Chapter 3

Aqua Ammonia VAR system

This chapter is concerned with the description of the brine chilling unit consisting of an 800 TR AAVAR system which is a part of Gujarat Narmada Valley Fertilizer Company (GNFC) Bharuch, Gujarat, a large fertilizer plant located at Bharuch, Gujarat State, India. The company manufactures many products related with chemical fertilizer. For the manufacturing of chemical fertilizer, large quantities of chilled brine at specified temperature is needed as one of the raw materials. As a number of sources of heat energy are available at GNFC plant, it is economical to use vapour absorption refrigeration system instead of a conventional vapour compression refrigeration system for the purpose of chilling as the vapour absorption system needs heat energy for its operation instead of electricity for vapour compression refrigeration system. Since there are a number of sources of heat energy available as under utilized, it is desirable to evaluate the techno-economic viability of using the heat energy source. Hence, the existing AAVAR system using an independent and dedicated boiler unit generating steam as heat source is considered first. Section 3.1 describes the various components of the system. Section 3.2 describes the other options of the heat energy sources considered during the techno-economic evaluation of the plant. The online steady state data during a normal operation of the brine chilling unit using AAVAR system with independent boiler as the source of steam (fuel), steam generated at HRSG of the gas turbine power plant and tapped steam from steam power plant are given in Section 3.3.

3.1 System Description

The basic components of AAVAR system consist of brine chilling unit and condensing unit. The brine chilling unit consists of pre-cooler-1, pre-cooler-2 and evaporator whereas the condensing unit includes solution heat exchangers, ammonia condenser, rectifier-generator assembly, aqua ammonia solution pump, expansion valve and pressure reducing valve and ammonia absorber. The working fluid (refrigerant) in the AAVAR system is ammonia and the absorbent is water having strong chemical affinity with ammonia. Fig. 3.1 gives the plant layout of the brine chilling unit of the fertilizer plant. The component-wise description of the chilling unit and condensing unit of AAVAR system as referred in Fig. 3.1 is given below:

3.1.1 Chilling Unit

The chilling unit consists of pre-cooler-1 (PC1), pre-cooler-2 (PC2), and evaporator. The incoming brine at a pressure and temperature of 1.01 bar and 24.7 °C, respectively is cooled at constant pressure in two stages while passing through PC1 and PC2.

In the fertilizer industry, the liquid ammonia is manufactured at two pressure levels, 2.3 bar saturated and 4 bar saturated in different plants. The liquid ammonia at 4 bar saturated is used as coolant in PC1. During evaporation, ammonia absorbs latent heat of evaporation (process 31 to 32) and chills the brine from 24.7°C to 15.9°C (process 29 to 30). Similarly, the liquid ammonia at 2.3 bar saturated evaporates in PC2 (process 33 to 34) further chilling the brine from 15.9°C to 5.7°C (Process 30 to 21). The chilled brine from PC2 enters the evaporator of AAVAR system where the remaining chilling is carried out from 5.7°C to -1.7°C. The evaporated ammonia from both the pre-coolers is utilized in the various chemical processes of the fertilizer plant. Thus, the AAVAR system is designed to chill brine from 5.7 °C to - 1.7°C.

3.1.2 Condensing Unit

The condensing unit consists of refrigerant heat exchangers (RHX 06 and RHX 05), ammonia absorber (E04), solution pump, solution heat exchanger (SHX E02), throttle valve (V111), generator, rectifier-reflux assembly and ammonia condenser (E03).

The ammonia vapour is liquefied (process 5-6) rejecting its latent heat in condenser E03 using cooling water (process 23-24) supplied by cooling tower No. 34/02. The high pressure liquid ammonia from condenser is collected in receiving tank D01. High pressure liquid ammonia collected in the receiving tank is partially supplied to the rectifier as a reflux and remaining liquid ammonia flows through RHX 06 and RHX 05 before expanded through an expansion valve V208 to evaporator pressure at E07.

