Factors influencing the economics of the Kalina power cycle and situations of superior performance

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Abstract

The Kalina technology has its advantages and disadvantages. Those in favor phrase it like new godsend while the opponents see in it only difficulties and additional complexity. The Kalina cycle is a power cycle and does as such compete with Rankine, Brayton, Diesel and Otto cycles. All theses cycles have their advantages and disadvantages and they are all a theoretical description of real-world machinery. Since the Kalina cycle is fully described in its physical values and material properties then we are able to compare it theoretically with other processes for different boundary conditions (in real life, energy situations). Accumulated cost-knowledge and operational experience, enables us to compare the real life performance of these cycles for a typical geothermal condition, that is source inlet and outlet temperatures and cooling fluid temperatures. The areas of superiority for the Kalina cycle are then presented.

Keywords: *geothermal, Kalina, efficiency, cost.*

1 Introduction

The second law of thermodynamics binds the conversion efficiency of low temperature heat into work or electricity. In addition to that, the conversion of heat from a heat source with a finite heat capacity has a lower upper bound for the efficiency due to the reduction of the source temperature as heat is removed from the source. This results in high cost for such low temperature power plants, as they have to handle large heat flows in order to produce acceptable power.

The Kalina cycle is a novel approach to increase this efficiency. The main benefit of the Kalina cycle is that the heat addition to the process happens at a variable temperature, and can thus be fitted to the falling temperature of a heat source with a finite heat capacity, reducing the generation of entropy in the heat exchange with the primary fluid. The temperature range for the boiling process of the ammonia-water mixture in the Kalina process may be as high as 100°C.

An Organic Rankine Cycle (ORC) is an alternative to the Kalina cycle and has found widespread use. There the boiling of the secondary fluid happens at a constant temperature, meaning that the vapour for the turbine in the process has relatively low temperature compared to the Kalina process.

The adoption of the Kalina cycle to a certain heat source and a certain cooling fluid sink has one degree of freedom more than the ORC cycle, as the ammonia-water composition can be adjusted as well as the system high and low pressure levels.

This paper presents calculations of the installed cost of power plants, both for Kalina and ORC cycles. These calculations are based on cost models from X-Orka Ltd., calibrated with data from tenders to the Husavik power plant in northern Iceland.

The Kalina cycle was selected for the Husavik plant. In their paper R. Maack and P. Valdimarsson (2002) give an overview of the operating experience of the power plant, as well as discussion on the bids that are used for model calibration in the paper.

2 The Models

Thermodynamic models have been established for the power cycles treated here. It is assumed that a fluid is available at temperatures ranging from 100 to 150°C. A heat customer is assumed for water at the temperature of 80°C, so that the temperature of the primary fluid after heat has been supplied to the power plant is fixed at that value. Flow of 50 kg/s is assumed. A large cooling water source is assumed, at the temperature of 15°C, and maximum cooling water temperature is fixed at 30°C. It is assumed that a cooling water pump has to overcome a pressure loss of 1 bar on the cooling waterside in the condenser.

The software Engineering Equation Solver (EES) is used to run the models for each operating condition, using the thermodynamic properties data supplied with that software package. Prof. Pall Valdimarsson described the modelling approach is in a paper (2002).

The cost model keeps the logarithmic mean temperature difference for each heat exchanger at the same value as found in the cycle data for the tenders for the Husavik power plant. Estimated cost figures for individual components were then added together in order to obtain the final cost value.

2.1 ORC Model

The OCR model is based on a system without regeneration. Isopenthane is assumed as a working fluid. Following is a flow sheet for the cycle.

