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Design and Field Testing of a Remote Ground-based Liquid Propane Dispenser

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Abstract. The design and field test results of a remotely operated ground-based liquid propane dispenser used for augmenting snowpack in the Sierra Nevada are described. Operation of the dispenser is controlled by a microprocessor interfaced to a VHF radio. Software resident on a Sacramento-based personal computer (PC) provides the necessary commands for dispenser operation via a microwave mountaintop repeater. Each microprocessor is programmed with a separate I.D. allowing independent operation. With eight analog and eight control channels available on the microprocessor, options are available both for dispenser control and monitoring dispenser performance. Verification of liquid propane release consists of monitoring air temperature within the evaporating liquid spray, and flow rate through the valve assembly. Based on a two-year test program, a final design has now been completed. Ten dispensers have been fabricated and installed in the field for operation this winter. If environmental procedures can be completed, this winter will be the first year of a five-year prototype test program to evaluate propane as an effective seeding agent for augmenting winter snowpack.

1.0 Introduction

Reynolds (1989, hereafter referred to as R89) presented the design of a ground-based snowpack enhancement program using liquid propane. The program is designed to increase the firm water yield to Oroville Reservoir, the main reservoir of the California State Water Project. Since completion of R89, two winter seasons of dispenser field testing have been completed. Remotely operated liquid propane dispensers were tested at high elevation sites typical of what would be used in a follow-on five-year demonstration program to begin during the winter of 1990-91.

The two-year test program determined dispenser and communications reliability. Seeding effectiveness could not be determined during this limited test period. Propane releases in supercooled fog over a mountain lake were used to determine that designed release rates (9 to 13L/hr) at temperatures anticipated at mountaintop level (-3 to -5°C) would be effective in producing sufficient ice crystal concentrations. These results will be reviewed in a forthcoming paper. This paper will concentrate on the design of the dispensers and results of two years of field testing.

2.0 Remote Liquid Propane Dispenser Design and Testing

2.1 1988-89 Dispenser Design and Testing

The initial design of the remote liquid propane dispenser is described in R89. This dispenser consists of three separate modules. Each module is installed in a weathertight box. The main module contains system electronics, Fig. 1, which perform two main functions. The first is communication via a VHF radio for receiving control instructions and telemetering

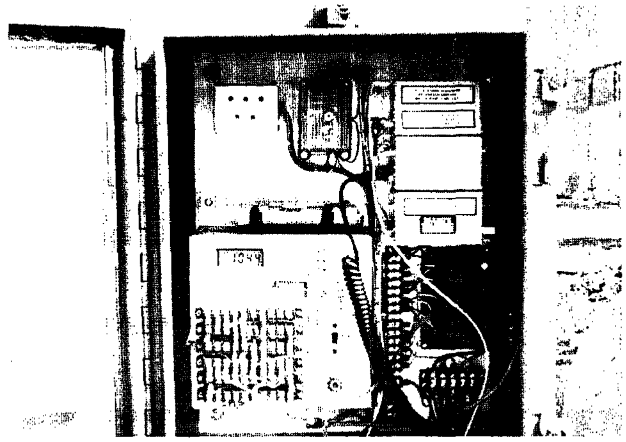

Figure 1 Electronics module showing microprocessor (lower left), VHF radio (upper right) flowmeter electronics (upper center) and switches for initiating manual release of propane (upper left).

verification data back to Sacramento. The second function is dispenser control and data collection via a microprocessor (Odessa Engineering DSM model 3260). Eight analog channels are available for recording data and eight control channels for operating tank, nozzle solenoids, and the radio. Included in this module is a calibration unit used to convert voltages from an in-line flowmeter to flow rates. The output of this is recorded to one of the eight analog channels.

