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ENERGY ANALYSIS OF DISTILLERY SYSTEMS OF AN ALCOHOL FACTORY BY ENERGY AUDIT

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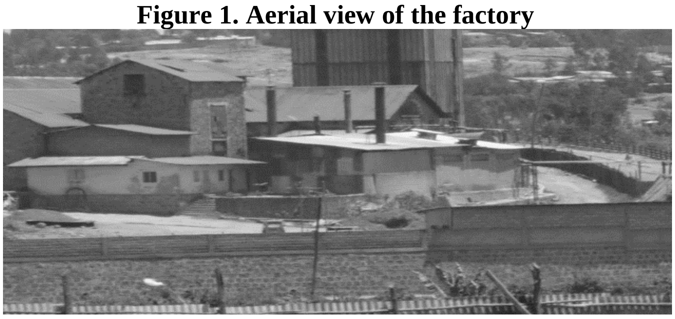
Abstract: *An Alcohol Factory use furnace oil and electricity as primary source of energy to generate thermal and electric energy to pursue its routine alcohol production. All the thermal energy developed by the boiler is used to evaporate alcohol in the distillery columns. The objective of this paper is to examine the way energy is being used in Alcohol Refining Factory, and identify energy conservation opportunities (ECO) so as to reduce energy costs. The nine energy systems of the factory were inspected to identify energy conservation opportunities (ECOS) and major energy consuming systems of the factory. Out of the nine energy systems, the boiler, distillery columns and pumps, air compressor and their prime movers were found to be major energy consuming systems. To perform the energy audit of these major energy consuming systems, different data were collected by using portable instruments, the instruments installed on major energy systems. Standard energy analysis methods were used to perform the energy audit of the boiler, distillery columns, pumps & air compressor and their prime movers. One of these like Distillery system is discussed in this paper. The energy audit results of the distillery revealed that the energy losses due to convection and radiation losses from distillery columns surfaces. By detailed energy audit of the distillery columns, we find that lot of energy is simply thrown away with the hot effluent. so we conclude that By using different kind of heat exchanger for extracting heat energy by hot fluent, the fermented wine temperature is increased and it reduce steam consumption by the distillery columns. Also By installing a double pipe heat exchanger to recover energy loss due to hot effluent, the life time of the heat exchanger is range 10 to 15 years so we conclude that it is economically feasible ECO.*

Keywords: *Alcohol, Distillation, Distillery columns, ECO, Effluent, Energy Audit, Fermented Wine, Heat.*

I. Introduction

Figure 1 show alcohol factory and it is a governmental organization which produces potable alcohol and currently it has a distillation capacity of 2,600,000 liters of alcohol per year. This implies the factory has an average production capacity of 8,666 liters of alcohol per day.

Figure 1. Aerial view of the factory



This paper revolves around the energy audit of Distillery system of an alcohol refining factories. The product of the factory alcohol is being used as a raw material in many areas of chemical industries. These include: pharmaceutical purpose, hospital service, production of plastic materials, mixing fuel products, fabrication of paints, production of synthetic rubber, laboratory service, heating purpose, etc. Even though the factory product has high market demand the factory is known to operate with loss in 2004/5 fiscal year due to the fact that the factory uses inefficient energy consuming systems [factory document]. The effluent at a temperature of 90°C is simply channeled to the river. The Problems signify that there are high probabilities of energy conserving opportunities (ECO) in the factory. Therefore it is absolutely essential for the factory to conduct energy auditing. Energy audit is completed for Boiler, Distillery system and motor and its prime movers and one of them like distillery system is discussed in this paper.

Objective of Audit: The general objective of this paper is to examine the way energy is being used in Alcohol Refining Factory, and identify energy conservation opportunities (ECO) so as to reduce energy costs and prepare an energy & documentation to implement cost effective energy utilization changes and The Specific Objectives of the Research are To clearly identify the types of energy and cost of energy use of the factory, To understand how that energy is being used and possibly wasted, To indicate better energy conserving opportunities by assessing the efficiency of its energy consuming devices, To examine energy consuming systems of the factory so the improvements can be quantified in terms of both energy and cost: obtain Sankey diagram of the energy use, To identify and analyze improved operational techniques and / or new equipment that could substantially reduce energy use, energy determine which ones are cost-effective and To prepare an energy action plan.