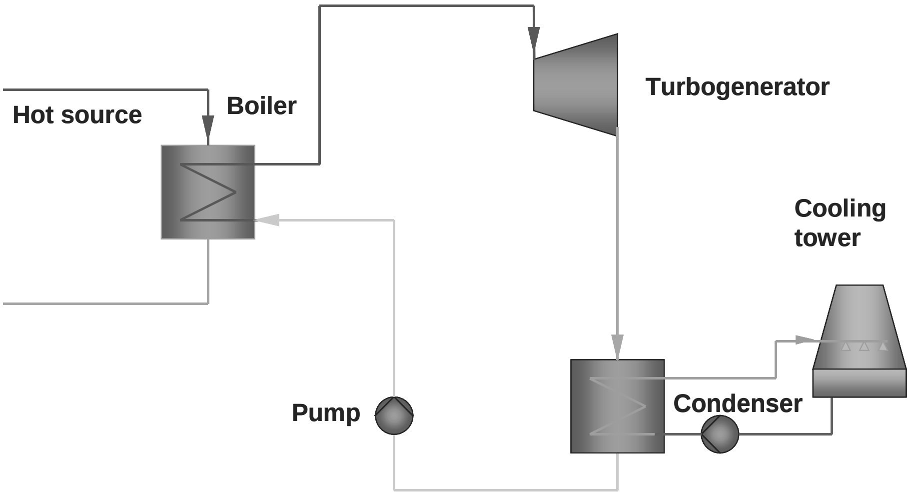

Figure 1: Typical ORC flow sheet.

2.2 Kalina Model

A Kalina cycle for generation of saturated vapour for the turbine is used. The cycle is shown on the following Figure. Henry A. Mlcakt’s (1996) *Introduction to the Kalina Cycle* contains an overview of the Kalina cycle and its applications.

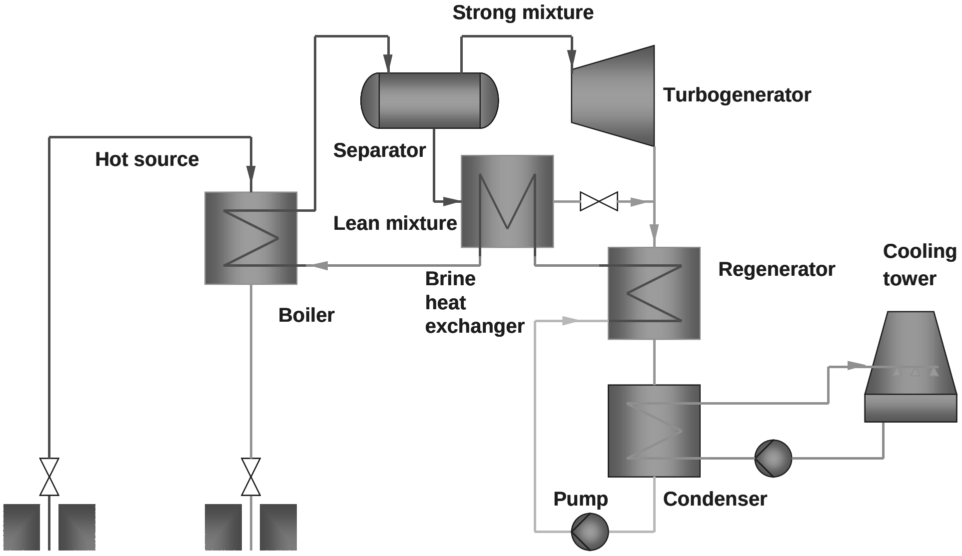

Figure 2: Typical Kalina flow sheet for a saturated vapour cycle.

This cycle will be limited by the dew point of the mixture, that is when the boiling of the mixture is complete, and no liquid remains at the boiler outlet. The bubble temperature of the mixture has an influence as well, as it has to be lower or equal to the primary fluid outlet temperature to ensure safe operation. Then good utilization of the primary fluid is ensured. A contour diagram of the bubble and dew temperatures for ammonia-water mixture as a function of ammonia content and pressure are found on Figures 3 and 4.

