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## CO<sub>2</sub> (DRY ICE) CLEANING SYSTEM

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### ABSTRACT

Tomco Equipment Company has participated in the dry ice (solid carbon dioxide, CO<sub>2</sub>) cleaning industry for over ten years as a pioneer in the manufacturer of high density, dry ice cleaning pellet production equipment. For over four years Tomco high density pelletizers have been available to the dry ice cleaning industry. Approximately one year ago Tomco introduced the DI-250, a new dry ice blast unit making Tomco a single source supplier for sublimable media, particle blast, cleaning systems. This new blast unit is an all pneumatic, single discharge hose device. It meters the insertion of 1/8 inch diameter (or smaller), high density, dry ice pellets into a high pressure, propellant gas stream. The dry ice and propellant streams are controlled and mixed from the blast cabinet. From there the mixture is transported to the nozzle where the pellets are accelerated to an appropriate blasting velocity. When directed to impact upon a target area, these dry ice pellets have sufficient energy to effectively remove most surface coatings through dry, abrasive contact.

The meta-stable, dry ice pellets used for CO<sub>2</sub> cleaning, while labeled "high density," are less dense than alternate, abrasive, particle blast media. In addition, after contacting the target surface, they return to their equilibrium condition: a superheated gas state. Most currently used grit blasting media are silicon dioxide based, which possess a sharp tetrahedral molecular structure. Silicon dioxide crystal structures will always produce smaller sharp-edged replicas of the original crystal upon fracture. Larger, softer dry ice pellets do not share the same sharp-edged crystalline structures as their non-sublimable counterparts when broken. In fact, upon contact with the target surface, dry ice pellets will plastically deform and break apart. As such, dry ice cleaning is less harmful to sensitive substrates, workers and the environment than chemical or abrasive cleaning systems.

Dry ice cleaning system components include: a dry ice pellet supply, a non-reactive propellant gas source, a pellet and propellant metering device, and a media transport and acceleration hose and nozzle arrangement. Dry ice cleaning system operating parameters include: choice of propellant gas, its pressure and temperature, dry ice mass flow rate, dry ice pellet size and shape, and acceleration nozzle configuration. These parameters may be modified to fit different applications. The growth of the dry ice cleaning industry will depend upon timely data acquisition of the effects that independent changes in these parameters have on cleaning rates, with respect to different surface coating and substrate combinations. With this data, optimization of cleaning rates for particular applications will be possible. The analysis of the applicable range of modulation of these parameters, within system component mechanical constraints, has just begun.

## INTRODUCTION

Dry ice cleaning is an environmentally sound and user friendly, dry, abrasive process. It is similar in principle to sandblasting, though much more broad in scope and application. Specially designed equipment is necessary to deal with the differences in mediums while taking full advantage of different applications. Using dry ice cleaning systems in place of grit or water blasting or chemical cleaning systems to remove a surface coating leaves only the waste behind. The carbon dioxide used in this cleaning process has already been generated by industry and thus does not increase the quantity of green house gasses that contribute to global warming. Furthermore, many cleaning applications would suffer from the use, or introduction, of moisture in the cleaning process. Dry ice cleaning may be performed without introducing moisture by careful specification of system components.

The use of sublimable-media, abrasive blasting systems will reduce the space required in landfills and eliminate the costly separation and filtration of potentially hazardous waste products from the blast media at the end of a job. Similarly, the remediation of cleaning or stripping chemicals adds time and cost to the inherent biological hazards associated with chemical cleaning systems. Stringent and costly masking requirements of some aerospace applications may be relaxed because dry ice pellets quickly sublime after impact, which makes dry ice cleaning an attractive alternative. Dry ice within the fuselage of an air- or spacecraft will eventually sublime, and thus the weight of the craft will not be increased.

