# U.S. Army Research Institute of Environmental Medicine

*Natick, Massachusetts*

**TECHNICAL REPORT NO. T08-11**
**DATE September 2008**
**ADA**

# ON-THE-MOVE NUTRIENT DELIVERY SYSTEM PERFORMANCE CHARACTERISTICS



**United States Army**
**Medical Research & Materiel Command**

| **REPORT DOCUMENTATION PAGE** | | | | | *Form Approved OMB No. 0704-0188* |
|---|---|---|---|---|---|



**1. REPORT DATE** *(DD-MM-YYYY)*
08-09-2008

**2. REPORT TYPE**
Technical Report

**3. DATES COVERED** *(From - To)*
Feb 2007 - Sept 2008

**4. TITLE AND SUBTITLE**
On-the-Move Nutrient Delivery System Performance Characteristics

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Scott J. Montain, Matthew R. Ely, Kenneth N. Racicot

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
U.S. Army Research Institute of Environmental Medicine, Natick, MA 07160-5007
Combat Feeding Directorate, Natick Research Development and Engineering Command, Natick, MA 01760-5007

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
U.S. Army Medical Research and Material Command
Fort Detrick
Frederick, MD 21702-5012

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release.
Distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
Dismounted operations make it difficult for Warriors to drink and eat enough. The Nutrient Delivery System (NDS) is an add-on to collapsible bladder with drink tube personal hydration systems, and is intended to facilitate fluid and on-the-move nutrient intake. Tests were performed using an artificial sipping system and carbohydrate- beverage concentrates (CHO) to characterize NDS performance attributes. A variety of CHO formulations were also studied to define the ideal beverage concentrate for maximizing system efficiency. The NDS performed optimally with concentrate bag oriented spout down with the top of bag positioned ~6-inches below the bite valve. Sip to sip coefficient of variation as measured by sip-to-sip changes in % solids was 2 [1.5] %. At faster sipping rates (13-14 ml/sec) the blended drink was 4 [13] % more concentrated compared to a lower sip rate (7-9 ml/sec). A concentrate viscosity of 0.022 Pa.s. created the desired dynamic range (0 to 7% CHO) and efficiency (~ 1 Liter of mixed drink from 100 ml concentrate). The NDS is a valid and reproducible system for mixing drinks with a PHS.

**15. SUBJECT TERMS**

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| | | | | | Scott Montain |
| Unclassified | Unclassified | Unclassified | UL | 17 | 19b. TELEPHONE NUMBER *(Include area code)* 508-233-4564 |

**Standard Form 298** (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

**USARIEM TECHNICAL REPORT T08-11**

# ON-THE-MOVE NUTRIENT DELIVERY SYSTEM PERFORMANCE CHARACTERISTICS


Scott J. Montain[1]
Matthew R. Ely[1]
Ken Racicot[2]

Military Nutrition Division[1]
Combat Feeding [2]


8 September 2008


U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

## TABLE OF CONTENTS


| Section | Page |
|---|---|
| List of Figures | iii |
| List of Tables | iii |
| Acknowledgments | iv |
| Disclaimers | iv |
| Executive Summary | 1 |
| Introduction | 2 |
| Methods | 3 |
| Results | 5 |
| Discussion | 9 |
| Overall Conclusions | 12 |
| References | 13 |

## LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| 1 | The Nutrient Delivery System components | 3 |
| 2 | Sip test experimental setup. | 4 |
| 3 | Impact of maltodextrin on viscosity. | 10 |
| 4 | Effect of temperature on viscosity of sucrose-electrolyte concentrates conducted at 40 mm pp, 3.972 (1/s) | 11 |


## LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1 | Influence of concentrate bag location and sip pressure on dilution characteristics of the NDS | 6 |
| 2 | Influence of concentrate bag height relative to bite valve on dilution properties of the NDS | 7 |
| 3 | The number of sips to reach steady-state drink blend and influence of sip rate | 8 |
| 4 | Impact of sugar type and viscosity on NDS dilutional characteristics | 9 |

## ACKNOWLEDGMENTS

The authors would like to thank Jeffery Staab and SGT. Erik Jacobsen for their assistance in the analysis of glucose samples ,as well as Leonard Elliott, Brett Ely, Daniel Goodman and Stephen Hennigar for their assistance with data collection.

## DISCLAIMERS

The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or as reflecting the views of the Army or Department of Defense.

Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

Approved for public release; distribution unlimited.

