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# Development of a Co-relation between Cycle Efficiency and Known System Conditions of an Ideal Reheat Rankine

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***Abstract*** **- The development of co-relations is an active field of research, carried out by engineers and scientists of today. The need for a co-relation arises from the advantages that it promises by drastically reducing time as well as computational power required in order to solve a specific problem. The problem could be a simple real-life problem or an iteration of a set of parameters, in order to determine the optimal ranges of a specific system. The main aim of this research paper focuses on sinusoidal technique to form a co-relation between the different design parameters (Independent Parameters), and the cycle efficiency (Dependent parameter). This co-relation technique has been implemented on an Ideal Reheat Rankine Cycle, which is the most common power cycle used in modern steam power plants. The field of this research can be extended to the determination of other system values such as pump power requirements, condenser power requirements, etc. The systematic method for the development of the co-relation is discussed in detail in the research paper. The mathematical modeling has been done on Engineering Equation Solver (E.E.S) software.**

***Keywords - Numerical Analysis, Thermodynamics, Curve Fitting, Co-relation, Rankine Cycle***

## I. Introduction

Rankine cycle is a thermodynamic cycle that produces work by consuming heat. Around 80% of the world electricity is generated by power plants using simple Rankine cycle or its derivatives, reheat Rankine cycle being a smart alternative. One of the most important features in this cycle is reheating of steam. Plant performance is increased by the reheating process as it increases power output and sometimes, the thermal efficiency of the plant. Pressure and temperature of the reheat process can be varied over a wide range of values. Therefore, there always exists an optimum value of the reheat temperature and pressure that produces the optimum efficiency [1].

## II. Description

The focus of the project was to devise a co-relation for an Ideal Reheat Rankine cycle using steam as its working fluid. It must be kept in mind that although the real Rankine cycles behavior deviates by a small extent from that of the Ideal Reheat Rankine cycle, however the calculations done for the Ideal Reheat Rankine cycle are still favored as they provide a value of the max possible efficiency obtainable by a Power plant [2].

The co-relation eliminates the tedious and orthodox process of calculating the efficiency of the cycle, which involved primarily extracting the corresponding values of the enthalpies at the six different states of the Rankine cycle using the IAPWS tables (International Association for the Properties of Water and Steam) tables, and then using these enthalpies for calculating the ratio of Net Workdone to Net Energy supplied to the cycle and thus calculating efficiency. The co-relation development method introduced by us creates a very accurate co-relation equation and completely eliminates the need for extracting enthalpies at the different states of the cycle. The co-relation equation besides being simple to use, provides fairly accurate results with a percentage error (percentage difference in actual and co-relation efficiency) of only ± 6%. It must also be pointed out that the research done in this regard is in no way exhaustive and further research will undoubtedly reduce the max percentage error. The max value of Percentage error occurs near the extreme values of the independent state parameters.

There are several different well established methods of developing co-relations equations such as the Pearson method, Spearman method, Point Biserial method as well as the Phi method [3]. Although all of these methods are well documented and have their specific domains of application. The method introduced by us possesses a unique set of characteristics and provides accurate results in several domains of application.

## III. Methodology

The following pages explain the development of the methodology step by step along with the relevant figures.

### *A. Slection of dependent and indenpent parameters*

The first step carried out was to establish an understanding of the independent parameters and differentiate them from the dependent parameters. Design parameters are usually considered to be the independent parameters which in our case are Condenser Pressure ($P_1$), Boiler Pressure ($P_2$), High Pressure Turbine Inlet Temperature ($T_3$), Reheat Pressure ($P_4$), and Low Pressure Turbine Inlet Temperature ($T_5$). Under the current field of research we have decided to choose Cycle Efficiency as the main parameter of interest, hence it becomes our Dependent Parameter throughout the course of this paper. It must be noted that this field of research can also be extended as to find different dependent parameters of our choosing [4].

Parameter Ranges

- $25 \leq P1 \leq 55$
- $8000 \leq P_2 \leq 16000$
- $450 \leq T_3 \leq 750$
- $4000 \leq P_4 \leq 8000$
- $450 \leq T_5 \leq 750$

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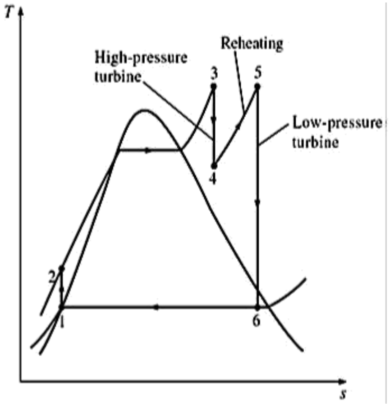


Figure 1: T-s diagram of Ideal Reheat Rankine Cycle

*B. Analyzing the individual effect of each independent parameter on Cycle Efficiency*

The second step involved analyzing the individual effect of each independent parameter on Cycle Efficiency. Although the efficiency of the cycle is dependent on the set of values of all the independent parameters, while observing the individual effect of a single independent parameter at a time, the values of all the other independent parameters were set to the median of their corresponding max possible ranges (The max possible ranges for every independent parameter were chosen after analyzing numerous number of examples from conventional power plant systems, however the co-relation method can be modified conveniently to accommodate the desired set of ranges).