The second major module consists of the plumbing and solenoid valve assembly. Two 2,176-L (575-gallon) propane tanks are used to supply propane to the dispenser. Fifty-seven liters of methanol are added to each tank to prevent freezing of the nozzle and temperature probe. Each line coming from the tank is connected to a solenoid allowing propane to be drawn from either tank so that a tank can be emptied before the next tank is used. All plumbing uses 6.33-mm (1/4-in) copper tubing. In line from the solenoids is a turbine flow transducer (manufactured by Flow-Scan (Model 201B)). This operates on the principle that the rotational velocity of the liquid is directly proportional to flow rate. A neutrally buoyant rotor spins between V-jewel bearings. Rotor movement is sensed when notches in the rotor interrupt an infrared light beam between an LED and phototransistor. The output of the meter is linear over a range of 2.27 to 22.7 L/hr (0.6 to 60 gal/hr). From the flowmeter, liquid is delivered to three separate solenoids that control three independent nozzles. Three nozzles are installed to provide redundancy in case a nozzle clogs or malfunctions. In line with the flowmeter is a pressure gauge and pressure relief valve. The pressure gauge has no analog output and is used for manual reading only. Seeding rates are directly proportional to internal tank pressure so that during initial testing it was important to monitor tank pressure.

From the solenoids, 0.9-meter-long copper tubing is run inside 7.6-cm-square reinforced steel tubing to the top of the dispenser where three standard off-the-shelf brass nozzles (Whirljet 1/4-SS-.5-.5w, orifice size 0.8mm (1/32 in) are mounted. These brass nozzles provide both a wide angle spray pattern and low flow capability. They are rated at 34 L/hr for propane (specific gravity 0.5) at 350 kPa. Small thermocouples with a measurement range from -173 to 737 °C for a 0- to 5-V output are mounted in the spray pattern within 5 cm of the nozzles. These temperature data provide verification that liquid propane is vaporizing from the nozzle. A small sheet metal wind screen is attached to the top of the dispenser to protect the nozzles from rime ice. A small whip radio antenna is also mounted at the top of the dispenser.

The third module consists of a battery box containing a 12-V deep-cycle battery. The battery is recharged by two 45-W solar panels mounted above the electronics module. A voltage regulator is used to protect the radio and microprocessor from excessively high voltages produced by the solar panels on cloudless days.

A prototype dispenser of this design was installed near Summit Lake, California at an elevation of 2146 m on March 8, 1989 (Fig.2). Initial problems in establishing radio communications to the dispenser via a repeater on Beckwourth Peak delayed installation until late winter. Due to half-duplex radio communication, proper time delays were required for transmitting and receiving through the repeater between the Sacramento-based PC used to control operations and the microprocessor at the dispenser. A simple schematic of the communications path is shown in Fig. 3.

Testing of the dispenser consisted of sending commands via radio to open a tank solenoid and a nozzle solenoid. Confirmation of liquid release was determined when the nozzle temperature dropped below -30 °C. About 30 hr of seeding were conducted during March.

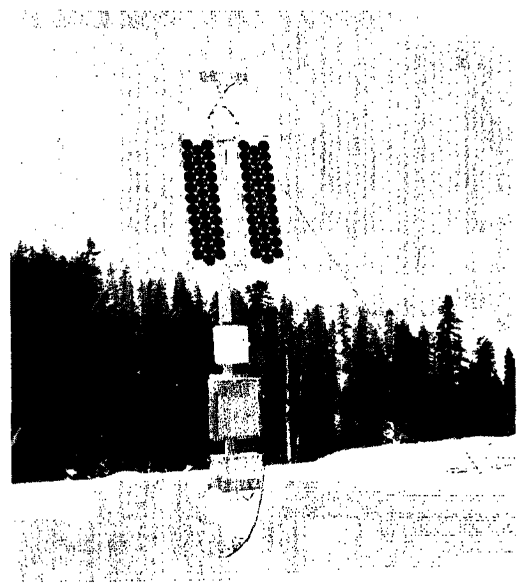

Figure 2 Prototype propane dispenser installed near Summit Lake in March of 1989. The two propane tanks are buried in the snow in the foreground of the picture.

