6. CONCLUSIONS

Economic analysis of a few energy sources has been carried out and the optimum generator temperatures obtained corresponding to the minimum operating costs of an absorption cycle with a heat recovery absorber, a two-stage dual-fluid absorption cycle and a two stage evaporation/absorption cycle.

The conclusions that emerge out of this study are as follows:

1. The coefficient of performance of the cycle using water-ammonia mixture increases with \( t_g \), reaches to a maximum value, and then decreases gradually with further increase in \( t_g \), whereas COP of the cycle using LiNO\(_3\)-NH\(_3\) and NaSCN-NH\(_3\) solutions reach to maximum values and become almost constant at high generator-temperatures. The same variation is observed in the two stage absorption-evaporation cycle with \( t_g \) and the cycle at the second stage of the dual-fluid system with \( t_{g2} \).

2. The optimum COP of the LiBr-H\(_2\)O cycle at the first stage in the combined dual-fluid cycle remains constant for all values of \( t_{g2} \) and \( t_{e2} \), irrespective of working fluid being used in the cycle at second stage. However, the optimum generator temperature \( t_{g1} \) depends upon the type of energy used.
3. The maximum value of COP for the two stage absorption evaporation cycle, the combined dual-fluid cycle and the ammonia cycle at the second stage, appear relatively at very low generator temperatures as compared to the single stage cycle.

4. Area of solar collectors and flow rate of gases, including their costs, decrease from high values, become minimum and then increase as generator temperature increases, the optimum generator temperatures being selected for the minimum energy requirement.

5. The optimum generator temperatures vary linearly with condenser temperature for fixed temperatures in evaporator. For the single stage cycle without HRA, ammonia cycle at the second stage of dual-fluid system and two stage absorption evaporation cycle, the optimum generator temperatures are related with condenser and evaporator temperatures in the respective form given below:

\[ t_g = m t_c - n t_e + c. \]
\[ t_{g2} = m t_{c2} - n t_{e2} + c. \]
\[ t_g = m t_c - n t_{e1} + c. \]

6. The optimum generator temperatures in the system using heat
recovery absorber (HRA) are slightly higher than those in the system without HRA. For ordinary flat plate collector operated cycle, they are higher by around 7%. However, for other energy sources, they increase by 2 to 14% in case of H$_2$O-NH$_3$ solution and by 3 to 5% in case of LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ solutions.

7. Among the three fluids selected for use in the single stage absorption cycle with HRA, the optimum generator temperatures in case of NaSCN-NH$_3$ solution come out to be relatively higher than those of H$_2$O-NH$_3$ and LiNO$_3$-NH$_3$ solutions. When compared with the optimum generator temperatures of H$_2$O-NH$_3$ cycle using HRA, percentage deviation in their values, from those of LiNO$_3$-NH$_3$ solution, are -5 to 2%, 3 to 10%, 9 to 14%, and 10 to 16%. And from those of NaSCN-NH$_3$ solution, they are 5 to 20%, 16 to 20%, 19 to 25%, and 22 to 32% when operated by flat plate collector, evacuated tubular collector, biogas and LPG, respectively.

8. Percentage deviation in the optimum generator temperature of the single stage cycle with HRA operated by evacuated-tubular collector, biogas and LPG, from those of flat plate collector operated cycle are respectively, 10 to 36%, 13 to 26%, and 15 to 30% for LiNO$_3$-NH$_3$; while 11 to 18%, 16 to 23%, and 18 to 26% for NaSCN-NH$_3$. However, for
9. The optimum generator temperatures, $t_{g2}$ in the cycle at the second stage of dual-fluid system are found to be around 17 to 90% lower than the temperatures in the single stage cycle with heat recovery absorber.

10. In case of the flat plate collector operated dual-fluid cycle, deviation in the optimum value of $t_{g2}$ in the cycle at second stage using LiNO$_3$-NH$_3$ solution from those of H$_2$O-NH$_3$ solution are very nominal, the latter having little higher values at low evaporator temperatures. However, in case of evacuated tubular collector, biogas and LPG-operated dual-fluid cycle, high temperatures are found. They are around 1 to 20%, 1 to 16%, and 3 to 18% in LiNO$_3$-NH$_3$ and 17 to 33%, 20 to 41%, and 20 to 45% in NaSCN-NH$_3$, respectively.

11. Increase in the optimum generator temperatures of the dual-fluid cycle operated by evacuated type collector, biogas and LPG from those of the flat plate operated cycle are 3 to 15%, 3 to 20% and 5 to 21% in case of LiNO$_3$-NH$_3$ mixture; while for NaSCN-NH$_3$ mixture, they are 5 to 16%, 9 to 20% and 11 to 22%, respectively. However, for H$_2$O-NH$_3$ mixture, they increase only up to 5%.

