Ammonia Absorption Refrigeration Plants for Economical and Enviro-friendly Refrigeration

Mr. Ajit Apte (Associate Member - ASHRAE, USA)

About the author

Mr. Ajit Apte is a post graduate engineer from IIT, Mumbai in Energy Systems Engineering and is presently Vice President (Cooling Systems) at **Transparent Energy Systems Pvt. Ltd**., Pune (India). He has been involved in development of Super Efficient Steam Boilers, Heat Recovery Systems, Cogeneration Systems, LiBr-Water Absorption Chillers and Ammonia Absorption Refrigeration Plants. He can be contacted at trans@pn2.vsnl.net.in or www.tespl.com

1. Abstract

Ammonia Absorption Refrigeration is the oldest known refrigeration technology invented in 19^{th} century. However the applications of this technology in last five decades have remained limited to large scale plants primarily in Petrochemical, Fertilizer and Food Processing Industry worldwide. In India these plants existed only in few Fertilizer plants installed in 70's and 80's.

Conventional compression cycle plants today consume most precious form of energy, i.e. - electrical or motive power. These plants became more popular during above period due to development of CFC refrigerants, cheap availability of electric power, low initial cost due to mass production and simple controls.

The global oil crisis in last decade has created an energy and power crisis in many parts of the world including India, forcing people to look for energy efficient alternatives. The environmental hazards of CFC refrigerants have also triggered the search for environment friendly refrigerants.

Ammonia Absorption Refrigeration Plants (AARP) are ideally suited to meet both the above requirements. **Transparent Energy Systems Pvt. Ltd. (TESPL)** offers Ammonia Absorption Refrigeration Plant with world class **"System BORSIG"** technology from Germany, proven for more than 80 years. These plants are modular in construction and are fully automatic in operation with a wide range of refrigeration temperature. The maintenance requirements of these plants are very low and these plants have a long life of at least 25 years.

Innovative application engineering and energy modeling by Transparent Energy Systems Pvt. Ltd. (TESPL) has opened many applications for Ammonia Absorption Refrigeration Plant with attractive energy savings. This paper describes following case studies for applications of Ammonia Absorption Refrigeration Plant

- Stand alone Cold Storages
- Stand alone Ice Plants
- Refrigeration from Low Grade Heat Rejection (Such as I. C. Engine Jacket Heat)
- Pasteurization of Milk from Combined Heating and Cooling
- Waste Heat Recycling for Ice Production
- Refrigeration from Process Vapours

Transparent Energy Systems Pvt. Ltd., backed by their application engineering expertise, provides many more innovative and economical refrigeration alternatives with Ammonia Absorption Refrigeration Plants.

2. Introduction

The energy and environment scenario in India as well as world is undergoing a rapid change. In the industrialized economy, energy is consumed in various forms, primarily heat, power and refrigeration. Currently each form of energy is generated separately. However, the concept of integrated energy solutions has become a key to energy conservation and optimization. As a result the concept of co-generation is being adapted increasingly in various forms, such as Combined Heat and Power (CHP) Plants; and Combined Heat, Refrigeration and Power (CHRP) Plants.

The energy and environmental norms are becoming more and more stringent in all the countries. The concept of energy consumption tax and CO_2 emission tax is becoming a reality in western countries.

The use of non-conventional and renewable sources of energy such as bio-mass, solar energy is expected to rise substantially in near future.

On this background, the Ammonia Absorption Refrigeration Technology has generated a renewed interest and is being viewed as a viable alternative for economical refrigeration due to following features -

- Potential for waste heat utilization and heat recycling
- Wide temperature range (+5 to -60 Deg. C)
- Ammonia is enviro-friendly refrigerant and is readily available
- No specialized materials are required

In Vapour Absorption Refrigeration Plant, a pair of refrigerant & absorbent is used as working media. Ammonia-water & water-lithium bromide solution are two most commonly used working media for absorbent have following advantages:

Ammonia-water as working media has following advantages:

a) High affinity
b) High stability
c) Moderate operating pressure. No vacuum up to -30 ^{0}C
d) Absence of solid phase
e) Non-corrosive to carbon steel.

