DIRECT CONDENSATION OF HYDROCARBON VAPORS

OCTOBER 6, 1998

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I. INTRODUCTION

Everyone who uses solvents in a manufacturing process must also load, unload, and store them. In doing so, vapors are generated at each step in addition to those generated when actually using these solvents in a manufacturing process. Edwards Engineering has developed expertise in all phases of recovering these vapors.

Edwards equipment is based on the Rankine Cycle of refrigeration. All units use refrigerant based compressors to cool vapors by way of a secondary heat exchanger. This is commonly known as the “refrigeration” or “condensation” based vapor recovery system. Liquid Nitrogen also can be used as a refrigerant to cool vapors. When combined with the Rankine Cycle refrigeration process, this becomes Edwards Engineering’s “Cryo-Mechanical” vapor recovery package. In gasoline recovery units, Edwards Engineering now offers a system that combines RECOvery with power GENeration. We are also in the process of developing other innovative designs that combine refrigeration with other technologies.

In general, there are two categories of solvent vapor recovery applications: storage/transfer related and process related. They will be discussed in the following paragraphs.

IIa. STORAGE SYSTEMS

For a single tank application, the simplest and most economical approach is to mount a vent condensing coil on the tank itself and to mount the refrigeration equipment on ground level near the tank. The condensed vapors can be gravity drained back into the tank (Figure 1). In general, by cooling these vapors to -20^{o}F, a 90-95% recovery can be attained. For higher efficiencies, lower temperatures may be required.

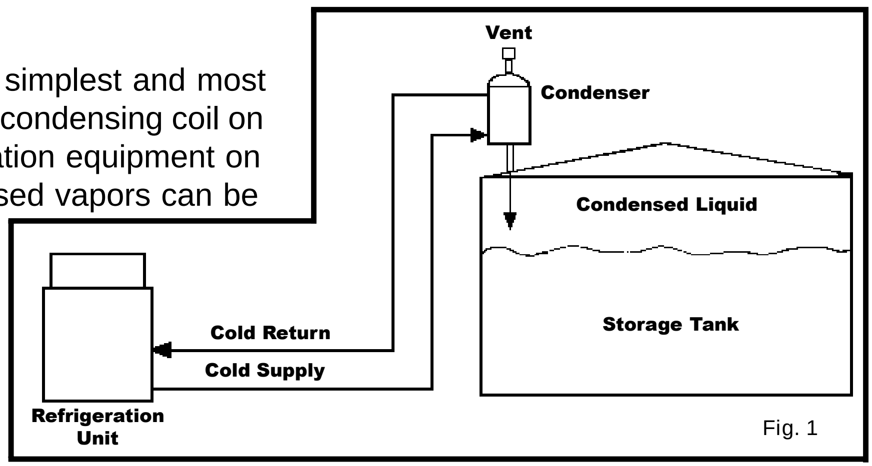


Fig. 1

For multiple tank applications where the liquid being stored is the same in all tanks, it is most economical to pipe the vent lines to a common recovery system and to pump the condensed liquid to a single point. (Figure 2)

For multiple tank applications where the liquids being stored are of different types, it is usually desirable to keep the condensate discrete. For this reason the best approach is to mount a vent condensing coil on each tank. These vent condensing coils are then supplied with a cold heat transfer fluid from a central refrigeration system. (Figure 3)

