DYNALENE
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# Engineering Guide and System Recommendations for Dynalene MS–1 and MS–2

## Product Overview

Dynalene MS-1 and MS-2 are environmentally friendly heat transfer salt fluids and storage media designed for ultra high-temperature applications. MS-1 is a binary salt mixture and MS-2 is a ternary eutectic salt mixture. They are specifically engineered to safely withstand excessive heat loads far above the boundaries of most alternative heat transfer fluids. They exhibit negligible vapor pressure near peak operating temperature and are non-toxic and non-flammable. The salts are odorless and appear off-white to slightly yellow.

All Dynalene MS-1 and Dynalene MS-2 salt fluid must surpass stringent quality inspections prior to shipment. It is essential that all personnel handling this product review and understand this manual that includes the Dynalene MS-1 or Dynalene MS-2 material safety data sheet (MSDS). Do not hesitate to contact the Dynalene Technical Support Group or your local representative for more information.

## Melting Point

Dynalene MS-1 has a melting point of 237°C, allowing for a wide temperature range for extremely hot systems. Dynalene MS-2 has a melting point of 127°C, further preventing freeze up in high-temperature applications while still retaining excellent thermal stability.

## Vapor Pressure

Dynalene MS-1 and MS-2 exhibit negligible vapor pressures even near their peak operating temperatures. This reduces the need for high-pressure plumbing materials and greatly reduces pressure-related system failure. Vapor products include $N_2$, $O_2$, NO, $NO_2$, $N_2O_3$, $N_2O_4$, and $N_2O_5$, with the latter decomposition products slowly produced at excessive temperatures. Due to the oxidative products that are released upon decomposition of MS-1 and MS-2, airtight containment is recommended to reduce safety hazards.

## Thermal Stability

Dynalene MS-1 can be used safely up to 565°C before showing signs of bubbling and vapor formation. Temperatures near 600°C and higher will cause the salt fluid to decompose slowly into solid oxides and its vapor products. Dynalene MS-2 can be used safely to 485°C, and temperatures approaching 500°C will slowly degrade the salt fluid into its solid oxides and vapor products. Temperatures near 550°C will greatly accelerate degradation of MS-2. It is recommended to follow the operating ranges for MS-1 and MS-2 depicted below when running a system.

| | MAX Fluid Range, °C | Operating Range, °C |
|---|---|---|
| Dynalene MS-1 | **237 - 565** | **285 - 550** |
| Dynalene MS-2 | **127 - 500** | **150 - 485** |

## Material Compatibility

Dynalene MS-1 and MS-2 are compatible with all stainless steels, Inconel, iron aluminides, nickel aluminides, and most alloy steel materials up to their maximum operating temperatures. 304, 316, and 321 stainless steels have been used up to 550°C with minimal corrosion. At lower operating temperatures, the corrosion rate is drastically reduced. Carbon steel can be used for both MS-1 and MS-2 for temperatures below 350°C, however it is strongly recommended to use higher-alloy steels. Iron alumnides perform considerably well to 650°C, with 35% Al showing the lowest corrosion rates in the Fe-Al group. Commercially available aluminized products showed little to no corrosion protection due to surface cracking of the aluminum layers. Porous ceramics are not advised due to salt uptake and crumbling which can enhance the corrosion rate.

## System Compatibility

### Valves

Due to thermal expansion and contraction, interior parts of the valves may become misaligned over time. It is strongly recommended to use valves made of stainless steel (316, 321 advised) with stainless steel ferrules to prevent corrosion at high

temperatures. High temperature sealant should be used with NPT fittings. Valves must be selected so that there is sufficient reduction in thermal conduction to the packing material to eliminate leakage. Bellows-sealed, mechanically operated, poppet valves have also shown reliable performance in larger-scale systems. Molybdenum against tungsten or copper and several titanium or tungsten carbide-cermets mating with each other also proved to be satisfactory valve materials that showed minimal signs of corrosion. Always consult your valve manufacturer's recommendations before selecting a valve to be used with Dynalene MS-1 or MS-2.

