TECHNICAL MANUAL

N° ......

Edition 2000

CRISTOPIA ENERGY SYSTEMS (I) PVT. LTD.
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Summary

INTRODUCTION

At the time when we talk more and more about ecological risks and the rationalisation of energy use, the thermal energy storage represents a technical solution adapted to industrial cooling and air conditioning systems.

Classical systems are designed for peak demand, even if we use the chillers at 100 % for only a few days or few hours every year.

Thermal storage by latent heat allows a reduction in chiller capacity. This storage provides shortfall of the energy when demand is higher than the chiller capacity. Thus chiller operation is continuous and its efficiency at maximum.

The STL allows real management of the cooling energy according to the demand. Also significant savings can be made on running costs using off peak electrical tariffs.

The reduction in the chiller size also reduces the quantity of refrigerant used, a point that is more and more important with the new restrictive laws on CFC's.

The STL improves system reliability and offers a safer mode of operation for processes or back-up systems.

Cristopia, a manufacturer of latent heat thermal storage systems present in this document the basic principles of thermal storage.

Additionally we detail the fundamental elements for calculation, selection, optimisation and the commissioning of the STL.

The Cristopia team is always at your disposal to assist in the design of thermal storage for A/C and industrial refrigeration.

1. ENERGY STORAGE

1.1 : WHY STORE ENERGY ?

Until now, it has not been possible to store reasonable quantities of heat or cold and as a result, chillers have been sized to satisfy maximum design load conditions ; much of this capacity being used for only a few hours per day (or even year).

Daily thermal storage allows the use of smaller chillers. During low demand periods the store is charged, then during high demand the energy stored is released.

For cyclic loads, Thermal Energy Storage permits smaller chillers to operate on a near continuous basis ; storing energy during off peak (usually cheaper) periods for use during peak hours.

1.2 : HOW IS ENERGY STORED ?

- SENSIBLE HEAT

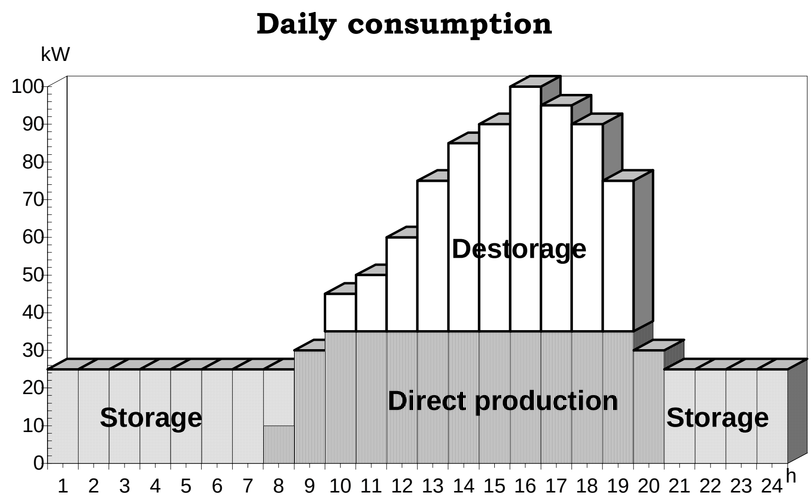
Principally, we consider water as the storage medium for sensible energy. As well as being available cheaply and in abundance, water has a volumetric heat capacity of 1.16 $kWh/m^3°C$; greater, for instance, than iron or stone. However, there are limitations to its use especially when used with large temperature differentials.
In cooling applications, a practical maximum of only 6 kWh/m^3 can be achieved in the absence of costly anti-freeze solutions.

- LATENT HEAT

Latent heat is the name given to the energy either stored or liberated when a substance changes phase.

<u>Example</u> : ice changes to water, water to gas or steam.

These changes occur at constant temperature. The energy absorbed or released during phase change is rather more significant than the energy required to decrease or increase the PCM (Phase Change Material) temperature (sensible heat).



To melt a material we require a quantity of energy. For instance to melt one gram of ice require 80 calories at constant temperature. This energy is released when the material is cooled down and returns to solid phase. Different materials have different fusion points. For Thermal Storage we use different materials to satisfy the requirements of a wide range of applications.
These materials are called PCMs (Phase Change Materials).

Latent heat storage presents us with two significant advantages :

- high thermal densities can be achieved,
- energy is released at almost constant temperature.

1.3 : STORAGE APPLICATIONS

When considering potential applications for Latent thermal storage it is necessary to examine the energy source being used.

Where cooling is generated by electricity through a thermodynamic machine (chiller), the attractiveness of storage is significantly increased if off peak (or cheap rate) tariffs are available outside the cooling demand period.

In industrial cooling and air conditioning systems, the process requirements do not permit large temperature differentials across the circuit. Thus, sensible energy storage requires very large storage volumes - witnessed by the lack of such systems.

The high cost of the chillers makes the reduction of installed power attractive. Industrial process cooling and air conditioning are favourable applications for the use of LATENT HEAT STORAGE.

Below are listed some typical applications for Thermal Energy Storage (T.E.S.) :

Air Conditioning

- Office building
- Hospital
- Banks
- Conference centres
- Museums
- Recording studios
- Theatres
- Department stores
- Supermarkets
- Airports
- Cinemas
- Sport centres

Process Cooling

- Dairy industries
- Slaughter houses
- Cold stores
- Central kitchens
- Pharmaceutical industries
- Bottling plants
- Breweries
- Skating rinks
- Meat industries

Back-up

- Computer rooms
- Clean rooms
- Operating Theatres
- Telephone exchanges
- Cold storage
- TV studios
- Explosive storages

(see our reference list)

The advantages of thermal storage are :

- a reduction of chiller size (50 to 90 %),
- a reduction of costs,
- an increase in reliability,
- simplified maintenance,
- refrigerant load reduction (CFC, HCFC, ammonia) (50 to 80 %).

Thermal storage is an efficient system for optimising air conditioning and refrigeration plant.

According to the application a significant installed chiller capacity reduction of 50 to 90 % can be achieved.

Also other components (transformer, cooling tower, etc....) are reduced in the same proportions and the servicing of equipment is simplified.

Also it allows the use of low cost electricity at night.

2. STL SYSTEM PRESENTATION

2.1 : STL : A SYSTEM APPROACH

The STL is composed of a tank filled with "nodules".

The tank has upper manholes to allow the filling with nodules. A lower manhole allows emptying. Inside the tank two diffusers (inlet and outlet) spread the heat transfer fluid along the tank. The pressure drop through the tank is 2.5 mWG. The inlet in charge mode must be via the lower diffuser in order to ensure the natural stratification.

The tanks are manufactured in black steel (test pressure between 4.5 to 10 bar), are delivered empty and positioned on site or, if the access to site is impossible, constructed on site.

The nodules are spherical with a diameter of 77 mm, 78 mm or 98 mm (depending on the nodule type).

The nodules contain the Phase Change Material (PCM). The mechanical and chemical characteristics of the nodule shell (manufactured in polyolefin) are well adapted to the conditions encountered in Air Conditioning or Refrigeration systems.

Once filled with PCM the nodule plugs are sealed by ultrasonics to ensure perfect watertightness.

The nodules are delivered in 22 kg bags. Tanks are filled on site. The filling is regular and homogeneous.

Filling procedures are described in chapter 7 of this manual.

2.2 : STL : A COMPETITIVE SYSTEM

The tank shape is usually cylindrical in order to withstand service pressure higher than 3 bar. The test pressure varies between 4.5 to 10 bar.
The spherical shape allows an easy filling.
The nodule diameter has been calculated to meet economical and technical requirements. The size allows high exchanges until the end of the cycle.

The use of modern technologies permits quality control. The materials used are completely neutral to the phase change materials and heat transfer fluid. The phase change materials used by CRISTOPIA *Energy Systems*, and also the nodules, have been laboratory tested in France and abroad. This product development work has led to a very high reliability of the STL.

CRISTOPIA *Energy Systems* offers a range of temperatures :

- 33°C to + 27°C

The STL has been conceived for hydraulic applications.
Please consult CRISTOPIA *Energy Systems* for any other application.

2.3 : STL : DESCRIPTION

The quantity of energy stored for each type of nodule is proportional to the storage volume. The number of nodules in a system determines the heat exchange rate between the nodules and the heat transfer fluid.

a) Terminology :

A STL is determined by the phase change temperature and the volume (i.e. the storage capacity and the heat exchange rate).There are 3 types of nodules characterised by their diameter : AC (98 mm), IC and IN (78 mm)

For example :

STL – AC.00 – 15

AC : 98 mm diameter nodules
00 : phase change temperature in °C
15 : tank volume in cubic metres

STL – IN.15 – 50

IN : 78 mm diameter nodules for negative temperature
15 : the phase change temperature (melting) is -15°C
50 : tank volume in cubic metres

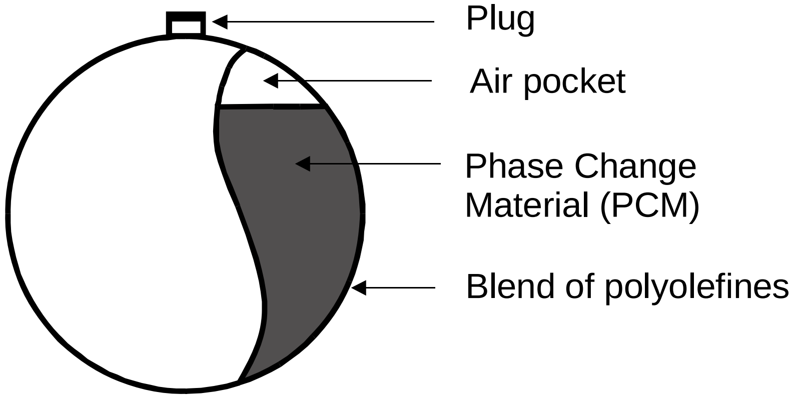
STL – IC.27 – 100

IC : 78 mm diameter nodules
27 : the phase change temperature (melting) is +27°C
100 : tank volume in cubic metres

b) The nodules :

The envelope :

- material : blend of polyolefins
- chemically neutral towards eutectics and heat transfer fluid
- thickness 1.0 mm : no migration of the heat transfer fluid
- sphere obtained by blow moulding : no leakage
- sealing of the cap by ultrasonic welding
- exterior diameter :
    - 98 mm : Air conditioning
    - 78 or 77 mm : Industrial Cooling or Back-up
- exchange surface
    - Diameter 78 or 77 mm : 1.0 m^2/kWh stored
    - Diameter 98 mm : 0.6 m^2/kWh stored
- air pocket for expansion : no stress on the nodule shell
- useful number of nodules per m^3 :
    - Diameter 77 mm : 2 548 nodules per m^3 .
    - Diameter 78 mm : 2 444 nodules per m^3 .
    - Diameter 98 mm : 1 225 nodules per m^3 .



Nodule characteristics

The table hereafter gives the nodules performances (latent energy, fusion point, etc...).

Nodule type	Phase change temperature °C	Latent heat Ql kWh/m3	Sensible heat solid Qss kWh /°C	Sensible heat liquid Qsl kWh /°C	Heat transfer PCM crystallisation Kvcr kW /°C	Heat transfer PCM fusion Kvfu kW /°C	Nodule weight kg	Toxicity LD50 value in mg/kg **a**	Operating temperature limits °C
SN.33	- 33	44.6	0.7	1.08	1.6	2.2	724	2,600	
SN.29	- 28.9	39.3	0.8	1.15	1.6	2.2	681	1,200	-40°C
SN.26	- 26.2	47.6	0.85	1.2	1.6	2.2	704	1,200	to
SN.21	- 21.3	39.4	0.7	1.09	1.6	2.2	653	1,300	+60°C
SN.18	- 18.3	47.5	0.9	1.24	1.6	2.2	706	2,700	
IN.15	- 15.4	46.4	0.7	1.12	1.6	2.2	602	8,400	
IN.12	- 11.7	47.7	0.75	1.09	1.6	2.2	620	5,000	-25°C
IN.10	- 10.4	49.9	0.7	1.07	1.6	2.2	617	11,000	
IN.06	- 5.5	44.6	0.75	1.1	1.6	2.2	625	18,000	to
IN.03	- 2.6	48.3	0.8	1.2	1.6	2.2	592	58,000	
IC.00	0	48.4	0.7	1.1	1.6	2.2	558	85,000	+60°C
AC.00	0	48.4	0.7	1.1	1.15	1.85	560	85,000	
IC.27	+ 27	44.5	0.86	1.04	1.6	2.2	867	2,500	