## EXECUTIVE SUMMARY

Warfighters don't eat enough relative to their energy expenditure during field training. Maintaining hydration is also a challenge, particularly during hot weather, as there is an aversion to the smell and taste of warm water, particularly when chlorine is present. The On-the Move Nutrient Delivery System (NDS) was developed to improve the taste of water and facilitate on-the-move energy intake, and provide the individual Warfighter with on-demand access to flavored electrolyte- and carbohydrate-enhanced drinks via their personal hydration system (PHS). Bench top tests were performed using an artificial sipping system and carbohydrate-electrolyte beverage concentrates to characterize the NDS performance attributes. Glucose concentrations or brix were used to assess NDS performance. A variety of carbohydrate formulations were also studied to define the ideal concentrate for maximizing NDS efficiency. Optimal performance of the NDS occurred with the concentrate bag oriented spout down, and positioned ~6-inches below the bite valve. Positioning the concentrate bag on the shoulder strap produced more concentrated drinks at any specific NDS valve position compared to upper back location. Sip to sip coefficient of variation was 2 [1.5]%. At faster sipping rates (13-14 ml/sec) the drink was 4 [13]% more concentrated compared to a lower sip rate (7-9 ml/sec). A concentrate viscosity of 0.022 Pascal seconds (Pa.s.) created the desired dynamic range (0 to 7% CHO), efficiency (~ 1 Liter of mixed beverage from 100 ml beverage concentrate), and temperature tolerance. The NDS is a valid and reproducible system for mixing drinks with a PHS.

## INTRODUCTION

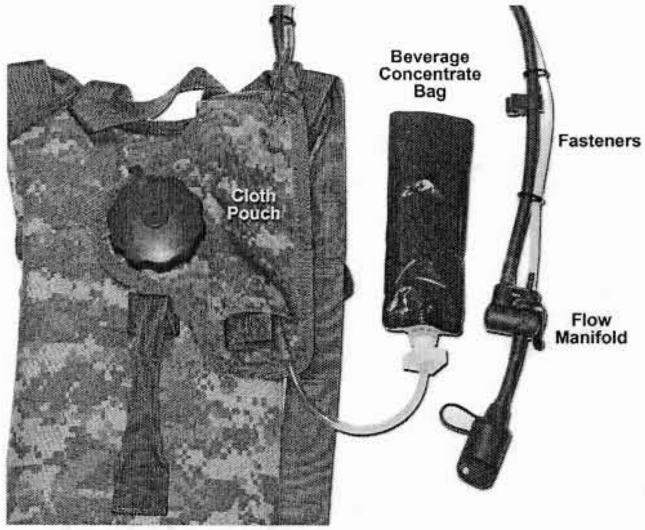
Military dismounted operations make it difficult for Warriors to drink and eat enough to meet the fluid and nutritional demands of their activities. This is in part due to the fact that Warriors often have to drink unpalatable water and eat while on-the-move to satisfy their fluid and nutrient intake requirements. Thus, new material solutions that facilitate fluid and on-the-move nutrient intake have long been desired.

Conventional methods of utilizing dry or liquid beverage concentrates include the canteen cup, the use of separate containers, and most recently, the use of disposable, collapsible, drinkable pouches pre-filled with beverage powder. A drawback of these approaches is that each requires some level of manual mixing by the user to blend the desired drink. Mixing a concentrate directly into a personal hydration system (PHS) is a separate option, but has several drawbacks that make it poor choice. First, introducing an additive to the water reservoir compromises the integrity of the entire water supply - eliminating the ability to intake only water, use the water to prepare a different mixture, or to use the water for cleaning, personal hygiene, wound cleansing, etc. Second, the addition of nutrients such as carbohydrate into the water reservoir, produces an environment conducive to mold and bacterial growth, and necessitates more frequent cleaning and/or reservoir replacement.

The Nutrient Delivery System (NDS) is an add-on to collapsible bladder with drink tube PHS. It enables the user to add flavoring and nutrients to the water as it is consumed, while preserving the integrity of the water reservoir. The NDS consists of an independent disposable bag filled with concentrate, a flow manifold, a cloth pouch for securing the concentrate bag to Soldiers PHS carrier, and accompanying tubing.

The NDS was developed jointly by the U.S. Army Research Institute of Environmental Medicine (USARIEM), Natick, MA and Designturn, Inc., Wellesley, MA. Prototype NDS systems were evaluated by Warriors and their positive feedback provided support for further advancing the NDS technology (Montain et al. 2005). The systems tested in this report were manufactured by Designturn, Inc., Wellesley, MA and designed to facilitate fluid and on-the-move nutrient intake and thereby increase mental awareness and stamina (TRADOC PAM 525-66 July 2005: CSS CPD 1.3.2 6/21/07). The NDS is also a potential solution for the CSS CPD requirement for a solution that enables Soldiers to consume nutrients in CBRNE situations (CSS CPD 6.2.2.2 6/21/07). Figure 1 presents a labeled picture of the system mounted on PHS.