II. Methodology

The methods employed to achieve the objectives of the research by audit are: (i) Literature review (ii) Preliminary data collection of the factory (iii) Inspection of factory energy consuming systems and equipment (iv) Perform desktop analysis (v) Identify feasible Energy Conservation Opportunities (ECOs) (vi) Perform technical feasibility of the identified (ECOs) (vii) Perform economic analysis of the identified (ECOs) (viii) Prepare list of recommended energy conservation measures (ECOs) (ix) Prepare action plan

*a) **Preliminary Energy Audit** : Preliminary audit methodology is a relatively quick exercise: (i) Establish energy consumption in the organization (ii) Estimate the scope for saving (iii) Identify the most likely and the easiest areas for attention (iv) Set a 'reference point' (v) Identify immediate (especially no-/low-cost) improvements/ savings (vi) Identify areas for more detailed study/measurement (vii) Use existing or easily obtained data*

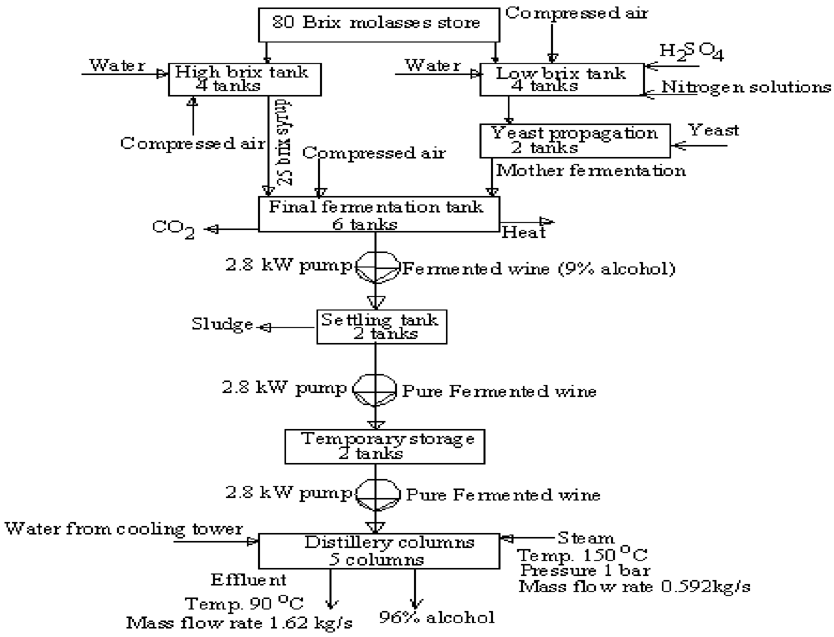
*b) **Detailed Energy Audit** : A detail audit evaluates the major energy using systems using energy balance based on an inventory of energy using systems, assumptions of current operating conditions and calculation of energy use. From industry to industry the metrology of detail energy audit is flexible and is carried out in the following three phases.*

Phase I Pre-Audit - Step 1: **Organize energy audit team**, Organize instrument and time frame and Familiarization of process or facility activities, **Step 2:** Conduct brief meeting /awareness program with all divisional head and person concerned **Phase II Audit Phase** - **Step 3**: Primary data gathering; Products/service of the facility, Process flow diagram and energy utility diagram, Identify major energy systems of the facility, **Step 4:** Conduct survey and monitoring and Measurement, **Step 5:** Analysis of energy use; Energy and material balance and energy lost/waste analysis, **Step 6:** Identification and development of energy conservation opportunities (ECOS), **Step 7:** Conduct cost benefit analysis; Conduct technical feasibility, Conduct economic feasibility, **Step 8:** Prepare energy action plane; Prioritize promising ECOS for implementation, Prepare action plan by low, medium and long term measures, **Step 9:** Reporting and presentation to the top management. **Phase III Post Audit Phase** - **Step 10:** Implementation and follow up.

III. Ethanol production process and the energy input

The raw material which is used for producing ethanol is molasses purchased from a Sugar Factory. The procedure and process required for the production of ethanol from molasses include dilution of 80^{O} brix molasses in to 25^{O} brix and 15^{O} brix molasses syrups, propagation of yeast to facilitate the fermentation process and fermented wine is separated from sludge. By distillation of fermented wine, ethanol can be produced and collected. The energy required to perform these process are thermal energy and electrical energy. The detail procedures and process of ethanol production of the factory are discussed below. Flow diagram of alcohol production is shown in Fig 2.