*The Effect of Boiler Pressure on Efficiency*

If a plot between boiler pressure and cycle efficiency is constructed, while all the other four variables are kept constant, then the trend observed indicates that increasing the boiler pressure increases the cycle efficiency, hence it can be concluded that boiler pressure has a "Positive" effect on Cycle Efficiency.

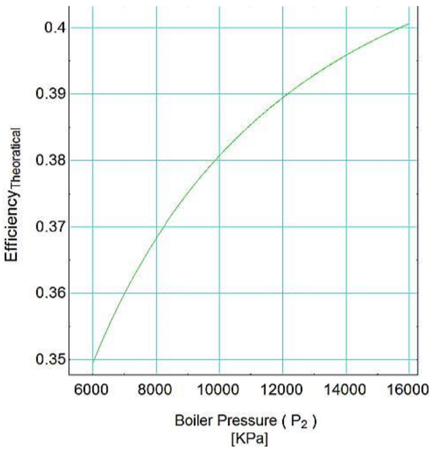


Figure 2: Effect on Efficiency due to variation in Boiler Pressure ($P_2$)

*The Effect of Reheat Pressure on Efficiency*

A plot between reheat Pressure and Efficiency clearly indicates that increasing the Reheat Pressure causes a decrease in efficiency, and hence it can be concluded that increasing the Reheat Pressure has an adverse or a "Negative" effect on Cycle Efficiency.

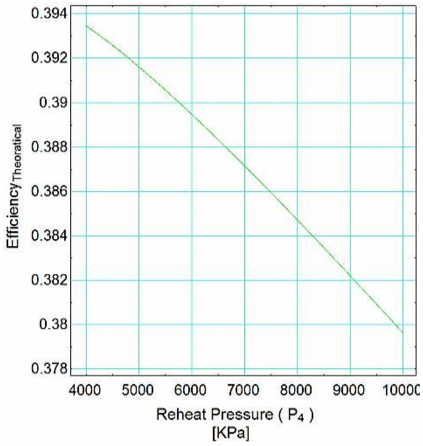


Figure 3: Effect on Efficiency due to variation in Reheat Pressure ($P_4$)

*The Effect of Condenser Pressure on Efficiency*

As the condenser pressure is increased it is observed that the cycle efficiency decreases, hence increasing the Condenser Pressure too has a "Negative" effect on Cycle Efficiency.

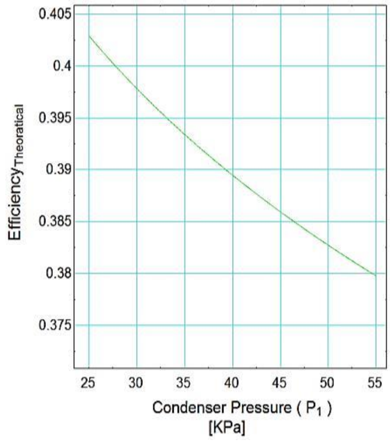


Figure 4: Relation on Efficiency with respect to Condenser Pressure ($P_1$)

*The Effect of High-Pressure Turbine Inlet Temperature on Efficiency*

As the high-pressure turbine inlet temperature is increased, the cycle efficiency increases, thus increasing the High-Pressure Turbine Inlet Temperature has a "Positive" effect on Cycle Efficiency.

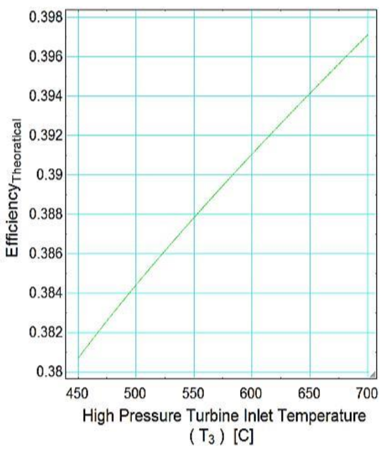


Figure 5: Effect on Efficiency due to variation in High Pressure Turbine Inlet Temperature ($T_3$)

*The Effect of Low-Pressure Turbine Inlet Temperature on Efficiency*

Similarly if we increase the low-pressure turbine inlet temperature, the cycle efficiency increases, thus increasing the Low-Pressure Turbine Inlet Temperature has a "Positive" effect on Cycle Efficiency.