3.0 Configurations and Application Range

3.1 Single Stage Ammonia Absorption Refrigeration Plant

3.1.1 Working Principle (Refer Figure 1 for a Schematic Diagram)

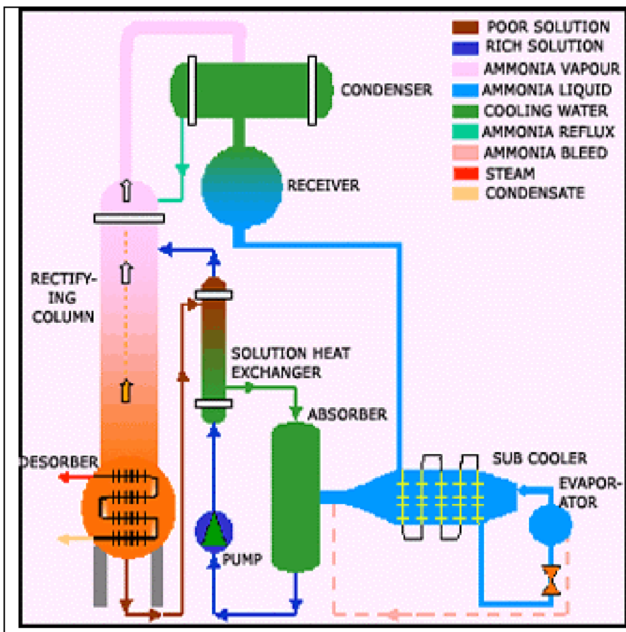


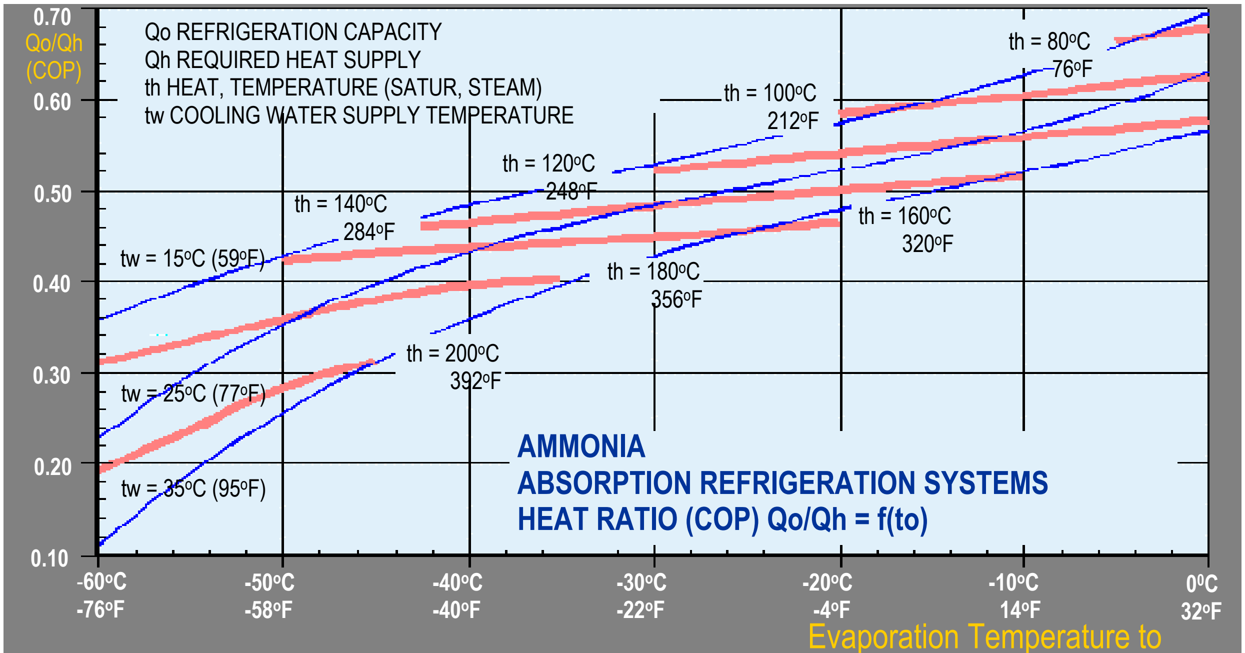
Figure 1 - Schematic Diagram of Single Stage Ammonia Absorption Refrigeration Plant. [1]

