NRL Memorandum Report 3776

Combustion Scaling and Modeling: Fire Suppression by Nitrogen Pressurization

III - Test Data, NRL 5000-liter Facility, Test Configurations 2 and 3

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Gas mixing rate studies in a 5000-liter cylindrical tank continue. Observations of gas temperatures are made with thermocouple probes during pressurization from 1 to 2 atmospheres through two- and three-nozzle arrays with diameters of 25.4 mm in ca. 5 and 7 s, respectively. Pressurant concentrations may be inferred from temperature measurements. Six experimental runs are reported in which air is used as both the pressurant and the resident gas under nonfire conditions.

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COMBUSTION SCALING AND MODELING: FIRE SUPPRESSION BY NITROGEN PRESSURIZATION
III — Test Data, NRL 5000-liter Facility, Test Configurations 2 and 3

INTRODUCTION

There is concern over potential destructiveness of unwanted submarine fires, but existing fire suppression techniques for submarines are limited. Addressing this problem, Carhart and Fielding (1) proposed nitrogen pressurization as a fire suppression technique for submarines.

Their concept derives from three basic premises: (a) A submarine is a gas-tight vessel, whose internal pressure can be varied over a limited range; (b) sustenance of human life requires an oxygen partial pressure of about 0.2 atmosphere regardless of total pressure, at least to several atmospheres; (c) combustion of fuels depend on atmospheric oxygen concentration; for instance, hydrocarbon diffusion flames extinguish at oxygen concentrations of 12 to 14 percent by volume. This is the basis of a patent by Carhart et al. (2).

For example, if a closed space with one atmosphere air pressure is pressurized to two atmospheres by addition of nitrogen gas, the oxygen partial pressure in the space remains a constant 0.21 atmosphere, while the oxygen concentration by volume reduces by 1/2 to 10.5 percent. This example demonstrates the nitrogen-pressurization concept, i.e., creation of an atmosphere that sustains human life but suppresses combustion. Other advantages include inertness of nitrogen to electrical wiring, machines, and air-purification devices as well as the relative ease of returning a submarine atmosphere to normal after nitrogen has been added.

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Initial tests support the nitrogen pressurization concept. Liquid hydrocarbon fuel pool fire suppression studies in 270- and 5000-liter chambers have demonstrated suppression capability for fires up to 20 cm in diameter (3-5). A study of biological effects on laboratory rats during pool-fire suppression experiments in the 5000-liter facility demonstrated that rats could survive during the suppression of pool fires by nitrogen pressurization (6).

Although initial experimental findings support the concept, many questions and problems remain. One of these problems involves rates of mixing of the pressurant gas with the resident gas during pressurization, and how various parameters such as geometry, nozzle design and location, and pressurization time affect these rates. Scale modeling is applied due to the complexities of processes that couple in fire suppression and the savings of time, money, and material that successful modeling affords.

Our present aim is to investigate nitrogen concentration profiles in chambers of different sizes, to link these experimental results to mathematical models, and to seek scaling rules which predict concentration profiles in larger chambers.

Two sets of experiments are in progress: the NRL 5000-liter experiment described here and a 1/6-scale (geometric) model of the NRL experiment performed at the University of Washington by Professor R.C. Corlett's group (NRL Contract N00014-75-C-0185). In addition, these experimental results are to be linked with two mathematical modeling studies by Professor Pratt's group at the University of Utah (NRL Contract N00173-76-C-0232) and by the Plasma Dynamics Branch, NRL, Code 6750. Because of its convenient size, concentration profiles in the 1/6-scale model are measured directly. This approach is less practical in the NRL facility, however, because of its larger size. Remoteness of chemical sensors from gas collection probes in the chamber can allow diffusion of sampled gas in the long sampling tubes (about 8 m) which connect to slow responding chemical detectors.

To avoid this problem, temporally responsive, in situ probes with electrical output signals are preferred. Since mechanisms of mass and momentum transfer are the same in separated flow, velocity and concentration profiles are similar (7). In addition, for gases which have a ratio of thermal and molecular diffusivity near unity, temperature and velocity profiles approximately coincide in time and space (8,9).

