology covered. This also gives the reference base cited in each. Certainly prominent among these is that in 2010 by M. Mani and R. Pillai, which summarized performance investigations, recommendations

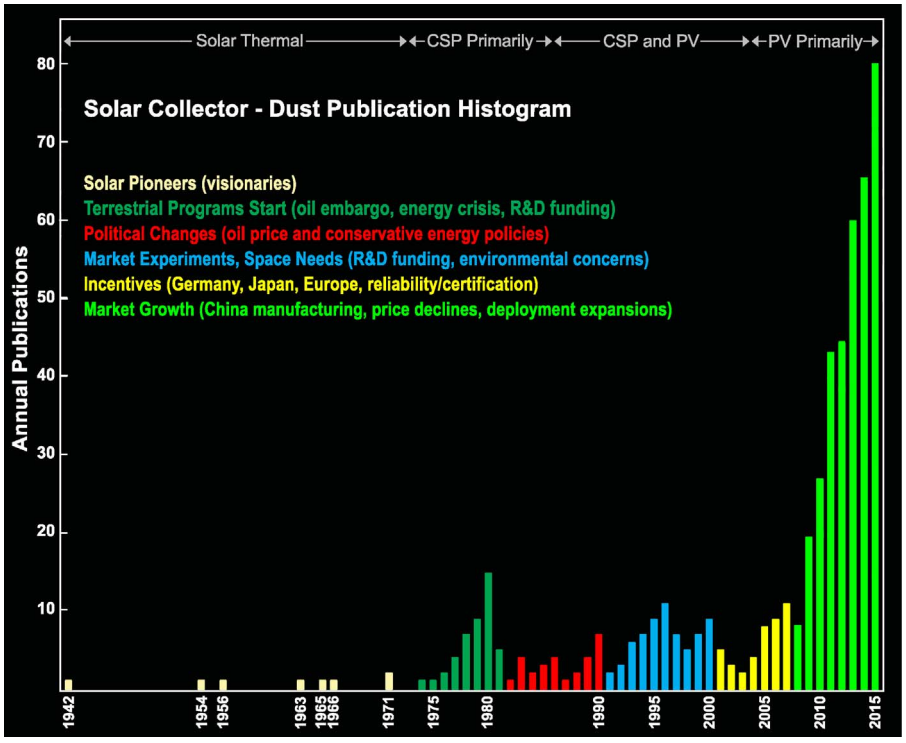

Fig. 1. Histogram of publications on dust and soiling showing general technology emphasis and driving forces (colored regions) underlying the positive or negative growth of the publication levels. Recent rise in publication volume responds to the significant lowering of PV costs and opening of markets in the solar-rich and dust-environment-rich areas of the world.