12. Decrease in the optimum generator temperatures of the two stage absorption-evaporation cycle (TSAEC) from those of...
the single stage cycle with HRA are nearly 23 to 85%.

13. The optimum generator temperatures in the TSAEC becomes lower than those in the dual-fluid cycle, especially at low evaporator temperatures.

14. The possibility of operating the dual-fluid and the two stage absorption-evaporation cycle, unlike the single stage cycle with and without HRA, increases even at very low evaporator temperatures, requiring relatively low generator temperatures.

15. The problem of crystallisation of the solid absorbents in LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ mixtures, especially at low evaporator temperatures and high condenser temperatures, can be eliminated by using either the two stage dual-fluid cycle or two stage absorption-evaporation cycle. However, at the evaporator temperatures below $-40^\circ$C, crystallisation may occur at some operating conditions.

16. Comparison of the optimum values of $t_g$, in the two stage absorption-evaporation cycle using different fluids, with H$_2$O-NH$_3$ solution, show that high generator temperatures, upto 9%, 11% and 12% in LiNO$_3$-NH$_3$, and 26%, 31%, and 33% in NaSCN-NH$_3$ are found for the tubular collector, biogas and LPG, respectively. However, for the flat plate collector, low values of $t_g$ (upto $-10\%$) in case of LiNO$_3$-NH$_3$ while high values (upto $+10\%$) in case of NaSCN-NH$_3$ fluids are observed.
17. For the two stage absorption-evaporation cycle operated by evacuated type collector, biogas and LPG, increase in $t_g$ from the cycle operated by flat plate collector are respectively, 8 to 12%, 7 to 17%, 9 to 23% for LiNO$_3$-NH$_3$ and 8 to 13%, 12 to 17%, 12 to 19% for NaSCN-NH$_3$; being only 1 to 3% for the H$_2$O-NH$_3$ mixture.

18. The optimum values of COP in the single stage cycle, two stage dual-fluid system and the two stage absorption-evaporation cycle (TSAEC), decrease almost linearly with condenser temperature in case of LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ mixtures. However, for H$_2$O-NH$_3$ mixture in the dual-fluid and the TSAEC cycles, it decreases gradually, with a little faster rate at around 30 to 35°C temperatures in the condenser.

19. Increase in the coefficient of performance of the absorption cycle with HRA is around 36 to 95%, 32 to 44% and 25 to 44% in case of H$_2$O-NH$_3$, LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ mixtures, respectively.

20. Increase in COP of LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ from those of H$_2$O-NH$_3$ in the cycle with HRA are 14 to 175%, 17 to 179%, 17 to 113%, 17 to 114% and 11 to 77%, 15 to 104%, 15 to 106% and 15 to 107%, respectively, when powered by flat plate solar collector, evacuated tubular collector, biogas and
LPG.

21. Percentage increase in the optimum values of COP for evacuated-tubular solar collector, biogas and LPG operated cycle with HRA, from those operated by the flat plate solar collector, are around 1 to 9%, 3 to 23%, and 4 to 12% for \( \text{H}_2\text{O-NH}_3 \), \( \text{LiNO}_3\text{-NH}_3 \) and \( \text{NaSCN-NH}_3 \) mixtures respectively; they being more at high values of \( t_c \) and low values of \( t_e \).

22. The conditions at which the cycle with HRA can operate easily, percentage increase in its COP from those of the dual-fluid cycle are around 25 to 102%, 38 to 124%, 28 to 100%, and 29 to 100% for \( \text{H}_2\text{O-NH}_3 \), 94 to 149%, 128 to 152%, 129 to 153% and 127 to 153% for \( \text{LiNO}_3\text{-NH}_3 \) and 94 to 152%, 139 to 157%, 141 to 158% and 140 to 158% for \( \text{NaSCN-NH}_3 \) solution when using ordinary flat plate solar collector, evacuated tubular collector, biogas and LPG, respectively. However, these deviations become low as the evaporator temperature goes down and the condenser temperature becomes high.

23. Increase in COP of the combined dual-fluid cycle, while operating by means of the evacuated type collector, biogas and LPG, from those of the ordinary flat plate collector powered cycle, are around 1 to 5%, 2 to 10% and 2 to 10%, respectively for \( \text{H}_2\text{O-NH}_3 \), \( \text{LiNO}_3\text{-NH}_3 \) and \( \text{NaSCN-NH}_3 \) mixtures.
24. Like those found in case of the dual-fluid cycle, COP of two stage absorption-evaporation cycle are also low as compared to those of single stage cycle with HRA.