In these initial mixing experiments, fine wire thermocouples are used to measure gas temperatures and infer pressurant concentrations and thus mixing rates. Jones, Boris, and Oran examined this approach with a view to first principles. They concluded that temperature as a diagnostic appeared feasible so long as initial temperatures of the pressurant gas are equal or less than those of the resident gas of the 5000-liter chamber (10).

This is the third reporting of a series (11,12).

DESCRIPTION OF EXPERIMENT

Procedure

Figure 1 schematically shows the experimental arrangements. Dry, compressed air blows from Tank 1 to Tank 2 through a galvanized, 3-in. pipe and a manifold which distributes the flow to three nozzle positions. Either a one-, two-, or three-nozzle configuration may be selected simply by insertion of pipe plugs into the unwanted nozzle positions. Jets of the incoming air blow from selected nozzles down vertical radii normal to the tank horizontal axis and mix with Tank 2 resident air. Temperature differences between incoming and resident air act as the diagnostic indicating mixing patterns. Thermocouples arrayed in the tank signal air temperatures and thus imply concentration profiles of incoming air (pressurant). The actuated ball valve, 3" AF Flanged Ball Valve by Jamesbury Corporation, allows either "no-flow" or "full-flow" conditions according to its "off" or "on" position, respectively.

Tank 1 is charged with clean, dry plant air through the air valve by Automatic Switch

Company (Figure 1) with the actuated ball valve closed. Compressed plant air is processed, at a controlled rate, by a Heatless Dryer, Model G.C., by Deltech Engineering, and passes through the 3-in. pipe section to Tank 1.

Tank 1

Tank 1, a steel cylindrical pressure tank with two dished ends, lays horizontally. Its volume is 2260 liters (79.9 cu ft) with a length of 2.334 m (7.66 ft), a diameter of 1.067 m (3.44 ft), and a wall thickness of 9.5 mm (3/8 in.). A pressure transducer, Model P24 by Validyne Engineering Corporation, connected to Tank 1 by a 6.35-mm (1/4-in.) tube indicates its pressure. Gas temperature in the tank is indicated by a bare thermocouple, type K, with a diameter of 0.2 mm (0.008 in.). The thermocouple extends radially into the tank near its exit. A similar thermocouple is installed at a 90-degree ell and extends into the 3-in. pipe just downstream from the Tank 1 exit.

Tank 2

Tank 2 is a modified decompression chamber. Cylindrical in shape and made of steel, its volume is 5000 liters (177 cu ft) with a length of 2.74 m (9 ft), a diameter of 1.546 m (5.07 ft), and a wall thickness of 11.1 mm (7/16 in.). A hatch on one end opens inwardly, allowing access to the interior. An air lock is centered on the opposite end. Three 5-in. view ports are located, two on a side and one on the hatch. The chamber was modified to allow numerous tubes, wires, thermocouples, and pipes to penetrate its walls. Original interior nozzle system, lighting system, and 6.4 mm (1/4 in.) steel floor plates remain; all other hardware associated with a manned chamber has been removed. In addition, two 12.7-mm (1/2-in.) aluminum plates were laid on the floor plates, as Figure 2 shows. The aluminum plates contain a square, 76.2-mm (3-in.) grid of tapped holes. These holes receive threaded, 12.7-mm aluminum rods which position thermocouples in the chamber interior space according to their length and grid position.

For convenience, a cylindrical coordinate system (r, θ, z) is chosen to indicate chamber interior positions. As Figure 2 shows, a vertical plane through the center of the cylindrical tank normal to its center axis is taken as the $z = 0$ plane, with the air lock selected as the positive z direction and the hatch as the negative z direction. The center, horizontal axis of the tank is taken as $r = 0$.

Tank 2 pressure is indicated by a transducer, Validyne Engineering Corporation, which connects to the chamber by a 3.2-mm (1/8-in.) tube.

Thermocouples

Chromel alumel (Type K) bare-wire thermocouples are mounted, as shown in Figure 3, on 12.7-mm diameter rods. Couple wire diameters are 0.2 mm with couple bead diameters from 2 to 2.5 times the wire diameters. The manufacturer (Conax Corporation) gives the accuracy as ±1.1K with time constants of ca. 0.3 s at flows of 19 m/s and 1.2 s at 3 m/s. Thermocouple chamber coordinates are given in Table 1.

