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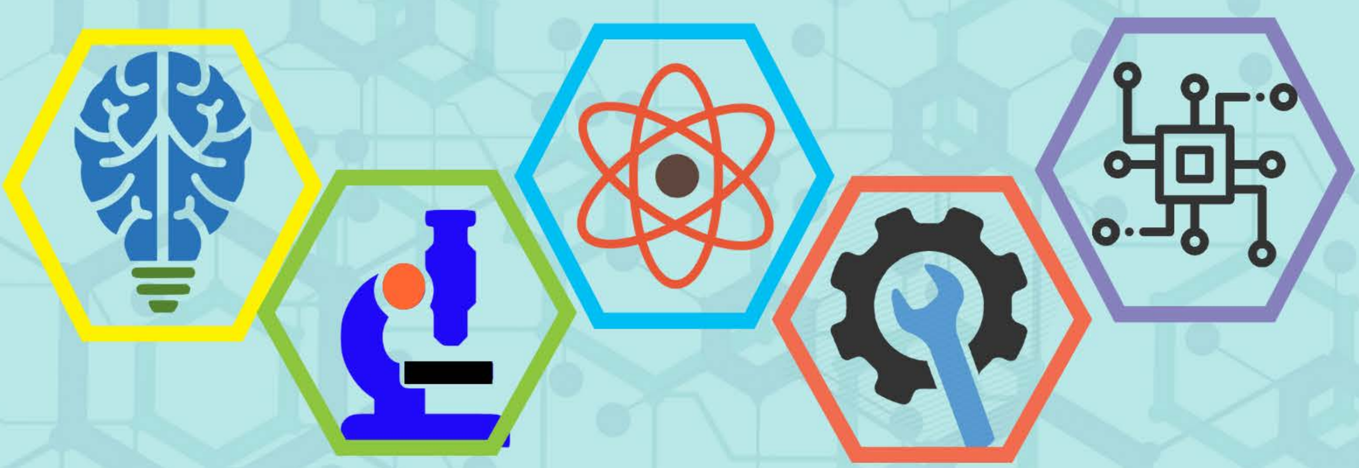

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THERMODYNAMIC MODELLING OF A SOLAR POWERED ORGANIC RANKINE CYCLE

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ABSTRACT: A considerable amount of thermal energy is available in the form of renewable energy source and this can reduce the consumption of fossil fuels. The solar organic rankine cycle is a promising technology which uses energy from the sun as a source of power and this does not affect the environment. However, due to the recent global warming, environmental pollution and energy crises coupled with the instability of oil prices, interest in renewable energy for mitigating these issues is growing once again. The aim of this study is to develop a model for evaluating and predicting the net power output and performance of a solar powered organic rankine cycle and to validate the model using experimental data.

A thermodynamic analysis was carried out to see how feasible the power plant will operate on the chosen site, simulation were done in a Matlab environment , parametric and sensitivity analysis were also carried out to know the parameters that effect the system the most. A model was developed to predict the net power output and thereby performing a performance analysis. The model was validated using an experimental setup by Braden Lee Twomey, 2015 at University of Queensland Australia.

Measured/calculated and predicted net power output of the solar organic rankine cycle using R134a are 0.905kW, 0.913kW, 0.919kW and 0.908kW, 0.929kW, 0.920kW respectively. Measured/calculated and predicted net power output of the solar organic rankine cycle using R245fa are 0.973kW, 0.976kW, 0.979kW and 1.041kW, 0.940kW, 0.953kW respectively. The organic rankine cycle efficiencies and the overall solar organic rankine cycle efficiencies using R134a are 0.093, 0.086, 0.077 and 0.000028, 0.000030, 0.000032 respectively.

The organic rankine cycle efficiencies and the overall solar organic rankine cycle efficiencies using R245fa are 0.200, 0.185, 0.167 and 0.000060, 0.000065, 0.000069 respectively.

From the above result it can be deduced that the measured and predicted net power output are close with very little percentage error and as such the model is able to perform a performance analysis of the system.

Keywords: Efficiency, Net Power Output, Solar Organic Rankine, Thermal Energy.

1. INTRODUCTION

Energy is one of the primary causes of a nation's development and sustenance. It has been reported that the global demand for primary energy is on the steady increase and if the demand is maintained at a conservative average rate of 2%, the total global energy demand will increase by 100% in 30 years. The accelerated consumption of fossil fuels, if not abated would lead to a major health and energy crisis. However, the utilization of low-grade energy has attracted appreciable attention due to its potential in relaxing environmental pollution and fossil fuel consumption [1].

Worldwide energy demand has been rapidly increasing but the fossil fuel to meet the demand is being drained, for the past 20 years efficient uses of low-temperature energy source such as geothermal energy, exhaust gas from gas turbine system, biomass combustion, waste heat from various industrial processes, and solar energy have attracted much attention and researches about them become more and more important. The organic rankine cycle (ORC) and the power generating system using binary mixture as a working fluid have been focused on as they are proven to be the most feasible methods to achieve high efficiency in converting the low-grade thermal energy to more useful forms of energy. ORC is a rankine cycle where an organic fluid is used instead of water as working fluid. Particularly in low temperature applications many benefits may be obtained by using ORC instead of steam rankine process [2].

By powerful nuclear fusion reaction, the Sun produces staggering amounts of energy and much of that energy is dispersed in space and practically all of it is lost. The energy intercepted by Earth over a period of one year is equal to the energy emitted in just 14minutes by the Sun. The Sun releases an enormous amount of radiation energy to its surroundings and when the energy arrives at the surface of the Earth, it has been attenuated twice by both the atmosphere (6% by reflection and 16% by absorption) and the clouds (20% by reflection and 3% by absorption), as shown in Fig. 1 [4].

Solar collectors and thermal energy storage components are the two core subsystems in solar thermal applications. A solar collector which is the special energy exchanger converts solar irradiation energy to the thermal energy of the working fluid in solar thermal applications. Solar collectors need to have good optical performance in order to absorb heat as much as possible. For solar thermal applications, solar irradiation is absorbed by a solar collector as heat and then is transferred to the working fluid. The heat carried by the working fluid can be used to either provide domestic hot water or to charge a thermal energy storage tank from which the heat can be drawn for use later [3].

The aim of this research is to develop a model for predicting the net power output of a solar organic rankine cycle as shown in figure 1.

2. THE SOLAR ORC SYSTEM CONFIGURATION

The solar evacuated tube collector is heated using the energy from the sun, the heat from the sun causes the fluid in the collector (heat transfer fluid) to gain an increase in temperature and it then flows to the evaporator/storage unit where there is heat exchange between the heat transfer fluid (water) and the working fluid (refrigerant).

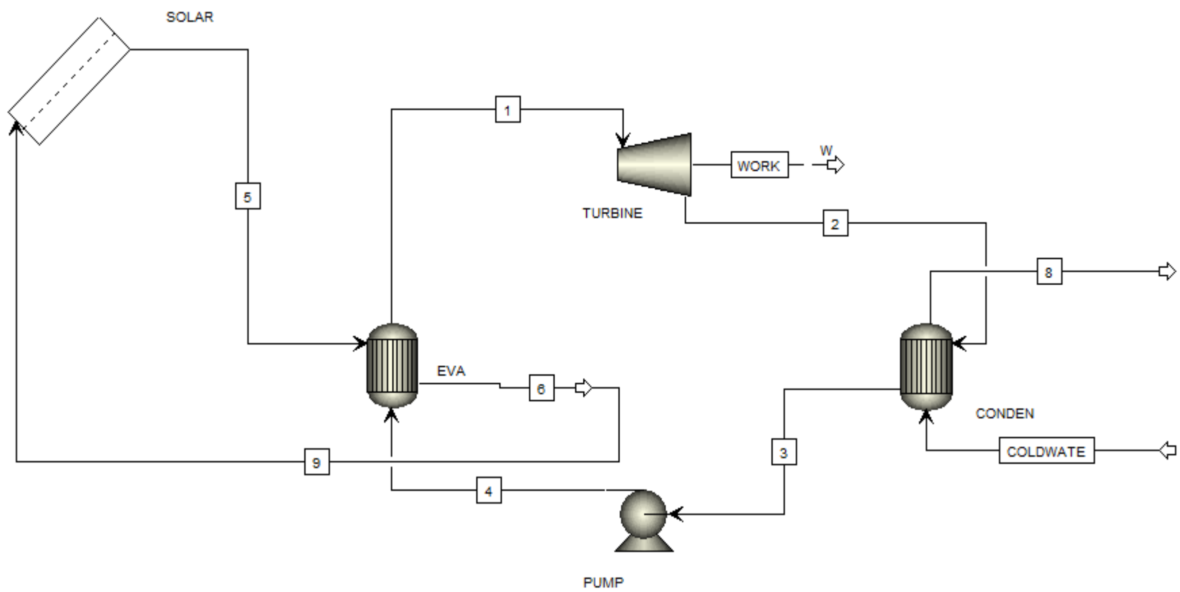

Figure 1. Schematic diagram of solar ORC.

As the working fluid gains more energy and increase in temperature, it moves to the expander/turbine where it causes expansion within the system and it connects to the generator for producing electricity. The remaining part of the refrigerant goes to the condenser where it loses energy in form of a drop in temperature as it mixes with cold water. The working fluid is then pumped back to the evaporator and the cycle continues.

2.1. Working Fluid Selection

R134a and R245fa are choosing for low-temperature and medium-temperature solar ORCS as working fluid respectively, considering the following factors like flammability, toxicity, and environmental conditions. Water is used as the heat transfer fluid and this solar ORC can be mostly suitable for remote places of developing countries that lack electricity. Therefore, this technology is expected to be used for small distributed power generations systems.

3. THERMODYNAMIC ANALYSIS

Data were collected putting into mind the site and location which is been used as case study. 1kW was fixed at the turbine/expander output, thermodynamic assumptions were used to conduct the thermodynamic analysis of this research putting into consideration the boundary conditions and the operational parameters are shown in Table 1.

The system was then simulated using MATLAB environment under steady state condition. A model was developed using dimensional analysis for performance prediction. The following equations were used for the analysis:

i. **Evaporator model**

$$\boldsymbol{Q_e = m_f(h_1 - h_4) = m_f C_{p,wf}(T_{C.I} - T_{C.O})} \quad \textbf{(1)}$$

The total heat rate in the evaporator from the heat transfer fluid (HTF) into the working fluid is given by using equation 1.

$Q_e = Heat\ rate\ of\ the\ evaporator, m_f = massflow\ rate\ of\ the\ heat\ trasfer\ fluid,\ h_1 = Specific\ enthalpy\ at\ inlet,\ h_4 = Specific\ enthalpy\ at\ outlet,\ C_{p,wf} = Specific\ capacity\ of\ water, T_{C.I} = Temperature\ at\ inlet\ of\ the\ evaporator$
$T_{C.O} = Temperature\ at\ \ outlet\ of\ the\ evaporator.$

ii. **Expander/turbine model**

$$\boldsymbol{W_t = m_f(h_1 - h_{2S})\eta_t \eta_g = m_f(h_1 - h_2)\,\eta_g} \quad \textbf{(2)}$$

The organic fluid which is the working fluid vapour passes through the expander/turbine to generate mechanical power. The turbine/expander can be analyzed using equation 2.

Where $\eta_t\ and\ \eta_g$ are the turbine/expander isentropic efficiencies and generator efficiency respectively. $h_1, h_{2S},\ h_2$ are the specific enthalpies of the working fluid at the expander inlet, expander outlet under ideal and actual conditions respectively.

iii. **Condenser model**

$$\boldsymbol{Q_C = m_f(h_2 - h_3) = m_f C_{p,w}(T_{C.O} - T_{C.I})} \quad \textbf{(3)}$$

The exhaust vapour at the expander exit is directed to the condenser where it is converted to the liquid state by rejecting its heat to the cooling water. This condenser heat rate can be estimated using equation 3.

$Where$ $\boldsymbol{Q_C, m_f\ , h_2\ , h_3}$ are the heat generated, mass flow rate of the working fluid, specific enthalpy at condenser inlet and outlet respectively $\boldsymbol{m_w\ , C_{p,w}\ , T_{C.O}}\ and\ \boldsymbol{T_{C.I}}$ are the cooling water mass flow rate, specific capacity of water, cooling water temperature of outlet and inlet of the condenser respectively.

iv. **Pump model**

$$\boldsymbol{W_p = \frac{m_f\, v_3\,(P_4 - P_3)}{\eta_p} = \frac{m_{f(h_{4s} - h_3)}}{\eta_p}} \quad \textbf{(4)}$$

The power consumed by the working fluid pump is estimated using equation 4. $Where\ \boldsymbol{W_p}, \boldsymbol{m_f}, \boldsymbol{v_3}, \boldsymbol{P_4}, \boldsymbol{P_3}, \boldsymbol{h_4}, \boldsymbol{h_3}\ and\ \boldsymbol{\eta_p}$ are pump work, working fluid mass flow rate, specific volume, pressure outlet, pressure inlet, specific enthalpy outlet, specific enthalpy inlet and pump efficiency of the pump respectively.

v. **Net power output and system efficiency**

The net power output generated by the SORC system is given as:

$$\boldsymbol{W_{net} = W_t - W_p} \tag{5}$$

The thermal efficiency of the ORC is the ratio of the net power output to the heat input in the evaporator. It can be expressed as:

$$\boldsymbol{\eta_{ORC} = \frac{W_{net}}{Q_e}} \tag{6}$$

The overall efficiency of the solar ORC system can be defined as follows:

$$\boldsymbol{\eta_{OVR} = \frac{W_{net}}{G_I \times A_{COL}}} \tag{7}$$

Table 1. Input parameters

S/N	COMPONENT	LEVEL 1	LEVEL 2	LEVEL 3
1	Low/medium SORC area	$32m^2/16m^2$	$30m^2/15m^2$	$28m^2/14m^2$
2	Low/medium solar ORC temperature	95 ^{O}C/130 ^{O}C	90 ^{O}C/120 ^{O}C	85 ^{O}C/110 ^{O}C
3	Pinch temperature difference at evaporator	10 ^{O}C	10 ^{O}C	10 ^{O}C
4	Low/medium ORC evaporator temperature	85 ^{O}C/ 120 ^{O}C	80 ^{O}C/ 110 ^{0}C	75 ^{O}C/ 100 ^{O}C
5	Expander power output	1kW	1kW	1Kw
6	Condenser outlet temperature	42 ^{0}C	42 ^{0}C	42 ^{0}C
7	Expander efficiency	70%	70%	70%
8	Pump efficiency	70%	70%	70%
9	Solar collector efficiency	70%	70%	70%
10	Generator efficiency	95%	95%	95%

3.1. Model Formulation and Performance Prediction

Dimensional analysis was carried out in order to establish an empirical correlation relative to each parameter. It is a mathematical technique which utilizes the knowledge of the dimensions by considering units of measurement.