Figure 2. Production Flow Diagram of Alcohol



a) **The Production Process**

The main raw material used for the production of ethanol in MAF is molasses. Molasses with black & brown color has 50% of sucrose by mass, average 45-50% alcohol content and 78-83 ^{0}brix. Brix is a measure of the amount of sucrose present in the molasses. For example 80 ^{0} Brix molasses contain (80*50) / 100 = 40 % of sucrose by mass. During winter and at night times, the molasses is made to flow with the help of a 5kW pump.

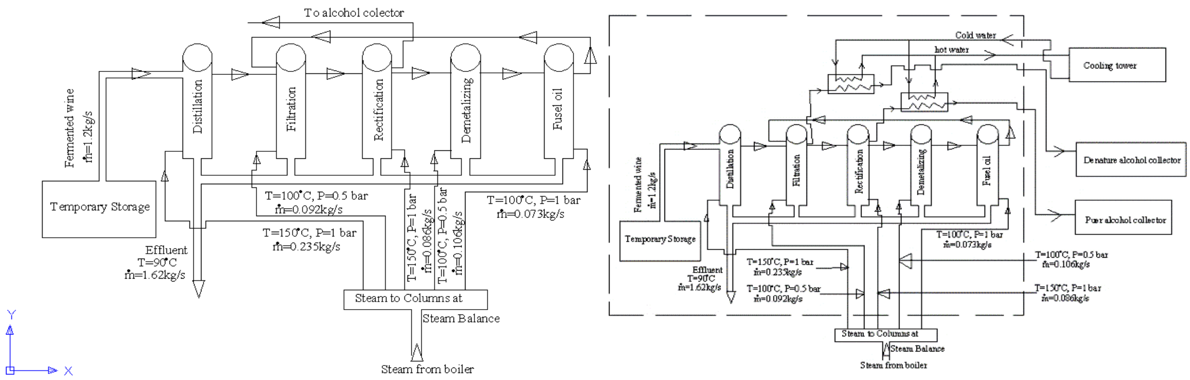
b) ***Distillation Process [1]***

Distillation is one of the major production processes of ethyl alcohol. It is the processes of boiling different mixtures, at different boiling points, in different columns and condensing the evaporation in order to separate one form the other by fractional distillation. And then the high boiling point fluid will remain at the bottom, the upper goes to the condenser and is cooled partially. This partially cooled fluid again goes to the top of other column. This process is called reflux. The boiling point of alcohol is 78.2 ^{0}C but the boiling point of water is 100 ^{0}C. The low boiling point and high volatile property makes alcohol to be easily distilled from water. The process of refining alcohol is called fractional distillation. There are different chemical by products during fermentation such as acetic acid, Aldehyde, and high alcohol ester. If the presence of these chemicals is above the limit, they will cause harmful effects including negative impact in the quality of alcohol produced. Therefore, they are removed in different columns during distillation. It is shown in Figure 3a.

IV. Detailed Energy Audit of distillery system

The major thermal energy utilizing equipment of the factory is distillery columns. Distillery columns are energy intensive part of the alcohol manufacturing system. The distillery columns are used to evaporate alcohol from water and other solutions by heating it using super-heated steam produce from the boiler. Distillation of alcohol takes place by using five columns namely distillation column, filtration column, rectification column, De-metalizing column and fusel oil column. The detail of these heating (distillation process) is discussed below. Distillation column consumes an average of 1.2 kg/s of fermented wine. Fermented wine contains 25^{0}brix molasses syrups and other solutions. In this column, the separation of alcohol plus some impurities, which have low boiling points from water and other solutions demands the solution temperature to be raised from room temperature to 90^{0}C. Alcohol and some impurities would be sent to the filter column for farther separation of alcohol from impurities. This is accomplished by heating the solution up to 73^{0}C. The remaining large amount of solution which is at a temperature of 90^{0}C is channeled to the river as effluent. After leaving the filter column the solution (alcohol) passes through a series of connected columns for further purification process as shown in Figure 3b.