### Piping

It is strongly recommended to use seamless piping where available to prevent flaws that can be worsened by thermal expansion and molten salt corrosion. Thermal expansion effects can be minimized by pre-stressing the piping or by using expansion loops and joints. Only select materials that are compatible with MS-1 and MS-2 as recommended by Dynalene.

### Pump Selection

Pneumatic stainless steel vertical submersible pumps have been successfully used by Dynalene. Vertical cantilever and centrifugal pumps have demonstrated satisfactory performance in larger scale systems. Ensure the pump motor is isolated sufficiently far away from the molten salt to reduce thermal conduction from the pump shaft to the pump motor. Choose pumps which isolate bearings and sealants from direct contact with the molten salt. Thermal barriers and radiant shields are strongly recommended to prevent pumping components from excessive heat sources. Metal or high-density ceramic mechanical seals should be used throughout the pumping assembly to reduce salt leakage. Liquid cooling of internal pump surfaces is another method that can be used to prevent overheating.

## Storage and Handling

Keep both Dynalene MS-1 and MS-2 in tightly sealed containers and store in a cool and dry environment with adequate ventilation. Avoid storing near organic and other combustible materials that can be readily oxidized. Avoid walking on the salt in prill form as it could create a slippery surface. Protect against physical damage and moisture and isolate from any source of heat or ignition. MS-1 and MS-2 ship within hazard class 5.1 in the USA.

## Installation and Operating Guidelines

The following recommendations are provided by the Dynalene Technical Support Group to assist the installer or end user in achieving a proper installation. Only qualified personnel with expertise in safely handling potentially hazardous liquids within the compliance of all local, state, and federal regulations should be involved in the work process.

### Pre–cleaning

Materials from welding operations, excess pipe joint compound, oils, and other unwanted contaminants must be removed completely prior to installing Dynalene MS-1 and MS-2. Ensure all other foreign contaminants are removed.

### Pressure Testing

Ancillary equipment designed with mechanically jointed sealing surfaces must be able to withstand a vapor tight seal when exposed to positive and/or negative pressures. This is commonly performed by subjecting the system or individual component to a leak test.

### Inert Gas Blanket

It is recommended to use an inert gas, preferably nitrogen, in the head space to prevent oxidative degradation of the molten salt. An inert gas blanket also has the additional benefit of reducing the corrosion of metals exposed to the salt.

### Salt Loading

It is advised to only use materials compatible with molten salt for the storage tank. Begin by inspecting the tank to make sure there are no foreign contaminants and evidence of cracking which could propagate with thermal expansion. As a general heuristic for the initial loading phase of the solid salt into the tank, the average volume of the prill form is generally twice that of the liquid volume due to air gaps. If the tank is not big enough to accommodate all prill form, it may be necessary to add the solid salt and melt down in stages until the desired amount is achieved. As the salt melts, it may be mixed or manually pushed around to evenly heat the molten salt near the burner tubes or resistance heaters. Ensure the tank drain valve is preheated and working properly before addition of the salt and prior to running the system. Thermally conductive materials (such as metal rods or slabs) should be added to the tank to allow for more uniform salt melting. Never add more salt than necessary as overflow may result. Always wear the proper personal protective equipment when charging the system with salt. For large-scale solar thermal storage applications, contact Dynalene for a detailed consultation.

### System Heating

Immersion heaters provide the most uniform method of tank heating and have the added benefit of reducing problems caused from

thermal expansion and contraction. Gas-fired tube burners or resistance heating methods are the two most common ways of heating a salt tank. Due to the high operating temperatures of the salt, material stability at these temperatures must always be taken into account. For gas-fired heaters, always use flame detectors and immediately close all gas lines in case of a fire. Resistance heaters should be grounded and covered to reduce exterior exposure.