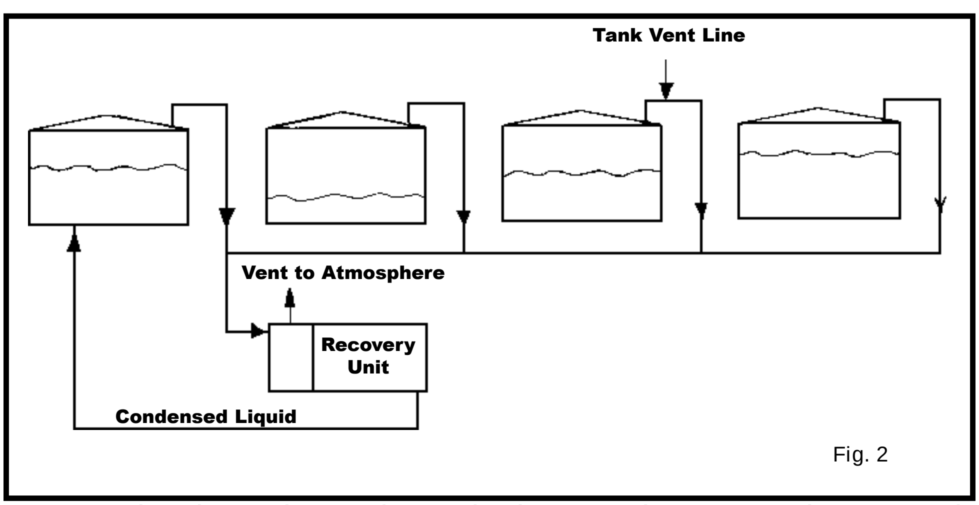


Fig. 2

In any of the above applications, when tank construction precludes mounting vent condensing coils on the tank, they can be mounted at ground level and the condensate is then pumped back into the tank.

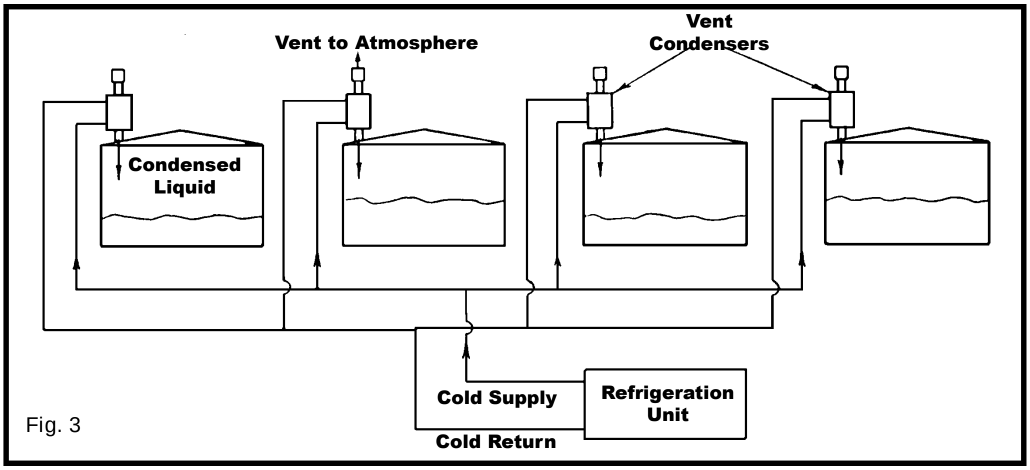


Fig. 3

Storage tanks with fixed roofs which vent to atmosphere will contain water vapor in the vapor space which will form hydrates on the vent condensing coil. These hydrates will return to the storage tank after defrosting, which may be undesirable. If a Nitrogen blanketing system is used, it will prevent ambient air and water vapor from entering the vapor space. This will eliminate the problem of water being condensed and returning to the storage tank and will eliminate the need for a defrosting system which in turn reduces the capital cost of the recovery equipment.

IIb. TRANSFER SYSTEMS

Edwards has supplied hundreds of vapor recovery units for gasoline truck loading terminals since 1973. We have also supplied a number of similar units for marine loading vapor recovery systems for various products (Figure 4). Most of these units have been of the refrigeration type. Power usage is less than 1 KWH/1,000 gallons loaded for gasoline and 0.35 KWH/1,000 gallons loaded for distillate. Stand-alone liquid Nitrogen vapor recovery systems can be provided for barge mounted operation. The small skid size, low power usage and low maintenance make the liquid Nitrogen VRS ideal for barge mounted operation. All marine vapor recovery systems meet or exceed U.S. Coast Guard Regulations for facilities (33 CFR 154 Subpart E) and vessels (46 CFR 39). Truck loading vapor recovery systems will meet and exceed EPA regulations 40 CFR Parts 9 and 63 dated December 14,1994.