Nozzles

Three pipe couplings are welded into the top of Tank 2 so that the $Z = 0$ plane bisects the center nozzle position. Likewise, the other two positions are bisected by the $Z = 0.914$ m (36 in.) plane and the $Z = -0.914$ m (−36 in.) plane.

Straight nozzles machined from high-density polyethylene rod, shown in Figure 4, are threaded to mate the couplings. Fits are such that nozzle exits extend 0.305 m (1 ft) into the tank interior, pointing downward along vertical radii. As Figure 1 shows, a bare-wire, 0.2-mm diameter thermocouple is positioned in the pipe immediately upstream of the center nozzle. A similar thermocouple is positioned at the center of the nozzle exit, tank position (0.475 m, $\pi/2$, 0).

Data Collection

The data collection system consists of two Doric Digitrend-220's, each with a magnetic tape device that can be started simultaneously by a remote control. In these experiments, 20 transducer outputs are read, 10 by one Doric system on channels 60 through 69 and 10 by the other system on channels 70 through 79. Each system records two additional channels: (a) the time indicated by an internal clock in hours: minutes: seconds, and (b) an eight-digit fixed data point in which the date and run number are entered. Thus 24 channels are scanned at a rate of 40 channels per second by the two systems to produce two magnetic tapes of data. A single scan requires ca. 0.6 s.

The two magnetic tapes are then processed with a Hewlett Packard 21MX minicomputer, for which programs are written to present the data in tabular form as shown in Figure 5.

The data from each Doric System are also compiled in tabular form onto a single magnetic tape. This tape contains time, and 10 channels of data (Channels 60 through 69), repetitively until reaching the end of run (end of file), followed by another file containing the same information for the second 10 channels of data (Channels 70 through 79). The format is 118 ASCII characters and end of record.

PROGRAM PLANS

Initial experiments include two sets of six test configurations as shown below. In one set, a nozzle diameter of 25.4 mm is used; in the other, 15.2 mm is used. Data presented in this report are for those test configurations and nozzle diameters shown in bold print.

Test Configuration	1	2	3	4	5	6
Nozzle Array	1	2	3	1	2	3
Thermocouple Array	I	I	I	II	II	II
Number of Expl. Runs	9	3	3	3	3	3
Nozzle Diameter		25.4			15.2	

Nozzle array 1 includes only the center nozzle, nozzle array 2 includes the center and hatch-end nozzles; nozzle array 3 includes all three nozzles. Thermocouple array I locates the thermocouples along the center, horizontal axis of the chamber (Tank 2), whereas thermocouple array II locates the thermocouples along a horizontal line parallel to the center axis, but displaced 0.457 m along the 45-degree radius normal to the tank axis, as viewed from the hatch end of the chamber, Figure 2. The test procedure in this phase remains the same, and no obstacles to flow are placed in the chamber.

TEST CONFIGURATION 1

Configurations

In test configuration 2 two nozzles are used, the center nozzle, N-2, and the air-lock-end nozzle, N-1. See Figures 1 and 2. All three nozzles are used in test configuration 3. In both configurations, thermocouple array I is used; thermocouples in the chamber (Tank 2) are positioned along its horizontal axis. Chamber coordinates of thermocouples and their respective channel readout are present in Table 1; Figure 2 establishes the coordinate system.

Procedure

Tank 1 is charged with clean dry air to a pressure of about 6.8 atm; the air temperature is allowed to equilibrate with the tank walls. Then with Tank 1 pressure at about 6.5 atm (ambient temperature) and Tank 2 pressure at 1 atm (ambient temperature) the actuated valve is opened. When Tank 2 pressure reaches 2 atm, the valve is closed.

Table 2 gives a chronological description of experimental runs 32 through 37.

REPORT SUMMARY

This is the third report of a series that aims to document and transfer experimental data quickly to users. Experiments presented here, Runs 32 through 37, are part of the initial experiments described above under Program Plans and shown in bold print in the listing. Runs 32 through 34 were made in test configuration 2, while Runs 35 through 37 were in configuration 3.

ACKNOWLEDGMENTS

The authors express their thanks to Doren Indritz and Omar Ahmed for programming and assistance with the minicomputer, and to Professor R.C. Corlett for his discussions and suggestions.