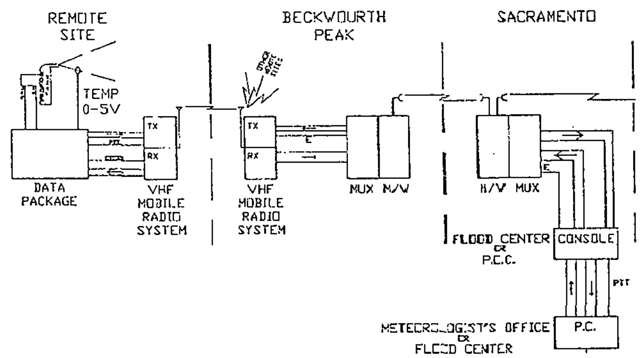

Figure 3 Communications path used to transmit and receive control and verification information to and from remote dispenser.

Several problems were discovered during this limited test period. It was observed that, during propane release, the measured flow rates barely increased above zero. It was determined after deinstallation that the flowmeter had been severely damaged prior to installation at Summit Lake. Compressed air was used to purge the plumbing of debris before field installation. This produced flow rates of 600 to 700 L/hr; when in fact, the meter was only rated for 225 L/hr. Many of the blades were broken off the small turbine resulting in the meter severely underestimating the flow rates.

Seeding rates were determined to be much higher than anticipated based on preliminary field testing. When the tanks were buried in snow, they maintained higher internal pressure than expected (propane vapor pressure is directly proportional to tank temperature). This caused seeding rates to be about a factor of 5 higher than the 11 L/hr desired. (As the flowmeter was inoperable, seeding rates were estimated based on the number of hours of seeding and that a full tank of propane was used).

The supply line used from the propane tank to the dispenser was a 9.5-mm flexible black high pressure hose. It was observed that the hose would absorb heat even at temperatures below freezing causing the propane to vaporize in the line thus causing line and internal plumbing freeze-up. This would render the dispenser inoperable. After mid-March it was not possible to release liquid propane due to this problem.

On March 20, the initial dispenser was removed from the field because of a radio transmitter component failure and a second dispenser installed. Since seeding could not be initiated from this dispenser due to supply line freeze-up, only communications reliability could be monitored during different weather conditions. It was determined that radio communications even in the worst weather were excellent. After the second tower was installed, communications was never a problem. This was verified by the fact that the station was automatically polled each hour by the computer in Sacramento. The computer kept daily statistics on data received (see bottom line in Fig. 7).

Although this first field program was limited in duration it identified several major design problems with the remote dispenser. These were addressed as described in the following section.

2.2 1989-90 Dispenser Design and Testing

During the summer of 1989, several major design changes were made to the dispenser. Not only were there fundamental problems with the original design as described above, but there were also problems with performing field maintenance with the initial design. This was especially true of the valve and plumbing assembly. With the nozzles and valve box separated, it was a major undertaking to replace solenoids or repair leaks in plumbing. Thus the first design change made was to move the valve assembly to the top of the dispenser and have the nozzles protrude from the valve box. This allowed the box to act as the shield for the nozzles. In addition, this allowed removal of the valve assembly without having to remove the supply line from inside the square tubing. Copper tubing was then insulated using foam and reflective tape and connected directly from the tank to the valve box at the top of the tower completely eliminating line freeze-up. Fig. 4 shows the modified valve assembly with supply line attached (uninsulated in this photo).

As a further aid to field maintenance and seeding operations, the original five valves (two for the tanks and one for each nozzle) were replaced with three large filtered lock-off valves (filtering debris in the liquid propane) to control the three nozzles, Fig. 5. This meant that the two propane tanks would be drawn down together. This not only simplified the plumbing but

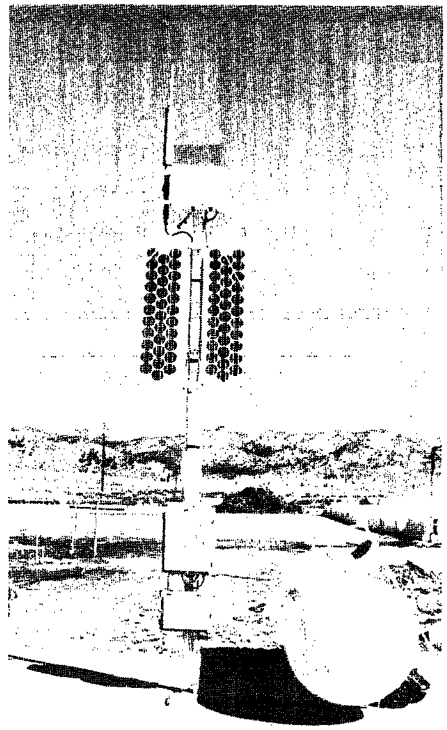

Figure 4 Modified propane dispenser used for the 1990 winter field program. Valve box is now at the top of the tower and acts to shield nozzles from icing.