25. Percentage increase in COP of the dual-fluid cycle from those of the two stage absorption/evaporation cycle, are around 5 to 50%, 3 to 11% and 4 to 11% for H₂O-NH₃, LiNO₃-NH₃ and NaSCN-NH₃ solutions, respectively. With increasing values of tₑ and decreasing value of tᵣ, these deviations become more in case of H₂O-NH₃ mixtures. However, in case of LiNO₃-NH₃ and NaSCN-NH₃ mixtures, they get reduced.

26. COP of the two stage absorption evaporation cycle using LiNO₃-NH₃ and NaSCN-NH₃ mixtures are generally higher than the one using H₂O-NH₃ solution; increasing upto 364% at low evaporator and high condenser temperatures. However, at high evaporator temperatures, COP of H₂O-NH₃ mixture becomes more, like those found also in the dual-fluid cycle.

27. Water-ammonia solution in the two stage absorption-evaporation cycle (TSAEC) may be operated using any of the energy sources, because there is no appreciable difference in its performance with change in the energy source.

28. Lithium nitrate-ammonia and NaSCN-NH₃ solutions in the
TSAEC, when operated by the evacuated type collector, biogas and LPG, result in high values of COP, around 2 to 16% from those when operated by the flat plate collector. These are same as found in case of the dual-fluid cycle. Therefore, the dual-fluid and the two stage absorption-evaporation cycle, using LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ solution should be operated preferably by the energy sources other than the ordinary flat plate collector.

29. For the flat plate collector-operated absorption cycles (using any of the working fluids) and the H$_2$O-NH$_3$ cycles (operated by any type of the energy sources), area of the solar collectors and volume flow rate of the gases, increase rapidly with the condenser temperature and become quite high at low evaporator temperatures. However, for absorption cycle using other energy sources and the working fluids, they increase almost linearly with the condenser temperature; showing slightly higher values at low evaporator temperatures.

30. Percentage decrease in the operating cost of the absorption system with HRA from those of the cycle without HRA are around 25 to 37%, 26 to 45%, 18 to 34% and 26 to 46% for H$_2$O-NH$_3$; 20 to 29%, 27 to 30%, 19 to 21% and 28 to 30% for LiNO$_3$-NH$_3$ and 21 to 28%, 25 to 29%, 18 to 20% and 26 to 29% for NaSCN-NH$_3$ with flat plat solar collector, evacuated tubular collector, biogas and LPG as the sources of energy, respectively.
31. Operating costs of the absorption cycle with HRA, using H$_2$O-NH$_3$ solution, are considerably higher than those of the cycle using LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ solutions. Decrease in the operating costs of the cycle using LiNO$_3$-NH$_3$ from those of H$_2$O-NH$_3$ are around 11 to 70%, 13 to 64%, 10 to 38% and 14 to 53% respectively when operated by ordinary flat plate collector, evacuated tubular collector, biogas and LPG. Similarly, while using NaSCN-NH$_3$ solution they are 5 to 37%, 11 to 48%, 8 to 37%, 13 to 50%, lower from those of H$_2$O-NH$_3$ solution when operated by the same energy sources, respectively.

32. Maximum increase in the operating costs of the evacuated type collector from those of the ordinary flat plate collector are 90%, 86% and 78% for H$_2$O-NH$_3$, LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ solutions respectively, which are at $t_e=25^\circ$C and $t_e=0^\circ$C. On the other hand, cost of the biogas and LPG-operated cycle, when compared with that of the ordinary type collector, are found to be very low. Percentage decrease in the costs of the biogas operated cycle are around 16 to 70%, 15 to 60%, 20 to 54%, while those of the LPG-operated cycle are 35 to 68%, 37 to 68% and 41 to 64% for H$_2$O-NH$_3$, LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ mixtures, respectively in the absorption cycle with HRA. The LPG-operated cycle seem to be cheaper than the other sources of energy under study.
However, costs of the biogas and LPG-operated cycle are almost equal, except at low values of $t_c$ and high values of $t_e$.

33. Although the single stage cycle with HRA has got limited range of operation, yet its operating costs are quite low, for the cycles operated by the energy sources other than the flat plate collector. For $\text{H}_2\text{O-NH}_3$ solution, they are around 15 to 54%, while for $\text{LiNO}_3\text{-NH}_3$ and $\text{NaSCN-NH}_3$ solutions, they are 41 to 60%. However, for the ordinary flat plate collector operated cycle, especially at low evaporator and high condenser temperature the single stage cycle with HRA become costlier than the dual-fluid cycle. The dual-fluid cycle would, thus be suitable at low evaporator and high condenser temperatures.