1. Liquid ammonia evaporates in the evaporator and cools the product.
2. Ammonia vapours from evaporator are used for sub-cooling the liquid ammonia supplied to evaporator. This reduces liquid ammonia flash loss in the evaporator.
3. Ammonia vapours from sub-cooler are absorbed in absorber by a spray of weak ammonia solution in water. The heat of absorption is removed by cooling water.
4. The strong ammonia solution formed after absorption is pumped to desorber.
5. Heat is supplied in the desorber to boil off the ammonia vapours from strong solution. These vapours also contain some water vapours due to affinity between ammonia and water.
6. The ammonia vapours are rectified in the rectifying column to remove the vapours and generate pure ammonia vapours with traces of water vapours.
7. These vapours are condensed and liquid ammonia is accumulated in the receiver.
8. The receiver supplies liquid ammonia to evaporator.
9. Weak ammonia solution left in the desorber is sent to absorber for absorption.
10. A solution heat exchanger is provided to cool the weak solution before entering the absorber and preheat the strong solution before entering the desorber.
11. The traces of water vapours during ammonia boil off in desorber accumulate in the evaporator. These are controlled by providing a bleed line from evaporator to absorber.

3.1.2 Application Range

Single stage Ammonia Absorption Refrigeration Plants normally cater to those applications having one or more chilling loads of nearly same temperature. Typically for applications ranging from +5 to -40 Deg. C, heat source temperature requirement varies from 95 Deg. C to 180 Deg. C, with normal cooling water as coolant for absorber and desorber. For temperatures lower than -40 Deg. C (up to -

60 Deg. C), chilled water at 10-15 Deg. C is a preferred coolant. Figure 2 shows a typical performance curve for single stage plants.



Cooling Water Temperature (tw) ————

Heat Source Temperature (th) — — — —

Figure 2 - Typical Thermodynamic Performance of Single Stage Ammonia Absorption Refrigeration Plamt. [2]

3.2 Two Stage Ammonia Absorption Refrigeration Plant

The working principle of two stage plants is similar to a single plant. Two stage plants are of two types

3.2.1 Two stage plants having Two Absorption Stages -

3.2.1.1 Working Principle

Refer Figure 3 for a Schematic Diagram. The absorption of refrigerant vapours at different temperatures is done by the same stream of solution in successive manner. This reduces the circulation losses. The requirement of heat source temperature is comparable with single stage plants. Due to reduced circulation losses, these plants have marginally improved COP and power consumption.

3.2.1.2 Application Range

These plants are used when two different refrigeration temperatures have to be achieved from the same plant.

3.2.2 Two Stage Plants having Two Desorption Stages -

3.2.2.1 Working Principle

Refer Figure 4 for a Schematic Diagram. The desorption of refrigerant vapours is done at two places, with an intermediate absorption stage. Due to desorption at two places the COP of these plants is much lower compared to single stage plants.

3.2.2.2 Application Range

These plants are used for meeting low temperature refrigeration requirements from heat source relatively at low temperature. Typically for refrigeration temperature range of 0 to -60 Deg. C, the heat source temperature requirement ranges from 85 to 125 Deg. C.

The typical heat sources for these plants are Solar heat and low grade heat rejection from co-generation plants, chemicals process plants etc.