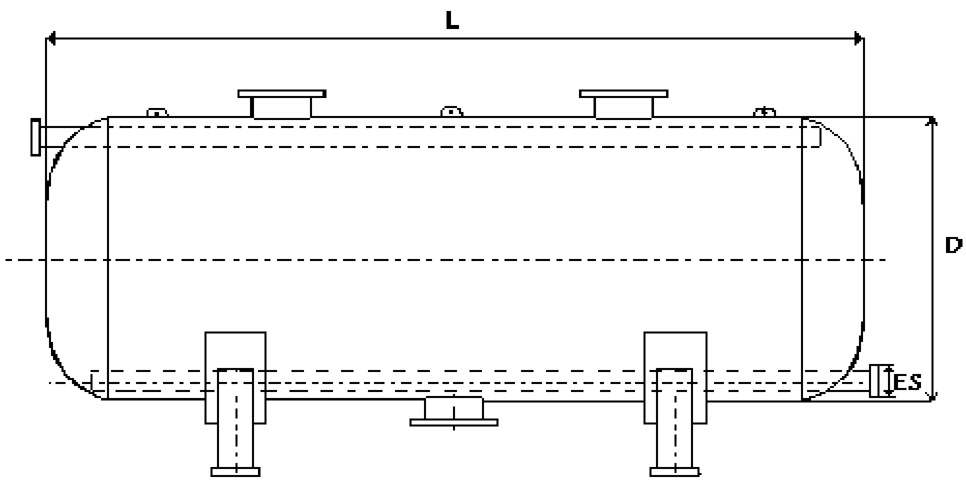
Data for 1 m³ of tank

a : according to the O.E.C.D. convention of May 12, 1981
LD 50 : (median lethal dose), oral, is a statistically derived single dose of a substance that can be expected to cause death in 50 % of animals when administered by the oral route. The LD 50 value is expressed in terms of weight of test substance per unit weight of test animal (mg/kg).

c) <u>The tank</u> :

Characteristics :

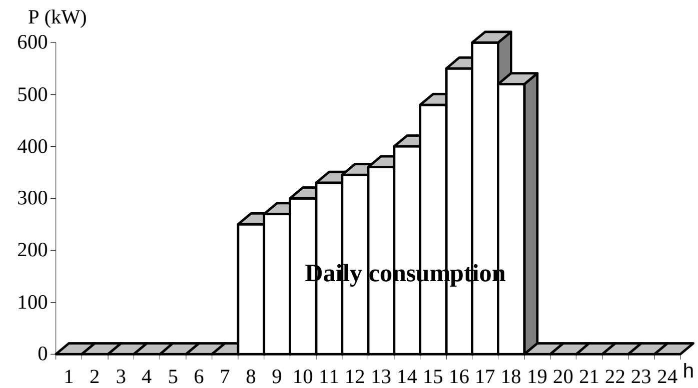
- black steel
- horizontal or vertical
- outside, inside, buried, built on site
- rustproof exterior paint
- insulation on site
- efficient diffuser system
- high service pressure
- pressure drop : 2.5 mWG
- made to measure according to site requirements



Volume in m^3	External Diameter D / mm.	Total length without flanges L / mm	External surface to be insulated m^2	Inlet and outlet flanges ES / mm	Number of cradles	Empty weight kg Pe 4.5 bars	Heat transfer fluid volume in m^3
2	950	2,980	10	40	2	660	0.77
5	1,250	4,280	18	50	2	1,050	1.94
10	1,600	5,240	29	80	2	1,890	3.88
15	1,900	5,610	37	100	2	2,540	5.82
20	1,900	7,400	47	125	3	3,200	7.77
30	2,200	8,285	61	150	3	4,580	11.64
50	2,500	10,640	89	175	4	6,860	19.40
70	3,000	10,425	106	200	4	8,400	27.16
100	3,000	14,770	147	250	6	11,700	38.80

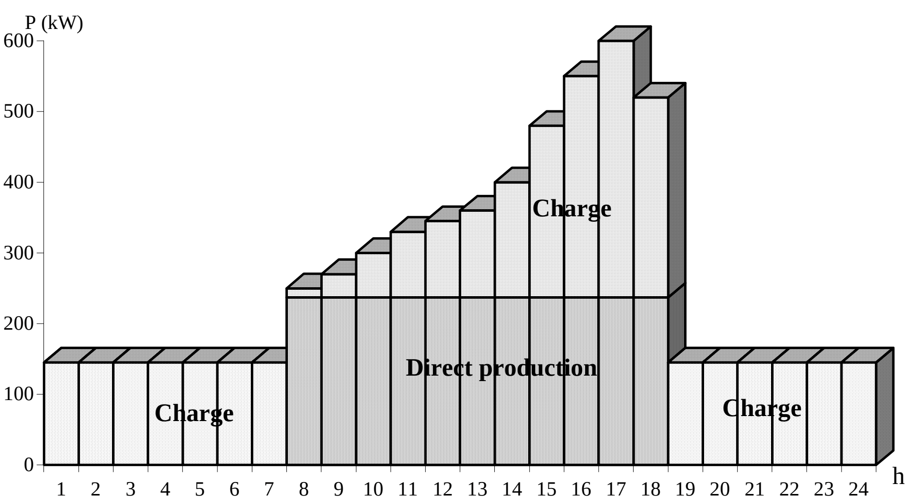
STL dimension example

3. STORAGE STRATEGIES



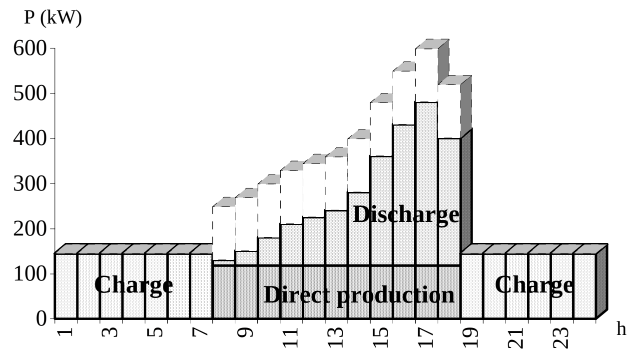
STL manages the cooling energy according to designer's requirements. There are various strategies that can be adopted.

3.1 : PARTIAL STORAGE (REDUCED CHILLER CAPACITY)

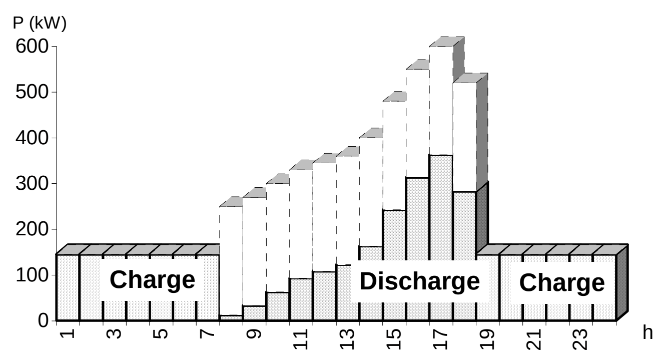


The chiller capacity is reduced to 30 to 60 % of the maximum demand. During night the energy is store. During day, priority is given to chillers which provide cooling energy, when the demand is higher than chiller capacity the STL provides the short fall in energy.

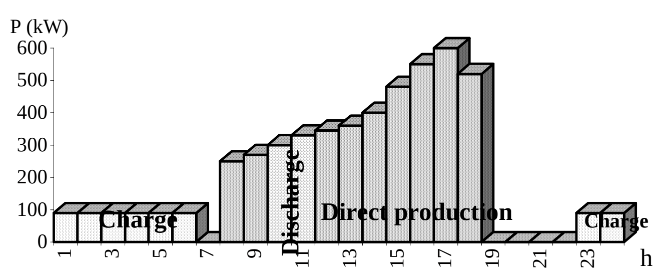
3.2 : LOW SEASON DISCHARGE



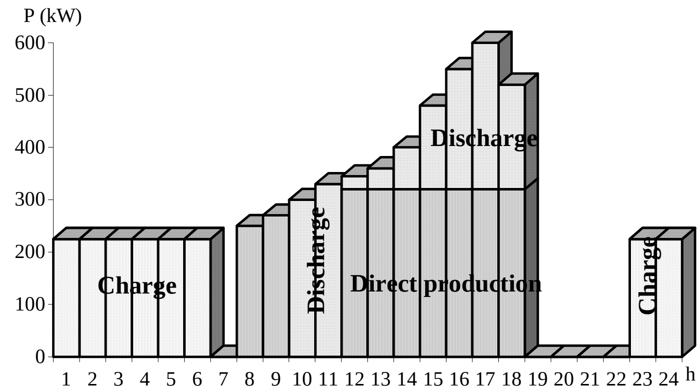
A partial storage in high season can be easily transformed into a total storage or time of day storage during low season in order to increase the running costs savings.



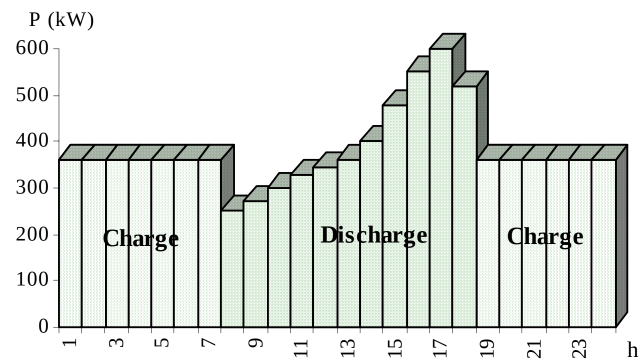
3.3 : TIME OF DAY



With the "time of day" type electrical tariffs charges at certain times of the day are particularly high. Energy can be stored during cheap off-peak periods then discharged during the high tariff periods.

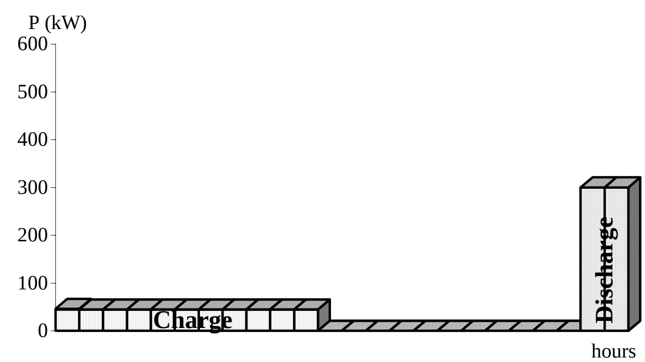


3.4 : TOTAL STORAGE



During the air conditioning period, the chillers are stopped and all the cooling energy is provided only by the STL.

3.5 : BACK-UP



The STL is used as back-up only when it is necessary. It replaces the main cooling system in case of failure. The STL is regularly recharged to compensate for standing losses.

4. DESIGN

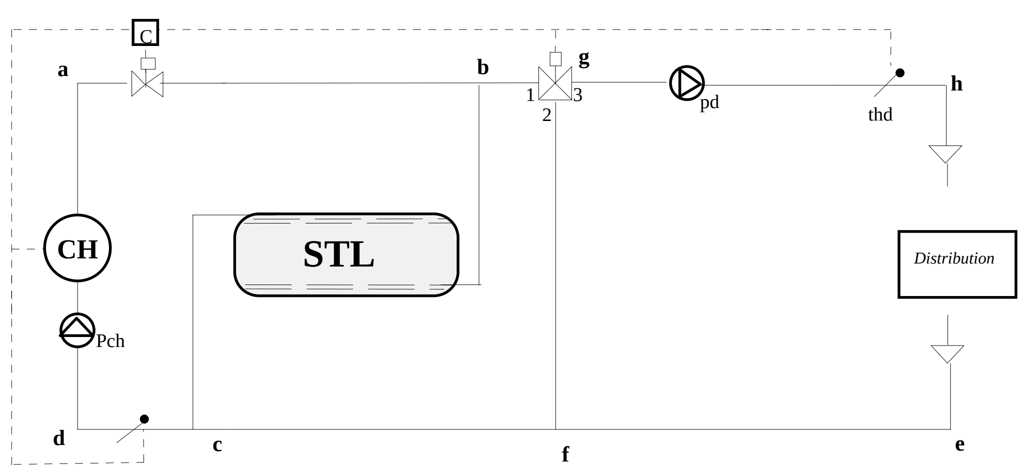
The operating cycle of the STL is divided into two distinct modes : charge and discharge - during which the nodules remain virtually at a constant temperature.

<u>The charge mode</u> : the store is charged by crystallisation of the salts contained within the nodules. This takes place when the temperature of the heat transfer fluid passing through the STL is lower than the phase change temperature of the salts. the store then acts as a heat exchanger, the heat transfer fluid releasing its energy to the nodules.

<u>The discharge mode</u> : the stored energy is released by fusion of the salts contained in the nodules. This takes place when the temperature of the heat transfer fluid passing through the store is higher than the phase change temperature of the salts. The STL then acts as a heat exchanger, the heat transfer fluid absorbing the energy of the nodules.

4.1 : RUNNING PRINCIPLE

During the charge and discharge cycle the temperature of the heat transfer fluid passing through the STL should vary as little as possible relative to the temperature at the end of the release mode. Distribution flow temperature is normally constant. The following lay-out meets these requirements. In this type of lay-out, there are two loops in parallel : a primary loop (abcd) and a secondary loop (efgh) which are connected by (bg) and (cf).



Primary loop (abcd) :

This has constant flow and varying temperature. The fluid is circulated by the. charging pump (Pch) .

When the temperature of the heat transfer fluid entering the evaporator (Ev) decreases, the chiller output reduces. A dynamic balance is created between energy absorbed by the store and chiller output.

Secondary loop (efgh) :

This has constant or variable flow and a constant temperature. The fluid is circulated by the distribution pump (Pd) .

The temperature is kept constant by mixing the return heat transfer fluid with the fluid coming from the chiller plant under control of a 3 way valve.

Regulation of the system :

The chiller compressor is controlled by a thermostat at outlet or inlet of the evaporator (Ev).
This thermostat unloads the compressor when the temperature is equal to or below the temperature set for the primary loop (abcd) at the end of the charging mode.

A shut-off valve can be installed at the inlet of the evaporator if one wants to shut down the chiller during certain periods .