A. Figure 3 (a) Distillation Process for production of alcohol (b) Energy and mass flow of the distillery columns



a) Collected Data for Conducting Detail Energy Audit of the Distillery

Inspection of manufacturing system means inspection of distillation system because it consumes all thermal energy produced by the boiler. Hence, inspection of distillation system is conducted using ultra sonic flow meter, infrared thermometer, tap rule and gage mounted on distillery system. The measured data at the distillery system include: external surface temperatures of the columns, ambient temperatures, length and diameters of the columns, steam consumption of each columns, steam pressure and temperature each columns, these data are presented in Tables 1 and Table 2.

Table 1. Data of Distillation Columns

Item	**Distillation column**	**Filtration column**	**Rectification Column**	**De-metalizing column**	**Fusel oil column**	**Data collection method**
Length [m]	10	12	3.73	7.75	9.15	Measured
Outside dia [m]	0.9	1	0.9	0.7	0.7	Measured
Surface Area[m^2]	28.27	37.7	10.6	17.04	20.12	Calculated
Inside dia.[m]	0.82	0.92	0.82	0.62	0.62	Measured
Ambient temp.[^{0}C]	41.50	42	40	47.2	42.7	Measured
Surface temp. [^{0}C]	86	76	67	86.5	83	Measured
Fluid temp.[^{0}C]	90	80	73	95	95	Gauge

Volume flow rate of steam [m^3/s]	0.455	0.167	0.341	0.326	0.124	Gauge
Steam Pressure [bar]	1	1	0.5	0.5	1	Gauge
Steam temp. [^OC]	150	150	100	100	100	Gauge

Table 2. Data on distillation column solutions

Item	**Reading**	**Unit**	**Data collection method**
Density of ethanol	790	Kg/m^3	From gauge
Density of fermented wine	1455	Kg/m^3	Catalogue
Temperature of fermented wine	28.34	^0C	Measured
Ambient temperature of fermentation room	24.21	^0C	Measured
Volume flow rate of ethanol to filter column	0.00023	m^3/s	From gauge
Volume flow rate of fermented wine to distillation column	3000	L / hr	From gauge
Temperature of the effluent	90	^0C	Measured
Ambient (datum) temperature	25	^0C	datum

b) Pre-Energy Performance Analysis of Distillery Columns

In order to perform the energy performance analysis of the distillery columns, the following parameters must be determined: the mass flow of effluent, mass flow rate of fermented wine, mass flow rate of steam for each columns, specific heat of fermented wine and effluent. Each parameter is discussed below.

Calculation of Mass Flow Rate of Steam in each Column: The volume flow rate, temperature and pressure of steam input to each column are read from the gage mounted on the control panel and tabulated in Table 1. Using the gage temperature and pressure of the steam, the density of steam is determined using standard steam table. The mass flow rate of the steam is calculated by multiplying volume flow rate of the steam by the density. The amount of steam supplied to each column is calculated using equation (1) - (5).

Mass flow rate of steam consumed by distillation column $\dot{m}_{s(dist.)} = \dot{V}_{s(dist.)} \times \frac{1}{v_{@1bar\&150^OC}}$

= 0.455 m^3/s * 0.516 kg/m^3 = 0.235 kg/s **(1)**

Mass flow rate of steam consumed by filtration column $\dot{m}_{s(filt.)} = \dot{V}_{s(filt.)} \times \frac{1}{v_{@0.5bar\&100^OC}}$

= 0.314 m^3/s * 0.293 kg/m^3 = 0.092 kg/s **(2)**

Mass flow rate of steam consumed by rectification column $\dot{m}_{s(rect.)} = \dot{V}_{s(rect.)} \times \frac{1}{v_{@1bar\&150^OC}}$

= 0.167 m^3/s * 0.516 kg/m^3 = 0.086 kg/s **(3)**

Mass flow rate of steam consumed by de-metalizing column $\dot{m}_{s(demt.)} = \dot{V}_{s(demt.)} \times \frac{1}{v_{@0.5bar\&100^OC}}$

= 0.362 m^3/s * 0.293 kg/m^3 = 0.106 kg/s **(4)**

Mass flow rate of steam consumed by fuel oil column $\dot{m}_{s(fuse.)} = \dot{V}_{s(fuse.)} \times \frac{1}{v_{@1bar\&100^OC}}$

