Energy Efficient Clothes Dryer with IR Heating and Electrostatic Precipitation

2017 Building Technologies Office Peer Review

Program Objective: Demonstrate a Ventless Residential Dryer with a EF >4.04

Project team members left to right Tom Stecher, Stan Weaver, Ralf Lenigk, Martin Vysohlid, Arin Cross, Francisco Moraga, absent from photo Nannan Chen.

Technical Approach
- Ventless closed loop system
- Advanced IR heating
- Modulated heater drying cycle
- Electrostatic Precipitator (ESP) for humidity removal

Technical Challenges
- Lint fouling in exchanger
- Efficient heat spreading in drum
- IR heater/ESP optimization
- ESP efficiency near end of cycle

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

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GE Global Research
Project Summary

Timeline:
Start date: 10/1/2014
Phase 1 to 2 delay 6/16-9/16
Planned end date: 9/30/2017

Key Milestones
Milestone 1: Demonstration of an ESP exchanger
Meeting program goals; 6/30/2016, Complete
Milestone 2: Demonstrate Integrated prototype MVP dryer operating at an EF goal of >4.04; 9/30/2017

Budget:
Total Project $ to Date:
DOE: $ 585,915
Cost Share: $146,479

Total Project $:
DOE: $1,040,040
Cost Share: $260,001

Key Partners:
None

Project Outcome:
The goal of the program is to design, build, and demonstrate a residential ventless dryer with an energy factor (EF) of >4.04.
Purpose and Objectives

Problem Statement: Current residential dryer EF’s (lbs/kWh) are ~3.73. DOE MYPP target is an EF of 6.0 by 2020 at a payback of less than 5 years.

• Target Market and Audience: Target market is the US residential clothes dryer market, consisting of ~ 84 million dryers, consuming ~64 billion kWh per year.

Impact of Project: A residential ventless dryer with an EF of 4.8 translating to energy savings 50.8 billion kWh (appliance and make up air savings). The planned EF is concurrent with DOE 2020 goals of 6.0.
  a. Near-term outcomes (during or up to 1yr after project)? – Licensing of the proposed technology.
  b. Intermediate outcomes (1-3yr after project)? – Commercialization of the proposed dryer and realization of energy savings.
  c. Long-term outcomes(3yr.+ after project)? Technology insertion broadening into other applications; i.e. industrial drying and smoke stack and exhaust effluent remediation.
**Approach**

**Approach**: Development of next generation technology prototypes.

- Construction of a “variable” dryer output simulator
- Model, design, testing, optimization and demonstration of key technologies
  - ESP/Exchanger and IR heaters
- Integration of key technologies into working prototypes meeting program goals

**Key Issues**: Current ESP/Exchanger efficiency of 50% will require higher steam extraction rate, when compared to a conventional dryer, or multiple stages to meet current drying times.

**Distinctive Characteristics**: High EF, non vented dryer with <5yr payback.

- Combined Nebulizer/ESP for water extraction and recycling of latent heat
- IR heating system tuned (~3um) for optimum heat transfer to water
Progress and Accomplishments

**Accomplishments**: Demonstration of an ESP/Precipitator with ~50% extraction efficiency. Phase 1 Go/No-Go milestone met. Phase 2 in progress.

**Market Impact**: Applications of the technology are broad and far reaching from drying, dehumidification, and industrial effluent cleaning. Current business status requires licensing strategies.

**Awards/Recognition**: Invention disclosure submitted.

**Lessons Learned**:
- Greatest improvements in efficiency from 13% (2015) to 50% (2016) were achieved through improved precipitator design, nebulizer flow and running the system in the laminar flow regime.
  