Based on the design parameters of the system, line and drain valves may need to be preheated to allow salt to flow through narrow orifices and fittings which can cause cold pockets and block the system lines. Straight tube furnaces and induction heating methods provide more uniform heating than traditional resistance heating through metal bands. Heating around irregular shapes and bends can be accomplished by tightly wrapping high-temperature heating tape or induction coil around the section. Preheating the system to 70-100°C above the melting points of MS-1 and MS-2 provides a sufficient temperature differential to eliminate cold pockets and allow the molten salt to flow through piping and plumbing. Use caution when opening a salt tank during the heating process as molten eruption can suddenly occur if the downward pressure of the solid material forces the molten phase through the cracks and potentially to the surface of the salt.

### Draining

All drain valves should be preheated with a heat source to allow the molten salt to flow without freezing in the orifices of the valves. If salt freeze up occurs in the valves, slowly reheat to avoid sudden melting and splashing caused by solid pockets formed inside the valves. Ensure there is an adequate storage vessel that can safely handle the temperatures of the molten salt leaving the outlet of the drain valve. The connection to the drain vessel should be sealed to avoid splashing and drain tank overflow.

### Cleaning the Tank Interior

Sufficiently drain the tank of all hot molten salt and ensure all heating elements are off and the system is allowed to cool. Clean the interior of the tank with water and scrub out any salt residue that remains on the tank walls and immersion heaters. Using distilled water will prevent foreign minerals from depositing on the tank. Prior to re-charging the system with salt, clean out any other contaminants and boil off all moisture.

### Maximum Surface Temperatures

Surface temperatures of all system components should not exceed the maximum operating temperatures of MS-1 and MS-2. Contact at the liquid-wall interface can promote degradation of the molten salt fluid after prolonged exposure.

### Volumetric Expansion upon Melting

A 3% expansion upon melting from room temperature has been observed with Dynalene MS-1 and MS-2. Systems should be designed to prevent damage caused by volumetric expansion upon re-melting in case of in-line freeze up. It is advised to re-heat the system starting with the sections closest to the drainage container to reduce pressures built up from the melting expansion. Thermally conductive rods and slabs can be placed in the bulk salt to enhance heat distribution in the tank.

## System Safety

Systems using Dynalene MS-1 and MS-2 should be designed and constructed with integrally safe methods of preventing exposure to excessive heat sources. Not using excessive pump velocities, insulating all heat sources, and eliminating flammable vapors are all common practices in molten salt convection skids. For precautionary measures, all metal components used in the manufacture of heat transfer fluid systems with the intent to use Dynalene MS-1 or MS-2 should be properly grounded as per the governing electrical codes. Proper engineering practices should also endorse methods to prevent sparks generated by energy such as eddy current, Foucault current, static discharges, etc., as the liquids mentioned above flow in the system. Unauthorized personnel should never be allowed near the molten salt system unless specifically instructed by an authorized employee.

Dynalene MS-1 and MS-2 can cause irritation by contacting the skin, eyes, or throat. If salt contacts the skin, immediately rinse with water and consult medical help for all burns. Respirators should be used if there is excessive salt dust present. In case of inhalation, remove the person to fresh air and provide oxygen if necessary. In case of ingestion, drink large amounts of water and seek medical attention.

Use caution when water is present near molten salt as any wet residue can explosively vaporize and can cause the molten salt to violently splash. Because of this, avoid using water to the quench the salt. In case of a leak, allow sufficient time for the salt to solidify and come to room temperature before cleaning.

## High–temperature Protective Equipment

Always use the proper personal protection equipment when dealing with MS-1 and MS-2 at their operating temperatures. Operating personnel should always wear long sleeved clothing, a face shield, gloves, and heavy-duty footwear. Wool, cloth, and other light clothing may not provide adequate protection in case of molten splash. Heavy aluminized clothing is recommended to reduce radiant exposure as well as conduction caused from potential molten salt splashing. Steel or composite toe boots with aluminized shielding are recommended for footwear. Ensure there is no skin or light clothing exposed prior to running the system. Facial protection should be made of heavy aluminized material that extends down to the shoulders to reduce injury due to molten splash. Full Nomex suits or heavy shielding is recommended for additional body protection. Showers and eye wash stations should be located within close proximity to the operating system.

