

Operational Experience from Solar Thermal Energy Projects

Christopher P. Cameron

Sandia National Laboratories

Albuquerque, New Mexico

Over the past few years, Sandia National Laboratories has been involved in the design, construction, and operation of a number of DOE-sponsored solar thermal energy systems. Among the systems currently in operation are several industrial process heat projects and the Modular Industrial Solar Retrofit qualification test systems, all of which use parabolic troughs, and the Shenandoah Total Energy Project, which uses parabolic dishes. Operational experience has provided insight to both desirable and undesirable features of the designs of these systems. Features of these systems which are also relevant to the design of parabolic concentrator thermal electric systems are discussed.

A key design requirement for all solar systems is the ability to operate in and survive a wide range of environmental conditions. In Albuquerque, wind has been observed to increase from less than 20 mph to 60 mph in less than 60 seconds upon the passage of a front while at the same time insolation was adequate for system operation. Since few concentrators can reach a safe stow position in such a short time, the capability to survive wind speeds well above operational limits, typically 25 to 35 mph, when out of the stow position, is highly desirable. Another effect which has been observed is wind-induced oscillation of some concentrators; this has caused significant damage. This possibility as well as the steady state effects of wind (e.g., overturning moments) must be considered in concentrator design. Wind-borne debris, such as small rocks, have apparently caused damage to certain types of glass mirrors. These mirrors have survived hail tests; however, rock can have sharp points which apparently penetrate the surface of the glass. In addition, temperatures well above ambient due to direct insolation on portions of the systems other than the reflectors have led to various problems including damage to the bond in glass-steel laminates and intermittent operation of electronic components.

Other design features discussed are system control functions which were found to be especially convenient or effective, such as local concentrator controls, rainwash controls, and system response to changing insolation. Drive systems are also discussed with particular emphasis on the need for reliability and the usefulness of a manual drive capability.

OBSERVATIONS ON RATE OF INCREASE OF WIND SPEED

- MISR SYSTEM DESIGN SPECIFICATIONS

SURVIVAL WITHOUT DAMAGE IN STOW POSITION IN WINDS UP TO 80 MPH.

OPERATE CONTINUOUSLY IN WINDS UP TO 25 MPH.

SHUTDOWN AUTOMATICALLY IN HIGH WINDS.

- MISR CONTROL SYSTEM PARAMETERS FOR SHUTDOWN IN HIGH WINDS

STOW IF WIND CONTINUOUSLY ABOVE SETPOINT FOR A MINIMUM PERIOD OF TIME.