About ninety per cent of the liquid ammonia absorbs heat energy from the brine during its flow in the evaporator E07 and flows out as vapour through RHX 06 (process 10-11), while the rest is un-evaporated and gets collected at the bottom of the evaporator and flows through RHX 05 (process 12-13). Both the liquid and vapour ammonia from RHX 06 and RHX 05, respectively are used to subcool (processes 6-7 and 7-8) the incoming high pressure liquid ammonia from the condenser E03 before expanding in V208 (process 8-9). The introduction of RHX E06 and RHX E05 helps to increase the refrigerating effect at the expense of addition of heat energy to the ammonia vapour entering the absorber E04 from the evaporator E07.

Vaporized ammonia from E07 after absorbing heat energy while passing through RHX 06 and RHX 05 is absorbed by the weak solution of ammonia in the absorber (E04) Since the absorption process is exothermic, heat should be removed from the absorber to maintain a specified low temperature in the absorber so that high chemical affinity between the ammonia vapour and weak absorption solution can be maintained so as to form a strong solution of ammonia. For the cooling purpose, water from the cooling tower 34/02 is used as a coolant.

The strong solution of aqua ammonia is pumped through solution heat exchanger (SHX E02) to generator. SHX E02 is used to recover heat from the weak aqua ammonia solution returning from the generator. The heat energy of the weak solution is used (process 2-16) to preheat the strong solution from the absorber (process 15-1). The pressure of weak aqua ammonia solution from solution heat exchanger (E02) is reduced to that of the absorber (E04) through a throttle valve (V111) (process 16 to 17). Rectifier-generator assembly is used to separate ammonia vapour at high pressure so that the heat energy absorbed from evaporator can be rejected at the condenser to be used again in the evaporator to absorb heat energy from brine.

The heat is added to the strong aqua ammonia solution in the generator (E01) during condensation of steam generated in the independent boiler No. 38/02. The condensate coming out of the generator is supplied back to the boiler (process 19-20). As a result, the strong aqua ammonia solution boils and ammonia vapour is relieved from the mixture and leaves the weak aqua ammonia solution in the generator. The weak aqua ammonia solution returns to the absorber through the solution heat exchanger.

Ammonia vapour leaving generator (E01) enters the rectifier (C01) which is installed between generator and condenser at station 3. Since the difference in the boiling point between ammonia and water (absorbent) is not very large, some amount of water is likely to evaporate along with ammonia in the generator. When this water vapour passes through the expansion device, freezes in to ice and chock the line. In the rectifier, some quantity of liquefied refrigerant in the condenser (E03) utilizes as a reflux at station 5 to condense the water vapour part and reduces the carryover of the absorbent in to the condenser. It acts as a desuperheater and condensed water vapour returns to the generator and improve the ammonia concentration in the flow to the condenser. It also helps in maintaining the required temperature of the refrigerant entering the condenser.

It should be noted that there are a large number of utility components and control systems in the AAVAR system for the brine chilling as can be seen in Fig. 3.1. However, they are not heat energy consuming or energy producing systems and hence not considered in the present analysis. Therefore, the schematic of the brine chilling unit using AAVAR system is given in Fig. 3.2 which illustrates the essential components for the purpose of techno-economic analysis.