## Spill Clean–up

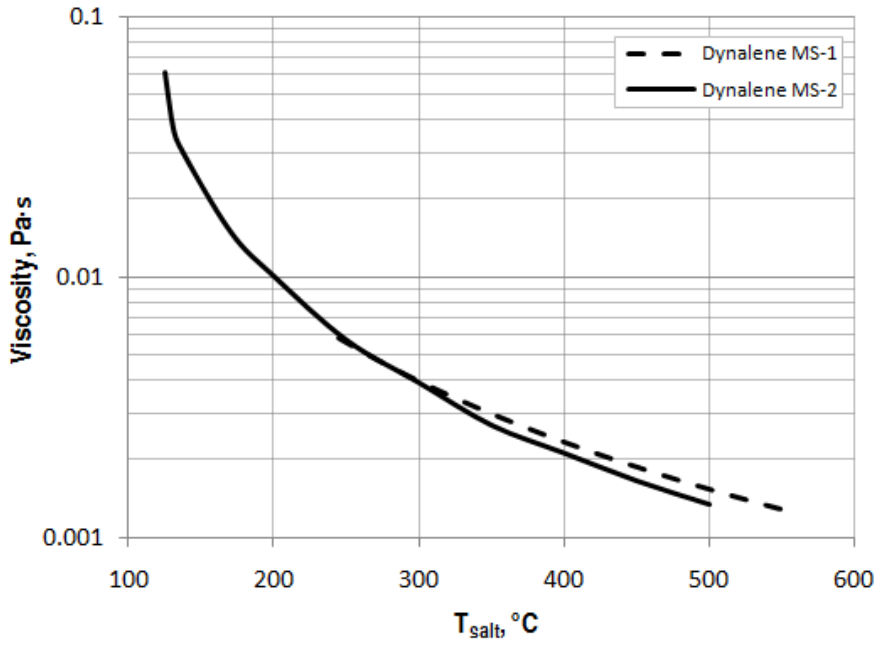
Always wear the proper personal protective equipment when cleaning up a spill. Allow the salt to come to a safe temperature before any clean-up tasks are performed. Small molten salt spills will usually solidify quickly on contact with a room-temperature surface, however larger spills will take a much longer time to cool. Barricade the spill and clear out all personnel that are not authorized to clean the salt. Alkali compounds can attack leather material, so it is advised to use rubber boots and gloves during cleaning. Ensure the area is sealed off and well ventilated and there are no fumes or sources of ignition which may ignite the salt. Use water on the spill to absorb the salt and reduce the amount of dust that can be distributed to the air. Clean up and dispose the salt into containers for waste processing or recovery. If water is used during spill clean-up and needs to be discharged into the sewer system, contact your local sewer authority.