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Table 1 — Transducer Channel Readouts, Locations, and Descriptions

Channel Number	Location	Readout
60	Tank 1	Pressure: 1 mV = 10.3 kPa
61	Tank 2	Pressure: 1 mV = 3.44 kPa
62	T_2 (0, 0, 0.533)*	Temperature, °C
63	Event Marker	mV
64	T_2 (0, 0, 0.991)	Temperature, °C
65	T_2 (0, 0, 0.914)	Temperature, °C
66	T_2 (0, 0, 0.584)	Temperature, °C
67	T_2 (0, 0, 0.762)	Temperature, °C
68	T_2 (0, 0, 0.686)	Temperature, °C
69	T_2 (0, 0, 0.610)	Temperature, °C
70	N-2 (0.457, $\pi 2$, 0)	Temperature, °C
71	T_2 (0, 0, 0)	Temperature, °C
72	Upstream of N-2	Temperature, °C
73	Downsteam Tank 1 exit	Temperature, °C
74	T_2 (0, 0, 0.076)	Temperature, °C
75	T_2 (0, 0, -0.076)	Temperature, °C
76	T_2 (0, 0, 0.152)	Temperature, °C
77	T_2 (0, 0, -0.152)	Temperature, °C
78	T_2 (0, 0, 0.229)	Temperature, °C
79	Tank 1	Temperature, °C

*T_2 (0, 0, 0.533) = temperature in Tank 2 (r, θ, z), where $r = 0$ m, $\theta = 0$ radian, $z = 0.533$ m. See Figure 2.

Table 2 — Chronological Description of Runs 32 Through 37

Time	Description
Run 32	For channels 60 through 69
10:09:00	Start data collection 30 s prior to blowdown
10:09:30	Open actuated valve to start blowdown
10:09:37	Actuated valve closed when Tank 2 pressure reaches 203 kPa
10:13:00	End
Run 32	For channels 70 through 79, same as channels 60 through 69
Run 33	For channels 60 through 69
10:33:00	Start data collection 30 s prior to blowdown
10:33:30	Open actuated valve to start blowdown
10:33:38	Actuated valve closed when Tank 2 pressure reaches 203 kPa
10:37:00	End
Run 33	For channels 70 through 79, same as channels 60 through 69
Run 34	For channels 60 through 69
10:57:00	Start data collection 30 s prior to blowdown
10:57:30	Open actuated valve to start blowdown
10:57:37	Actuated valve closed when Tank 2 pressure reaches 203 kPa
11:01:00	End
Run 34	For channels 70 through 79, same as channels 60 through 69
Run 35	For channels 60 through 69
12:53:00	Start data collection 30 s prior to blowdown
12:53:30	Open actuated valve to start blowdown
12:53:35	Actuated valve closed when Tank 2 pressure reaches 203 kPa
12:57:00	End
Run 35	For channels 70 through 79, same as channels 60 through 69
Run 36	For channels 60 through 69
13:16:00	Start data collection 30 s prior to blowdown
13:16:30	Open actuated valve to start blowdown
13:16:35	Actuated valve closed when Tank 2 pressure reaches 203 kPa
13:20:00	End
Run 36	For channels 70 through 79, same as channels 60 through 69
Run 37	For channels 60 through 69
13:35:00	Start data collection 30 s prior to blowdown
13:35:30	Open actuated value to start blowdown
13:35:34	Actuated valve closed when Tank 2 pressure reaches 203 kPa
13:39:00	End
Run 37	For channels 70 through 79, same as channels 60 through 69