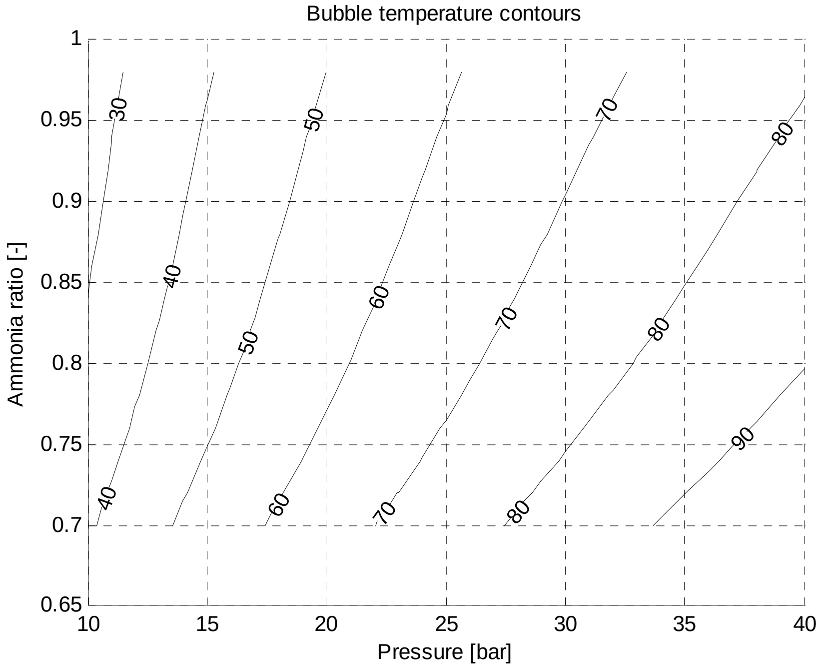

Figure 3: Bubble temperature contour for ammonia-water mixture.

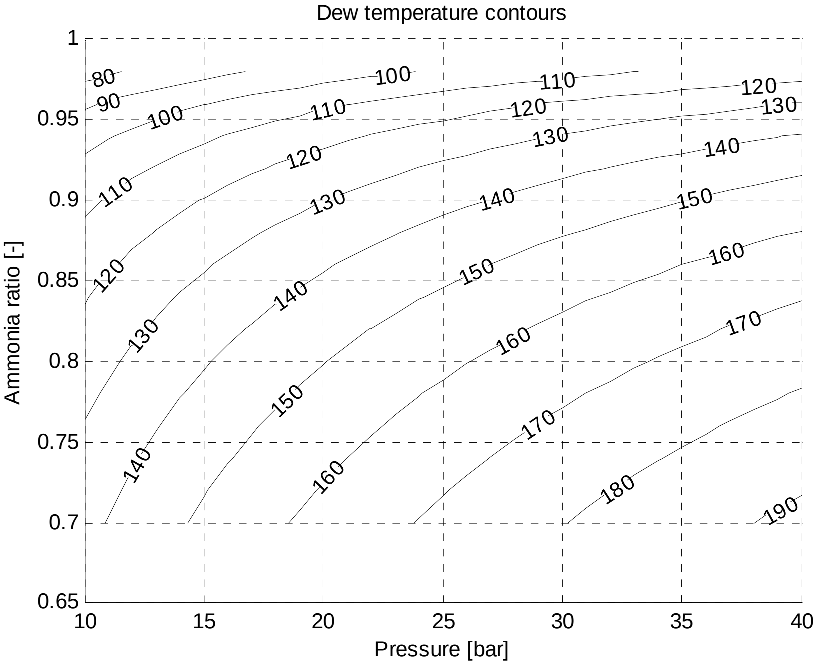

Figure 4: Dew temperature contour for ammonia-water mixture.

The region of feasible combinations of ammonia content and pressure will be in the area between the 70 and 80°C bubble contours. The feasible area regarding the dew temperature for the Kalina cycle studied here is limited on the right and lower side (south-east) by a contour line with a value some 2-4°C lower than the maximum temperature of the primary fluid.

A discussion on the general properties of the ammonia-water mixture in the Kalina cycle, as well as presentation of the cycle in a thermodynamic property diagram is given in the above cited paper by R. Maack and P. Valdimarsson (2002) *Operating experience with Kalina power plants*.

3 Further on the Kalina cycle

3.1 Flexibility

Both high-pressure level and ammonia content are design variables in the Kalina cycle. This gives the designer additional flexibility in the design of the cycle, and requires as well a certain design strategy. Market situations may demand that the plant is designed for absolute maximum power, and less regard paid to the cost per installed kilowatt, or if the load duration curve is not flat, strong demands on the investment cost, but less emphasis put on the total power. This is shown on Figures 5 and 6, where the contour lines for installed cost and power are drawn as a function of ammonia content and pressure. The source temperature is 100°C. The cost values are put at 100 for the lowest cost, and the power values at 100 for the highest power. An x denotes an infeasible solution, the cycle will not be able to run at these ammonia content - pressure combinations. In Geir Þórólfsson's MSc thesis (2002) a thorough study of the influence of these combinations on the final cost figures is made.