A temperature probe (thd), controlling the operating temperature of the outgoing heat transfer fluid, is placed after the pump (Pd) keeping the fluid at a constant temperature in combination with a 3 way valve.

There are 4 different modes of operation :

- charge mode
- charge and chiller operation mode
- discharge and chiller operation mode
- discharge mode only.

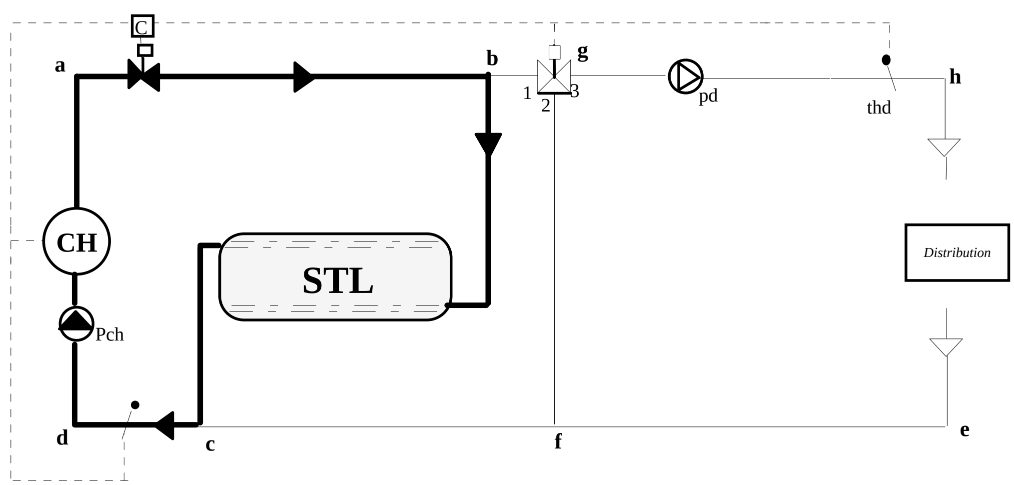
4.2 : DESCRIPTION OF THE DIFFERENT MODES OF OPERATION

Charge mode :

In this situation no cooling is required (e.g. A/C office building during night hours).

The pump (Pd) is shut down and the 3 way valve closes port 1 leading to the distribution system (see lay-out below).

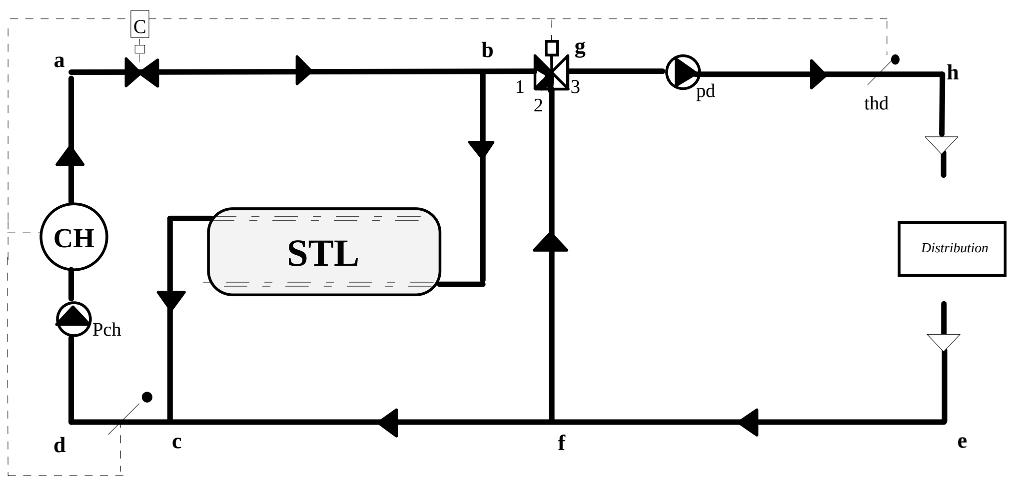
The chiller cools the primary loop (abcd) to below the crystallisation temperature of the nodules, which then start to change phase, absorbing the cooling energy from the chiller. Inside the nodules the crystallisation begins peripherally around the walls. The thickness of the crystals influences the energy transfer so that the exchange coefficient gradually decreases during this mode, proportionally diminishing the heat absorbing capacity of the nodules. The temperature of the heat transfer fluid from the chiller will decrease until it reaches the minimum temperature corresponding to the end of the charge (storage) period. Further sensible cooling of the solid PCM takes place causing the temperature of the heat transfer fluid to decrease rapidly. This temperature decrease indicates the end of the charge phase and the control thermostat shuts down the chiller.



<u>Store charge with distribution load</u> :

This occurs when the cooling demand is smaller than the chiller output (e.g. A/C of an office building in the morning) .

The pump (Pd) runs and the 3 way valve modulates in accordance with the requirements of the temperature probe (thd) controlling the temperature of the distribution system flow (efgh). The fluid circulated by the charge pump (Pch) is led partly through port 1 of the 3 way valve, partly through the store STL in the direction b to c thus charging the store (see lay-out below).



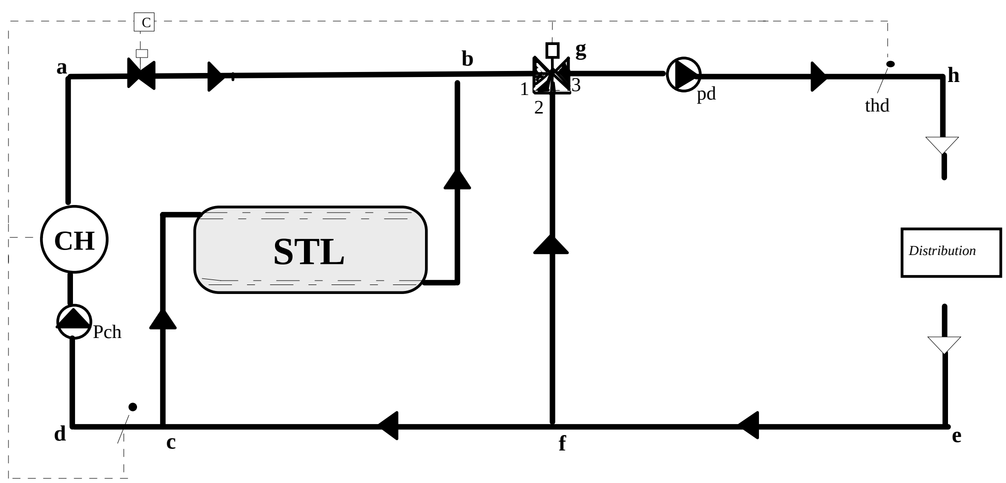
Store discharge with distribution load :

This situation occurs when the cooling requirement is higher than the chiller output (e.g. during maximum demand of A/C for an office building).

The pump (Pd) and (Pch) are operating and the 3-way valve modulates as described before (see lay-out below).

The energy required by the temperature probe (Thd) cannot be met by the fluid circulated through the 3 way valve. The flow circulated by pump (Pd) in direction (fc) is separated two ways :

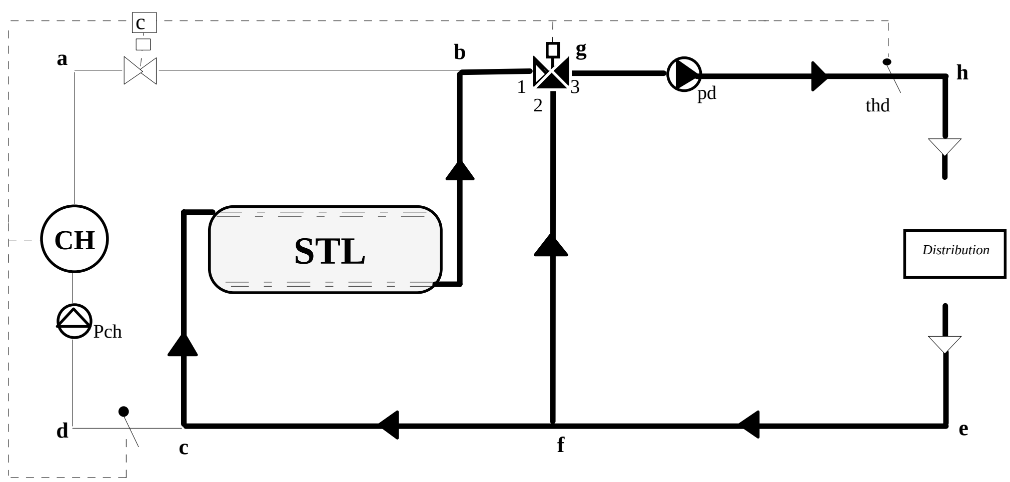
- constant flow (fdag) cooled by the chiller through the pump (Pch).
- variable flow through the STL (fcbg).



<u>Discharge mode only</u> :

This situation occurs when the user wishes to shut down the chiller and use the STL only during peak demand.

In this mode, the chiller is controlled by a "stop" system (electric utilities) in response to which the charge pump (Pch) and the chiller are shut down during peak hours. A shut off valve, placed after the evaporator, closes automatically when the pump (Pch) is shut down, so that the heat transfer fluid flows through the STL store alone.



4.3 : BACK-UP SYSTEM

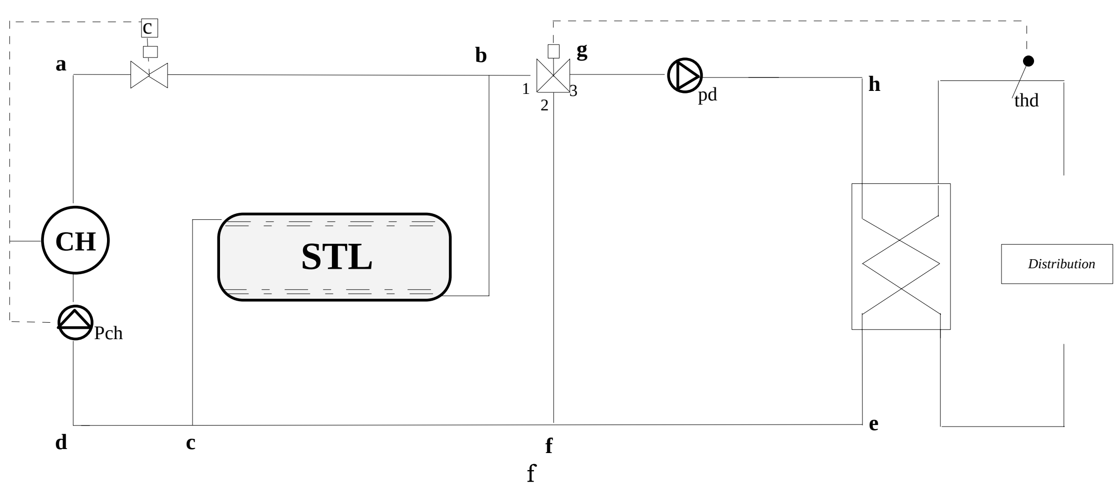
There are a number of parameters that need to be considered when designing a back-up system. To ensure reliability the following are essential :

- the quality of the material used
- back-up plant for cooling energy
- the available electrical supply required to generate the back-up cooling.

The STL store/exchanger has the double advantage of being a technology completely different to that of the other components in the system as well as being static (no moving part).

The STL size will be by the magnitude and duration of the standby requirement (i.e. the time required to shift the installation to another system).

- If the chiller group is sized for a constant load (i.e. 24 h/24 h), and independent system, is recommended with the selection of a chiller and store according to the lay-out below. The primary circuit is connected to the distribution system through a heat exchanger (see lay-out below).



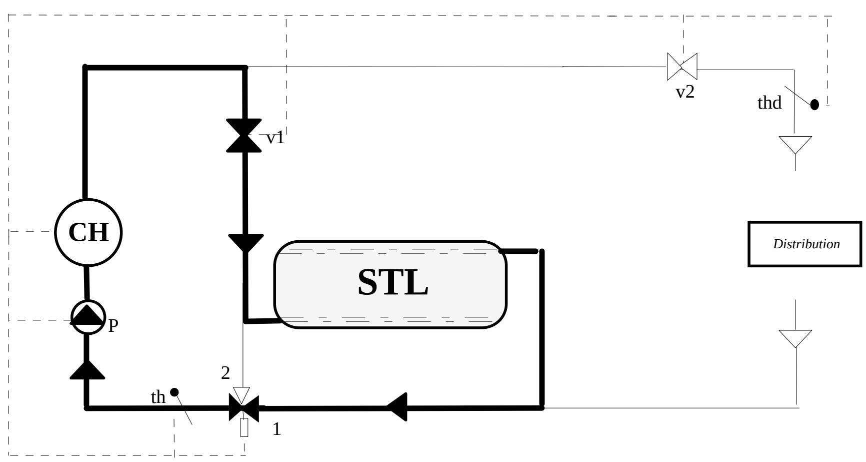
4.4 : SERIES LAY-OUT

The storage system may be used in parallel or in series with the chiller.

The decision whether to use parallel or series configuration depends primarily on the temperature difference across the distribution circuit. With a temperature difference of 5°C or 6°C (i.e. 5°C/10°C or 6°C/12°C) it is possible to use the STL in parallel so that the evaporator and STL operate on the same temperatures. If temperature differences of 8°C to 12°C or more are permitted (i.e. as in low temperature distribution systems) the STL and evaporator can be configured in series. In this case the STL and the evaporator each produce a proportion of the temperature differential. This permits the evaporator to work at a reasonable temperature differential. For example with a distribution circuit temperature difference of 4°C/12°C the STL and the evaporator will each produce 4°C of cooling and satisfy 50 % of the maximum load demand. With the series configuration there are two possibilities : STL downstream or STL upstream.