$\boldsymbol{W_{net}}$ is a variable which depends on other variables as shown in the functional equation 3.8.

$$\boldsymbol{W_{net} = f(A, m_f, G_l, t, h)} \ \textbf{or} \ \boldsymbol{f(A, m_f, G_l, t, h, W_{net}) = 0} \tag{8}$$

The net power output is dependent on mass flow rate, enthalpy, density, viscosity, temperature, pressure and area. Where;

$$\boldsymbol{W_{net} = ML^2T^{-3}} \tag{9}$$
$$\boldsymbol{A = L^2} \tag{10}$$
$$\boldsymbol{m_f = MT^{-1}} \tag{11}$$
$$\boldsymbol{G_l = MT^{-3}} \tag{12}$$
$$\boldsymbol{t = \theta} \tag{13}$$
$$\boldsymbol{h = Ml^2T^{-2}} \tag{14}$$

Based on the above observation using equation (9 – 14), the pi groups are modelled coupled with the repeating variables ($M = A, m_f, G_L, t$) as follows;

$$\boldsymbol{\pi_1 = A^{a_1}, m_f^{b_1}, G_L^{C_1}, t^{d_1}, W_{net}} \tag{15}$$

$$\boldsymbol{\pi_2 = A^{a_2}, m_f^{b_2}, G_L^{C_2}, t^{d_2}, h} \tag{16}$$

$$\boldsymbol{f_1(\pi_1, \pi_2)} \tag{17}$$

Using equation (3.20 – 3.22) the pi groups are modelled to obtain the following result

$$\boldsymbol{\pi_1 = \frac{W_{net}}{A\,G_l}} \tag{18}$$

$$\boldsymbol{\pi_2 = \frac{h}{A\,G_l^{\frac{1}{2}}\;m_f^{\frac{1}{2}}}} \tag{19}$$

$$\boldsymbol{f\left[\left(\frac{W_{net}}{A\,G_l}\right), \left(\frac{h}{A\,G_l^{\frac{1}{2}}\;m_f^{\frac{1}{2}}}\right)\right]} \tag{20}$$

$$\boldsymbol{W_{net} = A\,G_l\,\emptyset\left(\frac{h}{A\,G_l^{\frac{1}{2}}\;m_f^{\frac{1}{2}}}\right)} \tag{21}$$

From various literatures reviewed it was observed that low and medium SORC system works between 60^0C – 200^0C [Orosz and Dickes, 2017] using an evacuated tube. Refrigerant R134a was used for low temperature SORC considering its critical temperature of 101.06 ^{0}C and R245fa was used for medium SORC considering its critical temperature of 154.01^0C. Using simulated results and a correlation factor $R^2 = 0.987$ and $R^2 = 0.347$ regression analysis was done as shown in figure 2 and 3 respectively. Hence from the regression analysis Eq. (22 and 23) were obtained as follows:

$$\boldsymbol{Y = -6.5 \times 10^{-5} + 6.84 \times 10^{-5} X_1} \quad \textbf{(22)}$$

$$\boldsymbol{Y = -5.61715 \times 10^{-4} + 1.32115 \times 10^{-4} X_1} \quad \textbf{(23)}$$

By comparing Eq. (21) with Eq. (22 and 23), the empirical model or correlation for R134a and R245fa can be obtained as follows:

$$\boldsymbol{W_{net} = A\, G_l\, [-6.5 \times 10^{-5} + 6.84 \times 10^{-5} \left(\frac{h}{A\, G_l^{\frac{1}{2}}\, m_f^{\frac{1}{2}}}\right)]} \quad \textbf{(24)}$$

$$\boldsymbol{W_{net} = A\, G_l [-5.61715 \times 10^{-4} + 1.32115 \times 10^{-4} \left(\frac{h}{A\, G_l^{\frac{1}{2}}\, m_f^{\frac{1}{2}}}\right)]} \quad \textbf{(25)}$$

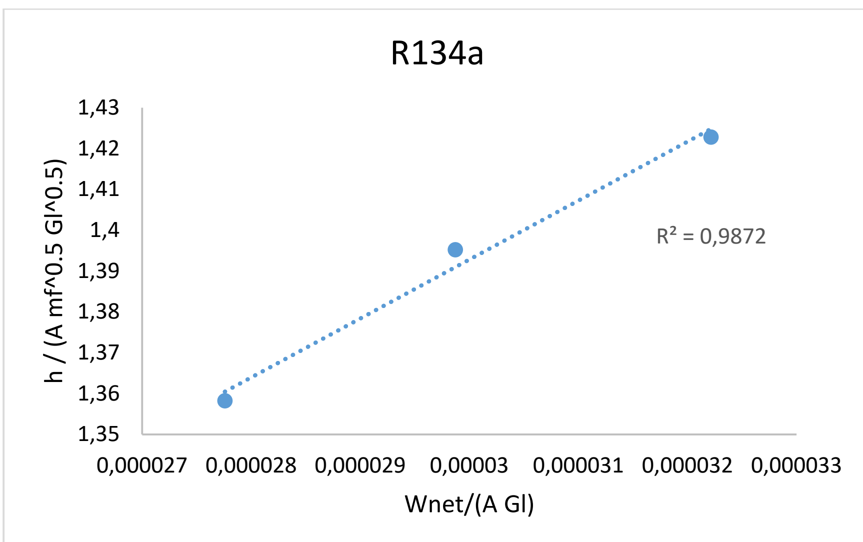

Figure 2. Regression plot of $\left(\frac{W_{net}}{A\, G_l}\right)$ as a function $\left(\frac{h}{A\, G_l^{\frac{1}{2}}\, m_f^{\frac{1}{2}}}\right)$ for R134a

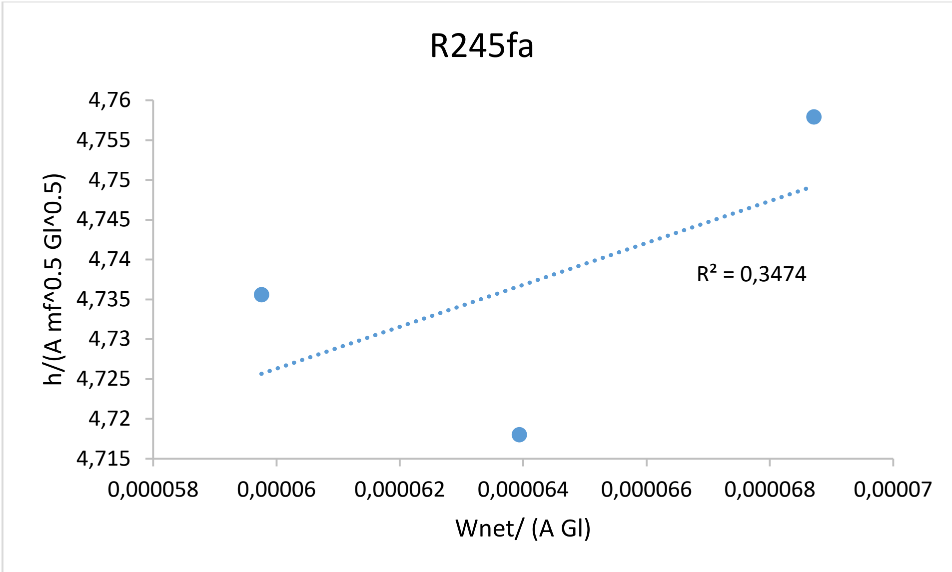

Figure 3. Regression plot of $\left(\frac{W_{net}}{A\,G_l}\right)$ as a function $\left(\frac{h}{A\,G_l^{\frac{1}{2}}\,m_f^{\frac{1}{2}}}\right)$ for R245fa

4. RESULTS

Table 2, 3 and 4 shows the result gotten form the thermodynamic analysis of using the equations from section 3.0.

Table 2. Result for both R134a and R245fa for level 1

Parameters	R134a	R245fa
h_1	427.760 kJ/kg	484.390 kJ/kg
h_2	409.830 kJ/kg	435.160 kJ/kg
h_{2S}	402.130 kJ/kg	414.060 kJ/kg
h_3	259.410 kJ/kg	255.290 kJ/kg
h_4	261.040 kJ/kg	256.580 kJ/kg
h_{4S}	260.550 kJ/kg	256.190 kJ/kg
m_f	0.059 kg/s	0.021 kg/s
Q_E	9.782 kW	4.871 kW
Q_C	8.825 kW	3.846 kW
W_P	0.096 kW	0.028 kW
W_{net}	0.905 kW	0.973 kW
η_{ORC}	0.093	0.200
η_{SORC}	0.000028	0.000060

Table 3. Result for both R134a and R245fa for level 2

Parameters	R134a	R245fa
h_1	428.810 kJ/kg	479.740 kJ/kg
h_2	412.240 kJ/kg	435.160 kJ/kg
h_{2S}	405.140 kJ/kg	416.050 kJ/kg
h_3	259.410 kJ/kg	255.290 kJ/kg
h_4	260.780 kJ/kg	256.300 kJ/kg
h_{4S}	260.370 kJ/kg	255.990 kJ/kg
m_f	0.064 kg/s	0.024 kg/s
Q_E	10.670 kW	5.275 kW
Q_C	9.710 kW	4.247 kW
W_P	0.087 kW	0.024 kW
W_{net}	0.913 kW	0.976 kW
η_{ORC}	0.086	0.185
η_{SORC}	0.000030	0.000065

Table 4. Result for both R134a and R245fa for level 3

Parameters	R134a	R245fa
h_1	429.020 kJ/kg	474.260 kJ/kg
h_2	414.170 kJ/kg	435.160 kJ/kg
h_{2S}	407.810 kJ/kg	418.410 kJ/kg
h_3	259.410 kJ/kg	255.290 kJ/kg
h_4	260.550 kJ/kg	256.060 kJ/kg
h_{4S}	260.210 kJ/kg	255.830 kJ/kg
m_f	0.071 kg/s	0.027 kg/s
Q_E	11.940 kW	5.874 kW
Q_C	10.970 kW	4.842 kW
W_P	0.081 kW	0.021 kW
W_{net}	0.919 kW	0.979 kW
η_{ORC}	0.077	0.167
η_{SORC}	0.000032	0.000069

5. CONCLUSION

A new model was developed to estimate net power output, the net power output gotten from R134a are 0.908kW, 0.929kW and 0.920 kW. The model estimated using R245fa generated the following net power 1.041kW, 0.940kW and 0.953kW. The model was also used to validate an experimental solar organic rankine cycle by Braden Lee Twomey, 2015 at University of Queensland Australia. The measured and calculate output was 1.0365kW and the predicted net output is 1.1937kW using R134a. The measured/calculated net power gotten was 3.853kW and the predicted net power was 3.833kW using R245fa.

From the above result it can be deduced that the measured and predicted results are close with very small percentage error and as such the model is able to perform a performance analysis of the system.

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SENSITIVITY ANALYSIS OF A SOLAR ORGANIC RANKINE CYCLE

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A thermodynamic analysis was carried out to see how feasible the power plant will operate on the chosen site, simulation were done in a Matlab environment, parametric and sensitivity analysis were also carried out to know the parameters that effect the system the most.

The organic rankine cycle efficiencies and the overall solar organic rankine cycle efficiencies using R134a are 0.093, 0.086, 0.077 and 0.000028, 0.000030, 0.000032 respectively. The organic rankine cycle efficiencies and the overall solar organic rankine cycle efficiencies using R245fa are 0.200, 0.185, 0.167 and 0.000060, 0.000065, 0.000069 respectively.

Keywords: Efficiency, Net Power Output, Solar Organic Rankine, Thermal Energy.

1. INTRODUCTION

Since worldwide energy demand has been rapidly increasing but the fossil fuel to meet the demand is being drained, for the past 20 years efficient uses of low-temperature energy source such as geothermal energy, exhaust gas from gas turbine system, biomass combustion, waste heat from various industrial processes and solar energy have attracted much attention and researches about them become more and more important. The organic Rankine cycle (ORC) and the power generating system using binary mixture as a working fluid have been focused as they are proven to be the most feasible methods to achieve high efficiency in converting the low-grade thermal energy to more useful forms of energy. ORC is a Rankine cycle where an organic fluid is used instead of water as working fluid. Particularly in low temperature applications many benefits may be obtained by using ORC instead of steam Rankine process [2].

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2. THE SOLAR ORC SYSTEM CONFIGURATION

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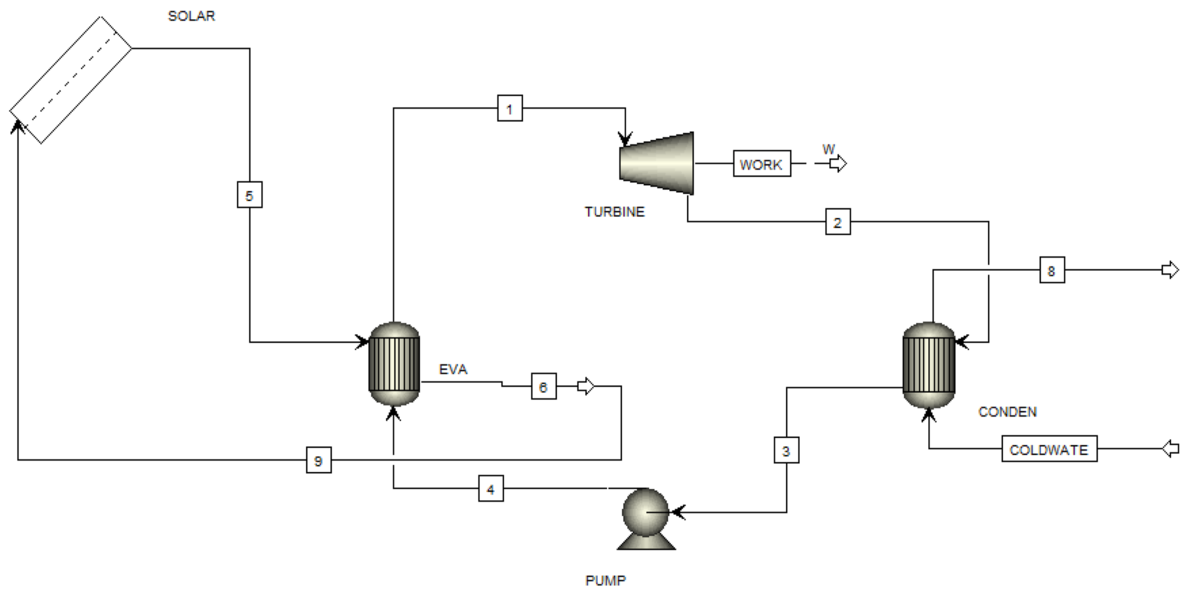

Figure 1. Schematic diagram of solar ORC.

As the working fluid gains more energy and increase in temperature, it moves to the expander/turbine where it causes expansion within the system and it connects to the generator for producing electricity. The remaining part of the refrigerant goes to the condenser where it loses energy in form of a drop in temperature as it mixes with cold water. The working fluid is then pumped back to the evaporator and the cycle continues.

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The system was then simulated using MATLAB environment under steady state condition. The following equations were used for the analysis and also the parametric and sensitivity analysis.

i. **Evaporator model**

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$$\boldsymbol{W_t = m_f(h_1 - h_{2S})\eta_t \eta_g = m_f(h_1 - h_2)\eta_g} \quad \textbf{(2)}$$

The organic fluid which is the working fluid vapour passes through the expander/turbine to generate mechanical power. The turbine/expander can be analyzed using equation 2.

Where η_t *and* η_g are the turbine/expander isentropic efficiencies and generator efficiency respectively. h_1, h_{2S}, h_2 are the specific enthalpies of the working fluid at the expander inlet, expander outlet under ideal and actual conditions respectively.

iii. **Condenser model**

$$\boldsymbol{Q_C = m_f(h_2 - h_3) = m_f C_{p,w}(T_{C.O} - T_{C.I})} \quad \textbf{(3)}$$

The exhaust vapour at the expander exit is directed to the condenser where it is converted to the liquid state by rejecting its heat to the cooling water. This condenser heat rate can be estimated using equation 3.