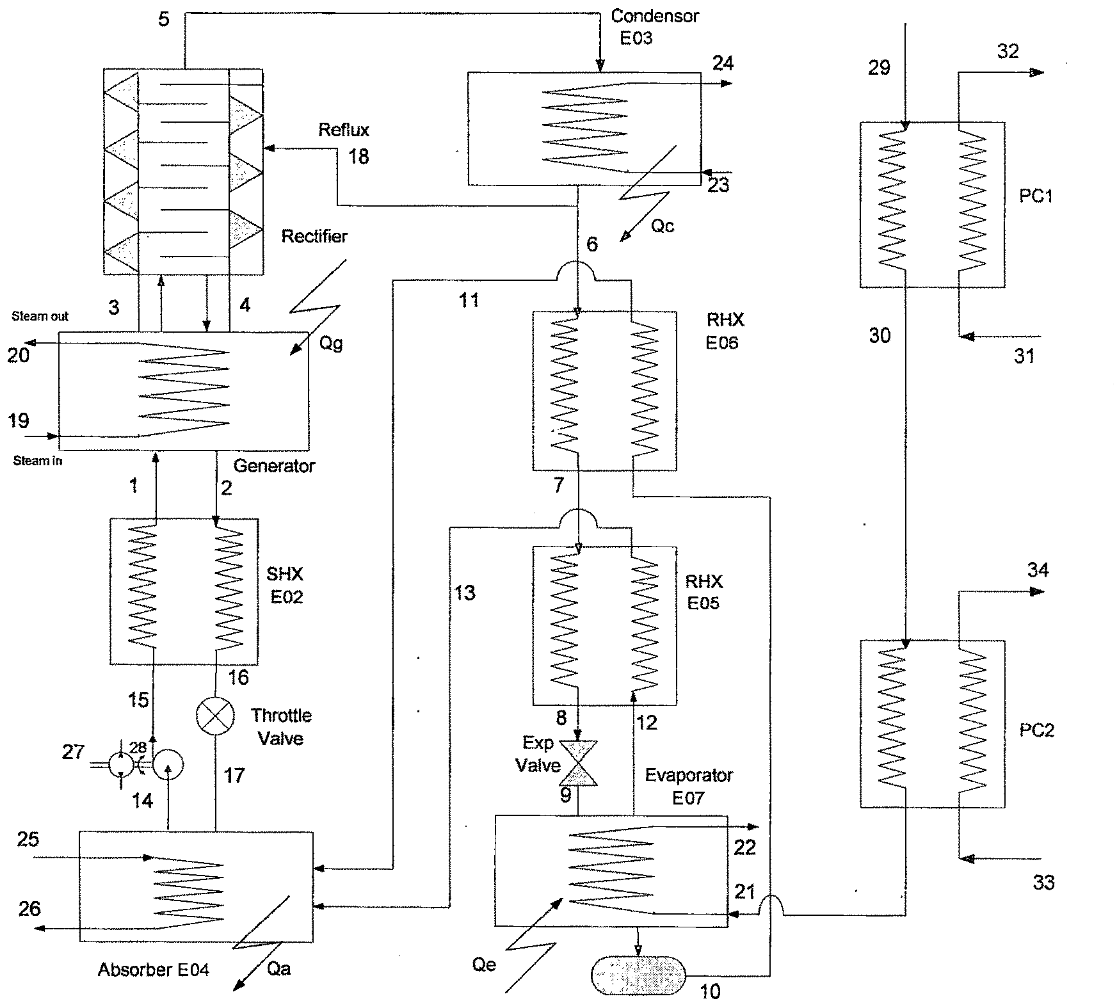

Fig. 3.2 Simplified Brine Chilling Unit with AAVAR System

3.2 Other Options of Heat Energy Sources

It should be recalled that the existing source of heat energy for the operation of 800 TR AAVAR system is steam from a dedicated independent boiler. In order to analyze the effect of the source of heat energy on the cooling cost to be estimated through the application of a proposed unified exergoeconomic optimization scheme, two other existing different schemes for the source of heat energy are also identified.