Figure 1. The Nutrient Delivery System Components




The NDS system is simple to set-up, operate, and maintain. The flow manifold replaces the on-off valve provided with PHS and replaces it with a rotary valve that provides an off position, water-only, and three discrete settings for adjusting the amount of concentrate added to the water stream during sipping. Built into the flow manifold are two one-way valves that preserve the integrity of the concentrate and water reservoirs. The hardware components are easy to clean and disinfect.

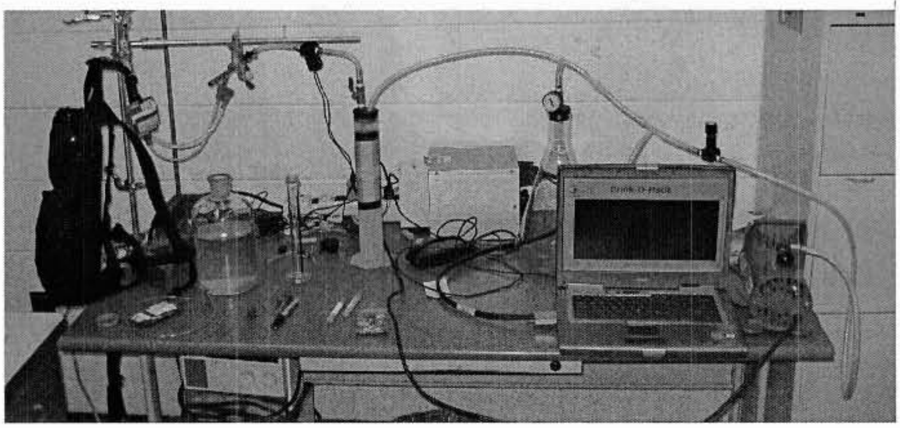
This technical report documents the performance characteristics of the manufactured NDS system; specifically the physical factors that affect performance, the dynamic range of the system, and sip-to-sip reproducibility. The impact of concentrate viscosity is also characterized.

## METHODS

A table top automated sipping system was built incorporating a solenoid, air pump, non-collapsible air reservoir, air pressure gauge, manual adjustable air flow manifold, laptop computer for controlling the solenoid, and the necessary tubing (reinforced PVC 8/13 mm ID/OD) and connectors. Preliminary tests revealed that the system closely mimics the flow properties of a typical human sip. A personal hydration system used by the Warfighters was fitted with a NDS and added to this apparatus (Figure 2; water and additive inlet line: PVC, 6/10 and 5/7 mm ID/OD, respectively). Sip rate was manipulated by adjusting the pressure drop across the solenoid with a needle valve, pressure gauge and electronic pump. Sip duration was precisely controlled with commercial hardware & software (Labview, National Instruments) directly interfaced with the solenoid.

Unless specified, the concentrate used was generated from commercially available Gatorade ® powder by mixing 80 grams of powder under heat with 100 milliliters of tap water. This mixture ratio produced a concentrate that contained 44% solids and 41% carbohydrate.

Figure 2. Sip test experimental setup.



The volume of each sip was manually measured with a graduated cylinder and an aliquot decanted for measurement of either glucose concentration (7100 MBS, Yellow Springs) or % soluble solids(Brix: PR-1 digital refractometer, Atago). Where glucose measurements were made, samples were stored frozen in Cryule Vial (Wheaton, Millville, N.J.) or refrigerated until analysis. Glucose samples were diluted 20-fold with de-ionized water.

To examine the impact of concentrate bag location on system performance, a series of sips were taken with the concentrate bag secured to the chest strap (chest) and to the hydration carrier (upper back). Additionally, repeated measurements were taken at two sipping rates to examine reproducibility and influence of sip rate on the dilution characteristics of the NDS.

For the chest position, the concentrate bag was oriented with the spout facing downwards and clipped to the carrier pack's right shoulder strap. The concentrate line was 12 inches long. For the back position, the concentrate bag was oriented spout facing downwards inside a cloth pouch secured to the upper portion of the PHS carrier. The height differential between the concentrate bag and bite valve was 6 inches. The concentrate line was 36 inches long. Four sips were collected at each of 3 NDS settings. The samples were collected at a sipping pressure of 3-in Hg (inches of Mercury) for a 3-second duration and 5-in Hg for a 2-second duration. The 3 NDS manifold positions were: mid-point of setting 2, mid-point of setting 3, and just past the threshold of the fourth setting. Performance and reproducibility were assessed by measurement of glucose in the sips. The total carbohydrate concentration in each sip was calculated with the assumption that glucose accounted for 40% of total carbohydrate.