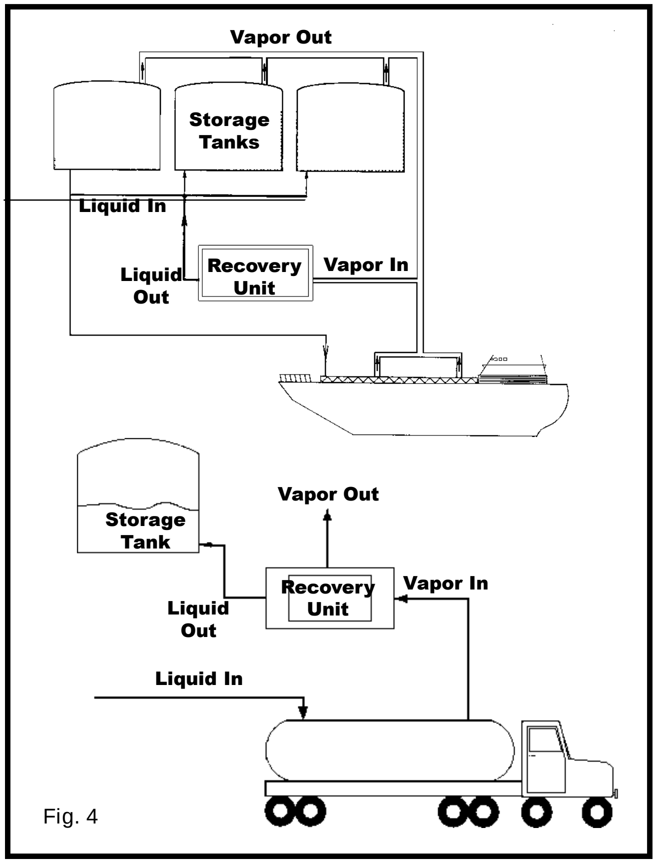


Fig. 4

There are a number of concerns in marine vapor recovery and truck loading vapor recovery; three of the important ones are 1) Safety, 2) Back Pressure, and 3) Efficiency.

1. Safety

Condensation is considered the safest of any control approach currently used. The vapors are simply passed over a cold metal surface and condensed. Marine loading regulations require either enrichment of vapors above the UEL (Upper Explosion Level) or dilution below the LEL (Lower Explosion Level) prior to transfer from the vessel to the shore. Condensation works best by using the enrichment technique so as not to introduce additional cooling load on the equipment and not require a lower than normal condensation temperature. This enrichment can easily be done using the product being loaded from storage and passing the vapor stream through this product to saturate the stream. Truck loading doesn't require any enrichment or dilution.

2. Back Pressure

Back pressure is of major concern due to vapor leakage from a barge/ship or loading truck design point. Condensation systems designed by Edwards typically have back pressure in the range of 1" to 2" w.c. (water column). This low back pressure means in most locations, that no additional blowers are necessary to transport the vapors. Addition of flame arrestors and length of piping may require the use of a blower system.

3. Efficiency

Condensation is the most effective vapor control system on the market today. Early units were designed to emit no more than 80 mg/liter of gasoline vapor effluent based on the original EPA standards. Second generation systems reduced this to 35 mg/liter. The addition of a Cryogenic third stage was then introduced to reach the 10 mg/liter EPA requirement, and most recently RECOGEN has been introduced to reach emissions levels of less than 0.5 mg/liter.

III. PROCESS VENT SYSTEMS

Process vent systems generally fall within four categories:

1. REACTORS - Where solvents are used in reactors and are displaced through vent systems. Many applications are multiple reactor systems which vent to a common recovery unit.

2. MIXERS - Where materials are blended in rotary type mixers and the heat of mixing evaporates solvent to a vent system.

3. PAN COATERS - Where materials are coated with a spray solution and the solvent is evaporated and exhausted to a vent system.

4. SPRAY DRYERS/GRANULATORS - Where solvents are used as a carrier for agglomeration of particles and powders and are subsequently evaporated and exhausted to the atmosphere.