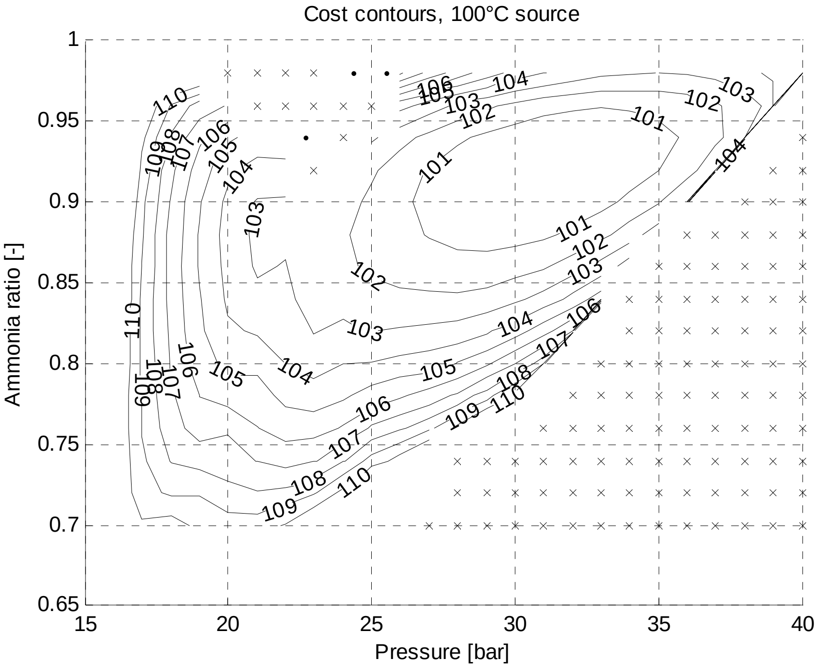

Figure 5: Cost contours for a Kalina cycle running at 100/80° source temperatures.

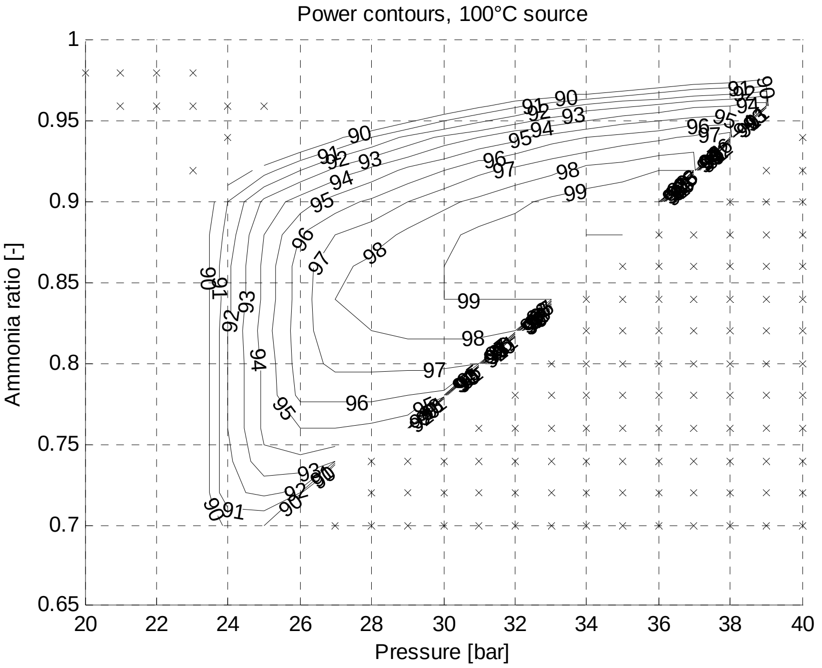

Figure 6: Power contours for a Kalina cycle running at 100/80° source temperatures

It can be seen from these contour diagrams, that the best power and best-cost points are different. The lowest cost is at 32 bar, 92% ammonia, but highest power is at 34 bar and 88% ammonia.

This leads to the definition of two different Kalina cycles, the best power and the best-cost cycles, with different pressure and ammonia content.

The same diagrams for 120 and 150°C source temperature are on Figures 7 to 10.