Where $\boldsymbol{Q_C, m_f, h_2, h_3}$ are the heat generated, mass flow rate of the working fluid, specific enthalpy at condenser inlet and outlet respectively $\boldsymbol{m_w, C_{p,w}, T_{C.O}}$ *and* $\boldsymbol{T_{C.I}}$ are the cooling water mass flow rate, specific capacity of water, cooling water temperature of outlet and inlet of the condenser respectively.

iv. **Pump model**

$$\boldsymbol{W_p = \frac{m_f v_3 (P_4 - P_3)}{\eta_p} = \frac{m_{f(h_{4S} - h_3)}}{\eta_p}} \quad \textbf{(4)}$$

The power consumed by the working fluid pump is estimated using equation 4. *Where* $\boldsymbol{W_p, m_f, v_3, P_4, P_3, h_4, h_3}$ *and* $\boldsymbol{\eta_p}$ are pump work, working fluid mass flow rate, specific volume, pressure outlet, pressure inlet, specific enthalpy outlet, specific enthalpy inlet and pump efficiency of the pump respectively.

v. **Net power output and system efficiency**

The net power output generated by the SORC system is given as:

$$\boldsymbol{W_{net} = W_t - W_p} \quad \textbf{(5)}$$

The thermal efficiency of the ORC is the ratio of the net power output to the heat input in the evaporator. It can be expressed as:

$$\boldsymbol{\eta_{ORC} = \frac{W_{net}}{Q_e}} \quad \textbf{(6)}$$

The overall efficiency of the solar ORC system can be defined as follows:

$$\eta_{OVR} = \frac{W_{net}}{G_I \times A_{COL}} \quad (7)$$

Table 1. Input parameters

S/N	Component	Level 1	Level 2	Level 3
1	Low/medium SORC area	$32m^2/16m^2$	$30m^2/15m^2$	$28m^2/14m^2$
2	Low/medium solar ORC temperature	95 ^OC/130 ^OC	90 ^OC/120 ^OC	85 ^OC/110 ^OC
3	Pinch temperature difference at evaporator	10 ^OC	10 ^OC	10 ^OC
4	Low/medium ORC evaporator temperature	85 ^OC/ 120 ^OC	80 ^OC/ 110 ^0C	75 ^OC/ 100 ^OC
5	Expander power output	1kW	1kW	1Kw
6	Condenser outlet temperature	42 ^0C	42 ^0C	42 ^0C
7	Expander efficiency	70%	70%	70%
8	Pump efficiency	70%	70%	70%
9	Solar collector efficiency	70%	70%	70%
10	Generator efficiency	95%	95%	95%

4. RESULTS

Table 2, 3 and 4 shows the result gotten form the thermodynamic analysis of using the equations from section 3.0.

Table 2. Result for both R134a and R245fa for level 1

Parameters	R134a	R245fa
h_1	427.760 kJ/kg	484.390 kJ/kg
h_2	409.830 kJ/kg	435.160 kJ/kg
h_{2S}	402.130 kJ/kg	414.060 kJ/kg
h_3	259.410 kJ/kg	255.290 kJ/kg
h_4	261.040 kJ/kg	256.580 kJ/kg
h_{4S}	260.550 kJ/kg	256.190 kJ/kg
m_f	0.059 kg/s	0.021 kg/s
Q_E	9.782 kW	4.871 kW
Q_C	8.825 kW	3.846 kW
W_P	0.096 kW	0.028 kW
W_{net}	0.905 kW	0.973 kW
η_{ORC}	0.093	0.200
η_{SORC}	0.000028	0.000060

Table 3. Result for both R134a and R245fa for level 2

Parameters	**R134a**	**R245fa**
h_1	428.810 kJ/kg	479.740 kJ/kg
h_2	412.240 kJ/kg	435.160 kJ/kg
h_{2S}	405.140 kJ/kg	416.050 kJ/kg
h_3	259.410 kJ/kg	255.290 kJ/kg
h_4	260.780 kJ/kg	256.300 kJ/kg
h_{4S}	260.370 kJ/kg	255.990 kJ/kg
m_f	$0.064\ kg/s$	$0.024\ kg/s$
Q_E	$10.670\ kW$	$5.275\ kW$
Q_C	$9.710\ kW$	$4.247\ kW$
W_P	$0.087\ kW$	$0.024\ kW$
W_{net}	$0.913\ kW$	$0.976\ kW$
η_{ORC}	0.086	0.185
η_{SORC}	0.000030	0.000065

Table 4. Result for both R134a and R245fa for level 3

Parameters	**R134a**	**R245fa**
h_1	429.020 kJ/kg	474.260 kJ/kg
h_2	414.170 kJ/kg	435.160 kJ/kg
h_{2S}	407.810 kJ/kg	418.410 kJ/kg
h_3	259.410 kJ/kg	255.290 kJ/kg
h_4	260.550 kJ/kg	256.060 kJ/kg
h_{4S}	260.210 kJ/kg	255.830 kJ/kg
m_f	$0.071\ kg/s$	$0.027\ kg/s$
Q_E	$11.940\ kW$	$5.874\ kW$
Q_C	$10.970\ kW$	$4.842\ kW$
W_P	$0.081\ kW$	$0.021\ kW$
W_{net}	$0.919\ kW$	$0.979\ kW$
η_{ORC}	0.077	0.167
η_{SORC}	0.000032	0.000069

4.1. Parametric and Sensitivity Analysis

A parametric sensitivity analysis was carried out using the simulated result. Figure 2 to 11 shows the variation of the design parameters and the performance of the solar organic rankine cycle. It shows that mass flow rate, heat generated and area $(m_f, Q_g\ and\ A_{COL})$ are very important parameters for optimizing the performance of the solar organic rankine cycle.

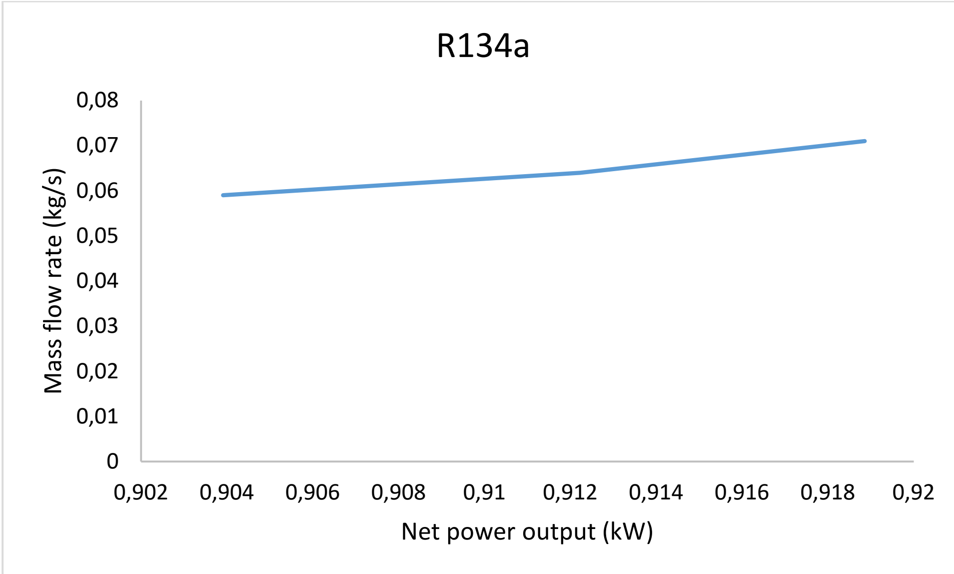

Figure 2. Mass flow rate against net power output

Figure 2 shows that the net power output increase significantly with the increase of the mass flow rate. The mass flow rate is a key parameter in enhancing the performance of the system. From various literature reviewed, the higher the mass flow rate the more expensive is the pump and as such an equilibrium has to be meet. So as not to increase the running cost of the overall system.

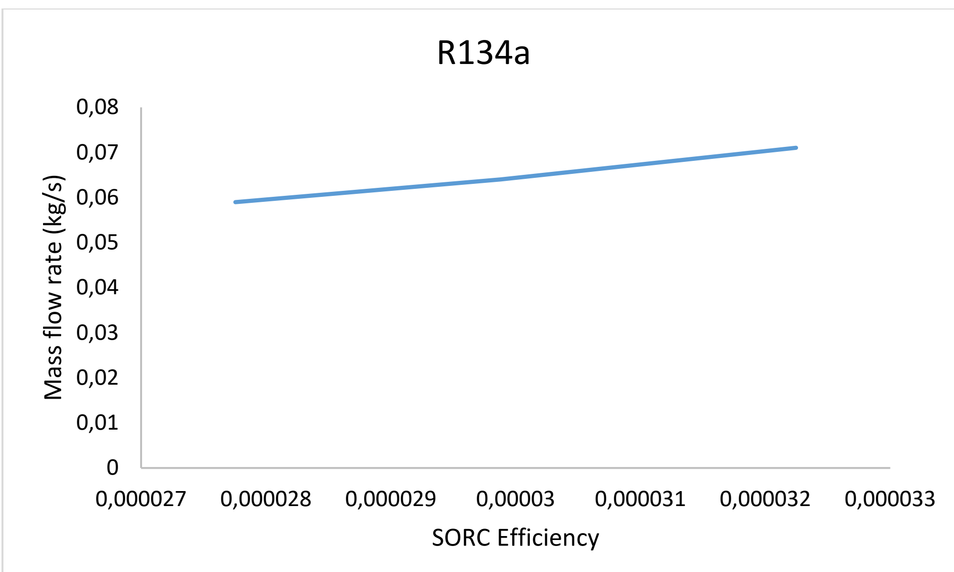

Figure 3. Mass rate flow against SORC efficiency

Figure 3 shows the effect of mass flow rate on the solar organic rankine cycle, an increase in the mass flow rate yields to an increase in the solar organic rankine cycle efficiency.

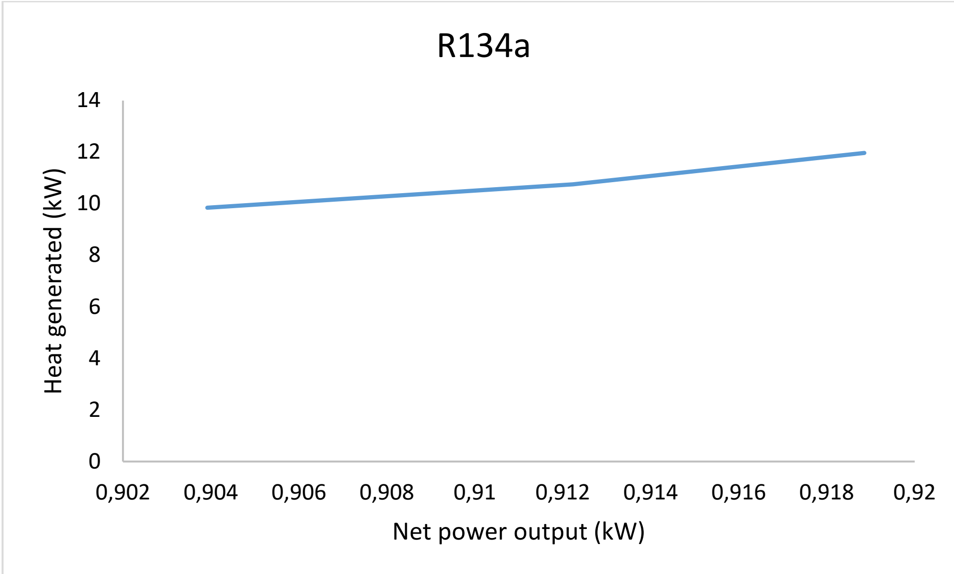

Figure 4. Heat generated against net power output

An increase in the heat generated leads to an increase in the net power output as shown in figure 4. This is as a result of the temperature of the working fluid at the evaporator exit into the turbine/expander.

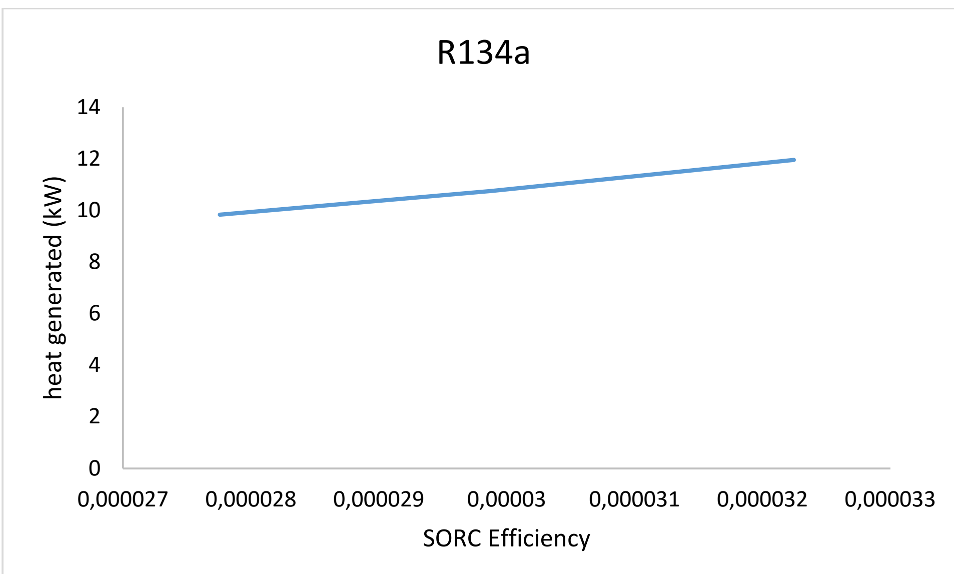

Figure 5. Heat generated against SORC efficiency

The heat generated affects the solar organic rankine cycle directly as shown in figure 5, an increase in heat generated results to a significant increase in the overall solar organic rankine efficiency of the plant. The mass flow rate and the enthalpy change of the evaporator yields the heat generated and as such the mass flow rate, enthalpy of entering and exit of the evaporator are optimal parameters to be considered.

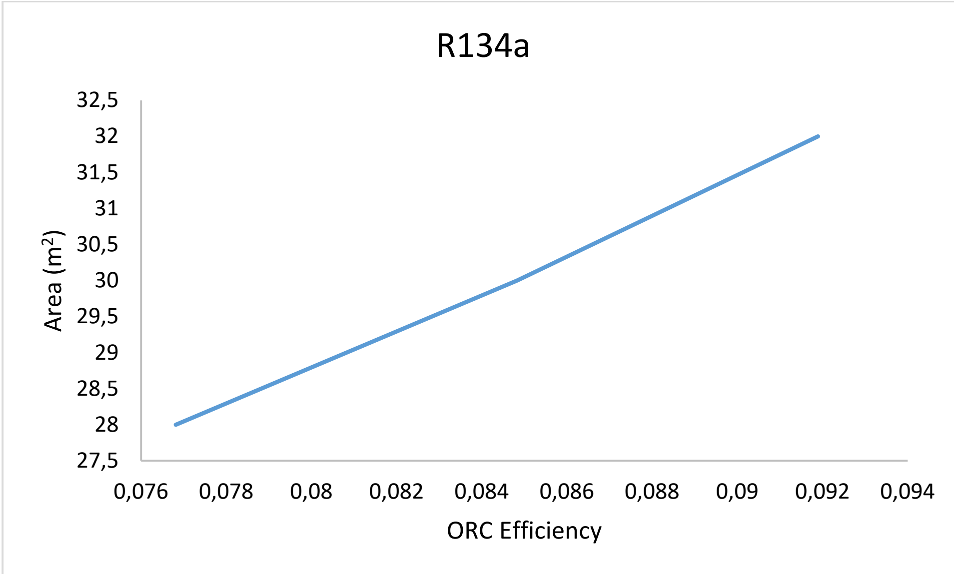

Figure 6. Area against ORC efficiency

Figure 6 shows that the area of the collector has great effect on the organic rankine cycle. This infers that an increase in the area of the collector results to a large increase of the organic rankine cycle efficiency. The larger the area the more expensive is the cost of the overall plant and as such the size of the solar collector is a very important factor to consider during the design of a solar power plant.