To assess the impact of concentrate bag height relative to the bite valve, the height of the concentrate bag was systematically lowered and repeat sips taken holding sip rate constant. Height difference was measured from solenoid to top of concentrate bag. At each 2-in interval, three sip samples were collected with the manifold set fully open and pressure set at 3 in Hg. Sip duration was 3-seconds. A total of 24 sips were collected and stored for carbohydrate analysis. Glucose concentration of the drink was measured and CHO concentration of the drink calculated as per above.

To identify the number of sips necessary to reach a steady-state drink blend, the concentrate bag was adjusted to be 6 inches below the solenoid, and the manifold and outlet line to solenoid were flushed so as to contain water only. The manifold was then adjusted to be fully open (i.e., the setting producing the highest drink mixture concentration) and eight repeat sips taken and the drinks were collected. Two pressure settings were studied (3 & 5 in Hg). The glucose concentrations of each sip were measured and the CHO concentrations were calculated as per above.

Lastly, the impact of sugar type and viscosity on NDS dilution characteristics were examined. A series of concentrates were formulated using water and varying sugar types - ranging from simple sugar (monosaccharide fructose or disaccharide sucrose) to more complex sugars (short length maltodextrin (Grain Processing Corp, Muscatine, IA).. The viscosity of these blends were measured on two separate rotational viscosity instruments; the Brookfield LV DV II+ Viscometer and TA Instruments AR2000ex Rheometer. The Brookfield was set to 3°C using a small sample adapter and water bath, and the rotational speed was set to 40RPM using spindle SC4-21 using a 10ml sample. The AR2000ex was affixed with a 40mm parallel plate, and temperature controlled to 19°C (unless otherwise specified) using a Peltier plate. Approximately 2g samples were used and the shear rate set at 3.972 (1/s). The dilutional characteristics of these concentrates were then determined at three NDS positions (2, 3 and 4), with sampling pressure set at 3-in Hg and sip duration set at 3 seconds. Triplicate samples were collected at each NDS position, and the Brix in each sip measured.

Statistical Analysis.

Descriptive statistics were generated to characterize the performance of the NDS in response to the various experimental interventions. The coefficient of variation was used to characterize the sip-to-sip variability of the system.

## RESULTS:

Impact of Concentrate Bag Location and Sipping Rate on NDS Performance. The location of the concentrate bag affected the dilution properties of the NDS, with chest location consistently producing a drink with higher carbohydrate concentration than the back location (Table 1). Sipping rate had less impact, but the higher sipping rate seemed to produce modestly higher drink concentrations than lower sipping rate. At each location and sipping rate, the NDS manifold settings produced a unique drink. The sip-to-sip CV% (as measured by glucose concentration in sip) ranged from 2 to 18%, with a median value of 8%.

Table 1. Influence of concentrate bag location and sip pressure on dilution characteristics of the NDS

| Position | Pressure, mm Hg | Setting | Time, s | Volume, ml | Flow Rate, ml/s | Glucose Conc in Sip, g/dl | Sip-to-Sip CV, % | Estimated CHO in Sip, g/dl |
|---|---|---|---|---|---|---|---|---|
| Chest | 3 | 2 | 3 | 26 (1.4) | 8.6 (0.5) | 3.0 (0.1) | 2 | 7.5 |
| Chest | 3 | 3 | 3 | 27 (0.5) | 9.1 (0.2) | 3.5 (0.3) | 8 | 8.8 |
| Chest | 3 | 4 | 3 | 27 (1.4) | 9.0 (0.5) | 5.5 (1.0) | 18 | 13.8 |
| Back | 3 | 2 | 3 | 21 (0.6) | 7.1 (0.2) | 1.9 (0.2) | 8 | 4.8 |
| Back | 3 | 3 | 3 | 23 (1.0) | 7.7 (0.3) | 2.6 (0.2) | 10 | 6.5 |
| Back | 3 | 4 | 3 | 24 (0.8) | 8.1 (0.3) | 3.3 (0.3) | 10 | 8.3 |
| Chest | 5 | 2 | 2 | 27 (0.8) | 13.3 (0.4) | 2.4 (0.2) | 8 | 6.0 |
| Chest | 5 | 3 | 2 | 27 (0.5) | 13.6 (0.3) | 3.6 (0.3) | 9 | 9.0 |
| Chest | 5 | 4 | 2 | 29 (1.0) | 14.3 (0.5.) | 5.8 (0.8) | 13 | 14.5 |
| Back | 5 | 2 | 2 | 26 (0.6) | 13.2 (0.3) | 2.2 (0.2) | 8 | 5.5 |
| Back | 5 | 3 | 2 | 27 (0.0) | 13.5 (0.0) | 3.0 (0.2) | 7 | 7.5 |
| Back | 5 | 4 | 2 | 27 (0.8) | 13.3 (0.4) | 3.6 (0.1) | 3 | 9.0 |

The concentrate was produced from a commercially available sports drink powder containing glucose and fructose. It was assumed that glucose made up 40% of the carbohydrate in blended drink.