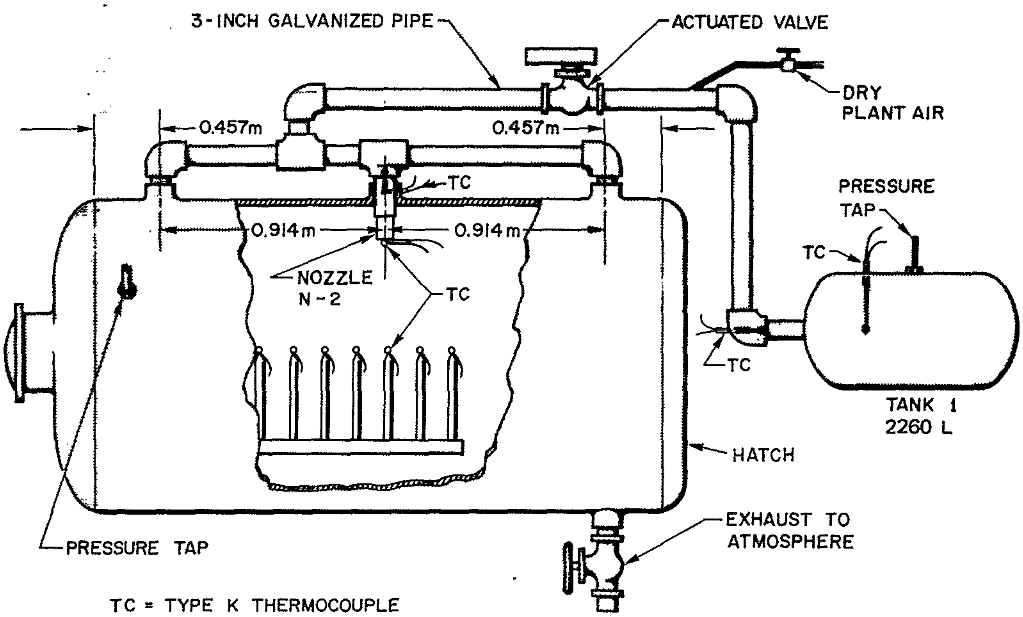

Fig. 1 – Schematic of apparatus

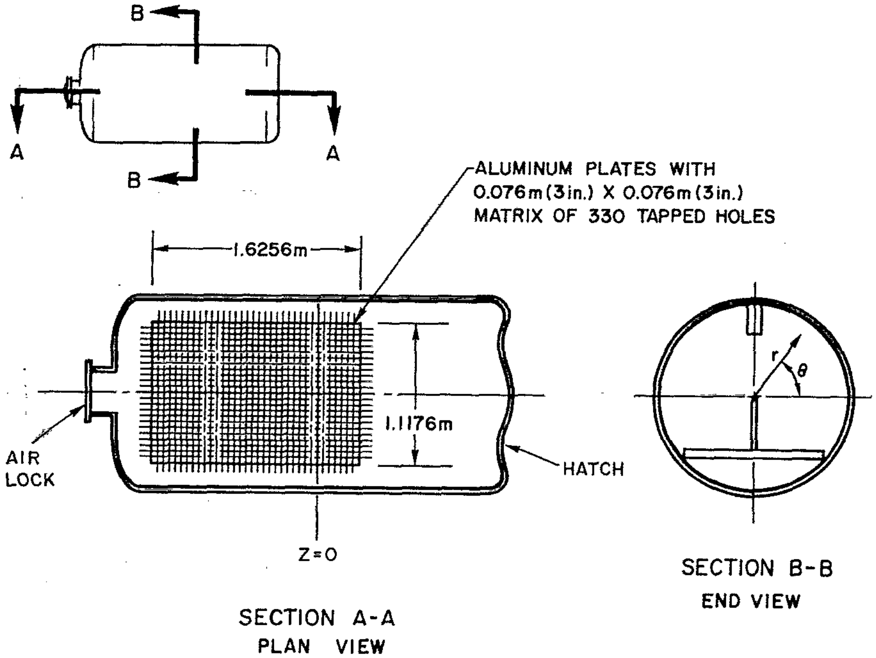

Fig. 2 – Plan and end views of Tank 2 showing cylindrical coordinates and matrix of 330 tapped holes