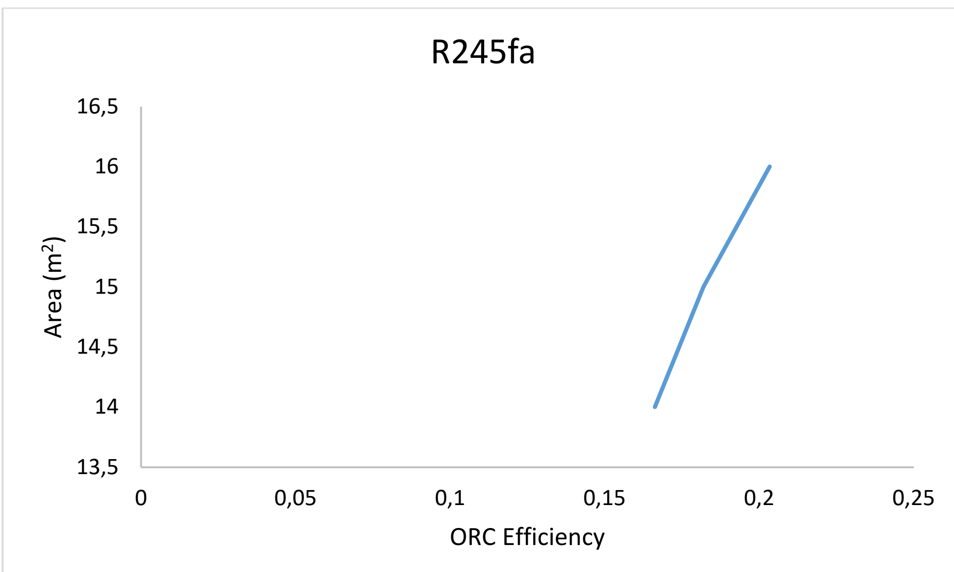

Figure 7. Area against ORC efficiency

As shown in figure 7, the refrigerant considered is R245fa and it shows that the area has a direct effect on the organic rankine cycle. An increase in the area leads to an increase in the organic rankine cycle efficiency.

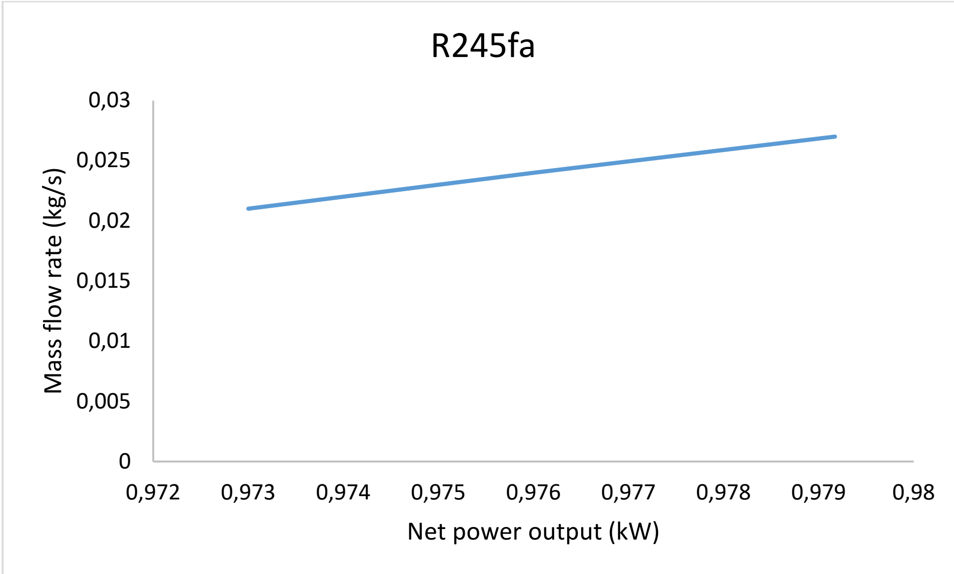

Figure 8. Mass flow rate against net power output

Figure 8 shows the direct relationship between mass flow rate and net power output using R245fa. An increase in the mass flow rate causes a significant increase in the net power output, this means that the higher the mass flow rate the higher the power produced by the turbine.

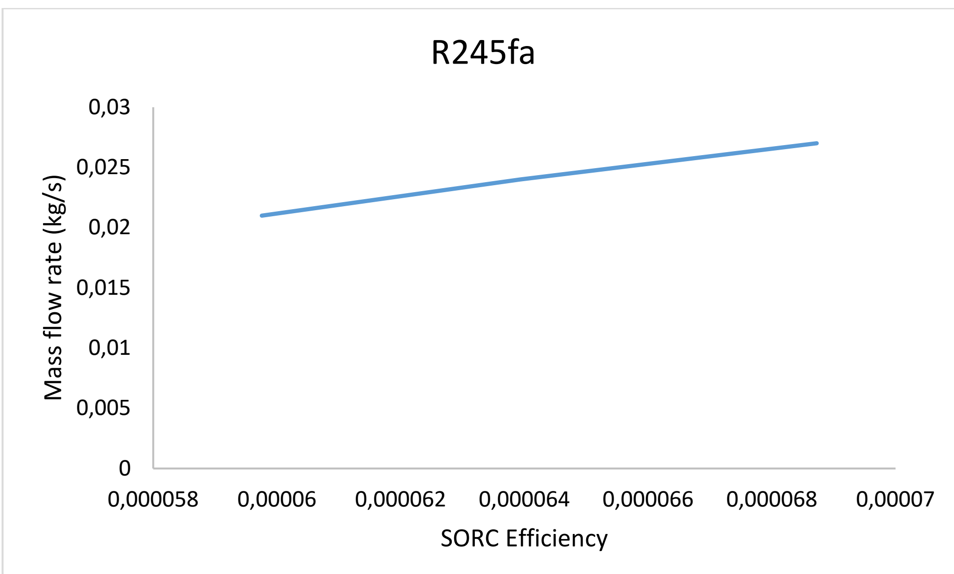

Figure 9. Mass flow rate against SORC efficiency

The mass flow rate affects the overall solar organic rankine cycle as shown in figure 9. An increase in the mass flow rate leads to an increase in the overall solar efficiency of the power plant.

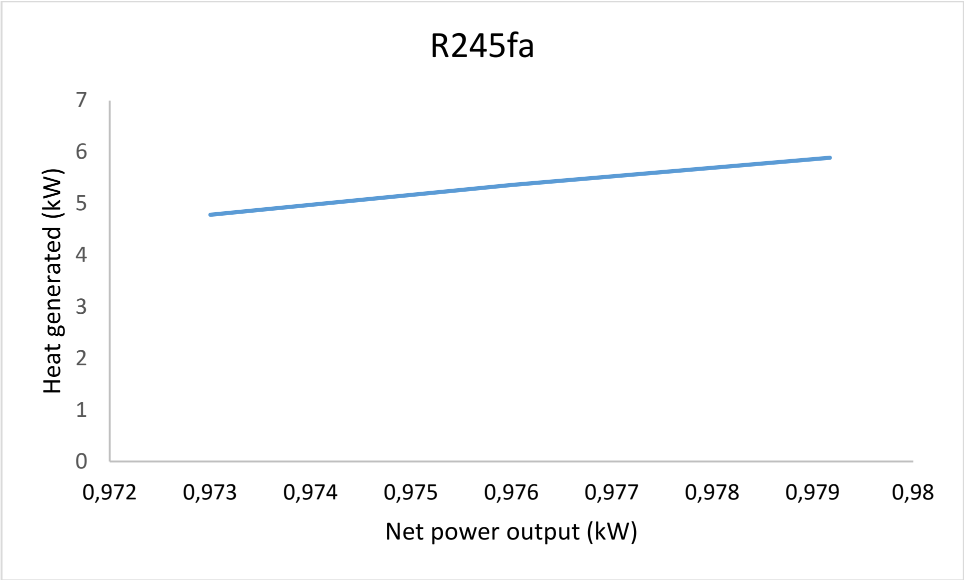

Figure 10. Heat generated against net power output

Figure 10 shows that the higher the heat generated the higher the net power output, the heat generated is one of the important parameters to consider for optimal condition of the solar organic rankine cycle.

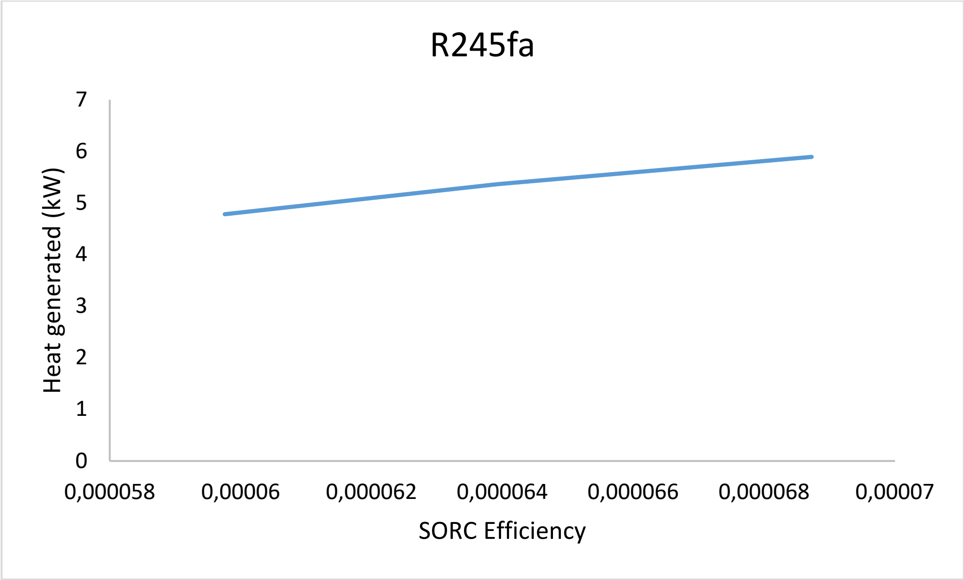

Figure 11. Heat generated against SORC efficiency

Considering R245fa as shown in figure 11, it shows the direct relationship between the heat generated by the evaporator and the overall solar organic rankine cycle efficiency. The higher the heat generated the higher the overall solar organic rankine cycle efficiency.

5. CONCLUSION

The various levels show the different conditions the SORC can be subjected to. The heat generated by the evaporator, organic rankine cycle efficiency and the overall solar organic rankine cycle efficiency are 9.782kW and 4.871kW, 9.3% and 20%, 0.0028% and 0.006% respectively. This shows that the temperature of R245fa at 120 ^{O}C generates a higher organic rankine cycle efficiency and overall cycle efficiency. R134fa generates a higher heat energy at the evaporator, the efficiencies are low due to its limitation of its critical temperature of 101.06 ^{O}C.

Table 3 shows how the system performed when the temperature entering the turbine using both refrigerant (R134a and R245fa) at 80 ^{O}C and 110 ^{O}C. The heat generated, organic rankine cycle efficiency and overall solar organic rankine cycle efficiency are 10.670kW and 5.275kW, 0.086 and 0.185, 0.000030 and 0.000065 respectively. Comparing result from both table 4.2 and table 4.1, it shows that the heat generated as shown in table 4.2 is higher than that in table 4.1, the organic rankine cycle efficiency is lower in table 4.2 and an increase in the overall solar organic rankine cycle efficiency. The organic rankine cycle efficiency is lower as a result of the decrease in the turbine intake temperature and a reduction in the area of the solar collector causes a reduction in the solar organic rankine cycle efficiency.

Table 4 gives a higher heat generated, a lower organic rankine cycle efficiency and a higher overall solar organic rankine cycle efficiency. A reduction in the temperature of the working fluid entering the turbine result in a decrease of the organic rankine cycle efficiency and a reduction in the solar collector area give rise to a decrease in the organic rankine cycle efficiency.

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SIMULATION OF A GAS TURBINE PLANT USING EVAPORATIVE COOLER

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ABSTRACT: This research work focus on the simulation of a gas turbine power plant using evaporative cooler. Aspen HYSYS software was used for the simulation of the gas turbine with and without cooling system using the actual operating data for performance evaluation. The results obtained on the simulation of the gas turbine at ambient air temperature of 29 ^{0}C without the use of cooling system showed that ambient air temperature decreases the net power output, thermal efficiency and power output. However, when the gas turbine was incorporated with air intake cooling system, there was drop in ambient air temperature which resulted to an increase in net power output, thermal efficiency and power output.

Keywords: Apen HYSYS Software, Gas Turbine.

1. INTRODUCTION

Gas turbines are used for electric power generation, operating airplanes and for several industrial applications. The gas turbine engine consist of a compressor to raise combustion air pressure, a combustion chamber where the fuel/air mixture is burned and a turbine that through expansion extracts energy from the combustion gases. The simple gas turbine plant operates according to the open Brayton thermodynamic cycle and present low thermal efficiency and are referred as combustion turbines.

The performance of a gas turbine power plant is commonly presented as a function of power output, specific fuel consumption and it is sensible to the ambient conditions [1]. Thermodynamic analyses from literature show that thermal efficiency and specific output decrease with the increase of humidity and ambient temperature, but the ambient temperature is the variable that has the greatest effect on gas turbine performance [2].

The ambient temperature rise results in decrease in air density, and consequently, in the reduction of the mass flow rate. Thereby, less air passes through the turbine and the power output is reduced, at a given turbine entry temperature. Moreover, the compression work increases due to the augmentation of the volume occupied by the air.

According to [1], the net power output produced by gas turbine is directly proportional to the air mass flow and decreases when ambient temperature increases. The work of Ibrahim [3] shows that an increment of 1 °C in the compressor air inlet temperature decreases the gas turbine power output by 1 %.

The aim of this research is to carry out a thermodynamic analysis of a gas turbine power plant (Niger Delta power plant Holding Company Omotosho Generation Station phase 2) using the evaporative cooler method.

Evaporative coolers, often called "swamp coolers", are cooling systems that use only water and a blower to circulate air. When warm, dry (unsaturated) air is pulled through a water soaked pad, water is evaporated and is absorbed as water vapor into the air. The air is cooled in the process and the humidity is increased [4].

Using evaporation media reduces NO_X in the emission from combustion chambers; and therefore, positive effects of environmental consequences are introduced. Cooling the air as much as 10℃ will increase approximately 6 −10% in electrical power generated [5].

Status of application of evaporative inlet air cooling systems in three great power plant including Rajaei, Qom and Fars were studied. Comparing economic and technical aspects showed that using evaporation media system was more effective than fog system. Using wetted media type to cool the gas turbine inlet air in five PG6581 and three PG6551 type gas turbine showed that wetted media caused the inlet air temperature drop at 12−14°C and increases 4MW for each of PG6581turbines and 3.5MW for each of PG6551gas turbines [6].

2. MATERIALS AND METHOD

Omotosho Generation Station (phase II) is a gas turbine plant owned by Niger Delta Power Holding Company (NDPHC). The power plant is located at Omotosho, Okitipupa Local Government area of Ondo State, Nigeria. It has four GE frame machines with the installed capacity of 125MW for each machine bringing its total installed capacity to 500MW.