Carbon dioxide is primarily generated by petrochemical and fertilizer production processes, and secondarily from flue gas purification processes. Thus it is readily available in most industrial locations in the US and abroad. The process of transforming CO<sub>2</sub> into a useable solid phase for dry ice cleaning systems is a technology that was borrowed from the food processing industry, which has also benefited from the advances in pellet production equipment. The replacement of sublimable dry ice pellets for non-sublimating, abrasive blasting media requires special pellet extrusion equipment, capable of producing a smaller, more dense pellet than what is currently being used in food processing. In addition to changes in dry ice pelletizers, blasting equipment modifications necessary to facilitate the use of this near cryogenic media necessitates a different system design than that used for sandblasting.

The dry ice cleaning process is just that: dry. No water is used in the dry ice cleaning process. While the dry ice temperature of -109.33°F will cause rime ice to temporarily freeze onto substrates in uncontrolled environments, this side-effect may be eliminated with proper specification of atmospheric and propellant characteristics. Small cleaning booths supplied with dry, inert, positive pressure atmospheres, used in conjunction with cryogenically produced nitrogen as the propellant gas will limit the introduction of moisture to that which may have been frozen to the surface of the dry ice pellets during production. In addition, by "tenting" the dry ice pellet extruder and insulated receiver container (enclosing the extrusion heads and container within a tent) and again providing a positive-pressure inert atmosphere inside, the introduction of atmospheric moisture to the cleaning process may be all but eliminated.

## SYSTEM EQUIPMENT

**A typical dry ice cleaning system will consist of the following components:**

- A supply of dry ice blasting pellets of proper size, shape and density.
- A propellant gas source of suitable temperature, pressure and dew point.
- A device for containing the media, and modulating the flow of dry ice and propellant to the delivery hose.
- A device to transport and accelerate dry ice pellets to high velocities, and direct them to the work surface.

## BLASTING MEDIA

Dry ice cleaning pellets are larger, and less dense than alternative grit blasting mediums. In addition, they are ductile and do not share the same molecular structure as their predecessors. Unlike their counterparts, the qualities of dry ice may be modified during production to better mate the cleaning pellet to the application. This ability to alter the physical characteristics of dry ice during the ice production or cleaning step enables the abrasive CO<sub>2</sub> cleaning process to compete in applications that were previously the sole domain of chemical solvent cleaning systems. Due to the meta-stable nature of dry ice, the problem of transportation of cleaning pellets to the work site is a primary concern of CO<sub>2</sub> cleaning equipment manufacturers.

The size of dry ice pellets best suited for use in CO<sub>2</sub> cleaning systems are 0.125 inch diameter, or less. However, unless special sizing equipment is incorporated within the pellet production equipment, the length of the extruded pellet will be proportional to its density. Currently, this length may range from 3/16 of an inch, to well over 6 inches. The suggested pellet length used in dry ice blasting equipment (to assure a reliable, steady, uninterrupted flow of pellets from the storage hopper to the insertion mechanism) is approximately 1/2 inch or less. Here smaller is definitely better. The minimum size should depend upon the application, with regard to the potential for substrate damage, and the nature of the coating being removed. Normal pellet production, storage, and handling will reduce the pellet length to this value. Furthermore, mechanical insertion into the propellant stream, the subsequent transport, (and accompanying sublimation) and acceleration processes will reduce the pellet length to a maximum of 0.125 inch at the target surface.

Tomco Equipment Company's High Density Pelletizers (HP equipment designation) extrude dry ice pellets in density ranges from 42 Lbm/F<sup>3</sup> to approximately 55 Lbm/F<sup>3</sup> for use in CO<sub>2</sub> cleaning systems. For comparison, the density range of dry sand is 90 - 105 Lbm/F<sup>3</sup>. This lower density of dry ice cleaning pellets is significant in that dry ice cleaning systems will exhibit less overall cleaning energy density at the work surface for the same particle and propellant velocities than those using smaller, sharper, grit-blasting media. Also different are the fracture mechanics of dry ice. Most currently used grit blasting media are silicon dioxide based, which possess a sharp tetrahedral molecular structure. These tiny, extremely hard substances ( $E=45 \times 10^6$  PSI) will always break into smaller sharp-edged replicas of the original grain. The softer dry ice pellets do not produce the same sharp-edged crystalline structures as their non-sublimable counterparts when broken. Upon contact with the target surface, the dry ice pellets will plastically deform and break apart. Any particle remnants left over from this collision will be repelled from the work surface by the gaseous forces from the propellant and the sublimating dry ice. Thus dry ice cleaning does not share the same potential for subsurface erosion (substrate etching) as alternative, grit-blasting systems. This enables CO<sub>2</sub> cleaning to be used in sensitive substrate applications.