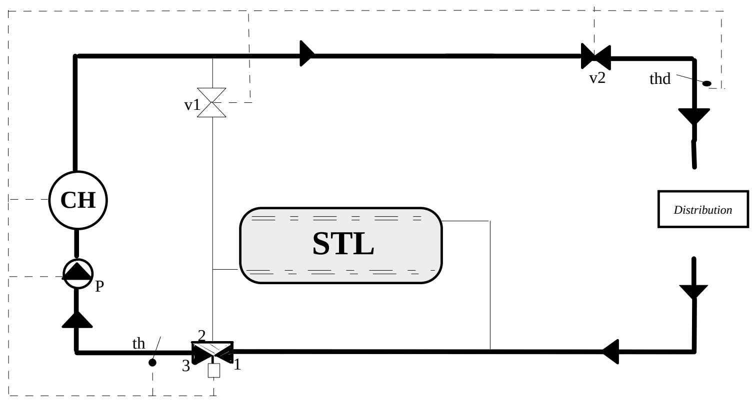
The lay-out below shows the operation of the STL in series with the chiller. The chiller has priority over STL in maintaining the base load while STL the peak-loops

CHARGE PHASE :

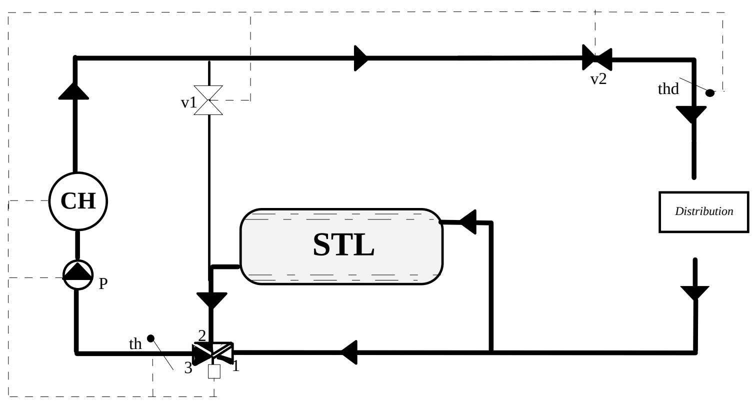


At the start of the charge period valve (V1) opens, (V2) closes and the 3-way valve modulates to full by-pass. As the charge progresses the outlet temperature of the chiller approaches its charge mode set point (say, -6°C). After a period of time the return temperature to the chiller starts to approach this temperature also. The chiller will unload indicating that the store is charged.

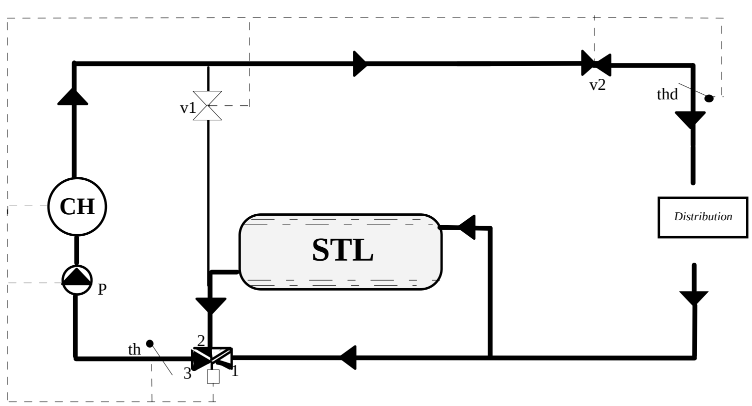
DISCHARGE PHASE :



At the beginning of the load period valve (V2) opens, (V1) closes and 3-way valve starts to modulate . The chiller has priority in satisfying the load demand and is controlled by temperature probe (thd) . If the load demand is smaller than the chiller capacity the STL is by-passed .



When the load demand is greater than the chiller capacity, thermostat (th) measures a temperature greater than 8°C (for instance) and starts to modulate the 3-way valve, causing flow through the store, to achieve its set point.



ABBREVIATIONS USED

dtlm 1 : log. mean temperature difference during storage (°C)
dtlm 2 : log. mean temperature difference during destorage (°C)

DSTL : heat density of storage

kvfu : the heat transfer coefficient during fusion (kW/°C/ m^3)
kvcr : the heat transfer coefficient during crystallisation (kW/°C/ m^3)

P : load demand (kW)
Pc : load charge (kW)
Pdst : storage discharge rate (kW)
Pm : maximum instantaneous demand (kW)
Pmin : minimum instantaneous demand (kW)
Pr : chiller capacity (kW)
Pr1 or Pr 2 : minimum chiller capacity (kW)
Pst : storage charge rate (kW)

Qj : daily consumption (kWh)

Ql : latent heat of the nodules (kWh/ m^3)
Qsl : sensitive heat of the nodules at liquid stage (kWh/ m^3/°C)
Qss : sensitive heat of the nodules at solid stage (kW/ m^3/°C)

Qst : maximum energy to be stored (kWh)
Qdst : energy to be destored (kWh)

T1 : charge output temperature (°C)
T2 : charge input temperature (°C)
T3 : discharge output temperature (°C)
T4 : discharge input temperature (°C)
Td : heat transfer fluid temperature at departure (°C)
Tm : average temperature of the STL at the end of the charge (°C)
Tst : phase change temperature of the nodules (°C)

tpd : functioning time during direct production (h)
tst : functioning time of the chiller during the storage (h)

V : storage volume (m^3)

5. STL SIZING

The following information is required when sizing a STL :

- the distribution system temperature differential,
- whether water/glycol can be used or a heat exchanger is required,
- design day cooling profile,
- type of chiller compressor (screw, reciprocating, centrifugal, ...).

5.1 : HISTOGRAM

Two parameters for the load curve :

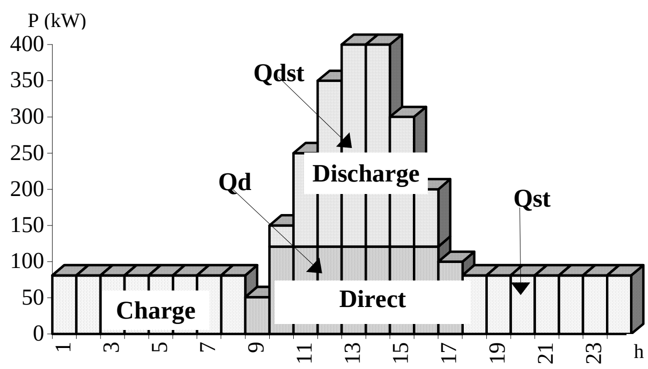
- peak instantaneous cooling demand Pm (kW)
- design day cooling requirement Qj (kWh)

The peak load Pm normally defines the size of an installation and is matched by installed chiller capacity if storage is not incorporated.

Qj is the maximum daily cooling requirement predicated for the peak design conditions.

The following illustrates a method for sizing a storage installation using the example of an air conditioning system.

- temperature range 7°C/12°C
- plate heat exchanger
- 5°C/10°C at the primary loop before the exchanger
- histogram
- reciprocating chiller.



Qd (kWh) : The installed refrigeration capacity (direct production).

Qst (kWh) : Energy to be stored

Qdst (kWh) : Energy to be discharged

$$Qj = Qd + Qdst$$

5.2 : NODULES SELECTION

The selection of nodules depends on the phase change temperature (Tst) and the operating conditions :

$$\mathbf{Tst < Td - 4\ °C}$$

Having selected the type of nodule it is still possible to select a lower phase change temperature in order to increase the rate of heat exchange.

In some cases this difference of 4°C between the phase change temperature and the leaving temperature of the heat transfer fluid can be reduced depending of the specific conditions of the installation.

When a phase change temperature of 0°C is selected, AC.00 nodules can be used to reduce system costs. However, if the maximum instantaneous demand is high, IC.00 nodules should be selected for output performance (i.e. : back-up cooling).

Example, for chilled water/glycol production at 5/10°C we choose the AC.00 nodules (Tst < 5-4).

5.3 : CHILLER CAPACITY

The curve gives the maximum daily consumption (kWh)

$$Qj = \sum_{i=1}^{24} P(i) = 2\ 200\ kWh$$

When sizing the chiller it is important to remember that the chiller capacity depends on evaporating temperature ; during the charge mode chiller capacity will be lower than during the direct production period.

The daily consumption has been spread over 24 hours and the minimum chiller capacity required is :

$$Qj / 24 = Pmin \text{ in } kW$$

i.e. 2 200/24 = 92 kW

We now calculate the period of operation of the chiller during direct production and with an output of 92 kW.
The chiller is working at 100 % between 9 h and 17 h (8 hours). Between 8 h and 9 h there are two possibilities :

Storage and direct production

or

Only direct production

In this example the second solution is chosen .
Between 8 and 9 h the chiller works partially to obtain an average capacity of 50 kW
(time of functioning = 50/92 = 0.54 h). The total time of operation of the chiller in direct production will be to 8.5 hours (tpd).
The chiller works in storage mode between 17 h and 8 h (tst = 15 hours).

$$\mathbf{Pr_1} = \frac{\mathbf{Qj}}{\mathbf{tst \times f + tpd}}$$

f is the coefficient of the capacity reduction of by the chiller between the direct production phase and the charge phase.
As a first approach we consider a reduction of 3% per °C temperature variation of evaporating temperature (T3-T2).

$$\mathbf{f = 1 - [0.03 \times (T3 - T2)]}$$

In this example, the temperature of the water/glycol water leaving the evaporator is 5 °C in direct production and -6°C in charge mode corresponding to a reduction of the evaporating temperature of 11°C.

Then : f = (1 - 0.03) x 11 = 0.67

$$\mathbf{Pr2} = \frac{\mathbf{2200}}{\mathbf{15 \times 0.67 + 8.2}} = \mathbf{121\ kW}$$

Direct production time :

$$\mathbf{tpd} = \mathbf{7} + \frac{\mathbf{50}}{\mathbf{121}} + \frac{\mathbf{100}}{\mathbf{121}} = \mathbf{8.2}$$

Obtaining the same operating time of the chiller in direct production as below we calculate the chiller capacity. The reduction coefficient of the chiller capacity in the storage phase will be :

Pc = f x Pr = 0.67 x 121 = 81 kW

We verify that the energy stored and discharged are equivalent :

Qst = 81 x 15 = 1 125 kWh

Qdst = (150-121)+(250+121)+(350-121)+2x(400-121)+(300-121)+(200-121)= 1 203 kWh

We have : Qst = Qdst

5.4 : STORE VOLUME

We calculate the storage density DSTL (stored energy per m^3 of STL)

$$DSTL = Ql + [Qsl \times (T3 - Tst)] + [Qdd \times (Tm - Tst)]$$

The temperature range in the discharge phase is 5/10°C so T3 = 5°C.
This range corresponds to a Δt input / output across the evaporator of 5°C. The reduction in capacity between storage and discharge modes is 0.67. The flow through the evaporator is the same during both phases. This reduction in capacity is matched by a reduction in temperature difference since the flow rate remains constant. The difference in the charge phase is therefore : 0.67 x 5 = 3.4°C. The temperature rate during this phase is : -6°C/-2.6°C.

$$Tm = \frac{(-6) - (-2.6)}{2} = -4.3$$

$$DSTL = 48.4 + (1.1 \times 5) + (0.7 \times 4.3) = 56.9 \text{ kWh/ m}^3$$

The energy stored is 1 215 kWh, the minimum volume will be :

$$V = \frac{Qst}{DSTL} \qquad V = \frac{1\,215}{56.9} = 21.4 \text{ m}^3$$

5.5 : HEAT EXCHANGE CAPACITIES

- Storage charge rate :

$$Pst = V \times kvcr \times lmtd1$$

$$lmtd1 = \frac{(T2 - Tst) - (T1 - Tst)}{\ln \dfrac{(T2 - Tst)}{(T1 - Tst)}}$$

$$Pst = 21.4 \times 1.15 \times \frac{(-6 - 0) - (-2.6 - 0)}{\ln \dfrac{(-6 - 0)}{(-2.6 - 0)}} = 100kW$$

It is necessary that : Pst >Pc (during the whole charge phase) in this case PC = 81 kW, so the system is correctly sized.

- Storage discharge rate :

$$Pdst = V \times kvfu \times lmtd2$$

$$lmtd2 = \frac{(T4 - Tst) - (T3 - Tst)}{\ln \dfrac{(T4 - Tst)}{(T3 - Tst)}}$$

$$Pdst = 21.4 \times 1.85 \times \frac{(10 - 0) - (5 - 0)}{\ln \dfrac{(10 - 0)}{(5 - 0)}} = 286 \text{ kW}$$

It is also necessary that during the whole discharge phase, the STL plus the chiller output are greater than the demand ; for example, during the period of maximum instantaneous demand.

P = 400 kW Pr = 121 kW Pdst = 286 kW

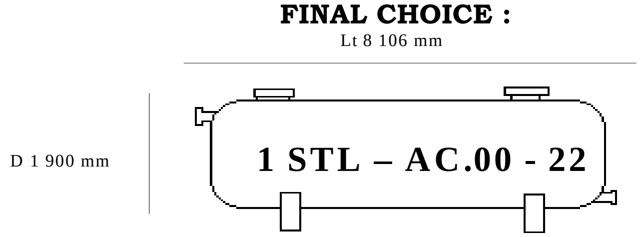
Pdst = Pr = 407 kW

Pdst + PR > P

The installation is compatible .