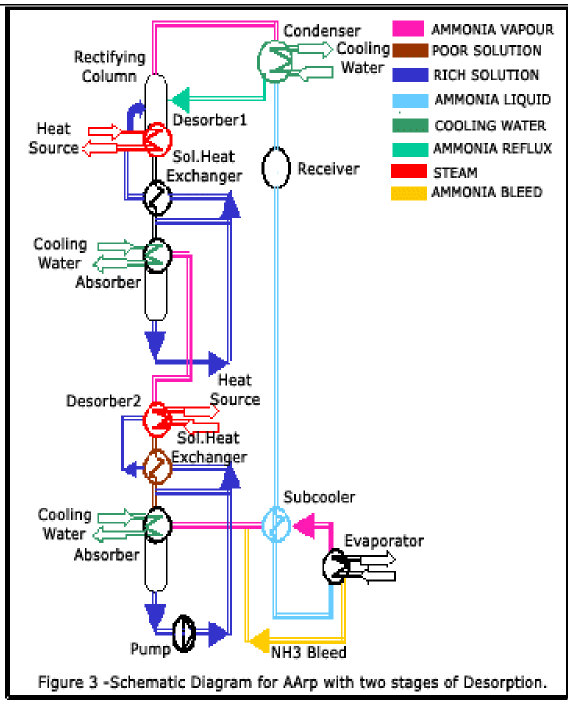


Figure 4 - Schematic Diagram for Ammonia Absorption Refrigeration Plant with Two Stages of Desorption. [2]

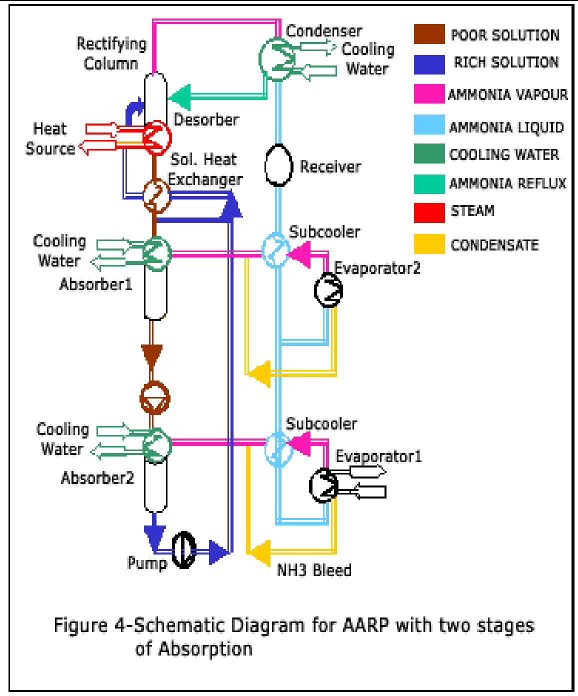


Figure 3 - Schematic Diagram for Ammonia Absorption Refrigeration Plant with Two Stages of Absorption. [2]

3.3 Heat Sources for Ammonia Absorption Refrigeration Plants –

The ammonia absorption refrigeration plants can be driven by various forms of heat energy such as

- Steam	- Hot Water
- Hot Oil	- Direct Firing

Typical heat sources for ammonia absorption refrigeration plants are –

1. Bio-mass fuels
2. Heavy Oil, Natural Gas or Bio-gas
3. Engine/Gas Turbine/Furnace Exhaust
4. Engine Jacket Heat
5. Low pressure steam from steam turbine exhaust or any other source
6. Vapours from Process Evaporators
7. Solar energy

4 Application and System Engineering

The working principle of Ammonia Absorption Refrigeration is known to refrigeration and chemical engineers for many years. In spite of it's potential for energy conservation, the proven technology of commercially operating plants is available with only select companies worldwide.

Transparent Energy Systems Pvt. Ltd., Pune (India) offers Ammonia Absorption Refrigeration Plants with know how from Mattes AG, Germany (formerly BORSIG GmbH). M/s Mattes AG are techno-legal owners of "System BORSIG" technology proven for more than 80 years. The salient of features of these plants are -

- Least dependence on availability of electric power.
- Wide operating range (+5 to -60 Deg. C)
- Fully automatic, modulating plant. No running attention required.
- Proportional heat consumption up to 30% modulation.
- Outdoor installation. Less civil work.
- Rooftop installation is also possible.
- Negligible maintenance and high reliability due to absence of moving parts other than a centrifugal pump.
- Long life of at least 25 years.