Tomco Equipment Company is preparing to research the effects of dry ice cleaning pellet size, shape, density and mass flow rate on cleaning rate and efficiency. To make this data relevant (and widen the application base for this cleaning technology) these rates must be referenced to surface coatings and substrates. This requires the assistance of industries interested in gaining from advances in CO<sub>2</sub> cleaning technology. It is reasonable to expect that blasting times in certain applications may be shortened with the use of smaller, more dense pellets dispersed over a given nozzle exit area. This is due to a smaller pellet's superior ability to penetrate coating grain boundaries. Smaller, irregularly shaped pellets should also possess sharper crystalline points than their larger counterparts, further enhancing cleaning rates.

Transportation of dry ice cleaning pellets over long distances tends to settle and compact the pellets into a large block. Any block or clumping of pellets must be broken up into free flowing pellets prior to use, and this separation process creates "fines". (Fines are 1-2mm sized dry ice particles.) These miniature particles will completely sublime within the delivery hose. Consequently, their mass can not be counted on for cleaning. Smaller pellets suffer more deterioration from settling and separation. For this

reason, Tomco believes that it is more desirable to include a device within the blast apparatus for reducing pellet size to that required in a specific cleaning application if the size required is less than 0.125 inch diameter. Currently, several low cost, prototype pellet sizing designs are being tested.

## PROPELLANT SYSTEMS

A CO<sub>2</sub> cleaning system utilizes a pressurized gas stream, under controlled expansion to the local surrounding environmental pressure, to accelerate the sublimable media pellets to cleaning velocities. The two propellants primarily used in dry ice blasters are compressed air and nitrogen. (Standard compressed air and nitrogen propellant supply systems are illustrated in Appendix B, Figures 1 & 2 at the end of this report. The equipment comprising either propellant system is largely contingent upon the application, its location and level of aggressiveness necessary to perform in that application.) Typically, the pressurized gas stream must exceed local surrounding pressure by a minimum of 100 PSIG. The volume of propellant used by any CO<sub>2</sub> cleaning system will be a function of the nozzle configuration (See Acceleration Nozzles), the molecular weight and the density of the carrier gas at the nozzle restriction.

Naturally, the pellet exit velocity (and thus cleaning capacity) is a function of the available propellant energy as well as the particle ballistics including: size, specific weight and any translation or tri-axial rotation. Using a ballistic chronograph, the dry ice pellet velocity from the DI-250 blaster operating on compressed air at 175 PSIG, 75°F and 40° pressure dew point has been measured. Due to the combined effects of non-uniform pellet size, 3-dimensional translation and tri-axial rotation of the pellets within the delivery hose and nozzle, the pellet velocities range from 350 to 550 feet per second. Clay target impregnation testing corroborated the wide dry ice particle energy range suggested by the 200 foot per second fluctuation in measured velocity.

The densities of compressed air and nitrogen throughout the operating pressure range of most currently available CO<sub>2</sub> cleaning systems differs by approximately 3.5%. Therefore, as has been confirmed by testing, a similar difference in volumetric flow rates between the two gasses will be encountered, given the same temperature, pressure and nozzle orifice diameter. The propellant properties having the greatest effect on cleaning pellet velocity are its pressure and the temperature. Tomco Equipment Company has produced a Nitrogen versus Air Propellant Report. In this report, the effects of variations in these properties on propellant consumption are investigated (as they relate to dry ice cleaning with the Tomco, DI-250 blast unit) in addition to providing readers with alternative system component configurations, specifications and general CO<sub>2</sub> cleaning information.