CHOICE OF STL : **1 STL – AC.00 - 22**

FINAL CHOICE :



5.6 : OPTIMIZATION

Then, it is necessary to choose the couple (Pr, V) according to economical data in order to obtain an optimum.

6 . CRISTOPIA TOOLS

6.1 : TEST FACILITY

CRISTOPIA *Energy Systems* has developed a test facility similar to a small installation. It includes all the equipment of a real installation as the STL, the chiller, the control, the expansion tank, …

This test facility is an unique and essential tool for a Thermal Energy Storage systems manufacturer. It has allowed us to fully test the STL, but also the operation of the full system.

The test facility can be used to simulate the operation of an installation with a STL.

This simulation can help the mechanical engineer in charge of the design :

- to check the hydraulic lay-out and the control system,
- to fully validate the sizing of the installation,
- to obtain a total guarantee of success.

6.2 : STOCKAID 2000

In addition to this test facility, a software has been developed for the sizing of the STL. This software (Stockaid 2000) was validated with the test facility.

Stockaid 2000 allows us to determine all the STL characteristics and to develop a study file.

- <u>Unknown histogram</u> :

When the histogram is unknown Stockaid 2000 allows a first approach from the following data :

- maximum demand,
- type of histogram,
- running hours during the day,
- distribution and return temperatures.

Stockaid 2000 calculates the STL volume, cooling capacities and nodule type.

- Known histogram :

Stockaid 2000 determines all parameters from the histogram, the operating temperatures (with or without heat exchanger) and the chiller operation hours.

After a first calculation, it is possible to modify several parameters in order to optimise the selection.

Stockaid 2000 gives also data like energy available in the STL, the chiller capacity, etc.

Stockaid 2000 liberates the engineer of the tricky and repetitive calculations, enabling the time saved to be used to optimise the selection.

7 . STL SETTING

7.1 : THE STL

The STL consists of :

- a tank,
- nodules.

First we describe the STL components, and then the installation procedure.

a) **The tank** :

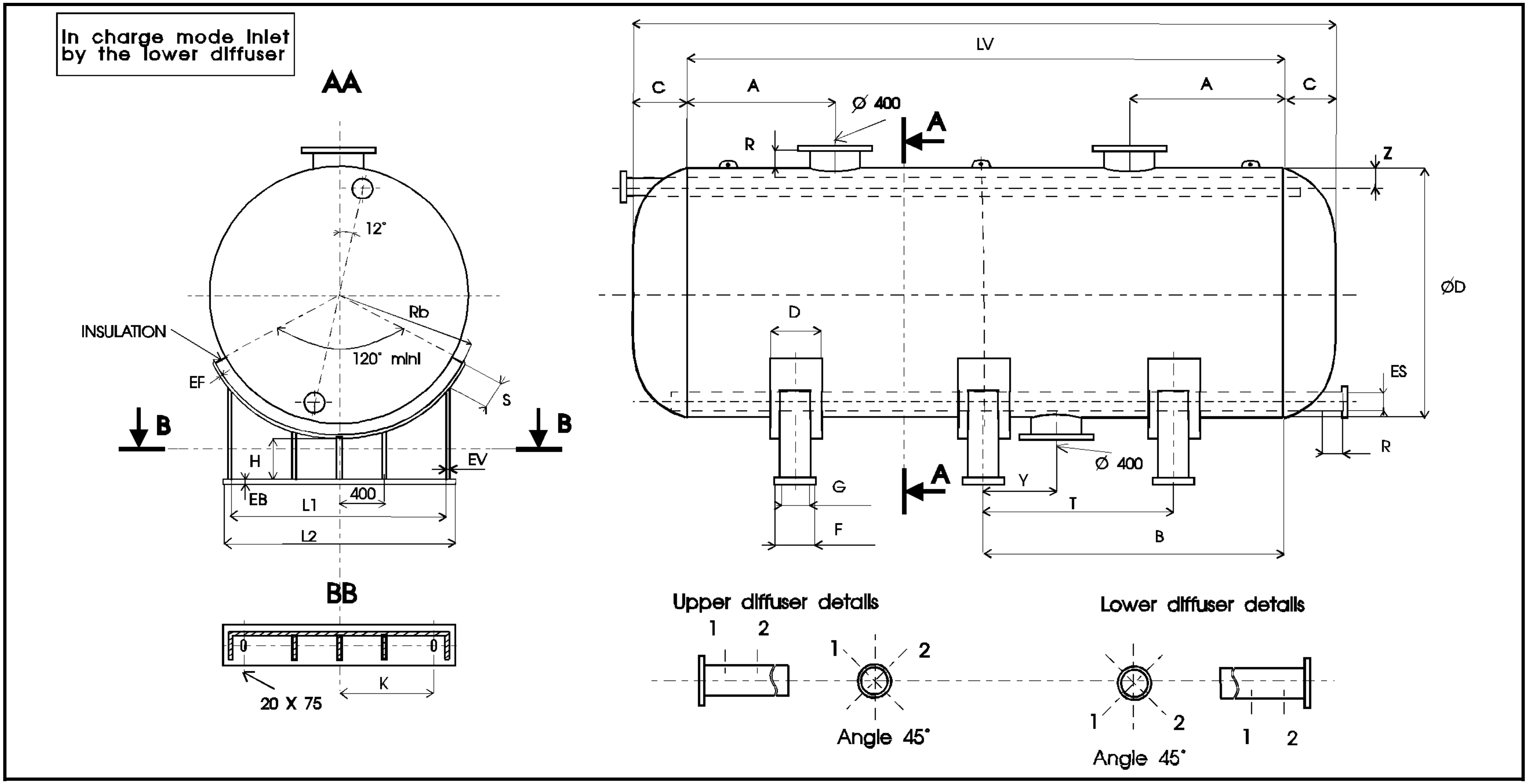
The horizontal cylindrical tank is made of black steel. As standard, the test pressure is 4.5 bars.
Two upper manholes allow the tank to be filled with nodules. Two connections are fitted on the manhole covers for filling air bleed valves and manometers.
The dimensions of the standard tanks are give in the table below.

The tank can be also vertical with a skirt (see drawing VA).

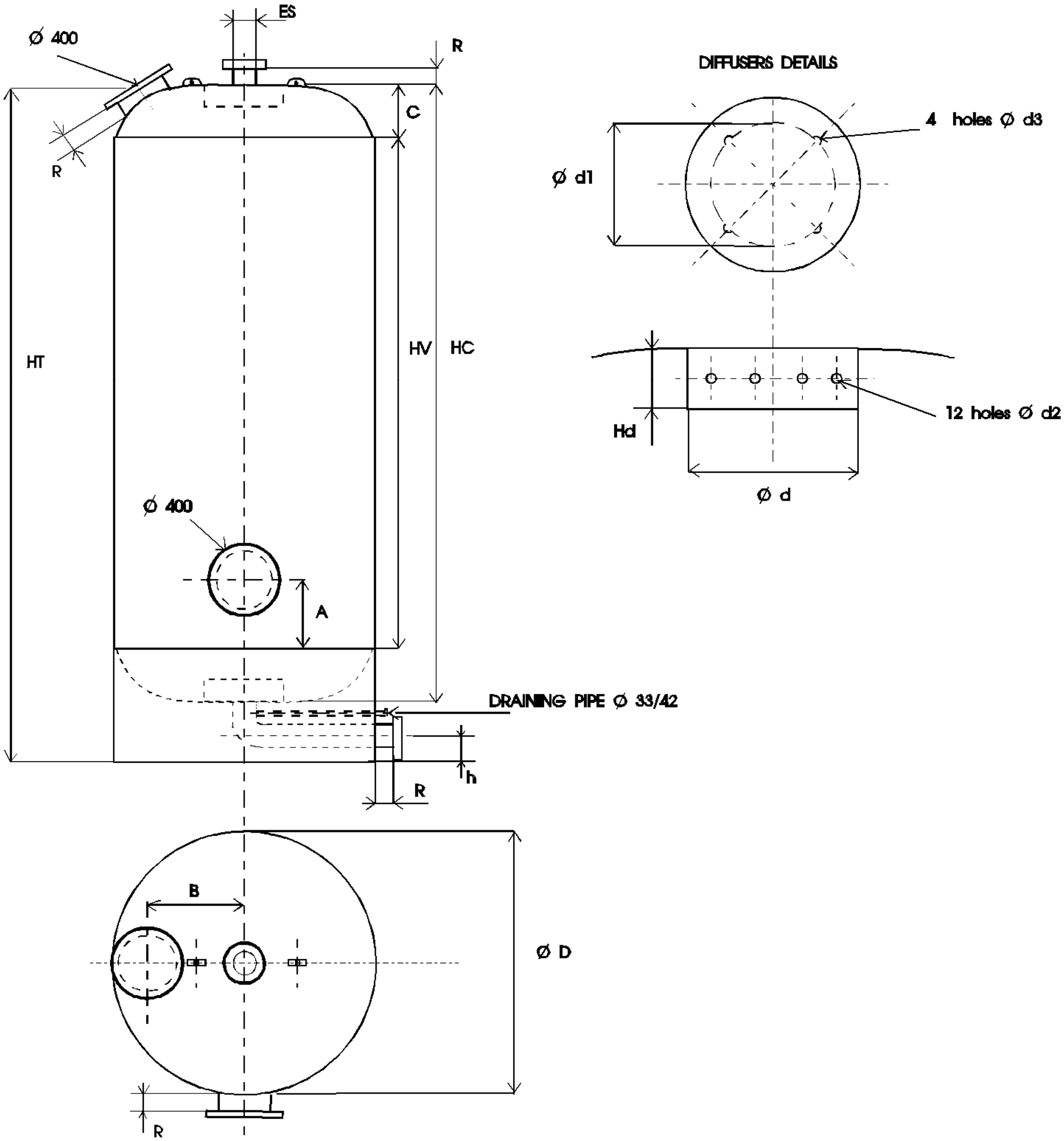
For systems working at atmospheric pressure is possible to use rectangular tanks (in steel or concrete).

According to the space available we can modify the diameter and length to fit the tank to the site. The tank is manufactured according to plant requirements.

Volume m^3	**2**	**5**	**10**	**15**	**20**	**30**	**50**	**70**	**100**
Diameters	950	1250	1600	1900	1900	2200	2500	3000	3000
LV	2530	3710	4530	4780	6570	7345	9590	9175	13520
LT	2980	4280	5240	5610	7400	8285	10640	10425	14770
C	225	285	355	415	415	470	525	625	625
A	520	785	955	987	1435	1600	2135	1981	3068
B	1265	1855	2265	2390	3285	3673	4795	4588	6760
ES	DN 40	DN 50	DN 80	DN 100	DN 125	DN 150	DN 175	DN 200	DN 250
F	200	200	200	250	250	250	300	300	300
H	350	350	350	350	350	350	350	350	350
K	300	450	600	700	700	850	900	1200	1200
No. cradles	2	2	2	2	3	3	4	4	6
T	1000	1500	1500	1500	3000	3000	xx	xx	xx
L2	850	1150	1400	1650	1650	1950	2200	2650	2650
Y	xx	xx	xx	xx	1000	1000	xx	xx	xx
Surface m^2	10	18	29	37	47	61	89	106	147



In charge mode inlet by the lower diffuser
AA
12°
Rb
INSULATION
120° mini
EF
S
B
B
H
EV
EB
400
L1
L2
BB
K
20 X 75
LV
C
A
A
C
Ø 400
A
R
Z
ØD
D
ES
R
Ø 400
G
Y
A
T
F
B
Upper diffuser details
1
2
1
2
Angle 45°
Lower diffuser details
1
2
1
2
Angle 45°