- Technologies to further reduce charged droplet size could lead to further efficiency improvements.
Dryer Simulator Test System Design Phase 1

Controls for:
- Steam Input/Humidity level
- Variable speed fan
- Heat Input
- Variable speed fan control
- Syringe pump for Nebulizer feed
- High voltage for Nebulizer
- High Voltage for Precipitator

Instrumentation for:
- Totalized water input to steam generator
- Temperature – multiple points
- Humidity – multiple points
- Pressure – multiple points
- Air Speed
- Total collected water

Approach
Modeling, Design, Experimentation and Prototyping

Air speed monitoring

Dryer Simulator test system
Factors driving efficiency:

Smaller higher charged droplets - droplet size/charge
  • Limited due to clogging (110um diameter)

Increased density of smaller charged droplets (nebulizer flow)
  • Limited due to pressure and number of nozzles

Optimized ESP heat rejection
  • Limited by passive exchanger design area

Laminar flow
  • Minimum limit determined balanced with heat rate input
Efficiency Improvement Timeline

- Laminar flow and increased Nebulizer input are the main drivers of efficiency
- IR Steam rejection rate will be critical to maintaining 1hr drying time
Phase 2 Dryer Prototyping

Dryer selection
- Manual, analog controls
- Timed dry and humidity sensing drying
- Stainless steel drum or polished metal drum
- No glass door
- 208V single phase operation
- Fixed back drum

Choice – Speed Queen electric dryer
Dryer Baseline Procedure

- Three baseline runs each:
  - “Sensor”: Permanent press, automatic “Less Dry”
  - “Timer”: Permanent press, timed dry 50 mins
  - 7.8 lbs white cotton towels + 5.0 lbs water = 65% water/fabric ratio
Dryer Baseline Data

**Power Usage**
- Mean: 4.94 kWh
- Max variation from mean: 0.37 kWh
- Mean: 3.29 kWh
- Max variation from mean: 0.03 kWh

**Cycle Duration**
- Mean: 79.09 min
- Max variation from mean: 6.74 min
- Mean: 47.77 min
- Max variation from mean: 0.07 min

**Water Left at Cycle End**
- Sensor cycle over dries; leads to lower EF
- Mean: 2.30%
- Max variation from mean: 0.40%

**Dryer Energy Factor (EF)**
- Mean: 2.61
- Max variation from mean: 2.03
- Mean: 3.89 min
- Max variation from mean: 0.04
Dryer Prototype Modifications

- Structural modifications necessary
- Custom IR heater to be located within depressed area on fixed back drum
- Targeting ~5000W, mid IR 2-5um
- Carbon filament, White ceramic reflector
- Quartz cover plate facing interior of drum to prevent scorching of clothes
- Soft start required for longevity
- Sapphire IR camera viewing window to be located at green circle.
IR Heater Control – Two pronged Approach

Control Approaches
- TC control from exhaust temperature
  - Lumped average
- IR camera control
  - Moving average of tumbling clothes
  - Identify and adjust for hot spots

Power Controller for IR heater
- Eurotherm 3216 PID controller
  - Universal inputs
    - TC, RTD, mV, mA, CT
- Eurotherm 32A Epack
  - Compact SCR power controller
  - >6500W capability
  - Soft start capable

Low cost IR Camera and Raspberry Pi processor
Project Integration: The project staff routinely collaborates with internal “GE Experts” and BDM’s to accelerate development.

Partners, Subcontractors, and Collaborators: DOE

Communications: NA to date. Research publications to follow.
Next Steps and Future Plans

Integrate IR heaters into dryer
  • Instrument temperature monitoring and over-temperature shutdown
  • Measurement of drying time and power consumed
    • Compare to baseline (expect 30% less energy usage)

Modify dryer blower motor or install separate motor for airflow control
  • Achieve laminar flow
  • Test IR operation at laminar flow
  • Compare energy use to baseline (expect 30% less energy usage)
  • Compare time to dry at laminar flow

Integrate Nebulizer/Precipitator with IR dryer prototype
  • Demonstrate MVP prototype operation at an EF >4.04

Pursue technology licensing opportunities through GE Ventures
REFERENCE SLIDES
**Project Budget**

**Project Budget**: DOE $1,040,040, Cost share $257,915

**Variances**: No cost extension, moving project completion to 9/30/2017

**Cost to Date**: $732,393

**Additional Funding**: NA

### Budget History

<table>
<thead>
<tr>
<th>Start Date –10/1/2014 (past)</th>
<th>FY 2016 (current)</th>
<th>FY 9/30/2017 –End Date (planned)</th>
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<td>DOE  125,461</td>
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<td>Cost-share  31,365</td>
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<td>257,915</td>
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Project Plan and Schedule