Figure 5 shows a view of typical Ammonia Absorption Refrigeration Plant-" System Borsig"

Figure 5 -Typical View of Ammonia Absorption Refrigeration Plant - "System Borsig" [1]

Transparent Energy Systems, with it's inherent strength in application engineering of thermal energy and co-generation have built many successful models for energy conservation using Ammonia Absorption Refrigeration Plants. Some the case studies presented here are illustrative of typical applications of Ammonia Absorption Refrigeration Plants

1. Stand alone cold storages
2. Stand alone ice plants
3. Refrigeration from Engine Jacket Heat Recovery
4. Pasteurization of milk from Combined Heating and Cooling

A more detailed information is available on website **www.tespl.com**

4.1 Stand-alone cold storages -

Conventionally cold storages are driven by Compression Cycle Refrigeration Plants. The cold storages for vegetables, agro-products, fish and meat products are generally located in remote and agriculturally rich area. The cost of electricity dominates the cost of storage. The rising cost and poor availability of electricity has adversely affected the viability of cold storages.

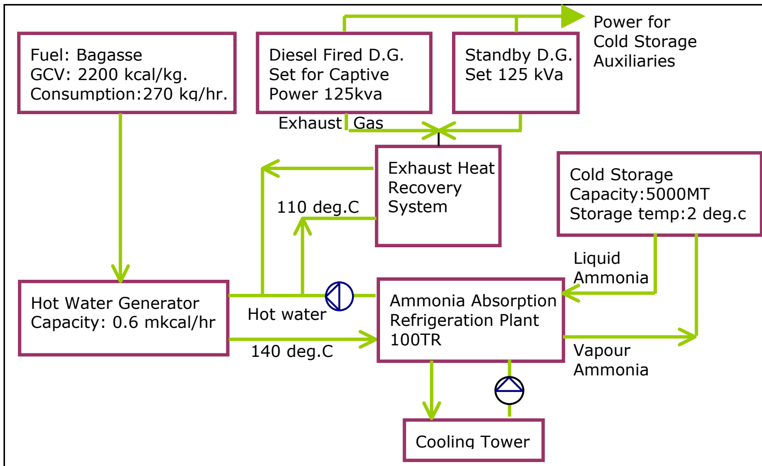


Figure 6 - Cold Storage Driven by Ammonia Absorption Refrigeration Plant using Agrofuels & Captive Power for Auxiliaries. [3]

When the same cold storage is driven by Ammonia Absorption Refrigeration Plant, the user has following advantages -

a) The total electricity requirement reduces substantially. A small DG set can be used to make the cold storage independent of grid power.
b) The bio-mass and other agro-fuels available locally can be used to drive Ammonia Absorption Refrigeration Plant. The operating cost and maintenance cost of the cold storage is very low.
c) The cold storage can store a wide range of products having different storage temperatures.
d) Any other simultaneous refrigeration load such as Ice Plant or Milk Chilling can be met with the same plant.
e) The investment in grid power connection, stand-by D.G. set, plant room etc. is substantially reduced.

The schematic diagram of the stand-alone cold storage is shown in Figure 6.
A summary of cost benefit analysis of a Cold Storage driven by Agro-fuel fired Ammonia Absorption Refrigeration Plant is furnished in Table 1.