Effect of concentrate bag height relative to bite valve position. The position of the concentrate bag had a significant impact on the drink produced (Table 2). When the top of the concentrate bag was level with the bite valve, the drink had an estimated carbohydrate concentration of 12.8%. The carbohydrate concentration in the drink fell progressively as the bag was lowered relative to bite valve, falling to 1% with a 10 inch differential, and 0.05% with a 14 inch differential. Thus concentrate bag position relative to bite valve can greatly effect the drink produced and should be controlled in operation so that the manifold is producing the desired drink when actuated.

Table 2. Influence of concentrate bag height relative to bite valve on dilution properties of the NDS

| Height, in | Pressure, mmHg | Setting | Time, s | Volume, ml | Flow rate, ml/sec | Glucose conc. in sip, g/dl | Est. CHO conc in sip, g/dl |
|---|---|---|---|---|---|---|---|
| 0 | 3 | Full (5) | 3 | 20.2 | 6.7 | 5.1 | 12.8 |
| -2 | 3 | Full (5) | 3 | 19.5 | 6.5 | 4.0 | 10.0 |
| -4 | 3 | Full (5) | 3 | 19.5 | 6.5 | 3.6 | 9.0 |
| -6 | 3 | Full (5) | 3 | 18.1 | 6.0 | 2.6 | 6.5 |
| -8 | 3 | Full (5) | 3 | 18.5 | 6.2 | 1.6 | 4.0 |
| -10 | 3 | Full (5) | 3 | 18.2 | 6.1 | 0.4 | 1.0 |
| -12 | 3 | Full (5) | 3 | 17.9 | 6.0 | 0.1 | 0.25 |
| -14 | 3 | Full (5) | 3 | 17.8 | 5.9 | 0.02 | 0.05 |

Transient response to change in manifold setting. When the pressure setting was set at 3 in Hg and sip duration at 3 seconds, it took 3-4 sips to reach a new steady-state drink blend (Table 3). Whereas when pressure setting was set to 5 in Hg, it took only 2-3 sips to reach steady state value. Thus, more forceful and larger sips appeared to shorten the number of sips necessary to clear the system of previous drink blend and create the new drink blend. At either sip rate, ~40-50 ml of fluid flux was necessary before new steady state was present.

Impact of viscosity and sugar type on NDS performance. As concentrate viscosity increased, the carbohydrate concentration of the blended drink fell in exponential manner, and this relationship was consistent at each manifold setting tested (Figure 3). The desired viscosity level appeared to be <0.05 Pa.s.; as beyond this level too little of the concentrate was added to the drink. Table 4 presents the outcome of drinks with increasing viscosity on NDS dilution characteristics. Sucrose beverage concentrates of ~50% wt:wt produced the same dilution as ~60% wt:wt fructose concentrates, and both made the most efficient use of the concentrate bag volume. More concentrated drinks (increased sugar content) of either formulation were associated with a precipitous falloff in performance – presumably because the concentrate viscosity exceeded the critical level to flow acceptably from the concentrate bag and through the NDS. The sip-to-sip CV%, using brix as outcome measure, averaged 2.2 [1.5]% with range from 0.0 to 4.6%.

Table 3. The number of sips to reach steady-state drink blend and influence of sip rate.

| Pressure | Setting | Volume, ml | Time, sec | Flow, ml/sec | Glucose conc. of sip, g/dl | Est. CHO conc. of sip, g/dl |
|---|---|---|---|---|---|---|
| 3 | Full (5) | 16.8 | 3.0 | 5.6 | 0.47 | 1.2 |
| 3 | Full (5) | 16.2 | 3.0 | 5.4 | 2.22 | 5.6 |
| 3 | Full (5) | 13.8 | 3.0 | 4.6 | 2.62 | 6.6 |
| 3 | Full (5) | 15.9 | 3.0 | 5.3 | 2.94 | 7.4 |
| 3 | Full (5) | 14.8 | 3.0 | 4.9 | 2.99 | 7.5 |
| 3 | Full (5) | 15.9 | 3.0 | 5.3 | 2.73 | 6.8 |
| 3 | Full (5) | 13.9 | 3.0 | 4.6 | 3.03 | 7.6 |
| | | | | | | |
| 5 | Full (5) | 29.1 | 3.0 | 9.7 | 0.67 | 1.7 |
| 5 | Full (5) | 29.0 | 3.0 | 9.7 | 2.73 | 6.8 |
| 5 | Full (5) | 28.2 | 3.0 | 9.4 | 2.78 | 7.0 |
| 5 | Full (5) | 28.2 | 3.0 | 9.4 | 2.73 | 6.8 |
| 5 | Full (5) | 28.3 | 3.0 | 9.4 | 2.83 | 7.0 |
| 5 | Full (5) | 28.1 | 3.0 | 9.4 | 2.82 | 7.0 |
| 5 | Full (5) | 28.8 | 3.0 | 9.6 | 2.90 | 7.3 |
| 5 | Full (5) | 28.8 | 3.0 | 9.6 | 2.65 | 6.6 |