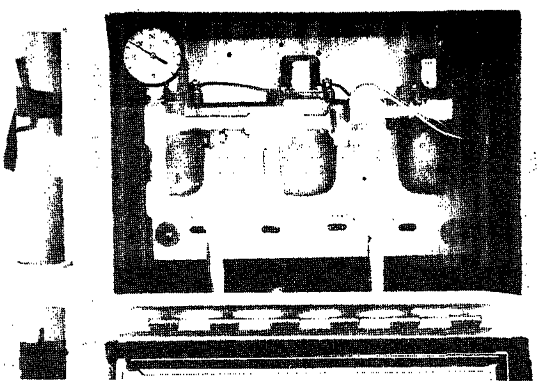

Figure 5 Valve assembly showing flowmeter in-line with plumbing in foreground and three lock-off valves in the background.

reduced the power drain during operation (each solenoid requires 1 A to operate).

The nozzles were changed to a fine spray atomizing type for which flow rates could be repeatedly obtained of 9.5 to 11.5 L/hr. These nozzles had an inlet diameter of 0.4 mm, requiring internal filters to screen any small particles not filtered by the lock-off valves.

The antenna design (folded dipole) was changed to ensure antenna integrity during extreme icing events.

In addition, a tank level sending unit was installed on each tank and connected to an analog channel of the microprocessor. This was an attempt to have further independent documentation that liquid propane was being released and to monitor propane reserves.

Two dispensers of this new design were installed on Haskell Peak (2,372 m) on Jan. 8, 1990. Two dispensers were installed to check consistency between the dispensers and exercise the capabilities of the microprocessor in ensuring that each tower could communicate independently. Fig. 6 shows the two dispensers operating at this site. An hourly data summary for one of these dispensers is shown in Fig. 7 as recorded by the PC in Sacramento. Seeding began at 4:15 a.m. PST and is indicated by the drop in temperature for nozzle three (CH 08) and the increase in flow rate shown in CH 02. One also sees the tank level dropping (CH 04). It was found, however, that the sending unit used for monitoring tank level was not sensitive enough to reliably respond to small changes. In fact, as much as a 190 L drop in liquid level was required before the sending unit would change.

It can be seen in Fig. 7 that when the solenoids were actuated, the temperature for the non-operating nozzles would drop by 5 to 10°F since both the solenoids and the temperature transducers are referenced to the same battery. When battery voltage drops, it produces an artifical temperature drop. This could only be corrected by having a different power supply for the solenoids and the transducers. This is being corrected for the coming winter's program. Fig. 8 is a closeup of a nozzle after 14 hours of operation. One can see that ice has built up on top of the temperature arm and around the outer edge of the nozzle, but the nozzle is still spraying adequately. This would not be the case if methanol had not been added to the propane. Note the rime ice on the tower guy wires and antenna.

Figure 6 Two second-generation propane dispensers operating on Haskell Peak Jan. 30, 1990. Note distinct ice crystal plume moving downwind from dispensers.