3.2.1 Steam from GT-HRSG Plant as Heat Source

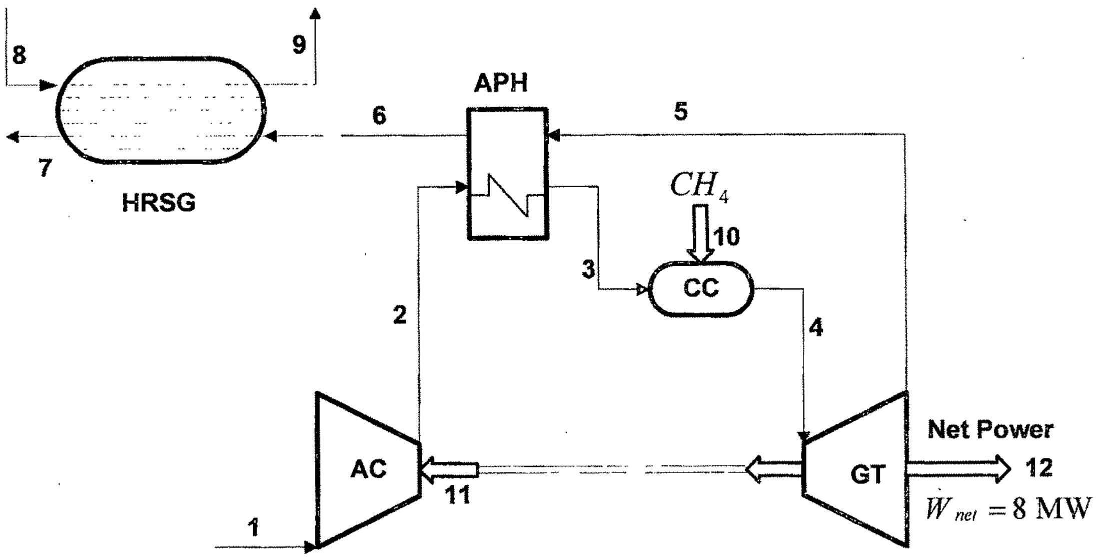

Fig. 3.3 Gas Turbine Power Plant

AC-Air compressor, **GT**- Gas turbine, **APH**- Air Preheater, **CC**- Combustion Chamber, **HRSG** - Heat Recovery Steam generator.

1- Atmospheric air
2 – Compressed air
3 – Preheated air
4- Combustion product
5 – Exhaust gas from turbine
6 – Exhaust gas from APH
7 – Waste gas
8 – feed water
9 – Steam generated
10 – Fuel supply

The first option for replacing the existing heat energy source of steam from the independent boiler for the AAVAR system for brine chilling unit is the steam from the existing 8 MW combined gas turbine power plant with heat recovery steam generator (GT-HRSG). GT-HRSG utilizes natural gas as fuel for its operation. "The waste heat energy" from the exhaust gases from gas turbine power plant is utilized in the generation of steam at a pressure of 33 bar at the existing HRSG (station 9). If the steam generation in HRSG is carried out at 15 bar saturated instead of 33 bar saturated, then this steam will be useful as input heat energy (known as fuel) in AAVAR system. The 8 MW gas turbine power plant with HRSG is shown in Fig. 3.3. The figure is self explanatory.

3.2.2 Tapped Steam from Steam Power Plant as Heat Source

The fertilizer industry also operates a condensing type 50 MW regenerative type steam power plant for its captive power requirement. The steam turbine is having three steam tappings for regeneration purpose at 17 bar, 7 bar and 4 bar. The exhaust steam from the turbine is condensed in the condenser and the condensate is sent to the open feed water heater where the steam from the tap at 4 bar is utilized for heating purpose by direct contact. The resulting feed water is supplied to the second feed water heater which is a closed one in which the steam from the tap at 7 bar is used for heating purpose. After the heating is completed in the closed feed water heater, the feed water is further heated using another closed feed water heater in which the tapping steam at 17 bar is used. After the heating is completed in the heater, the feed water is sent back to the boiler.

Thus, the second option of the heat energy source for the AAVAR system can be the tapping steam from a steam turbine of the existing 50 MW steam power plant. Therefore, it is proposed to increase the steam flow rate from the tapping at 17 bar by 3.2 kg/s and throttle it to 15 bar before sent to the generator of the vapour absorption refrigeration system. The combined system of AAVAR system and the proposed heat energy source from steam power plant is to be exergoeconomically analyzed for minimum cost of power generation and tapping steam for the brine chilling plant. Fig. 3.4 gives the schematic of the Steam power plant considered for the second option of the heat energy source.