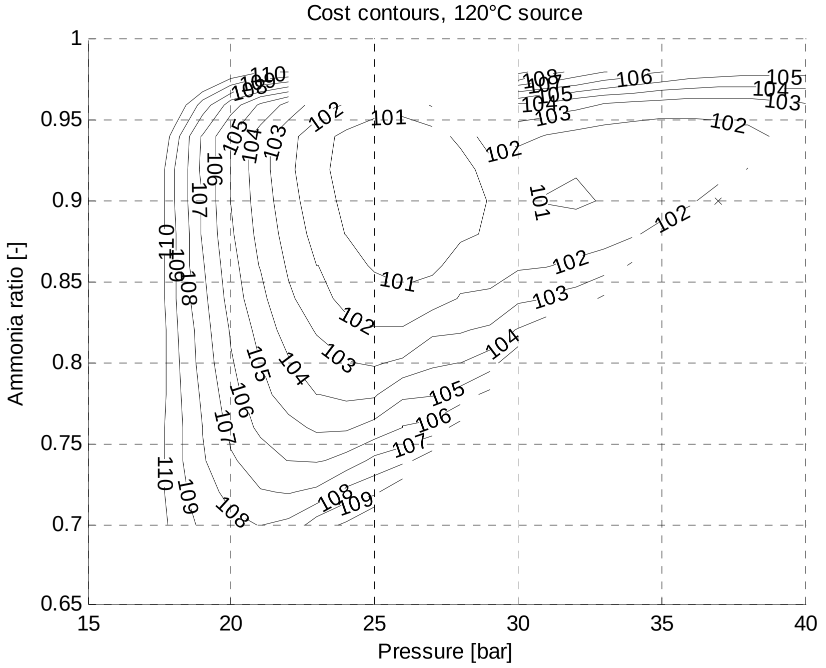

Figure 7: Cost contours for a Kalina cycle running at 120/80° source temperatures.

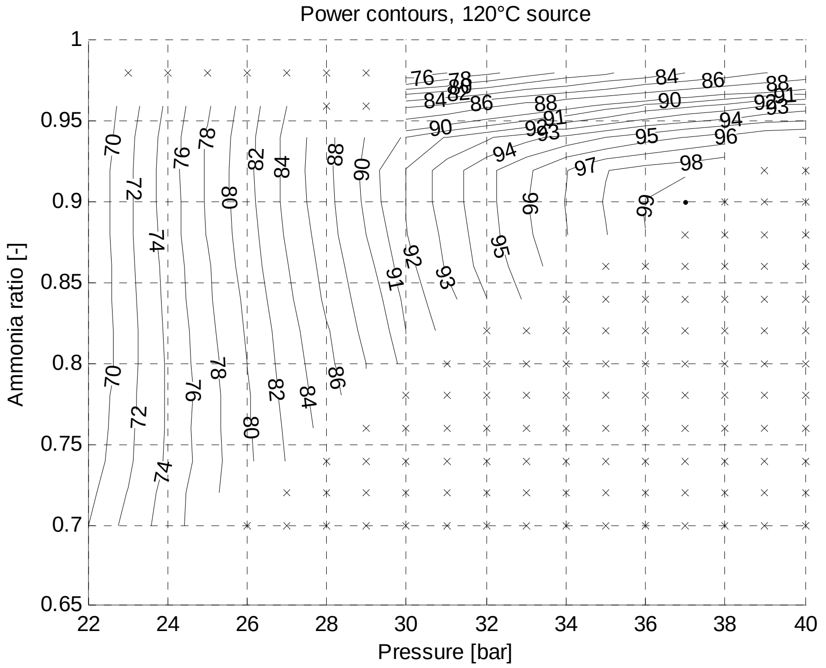

Figure 8: Power contours for a Kalina cycle running at 120/80° source temperatures.