DAILY DATA SUMMARY

NAME: HASKELL PEAK #1 LOCATION: HASKELL PEAK, CA STATION ID: 1

CHAN NAME		Ch 01	Ch 02	Ch 03	Ch 04	Ch 05	Ch 06	Ch 07	Ch 08
CHAN UNITS			GPH	GAL	GAL	VOLTS	DEG F	DEG F	DEG F
FULL SCALE		1.000	60.0	461	461	60.83	1356.0	1340.0	1345.0
ZERO OFFSET		0.000	0.0	0	0	0.00	-460.0	-460.0	-460.0
START / CHANNEL		01	02	03	04	05	06	07	08
01/30/90	00:00:00	0.000	0.0	419	446	13.50	12.91	16.78	16.29
01/30/90	01:00:00	0.000	0.0	419	446	13.49	13.36	16.78	16.29
01/30/90	02:00:00	0.000	0.0	415	446	13.47	13.82	17.90	17.20
01/30/90	03:00:00	0.000	0.0	419	446	13.47	14.27	17.68	17.20
01/30/90	04:00:00	0.000	1.8	419	447	13.07	7.91	11.60	-75.99
01/30/90	05:00:00	0.001	2.3	420	447	12.98	7.00	10.03	-10[illegible].2
01/30/90	06:00:00	0.001	2.3	420	447	12.97	4.95	6.45	-104.0
01/30/90	07:00:00	0.001	2.4	419	448	12.95	1.77	5.75	-105.6
01/30/90	08:00:00	0.001	2.6	419	445	12.92	0.64	4.16	-107.1
01/30/90	09:00:00	0.001	2.6	419	442	12.88	0.64	4.18	-106.7
01/30/90	10:00:00	0.001	2.6	419	442	12.87	0.86	4.63	-106.0
01/30/90	11:00:00	0.001	2.6	419	439	12.84	1.09	5.08	-106.9
01/30/90	12:00:00	0.001	2.6	419	434	12.80	-0.05	3.95	-107.6
01/30/90	13:00:00	0.001	2.6	419	434	12.77	0.64	4.18	-108.0
01/30/90	14:00:00	0.001	2.6	419	434	12.73	0.18	3.73	-108.5
01/30/90	15:00:00	0.001	2.6	419	431	12.69	-0.05	3.95	-108.7
01/30/90	16:00:00	0.001	2.6	419	430	12.65	0.64	4.18	-106.7
01/30/90	17:00:00	0.001	2.4	419	431	12.60	0.64	4.85	-106.3
01/30/90	18:00:00	0.001	2.4	419	427	12.55	1.09	5.08	-108.3
01/30/90	19:00:00	0.001	2.5	419	425	12.51	0.64	4.40	-108.5
01/30/90	20:00:00	0.000	0.3	419	422	12.92	7.23	11.30	-3.56
01/30/90	21:00:00	0.000	0.0	419	423	12.98	7.23	11.30	10.65
01/30/90	22:00:00	0.000	0.0	419	422	12.98	8.62	12.95	12.23
01/30/90	23:00:00	0.000	0.0	419	422	12.96	6.32	15.46	9.90
		00:00	00:00	02:00	23:00	19:00	15:00	08:02	14:15
Daily Minimum		0.000	0.0	419	422	12.50	-0.95	3.57	-108.9
15-minute Values									
Daily Maximum		0.001	2.6	420	449	13.50	14.50	17.90	17.42
		04:15	07:45	05:30	07:30	00:15	02:30	02:00	02:15
		00:00	00:00	03:00	23:00	19:00	12:00	14:00	15:00
Daily Minimum		0.000	0.0	419	422	12.51	-0.05	3.73	-108.7
1-hour Values									
Daily Maximum		0.001	2.6	420	448	13.50	14.27	17.90	17.20
		05:00	11:00	05:00	07:00	00:00	03:00	02:00	03:00
Daily Average		0.000	1.7	419	437	12.94	4.69	8.40	-66.03
Daily Total		0.031	158.5	40247	41909	1242.1	450.09	813.50	-6339
Daily Recovery (%)		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Figure 7 Printout of hourly data from one of two stations operated on Haskell Peak on Jan. 30, 1990. Nozzle 3 (CH 08) shows temperature in evaporating plume of propane.