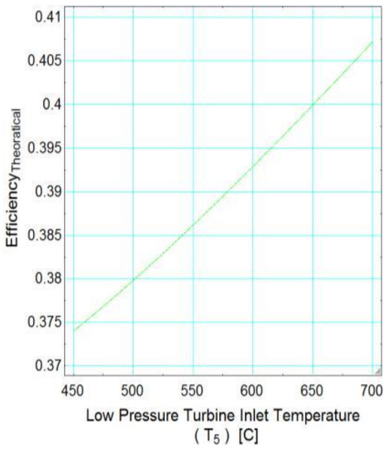


Figure 6: Effect on Efficiency due to variation in Low Pressure Turbine Inlet Temperature ($T_5$)

## C. *Formulation of Co-relation*

This is the most important step in the creation of our co-relation method. It involved choosing a fundamental graph of any independent parameter vs. efficiency and superimposing the graph with the effects on efficiency as a second independent parameter's value fluctuates in its max possible range.

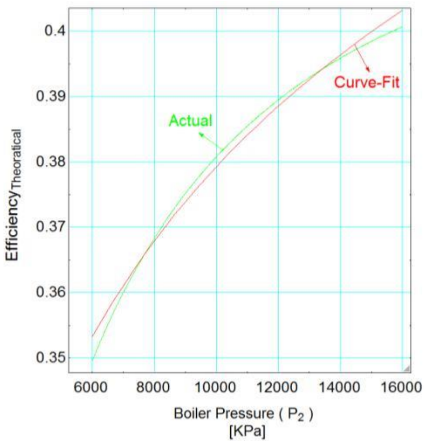


Figure 7: Curve Fit on the plot of Boiler Pressure versus Efficiency

We chose the graph of Boiler Pressure vs. Efficiency as our fundamental graph. In order to find a direct one-to-one relation between the Boiler Pressure and Efficiency, there are several different methods available. Some methods involve the manual iterations of mathematical polynomial, logarithmic or exponential equations of different functions. Other methods take the use of specially developed mathematical software to automatically compute the equation with the "best-fitting" characteristics. There were even some "curve-fitting" built in options in the E.E.S software. Using this command in the software we found the "best-fitting" curve to be logarithmic in nature and posses the least percentage error. Although a higher degree polynomial equation was giving an equation with an even lower percentage error, however it was not taken into account as it was tedious in nature.

The corresponding equation for the logarithmic curve-fit is as follows:

$$Efficiency = -0.0895389 + 0.0508975 \ln P_2$$

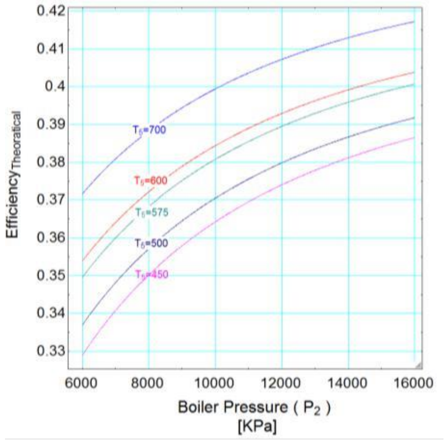


Figure 8: Low Pressure Turbine Inlet Temperature's effect on Boiler Pressure versus Efficiency Plot.

Recall, that the plot of Boiler Pressure vs. Efficiency was made while keeping the values of all the other Independent parameters to be the median of their ranges. Now if we overlay the original plot of Boiler Pressure vs. Efficiency with its different trends during the variation of the Low-Pressure Turbine Inlet Temperature, the following multi-plot graph is obtained. It must be noted that the "center-plot" in the following graph corresponds to the original Boiler Pressure vs. Efficiency plot. This central plot will be the "key-stone" in the formulation of our co-relation method.

If we look closely, we observe that the arc-like graphs seem to be identical in nature and can be called as the translations along the y-axis of the Key-stone plot (Plot at $T_5$= 575). This forms the basis of converting physical plots into mathematical equations.

One who is familiar with trigonometric functions realizes the fact that different coefficients of a trigonometric equation control or dictate the amplitude as well as the number of periods of the trigonometric graph [5]. For example, let us consider the following trigonometric equation;

$$y = A \sin(B)$$

In this case the Coefficient 'A'decides the amplitude (height of the max point above the normal), whereas the Angle 'B' decides the number of periods (number of complete graphs) of the trigonometric function. The main feature of our co-relation was to physically quantify the phenomenon observed in the above graph, by manipulating the value of Coefficient "A" and Angle "B" and thus "quantize" the physical translation of these graphs. Throughout the course of research we agreed on using the Sinusoidal Trigonometric function for manipulation of the physical graphs as it was the simpler as compared to the Cosine Trigonometric function. Further manipulation can ensure the integration of the Cosine Trigonometric function, however there is no apparent advantage of doing so.

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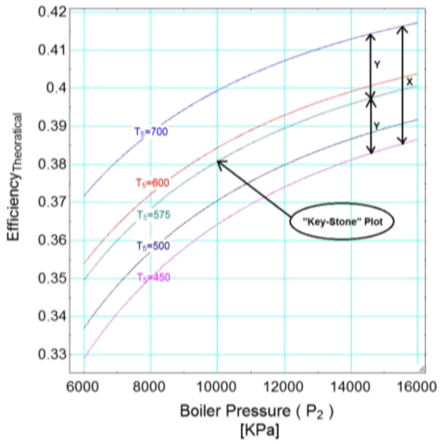


Figure 9: Referencing on the graph indicating Low Pressure Turbine Inlet Temperature's effect on Boiler Pressure versus Efficiency Plot.