2.1. Data Collections

The operating data for gas turbine unit from (2013 to 2016) of Omotosho Power Plant were collected from the daily turbine control log sheet. The daily average operating variables were statistically analyzed and mean values were collected for the period of January to December with an overall average.

Summary of operating parameter of a (GE Frame) gas turbine unit used for this study is presented in Table 1. The thermodynamic analysis of the plant and its performances was carried out without cooling and with cooling of the inlet air entering the compressor.

The basic gas turbine cycle is Brayton cycle; it consists mainly of compressor, combustion chamber and turbine. Air enters the compressor where it is compressed and heated after that its goes to the combustion chamber, where fuel is burned at constant pressure before it eventually raises the temperature of air to the firing temperature. The resulting high temperature gases enter the gas turbine where they expand to generate the useful work. Figure 1 shows the flow chart of the system without cooling while figure 2 shows modelling of gas turbine unit by incorporating an evaporative cooler.

Table 1. Summary of operating data for the 125MW G.E simple cycle gas turbine power plant of Omotosho power plant (phase II).

S/N	Operating Parameters	Valve	Unit
1	Mass flow rate of air through compressor (ma).	361	Kg/s
2	Temperature of inlet air to compressor (T_1)	302	K
3	Pressure of inlet air to compressor (P_1)	101.3	Kpa
4	Outlet temperature of air from compressor (T_2)	611	K
5	Outlet pressure of air from compressor (P_2)	1066	Kpa
6	Fuel gas (natural gas) mass flow rate (mf)	6.5	Kg/s
7	Fuel – air ratio at full load (on mass basis)	56:1	
8	Inlet pressure of fuel gas	24	Bar
9	Inlet temperature of gas turbine (T_3)	1405	K
10	Maximum exhaust temperature of T. outlet	851	K
11	Combustion efficiency $\cap_{ce}$	90	%
12	Pressure drop in the combustion chamber	10	%
13	Installed capacity	125	MW
14	Isentropic eff. Of compressor	89.20	%
15	Isentropic eff. Of Turbine	89.80	%
16	Specific heat capacity of air 1 Cpa	1.005	KJ/kg K
17	Specific capacity of gas Cpg	1.15	KJ/kg K
18	Lower heating value (LHV)	45880	KJ/kg K

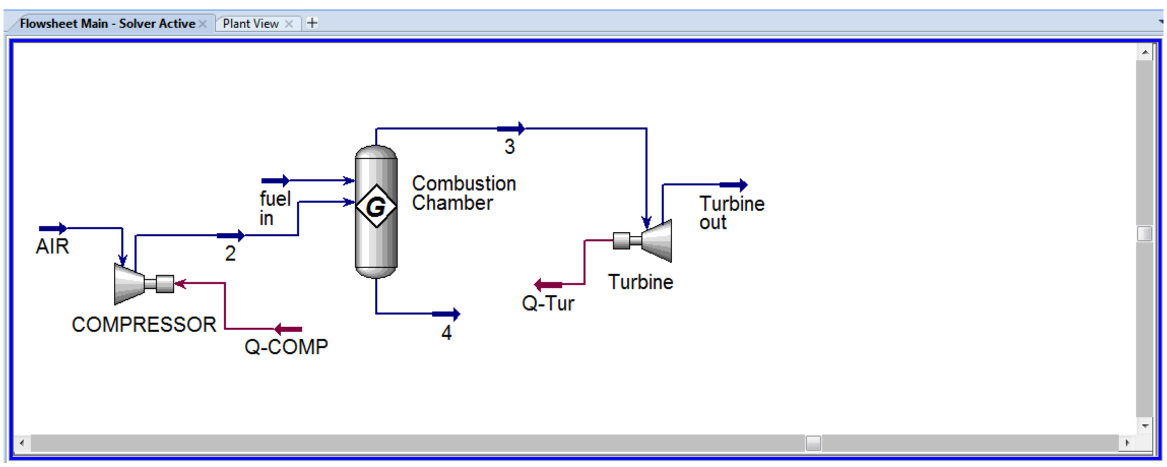

Figure 1. Simulated schematic of a simple gas turbine cycle without a cooling system.

The gas turbine power plant with inlet air cooling is modeled in the following assumptions. The following assumptions were made in the simulation of the gas turbine using the evaporative cooling system, compressor inlet temperature, the air and combustion products are assumed to behave as ideal gases.

I. The process modeling uses a steady-state simulation, that is, all the operating conditions are constant.
II. All component have adiabatic boundaries.
III. The ambient conditions of temperature and pressure are at 15^0C and 101.3kpa.

IV. The air and the combustion products are assumed to be ideal.
V. Kinetic and potential components of energy are neglected.
VI. The combustion process is assumed to be a conversion reaction during simulation using ASPEN HYSYS.
VII. There is about 90% energy conversion in the reactor.
VIII. The compressor and turbine has an adiabatic efficiency of 89.20% and 89.80% respectively.
IX. The component of the natural gas is Methane and temperature at entering is 55^{o}C.
X. The natural gas inlet pressure is 24 bars.
XI. The pressure drop across the combustion chamber was assumed to be 0.010%.

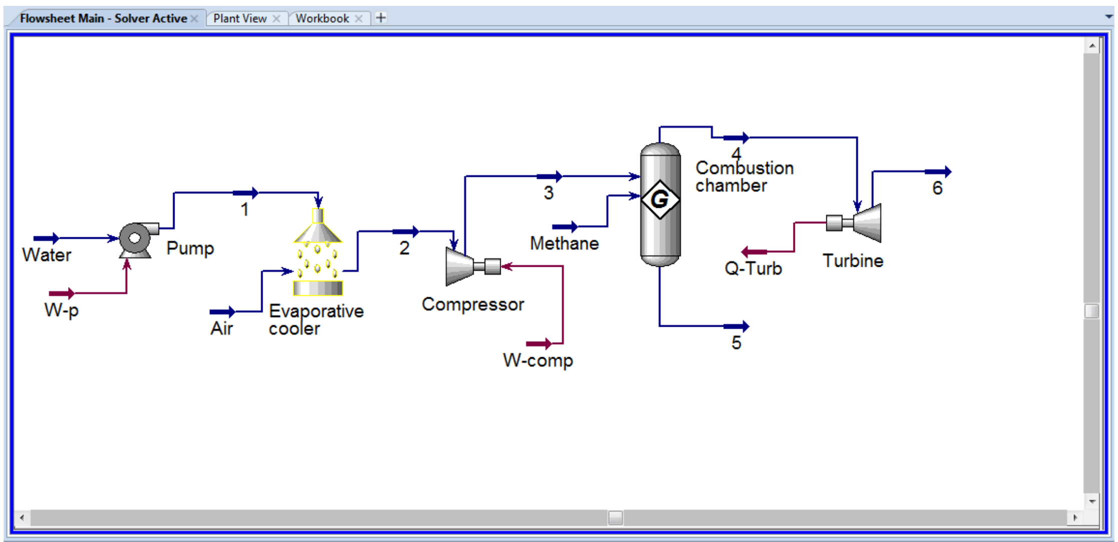

Figure 2. Simulated schematic layout of the gas turbine cycle with an evaporative cooler.

Aspen HYSYS was used to model the gas turbine without cooling and gas turbine with an evaporative cooler units. The first step in creating the model was the selection of a standard set of components and a thermodynamic basis to model the physical properties of these components.

When the component list was created, HYSYS created a new component list called Component List-1. The next step was the selection of a Fluid Package for it.

The Simulation Environment was entered to begin building the process model. The Pump, cooler unit, Compressor, Conversion Reactor, Turbine icons from the model palette were clicked and placed on the flow sheet in Figure 2. The combine unit of pump and evaporative cooler are used to simulate an evaporator unit: when the incoming air enters the evaporative unit, the intake air mixes with the cold water from the pump thereby reducing the temperature of the air entering the compressor.

3. RESULT AND DISCUSSION

Aspen HYSYS software was used to simulate the performance of the plant. The result obtained is shown in Table 2 and Table 3 to know the influence of a change in input variable such as temperature on the net power output, power generated thermal efficiency and heat rate. The results were used to compare the performance of the plant when it is incorporated with air intake cooling system (evaporative cooler).

Table 2. Simulated result obtained by simple type gas turbine

S/N	Result of Simulation	Output	Output
1	Compressor work W_c	116500kW	116.5MW
2	Turbine work W_t	217900kW	217.9MW
3	Power generated	101400kW	101.4MW
4	Thermal efficiency	0.2985	29.85%

Table 3. Simulated result obtained by adding an evaporative cooler

S/N	Result of Simulation	Output	Output
1	Pump work W_p	0.0611kW	0.0000611MW
2	Compressor work W_c	100400kW	100.400MW
3	Turbine work W_t	214000kW	214.000MW
4	Power generated	112989kW	112.989MW
5	Thermal efficiency	0.3213	32.13%

4. CONCLUSION

The power generated and thermal efficiency of a gas turbine power plant without an air inlet cooler are 101.4MW and 29.85% respectively. Power generated and thermal efficiency of a gas turbine power plant with an air inlet cooler are 112.989MW and 32.13% respectively.

As shown in table 2 and 3.2 the power generated and the thermal efficiency is higher when the power plant is incorporated with an evaporative cooler than a normal gas turbine without an inlet air cooler. An increase in power generated means more mega Watts of electricity is generated, more money is made and the running cost reduces.

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REALIZATION OF A BUILDING AUTOMATION SYSTEM USING PLC AND SCADA

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ABSTRACT: Building automation systems are inevitable in every building in order to make life easier, decrease work load, and create safer and higher quality environments. Today's automation technology generally makes use of computer enhanced automation. PLC and SCADA Systems are the most commonly preferred systems. With the developments n technology, various equipment and procedures are found to be in use in this field. In the present study, a system has been implemented in order to monitor and remotely control the parameters of a building automation system and to gather data. The system is a PLC and SCADA based system. The proposed system was applied in Tekirdağ Namık Kemal University Vocational School of Technical Sciences Control and Automation Technology laboratory.

Keywords: Building Automation, PLC, SCADA.

1. INTRODUCTION

Building automation systems are used for several reasons including the safety of residents and physical assets in the building, air quality and comfort, quality and sustainability of energy transmission [1-2].

Expectations of individuals from building automation systems can vary. While the expectations of comfort are high for those who live or work in the building, concepts such as the ability of control and productivity would be among the top expectations of those who manage the building [3]. A building automation system is expected to meet this kind of expectations [4]. New generation building automation systems are designed according to both the residents and building managers' expectations.

Building automation systems can be carried out by classic remote systems of PLC based automation systems. PLC-based automation systems are frequently preferred in building automation designs due to its high security levels, easy set-up, being less affected by bad environment conditions, taking a small space, ability to monitor data received from field workers, and easy tracking.

SCADA is used to monitor and control processes real-time. This control can be automated or manual. Information received from the sensors in the field are evaluated by PLC [5]. The results are, then, snet to components connected to the PLC output. This process can be monitored through SCADA software's and controlled remotely.

PLC and SCADA systems should have the desired components in building automation systems. PLCS and SCADA systems include a central station, field station, communication system, and PLC and SCADA software's. The central station controls the system and stores the data. Building automation components can be controlled via the software installed in this central station. Field station audits the data obtained by field components through PLC systems and sends the data to the central station. Communication system provides communication between the central station and others. Software controls all the data and stores the data for the central station.

A literature search was conducted and resulted in finding systems built by using PLC and SCADA. The commonality of these studies is that buildings and industrial environments equipped with sensors are controlled and monitored through PLC and SCADA [6]. In building automation systems, PLC and SCADA-based applications such as control and monitoring of heating-cooling systems [5], sustaining energy transmission system and productivity [7], safety precautions against physical attacks [8] and pressure control were found. There are also control studies that used PLC and SCADA in industrial environments [9-10].

In this study, a multi-purpose automation system, called "Model System," was designed by using PLC and SCADA. This system was applied in the Control and Automation Laboratory in the Vocational School of Technical Sciences at Tekirdağ Namık Kemal University. SCADA software was used to control the Model System real-time, and to obtain, evaluate, and command data continuously.

2. MATERIAL AND METHOD

The designed model system for a building automation by using PLC and SCADA is presented in figure 1. The system consists of two components that are, hardware and software.

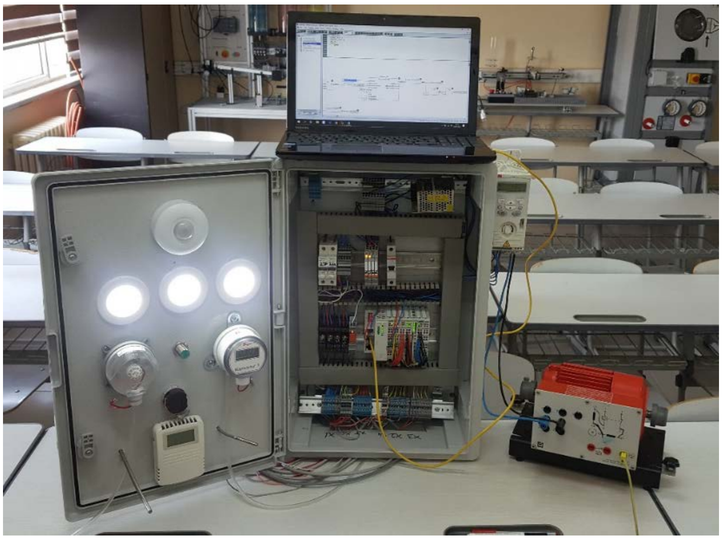

Figure 1. Overview of the study.

The hardware of the Model System is a Wago 750-852 model PLC, PT 100 type heat sensors, DWYER RHP-3W44-LCD heat and humidity sensor, and differential-pressure sensor.

The PLC and SCADA softwares developed for real-time process monitoring and remote control of the system, operation of the Model System through PLC according to the developed algorithm, are monitored through the main computer connected to the system. To program the Wago 750-852 PLC which is used in the Model System, Codesys (Controller Development System) 2.3 editor was used.

Codesys, developed by the compnay anmed 3smart, is a programming editor with an open source coding. It is the common PLC software development editor for companies producing PLC such as Wago, ABB, Schneider, Beckhoff, and Mitsubishi. As it supports several PLC programming language, has access to many training materials, being an open source software and other benefits abovementioned contributed in choosing it for this thesis.

The PLC software in the Model System consists of heating-cooling automation (HVAC) software, dampening automation software, alarm system automation software, and main software controlling this sub software's. The PLC software operating the heating and cooling control is shown in figure 2, the PLC software for humidity control is shown in figure 3, and the alarm PLC is shown in Figure 4.