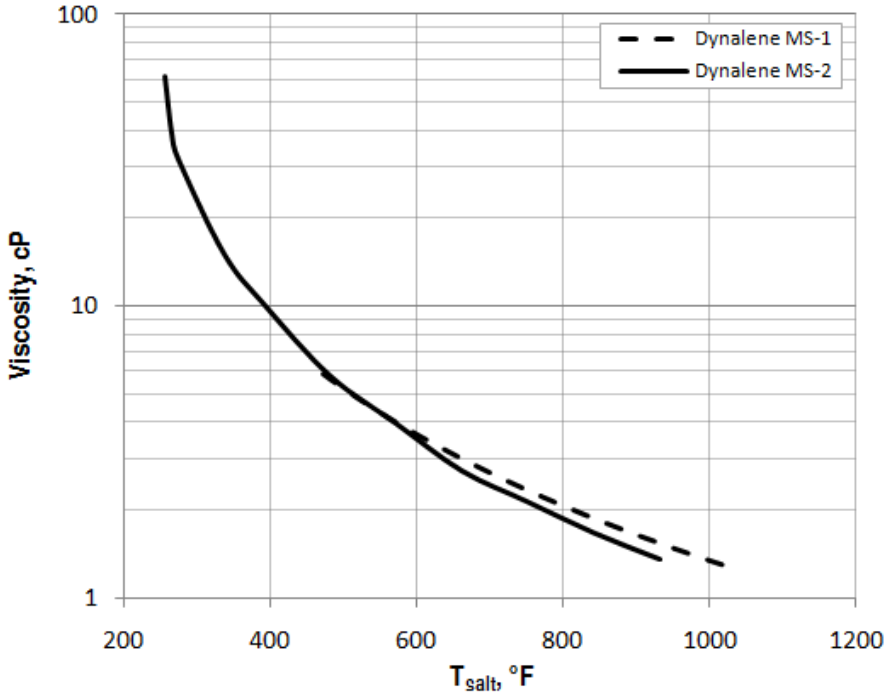
## Sampling Procedure

Always wear the proper personal protective clothing when taking a sample of molten Dynalene MS-1 or MS-2. With the salt still molten, dip a cleaned, dried steel rod into the molten salt and slowly remove it to prevent salt splashing. The salt will solidify quickly (depending on the operating temperature) and should be gently scraped off as to not affect the sample. Deposit the salt solids into a clean, dry glass container and send to Dynalene for analysis.

# VISCOSITY OF DYNALENE MS-1 AND MS-2

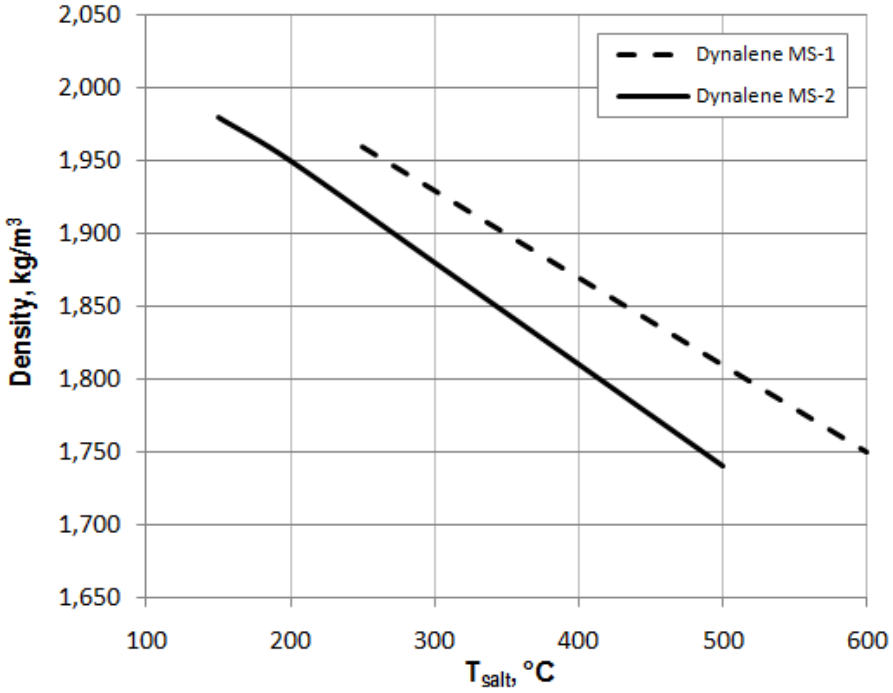
Using ARES Rheometer with fixed couette to 550°C