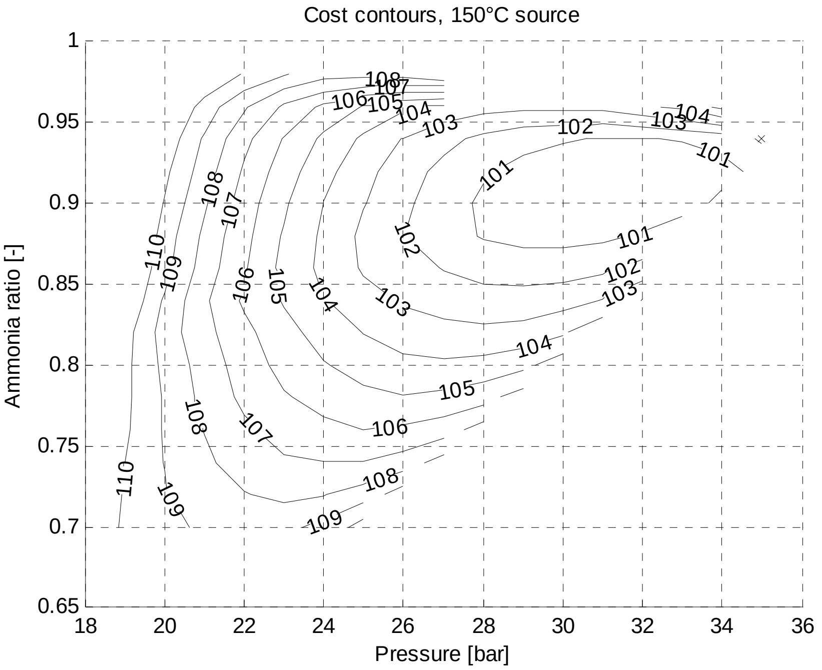

Figure 9: Cost contours for a Kalina cycle running at 150/80° source temperatures.

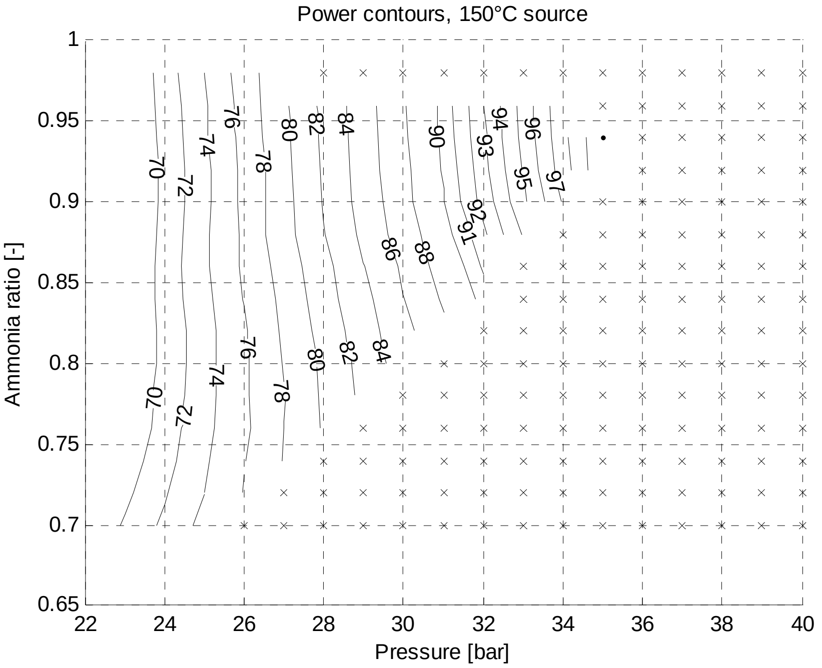

Figure 10: Power contours for a Kalina cycle running at 150/80° source temperatures.

4 Comparison

Two ORC companies made a tender in the Husavik bid. Manufacturer A offered a high power, high cost power plant, where manufacturer B took a more conservative approach.

Figures 11 and 12 contain the results of the calibrated model. The two ORC power plants are indicated with dotted lines. Solid lines indicate Kalina power plants, the + marker the high power variant, and the o marker the low cost variant.