Table 1

Cold Storage driven by Ammonia Absorption Refrigeration Plant
Summary of Cost Benefit Analysis

No.	Parameter	Unit	Conventional Compression Cycle Refrigeration Plant		Ammonia Absorption Refrigeration Plant (with Grid Power for Auxiliaries)			Ammonia Absorption Refrigeration Plant (with DG set for Auxiliaries)		
1	Capacity of Cold Storage	Tons	5000	5000	5000	5000	5000	5000	5000	5000
2	Storage Temperature	Deg. C	2	2	2	2	2	2	2	2
3	Refrigeration Load	TR	100	100	100			100		
4	Source of Power		Grid Power	D.G. set	Grid Power			D.G. Set with Exhaust Heat Recovery		
5	Cost of Power	Rs./kWh	5	6	5	5	5	6	6	6
6	Fuel		N.A.	N.A.	Bagasse	Rice Husk	Coal	Bagasse	Rice Husk	Coal
7	Gross Calorific Value	kcal/kg	N.A.	N.A.	2200	3200	4500	2200	3200	4500
8	Cost of Fuel	Rs./ton	N.A.	N.A.	400	500	1500	400	500	1500
9	Incremental Initial Cost	Rs. in Million			2	2	2	2.5	2.5	2.5
10	Annual Savings in Running Cost	Rs. in Million			1.94	2.06	1.25	2.57	2.68	1.92
11	Payback Period	Months			12.33	11.64	19.22	11.69	11.20	15.64

4.2 Stand-alone Ice Plants

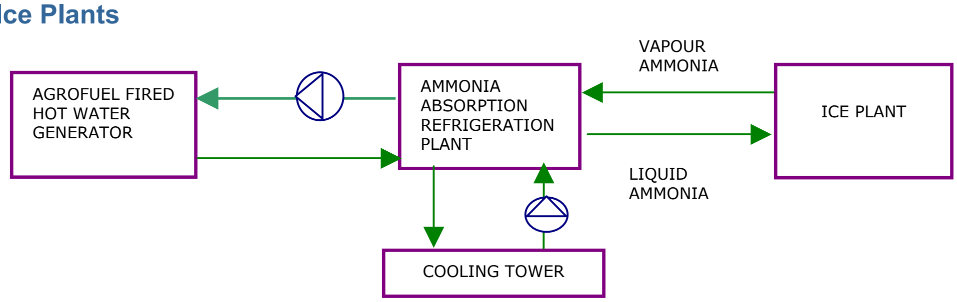


Figure 7 - Schematic Diagram of Ammonia Absorption Refrigeration for Ice Plant. [3]

The concept of a stand-alone ice plant is similar to that of a cold storage. The schematic diagram is shown in Figure 7. A summary of running cost based on per ton of ice produced is furnished in Table 2.

Table 2

Ice Plant Driven By Ammonia Absorption Refrigeration Plant
Summary of Cost Benefit Analysis

No.	Parameter	Unit	Conventional Compression Cycle Refrigeration Plant		Ammonia Absorption Refrigeration Plant (with Grid Power for Auxiliaries)			Ammonia Absorption Refrigeration Plant (with DG set for Auxiliaries)		
1	Capacity of Ice Plant	Tons/day	30	30	30	30	30	30	30	30
2	Ammonia Temperature	Deg. C	-20	-20	-20	-20	-20	-20	-20	-20

3	Refrigeration Load	TR	50	50	50			50		
4	Source of Power		Grid Power	D.G. set	Grid Power			D.G. Set		
5	Cost of Power	Rs./kWh	5	6	5	5	5	6	6	6
6	Fuel		N.A.	N.A.	Bagasse	Rice Husk	Coal	Bagasse	Rice Husk	Coal
7	Gross Calorific Value	kcal/kg	N.A.	N.A.	2200	3200	4500	2200	3200	4500
8	Cost of Fuel	Rs./ton	N.A.	N.A.	400	500	1500	400	500	1500
9	Incremental Initial Cost	Rs. in Million			1.5	1.5	1.5	2	2	2
10	Annual Savings in Running Cost (300 days)	Rs. in Million			1.80	1.94	1.39	2.30	2.44	1.89
11	Payback Period	Months			8.32	7.73	10.74	8.7	8.2	10.54
12	Savings per Ton of Ice produced	Rs./Ton			200	216	155	256	271	211