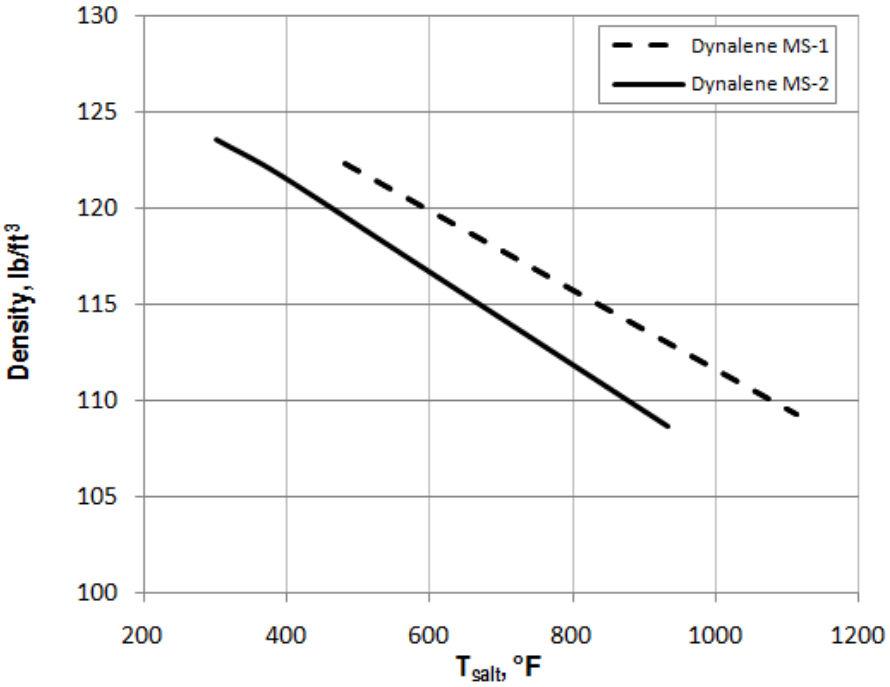


# DENSITY OF DYNALENE MS-1 AND MS-2

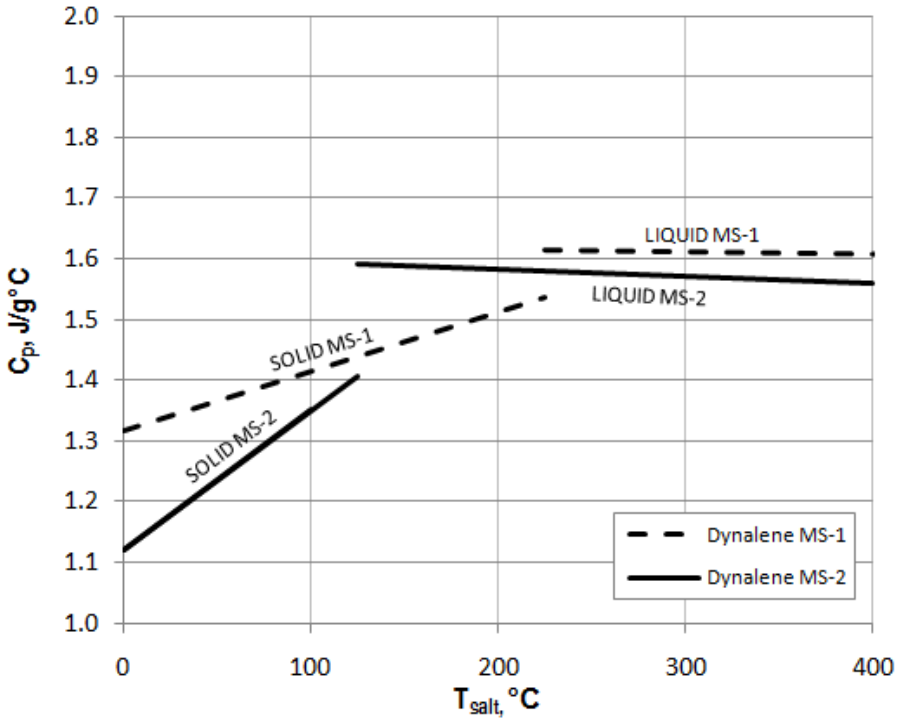
In the molten state from 150°C to 600°C (302°F to 1,112°F)