Dimensions in mm

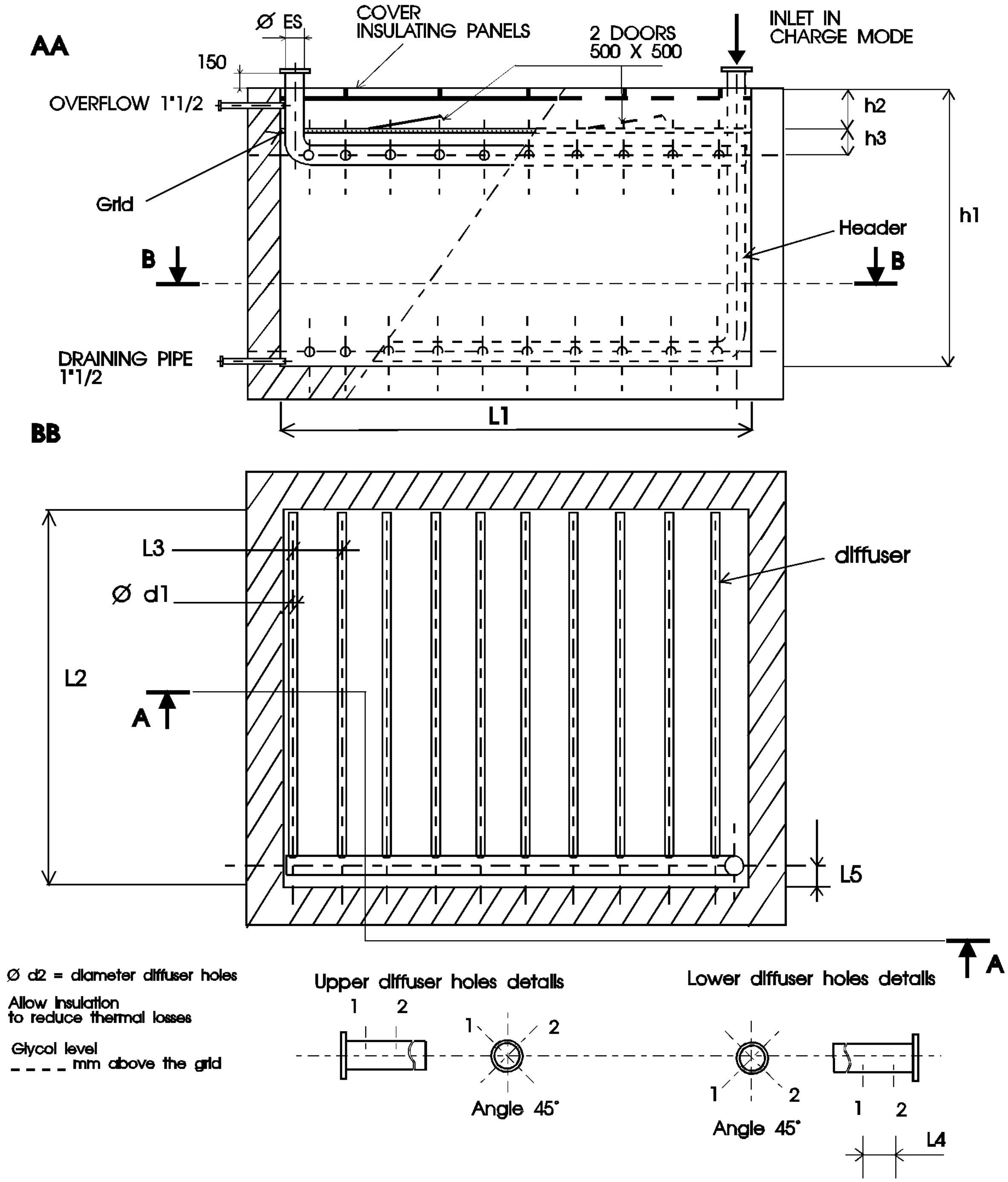
Φ D		B		Hd	
HV		C		Φ d	
HC		R		Φ d1	
HT		h		Φ d2	
A		ES		Φ d3	

IN CHARGE MODE INLET BY THE LOWER DIFFUSER

Service pressure	
Test pressure	
Service weight	
Empty weight	

Pressure drop		Flow		Volume	

Drawn : Date :	Index :	**CRISTOPIA** ***ENERGY SYSTEMS***
PROJECT : **CUSTOMER :**		NB : VE/ STL - -



L1		Nb diffusers		h1	
L2		Nb holes dif.		h2	
L3		ES		h3	
L4		d1			
L5		d2			

Pressure drop		Flow		Volume	

Drawn : Date :	Index :	**CRISTOPIA** ***ENERGY SYSTEMS***	
PROJECT :			
CUSTOMER :		NB : COE/	STL - -

b) **The nodules** :

Nodule type	Phase change temperature °C	Nodule weight kg	Toxicity Value LD50 in mg/kg **a**
SN.33	- 33	706	2.600
SN.29	- 28,9	677	1.200
SN.26	- 26,2	712	1.200
SN.21	- 21,3	558	1.300
SN.18	- 18,3	705	2.700
IN.15	- 15,4	604	8.400
IN.12	- 11,7	630	5.000
IN.10	- 10,4	625	11.000
IN.06	- 5,5	632	18.000
IN.03	- 2,6	603	58.000
IC.00	0	566	85.000
AC.00	0	559	85.000
IC.27	+ 27	881	2.500

a : LD50 (median lethal dose), oral, is a statistically derived single dose of a substance that can be expected to cause death in 50 % of animals when administered by the oral route. The LD50 value is expressed in terms of weight of test substance per unit weight of test animal (mg/kg).

7.2 : STL INSTALLATION

Nodules and tanks are delivered separately. The installation consists of two steps :

- **tank positioning,**
- **nodules filling.**

PRE-DELIVERY RECOMMENDATIONS

STL tanks :

Check before delivery that the access to site is adequate (clearance, road, working area, etc...).

The tanks are delivered on <u>trucks without unloading facilities</u>, lifting equipment must be on site on the delivery day (tanks are provided with lifting rings fitted).

If it is a horizontal tank on cradles it is necessary to insulate also the tank section corresponding to the cradle positions. If the cradles are welded it is necessary to insulate the surface between the nodules and the basement and also to insulate the cradles. This insulation work and tank positioning should be done on the same day.

Nodules :

The nodules must be delivered as soon as possible after the tank delivery. First check that the tank is ready for filling.

Nodules are delivered in plastic bags of appr. 22 kg (AC.00 nodules) on trucks without unloading facilities.

In order to save time and money, it is better to fill the tank just after unloading the truck. In this case, allow approximately 1 man hour/m^3 (except difficult access).

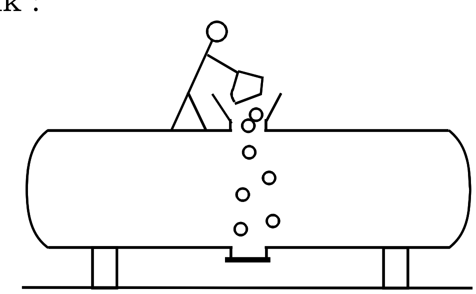
If this is not possible the nodules must be stored, sheltered from day-light. Although the nodules have been designed to support high strains, the storage height must be lower than 4 m.

For quick loading and optimum safety, the top manholes must be easily accessed.

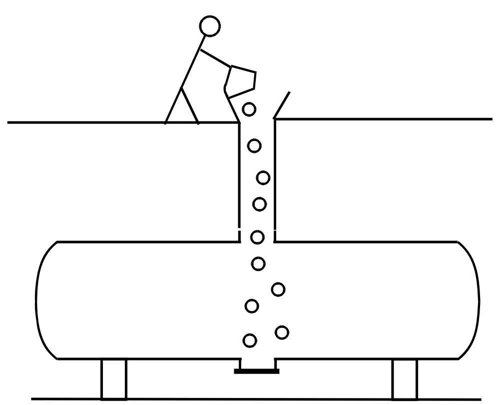
If necessary, allow scaffolding, access ramp, or similar system, so facilitate this man-handling operation.

The following represents the most common scenario :

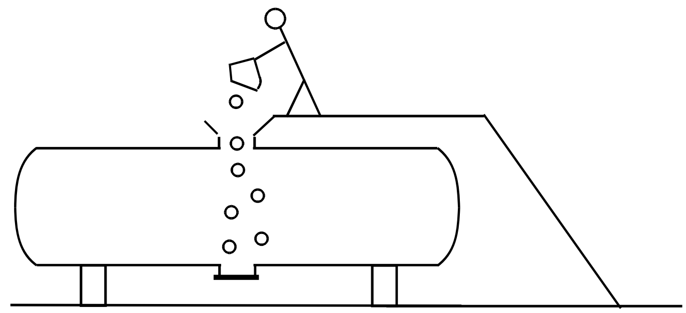
- small tank :



- underground or buried tank :



- scaffolding :



In all cases it is essential that the installing company respects the relevant health and safety regulation laws.

Tanks sitting

Check the tanks on receipt and if the tank is damaged, make an official declaration immediately.

Tanks must be handled with care and site at level.

You must leave a minimum space above the manhole around 0.60 m (and 0.25 m below the lower manhole). If the available plant room height is severely restricted, the manholes (top and bottom) can be moved to 30° from the vertical. This will allow the maximum diameter tank to be used.

Hydraulic piping and inlet/outlet flanges must be correctly connected:

- Heat transfer fluid inlet is via the lower diffuser during the charge phase.

Loading the tanks with nodules

After opening the upper manholes, check the following points inside the tank :

- presence and quality of gaskets,
- presence of diffusers,
- presence of the lower manhole grid,
- tank cleanliness.

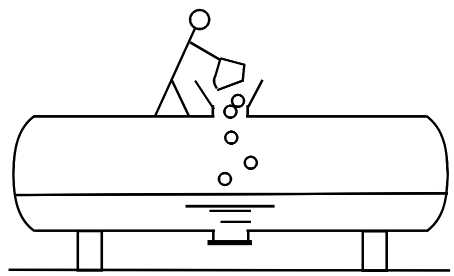
Nodules are delivered in plastic bags, sealed with a wire. It is necessary to have pliers or cutters in order to open the bags easily.

Tanks must be correctly filled with nodules. It is essential to spread the nodules in the tank. The procedure of filling must be followed correctly :

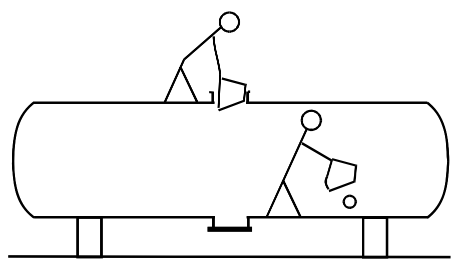
Beginning of loading

Fill the tank up to one third of the height with water to absorb the nodules' fall and to obtain a natural spread of the nodules.

The bags are opened and emptied through the upper manhole.

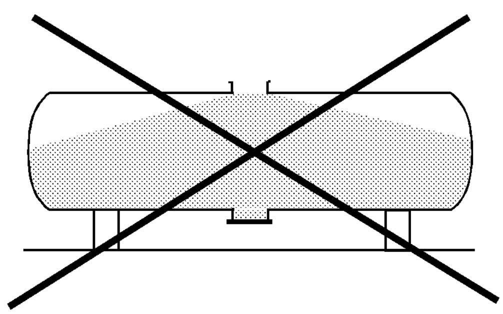


If water is not available on building site, proceed as shown next drawing :

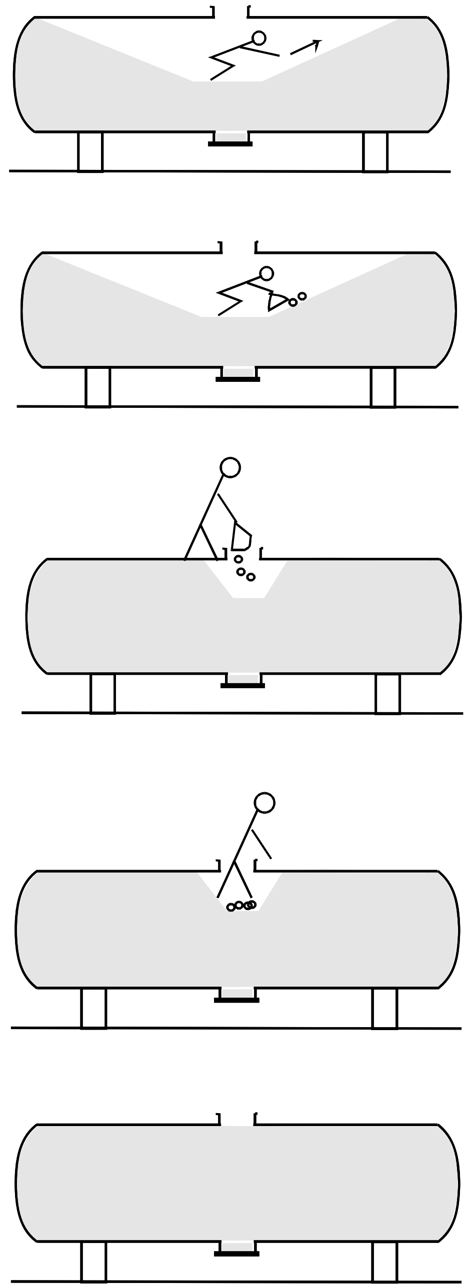


End of filling

It is essential to avoid incorrectly filling the tank as shown in the next drawing :



Proceed as shown :



In most cases (horizontal tanks) and when the tank is half full, one or two persons must enter the tank to ensure the spread of nodules. This spread is carried out up to the end of the filling process. Nodules must always be pushed to the ends of the tank.

8 . COMMISSIONING

8.1 : BEFORE COMMISSIONING

- ***Pipe leak tests and cleaning***

It is essential to check for leaks before the tanks are insulated and the system is commissioned.

Tanks are tested under pressure in the factory, however after delivery, it is necessary to check the gaskets are still watertight

The installation must be tested under pressure after all air is bled from the system.

The pipework must be correctly cleaned before filling the system, especially when significant rust deposits exist.

In all cases, do not use heat transfer fluid for leak testing (in case of leak you will have to empty the system).

It is possible to clean the pipe work and test for leaks at the same time. The plant with anti-freeze solution must respect the sanitary rules and must include a system to avoid leakage into drinking water (contact the local authorities to gain information).

Installations using a mixture of monoethylene and water, the following steps are recommended :

- after allowing the water circulate through the system for 1 to 2 hours, drain it as quickly as possible at the lowest point,
- prepare a mixture of 10 g water/litre of hexametophosphate of sodium,
- put this mixture in the installation,
- let the system run for a minimum of 2 hours,
- rinse the pipes with water,
- a second cleaning may be necessary ; after each one, drain and rinse the pipes with care.