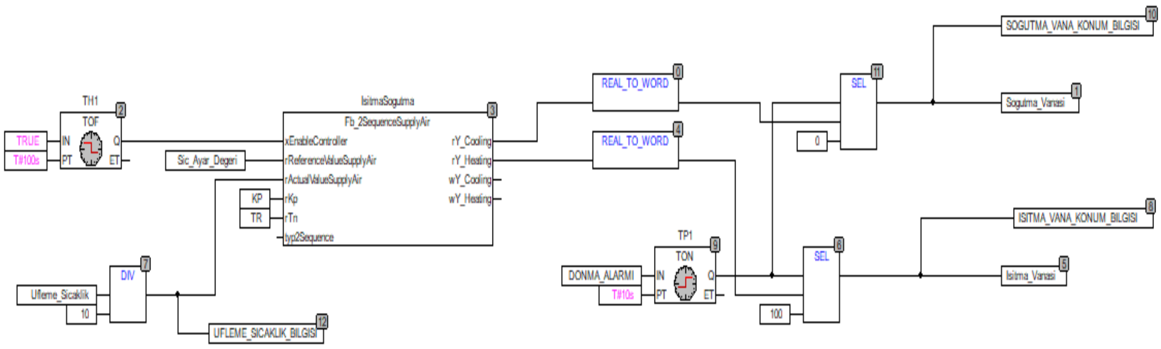

Figure 2. PLC subprogram for heating and cooling control

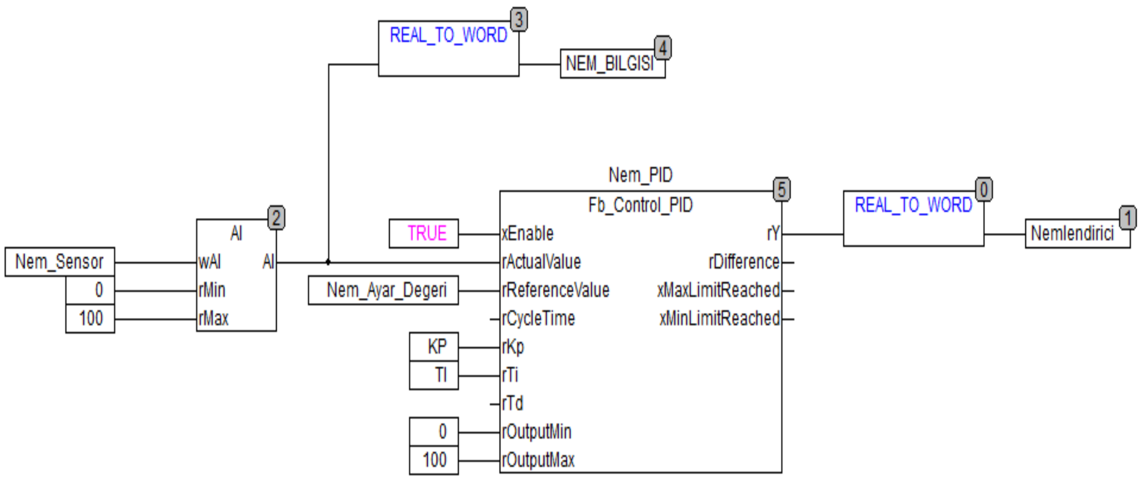

Figure 3. PLC subprogram created to measure moisture information and set humidity level to desired value

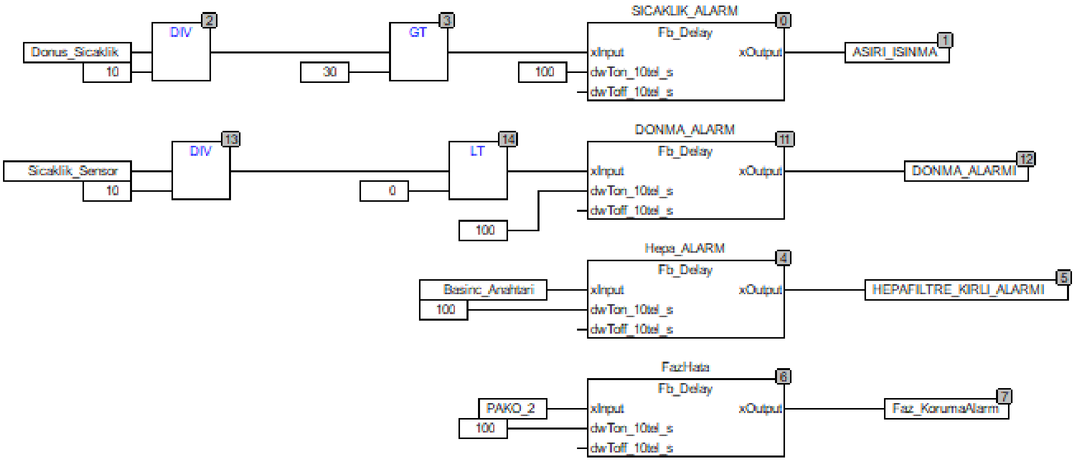

Figure 4. PLC subprogram created for overheating, freezing condition, hepa filter pollution information, phase failure

A SCADA software was developed to control the developed model system real-time, to collect, evaluate, and command data continuouslt and real-time. This software was developed by using Visu + Scada editor.

In the software developed with Visu + Scada editor, first the points used in the model system as seen in Figure 5 were created according to the Modbus protocol.

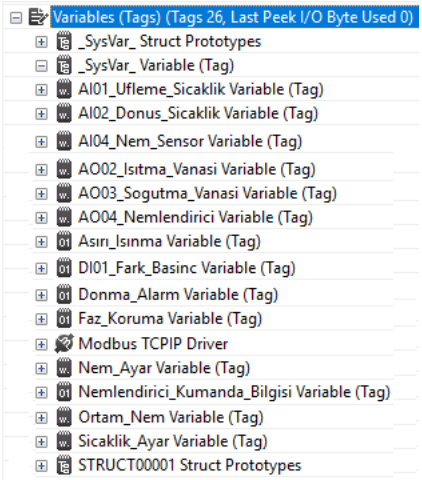

Figure 5. ModBus SCADA points

The SCADA software of the Model System consists of 3 pages. In Figure 6, the introduction page, in figure 7, the HVAC page in which heating and cooling functions are performed, and in figure 8, the alarm page is presented.

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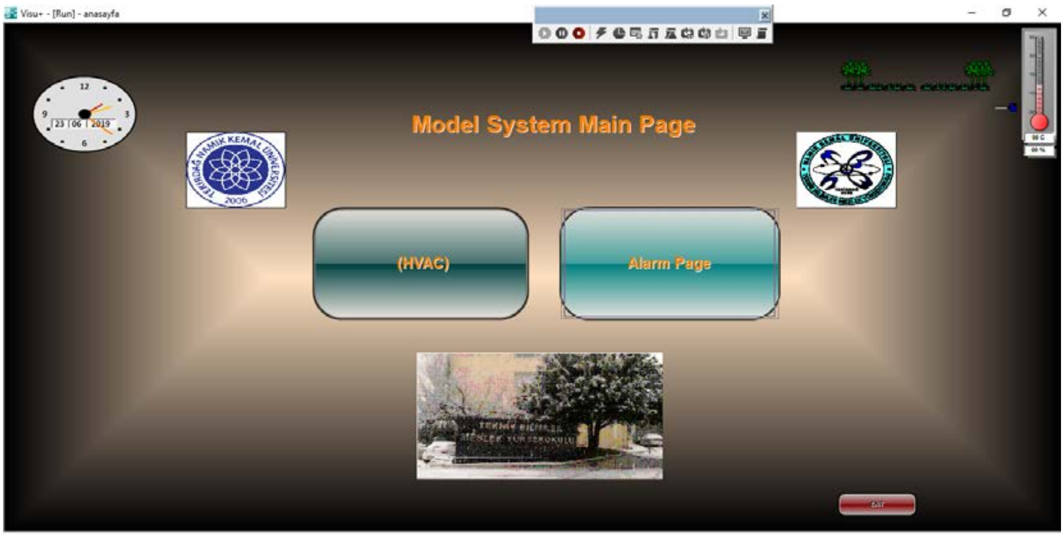

Figure 6. SCADA page

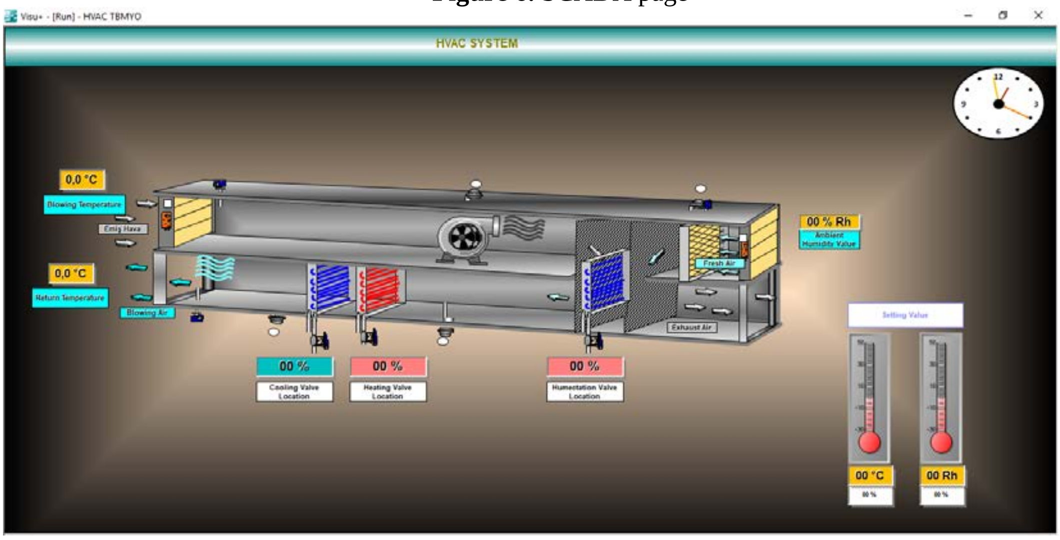

Figure 7. HVAC

Figure 8. Alarm Page

3. FINDINGS

Building automation refers to monitoring-commanding, and controlling systems such as lighting, elevator, fire, alarm, and security, in a system. Taking precautions against pre-determined emergency scenarios, energy saving, increasing life quality, providing air quality and comfort, and increasing security level to the highest are the fundamental goals of building automation systems. Research in the literature show that as there is a need for multiple points in big building, PLC systems are preferred. For the control of these systems and management by the user, certain visual applications are needed. Therefore, SCADA systems were developed.

Within the scope of this study, a system called the "Model System" was designed. This system was applied in the Control and Automation Laboratory in the Vocational School of Technical Sciences at Tekirdağ Namık Kemal University.

The hardware of the system consists of PLC and input and output elements connected to PLC that are' humidity sensor, heat sensor, differential-pressure key and relays.

The software of the Model System consists of two components; PLC software and SCADA software. CodeSys editor was used for the Wago 750-852 PLC software used in the Model System. The reasons for preference of this editor include being open-source coded, supporting multiple PLC programming language, and having access to many training materials. The model system consists of heating-cooling automation software, humidity automation software, and the main software controlling this sub software's.

4. RESULTS AND RECOMMENDATIONS

In this study, a building automation system, called the Model System, that allows real-time monitoring and controlling of data by using PLC and SCADA was used. The Model System provides controlling and monitoring of functions such as heating cooling, dampening, and alarm system. The significance of the study is that the control structures are provided together. With PLC and SCADA programs, the system has a feature of remote monitoring and control.

As the Model System was designed in a module at structure, it is easy to add sub-systems and to increase the number of points. Thus, the planned additions in future studies are listed below:

- By adding a camera to the system that has a virtual laboratory characteristic due to its web interface to provide real-time visual control,
- To provide communication with other electronic devices,
- Adding a fire alarm system,
- Controlling and monitoring security camera system remotely,
- Adding graphics to SCADA software's,
- Creating an infrastructure for energy transmission and auditing system.

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RESEARCH OF A DRY PORT WHICH CAN SUPPORT CONTAINER TRANSPORTATION FROM KOCAELI PORTS IN TERMS OF POSSIBILITIES AND CAPABILITIES

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ABSTRACT: While the containerization and intermodal transportation become widespread, dry ports within the transport network in the hinterland of a sea port have begun to play an important role in freight transport. In addition to providing the opportunity to expand the hinterland of sea ports, a dry port can also relieve a sea port that is experiencing capacity problems.

It is thought that the total capacity of Kocaeli container terminals, which play an active role in Turkish foreign trade, may be insufficient to meet the needs in the coming years and therefore a dry port to be established in the region may support the seaports in increasing their throughput volumes. The Köseköy logistics center, which is considered to be a suitable candidate in this regard, has been examined in terms of the facilities and capabilities it has to possess, and the minimum land area of that dry port has been determined by taking into account the demand of 2035 through a mathematical model.

In this study, it is assessed that the Köseköy logistics center has enough space to construct the required facilities in supporting the ports in the region in terms of container transportation, however, it must acquire new abilities. On the other hand, it is considered necessary that TCDD (Turkish Republic State Railways) complete its infrastructure investments to increase the freight transport capacity to a minimum one million TEU a year between Gebze and Köseköy.

Keywords: Dry port, container transportation, intermodal transportation, maritime management.

1. INTRODUCTION

Containerization, since its first launch in 1956, has boosted the maritime transportation and the globalization within a few decades [1]. The invention of the container at first was targeting take place in maritime transportation, but in time it also took place in inland transportation [2]. In addition to the possibility of storing the goods to be carried, containerization has provided great flexibility to the logistics system [3], making it feasible to integrate the maritime and inland transportation [4].

While opening new global markets by the way of quick distribution method [2], container transportation also brought in a new concept, “Door – to – door” service, which stimulated the development of intermodal transportation [5]. Intermodal transportation requires the development of proper infrastructure such as roads, railways, and terminals [6]. It is also seen as a solution for congestion on roads [7]. The increase in global trade brings in the need to develop the transportation network as well as the terminals which are having difficulty to accommodate the increasing throughput [8, 9].

While the carriers take into account the total cost of transportation inland transportation is getting higher importance as an important dimension of maritime transportation [10]. The increase in demand for inland freight transportation has triggered the emergence of dry ports [11]. Intermodal transportation enabled the carriers to transport their goods through the environmental and cost-friendly systems, such as railway and inland waterway, to the dry ports before distributing to the markets.

UN ECE [12] defines the dry port as the “Inland terminal which is directly linked to a maritime port.” This definition mainly emphasizes the direct linkage between the seaport and the dry port. Leveque and Roso [13] added the quality of the linkage in the definition as stating that; “A dry port is an integrated intermodal terminal directly connected to the seaport(s) with high capacity transport mean(s) where customers can leave/pick up their standardized units as if directly to/from a seaport”. According to Leveque and Roso, it should enable high capacity transportation between the seaport and the dry port. Another detail in this definition implies that the direct link should ensure the customers so that their goods will easily flow through it.

Dry ports are crucial nodes assisting efficient global freight transportation by connecting the consumption centers, production centers and seaports [14]. These inland terminals can be regarded as extended gates of the seaports and they can serve as reducing the dwell time of the containers [15]. According to Werikhe and Jin [16], the evolution of a dry port creates a cycle in the continuous development of containerization and intermodal transport.

According to Cullinane and Wilmsmeier [17], the dry port concept recently has been being applied mainly for two reasons. One of them is to overcome the problems of capacity constraints [18] in a container port. The other reason is expanding the hinterland of a container port.

Unlike the general situation of the world, in Turkey, the distribution of freight from seaports to inland destinations to a large extent is accomplished by road transportation. The contribution of the railway system to this transportation is unfortunately at a level of 2% [19]. However, the Ministry of Transport and Infrastructure (MTI) targets a rate of 20% for railway freight transport between 2023 and 2035 [20]. Therefore, it is assessed that the Turkish Republic State Railways (TCDD) will provide higher transportation capacity in the future.

The aim of this study is to evaluate the capacity of the ports of Kocaeli and intermodal transportation facilities in the region by taking into consideration the possible container traffic in 2035 and to make a proposal in line with the emerging needs.

2. CONTAINER TERMINALS

Currently, there are six container terminals within the Kocaeli Gulf. The locations of these ports are seen in Figure-4.1. Among them, SAFIPORT has been undergoing a modernization phase since 2015 after the privatization process, and BELDEPORT is a newly constructed seaport which is in service since 2018 with limited capabilities.