34. At high evaporator temperatures, the cycle using $\text{H}_2\text{O-NH}_3$ mixture has the operating costs cheaper than those using the other fluids. But, as the evaporator temperature becomes low, its operating cost increases. Thus, decrease in the operating costs of $\text{LiNO}_3\text{-NH}_3$ from those of $\text{H}_2\text{O-NH}_3$ in the cycle at the second stage of the dual-fluid system, with the ordinary collector, evacuated collector, biogas and LPG as the energy sources are, respectively 76%, 50%, 56% and 70% and with $\text{NaSCN-NH}_3$ mixture, they are around 40%, 33%, 11% and 35%, respectively.
35. Comparison with the ordinary type collector, show that the evacuated type collector would be costlier by around 6 to 117%, 19 to 117% and 41 to 114%, respectively for H$_2$O-NH$_3$, LiNO$_3$-NH$_3$ and NaSCN-NH$_3$ mixtures used in the dual-fluid cycle. While the biogas and LPG-operated cycles would be around 18 to 80% cheaper than those operated by the ordinary type collector.

36. Although, high operating costs, as compared to the cycle with HRA, are found in case of the TSAEC, operated by the evacuated-tubular solar collector, biogas and LPG. The operating costs of the flat plate operated TSAEC get reduced, especially at low evaporator and high condenser temperature.

37. Except for some operating conditions in case of the ordinary flat plate operated H$_2$O-NH$_3$ cycle, the operating costs of the TSAEC are generally higher than the cycle with HRA; decreasing towards low evaporator and high condenser temperatures. With ordinary flat plate collector, evacuated-tubular collector, biogas and LPG as the energy sources, percentage deviation in the costs of the cycle with HRA from those of the TSAEC, for H$_2$O-NH$_3$ solution are +0.36 to -49%, -27 to -55%, -22 to -42% and -32 to -56%, for LiNO$_3$-NH$_3$, they are -4 to -56%, -55 to -63%, -45 to -49% and -59 to -64%, and for NaSCN-NH$_3$ are +5 to -55%, -57 to -63%, -46 to -50% and -61 to -64%.
38. The range of variation in the operating costs of the absorption cycle with HRA and the TSAEC given above, are very large for the flat plate operated cycle, little less for the evacuated-tubular collector and LPG; being least for the biogas operated cycle.

39. The single stage cycle having the heat recovery absorber will be more economical, especially at high evaporator and low condenser temperatures. However, for the evaporator temperatures below \(-30^\circ C\), and in some cases below \(-15^\circ C\), the single stage cycle may not operate due to some limiting conditions of the working fluids. The only alternative then remains, is to use either the dual-fluid cycle or the two stage-absorption and evaporation cycle.

40. The operating costs of the two stage absorption and evaporation cycle are more than those of the two stage dual-fluid cycle, except for some conditions in case of the flat plate operated cycle, where the dual-fluid cycle shows high operating costs.

41. The deviation in the operating costs of the dual-fluid cycle from those of the TSAEC, for \(H_2O-NH_3\) solution, becomes more towards the low evaporator and the high condenser temperatures. While for \(LiNO_3-NH_3\) and \(NaSCN-NH_3\) solutions, this deviation is generally more towards low condenser and high evaporator temperatures.
42. The range of deviation in the operating costs of the two cycles is very large with the ordinary flat plate collector around +7.4 to -44% for H₂O-NH₃, +12 to -34% for LiNO₃-NH₃ and +7 to -30% for NaSCN-NH₃ mixture. For H₂O-NH₃ solution, operated by the evacuated type solar collector, biogas and LPG, decrease in the operating costs of the dual-fluid cycle from those of the TSAEC are, -5 to -34%, -0.26 to -30% and -3 to -34%, respectively. With the same energy sources, decrease in the costs of LiNO₃-NH₃ and NaSCN-NH₃ solutions are, -4 to -10%, -3 to -6% and -5 to -9%, respectively.

43. For some operating conditions, especially at high evaporator and low condenser temperatures, the operating costs of the TSAEC, using LiNO₃-NH₃ and NaSCN-NH₃ solutions are more than the one using H₂O-NH₃ solution.

44. The evacuated-tubular type solar collectors, having sophisticated construction and high quality materials, are much costlier, rising upto 114%, 120% and 114%, from the ordinary type collector when using H₂O-NH₃, LiNO₃-NH₃ and NaSCN-NH₃ solutions in the TSAEC, respectively.

45. The biogas and the LPG operated cycles are cheaper than the ordinary flat plate operated cycles. They are -27 to -87% and -26 to -74% for H₂O-NH₃, -26 to -70% and -24 to -63% for LiNO₃-NH₃, while -30 to -70% and -26 to -62% for NaSCN-NH₃ solution, respectively.