All of the aforementioned processes generally require temperatures from -20°F to -110°F to attain 90% to 95% recovery. For higher efficiencies, lower vapor temperatures down to -300°F may be obtained using our “Cryo-Mechanical” vapor recovery package.

The reactor vents generally are “one-pass” systems whereby the vapors are exhausted from the reactor, pass through the recovery unit, are cooled, and expelled to the atmosphere. In the mixing, coating, and drying/granulating operations, a more efficient and economical method of recovery is to use a “closed-loop” system. In either case, one important point to consider is the installation of filters so that dust and other particles are not carried over to the condensing coils.

A closed-loop system is best utilized on a batch process system, but can be adapted to a continuous feed system. The closed-loop system has the advantage of having no emissions during operation, which in effect gives a 100% recovery of the solvent. The temperature required can be as warm as desired (+35°F to +60°F) and is only limited by the maximum allowable concentration in the return stream or LEL concentrations at the end of the cycle. The only emission occurs when the process is opened to empty and refill, or if there is leakage.

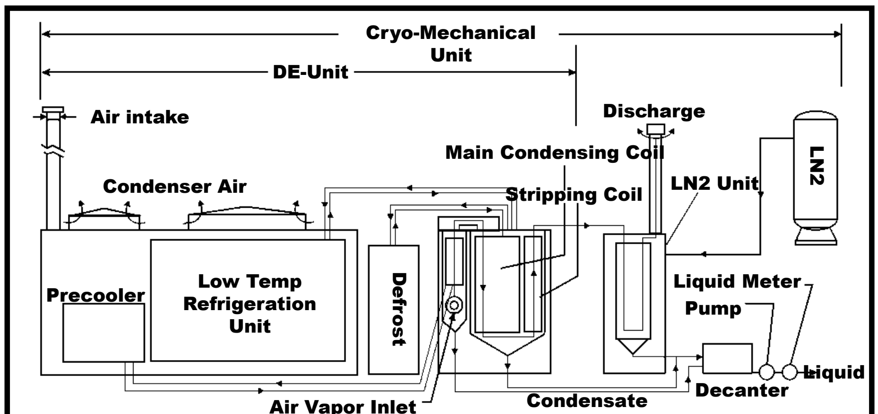
For some processes that are continuous feed or cannot be made vapor tight, a modified closed-loop system may be required. In this case a side stream of air and vapor is pulled out of the closed-loop after cooling, so that any leakage will be into the system. The solvent vapor present in this side stream now determines the overall recovery efficiency and the required temperature.

In recommending a condensation unit to a potential user, the primary concern is the characteristics of the process stream introduced into the vapor recovery unit so that sufficient refrigeration and heat transfer capacity can be calculated. This allows for simple straightforward design, construction, operation and maintenance of the vapor recovery equipment.

In order to make the proper recommendation of unit size, the following information is required:

1. The components of the vapor stream.
2. The concentration of the various components.
3. The volume flow rate of the stream; cfm, gpm, or lbs./hr.
4. Inlet temperature & pressure.
5. Desired recovery.
6. Hours of operation.

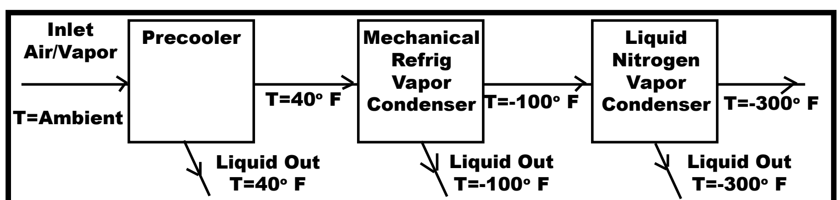
In condensation based vapor recovery, the VOC's are recovered as a liquid. If the inlet vapor stream contains more than one condensable vapor, the recovered liquid will contain the same mixture of components, depending on the outlet vapor temperature. If the VOC's are immiscible with water, condensate can be gravity separated and the water free product can be returned to storage. If these liquids are miscible with water, the mixture must be separated or disposed of. (Figure 5a, b, c)