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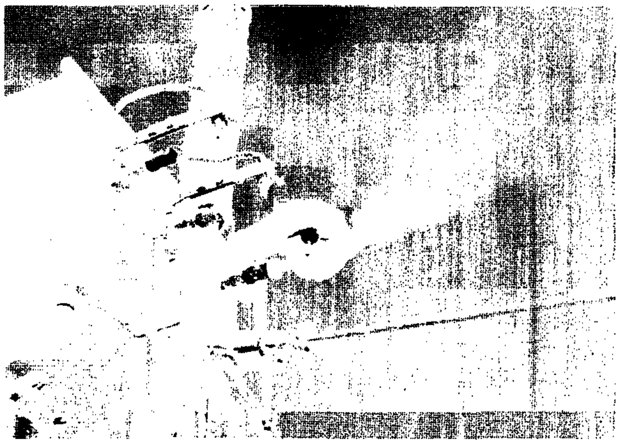

Figure 8 Closeup view of nozzle after 14 hours of operation on Jan. 30, 1990. Methanol added to propane tank has prevented nozzle and temperature probe from icing.

The seeding log for the 1989-90 winter season is shown in Table 1. The table shows that both dispensers were operated for about 80 hr. However, various nozzles were tested on each dispenser so that seeding rates varied slightly. Thus the volume of liquid used is slightly different. Several tests were performed to see how well release rates could be matched using identical nozzles on each dispenser. These tests were run on 1/12, 1/30, 1/31-2/1, and 3/4. Very consistent seeding rates were found between the two dispensers and within a few tenths of 9 L/hr (2.5 gal/hr). The two dispensers operated without failure from January 8 through April 30, 1990. One hundred percent of the data were recovered from each site during this time period.

2.3 Further Design Considerations for 1990-91

As mentioned above, a few minor design changes were needed before dispensers were installed this season. The first was the addition of a 5 V regulator to operate the temperature sensors. This has been completed and tested and has eliminated the problem of artificially low temperature values when a solenoid is on. Secondly, the supply line has now been installed inside 5-cm-square tubing (the tower had 7.6-cm tubing, but it was reduced in size to reduce weight of the tower) running from the base of the tower to just below the valve box. [The supply line hooks externally to the valve assembly.] The tube is filled with foam insulation. A second supply line comes from the tank to the bottom of the tower and is wrapped in foam insulation and reflective tape. Tank level sending units are not being used as they were found to be unreliable. More reliable units are available but were not purchased to keep cost down.

It is believed that the current design should perform satisfactorily. However, at this writing, operation of the dispensers is being delayed until appeals to the environmental documentation submitted by the State of California and the U.S. Forest Service (for obtaining use permits to operate the dispensers on Forest Service land) can be adequately addressed. It is anticipated that seeding will not be permitted this winter.

3.0 Acknowledgments

This work was sponsored by the California Department of Water Resources (DWR) through Cooperative Agreement B-57788. Without the dedicated efforts of Mr. Bruce Gillette, Mr. Conrad Lahr and Mr. Jim Hespen of DWR and the continued encouragement of Mr. Larry Mullnix, Deputy Director of DWR, this work would not have been possible.

4.0 References

Reynolds, D. W., 1989: Design of a ground-based snowpack enhancement program using liquid propane. J. Weather Mod.,21,29-34.

	HP1				HP2			
Date	Time On PST	Time Off PST	Total Time	#Gallons Propane	Time On PST	Time Off PST	Total Time	#Gallons Propane
1/12/90	12:35	17:20	3.5hrs	12.8	12:15	17:20	3.5hrs	13.7
1/13/90	09:40	12:00	2.3hrs	5.9	09:40	12:00	2.3hrs	10.
1/16/90	07:15	17:15	10hrs	24.2	07:15	17:15	10hrs	40.7
1/26/90	06:15	10:15	4hrs	9.6	06:15	10:15	4hrs	16.35
1/30/90	04:15	20:05	15.83hrs	39.8	04:15	20:05	15.83	37.8
1/31-2/1	20:05	13:30	17.42hrs	38.3	20:05	13:30	17.42	37.0
3/3/90	04:30	16:05	11.58hrs	27.7	04:30	16:05	11.58	29.02
3/4/90	14:50	21:40	6.83hrs	16.9	14:50	21:40	6.83	18.2
3/10/90	08:10	17:10	9hrs	27.3	08:10	17:10	9.0	32.44
			80.46hrs.	202.5gal			80.46hr	235.27gal.
			Avg. 2.51	gal/hr			2.92	gal/hr.

Table I Seeding log for 1990 for two dispensers operated on Haskell Peak.