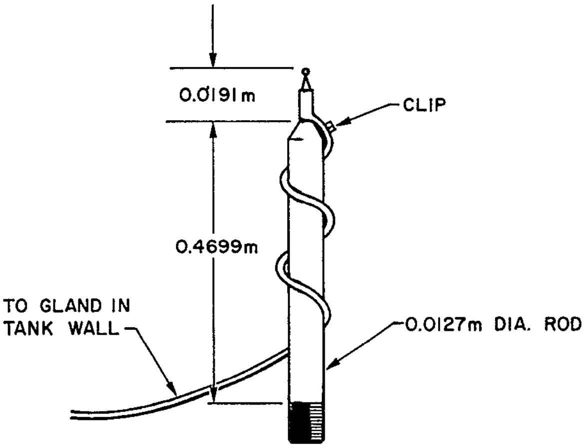

Fig. 3 – Thermocouple fixture

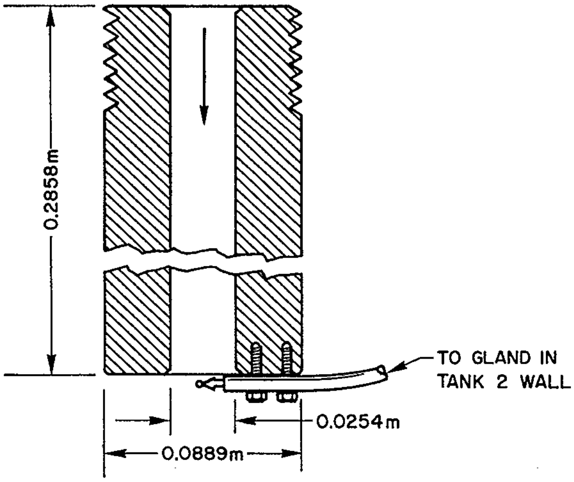

Fig. 4 – Sectional view of straight nozzle

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    PRELIMINARY S CALING RUN18: 30  SEC PRE-BLOWDOU N, 17 SEC BLOWDO WN, 133 SEC POST  BL
0 CHANNELS        60         61          62         63        64          65         66         67         68         63
0 TIME
  13:35: 0      5 81.7     289.1        26.5      26 .9      27.0        26.5       27.1       27.3       24.9       25.8
  13:35: 0      6 09.0     292.1        27.2      27 .5      27.2        27.2       27.5       27.3       25.5       26.1
  13:35: 1      6 07.4     292.2        27.5      27 .3      27.2        27.5       27.3       27.4       25.7       26.1
  13:35: 2      6 09.4     292.2        27.5      27 .4      27.5        27.3       27.4       27.7       25.6       26.0
  13:35: 2      6 09.6     292.7        27.4      27 .6      27.2        27.4       27.4       27.4       25.6       26.3
  13:35: 3      6 09.6     292.3        27.6      27 .4      27.4        27.4       27.4       27.6       25.6       26.1
  13:35: 4      6 11.7     292.7        27.4      27 .7      27.3        27.3       27.7       27.7       25.6       26.3
  13:35: 4      6 08.2     292.5        27.6      27 .4      27.3        27.5       27.4       27.6       25.9       26.2
  13:35: 5      6 12.4     292.6        27.4      27 .7      27.4        27.3       27.6       27.7       25.7       26.3
  13:35: 6      6 08.1     292.5        27.7      27 .4      27.4        27.6       27.4       27.5       25.9       26.3
  13:35: 6      6 12.2     292.6        27.5      27 .6      27.4        27.3       27.6       27.7       25.7       26.3
  13:35: 7      6 08.1     292.6        27.6      27 .5      27.3        27.6       27.6       27.5       25.9       26.3
  13:35: 8      6 11.9     292.5        27.6      27 .6      27.5        27.4       27.6       27.7       25.7       26.3
  13:35: 8      6 08.4     292.7        27.6      27 .6      27.3        27.6       27.6       27.5       25.8       26.4
  13:35: 9      6 11.5     292.5        27.6      27 .6      27.6        27.4       27.4       27.7       25.8       26.2
  13:35:10      6 08.7     292.8        27.6      27 .6      27.3        27.6       27.6       27.5       25.8       26.4
  13:35:10      6 10.8     292.5        27.7      27 .4      27.6        27.4       27.4       27.7       25.8       26.3
  13:35:11      6 10.4     292.8        27.5      27 .6      27.3        27.4       27.7       27.6       25.8       26.3
  13:35:12      6 09.7     292.5        27.7      27 .4      27.4        27.6       27.4       27.6       25.9       26.3
  13:35:12      6 12.6     292.7        27.4      27 .7      27.4        27.4       27.7       27.7       25.7       26.3
  13:35:13      6 08.2     292.6        27.6      27 .4      27.3        27.6       27.5       27.6       25.9       26.3
  13:35:14      6 12.6     292.6        27.6      27 .6      27.5        27.3       27.6       27.7       25.8       26.3
  13:35:14      6 08.6     292.7        27.6      27 .6      27.3        27.6       27.6       27.5       25.9       26.5
  13:35:15      6 11.1     292.5        27.6      27 .6      27.6        27.4       27.4       27.7       25.9       26.3
  13:35:16      6 09.5     292.9        27.6      27 .7      27.3        27.4       27.7       27.5       25.8       26.4
  13:35:16      6 09.9     292.5        27.7      27 .4      27.6        27.6       27.4       27.7       25.9       26.3
  13:35:17      6 12.3     292.8        27.5      27 .7      27.5        27.4       27.6       27.7       25.8       26.3
  13:35:18      6 08.4     292.7        27.7      27 .4      27.4        27.6       27.6       27.5       26.0       26.3