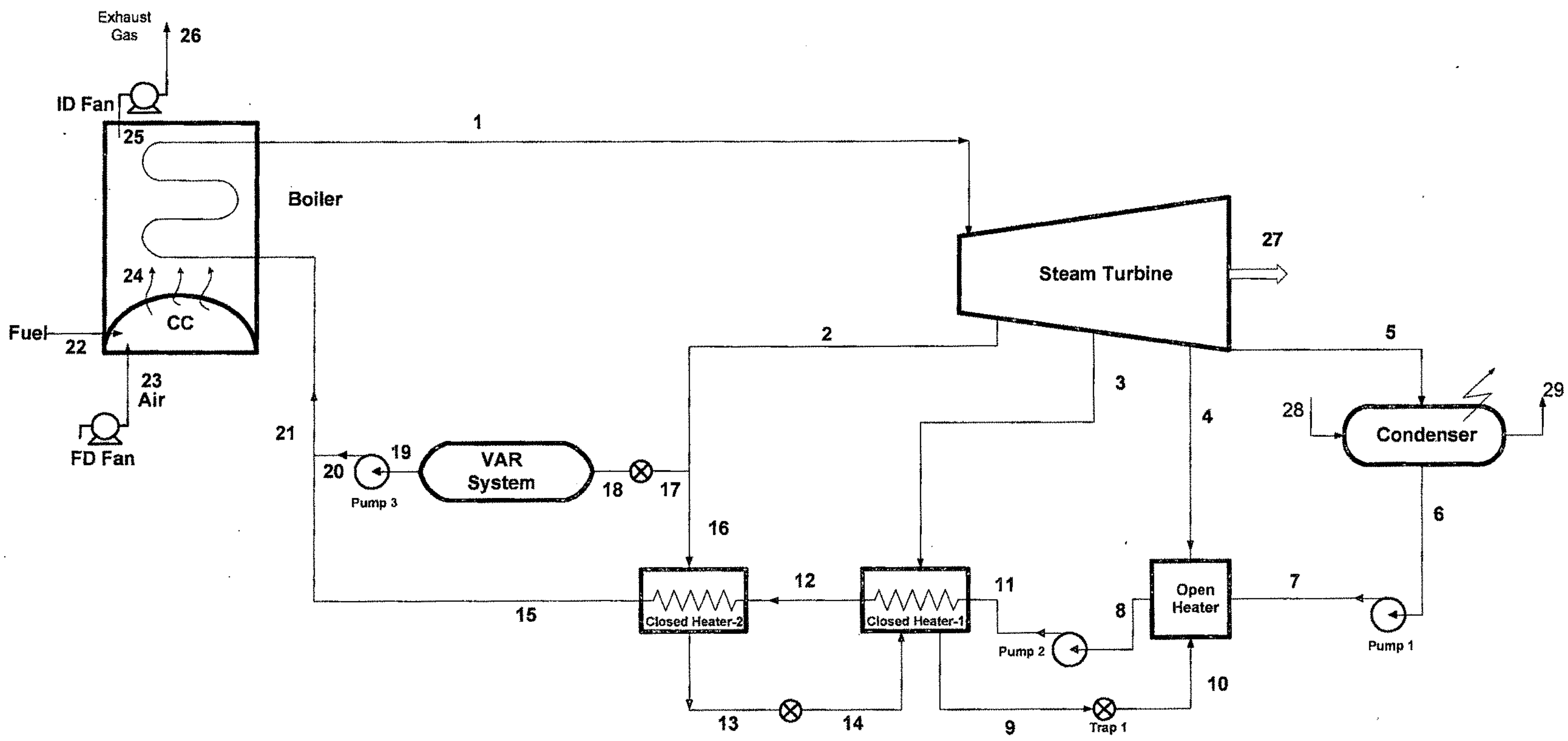

Fig. 3.4 Steam Power Plant

CC-Combustion Chamber, **ID**- Induced Draught, **FD**- Forced Draught, **VAR**- Vapour Absorption refrigeration System.

3.3 Steady State Online Data

The steady state online data during the normal operation of all the three systems are collected from control panel as well as some design data are collected. As the panel data are not complete for the purpose of exergoeconomic analysis, the necessary missing data are generated through system simulation, the details of which are given in Chapter 5.