System performance was best with simple sugars as maltodextrin-based concentrates generally resulted in viscosities outside the limits of the system (data not presented). Tests using the shortest length maltodextrin sugars available (20 dextrose equivalents) revealed that a concentrate containing a range of simple and complex carbohydrates is a viable alternative to just simple sugars, but the concentrate formulation could not exceed 50% (wt:wt) carbohydrate relative to water (Figure 3).

To further define the best formulation for NDS performance, the impact of beverage concentrate temperature on beverage concentrate viscosity was characterized. Sucrose-electrolyte concentrates hydrated to the approximate range shown to optimize NDS performance (at room temperature) were put through a stepwise reduction in fluid temperature and viscosity measured at each temperature. As shown in Figure 4, a 53% solution could be reduced to ~3°C before exceeding 0.05 Pa.s., whereas a 56% solution reached the same viscosity threshold at ~10°C. Thus, 53% sucrose solutions appear to be upper end of acceptable concentration if performance over a dynamic range of environmental conditions is a desired performance attribute.

Table 4: Impact of sugar type and viscosity on NDS dilutional characteristics

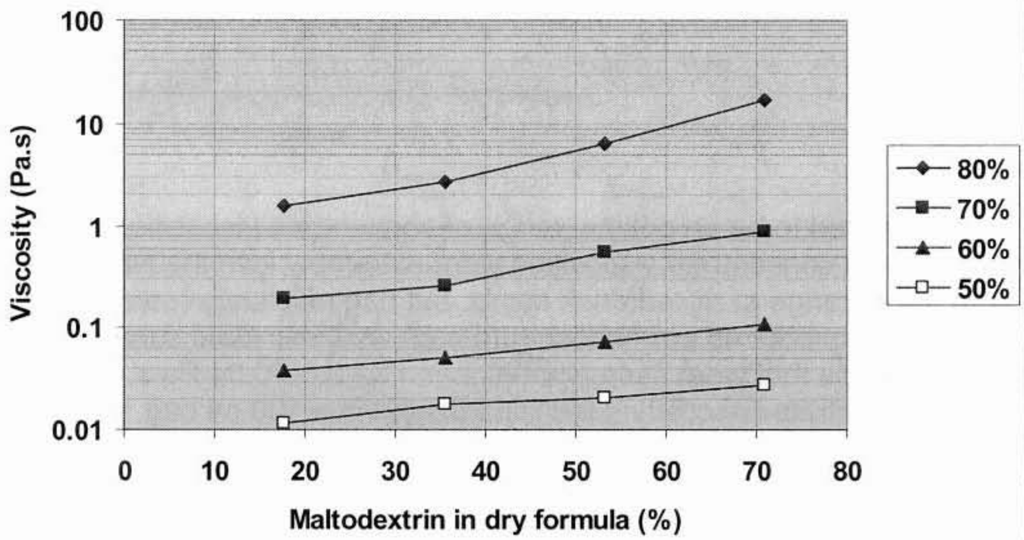
| Sugar Type | Viscosity | % Solids | NDS setting | % Solids of sip Mean (SD) | Dilution Factor |
|---|---|---|---|---|---|
| Sucrose | 0.0075 | 40 | 2 | 5.6 (0.06) | 7.1 |
| | | | 3 | 6.8 (0.30) | 5.9 |
| | | | 4 | 10.4 (0.40) | 3.9 |
| Fructose | 0.0122 | 50 | 2 | 6.3 (0.05) | 8.0 |
| | | | 3 | 6.7 (0.06) | 7.4 |
| | | | 4 | 10.6 (0.20) | 4.7 |
| Sucrose | 0.0170 | 50 | 2 | 5.1 (0.00) | 9.8 |
| | | | 3 | 6.3 (0.06) | 7.9 |
| | | | 4 | 9.5 (0.26) | 5.3 |
| Sucrose | 0.0233 | 51 | 2 | 4.5 (0.20) | 11.2 |
| | | | 3 | 5.3 (0.15) | 9.6 |
| | | | 4 | 6.9 (0.15) | 7.3 |
| Fructose | 0.0389 | 60 | 2 | 5.1 (0.14) | 11.8 |
| | | | 3 | 5.9 (0.10) | 10.2 |
| | | | 4 | 8.2 (0.38) | 7.3 |
| Sucrose | 0.1141 | 60 | 2 | 3.3 (0.06) | 18.0 |
| | | | 3 | 3.8 (0.15) | 16.0 |
| | | | 4 | 4.7 (0.10) | 12.8 |
| Fructose | 0.2610 | 70 | 2 | 1.4 (0.1) | 48.8 |
| | | | 3 | 2.1 (0.1) | 33.3 |
| | | | 4 | 2.0 (0.1) | 34.5 |