- Project origination date 10/1/2014, Completion date 9/30/2017
- First Go/No-Go Milestones met 6/31/2016 – Demonstration of ~50% extraction efficiency
- 6 Month no cost extension granted

### Milestone summary table.

<table>
<thead>
<tr>
<th>Task</th>
<th>Milestone Type</th>
<th>Milestone Number</th>
<th>Milestone Description</th>
<th>Milestone Verification Process</th>
<th>Anticipated Date</th>
<th>Anticipated Quarter</th>
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<tbody>
<tr>
<td>1. Dryer System Level Design</td>
<td>Milestone</td>
<td>M1.0</td>
<td>Report summarizing the dryer design and required subcomponent performances to exceed an EF of 4.04</td>
<td>Report submitted to DOE</td>
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<td>1</td>
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<td>2. Design and Testing of the ESP and Exchanger</td>
<td>Milestone</td>
<td>M2.1</td>
<td>Demonstration of an ESP meeting the system Subtask1.1 requirements</td>
<td>Measured results from ESP testing</td>
<td>12</td>
<td>4</td>
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<td>2. Design and Testing of the ESP and Exchanger</td>
<td>Milestone</td>
<td>M2.2</td>
<td>Report summarizing the ESP design and performance</td>
<td>Report submitted to DOE</td>
<td>21</td>
<td>7</td>
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<tr>
<td>2. Design and Testing of the ESP and Exchanger</td>
<td>Go/No-Go 1</td>
<td>Go/No-Go 1</td>
<td>Measured efficiency of the ESP must meet system requirements from Subtask 1.1</td>
<td>Measured results from the ESP testing</td>
<td>21</td>
<td>7</td>
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<td>3. Design and Testing of the IR heater system</td>
<td>Milestone</td>
<td>M3.1</td>
<td>Demonstration of IR dryer assembly meeting requirements of Subtask 1.2</td>
<td>Measured results from the IR dryer testing</td>
<td>27</td>
<td>9</td>
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<tr>
<td>3. Design and Testing of the IR heater system</td>
<td>Milestone</td>
<td>M3.2</td>
<td>Report summarizing the IR heater design and performance</td>
<td>Report submitted to DOE</td>
<td>27</td>
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<td>4. Integration, testing and optimization of the IR/ESP clothes dryer</td>
<td>Milestone</td>
<td>M4.1</td>
<td>Demonstration of integrated dryer exceeding 4.04 EF</td>
<td>Measured results of integrated dryer testing</td>
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<tr>
<td>4. Integration, testing and optimization of the IR/ESP clothes dryer</td>
<td>Milestone</td>
<td>M4.2</td>
<td>Report summarizing the integrated dryer performance</td>
<td>Report submitted to DOE</td>
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<td>5. Technology to Market Strategy Plan and Commercialization</td>
<td>Milestone</td>
<td>M5.1</td>
<td>1. Develop a detailed market strategy and commercialization plan with a market analysis of potential sales and an evaluation of potential US jobs created by commercialization. A target range for total system cost will be identified.</td>
<td>Report submitted to DOE</td>
<td>33</td>
<td>11</td>
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</table>
Back up slides
Efficiency vs Nebulizer input at laminar flow

Extraction Efficiency vs Nebulizer water input (ml) in 10min

Efficiency
Lessons learned:
- Dryer is temperature limited at ~160F; goes into pulse mode after limit reached
- Sensor mode, even on “less dry”, over-dries and lowers EF
- Timed dry is fairly repeatable with respect to time and temperature
2017 BTO Peer Review - Presentation Instructions
(not a template slide – for informational purposes only)

• Presentation Submission Requirements:
  – MS PowerPoint format
  – Size Limit: 15 MB (prefer smaller file)
  – Due Date: **Monday, February 27, 2017**
  – Submit via email to BTOPeerReview@ee.doe.gov
  – Name your electronic MS PowerPoint presentation file as follows (use the first 4 letters of your title):
    [TitleOrganization_LastName.ppt]

• **NOTE:** We will send your presentations to reviewers prior to the meeting. To provide adequate time for the reviewers, you **MUST** submit your presentation by **Midnight (EDT) on February 27, 2017**.

• You may **NOT** bring a different presentation to the event. Reviewers will see the same presentation at the peer review event that they review off-line in advance.