Since the graphs are actually translations of the "Key-Stone" Plot, the distance marked as 'X' remains constant throughout the graph. Its physical value can be easily estimated by taking the difference of the Efficiency values of the extreme graphs at the point where Boiler pressure is equal to 10,000 KPa.

$$X = (\text{Efficiency of plot at } T_5 = 700) - (\text{Efficiency of plot at } T_5 = 450)$$
$$X = (0.39555) - (0.365525)$$
$$X = 0.030025$$

Since from the graph it is apparent that '2Y'= 'X'

$$Y = 0.0150125$$

Hence we have been able to acquire the equivalent of 'A' in our example trigonometric equation.

Where 'A' = 'Y'

$$A = 0.0150125$$

The tricky part now is to obtain the equivalent value of the Angle 'B' such that the increment of values of temperature T5 from 575 to 700 results in a "linear increment" in the value of efficiency and the decrement of values of temperature T5 from 575 to 450 results in a "linear decrement" in the value of efficiency.

Let us look back at the example trigonometric Sinusoidal function;

$$y = A\sin(B)$$

If A=1 and if B is in degrees and fluctuates from -90 to +90, then y fluctuates from -1 to +1 respectively.
$(-90 \le B \le +90)$ $\rightarrow (-1 \le y \le +1)$

So if we chose the value of our Custom Angle 'B', such that it is dictated by the value of T5, however the Angle itself still fluctuates between the range of -90 to +90.

$$[450 \le T_5 \le 575]$$

Subtracting 575 (the median value of T5) from all the three sides we get;

$$((450 - 575) \le (T_5 - 575) \le (700 - 575))\ (-125 \le (T_5 - 575) \le +125)$$

Next in order to convert the range values of -125 and +125 to -90 and +90 respectively, we multiply it with a "Correction Factor", 'Z' that is calculated as follows;

$$-125 \times (\,) = -90 \quad -90 \quad 18$$
$$(\,) = {}_{-125} = {}_{25}$$

When we multiply all the three sides of the equation with this Correction Factor, the equation becomes;

$$18 \qquad 18 \qquad 18$$
$$((-125 \times \quad {}_{25}) \le ((T_5 \quad - 575) \times ( \quad {}_{25})) \le (+125 \times \quad {}_{25} \quad ))$$
$$18$$
$$(-90 \le ((T_5 - 575) \times (25)) \le +90)$$

Hence our Custom Angle 'B' comes out to be equal to;

$$18\ ((T_5 - 575) \times (25))$$

Hence our final Custom trigonometric equation which "quantizes" the effect of the variation of the second independent parameter turns out to be as follows;

Compensation of the Effect of variation of Low Pressure turbine inlet temperature

$$18 = 0.0150125 \sin((T_5 \quad 575) \times (25))$$

Recall that, increasing the Low-Pressure Turbine Inlet Temperature has a "Positive" effect on Cycle Efficiency. Hence, we must add this effect to the original equation simply relating Boiler Pressure and Efficiency;

$$\text{Efficiency} = (-0.0895389 + 0.0508975 \ln P_2) + ( \quad h \quad )$$
$$\text{Efficiency} = (-0.0895389 + 0.0508975 \ln(P_2)) + 0.0150125\ {}_{18} \sin((T_5 - 575) \times (25))$$

Hence we get the cycle efficiency which currently accounts for two independent parameters namely; Boiler Pressure and Low-Pressure turbine inlet temperature. In order to account the effect on efficiency by the remaining three independent parameters, we carry on the same procedure as mentioned above and gradually account for all the remaining Independent Parameters.

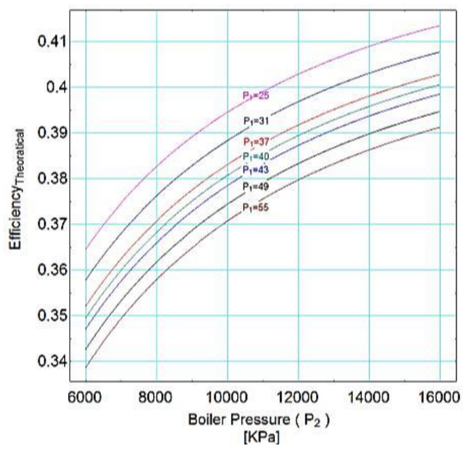


Figure 10: Condenser Inlet Pressure's effect on Boiler Pressure versus Efficiency plot.

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Next we consider the effect of the variation of the Condenser Inlet pressure on the trends of the plot of Boiler Pressure vs. Efficiency.