SCHEMATIC OF EDWARDS VAPOR RECOVERY SYSTEM Fig. 5a

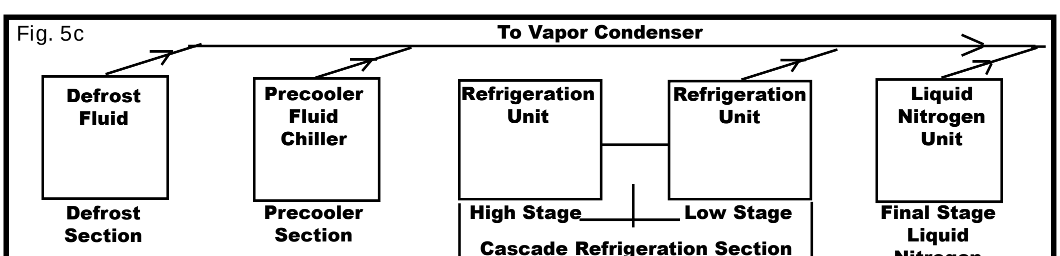
IV. TEMPERATURES

The temperatures required to recover 95% or 99% of a given vapor depend primarily on the type of vapor involved. Most chlorinated hydrocarbons encountered in tank breathing can be recovered with a 95% efficiency by cooling to -20°F. Different applications may require lower temperatures, such as reactor vent recovery which generally requires temperatures of -60°F to -200°F. Typical working ranges of refrigeration systems are listed in Figure 6.



VAPOR RECOVERY SYSTEM: REFRIGERATION/LIQUID NITROGEN AIR/VAPOR STREAM Fig. 5b

All of the listed (Figure 6) refrigerants are available for any combination of vapor recovery effect desired and, in many applications, combinations of these can be used to cool the vapor stream in stages. All of the above refrigerants are considered to be environmentally safe and meet or exceed the strictest regulations as established by the Montreal Protocol.

Fig. 5c


VAPOR RECOVERY SYSTEM: REFRIGERATION/LIQUID NITROGEN SECTIONS

V. PRECOOLER

The precooler refrigeration system consists of a standard single stage chiller that is set to operate just above the freeze point of all components in the vapor stream (35° F is usually the set point when water is present). The precooler refrigeration system, equipped with either an air-cooled or water-cooled condenser, reduces power costs, minimizes subsequent frost formation, and standardizes the condition of the vapor entering the low temperature condensers.

Single Stage	**Cascade**	**Cryo-Mechanical**
R-22/AZ-50 (or equivelant new refrigerants) +50° F to -40° F	AZ-50/R23 or SUVA95 -40° F to -100° F	AZ-50/R-23 or SUVA95/LN_2 +50° F to -300° F

Fig. 6

VI. LOW TEMPERATURE COILS - CRYO/MECHANICAL OPTIONS

After leaving the precooler, the vapors pass to the low temperature coils. When water vapor is present, hydrates form on the finned surfaces. These hydrates may contain from 50% to 80% hydrocarbons. The coils are constructed to accommodate the formation of a considerable quantity of hydrate, or frost from other components that may freeze, without seriously affecting the heat transfer rate of the system, or increasing the pressure drop. Periodically, the low temperature coils must be taken out of service for removal of the frost. The low temperature coils can be constructed in two halves so that the coil sections can be defrosted on an alternating basis and the unit can be operated continuously, thus eliminating down-time for defrosting of these coils.

During normal operation, the condensate and melted frost from the low temperature coils drops into the drain pan under the coils. From the drain pan the condensate passes into a receiver or decanter.

Based on new regulations mandating lower emissions, Edwards Engineering now offers additional lines of simple, safe and economical vapor recovery systems using liquid Nitrogen, power generation, and adsorption technology, that make it possible to achieve recovery rates that have been unobtainable using mechanical refrigeration alone.