3.3.1. Online Data for Brine Chilling Unit

Table 3.1. Steady State Online Data for Brine Chilling Unit

Stations	Mass Flow rate kg/sec	Pressure bar	Temp. °C	NH_3 Concentration % wt
1	--	18.90	--	0.270
2	--	18.90	140	0.150
3	--	18.90	140	0.990*
4	--	18.90	100*	
5	--	18.90	60	0.998
6	--	18.00	40	0.998
7	--	18.00	--	0.998
8	--	18.00	--	0.998
9	--	1.90	--	0.998
10	--	1.90	-20	0.970
11	--	1.90	--	0.970
12	--	1.90	-20	1.000
13	--	1.90	--	1.000
14	--	1.77	40	0.270
15	--	18.90	--	0.270
16	--	18.90	--	0.150
17	--	1.77	--	0.150
18	--	18.00	40	0.998
19	--	15.00	198.30	--
20	--	15.00	198.3	--
21	125.00	1.01	5.4	--
22	125.00	1.01	-1.7	--
23	88.06	1.01	33	--
24	88.06	1.01	--	--
25	125	1.01	33	--
26	125	1.01	--	--
27	--	--	--	--
28	--	--	--	--
29	125	1.01	24.70	--
30	125	1.01	--	--
31	2.56	4.00	-1.89	--
32	2.56	4.00	6.40	--
33	2.85	2.3	-15.62	--
34	2.85	2.3	12.50	--

For the chilling unit using vapour absorption refrigeration system the online data are given in Table 3.1. The additional data known are given in Table 3.2.

*Assumed Data

Table 3.2. Additional Data for Brine Chilling Unit

• Steam Condition inlet	15 bar saturated
• Steam condition exit	15 bar,0.27 % dry
• System Capacity	Q_e = 800 TR
• Liquid ammonia passed from PC-1	9.2 tons/hr at 4 bar saturated
• Liquid ammonia passed from PC-2	10.3 tons/hr at 2.3 bar saturated

3.3.2. Online Data for GT-HRSG

The available data for GT-HRSG are given in Table 3.3 and additional data are given in Table 3.4.

Table 3.3. Steady State Online Data for GT-HRSG

Stations	Flow rate m^3/hr	Pressure bar	Temp. °C
1	--	1.013	25
2	--	--	--
3	--	--	--
4	--	--	1247
5	--	1.099	--
6	--	--	--
7	--	1.013	--
8	--	15	25
9	--	15	--
10	--	25	12
11	--	--	--
12	--	--	--

Table 3.4. Additional Data for GT-HRSG

- *Air Compressor*
  - Pressure Ratio : 10 : 1
- *Air Preheater*

- ➢ Pressure drop: 3% on gas side and 5% on the air side
- ➢ Effectiveness: 0.75 (Considered for base case)

- *Heat Recovery Steam Generator*
  - ➢ Pressure drop: 5 % on gas side
- *Combustion Chamber*
  - ➢ Pressure drop: 5 %
- *Gas turbine*
  - ➢ Power Out-Put Rating: 8 MW
  - ➢ Speed: 14045 RPM

3.3.3. Online Data for Steam Power Plant

Table 3.5. Steady State Online Data for Steam Power Plant

Stations	Flow rate kg/sec	Pressure bar	Temp. °C
1	--	96	500
2	--	17	--
3	--	7	--
4	--	4	--
5	--	0.1	--
6	--	--	--
7	--	--	--
8	--	2	--
9	--	6	--
10	--	4	--
11	--	135	--
12	--	134	154
13	--	15	--
14	--	7	--
15	--	133	190
16	--	--	--
17	3.2	--	--
18	--	15	--
19	--	15	--
20	--	133	--
21	--	--	--
22	--	--	--
23	--	--	--
24	--	--	1227
25	--	--	160
26	--	--	--
27	--	--	--
28	2555	1.01	33
29	2555	1.01	--

The online data available for steam power plant in the form of independent variables whose values are specified are kept fixed are given in Table 3.5 and additional data are given in Table 3.6.

Table 3.6. Additional Data for Steam Power Plant

- *Boiler*
  - FD fan draught: 472 mmWC
  - ID fan draught: 230 mmWC
  - Gas side pressure drop in the boiler 170 mm WC approximately.
- *Steam turbine*
  - Rated output: 50 MW
- *Surface condenser*
  - Cooling water flow: 92 m^3/hr