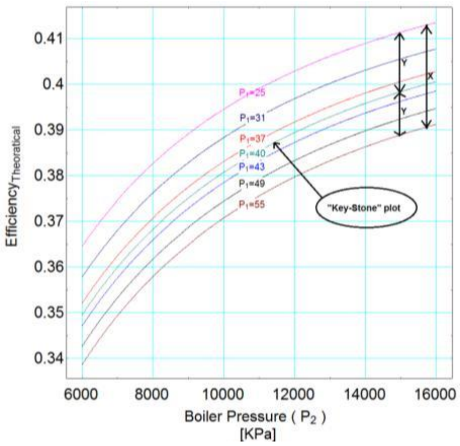


Figure 11: Referencing on the graph indicating Condenser Inlet Pressure's effect on Boiler Pressure versus Efficiency Plot.

Once again applying the same methodology, we extract the constant distance 'X' by taking the difference of the efficiencies of the extreme plots at a clearly visible value of Boiler Pressure say at 12,000 KPa, and calculate the distance 'Y'.

$$X = (\text{Efficiency of plot at } P_1 = 25) - (\text{Efficiency of plot at } P_1 = 55)$$
$$X = (0.4055) - (0.3790)$$
$$X = 0.0265$$

From the graph, in this case, we can approximate that '2Y' ≈ 'X'

$$Y = 0.01325$$

Hence

$$= 0.01325$$

Similarly the next step is to obtain the equivalent value of the Angle 'B' such that the increment of values of Pressure P1 from 40 to 55 results in a "linear decrement" in the value of efficiency and the decrement of values of temperature P1 from 40 to 25 results in a "linear increment" in the value of efficiency.

So we chose the value of our Custom Angle 'B', such that it is dictated by the value of P1, however the Angle itself still fluctuates between the ranges of -90 to +90.

$$[25 \leq P_1 \leq 55]$$

Subtracting 40 (the median value of P1) from all the three sides we get;

$$((25 - 40) \leq (P_1 - 40) \leq (55 - 40)) \; (-15 \leq (P_1 - 40) \leq +15)$$

Next in order to convert the range values of -125 and +125 to -90 and +90 respectively, we multiply it with a "Correction Factor", 'Z' that is calculated as follows;

$$-15 \times (Z) = -90$$
$$(Z) = \frac{-90}{-15} = 6$$

When we multiply all the three sides of the equation with this Correction Factor, the equation becomes;

$$((-15 \times 6) \leq ((P_1 - 40) \times (6)) \leq (+15 \times 6))$$
$$(-90 \leq ((P_1 - 40) \times (6)) \leq +90)$$

Hence our Custom Angle 'B' comes out to be equal to;

$$((P_1 - 40) \times (6))$$

Hence our final Custom trigonometric equation which "quantizes" the effect of the variation of this third independent parameter turns out to be as follows;

$$\text{Compensation of the Effect of variation of Condenser Pressure} = 0.01325 \sin((P_1 - 40) \times (6))$$

Recall, that increasing the Condenser Pressure has a "Negative" effect on Cycle Efficiency, hence we must assign a negative sign to this "effect" and add it to the equation currently accounting only for the two independent parameters; Boiler Pressure and High-Pressure Turbine inlet temperature.

$$\text{Efficiency} = (-0.0895389 + 0.0508975 \ln P_2) + \frac{}{18}(0.0150125 \sin((T_5 - 575) \times (25))) + (-\text{Compensation of the Effect of variation of Condenser Pressure})$$

Hence, now the equation becomes:

$$\text{Efficiency} = (-0.0895389 + 0.0508975 \ln P_2) + \frac{}{18}(0.0150125 \sin((T_5 - 575) \times (25))) - (0.01325 \sin((P_1 - 40) \times (6)))$$

Next, catering for the effect of the variation of the High-Pressure Turbine Inlet Temperature on the trends of the plot of Boiler Pressure vs. Efficiency.

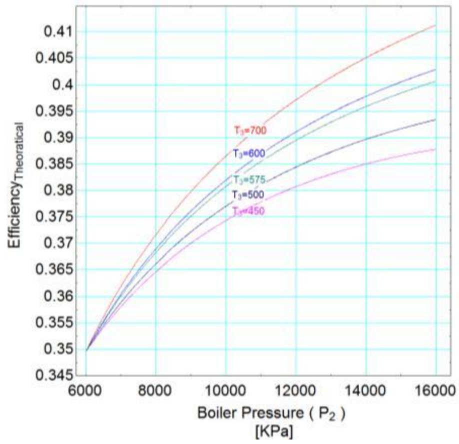


Figure 12: High Pressure Turbine Inlet Temperature's effect on Boiler Pressure versus Efficiency Plot.