VII. DEFROSTING

When processing gasoline, the condensing coils are defrosted once every 24 hours, or as required, by passing a warm fluid through a second set of tubes in the condensing coils. Heat for the defrost system is collected from the compressors by a gas-to-liquid heat exchanger. The defrost liquid is held in a storage reservoir for use as needed. Defrosting takes about one hour and can be scheduled to take place during periods when loading or tank breathing is not occurring. The defrosting shutdown period can be eliminated by installing two complete condensing coils in parallel, if continuous 24 hour operation is required. For units designed for chemical applications, defrost cycles are generally shorter than for gasoline applications.

VIII. SAFETY

Safety from explosions or fire is of primary concern to all operators. The low temperature refrigeration vapor recovery condensers are safe for processing vapors in all concentration ranges. The vapors pass through between 10 and 12 feet of finned, frost covered surfaces chilled as low as -300°F. The vapors pass through the explosive range at greatly reduced temperatures. The space between the fins is 0.230 inches with a fin thickness of 0.020 inches. The tubes are of copper or stainless steel. The refrigerant is non-flammable, and therefore, the vapor recovery machine is inherently safe. The finned coils, the heart of the machine, contain only a small quantity of hydrocarbons in the form of a frozen hydrate.

IX. MATERIALS OF CONSTRUCTION

Piping on the refrigerant circuit is usually copper, in accordance with ANSI B 31.5. Piping in contact with the condensate is usually copper or 304 stainless steel. The shed enclosure and frame are usually constructed of carbon steel. The coil, vapor box and decanter/receiver are usually 304 stainless steel. Other materials such as Hastelloy, 316 stainless steel, Monel or titanium can be used in these designs as required.

X. FLEXIBILITY OF DESIGN (0-100% TURNDOWN RATIO)

The units are sized for the maximum anticipated load and operate as required to maintain the design temperature in the condensing coils. When no vapor is being processed, the only operation is to maintain the coil temperature and the unit(s) will cycle off. This gives 0-100% turn-down ratio. This type of system ideally handles “spikes” typical in loading facilities and batch manufacturing processes.

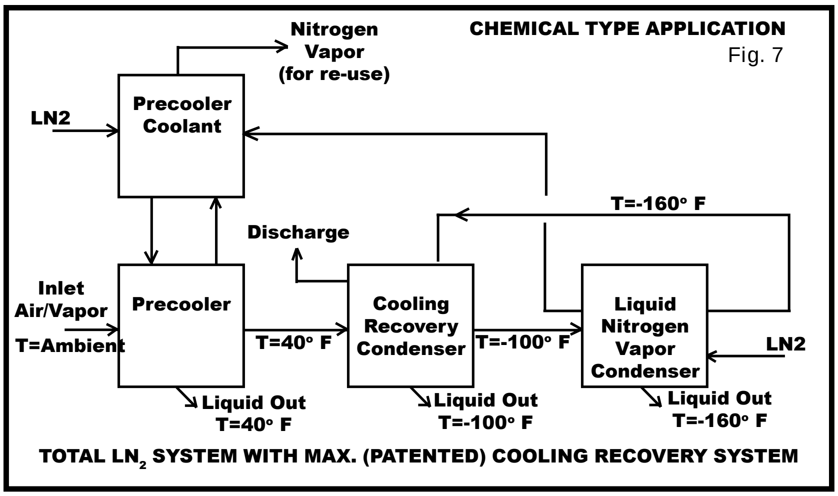


Fig. 7

The Cryo-Mechanical combination offers additional flexibility of operation and is often used for batch type chemical applications (Figure 7). If the mechanical system is overloaded, the liquid Nitrogen storage tank serves as a large reservoir of stored coolant, thus allowing a reduced cost for the mechanical section. The LN_2 is instantly available for use and automatically compensates for overload conditions. In addition, if maintenence is required within the mechanical system, the LN_2 system can carry the entire load during this period. Under these conditions, frost accumulation will occur more quickly and defrost will have to be done more frequently.