  13:35:18      6 12.5     292.6        27.6      27 .6      27.6        27.4       27.6       27.7       25.8       26.3
  13:35:19      6 09.4     292.8        27.5      27 .7      27.3        27.5       27.7       27.5       25.9       26.4
  13:35:20      6 10.9     292.5        27.6      27 .5      27.6        27.5       27.5       27.7       25.9       26.3
  13:35:21      6 11.3     292.8        27.5      27 .7      27.4        27.4       27.7       27.7       25.8       26.3
  13:35:21      6 08.7     292.6        27.7      27 .4      27.4        27.6       27.5       27.6       26.1       26.3
  13:35:22      6 12.9     292.7        27.6      27 .7      27.6        27.4       27.6       27.7       25.8       26.3
  13:35:23      6 08.3     292.8        27.6      27 .6      27.4        27.6       27.6       27.6       26.0       26.5
  13:35:23      6 11.6     292.6        27.6      27 .6      27.6        27.4       27.5       27.7       25.9       26.3
  13:35:24      6 09.2     292.8        27.6      27 .7      27.4        27.6       27.7       27.5       25.9       26.5
  13:35:25      6 10.5     292.5        27.7      27 .5      27.6        27.6       27.5       27.7       26.0       26.3
  13:35:25      6 11.5     292.9        27.6      27 .7      27.4        27.4       27.7       27.6       25.8       26.5
  13:35:26      6 09.3     292.6        27.7      27 .4      27.4        27.6       27.5       27.6       26.1       26.3
  13:35:27      6 12.6     292.6        27.6      27 .6      27.6        27.4       27.7       27.7       25.8       26.3
  13:35:27      6 08.7     292.8        27.6      27 .7      27.4        27.6       27.6       27.5       26.0       26.5
  13:35:28      6 11.5     292.6        27.7      27 .6      27.6        27.4       27.5       27.7       25.9       26.3
  13:35:29      6 10.5     292.8        27.4      27 .7      27.4        27.4       27.7       27.7       25.9       26.4
  13:35:29      6 08.6     292.7        27.7      27 .5      27.4        27.6       27.5       27.6       26.1       26.3
  13:35:30      6 13.0     292.8        27.6      27 .6      27.4        27.4       27.7       27.8       25.8       26.6
  13:35:31      6 08.9     292.8        27.2      27 .8      26.8        27.7       27.8       27.6       26.1       26.7
  13:35:31      5 97.5     302.1        28.6      28 .6      28.5        28.8       29.0       29.2       27.7       28.6
  13:35:32      5 76.4     323.7        31.6      30 .6      30.6        30.5       30.8       31.0       29.5       31.3
  13:35:33      5 57.2     342.9        33.6      33 .0      32.4        32.2       33.4       33.3       31.2       33.9
  13:35:33      5 35.1     360.8        36.4      35 .1      34.6        34.3       34.4       35.2       33.1       35.0
  13:35:34      5 17.0     378.0        37.7      36 .9      36.2        35.6       36.4       36.4       34.8       37.0
  13:35:35      5 00.8     393.9        39.0      38 .0      37.7        36.3       37.5       37.8       35.5       38.1
  13:35:35      4 79.8     409.3        39.2      38 .9   [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
  13:35:36      4 68.2     423.9        40.0      39 .6      38.8        37.7       38.4       39.0       37.0       38.7
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Fig. 5 – Representative printout of tabular data. Channels 60 and 61 present pressures of Tanks 1 and 2, respectively, in millivolts times 10 as indicated by pressure transducers (for ch 60, 1 mV = 0.102 atm; for ch 61, 1 mV = 0.034 atm); channel 63 marks the time interval during which the actuated-valve switch is open by display of a positive voltage; other channels present temperatures in degrees centigrade; the first column gives time in hours:minutes:seconds.