= 0.124 m^3/s * 0.589 kg/m^3 = 0.073 kg/s **(5)**

The total amount of steam consumed by factory distillery columns is the sum of steam consumed by each column.

$$\dot{m}_{S(total)} = \dot{m}_{(dist.)} + \dot{m}_{(filt)} + \dot{m}_{(rect)} + \dot{m}_{(demt)} + \dot{m}_{(fuse)}$$

= 0.235 kg/s +0.092 kg/s +0.086 kg/s+ 0.106 kg/s+ 0.073 kg/s = **0.592 kg/s** **(6)**

Concluding remark on mass balance of the steam

The mass balance of the produced steam consist of operating steam input mass and steam supplied to each distillery columns, vent steam, and steam supplied to de-aerator as output mass. The mass balance of the steam is as shown below.

Input mass (operating) of steam = 0.828 kg/s

Output mass: Total steam supplied to each distillery columns = 0.592 kg/s, Mass flow rate of vent steam = 0.15 kg/s, Mass flow rate of de-aerator steam = 0.0563 kg/s, Total output mass = 0.7983 kg/s
The difference of input and output mass of the steam is 0.0297 kg/s. This difference is due to measuring errors.

Calculation of Mass Flow Rate of Fermented Wine

Total amount of fermented wine sent to distillation column from fermented wine tank is 3000 lit/hr [Table 2]. Therefore, the total amount of mass flow rate of fermented wine can be calculated by multiplying the volume flow rate by its density.

$$\dot{m}_{wine} = \dot{V}_{wine} * \rho_{wine} \qquad \textbf{(7)}$$

But $\dot{V}_{wine} = 3000\frac{lit}{hr} * \frac{1}{1000\frac{lit}{m^3} * 3600\frac{s}{hr}} = 0.000833\frac{m^3}{s}$; $\rho_{wine} = 1455\frac{kg}{m^3}$ [11]

Hence substituting the above data in Equation (7) the mass flow rate of fermented wine is equals to

$$\dot{m}_{wine} = \dot{V}_{wine} * \rho_{wine} = 0.000833\frac{m^3}{s} * 1455\frac{kg}{m^3} = 1.21\frac{kg}{s}$$

Calculation of Mass Flow Rate of Ethanol

Total amount of alcohol sent to filtration column from distillation column is 828 lit/hr [Table 2]. Therefore, the total amount of mass flow rate of alcohol can be calculated by multiplying the volume flow rate by its density.

$$\dot{m}_{alcohol} = \dot{V}_{alcohol} * \rho_{alcohol} \qquad \textbf{(8)}$$

But $\dot{V}_{alcohol} = 828\frac{lit}{hr} * \frac{1}{1000\frac{lit}{m^3} * 3600\frac{s}{hr}} = 0.00023\frac{m^3}{s}$; $\rho_{alcohol} = 790\frac{kg}{m^3}$ [11]

Hence substituting the above data in Equation (8) the mass flow rate of alcohol is equals to

$$\dot{m}_{alcohol} = \dot{V}_{alcohol} * \rho_{alcohol} = 0.00023\frac{m^3}{s} * 790\frac{kg}{m^3} = 0.182\frac{kg}{s}$$

Estimation of Mass Flow Rate of Effluent

Due to pipe surface corrosion, direct measurement of flow velocity of an effluent is impossible. But assuming no leakage is observed in the distillery columns we can estimate the mass flow rate of the effluent by equating mass in equal mass out in columns using equation (9).

$$\dot{m}_{s(total)} + \dot{m}_{wine} = \dot{m}_{effl} + \dot{m}_{alco} \quad \text{Or} \quad \dot{m}_{effl} = (\dot{m}_{s(total)} + \dot{m}_{wine}) + \dot{m}_{alco} \qquad \textbf{(9)}$$

Substituting the results of equation (6 – 8) in (9) the mass flow rate of effluent is

$$\dot{m}_{effl} = (\dot{m}_{s(total)} + \dot{m}_{wine}) - \dot{m}_{alco} = (0.592 \text{ kg/s} + 1.21 \text{ kg/s}) - 0.182 \text{ kg/s} = 0.162 \text{ kg/s}$$

Calculation of Specific Heat

Specific Heat of Effluent

The specific heat of effluent during the distillation of alcohol is given by [9]

$$C_{p\,(eff)} = (3.14 + (0.000025(T_{eff} – T_{amb}))) \qquad \textbf{(10)}$$

Where T_{eff} = Effluent Temperature = 90^0 C [Table 2], T_{amb} = Ambient temperature = 25^0C [Table 2]
Substituting the above data in equation (10) the specific heat of the effluent will be
= $(3.14 + (0.000025(90^0 – 25^0))) = 3.14$ KJ/kg ^{0}C

Specific Heat of Fermented Wine

According to [9], the specific heat of fermented wine is determined by substituting the values of temperature of fermented wine instead of temperature of the effluent in equation (10).Therefore the specific heat of fermented wine is given by.