4.3 Refrigeration from Engine Jacket Heat Recovery (Co-generation Plant)-

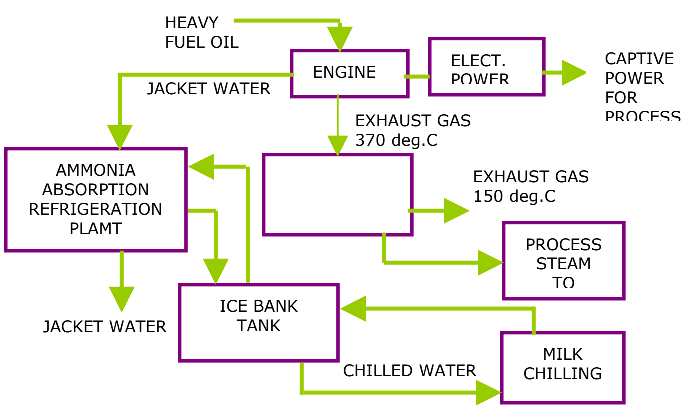


Figure 8 - Schematic Diagram of Captive Co-Generation for Dairy. [3]

Figure 8 shows the schematic diagram of a captive co-generation plant for dairy industry, using heavy oil fired Engine Genset. The power produced from the engine is consumed as captive power for the dairy. The exhaust heat from the engine is used for generating steam for process requirement in dairy. The heat from engine jacket hot water is used for driving an Ammonia Absorption Refrigeration Plant with Ice Bank Tank. The refrigeration capacity generated from jacket heat recovery is consumed on priority and only balance refrigeration load is met with compression cycle plant. Table 3 provides cost benefit analysis of Refrigeration from Jacket Heat Recovery.

Table 3
Ammonia Absorption Refrigeration Plant driven by Engine Jacket Heat Summery of Cost Benefit Analysis

No	Description	Unit	Conventional Compression Cycle Refrigeration Plant	Ammonia Absorption Refrigeration plant with Jacket Heat Recovery
1	Refrigeration Capacity	TR	130	130
2	Power Consumption for Compressor	KW	130	N.A.
3	Auxiliary Power Consumption	KW	15	25
4	Total Power Consumption	KW	145	25
5	Cost of Power	Rs/kWh	5.0	5.0
6	Running Cost	Rs/hr	725.0	125.0
7	Savings in Running Cost	Rs/hr	N.A.	600.0
8	Annual Savings (8000 hrs)	Rs. in Million	N.A.	4.8
9	Initial Investment	Rs. in Million	N.A.	7.5
10	Payback period	Months	N.A.	18.75

4.4 Pasteurization of Milk with Combined Heating and Cooling

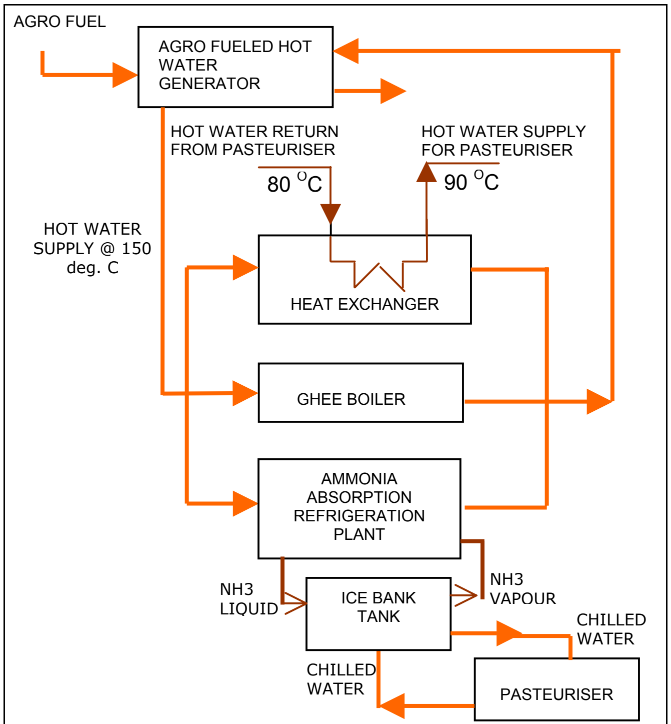


Figure 9 - Schematic Diagram of Agrofuel fired combined Heating & Cooling System for Milk Processing. [3]

Pasteurization of milk involves heating and chilling of milk in predetermined cycle. There are few other heat loads such as ghee (butter) boiling, milk can washing etc. Also there are few more chilling loads such as milk storage.