As you can observe that the above graph differs from the rest of the graphs as the distance between its plots does not remain constant, hence in this case we make a simplifying approximation by treating the distance between the graphs as a constant. This is done by taking the average distance between the extreme graphs. This is done by firstly measuring the lengths 'U' and 'V' and taking their average. Hence, in this case the distance 'X' is equal to as follows;

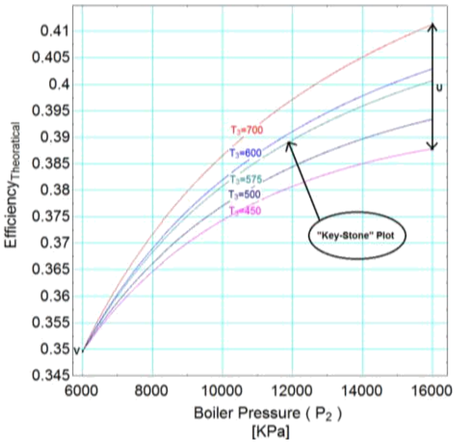


Figure 13: Referencing on the graph indicating High Pressure Turbine Inlet Temperature's effect on Boiler Pressure versus Efficiency Plot.

$$X = \frac{U + V}{2}$$

$$X = \frac{(0.4125 - 0.3855) + 0}{2}$$

$$X = 0.0135$$

Hence

$$A = Y = \frac{0.0135}{2}$$

$$A = 0.00675$$

Next to obtain the equivalent value of the Angle 'B', the same procedure as before is carried out.

$[450 \leq T_3 \leq 575]$

Subtracting 575 (the median value of T3) from all the three sides we get;

$$((450 - 575) \leq (T_3 - 575) \leq (700 - 575)) \ (-125 \leq (T_3 - 575) \leq +125)$$

Next in order to convert the range values of -125 and +125 to -90 and +90 respectively, we multiply it with a "Correction Factor", 'Z' that is calculated as follows;

$$-125 \times (Z) = -90 \quad 18$$

$$(Z) = -125 = 25$$

When we multiply all the three sides of the equation with this Correction Factor, the equation becomes;

$$((-125 \times \frac{18}{25}) \leq ((T_3 - 575) \times (\frac{18}{25})) \leq (+125 \times \frac{18}{25}))$$

$$(-90 \leq (T_3 - 575) \times (25) \leq +90)$$

Hence our Custom Angle 'B' comes out to be equal to;

$$((T_3 - 575) \times (\frac{18}{25}))$$

Hence our final Custom trigonometric equation which "quantizes" the effect of the variation of this fourth independent parameter turns out to be as follows;

Compensation of the Effect of variation of High Pressure turbine inlet temperature $= 0.00675 \sin((T_3 - 575) \times (\frac{18}{25}))$

Recall that, increasing the High-Pressure Turbine Inlet Temperature has a "Positive" effect on Cycle Efficiency; hence we must add this effect to the original equation simply relating Boiler Pressure and Efficiency;

$$Efficiency = (-0.0895389 + 0.0508975 \ln P_2) + (0.0150125 \sin((T_5 - 575) \times (25))) - (0.01325 \sin((P_1 - 40) \times (6))) \quad 18$$

+Compensation of the Effect of variation of High Pressure turbin inlet temperature

$$Efficiency = (-0.0895389 + 0.0508975 \ln P_2) + (0.0150125 \sin((T_5 - 575) \times (25))) - (0.01325 \sin((P_1 - 40) \times (6))) + (0.00675 \sin((T_3 - 575) \times (25))) \quad 18 \quad 18$$

Finally, we cater for the last Independent parameter; Reheat Pressure and study the effect of its variation on the trends of the plot of Boiler Pressure vs. Efficiency.

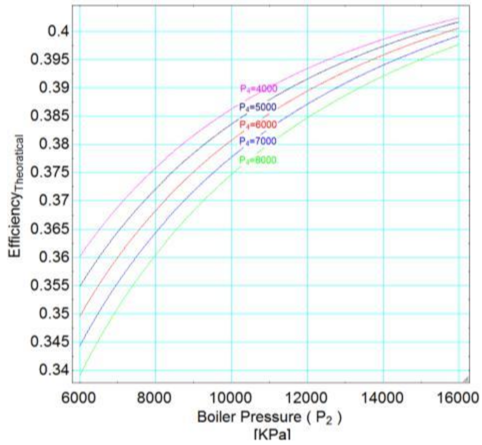


Figure 14: Reheat Pressure's effect on Boiler Pressure versus Efficiency plot.

In order to simplify the graphical data, we once again approximate the distance between the plots in the graph to be constant by taking the average of the maximum and the minimum distances between the extreme graphs. So in this case;

$$X = \frac{U + V}{2}$$

$$X = \frac{(0.4025 - 0.3955) + (0.3600 - 0.3395)}{2}$$

$$X = \frac{0.007 + 0.0205}{2}$$

$$X = 0.01375$$

Hence

$$A = Y = \frac{0.01375}{2}$$

$$A = 0.006875$$

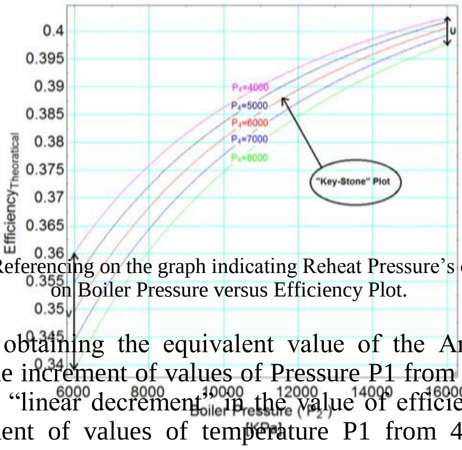


Figure 15: Referencing on the graph indicating Reheat Pressure's effect on Boiler Pressure versus Efficiency Plot.