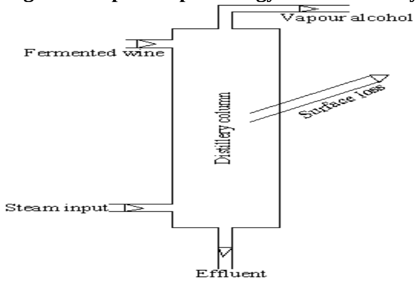
$$C_{p\,(wine)} = (3.14 + (0.000025(T_{wine} – T_{amb}))) \qquad \textbf{(11)}$$

Where T_{wine} - Fermentation temperature = 28.34 ^{0}C [Table 2], T_{amb} - Ambient temperature = 25 ^{0}C [Table 2]
Substituting the above data in equation (11) the specific heat of the fermented wine is given
$C_{p\,(wine)} = (3.14 + (0.000025(28.34^0C – 25^0C))) = 3.14$ kJ/kg ^{0}C

c) Detail Energy Analysis of the Distillery Columns

To perform the thermal energy audit of the distillery columns and thereby obtain the net energy loss from the distillation process, thermal energy analysis of the distillery columns must be conducted. The energy analysis is based on the energy input and output of the distillery columns. All the input-output energy of the distillery is as shown in figure 4.

Figure 4. Input-output energy of the distillery



Analysis of the Input Energy in the Distillery

As illustrated in Figure 4 steam and fermented wine are the input energy of the distillery columns. The two energy sources of the distillery columns are discussed below.

Steam Energy to the Distillery Columns: one of the major energy sources of the distillery columns is steam energy. The amount of heat energy supplied to the distillery columns can be calculated by multiplying the mass flow rate of steam to each column by its enthalpy. The input steam energy can be obtained using equation (12).

$$Q_{(i)s} = \dot{m}_{(i)s} \times h_{(i)gs} \quad \textbf{(12)}$$

Where $\dot{m}_{(i)s}$ - Mass flow rate of steam to columns, $h_{(i)gs}$ - Enthalpy of super-heated steam at a given temperature and pressure [Table 3]

Substitute the values of $\dot{m}_{(i)s}$ from equation (1) to (5) and the corresponding $h_{(i)gs}$ from steam table according to temperature and pressure values and finally the results are summarized in Table 3

Table 3 Input steam energy in distillation columns

Columns	Steam ($\dot{m}_s$) [kg/s]	Temp. [^{0}C]	Pressure [bar]	Enthalpy (h_{gs}) kJ/kg	Heat input [kW]
Distillation	0.235	150	1	2776.4	652.5
Filtration	0.092	100	0.5	2682.5	246.79
Rectification	0.086	150	1	2776.4	239
De-metalizing	0.106	100	0.5	2682.5	284.34
Fusel oil	0.073	100	1	2676.2	195.4
Total					1618.03

Energy in the Fermented Wine: The energy of fermented wine is the enthalpy of fermented wine by virtue of its temperature elevation relative to the ambient temperature of fermentation room. The enthalpy of fermented wine due to its temperature elevation from the ambient temperature fermentation temperature can be obtained using the following equation (13).

$$Q_{wine} = \dot{m}_{wine} \times C_{P(wine)} \left(T_{wine} - T_{amb} \right) \quad \textbf{(13)}$$

Where Q_{wine} – Energy of fermented wine, $\dot{m}_{wine}$ – Mass flow rate of fermented wine =1.21 kg/s (7), $C_{p\ (wine)}$ - Specific heat of fermented wine = 3.14 kJ/kg ^{0}C (12), T_{wine} – Fermentation temperature = 28.34 ^{0}C (Table 2), T_{amb} – Ambient temperature = 25^{0}C (Table 2)