XI. RELIABILITY/PLC CONTROLS

Edwards experience in manufacturing vapor recovery systems since 1974 shows that the life span of typical systems are 20 years or more, without the need to replace any major components. Modern PLC control with modem capability allow ease of monitoring for service and maintenance purposes. Edwards offers service contracts on all equipment.

For larger units, screw compressor alternates are available. With fewer moving parts, these units provide both a higher service factor and electrical efficiency.

A variety of monitoring options are available, ranging from flow to vapor analysis devices. It should be noted, however, that the controlling parameter is the vapor discharge temperature. This parameter is accepted by regulatory agencies, thus minimizing the cost required to monitor these systems for regulatory companies.

XII. DECANTER/RECEIVER

Several options are available for condensate formed in the units. The no cost option is to located the condenser above the liquid tank and allow the condensate to drain by gravity back into the tank.

When single fluids or miscible fluids are processed a condensate receiver design is proposed. When immiscible fluids are processed, a decanter design is proposed.

Float activated pumps are provided to pump the recovered products back to the storage tanks for safe disposal. When water is decanted, it flows to the oily water drain, or it can be removed via a second pump system.

These systems are heat traced and insulated to meet the requirements for the materials being processed.

XIII. EQUIPMENT

The advantages for refrigeration based vapor recovery systems are as follows:

Low Capital Cost - for the proper application.

Low Power Cost - Units operate on demand only.

Low Maintenance Cost - No scheduled tear down; only preventative maintenance is required.

Availability of Maintenance Personnel - using plant or local refrigeration personnel.

Inherent Safety - No possibility of a fire or explosion.

Ease of Performance Monitoring - Reading outlet temperature and correlate with Vapor Pressure Chart as accepted by EPA Regulation 40 CFR parts 9 and 63 dated 12/14/94.

Low Pressure Drop through the unit.

Product recovered is in liquid state - easily measured, ready for immediate distribution or sale.

No additional pollution problem of ash, contaminated carbon, waste water or other products or processing to contend with.

Refrigerants/LN_2 are tubeside. Vapor is shellside, resulting in low pressure vessels and non-contaminated refrigerants or vapor Nitrogen discharge.

XIV. PACKAGED SYSTEMS - ENHANCED CARBON ADSORPTION SYSTEMS

Edwards Engineering Corp. Vapor Recovery Systems can easily be combined with other technologies to recover VOC’s more efficiently and economically. For example, for process streams with high flow rates (> 5,000 SCFM), a Mechanical Vapor Recovery System can be combined with adsorption type systems. For vapor streams with high VOC concentrations, Mechanical Vapor Recovery Systems can be used to remove a high percentage of the VOC’s from a vapor stream, thus significantly reducing the size of a downstream adsorption or combustion system. A Liquid Nitrogen Vapor Recovery System can be supplied as a retrofit to any type of vapor control technology as a final polishing step or protection against overloads or capacity surges. Where economics dictate, Edwards Engineering can supply regenerable carbon adsorption systems either in conjunction with refrigeration units or as stand alone units. Edwards Engineering Systems are custom designed to fit any application.

XV. RECOGEN GASOLINE VAPOR RECOVERY

The RECOGEN Gasoline Vapor Recovery System is designed to meet all current and expected future gasoline emission specifications.

The RECOGEN Series uses a combination of RECOvery-GENeration for cooling the vapor stream to achieve recovery rates in excess of 99%. The RECOGEN system recovers 85-90% of the gasoline as liquid and consumes the remaining 10-15% in an engine driven generator. This generator provides power equal to or greater than that used by the refrigeration system so that the entire operation is POWERFREE. The emissions from this system are less than 0.5 mg/liter.