Finally obtaining the equivalent value of the Angle 'B' such that the increment of values of Pressure P1 from 40 to 55 results in a "linear decrement" in the value of efficiency and the decrement of values of temperature P1 from 40 to 25 results in a "linear increment" in the value of efficiency.

So we chose the value of our Custom Angle 'B', such that it is dictated by the value of P1, however the Angle itself still fluctuates between the range of -90 to +90.

$[4000 \le P_4 \le 8000]$

Subtracting 6,000 (the median value of P4) from all the three sides we get;

$((4000 - 6000) \le (P_4 - 6000) \le (8000 - 6000))$ $(-2000 \le (P_4 - 6000) \le +2000)$

Next in order to convert the range values of -2000 and +2000 to -90 and +90 respectively, we multiply it with a "Correction Factor", 'Z' that is calculated as follows;

$$-2000 \times (Z) = -90$$

$$(Z) = \frac{-90}{-2000} = \frac{9}{200}$$

When we multiply all the three sides of the equation with this Correction Factor, the equation becomes;

$$((-2000 \times \frac{9}{200}) \le ((P_4 - 6000) \times (\frac{9}{200})) \le (+2000 \times \frac{9}{200}))$$

$$(-90 \le ((P_4 - 6000) \times (\frac{9}{200})) \le +90)$$

Hence our Custom Angle 'B' comes out to be equal to;

$$((P_4 - 6000) \times (\frac{9}{200}))$$

Hence our final Custom trigonometric equation which "quantizes" the effect of the variation of this fifth Independent parameter turns out to be as follows;

Compensation of the Effect of variation of Reheat Pressure

$$= 0.006875 \sin ((P_4 - 6000) \times (\frac{9}{200}))$$

Recall, that increasing the Reheat Pressure has a "Negative" effect on Cycle Efficiency, hence we must assign a negative sign to this "effect" and add it to the equation currently accounting only for the rest of the independent parameters.

= (−0.0895389 + 0.0508975 ... 2)

(25)) −( 0.01325 (( 1 − 40) × (6)))

−( ... h ... h )

$$\begin{aligned}
\text{Efficiency} = {} & (-0.0895389 + 0.0508975 \ln P_2) \\
& + \left(0.0150125 \sin\left((T_5 - 575) \times \left(\frac{18}{25}\right)\right)\right) \\
& - \left(0.01325 \sin((P_1 - 40) \times (6))\right) \\
& + \left(0.00675 \sin\left((T_3 - 575) \times \left(\frac{18}{25}\right)\right)\right) \\
& - \left(0.006875 \sin\left((P_4 - 6000) \times \left(\frac{9}{200}\right)\right)\right)
\end{aligned}$$

## IV. VERIFICATION OF EQUATION

The most important stage in order to validate a research is to verify the research thesis results with actual results and calculate the percentage error. We have tested the above developed Co-relation with a lot of examples, and were grateful for the fact that our results had normal percentage errors of less than 2% at moderate parametric conditions and a maximum percentage error of less than 6% at the extreme values of independent parameters. The following is actually a small table extracted from the huge set of values of test examples.