Conventionally in a small scale dairy industry (typically 50000 Lit/day milk handling capacity), the heating of milk is done by an oil/gas fired hot water generator/steam boiler and chilling is done by a compression cycle refrigeration plant coupled to an Ice Bank Tank. The rising cost of fuel oil as well as electric power has increased the cost of milk processing substantially, adversely affecting the viability of small scale dairy plants.

A bio-mass fired combined heating and cooling system substantially reduces the cost of milk processing. A schematic diagram of this system is shown in Figure 9. A bio-mass fired Superheated Water Generator as the heat source for driving all heat loads as well as an Ammonia Absorption Refrigeration Plant coupled to Ice Bank Tank. All modern pollution control equipment such as cyclone separators and bag filters can be provided for clean and smoke-less exhaust. Table 4 provides a summary of cost benefit analysis for a typical dairy having 50000 Lit/day milk handling capacity.

Table 4
Pasteurisation of Milk with Combined Heating & Cooling Cost Benefit Analysis

No	Description	Unit	Conventional System for Heating and Cooling	Combined Heating and Cooling with Ammonia Absorption Refrigeration Plant
A	Milk Processing Capacity	Lit/day	50000	50000
B	Heating for Pasteurization			
1	Heat Load	Kcal/hr	80000	80000
2	Equipment Used		Diesel Fired Hot Water Generator	Rice Husk Fired Hot Water Generator
C	Cooling for Pasteurisation			
1	Refrigeration Load	TR	40	40
2	Equipment		Compression Cycle Refrigeration Plant	Ammonia Absorption Refrigeration Plant
3	Driving Source		Electric Power	Rice Husk fired Hot Water Generator
D	Cost Benefit Analysis			
1	Fuel Used		Diesel	Rice Husk
2	Gross Calorific Value	kcal/kg	11300	3200
3	Cost of Fuel		18.0 Rs/Lit	500 Rs./Ton
4	Total Fuel Consumption		11 Lit/hr	108 kg/hr
5	Cost of Electric Power	Rs./kWh	5.0	5.0
6	Total Power Consumption	kWh	50	10
7	Hourly Fuel Cost	Rs./hr	198	53
8	Hourly Power Cost	Rs./hr	250	50
10	Total hourly Cost	Rs./hr	448	103
11	Hourly Savings	Rs./hr	N.A.	345

12	Annual Savings (7200 hrs)	Rs. in Million	N.A.	2.5
13	Initial Investment	Rs. in Million	N.A.	3.5
14	Payback Period	Months	N.A.	17

5.0 Future Trends in Technology Development

The renewed interest in Ammonia Absorption Refrigeration technology in last decade has also stimulated research and development work on various aspects of this technology. Some important areas of development are -

a) Building components from Plate Heat Exchangers.
b) Building compact, factory assembled and hermetically sealed plants.
c) Development of efficient air-cooled plants for low temperature applications.

6.0 Conclusion

Ammonia Absorption Refrigeration Technology has great potential to offer economical and innovative solutions to various refrigeration requirements. Appropriate application engineering is a key to success of Ammonia Absorption Refrigeration Plants.

Economical refrigeration available with Ammonia Absorption Refrigeration Plants can provide a major boost to viability of Food Processing, Food Storage and Food Preservation Applications.

The application potential of Ammonia Absorption Refrigeration Technology makes it a strong candidate for the refrigeration technology of the millennium.

References:

1. "Ammonia Absorption Refrigeration Plants" **-** Technical Product Information by Transparent Energy Systems Pvt. Ltd., Pune (India).
2. "Ammonia Absorption Refrigeration Systems" product information published by Mattes AG, Germany.
3. Case Studies by Transparent Energy Systems Pvt. Ltd., Pune (India).