TYPICAL SETPOINTS

25 TO 40 MPH

10 TO 30 SECONDS

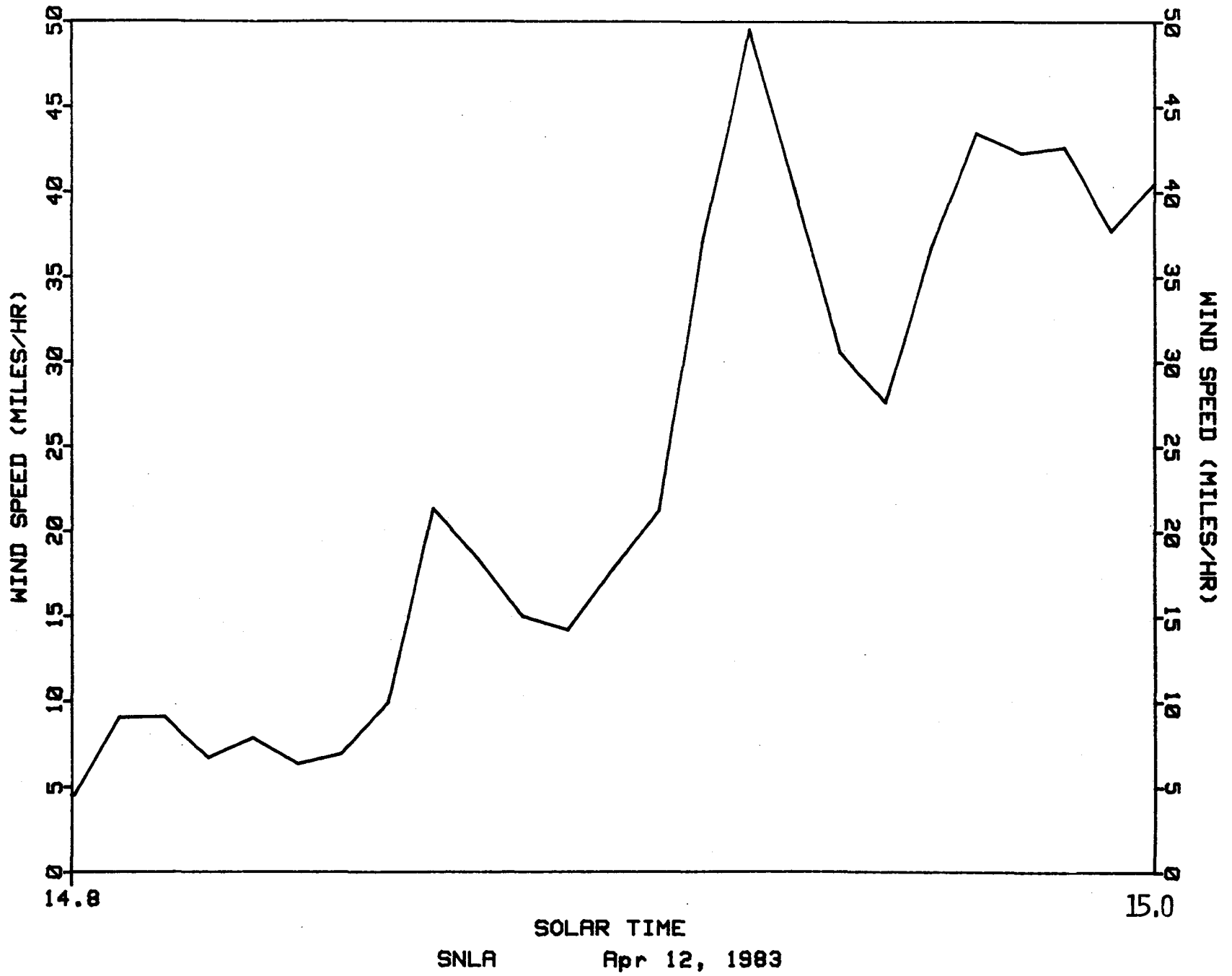
- TIME TO STOW FROM FAR HORIZON IS 3 TO 9 MINUTES

- OBSERVED WIND CHANGE AT MISR SITE

INCREASE FROM LESS THAN 20 MPH TO 60 MPH IN LESS THAN 60 SECONDS.

THIS RATE OF INCREASE GREATLY EXCEEDS SPEED WITH WHICH SYSTEMS CAN REACH THE SAFE STOW CONFIGURATION; FORTUNATELY, NO DAMAGE TO SYSTEMS OCCURRED.

- RECOMMENDATION - SURVIVAL CRITERIA FOR CONCENTRATOR WHEN OUT OF STOW SHOULD BE ESTABLISHED.



WIND-INDUCED OSCILLATIONS

- MANUFACTURERS HAVE SUBJECTED COLLECTORS TO VARIOUS TESTS TO DETERMINE ABILITY OF COLLECTORS TO SURVIVE HIGH WINDS.
- TYPICALLY, A TORQUE HAS BEEN APPLIED TO THE COLLECTOR AND/OR DRIVE TO SIMULATE WIND LOAD.
- COLLECTORS OF DESIGN WHICH SURVIVED THESE TESTS HAVE BEEN SEVERELY DAMAGED IN THE FIELD, APPARENTLY DUE TO WIND-INDUCED OSCILLATIONS.
- IN THIS CASE, THE MANUFACTURER MODIFIED THE COLLECTOR STRUCTURE TO PREVENT OSCILLATION.
- RECOMMENDATION - WIND-INDUCED OSCILLATIONS NEED TO BE CONSIDERED IN THE DESIGN.

OTHER ENVIRONMENTAL EFFECTS

- HIGH AMBIENT TEMPERATURES

ELECTRONICS CABINETS AND EQUIPMENT SKIDS CAN BECOME EXCESSIVELY HOT IF NOT PROPERLY SHADED OR VENTILATED.

EXAMPLE - THE TEMPERATURE INSIDE A CABINET SHADED BY AN ENCLOSURE REACHED 120 F WHEN AMBIENT TEMPERATURE WAS ONLY 85 F. THE TEMPERATURE INSIDE THE SHADED, BUT NOT WELL VENTILATED, ENCLOSURE WAS 99 F.

- SUNLIGHT

ALARM AND CONTROL PANEL LIGHTS AND LED'S CAN BE NEARLY IMPOSSIBLE TO SEE IN BRIGHT SUN. SHADING IS REQUIRED.