| 1..20 | $P_1$ [kPA] | $P_2$ [KPA] | $P_4$ [kPA] | $T_3$ [C] | $T_5$ [C] | $EFFICIENCY_{ACTUAL}$ | $EFFICIENCY_{CORRELATION}$ | $PERCENTAGE_{ERROR}$ |
|---|---|---|---|---|---|---|---|---|
| Run 1 | 25 | 8000 | 4000 | 450 | 450 | 0.36584 | 0.36625 | -0.11188 |
| Run 2 | 26.58 | 8421 | 4211 | 463.2 | 463.2 | 0.36826 | 0.36888 | -0.16883 |
| Run 3 | 28.16 | 8842 | 4421 | 476.3 | 476.3 | 0.37070 | 0.37143 | -0.19620 |
| Run 4 | 29.74 | 9263 | 4632 | 489.5 | 489.5 | 0.37317 | 0.37391 | -0.19828 |
| Run 5 | 31.32 | 9684 | 4842 | 502.6 | 502.6 | 0.37565 | 0.37632 | -0.17838 |
| Run 6 | 32.89 | 10105 | 5053 | 515.8 | 515.8 | 0.37814 | 0.37867 | -0.13900 |
| Run 7 | 34.47 | 10526 | 5263 | 528.9 | 528.9 | 0.38065 | 0.38096 | -0.08190 |
| Run 8 | 36.05 | 10947 | 5474 | 542.1 | 542.1 | 0.38316 | 0.38319 | -0.00828 |
| Run 9 | 37.63 | 11368 | 5684 | 555.3 | 555.3 | 0.38568 | 0.38537 | 0.08112 |
| Run 10 | 39.21 | 11789 | 5895 | 568.4 | 568.4 | 0.38821 | 0.38749 | 0.18594 |
| Run 11 | 40.79 | 12211 | 6105 | 581.6 | 581.6 | 0.39074 | 0.38954 | 0.30610 |
| Run 12 | 42.37 | 12632 | 6316 | 594.7 | 594.7 | 0.39327 | 0.39154 | 0.44170 |
| Run 13 | 43.95 | 13053 | 6526 | 607.9 | 607.9 | 0.39581 | 0.39346 | 0.59297 |
| Run 14 | 45.53 | 13474 | 6737 | 621.1 | 621.1 | 0.39834 | 0.39532 | 0.76016 |
| Run 15 | 47.11 | 13895 | 6947 | 634.2 | 634.2 | 0.40088 | 0.39709 | 0.94352 |
| Run 16 | 48.68 | 14316 | 7158 | 647.4 | 647.4 | 0.40341 | 0.39880 | 1.14321 |
| Run 17 | 50.26 | 14737 | 7368 | 660.5 | 660.5 | 0.40594 | 0.40042 | 1.35928 |
| Run 18 | 51.84 | 15158 | 7579 | 673.7 | 673.7 | 0.40846 | 0.40196 | 1.59160 |
| Run 19 | 53.42 | 15579 | 7789 | 686.8 | 686.8 | 0.41099 | 0.40342 | 1.83986 |
| Run 20 | 55 | 16000 | 8000 | 700 | 700 | 0.41350 | 0.40480 | 2.10354 |

Figure 16: Table showing validation of our results.

In order to validate our results from a documented source we have decided to solve an example from the textbook of Thermodynamics, an engineering approach, by Michael A. Boles and Yunus A. Cengel.

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**Question**

A steam power plant operates on the ideal reheat Rankine cycle. Steam enters the high-pressure turbine at 8 MPa and 500°C and leaves at 3 MPa. Steam is then reheated at constant pressure to 500°C before it expands to 20kPa in the low-pressure turbine. Determine the turbine work output, in kJ/kg, and the thermal efficiency of the cycle.

**Solution by Thermodynamic Equations**

Since we are basically concerned with the cycle efficiently currently, hence we will only deal with this part. The solution is obtained using the standard system of thermodynamic equations, giving a cycle efficiency of 0.38455. For further details refer to the code of the E.E.S software assisting this paper.

**Solution by our Co-relation**

Substituting the indicated parameters in our equation, the solution is obtained as follows:

$$= (-0.0895389 + 0.0508975 \ln P_2) + (0.0150125 \sin((T_5 - 575) \times (\tfrac{25}{18}))) - (0.01325 \sin((P_1 - 40) \times (\tfrac{6}{18}))) + (0.00675 \sin((T_3 - 575) \times (\tfrac{25}{9}))) - (0.006875 \sin((P_4 - 6000) \times (\tfrac{200}{18})))$$

$$= (-0.0895389 + 0.0508975 \ln(8000)) + (0.0150125 \sin((500 - 575) \times (\tfrac{25}{18}))) - (0.01325 \sin((20 - 40) \times (\tfrac{6}{18}))) + (0.00675 \sin((500 - 575) \times (\tfrac{25}{9}))) - (0.006875 \sin((3000 - 6000) \times (\tfrac{200}{18})))$$

$$= (-0.0895389 + 0.45742585) + (0.0150125 \sin(-54)) - (0.01325 \sin(-120)) + (0.00675 \sin(-54)) - (0.006875 \sin(-135))$$

$$= (0.36788695) + (-0.01214536763) - (-0.0114748366) + (-0.005460864712) - (-0.004861359121)$$

$$= 0.36662$$

## V. Conclusion

As you can observe, the resulting solutions obtained from our co-relation posses a very small percentage error (4.66% only) besides the fact of off-shooting of the ranges of some of the independent parameters. Hence this proves that this co-relation technique is highly accurate and its development technique can be applied in a wide variety of fields.

## References


[1] M.A. Habib , S.A.M. Said, and I. Al-Zaharna, "Thermodynamic optimization of reheat regenerative thermal-power plants," Applied Energy 63, pp. 17-34, 1999.

[2] Y. A. Çengel and R H. Turner, Fundamentals Of Thermal-Fluid Sciences, 2nd ed., 2007, pp. 377-390.

[3] Randall E. Schumacker & Susan T. Beyerlein, " Confirmatory Factor Analysis With Different Correlation Types and Estimation Methods", Structural Equation Modeling: A Multidisciplinary Journal, Volume 7, pages 629-636, 2000.

[4] Michael J. Moran, Howard N. Shapiro, Fundamentals of Engineering Thermodynamics: SI Version, 5th ed., 2006.

[5] E. W. Swokowski, M. Olinick, D. Pence and J. A. Cole, Calculas, 6th ed., 1994, pp. 36-53.