In most dry ice cleaning systems there is a temperature differential between the dry ice, which is usually manufactured and transported at atmospheric pressure, and the propellant gas. The dry ice temperature will be -109.33°F, and the propellant gas will usually be close to ambient temperature. The effects of propellant pressure and temperature on dry ice pellet sublimation rates within single hose blasting equipment has been investigated. As expected, higher propellant gas temperatures and longer delivery hoses will increase the mass of dry ice lost to sublimation within the hose. Losses of 100% are possible in some circumstances. As long as the propellant temperature is greater than -109.33°F, a quantity of dry ice will sublime in the delivery hose.

Testing results on the DI-250 (See Appendix A) show that the propellant and dry ice mixture temperature, as measured at the acceleration nozzle, got colder as the pressure was decreased. This indicated an increase in pellet sublimation within the delivery hose as the pressure decreased. Because the transport hose diameter was unchanged, this increase was attributed to the longer time the pellets were in the delivery hose at the lower pressures.

The problem of pellet sublimation may be all but eliminated by lowering the propellant gas temperature to the dry ice temperature to eliminate the transfer of heat from the propellant gas to the cleaning pellets. This may be done by injecting cryogenic, gaseous nitrogen into the propellant supply line prior to the insertion of the cleaning pellets. However, operation at this low temperature will cost more, because a greater quantity of gas will be required to maintain both gas and pellet velocities. In addition, the Tomco machine uses a silicone rubber, pellet transport hose that would have to be replaced with a (less) flexible stainless hose due to the lower temperature.

## BLASTING EQUIPMENT

The blasting equipment itself must be capable of storing a quantity of dry ice pellets that will allow operation over a period of time without excessive handling of the dry ice media. The duration of blasting between pellet refills will be dictated by the location, ambient conditions and by the cleaning operation itself. This is where Tomco and some of its competitors diverge in theory of operation. Tomco believes that it will benefit the cleaning industry in the long run to separate pellet production and blasting equipment. This separation keeps initial capital costs low by allowing small or occasional users to purchase blasting units only, without incorporating heavy, cumbersome, pellet extruding devices that require high voltage electrical inputs that make them very unwieldy. Occasional users may then purchase the cleaning pellets on an as needed basis from manufacturers near the cleaning location.

Beyond the pellet storage capacity, blasting equipment must include an apparatus for metering and delivering the flow of dry ice to the work surface. CO<sub>2</sub> Cleaning machines usually incorporate a means for operator control of the inlet propellant pressure, or the dry ice pellet flow, or both. The capacity to modulate dry ice flow and propellant pressure allows economical cleaning through a wide range of applications from sensitive substrates and light contaminants to extremely tough powdered paint coatings with the same piece of equipment.

## TRANSPORT AND ACCELERATION DEVICES

### TRANSPORT METHODS

Typically, the delivery of pellets to the work surface is accomplished with either a single- or a dual-hose system. Currently, it is believed that the single-delivery hose is the configuration of choice for more aggressive application requirements, such as paint and hard coating removal processes. Through the adaptation of interchangeable components and/or equipment modifications, the single-hose apparatus will be capable of performing in the more highly sensitive substrate applications. Most single-hosed blasting equipment pellet insertion and modulation apparatus are patented and/or proprietary. The single-delivery hose method inserts dry ice cleaning pellets into the high pressure propellant stream within the blasting cabinet. This must be done downstream of the propellant throttling valve to eliminate erosion of the throttling valve. In addition, the single hose apparatus presents the ideal platform for the addition of sublimation reduction components.

The dual-hose system, on the other hand, dedicates one hose for propellant gas delivery to the acceleration nozzle, while the second hose delivers dry ice pellets to the same nozzle. At the nozzle, the pellets are drawn into a lower pressure area created behind the expanding propellant stream. The second, or pellet delivery, hose may transport the pellets to the nozzle via positive pressure or vacuum induction. The vacuum method of two-hose pellet transport necessarily introduces atmospheric moisture to the blasting process, which is unwelcome in some applications.