## DISCUSSION:

The primary outcomes of this series of bench evaluations is that the NDS produces a graded dilution of the concentrate with acceptable sip-to-sip consistency in drink blend, however, the drink blend produced by the system is dependent on a number of factors, including concentrate viscosity. At concentrate viscosities ranging between 0.02 and 0.04 PaS, the NDS diluted the concentrate ~11.5, 10 and 7 fold. A sucrose-based drink in this range, produced a drink ranging from 4.5% up to 6.9% carbohydrate over the 3 NDS settings. The sip-to-sip variability when measured by Brix, was 2.2%.

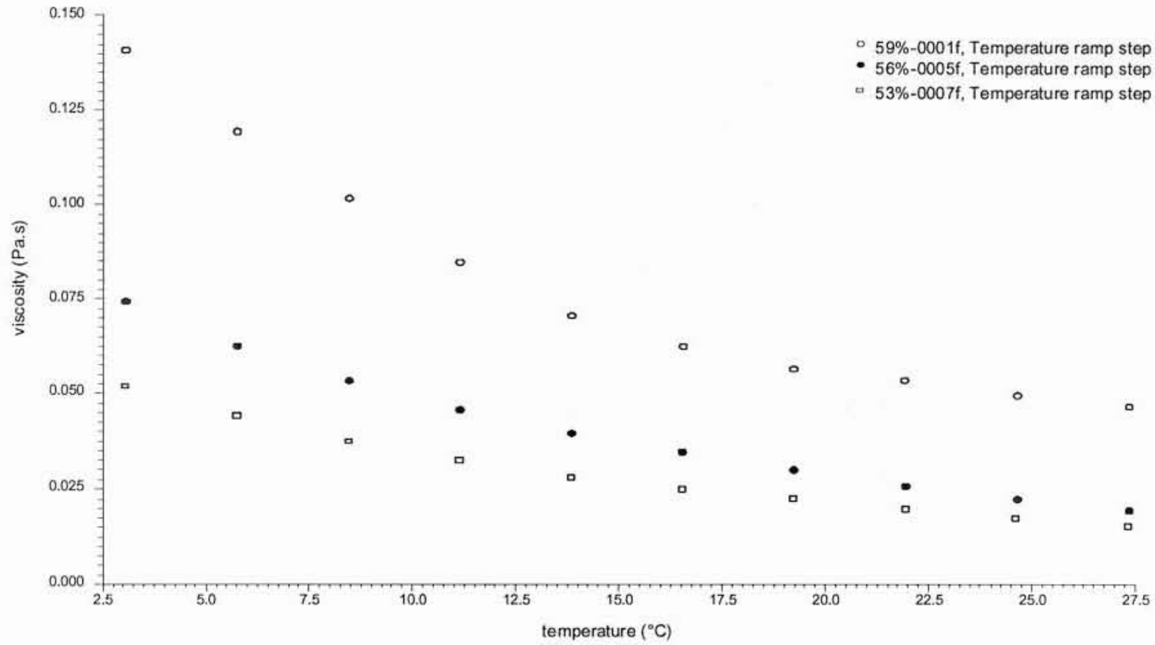
The tests revealed a number of practical issues that can affect NDS performance. Concentrate bag orientation can greatly affect performance. The highest drink carbohydrate concentrations were generated when the concentrate bag was oriented spout down, ie., bag was secured inverted. Where the concentrate bag is positioned with respect to PHS and/or human body also affects system performance. Securing the concentrate bag to chest strap compared to upper back location consistently produced relatively stronger drinks. The stronger drinks may be due to the height differential between concentrate bag and bite valve as this distance can greatly affect the drink produced. If the concentrate bag is placed on a low location relative to the water reservoir, e.g., low on the water carrier vs. near the top, the resulting drink at any manifold setting is much weaker than if secured higher. Securing the concentrate bag to upper section of the PHS produced drinks that spanned the desired range of carbohydrate concentrations, specifically the desired strength at the second setting, or middle gain position, of the NDS.