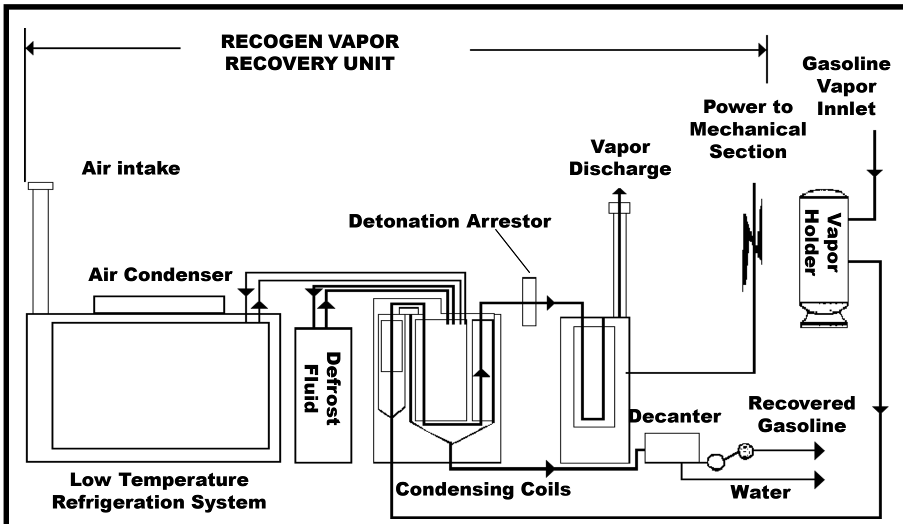


Fig. 8

The power generated in this system is 1.1 kw for every 1,000 gallons of gasoline loaded. The power usage of the refrigeration system is 0.5 kw for every 1,000 gallons loaded which means that there is a net generation of 0.6 kw for every 1,000 gallons loaded. (Figure 8)

A standard range of RECOGEN units is available that meet the requirements of small, medium and large sized petroleum truck and marine loading terminals. Units can be provided that meet customer site specific requirements and comply with 40 CFR Parts 9 & 63 NESHAPS, 14 December 1994 as well as all current European Union and TA Luft standards. For gasoline vapor recovery, the standards are as follows:

XVI. REGULATIONS

1. The US standard of 35 mg of hydrocarbon in the exhaust per liter of liquid transferred can be achieved with a vapor temperature of -100°F (-73°C). This specification can easily be met using only a mechanical refrigeration system. Typical gasoline recoveries at this temperature are in the 98 to 99% range.

2. The U.S. standard of 10 mg of hydrocarbon in the exhaust per liter of liquid transferred can be achieved by adding a LN_2 stage to cool the vapor down to -180° F, or by using Edwards Engineering RECOGEN Gasoline Vapor Recovery System. The LN_2 System or the RECOGEN can be used to upgrade mechanical refrigeration units that were designed to meet the 35 mg specification.

3. The ECM standard of 35 gm of hydrocarbon exhausted per cubic meter of vapor exhausted requires a vapor temperature of approximately -140°F (-95°C) if LN_2 is used. Alternately, this specification can be achieved using the RECOGEN System.

4. The TA Luft standard of 0.150 grams of hydrocarbon in the effluent per cubic meter of vapor exhausted requires a vapor temperature of approximately -270°F (-168°C), if LN_2 is used. The RECOGEN System, again, is generally the more viable option for this application.

XVII. CONCLUSION

Vapor recovery by direct condensation is the cleanest and in many cases the most energy efficient method of control for hydrocarbons typically encountered in today's vapor recovery applications. Its flexibility in design and broad range of applicability for vapor streams of practically any type, make it the preferred method of emissions control in the 1990s and beyond.

With Edwards Engineering recent technology developments and acquisitions Edwards Engineering is in a preeminent position to serve your vapor recovery requirements regardless of your vapor flow rates, compositions or VOC types.

Edwards Engineering Corp. has over 25 years experience in condensation based vapor recovery, and has designed over 450 vapor recovery systems for a wide range of clients for locations throughout the world. Our primary design and fabrication facility is in Pompton Plains, NJ. We also manufacture under license in England, Germany, and Australia. Our facility in New Jersey is over 150,000 square feet and employs about 150 persons in design, service, and manufacturing. The shop is union and is ASME qualified. We build UL listed equipment and ETL tested chillers using the National Electric Code. We work in a wide range of metallurgies, including stainless steel, Hastelloys, monel, and titanium.

We look forward to serving you and invite inquiries about your specific application(s).