Beyond the single hose equipment being more aggressive, it also facilitates the option of nearly eliminating the sublimation of cleaning pellets within the delivery hose on the path to the acceleration nozzle. As cited in the PROPELLANT SYSTEMS section, the sublimation losses will depend on the

length of the delivery hose, the velocity of the propellant gas, and the temperature difference between the dry ice and the gas. Any ancillary sublimation reduction components or systems will require the replacement of the standard, highly flexible silicone delivery hose for a less flexible, stainless steel hose. While unfortunate for operator ergonomics, it is necessary for safety reasons.

### ACCELERATION NOZZLES

Once a controllable and reliable means of delivering dry ice pellets and high pressure gas to the actual work surface is accomplished, the last item necessary is a means of delivering this solid-gas mixture to the work surface over a wide enough area and with sufficient energy to remove contaminants or coatings. This requires an acceleration nozzle of sufficient length to allow the velocity of the cleaning media to approach the velocity of the expanding carrier gas. Most of these nozzles are interchangeable enabling the operator to tailor the pellet's kinetic energy to the specific application. Often, these nozzles incorporate bends that ergonomically enhance operator and cleaning system performance.

Nozzle design is highly proprietary. Frequently, different applications require compromises in pellet velocity to provide a convenient, ergonomic nozzle exit angle, length, or width. A nozzle designed to work optimally over one range of pressures, temperatures or dry ice flow conditions may be barely adequate in others. Therefore, as the range of applications for CO<sub>2</sub> cleaning expands, nozzle design will be one of the most important areas of growth and development.

An important area of nozzle research is the adaptation of sound attenuating technology to the blasting process. Currently, operating sound levels are in excess of 112 dBA at distances less than 6 feet. OSHA regulations require an ongoing hearing analysis program for workers continually exposed to this noise level, in addition to all workers within 200 feet wearing hearing protection. (This assumes 6-hours of continuous blasting in an 8-hour day.)

### CONCLUSION

The current range of applications for dry ice cleaning systems is growing rapidly. Paint removal, including epoxies, enamels, acrylics, and lead rich paints, is an area in which CO<sub>2</sub> cleaning is becoming highly cost competitive. The electronic industry is beginning to look toward dry ice blasting as a means of removing flux from electronic circuit boards. The automotive (and supporting) industries are using dry ice cleaning in applications ranging from the degreasing of engine blocks to the removal of rubber from hot tire molds, to general plant maintenance clean-ups. The nuclear industry is using CO<sub>2</sub> cleaning for the decontamination of tools and equipment. Most of these applications produce what the EPA considers hazardous waste. With state and federal waste disposal laws becoming more stringent, a reliable economical replacement for those cleaning systems that produce more waste than they remove will be necessary.

Current areas of research and development include: the development of acceleration nozzles to cover a wide range of applications; research on the effects of dry ice pellet shape, size and density on cleaning efficiency; the development of noise attenuation devices; and research on the effects of propellant temperature on sublimation rates and cleaning efficiency. The range of applications of CO<sub>2</sub> cleaning are expected to grow substantially, with strategic alliances forming between Tomco, its potential customers and engineering research firms.

The Tomco dry ice cleaning system is highly flexible. With interchangeable nozzle capability, (which may be specifically designed for certain coatings, substrates and propellant flow ranges and pressures) adjustable media density and flow rates, and a present operating pressure range from 100 to 350 PSIG, the Tomco system is the ideal replacement for older, and more hazardous chemical and abrasive cleaning systems.

**FIGURE 1: LIQUID NITROGEN PROPELLANT DELIVERY SYSTEM**

**LOCATIONS:**

- ① LIN STORAGE - DAY TANK
  - ② LIN DOWNSTREAM OF REGULATOR
  - ③ GN2 OUT OF VAPORIZER
  - ④ GN2 DOWNSTREAM OF OPTIONAL TEMPERATURE CONTROL POINT
- = NOT REQUIRED FOR SYSTEM OPERATION