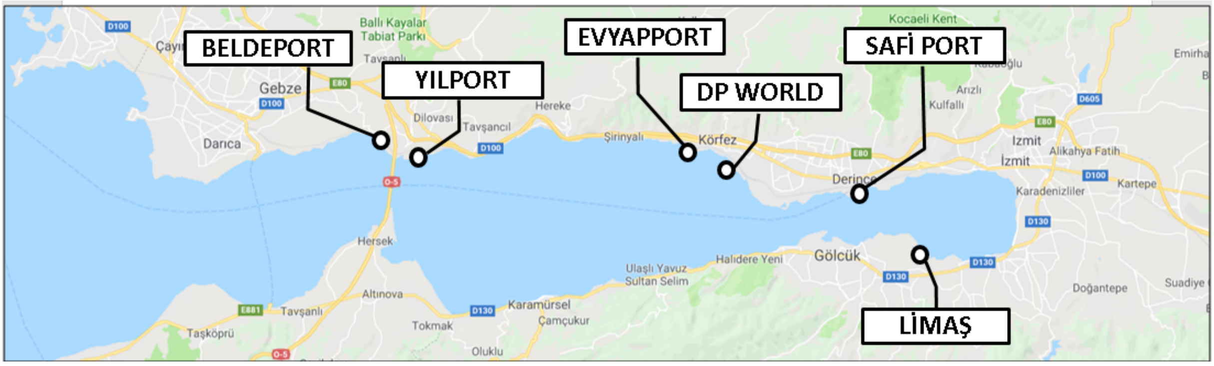

Figure 1. The locations of the Kocaeli container terminals.

The statistics of these terminals are seen in Table-2. BELDEPORT and SAFIPORT are not included in this table since their construction periods are not completely finished.

Table 2. Container Throughput Values and Annual Change in Kocaeli Ports.

Year	YILPORT		EVYAP		DP WORLD		LİMAŞ	
	Value (1000 TEU)	Change %	Value (1000 TEU)	Change %	Value (1000 TEU)	Change %	Value (1000 TEU)	Change %
2010	184		248					
2011	230	25,0	283	14,1				
2012	230	0	400	41,3				
2013	305	32,6	457	14,3			46	
2014	354	16,0	522	14,2			25	-45,6
2015	375	5,9	605	15,9			13	-48,0
2016	396	5,3	688	13,7			13	0
2017	499	26,3	369	-46,3	437		16	23,0
2018	552	10,6	465	26,0	576	31,8	16	0

Source: TURKLIM (Port Operators Association of Turkey).

Recently, YILPORT and DP WORLD have exhibited remarkable performance, with an annual increase of 26.3% in 2017 and with that of 31.8% in 2018 respectively. The involvement of DP WORLD affected adversely the neighbor of EVYAP in 2017. Although EVYAP showed another remarkable increase last year with 26.0%, it was not sufficient to meet the loss of the previous year. The values of LİMAŞ are very low compared to the other terminals. This situation derives from the feature of the accessibility of the main routes. The ports located at the north side of the gulf are in advantageous situations since both highways and the railways pass very closely to those ports. Their location makes it easier to reach inland locations in Anatolian part and also to Istanbul which takes the lion's share in traded goods. On the contrary, the distance of LİMAŞ from Istanbul is more than that of other ports. That its access to highways takes longer time than other ports is another disadvantageous feature. Besides that, LİMAŞ lacks the railway alternative which provides a highly important advantage to the other ports located at the northern side of the Kocaeli Gulf.

When examining the last eight years of performance, the Compound Account Growth Rate (CAGR) of YILPORT has been 14,72% whereas it has been 8,17% for EVYAP. Although the throughput values are quite lower than the world's leading ports, the performance of Kocaeli ports is on the rise with higher CAGR values than the world average. Approximately 5% of Turkey's total foreign trade is formed in Kocaeli. The position of the Kocaeli Gulf is very influential on this continuous rise. Considering the contributions of the neighboring cities, especially Istanbul with a contribution of 55%, it is seen that the ports in Kocaeli Gulf serve a region where approximately two-thirds of Turkish foreign trade is formed. Transportation to almost every side of Turkey can be easily managed from Kocaeli Gulf. So, the Kocaeli ports whose hinterland covers a substantial part of the Anatolian peninsula plays an important role in maritime transportation in Turkey. Last year, 16% of all goods in tonnage were handled in

Kocaeli Port. Based on the assumption that the added value created by the Kocaeli economy and the proportion of foreign trade volume reached by country does not change until 2023, Erdoğan [21] estimated that the container load of the Kocaeli region can reach 4 million TEUs by 2023. The projections of the authors also imply similar values as seen in Table-3.

It is foreseen that the container transportation will continue to increase. Lloyd's List Intelligence (LLI) predicts a 3,1% annual growth rate for seaborne trade and a 4,6% annual growth rate for containerized trade between 2017 and 2026. UNCTAD predicts a bit more like 3,8% annual growth rate for seaborne trade and a 6,0% annual growth rate for containerized trade between 2018 and 2023 [22]. Three different scenarios are predicted for the transaction volumes of Turkey's and Kocaeli ports (see Table-3) that may occur in the future. In these scenarios, the predictions of LLI and UNCTAD are accepted as the average rates. The pessimistic scenario is based on lower rates than LLI and UNCTAD predict, and the optimistic scenario is based on that Turkey's ports will be able to maintain a rate close to the increase they have shown over the last period.

Table 3. Predictions for Future Throughput Values of Turkey's Ports.

<table>
<tr><th colspan="2" rowspan="2"></th><th rowspan="2">Year</th><th colspan="2">Turkey Total</th><th colspan="2">Kocaeli Ports</th></tr>
<tr><th>Value (1000 TEU)</th><th>CAGR %</th><th>Value (1000 TEU)</th><th>CAGR %</th></tr>
<tr><td colspan="2">Recent Throughput Value</td><td>2018</td><td>10.843</td><td></td><td>1.597</td><td></td></tr>
<tr><td rowspan="9">Projected Throughput Values in Scenarios</td><td rowspan="3">Scenario-I (Pessimistic)</td><td>2023</td><td>12.570</td><td>3,0</td><td>1.851</td><td>3,0</td></tr>
<tr><td>2029</td><td>15.009</td><td>3,0</td><td>2,210</td><td>3,0</td></tr>
<tr><td>2035</td><td>17.922</td><td>3,0</td><td>2.639</td><td>3,0</td></tr>
<tr><td rowspan="3">Scenario-II (Average)</td><td>2023</td><td>14.510</td><td>6,0</td><td>2.137</td><td>6,0</td></tr>
<tr><td>2029</td><td>20.583</td><td>6,0</td><td>3.032</td><td>6,0</td></tr>
<tr><td>2035</td><td>29.198</td><td>6,0</td><td>4.301</td><td>6,0</td></tr>
<tr><td rowspan="3">Scenario-III (Optimistic)</td><td>2023</td><td>15.567</td><td>7,5</td><td>3.212</td><td>15,0</td></tr>
<tr><td>2029</td><td>24.025</td><td>7,5</td><td>5.690</td><td>10,0</td></tr>
<tr><td>2035</td><td>34.080</td><td>6,0</td><td>8.072</td><td>6,0</td></tr>
</table>

Source: Prepared by the Authors.

The optimistic scenario predicts that the Kocaeli container terminals can load and unload an approximate value of eight million TEUs in total in 2035. As mentioned above there are six container terminals located within Kocaeli Gulf. The annual throughput capacities of these container terminals are seen in Table 4.

Table 4. The Total Throughput Capacity of Kocaeli Container Terminals.

Container Port	Current Annual Capacity (TEU)
YILPORT	1.000.000
EVYAP	855.000
DP WORLD	1.300.000
LİMAŞ	200.000
SAFİPORT	1.500.000
BELDEPORT	550.000
Total Capacity	**5.405.000**

Source: Web sites of each port authority and authors' own source.

SAFIPORT will gain an additional one million TEUs capacity at the end of the renovation period. This extra capacity will increase the total capacity of Kocaeli container terminals to approximately 6,4 million TEUs. If there will be no additional capacity increase in the medium term, the total capacity of Kocaeli container terminals will not be able to meet the possible demand in the years the 2030s according to the optimistic scenario.

In Turkey, most of the ports have difficulty because of the limited area [23]. One of the constraining disadvantages of the ports located on the shores of Kocaeli is that they are surrounded by cities and there is no expansion area. The only possibility of expansion of the ports, in this case, would be filling the sea, which is a very laborious and costly process. For example, SAFIPORT is undergoing such a process, filling the sea, a very large area will be gained and the stacking capacity of the container will be increased in this way.

The proximity of the ports to the highway and railway is considered to be an advantage except for the case of LİMAŞ. However, it is necessary to pass by a certain route to reach the highway from the ports, except the cases of EVYAP and DP WORLD. These are the roads that mostly pass through urban settlements. Sometimes there occur great congestions causing loss of time for transporters on these routes. The time loss means an increase in transportation costs. One advantage of the EVYAP and DP WORLD is that they have direct entrance and output to the highway. However, the zone between Istanbul and Kocaeli is one of the busiest highway zones in Turkey. The whole freight transportation in relation to these five ports is carried out in this zone. As the country's volume of foreign trade increases, the number of heavy vehicles on the highway also increases which brings in a higher risk of an accident on the roads.

In Kocaeli, due to the fact that highways and railways remain in the city and that transit and urban transportation are carried out on the same route, traffic congestion is high. Reducing freight traffic to the highway will benefit in many ways. The most important benefit is the cost. The railway, which is known as an environmentally friendly transport system, is very advantageous in mass freight transportation. This advantage increases even more as the distance increases. The more widespread use of rail will reduce the turmoil in port cities, and contribute to the reduction of air pollution as well as noise and visual pollution.

In relation to the reasons mentioned above, a seaport with a railway connection will have a higher competitive power against its competitors. Among the ports connected to the railways, the one that allows a more rapid flow of the cargo and which brings in the minimum cost would be preferred by the carriers. Being connected to a dry port and providing a high capacity freight transportation to that dry port will provide a great advantage in competitiveness. Another advantage that a dry port can provide for sea port is that it can offer additional room to the port which has problems in terms of stacking capacity. If it is a well-established dry port, it will be able to relieve the seaport in terms of every activity other than loading and unloading to and from the vessels. If all the operations that previously were being managed in a seaport can be carried out in the dry port with a suitable location for the final destination of the cargo, it will be the reason for the preference of the transportation provider.

3. ASSESSING THE FUTURE REQUIREMENTS AND THE CAPABILITIES, TO SUPPORT CONTAINER TRANSPORTATION

The Kocaeli region hosts settlements where significant demand is generated for consumption centers as well as an important industrial power. This region and the ports in Kocaeli Gulf are expected to play active roles in the future too in forming Turkey's foreign trade and fulfilling the transportation of the goods. A "Common Mind Forum" event in the coordination of the Kocaeli Chamber of Industry was held on 16 September and 21 September 2011 with the participation of 69 people in two separate sessions in order to reveal the needs of the Kocaeli ports [21]. The prominent requirements can be listed as follows:

(1) Integration of ports with industrial organizations via railways,
(2) Integration to Anadolu via railways,
(3) Planning logistics villages and dry ports,
(4) Connecting the North Marmara Highway with Kocaeli ports.

Dry ports in Europe are generally operated by partnerships. Municipalities and other local authorities, the chambers of commerce and industry of the region, transport organizations (usually railway operators) are among these partners.

In our country, a dry port operating in accordance with the concept is not yet available. In this regard, TCDD has taken the initiative to encourage railway freight transportation by establishing logistics centers. Currently, there are nine logistics centers that are in service. Additionally, two of them are newly completed and about to come into service, two are under construction and eight are in the project phase. All these logistics centers are seen in Figure 2.

Figure 2. The logistics centers of TCDD.

Other than the two lines of high speed-train, a third railway line between Köseköy and Gebze is on construction for the purposes of conventional and freight transportation. To support the freight transportation on this line, TCDD is planning to construct some siding sites. Those siding sites ensure the traffic flow and line capability by providing meeting points. In a working group meeting held at the "First Regional Directorate of TCDD" on 13th February of 2019, the Capacity Department Manager stated that, after the construction of all planned siding sites over the aforementioned railway line, the capacity of the line can rise to 72 train services reciprocally in a day.

3.1. Köseköy Logistics Center

When examining the potential facilities to become dry ports in the region it is observed that Köseköy Logistics Center is a powerful candidate. It has a large area of more than 300.000 m2, in terms of its size and the additional capabilities it may have in the future, it is considered to be an ideal dry port alternative that can solve the problems of the region. The factors to determine the Köseköy logistics center as a close dry port candidate for Kocaeli container terminals can be listed as follows:

(1) In addition to being close to Istanbul, it is also close to the central warehouses of large industrial facilities in the surrounding provinces.

(2) It has a large and entire geographical area that can meet the needs of ports and industrial facilities in the region by means of the logistics facilities to be built on it.

(3) It is the most easily accessible intermodal terminal for Kocaeli ports through the railway.

The first part of the Köseköy Logistics Center was put into service in 2010. It is located five kilometers away from Izmit city center, in an area close to large production facilities. It is an important project in terms of transferring the freight from road to railway since the main roads of Kocaeli are about to be blocked in the near future [24]. It is also the closest intermodal terminal to the Asian side of Istanbul, Adapazarı, and Bursa. There are five 600 m long railway lines for loading and unloading, an open storage area of 65.000 m2 and a temporary storage area of 6.000 m2 for customs clearance [25]. The 286,000 m2 land adjacent to the terminal was expropriated in 2012 by the decision of the Council of Ministers for the second part of the project [26]. According to the TCDD Köseköy Logistics Directorate, the logistics center reached a size of 360,000 m2 with the new land area and a capacity of 1.500.000 tons per year is targeted with the completion of the project.

3.2. Investigating the Rail Freight Transport Capacity between Kocaeli Ports and Köseköy Logistics Center

The total load a train can pull depends primarily on the capacity of the locomotive. It is generally accepted that the total load, including the weight of the carrier wagons, should not exceed 2000 tons. Depending on the railway infrastructure, there may be some restrictions in various sections. However, the restrictions in these sections can be overcome by using more than one locomotive.

A typical railway car to transport container is seen in Figure-3. The cars produced to carry 40 feet containers have a length of 13.86 meters between the two car-bumpers, and the ones to carry 60 feet container (generally two containers, 20 feet plus 40 feet) have a length of 19.64 meters between those bumpers [27].

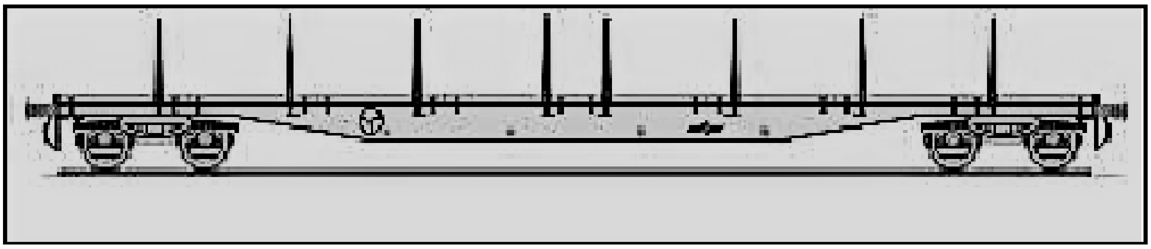

Figure 3. A typical railway car to transport container.