- ***Hydraulic and electrical components checks***

After the leak test is complete, and before the water is drained, it is possible to check the correct operation of the regulation system and electrical devices.

Check :

- connections between STL and piping (see chapter 1.2),
- hydraulic layout,
- presence of safety devices (safety valve, expansion tank, ...).

In the case of using a pressurised expansion tank, you will have to check the nitrogen pressure and adjust it if necessary. This pressure corresponds to the minimum pressure in the system.

When adjusting the nitrogen pressure, you must be sure that the water side is empty.

- ***Heat transfer fluid filling (for glycol + water)***

Prepare the mixture of water plus glycol before filling. The quantity of heat transfer fluid required is approximately 388 litres per cubic meter of STL tank.

It is important to mix the fluids to a homogenous consistency (leave the pumps running for 24 hours). The chiller should be off and you should check that the flow goes through the STL tank.

During filling, bleed off air from the piping and the tank continuously efficiently.

For bleeding, air bleed valves should be sited at the highest points of the piping network and on the top of the tank.

This operation is very important, since air in the network will reduce the store performance and will prevent effective system operation.

Check the glycol concentration at different points of the network.

<u>Filling procedure</u> :

- preparation of the heat transfer fluid,
- filling of the heat transfer fluid up to the minimum level[1]
- switch on the pump (chiller off), bleeding of the installation,
- maintain during 24 hours the level (or the pressure) constant while keeping the pump on to fully bleed the installation,
- check the glycol concentration.

Next, heat transfer fluid must be added to the system during the first charge cycle to ensure that the minimum level is maintained.

[1] A safety factor should be taken. For example for a pressurised expansion tank a minimum pressure of 1.6 bar in the installation should be used for a pressure of 1.5 bar in the expansion tank.

This stage must be carried out carefully especially during the first 3 to 4 hours of the charge phase.

This time is necessary for lowering the temperature of heat transfer fluid to its minimum temperature, thus to a minimum volume.

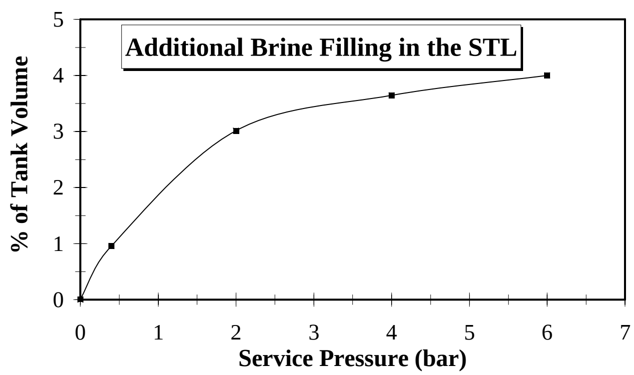
Next, check that the system pressure does not exceed the design maximum operating pressure (check the relief valve setting).

We remind you once again that a system running with anti-freeze mixture must comply with local sanitary laws and be equipped with a suitable drainage system to avoiding drinking water pollution (check local laws).

Case of STL – AC, STL – IN and STL – IC : additional filling after putting the pressure to its service value.

After putting the pressure in the STL, heat transfer fluid must be added to compensate the variation of volume due to the service pressure.

This additional brine filling is generally done one week after putting the service pressure to its normal value. The quantity of heat transfer fluid needed is lower than 4 % of the STL volume. It depends on the service pressure (see curves below).



Note : Respect the rules of art and the Health & Safety Regulations especially for the safety equipment (air bleed valves, etc.) and also for the position of the service valves.

8.2 : COMMISSIONING

- **Chiller commissioning**

Start up chillers in accordance with the manufacturer's instructions. Ensuring that thermostats are correctly set for the direct production and charge phases.

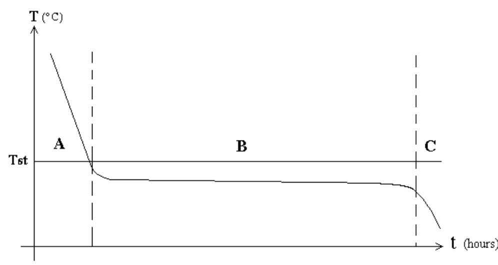
Check the cooling capacities in storage and discharge modes.

- **Validation of STL operation**

    - STL charge

The validation of storage capacity is achieved by recording the evolution of the storage inlet and outlet temperatures.

These temperatures must evolve as shown in the curve below :



Tst : nodule phase change temperature (°C).

Notice : *This curve represents a total storage of STL with no energy stored at the beginning.*

* Area A corresponds to removal of sensible heat (liquid phase) from the heat transfer fluid and nodules at the storage temperature - leaving temperature to the network.

* Area B corresponds to the phase change of the eutectic inside the nodules. This phase change occurs at constant temperature. The STL works as a heat exchanger and we can observe a constant heat transfer fluid temperature.

* Area C corresponds to the removal of sensible heat (solid phase). The chiller thermostat will be set to operate just after this rapid decrease in temperature.

It must be avoided that the chiller reduces its capacity before the end of the STL charge otherwise the STL is not fully charged.

We recommend that the chiller set point temperature is set 2°C below the charge temperature : for example for a typical charge temperature range of –5°C/-2°C, the set point should be –4°C if the temperature sensor is located on the chiller return.

The chiller is switch off during the storage of the solid sensible heat after the latent plateau.

At the end of the charge phase check that there is no condensation on tank and pipe insulation. Check that the heat transfer fluid level never exceeds the maximum design value.

- STL discharge

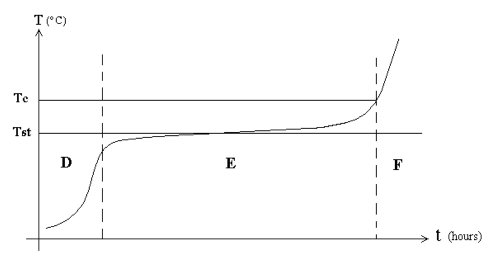
A discharge test can then be performed.

Procedure :

- chiller and charge pumps off,
- by-pass chiller,
- discharge pump and 3 way valve regulation on.

Notice : *Let the 3 way valve operate under normal control alone in order to avoid very cold heat transfer fluid entering the network.*

With this test check that the stored energy is released properly. The temperatures (inlet/outlet) must evolve as shown in the following drawing :



Tc : leaving temperature set point (3 way valve set point)

* Area D corresponds to the release of sensible heat from the solid (eutectic sensible heat (solid) and the heat transfer fluid sensible heat).

* Area E corresponds to the eutectic phase change solid/liquid in the nodules. This fusion is occurs at constant temperature.

Notice : *The step will be longer or shorter depending on the cooling capacity required of the STL.*

* Area F corresponds to the liquid sensible heat (eutectic and heat transfer fluid). The end of discharge will be reached when the STL leaving temperature is equal to the network leaving temperature.

Once these 2 tests are completed, the system can be left running automatically.

- **Plant commissioning**

Switch the whole installation to automatic mode so it will start up in accordance with its program.

Check after a complete charge and discharge cycle :

- pump flow rates relative to the pressure drop (inlet/outlet) with manufacturer's curves,
- regulation system according to the different steps,
- chiller operation and condenser circuit.

Check that the specified values are respected (chilled water leaving temperature).

A second check should be carried out during or after the system is commissioned. For this, follow the procedure in section 8.1.

8.3 : STL PERFORMANCES CHECKS

A check of storage performance characteristics can be done after the commissioning. This check allows us to measure exactly the STL exchange capacities, and the quantities of energy charged and discharged.

- **Procedure using the performance control sheet**

General data :

- charge and discharge cycle,
- date and time of cycle beginning (important to calculate the energy stored and destored),
- type of STL storage,
- trade mark and chiller type,
- number of capacity reduction steps and the corresponding capacities,
- name and location of the plant,
- name of the engineer (and his company name) who operate the plant,
- heat transfer fluid type and concentration.

You must indicate for each record the date and the time. Try to ensure a regular time step (we recommend to record every 15 minutes, 20 maximum).

Two measures, one on the STL, one on the chiller, will be required in order to validate the results during a charge cycle.

During the discharge cycle the measure of the energy flows allows us to check the total energy and thus the plant demand.

Similarly, with evaporating temperatures, condensing temperatures and the chiller manufacturer’s curves, you can estimate the chiller capacity.

STL PERFORMANCE CONTROL SHEET

Running cycle : STORAGE

DESTORAGE

Cycle beginning : ___/___/ 19___ at ___h ___mn

STL type : STL-____-____

Chiller type : ____________________

Reduction step/capacity reductions : ___/______

Heat transfer fluid type / concentration :________/_____

Plant/address :

Engineer/Company : Mr _________/_____________

Mr ________/_________

Mr ________/_________

Mr ________/_________

Date	Hour	STL measurements					Chiller measurements					Comments
		Inlet T° (°C)	Outlet T° (°C)	Flow (m^3/h)	Capacity (kW)	Energy (kWh)	Inlet T° évap.(°C)	Outlet T° evap.(°C)	Flow rate (m^3/h)	Capacity (kW)	Energy (kWh)	

Control sheet N°______ TOTAL ______ **kWh** ______ **kWh**

<u>Heat transfer fluid level control</u> (see control form) :

- inlet and outlet temperatures of STL,
- STL flow,
- evaporator inlet and outlet temperatures,
- evaporator flow.

<u>Calculations</u> :

- cooling capacity on STL with the previous measures of temperatures and the characteristic of heat transfer fluid,[1]
- energy exchanged between two measured points (we should find that the capacity is constant between 2 points),
- cooling capacity provided by the chiller,[1]
- energy provided by the chiller between 2 points.

Then sum the total of the energies calculated on the performance control form. The total energy calculated will be compared to the theoretical ones.

(1) P = M x Qv x Cp x dT (kW)
P : capacity
M : heat transfer fluid density in kg/m^3
Qv : heat transfer fluid flow in m^3/h
Cp : heat transfer fluid specific heat in kWh/m^3
dT : heat transfer fluid difference of temperature in °C.

8.4 : SERVICING

- **STL**

Once the tank and nodules are installed, the STL does not require any servicing, since it is a static system.

However for the STL – IC.27, due to the nature of the PCM (Phase Change Material) it is necessary to install a water treatment system and regularly check the water to avoid any corrosion phenomenon.

- **Other components**

See manufacturers service manuals and respect the manufacturer's recommendations.

- Insulation :

A systematic insulation check quality must be carried out by the servicing company during operation.

- Heat transfer fluid :

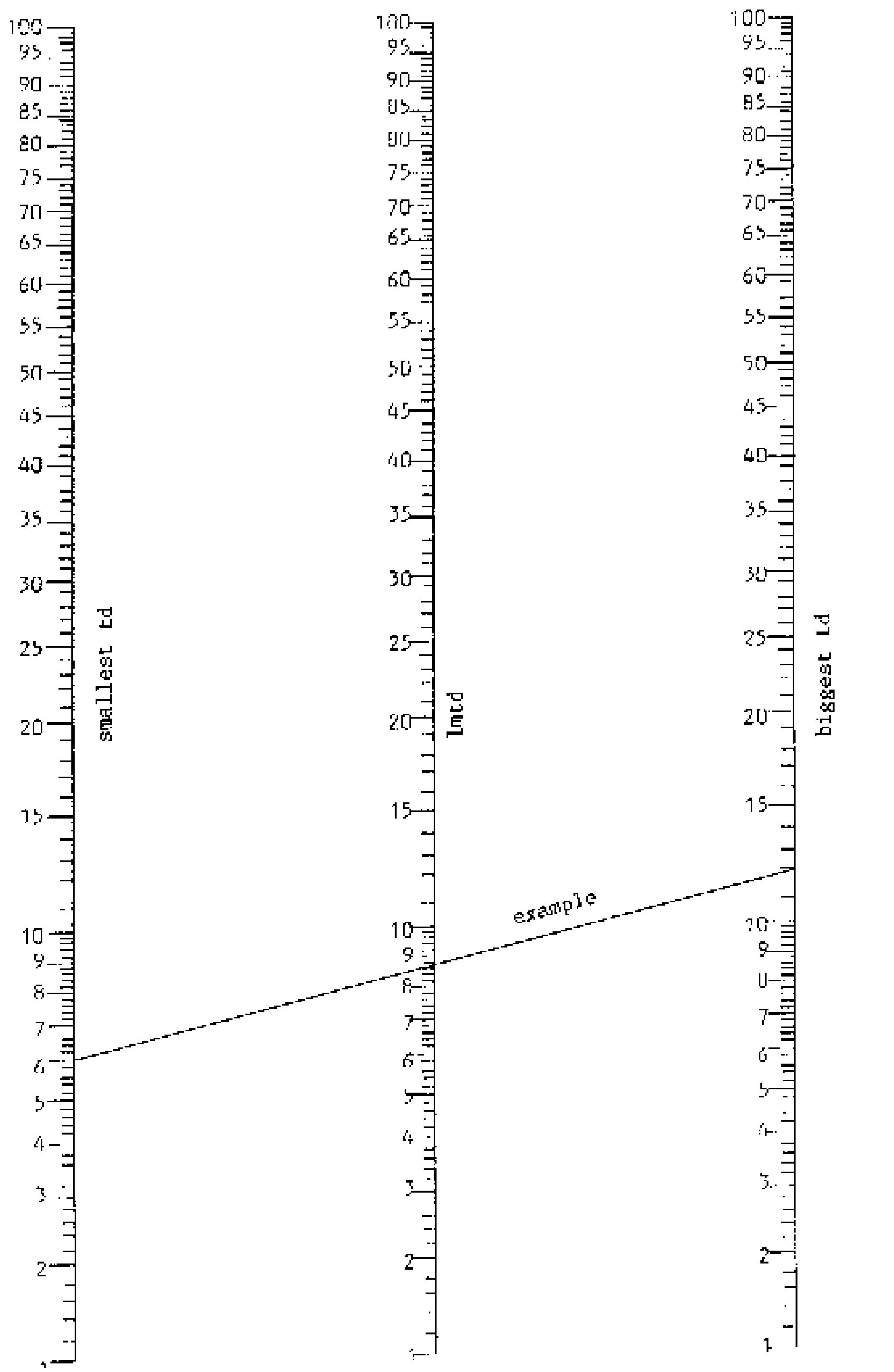
Check the concentration using a densimeter every year.