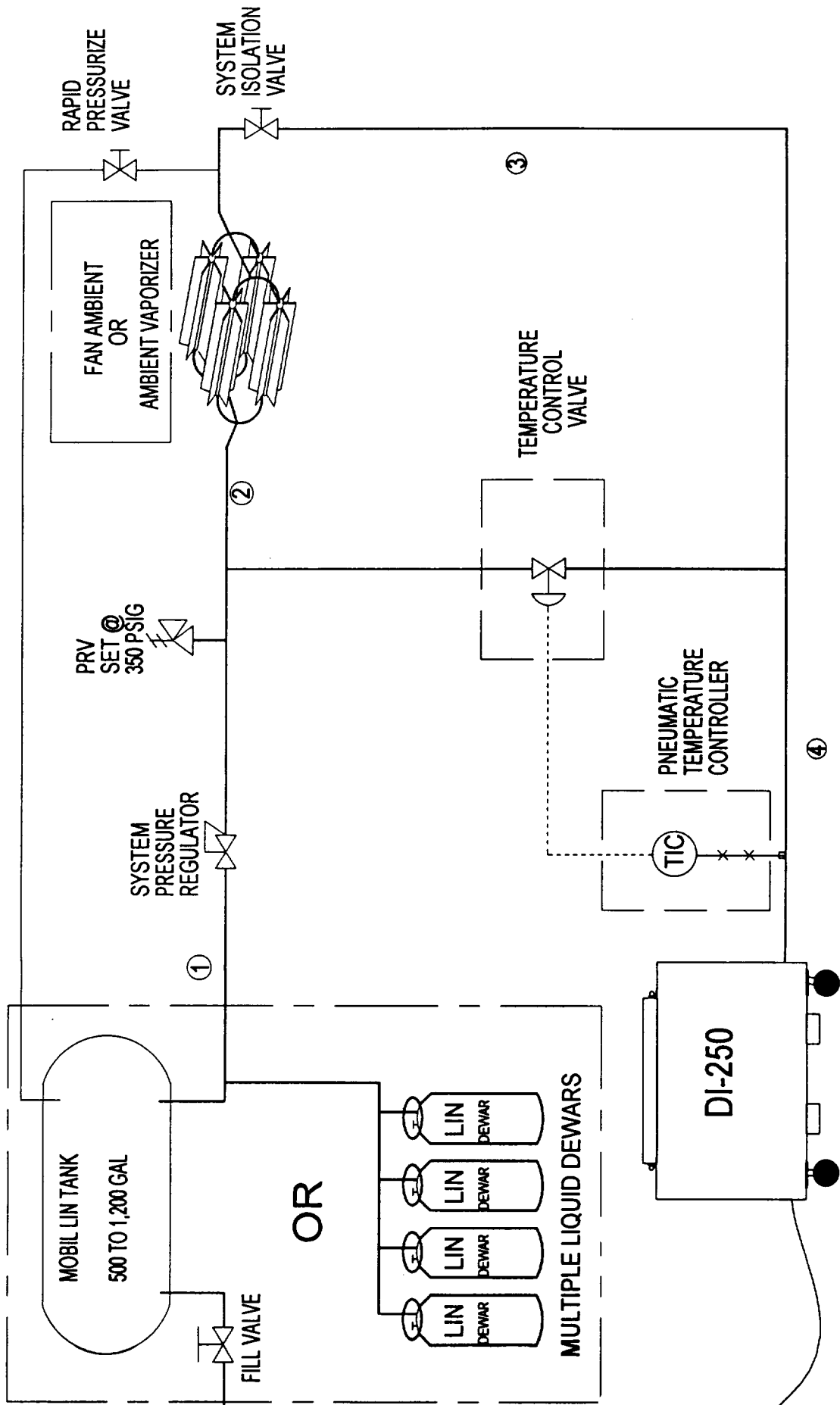
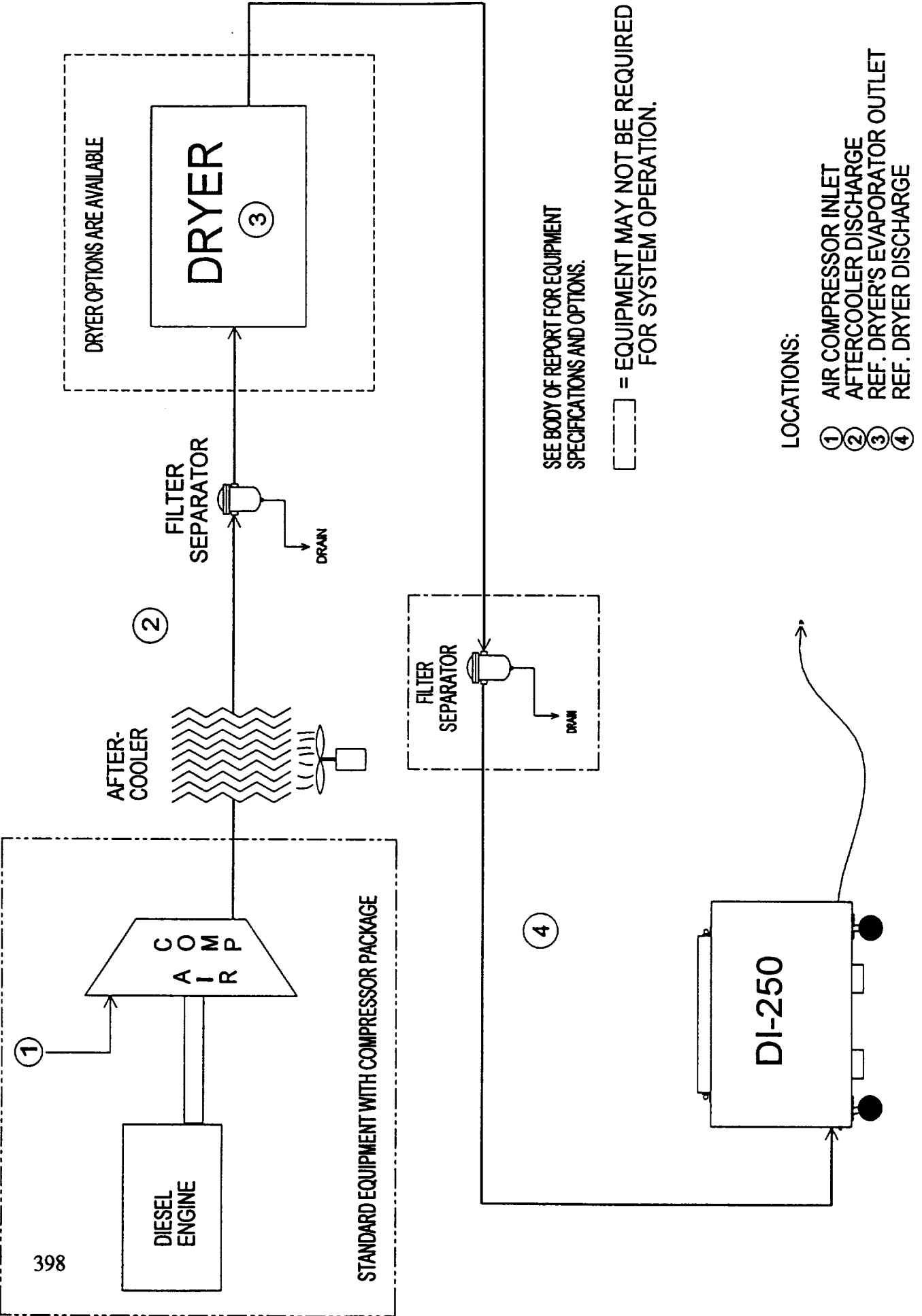


FIGURE 2: COMPRESSED AIR DELIVERY SYSTEM



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STANDARD EQUIPMENT WITH COMPRESSOR PACKAGE

DRYER OPTIONS ARE AVAILABLE

DRYER

FILTER SEPARATOR

AFTER-COOLER

FILTER SEPARATOR

SEE BODY OF REPORT FOR EQUIPMENT SPECIFICATIONS AND OPTIONS.

[Dashed Box] = EQUIPMENT MAY NOT BE REQUIRED FOR SYSTEM OPERATION.

LOCATIONS:

- ① AIR COMPRESSOR INLET
- ② AFTERCOOLER DISCHARGE
- ③ REF. DRYER'S EVAPORATOR OUTLET
- ④ REF. DRYER DISCHARGE

DI-250