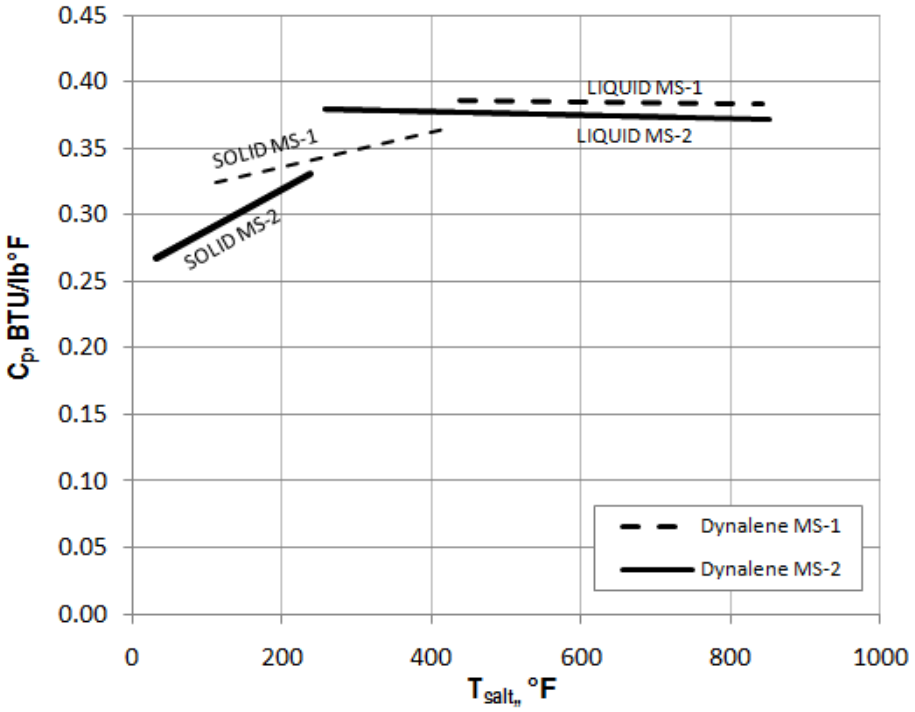


# SPECIFIC HEAT OF DYNALENE MS-1 AND MS-2

Using modulated differential scanning calorimetry to 400°C



# PHYSICAL PROPERTIES OF DYNALENE MS-1 AND MS-2

Revised 5–1–2011

| Property | Dynalene MS–1 | Dynalene MS–2 |
|---|---|---|
| **Appearance** | Granular solid | Granular solid |
| **Color** | White/light yellow | White/light yellow |
| **Composition** | Binary nitrate mix | Ternary nitrate mix |
| **Average Molecular Weight** | 91.44 g/mol | 88.07 g/mol |
| **Viscosity** | 4.0 cP @ 300°C (572°F) | 3.95 cP @ 300°C (572°F) |
| **Density** | 1930 kg/m$^3$ @ 300°C (572°F) | 1880 kg/m$^3$ @ 300°C (572°F) |
| **Melting Temperature** | 237°C (459°F) | 127°C (261°F) |
| **Specific Heat** | 1.61 J/g°C @ 300°C (572°F) | 1.57 J/g°C @ 300°C (572°F) |
| **Thermal Conductivity** | 0.5 W/m°C @ 300°C (572°F) | 0.5 W/m°C @ 300°C (572°F) |
| **Latent Heat of Fusion** | 117 kJ/kg | 129 kJ/kg |
| **Degradation Temperature** | 565°C | 500°C |
| **Maximum Fluid Range** | 237°C–565°C | 127°C–500°C |
| **Recommended Fluid Range** | 285°C–550°C | 150°C–485°C |
| **Flash Point** | N/A | N/A |
| **Auto–ignition Temp** | N/A | N/A |

## Contact Information

For information regarding molten salt system procedures, design, sampling, and any other inquiries contact a Dynalene representative today with your requirements.


**Toll free:** 1-877-244-5525
**Phone:** 610-262-9686
**Fax:** 610-262-7437
**General Email:** info@dynalene.com
**Lab Services Email:** lab@dynalene.com

**or write to us at:**
Dynalene Inc.
5250 West Coplay Road
Whitehall, Pennsylvania 18052

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