The capacity of these railway cars may vary between 50 to 80 tons. If the average weight of a container is assumed to be 20 tons, and taking into account the tare of the cars as varying between 18-25 tons, it can be inferred that a train shuttle may include 45 to 90 TEUs of containers in total. If the containers are transported with 60 feet long railway cars, a total of 75 TEUs require 25 railway cars, making a total length of 491 meters. The length of the locomotive in addition to 491 meters will make a total shuttle length more than 510 meters. EVYAPPORT and SAFİPORT are capable to accept such a train shuttle since having railway lines more than 600 meters. But DP WORLD has only one railway line with 500 meters. Taking into account the maneuver requirements, the length of the shuttle that DP WORLD can accept would be a little shorter than that. It is not yet possible to express anything about this subject for BELDEPORT, which is planned to have a railway connection. However, it is expected to have at least 600 meters of railway line within the terminal to meet the above-mentioned need.

According to the information mentioned above, it is assessed that a train shuttle between Gebze and Köseköy can carry 75 TEUs as an average value to transport the freight between the seaports and the dry ports or other load centers. If two-thirds of the capacity of the conventional railway line is allocated for freight transportation, 48 train services reciprocally could be implemented in a day. Allocation of this capacity for freight transportation would enable to transport 3600 TEUs of import containers from seaports to inland terminals in a day. Such a daily capacity creates a total of 1.314.000 (365*3600) TEUs capacity in a year. Although an assessment has been made on the capacity of the railway line between Gebze and Köseköy, the cargo arriving at Köseköy will also have the chance to reach all the points on the way that railway transport is possible. Similar capacity is considered to be valid for the road after Köseköy. In addition, it will be possible to carry out longer shuttle services to distant points by the combination of the load and including additional locomotive in Köseköy.

4. MINIMUM REQUIREMENTS OF A DRY PORT IN SUPPORTING CONTAINER TRANSPORTATION

The current total capacity of Kocaeli container terminals is calculated as 5,4 million TEUs as indicated in Table-4. This total capacity might rise up to 6,4 million TEUs according to the on-going development projects in SAFİPORT. Although there is no possibility of expansion of the ports, the ports are trying to increase their stacking capacity either by filling the sea or by making arrangements within the borders of the port. It is assumed that such efforts will bring in about 10% additional stacking capacity for other Kocaeli terminals. With this assumption, the total stacking capacity of Kocaeli container terminals is estimated to reach about 7 million TEUs by 2035. On the other hand, the optimistic scenario for the projections of future throughput volumes indicates that even the increased capacity may not meet the demands of 2035.

Based on the optimistic scenario and the assumptions mentioned above, additional stacking area will be required for approximately one million TEUs of containers. In this circumstance, approximately 7 million TEUs of containers would be stacked and processed in Kocaeli terminals, whereas one million TEUs of containers could be directed to a dry port for the same procedures. As stated in the previous section, the conventional railway line between Gebze and Köseköy could produce a total capacity of approximately 1,3 million TEUs provided that the TCDD's projects of siding sites are completed. This capacity would be sufficient to meet the possible demand of transporting approximately one million TEUs of containers from Kocaeli terminals to a dry port via railways.

Transporting the containers just after unloading them from a vessel directly to a dry port, related to the dry port concept would require that every capability of a seaport, other than unloading from the vessels, should be acquired by the dry port. Those required capabilities for a dry port can be listed as follows [28, 29]:

(1) Container loading and unloading: To be capable of loading and unloading the containers to and from railway cars and trucks.

(2) Container stacking areas: The area should be allocated for each type; including empty, filled, and refrigerated containers. The area should be designed to provide convenience for unloading from railway cars, and loading to trucks, or vice versa.

(3) Railway lines: In order to unload the incoming cargo, load the departures and change the line of the locomotives, at least three lines should be constructed, each having minimum 700 m. length. The maneuvering areas for vehicles should also be taken into account.

(4) Customs inspection: Separate plant for inspection and separate stacking area for the containers waiting for inspection should be taken into account.

(5) Container freight station: Process for stuffing, stripping, and value-added activities.

(6) Container maintenance/repair: A separate station should be constructed for maintenance and repairing of the containers.

(7) Corporate buildings: Working offices and/or buildings should be allocated for the companies undertaking logistics roles.

(8) Parking space for carriers: For the trucks and other carriers a sufficient area should be allocated for parking and waiting.

(9) Social facilities: Social requirements for both personnel and customers should be taken into account.

Considering the capabilities required of a dry port, the Köseköy logistics center needs significant investment and modern equipment. A limited number of reach stackers are currently available for container loading and unloading operations. A dry port, which is likely to handle cargoes between 2000 and 3000 TEUs per day in the 2030s, will have to carry out these operations with the help of advanced crane systems such as Rubber Tyred Gantry (RTG) or Rail Mounted Gantry (RMG).

At the Köseköy logistics center, the areas over which the containers would be stacked have not been designated as ground slots. Stacking areas should be planned as designating the ground slots similar to Figure-4 in order to enable loading and unloading from railway cars, and high capacity cranes such as RTG or RMGs should be used in these areas. There are sufficient railway lines within the Köseköy logistics center. However, these lines should be evaluated and planned in conjunction with other systems in order to allow for the arrangement seen in Figure-4.

There is a need to establish a facility in order to carry out the customs inspections more systematically and quickly. There is no facility for stuffing, stripping, and value-added activities and for maintenance and repair operations. Arrangements are needed to meet these needs of customers. There is a need for a separate building in order to enable logistics companies and other relevant companies to carry out their operations within the dry port. A large parking space is needed for the carriers (trucks) to wait. Social facilities are also needed to meet the needs of both employees and customers. Meeting these needs will promote the Köseköy logistics center to a dry port which is demanded by many logistics actors.

5. DESIGNING A DRY PORT

The total terminal area is usually divided into three sections, as (1) the apron, (2) the primary yard area or the container storage area, and (3) the secondary yard area including the entrance facility, parking, office buildings, customs facilities, container freight station for stuffing and stripping, empty container storage, container maintenance and repair area [30].

The width of the apron may vary between about 15-50 m depending on the loading and unloading equipment. In seaports, apron states the area just behind the berthing front. Similarly, in an intermodal terminal, it states the area of loading and unloading to and from the railway cars.

The primary yard or the storage area is the area immediately adjacent to the apron and is used primarily for storing inbound and outbound cargo. The land requirement is mainly related to the storage density and the time that the cargo stays in the terminal. Thorosen [30] formulates the total yard area (AT) and explains each variable in formula (1) as stated below:

$$A_T = A_{PY} + A_{CFS} + A_{EC} + A_{ROP} \quad (1)$$

Where,

A_{PY} = the primary yard area or container stacking area. This area is approximately between 50-75% of the total area.

A_{CFS} = the container freight station (CFS) with area for stuffing and stripping, etc. This area is approximately between 15-30% of the total area.

A_{EC} = the area for empty container, container maintenance and repair area, etc. This area is approximately between 10-20% of the total area.

A_{ROP} = the area for entrance facility, office buildings, customs facilities, parking, etc. This area is approximately between 5-15% of the total area.

According to the information given above, a general prototype of a dry port terminal, which have the modes of road and railway transportation, could be as the one seen in Figure-4.

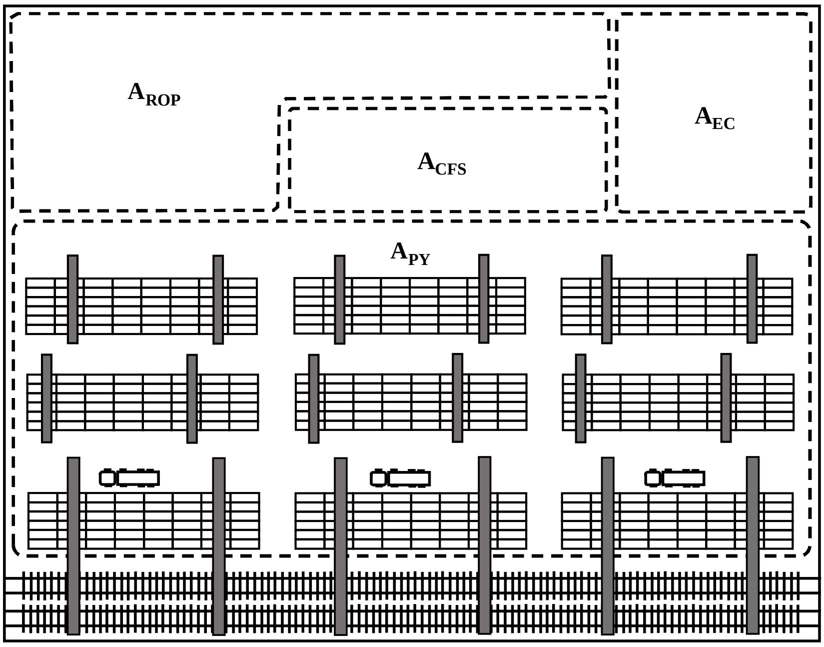

Figure 4. A general prototype of a dry port terminal.

Such a dry port terminal should have at least three railways within the port area; one line for maneuvering purposes, one line for loading and the other line for unloading purposes. The gantries next to the apron must be installed so that they can operate over the railway cars on two lines, for both loading and unloading purposes at the same time.

6. CALCULATING THE REQUIRED AREA FOR A DRY PORT

It has been discussed by various authors in calculating the surface area that a container terminal will need for the storage of the containers. Chu [31] includes studies on this subject within the scope of the source search. Hoffmann [32] proposed an equation including the variables of expected container volume (TEUs), average container dwell time (days), and peaking factor. UNCTAD [33] produced a procedure to calculate the required area, using the maximum stacking height (H) as a factor in addition to the factors proposed by Hoffmann in addition to some constant values in formulizing the required container yard area (m^2). Frankel [34] put in another factor, storage utilization, taking into account that the gantries cannot operate by constituting maximum number of tiers. This factor corresponds to the operational factor, aiming to keep the system in operative bands. Another factor added by Frankel was the total area utilization factor considering that the total area is affected by the choice of equipment, the width of lanes and other issues related to the design of the terminal. Güler [35], Tsinker [36], and Thoresen [30] used similar equations with Frankel. The below stated formula (2) has been produced by harmonization of those authors' studies.

$$A = \frac{C * a * DT * P}{W * S * H * U} \quad (2)$$

Where,

A = required container yard area (m^2),

C = expected container volume (TEU),

a = area (m^2) per one TEU container (21,60 m^2) [35],

DT = average container dwell time,

P = peaking factor ($P \geq 1$),

W = total number of working days in the period (365 days per year),

S = storage utilization/operational factor, as a proportion ($0 < S < 1$),

H = number of tiers/stacking height of containers,

U = total area utilization factor, as a proportion ($0 < U < 1$).

The total area utilization factor (U) is usually taken between 0,4 and 0,6 [35].

The size of the yard area required for container storage in the dry port, which is planned to be established to support container transportation through Kocaeli terminals, shall be calculated according to the formula explained above. The factors and the values to be applied in the formula are explained below.

(1) Expected container volume (C): As explained in the fourth section, one million TEUs of container is expected to be processed in a year, in the prospective dry port.

(2) Area (m^2) per one TEU container (a): This value indicates the total area allocated for one TEU, as a ground slot. It is a constant value, 21,60 m^2 [35].

(3) Average container dwell time (DT): It is assumed that the container dwell time will be similar to that of the seaports. It is taken as seven days (DT = 7).

(4) Peaking factor (P): Since the freight transportation to the dry port is predicted to go on related to scheduled programs, it is not expected to occur a considerable peak. However, it is assumed to make a peak about 10% (P = 1,1).

(5) Total number of working days (W): Since the period is one year, it is taken as 365 days (W = 365).

(6) Storage utilization/operational factor (S): It is assumed that the storage utilization will be realized as a proportion about 75% (S = 0,75).

(7) Number of tiers/stacking height (H): The storage equipment are assumed to have the capacity of making maximum six tiers (H = 6).

(8) Total area utilization factor (U): It is assumed that 60% of the total yard area is allocated for container storage (U = 0,60).

The formula (2) for the required container yard area is shaped as stated below related to the values explained above:

$$A = \frac{1.000.000 * 21{,}6 * 7 * 1{,}1}{365 * 0{,}75 * 6 * 0{,}6} = \frac{166.320.000}{985{,}5} = 168.767$$

This calculation states that an area of 168.767 m^2, or approximately 17 ha, is required for the purposes of container storage in the prospective dry port.

As explained in sixth section and simulated in Figure-4, a container terminal involves mainly four parts, as (1) primary yard area (A_{PY}), (2) container freight station (A_{CFS}), (3) area for empty container, container maintenance and repair (A_{EC}), and (4) area for entrance facility, office buildings, customs facilities, parking, etc. (A_{ROP}). The proportions of these four sections within the total area (A_T) are considered as follows taking into account the explanations of Thorosen [30].

A_{PY} : 65%,

A_{CFS} : 15%,

A_{EC} : 10%,

A_{ROP} : 10%.

Since we know the volume of A_{PY} as approximately 17 ha, we can calculate the total area of the dry port by constituting the following proportion:

$$\frac{65\%\ of\ AT}{100\%\ of\ AT} = \frac{17\ ha}{?}$$

$$A_T = (17 * 100) / 65 = 26{,}15 \text{ ha}$$

The study and the calculation exhibits that the prospective dry port which will be constructed with the intent of supporting container transportation through Kocaeli terminals should have an approximate total area of 26 ha, in other words 261.500 m^2.

According to the terminal design the volumes of the other parts of the dry port are calculated as follows:

A_{CFS} = 0,15 * 26 ha = 3,9 ha,

A_{EC} = 0,10 * 26 ha = 2,6 ha,

A_{ROP} = 0,10 * 26 ha = 2,6 ha.

7. CONCLUSIONS

Container transportation is expected to grow increasingly. The fact that general cargo loads are transformed into container loads is thought to be effective in this increase. This development is expected to be realized with a higher rate for Kocaeli ports. While it is estimated that the total capacity of the Kocaeli container terminals might reach seven million TEUs per year until 2035, the demand for those ports is expected to increase to eight million TEUs in that time with an optimistic projection. It would be appropriate to take measures to meet this possible surplus. The construction of a dry port to support container transportation through Kocaeli container terminals is considered a viable option.

It is obvious that rail transport will be the most important means for Kocaeli container terminals to adapt to the dry port concept. Currently, two ports have railway connections, construction for one port is in progress and a connection for one port is within the planning stage. On the other hand, TCDD is planning to increase the transportation capacity between Gebze and Köseköy. It is assessed that the railway capacity will be able to meet the possible demand in 2035, provided that those projects are completed.

A dry port constructed with the intent of supporting container transportation should have almost all abilities that a seaport has, except the capability of loading and unloading to and from a vessel. Therefore, a dry port terminal might be designed similar to a container terminal. Approximately two-thirds of a terminal shall be allocated for the purpose of storage. Taking into account this approximate ratio, it's been calculated that a minimum land area of 17 ha is required for container stacking, whereas a minimum 26 ha land area in total is needed to constitute such a dry port. Since the Köseköy Logistics Center has reached a size approximately 36 ha after the expropriation decision of the Council of Ministers in 2012, it is understood that this logistics center already has the required land area to meet the demand of 2035.

The development of ports and the establishment of dry ports to support the growth of the economy is an important component of the countries' maritime strategies. It is considered that if the capabilities stated in this study are brought in to the Köseköy Logistics Center during the ongoing project process, the potential demand that may arise in the coming years can be met appropriately.

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