PLEXIGLASS OVER CONTROL PANELS LEADS TO A GREENHOUSE EFFECT AND GREATLY INCREASED TEMPERATURES.

- MOISTURE/CONDENSATION

COLLECTORS CAN FROST UP OR BECOME COVERED WITH CONDENSATION WHEN ROTATED OUT OF STOW. MOISTURE MAY REMAIN ON COLLECTOR, ADVERSELY AFFECTING PERFORMANCE FOR SOME TIME. IT CAN BE MORE PROFITABLE TO DELAY OPERATION UNTIL THE COLLECTORS HAVE WARMED ABOVE THE DEWPOINT; HOWEVER, THERE ARE NO CONTROLS AT PRESENT TO PERFORM THIS FUNCTION AUTOMATICALLY.

COLLECTORS WHICH HAVE NO BACK SHEET ARE MUCH MORE LIKELY TO ATTRACT CONDENSATION OR FROST IN THE STOW POSITION THAN THOSE WITH BACKSHEETS.

COLLECTORS WHICH ARE NOT STOWED FULLY INVERTED TEND TO COLLECT A LOT OF DIRT ON THE PORTION OF THE MIRROR WHICH IS CLOSE TO THE GROUND.

COLLECTORS MIRRORS ALSO ARE SOILED BY DIRT CARRIED IN THE RAIN FROM SHOWERS WHICH ARE TOO BRIEF TO WASH THE AIR CLEAN AND THEN RINSE THE MIRRORS.

ENVIRONMENTAL DAMAGE TO REFLECTIVE SURFACES

STRESSED GLASS

- STRESSED GLASS (CHEM-COR) MIRRORS ON A 2 METER PARABOLIC COLLECTOR DURING DEVELOPMENT TESTING HAD BEEN DEMONSTRATED TO SURVIVE HAIL (0.75 INCHES AT 55 FPS).
- THIRTEEN MIRRORS HAVE FAILED IN THE MISR QTS, APPARENTLY DUE TO WIND-BORNE DEBRIS SUCH AS ROCK AND TUMBLEWEEDS.
- SUCH DEBRIS MAY CAUSE DAMAGE WHEREAS HAIL DOES NOT BECAUSE THE DEBRIS MAY HAVE SHARP POINTS.
- DEBRIS-CARRYING WINDS ASSOCIATED WITH "DUST DEVILS" ARE OFTEN HIGHLY LOCALIZED AND OFTEN ARE NOT DETECTED AT ALL BY THE SYSTEM WIND SENSOR.
- DAMAGE HAS OCCURRED BOTH IN AND OUT OF THE PROTECTIVE STOW POSITION.
- RECOMMENDATION - DEVELOPMENT TESTING SHOULD INCLUDE SUCH DEBRIS AS WELL AS HAIL.

ENVIRONMENTAL DAMAGE TO REFLECTIVE SURFACES
(CONTINUED)

THIN-GLASS/STEEL LAMINATES

- THIN-GLASS/STEEL LAMINATES HAVE FAILED AT THE ADHESIVE BOND BETWEEN THE GLASS AND THE STEEL.
- THE EFFECT IS PROBABLY ACCELERATED WITH TEMPERATURE.
- ABOVE AMBIENT TEMPERATURE WILL OCCUR WHEN COLLECTORS ARE IN STOW, AS THEY ARE MOST WEEKENDS AT THE MISR SITE, ESPECIALLY WHEN THERE IS NOT A BACKSHEET ON THE COLLECTOR.
- DELAMINATION HAS ALSO BEEN OBSERVED IN COLLECTORS WHICH HAVE BACKSHEETS AND ALSO WHICH HAVE BEEN OPERATED ESSENTIALLY CONTINUOUSLY AND ARE THEREFORE NOT EXPOSED TO SUN ON THE BACK SIDE.
- RECOMMENDATIONS

ALTERNATE ADHESIVES - EPOXY HAS BEEN TESTED, BUT IS MORE EXPENSIVE TO APPLY.

ALTERNATE REFLECTIVE SURFACES - SAGGED GLASS, FILM.

CONTROLS

- ALL MISR SYSTEMS WERE REQUIRED TO HAVE A RAINWASH CAPABILITY

A RAINWASH CAPABILITY MEANS THE ABILITY TO POSITION ALL OF THE COLLECTORS FACING UP FROM A CENTRAL CONTROL.