- Filters :

Check the filters during commissioning and regularly thereafter (every 6 or 12 months).

9 . DESIGNER HELP

9.1 : LMTD CALCULATIONS



9.2 : STL PROJECT SHEET

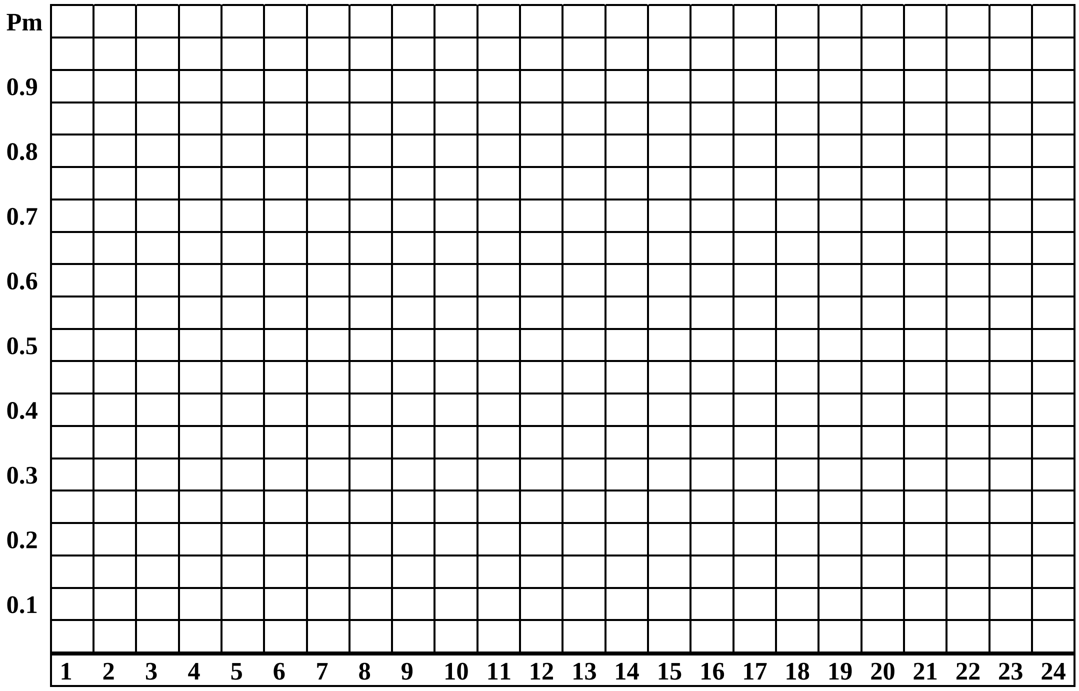
From : .... **Company :**	For the attention of : CRISTOPIA ENERGY SYSTEMS (I) PVT. LTD. Works:12th Km, Indore Khandwa Road, Village Umrikheda, INDORE (M.P)-452020 Correspondance Address: 4-B, BCM City C-Block, 5th Floor Navlakha Square, A.B. Road Indore (M.P.)-452001
Telephone : .... Telefax : .... e-mail :	
Date :	PLEASE CONTACT US IMMEDIATELY IF ALL PAGES ARE NOT RECEIVED.

Name of the project : ....
Maximum demand Pm = ... kW
Outlet temperature : .... °C
Inlet temperature : .... °C
Heat exchanger ? ....

TIME OF THE DAY	INSTALLED CHILLER CAPACITY REDUCTION	BACK UP	OTHERS

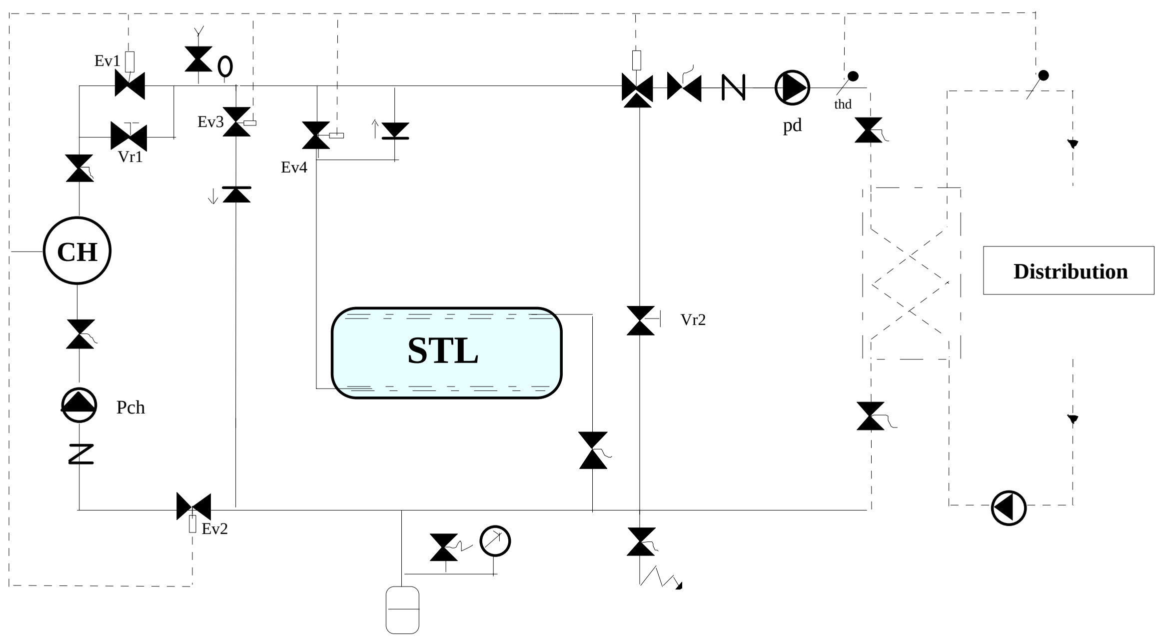
....
....
....
....
....

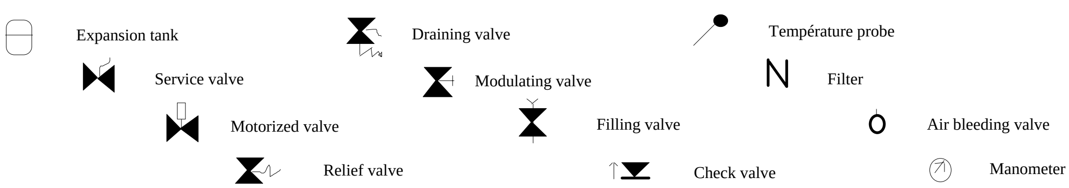
COOLING PROFILE



Thank you for your answer. Best regards.

9.3 : LAY-OUT EXAMPLE





9.4 : SPECIFICATIONS

STL store :

STL store trade mark : CRISTOPIA
Type : STL - .... - ....

Nodules :

The nodules are .... mm diameter and have an expansion pocket to absorb the expansion.
The phase change temperature is ....°C.
The tank is completely filled with nodules, the number of nodules per m^3 is .....

Tank :

The ....[1] tank is manufactured in black steel with an external anti-rust paint protects the tank.
The test pressure is .... bar and minimum service pressure is .... bar.
The tank is set ... [2] it has .... upper manholes and one lower manhole.
Two diffusers spread the heat transfer fluid along the tank.

[1] horizontal or vertical
[2] set indoor, outdoor or buried

10 . OTHER COMPONENTS & MISCELLANEOUS

10.1 : INSULATION

Cold storage :

Insulation is essential and has two objectives :

- to reduce thermal losses,
- to avoid condensation.

The insulation will be of Styrofoam type, injected mineral, etc... as commonly used in A/C or refrigeration.

The insulation includes two vapour barriers to avoid water migration through the insulation.

Tanks sited outdoors must have external waterproof cladding to protect the tank.

Mild storage :

The insulation will respect the same rules as for water storage. If, for transport reason, the cradles are welded to the tank, insulate the cradles themselves and put an insulation material between the cradles and the basement.

In both cases :

- If the cradles are not welded to the tank it is necessary to insulate the section of the tank corresponding to the cradles position. The insulation material must respect the following criteria :
  - its characteristics must be similar as the insulation material described previously,
  - its compression resistance must be high enough to withstand pressure stress due to the STL (~1500 kg/m^3). High density Neoprene or equivalent material can be used.
- If the cradles are welded to the tank :
  - insulate the cradles,
  - an insulation material must be placed between the cradles and the basement.

To use the lifting equipment available on site, this insulation work can be done when the tank is positioned. If the tank is vertical, insulate the dished ends before setting the tank.

10.2 : HEAT TRANSFER FLUID

The heat transfer fluid must be compatible with all the hydraulic network components, and with the operating temperatures.

For "hot storage" (temperatures higher than 4°C) the heat transfer fluid must respect classical heating plant network conditions (the heat transfer fluid is water + additives).

- For cold storage, water alone can not be used. It is necessary to use a brine or glycoled water.
- In the food industry, the heat transfer fluid must be compatible with foodstuff.

10.3 : EXPANSION

- The sizing of the expansion tank must take into account the maximum and minimum pressures of the installation. For usual temperature differences of the loops (20-25°C maximum) and for normal heat transfer fluid volume we recommend the following useful expansion volume (in % of the STL tank volume).
  - 1 % for atmospheric STL tank,
  - 5 % for pressurised STL tank (maximum 10 bars).

10.4 : STL PRESSURE DROP

- The STL consists of a tank filled with nodules. The flow is spread along the tank by the diffusers. Inside the tank the heat transfer fluid speed is very low, and the flow is laminar. The pressure drop due to nodules is almost nil. The pressure drop is only due to the diffusers.
- Typically, for an usual flow rate of 2.5 m^3/h per m^3 of tank, the pressure drop of a STL is 2.5 mWG. Before manufacturing the tank it is important to determine the maximum flow rate and the pressure drop wanted.

From this information (maximum flow rate and maximum pressure drop), the diameter and the number of holes per diffuser are calculated.
This calculation is done by the Technical Department of CRISTOPIA *Energy Systems*. At the order, it is then important to indicate the maximum flow rate and the pressure drop wanted.

10.5 : PUMPS

For parallel lay-out two pumps are required to ensure circulation of the heat transfer fluid (charge pump and distribution pump).

- **Charge pump**

The charge pump flow rate depends on chiller capacity and Δt. The heat transfer fluid characteristics must be taken into account.

- **Distribution pump**

The distribution flow rate depends on the maximum demand and Δt. The heat transfer fluid characteristics must also be taken into account.

10.6 : THREE-WAY VALVE

The 3-way valve must be a modulating type. For systems below 0°C allow for a spindle element heater. For selection, see manufacturer's documentation.

11 . CRISTOPIA *Energy Systems* GUARANTEE

Five year warranty

STL – AC.00

1. **CRISTOPIA *Energy Systems* warrants the STL energy storage components (nodules AC.00)** to be free of material defects or manufacturing defects for a limited time under the following conditions. The guarantee time is five (5) years after receipt of the goods. This time will not exceed sixty six (66) months after the shipment of goods by CRISTOPIA *Energy Systems*.

2. **STL components must be used normally**, meaning in accordance with the instructions of CRISTOPIA's official technical documentation.
   In order for this limited warranty to take effect, a copy of it must be fully completed with purchaser's name, address, date of purchase and distributor's or dealer's names and address and returned to CRISTOPIA *Energy Systems* within thirty (30) days following the date of receipt of the goods by registered letter with acknowledgement of receipt.

3. **CRISTOPIA *Energy Systems* obligations** under this warranty is expressly limited to the replacement of the STL components which prove defective.
   The replacement is free up to the original sale price. Any price increases, transport and replacement costs will be met by the buyer.

4. **This guarantee does not cover** :
   - damages or leaks caused by mishandling or manipulation during transport or commissioning,
   - damages or leaks due to the system pressure rising above its design value,
   - damages due to operations not conforming to CRISTOPIA Energy Systems recommendations,
   - damages due to strikes, attacks, natural disasters, etc....

5. If a problem arises with a product covered by this warranty, buyer should notify CRISTOPIA *Energy Systems* or authorised Distributor in writing as soon as possible and no later than thirty (30) days after such a problem has arisen.

6. **CRISTOPIA *Energy Systems*** shall not be liable for any direct, consequential or special damages resulting from the use of these products or caused by any defect, failure or malfunction of the products whether a claim for such damage is based upon warranty, contract, negligence or otherwise. In no event will CRISTOPIA *Energy Systems'* liability exceed the amount of money paid to **CRISTOPIA *Energy Systems*** for the particular item involved.

Invoice No   Delivery date   Authorised signature