Figure 3. Impact of maltodextrin on viscosity. Beverage was ERGO drink prepared with varied amounts of 20DE maltodextrin. Viscosity measured at 3.972 (1/s) shear rate, and 19°C.




A primary objective of these tests were to define the performance capabilities of the NDS. It was observed that ~40 ml (~3-4 sips) of fluid needs to pass through the flow manifold after changing between NDS settings before a new equilibrium drink formulation is achieved. While initial tests using biochemical analysis of drink glucose concentration and extrapolation to carbohydrate composition suggested sip-to-sip variability of ~8%, subsequent tests using Brix produced sip-to-sip variability of 2%. Our interpretation of these divergent outcomes is that the former included multiple sources of experimental error, independent of carbohydrate in the final drink, e.g., a dilution step, assay variability, whereas the measurement of Brix by refractometer did not. Regardless of the reason for differences in CV% between methods, the low sip-to-sip CVs would barely be distinguishable by the Warfighter.

Figure 4. Effect of temperature on the viscosity of sucrose -electrolyte concentrate conducted at 40mm pp, 3.972 (1/s)




There appeared to be an optimal range of concentrate viscosities for NDS performance. When concentrate viscosities were extremely low, the NDS was capable of blending a broad range of mixed drink levels, but bag efficiency (determined by the volume of final drink produced per concentrate bag) was less ideal compared to concentrate viscosites that were somewhat higher, i.e., 0.02-0.04 Pa.s. For example, a 40% sucrose concentrate (viscosity < 0.01) packaged in a 100 ml bag, would only produce 390 to 710 ml of drinks over the 3 NDS settings evaluated, whereas a 51% sucrose concentrate (viscosity = 0.02) produced 730 to 1120 ml over the same 3 NDS settings. As the viscosity of the beverage concentrate approached 0.05 Pa.s, the NDS system performance began to degrade. As beverage concentrate viscosity approached 0.100 Pa.s, the thickness of the concentrate severely inhibited NDS functionality. Equally important, changing the NDS manifold from weak blend (setting 2) to stronger blend setting (setting 4), at viscosities > 0.05 Pa.s.,had minimal effect on the final drink produced. Thus, viscosity is a functional tool that can be used to optimize the efficiency of the NDS. The tests conducted suggest a viscosity between 0.02 and 0.04 is a good level to maximize efficiency of concentrate without unduly compromising NDS dilution capabilities.

Carbohydrate concentrates composed of simple sugar formulations appear best suited for use with NDS. Concentrates composed of fructose (~60% wt:wt) were equally as effective those composed of sucrose (~50%). The same level of viscosity was reached, however, when short-chain length (20 dextrose equivalents) maltodextrins made up only 70% of a 50% carbohydrate solution. Thus, iIf maltodextrins are used in carbohydrate concentrates for NDS, they can either only make up a portion of the sugar in the formulation, or the concentrate must be made less energy dense.

NDS performance will be influenced by environmental and/or beverage concentrate temperatures. As illustrated in figure 4, the viscosity of simple sugar formulations rises exponentially as environmental (and liquid) temperatures fall and the magnitude of viscosity change is a function of starting concentration. In the experiment performed, a 53% sucrose solution rose from starting viscosity of ~0.018 Pa.s at 27°C to a viscosity of ~0.040 at 7.5°C; whereas, a 56% sucrose reached the same viscosity threshold at ~13°C. Thus, it would be expected that the gain of the NDS beverage profile would begin to be compromised below ~7°C if a 53% sucrose formulation was being consumed and below ~ 13°C if a 56% sucrose formulation was in use. Thus, the beverage concentrate properties need to be considered carefully to maximize the efficiency and performance attributes of the NDS.

## OVERALL CONCLUSIONS

The NDS provides on-the-move access to a mixed drink without contamination of water reservoir or carrying an additional drinking reservoir. The bench top tests performed reveal that it produces broad range of mixed drink levels with a sip-to-sip variability of ~2%. Concentrate formulations with a viscosity between 0.02 and 0.04 PaS. are best suited for use in the NDS as they maximize the volume of mixed drink that can be produced from concentrate bag and deliver desired range of mixed drink concentrations.

# REFERENCES

1. Montain, S.J., W.J. Tharion, R.W. Hoyt. On-the-move nutrient delivery system - Description and initial evaluation. USARIEM Technical Report T05-02 (AD A428339), 2005.