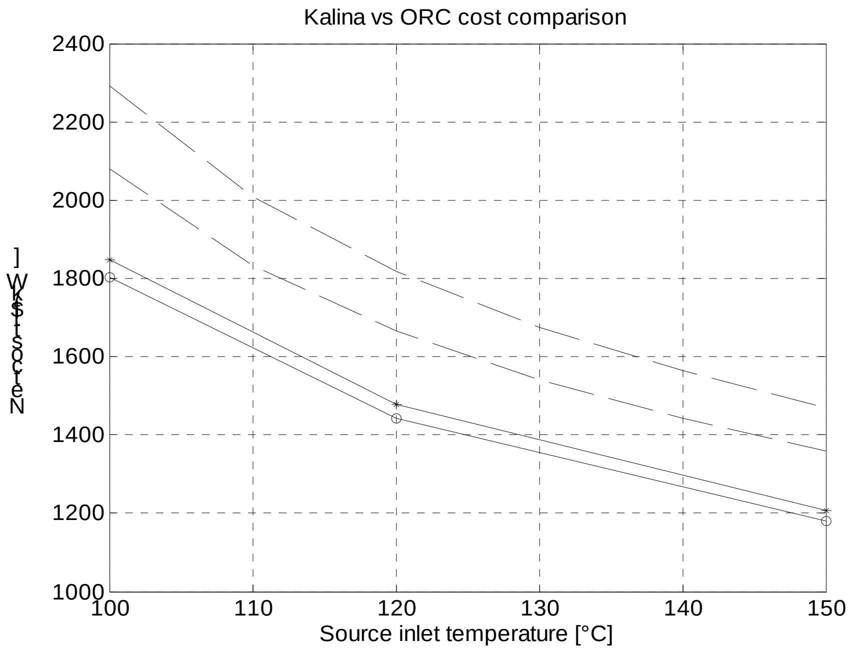

Figure 11: Kalina vs ORC cost comparison.

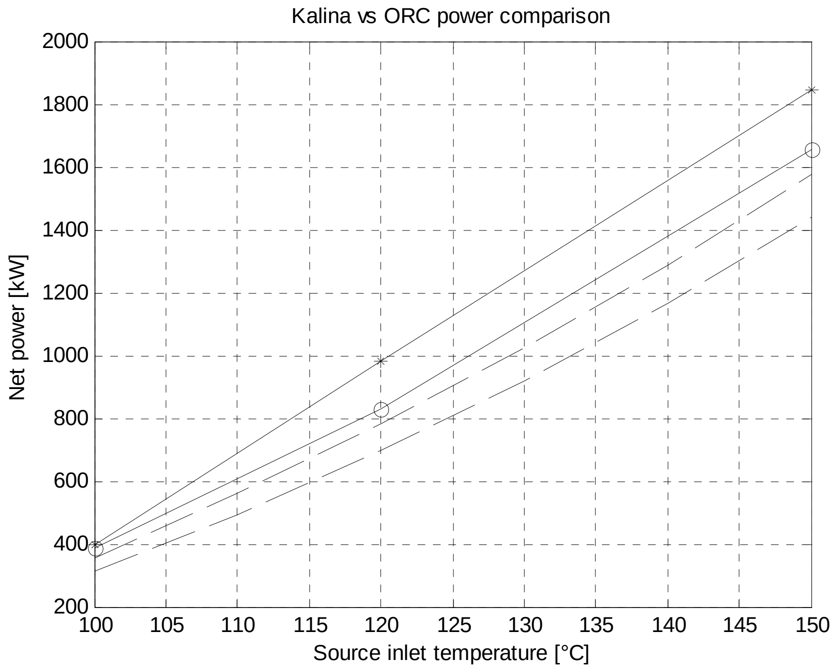

Figure 12: Kalina vs ORC power comparison.

5 Conclusion

The model results presented in Section 4 show that the Kalina cycle has similar installed cost to a high power ORC cycle. The maximum power generated for a given source is greater for the Kalina cycle.

This leads to the obvious conclusion that the Kalina cycle is well positioned against an ORC cycle for applications with high utilization time, a base load application.

It is to be stated here as well, that the assumption of a heat consumer is beneficial for the ORC cycle as it results in less temperature change of the primary fluid during the boiling process. The Kalina cycle has the boiling or vaporization of the fluid happening over a temperature range up to 100°C, which is beneficial when the primary fluid return temperature has to be minimized.

There has been a heated debate when one is comparing ORC and Kalina. The theoretical efficiency and cost/production ratio are much better for Kalina as shown above. Other arguments like difficulties with machinery and lesser operational security or uptime are only_temporary discussion items, as always for a new technology. These arguments were exactly the same between conventional flash cycle and ORC when the latter popped up 30 years ago with better efficiency but little track record.

Ammonia has been used in a freezing plant for decades and ammonia-water mixture on heat pumps (and small refrigerators), so the fluid is not new. It has also been the cornerstone of geothermal utilization to overcome technical difficulties such as from aggressive geothermal fluid and view such issues rather as tasks than obstacles in our quest for best possible use of our geothermal resources.

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