THE HELIOSTATS AT THE CENTRAL RECEIVER TEST FACILITY HAVE NEVER BEEN WASHED EXCEPT BY RAIN.

MANUAL INITIATION WAS A REQUIREMENT SINCE AN OPERATOR MUST EXERCISE JUDGMENT CONCERNING THE PROBABLE DURATION OF THE RAIN AND POSSIBLE SEVERE WEATHER CONDITIONS.

ALL SYSTEMS DISCONTINUE THE RAINWASH ATTITUDE DUE TO HIGH WINDS AND, IN SOME FASHION, PROTECT THE COLLECTORS FROM ACCIDENTAL FOCUSING WITHOUT FLOW.

SOME OF THE SYSTEMS AUTOMATICALLY RESUME NORMAL SOLAR OPERATION WHEN INSOLATION IS ABOVE MINIMUM LEVELS.

SIMPLE, REMOTE ACTUATION IS DESIRABLE SINCE AN OPERATOR MAY BE RELUCTANT TO STAND OUT IN THE RAIN WHILE ESTABLISHING THE RAINWASH CONFIGURATION.

CONTROLS
(CONTINUED)

- LIGHT SWITCHES

LIGHT SWITCHES ARE USED TO DETERMINE WHETHER INSOLATION IS SUFFICIENT FOR SYSTEM OPERATION.

THE LIGHT SENSOR MUST VIEW THE PORTION OF THE SKY THROUGH WHICH THE SUN PASSES DURING THE YEAR. WHEN A LARGE PORTION OF THE SKY IS VIEWED, INDIRECT LIGHT ON A BRIGHT, CLOUDY DAY CAN CAUSE THE SENSOR OUTPUT TO EXCEED ITS THRESHOLD LEVEL.

THE MOST EFFICIENT SENSORS HAD SOME TYPE OF TRACKING ABILITY TO LIMIT THE ACTIVE FIELD OF VIEW. IN ONE CASE, THIS WAS ACHIEVED ELECTRONICALLY WITH NO MOVING PARTS.

- LOCAL CONTROLS

FEATURES FOUND TO BE CONVENIENT INCLUDE:

NON-MOMENTARY SWITCHES FOR MANUAL ROTATION OF COLLECTORS, ALTHOUGH MOMENTARY SWITCHES ARE PROBABLY SAFER.

THE ABILITY TO ROTATE THE COLLECTOR THROUGH FOCUS WITHOUT THE COLLECTOR ACQUIRING THE SUN.

A LOCAL CONTROL THAT ALLOWED AUTOMATIC POSITIONING OF A DRIVE GROUP FOR SPRAY WASHING.

WITH THE EXCEPTION OF A SYSTEM WHICH USED POWER-CABLE CARRIER-FREQUENCY CONTROL TECHNOLOGY, AN ENTIRE SYSTEM HAD TO BE SHUT DOWN IN ORDER TO BLOCK ELECTRICAL CONTROL SIGNALS FROM ENTERING A LOCAL CONTROLLER DURING REPAIR. A SINGLE MULTI-PIN PLUG WITHIN THE CONTROLLER SERVED THIS FUNCTION IN ONE CASE.

DRIVE SYSTEMS

- RELIABILITY

RELIABLE DRIVE SYSTEMS ARE ESSENTIAL.

ONE SET OF RECEIVERS WERE RUINED ON A MISR SYSTEM DUE TO A MOTOR CONTROLLER FAILURE.

- MANUAL BACKUP

IN THE EVENT OF A DRIVE SYSTEM FAILURE, A MANUAL BACKUP CAN ALLOW AN OPERATOR TO ROTATE THE COLLECTOR TO SAFE STOW.

- MECHANICAL STOPS

MECHANICAL STOPS TO STOP THE ROTATION OF A COLLECTOR IN THE EVENT OF FAILURE OF A LIMIT SWITCH OR OTHER DRIVE SYSTEM COMPONENTS IS ESSENTIAL.

THE MECHANICAL STOP SHOULD BE DIRECTLY TIED TO THE COLLECTOR. AT MISR, A DRIVE CHAIN JUMPED A COG, AND BECAUSE THE MECHANICAL STOP WAS PART OF THE CHAIN AND NOT THE COLLECTOR, IT DID NOT PREVENT THE COLLECTOR FROM BEING DESTROYED BY OVERDRIVING ITS LIMIT.