Substituting the above data in Equation (13) input energy due to fermented wine is given

Q_{wine} = 1.21 kg/s * 3.14 kj/kg ^{0}C (2834 ^{0}C - 25 ^{0}C) = 12.7 kW

Analysis of the Output Energy in the Distillery

The energy losses associated with the distillation of alcohol in the distillery columns is indicated in figure 4 include energy loss due to:

Energy Loss Due to Effluent: The energy loss due to effluent leaving the distillation column can be obtained using the mass flow rate of effluent and enthalpy change of effluent at effluent temperature relative to the ambient temperature. The analysis is executed using equation (14).

$$Q_{eff} = \dot{m}_{eff}\ C_{P(eff)}\left(T_{eff} - T_{amb}\right) \quad \textbf{(14)}$$

Where Q eff = Energy loss with the effluent, $\dot{m}_{eff}$ – Mass flow rate of effluent = 1.53 kg/s (Eq. 9), $C_{p\ (eff)}$ = Specific heat of effluent = 3.14 kJ/kg ^{0}C (Eq. 11), T_{eff} = Effluent temperature = 90 ^{0}C (Table 2), T_{amb} = Ambient temperature = 25 ^{0}C (Table 2)

Substituting the above data in Equation (15) energy loss with the effluent is given

Q_{eff} = 1.53 kg/s * 3.14 kj/kg ^{0}C (90 ^{0}C - 25 ^{0}C) = **312.3kW**

***Heat loss due to Radiation and Convection from the Distillery Surface*:** As wind cruises over the distillery surface, energy will be lost from the distillery surface to the wind by convection. In addition, due to difference in temperature between the ambient air and the distillery surface, there is also radiation energy loss. The energy loss due to convection and radiation in watt per unit area of the distillery surface exposed to the ambient temperature condition is given by [4].

$Q_{(i)s} = [0.548\{(T_{(i)s} / 55.55)^4 - (T_{(i)a} / 55.55)^4\} + 1.957(T_{(i)s} - T_{(i)a})^{125} \sqrt{\{(19685V+689)/689\}}$ w/m^2 $*S_{(i)A}$ **(15)**

Where T(i)S- Surface temperature of the ith distillery column (Table 1), T (i)a- Local ambient temperature of the ith distillery column (Table 1), S(i)A- Surface area of the ith distillery column(Table 1), V- Wind velocity = 2.56 m/s

Substituting the values of the above data from (Table 1) in Equation (15) the total heat loss due to convection and radiation is summarized in Table 4.

Table 4 Heat loss from distillery surface

Columns	Ambient temperature (K)	Surface temperature (K)	Surface area (m^2)	Heat loss (kW)
Distillation	314.5	359	28.27	29.57
Filtration	313	340	10.6	5.97
Rectification	315	349	37.7	28.42
De-metalizing	320.2	359	17.04	12.31
Fusel oil	315.7	356	21.12	19.63
Total				95.90

Heat to Evaporate Alcohol: The heat energy used to perform the evaporation of alcohol from fermented wine can be found from energy balance of heat entering and leaving the distillery columns.

Heat in steam + Heat in fermented wine = Heat in effluent + Heat loss by radiation and convection + Heat in vapor alcohol

Mathematically

$Q_S + Q_{wine} = Q_{eff} + Q_{surf} + Q_{alcoh}$ **(16)** $Q_{alcoh} = (Q_S + Q_{wine}) - (Q_{surf} + Q_{eff})$

(17)

Substitute the values of Equations (13) to Equation (17) the heat energy carried by evaporation of alcohol is given by

$Q_{alcohol}$ = (1619.35 kW + 12.7 kW) – (95.90 kW +312.3 KW) = **1223.9 kW**

V. Result and discussion

The unwanted energy losses are energy loss from distillery surface and energy that is leaving with effluent. According to detailed energy audit of the distillery columns, 312.3kW of energy is simply thrown away with the effluent. The energy audit results of the distillery revealed that the energy losses due to convection and radiation losses from distillery columns surfaces are 5.86% of input energy. The energy losses due to the heat that is leaving with effluent is 15.86% of the input energy. According to [9], the recommended percentage of heat carried away by the effluent is not greater than 10% of the input energy. This indicates that, the percentage of heat carried away by the effluent in the factory distillery columns is more than the recommended value. From detailed energy audit conducted, this energy conservation opportunities (ECOs) is found:

1. ***Recovering heat from the hot effluent.***

VI. Recommendation

a) Technical Evaluation of Recovering Heat from Hot Effluent

According to detailed energy audit of the distillery columns, 312.3kW of energy is simply thrown away with the effluent. But most of alcohol producing factories extracts heat energy from hot effluent by using different types of heat exchangers for preheating fermented wine and thereby reduces their steam consumption. According to [10], using double pipe heat exchangers, for preheating fermented wine by hot effluent, the temperature of fermented wine can be increased from 20 to 30 ^{0}C. Thus the factory must be using a heat exchanger to increase their fermented wine temperature in order to reduce steam consumption by the distillery columns. The technical

evaluation to determining fermented wine temperature when the fermented wine is preheated by hot effluent is discussed below. Let the heat exchanger is counter flow double pipe heat exchanger type.
For counter flow, the outlet temperature of the cooler fluid (fermented wine) can be ether equal or made to exceed the outlet temperature of warmer fluid (effluent). Assuming the outlet temperature of the fermented wine and effluent is equal. So for calculating the effluent temperature the equation is

$$T_{eff\,(out)} = T_{wine(out)}\ \frac{T_{eff\,(in)} + T_{wine(in)}}{(1+R)} \quad \textbf{(18)}$$

Where Mass flow rate of the effluent = $\dot{m}_{eff}$ = 1.62 kg/s, Inlet temperature of the effluent = $T_{eff\,(in)}$ = 90^{0}C, Inlet temperature of wine = $T_{wine(in)}$ = 28.34 ^{0}C, Specific heat the effluent = $c_{p_{eff}}$ = 3.14 kJ/kg ^{0}C, Specific heat the wine = $C_{p\ wine}$= 3.14 kJ/kg ^{0}C, Mass flow rate of the wine = $\dot{m}_{wine}$ = 1.21kg/s
Substituting the above data in Equation (18) the outlet temperature of the fluid is 51.52 ^{0}C, thus the fermented wine temperature will be increased by 23.18^{0}C.
Using the known mass flow rate and density of the fluids, and the economic range of fluid velocity it is possible to determine the size of the exchanger.

b) Economical Evaluation of Recover heat from hot effluent by installation double pipe heat exchanger

The economic evaluation and analysis of the feasible energy conservation opportunities involves calculating the energy to be saved, the cost of implementing the energy saving opportunities and determining the payback period of the energy investment. These analyses are performed below.

Energy Saving Analysis: From the results of the energy audit analysis performed so far, it is known that the energy gained by fermented wine at a temperature of 28.34^{0}C is 16.03 kW. But using a double pipe heat exchanger to preheat the fermented wine by hot effluent, the temperature of fermented wine can be brought to 51.52 ^{0}C. The energy of the fermented wine that could be increased by installing a double pipe heat exchanger is given by

$$Q_{New(\,wine)} = \dot{m}_{wine}\left(T_{wine} - T_{amb}\right) \quad \textbf{(19)}$$

Where $Q_{new\ (wine)}$ = Energy gained by preheated of fermented wine, $\dot{m}_{wine}$ - Mass flow rate of fermented wine = 1.21 kg/s (Eq.7), $C_{p\ wine}$= Specific heat of fermented wine = 3.14 kJ/kg ^{0}C (Eq.11), T_{wine}-Fermentation temperature = 51.52 ^{0}C (Eq.20), T_{amb}- Ambient temperature = 24.12 ^{0}C (Table 2)
Substituting the above data in Equation (19) the energy gained due to preheated fermented wine is given
Q_{wine} = 1.21 kg/s * 3.14 kJ/kg ^{0}C (51.52 ^{0}C - 24.12 ^{0}C) = 104.10 kW
Therefore, the net energy gained due to preheating fermented wine is 104.10 kW – 16.03 kW = 88.07 kW.
The equivalent fuel and money saved is 55,107.80 litre and 229,523.99 Ethiopian birr (11034 USD) per year respectively.

Cost Analysis: The cost of a typical double pipe heat exchanger ranges from 50,000 – 60,000 Ethiopian Birr (2400–2500 USD) depending on size, length and feature. An average effective life time of the heat exchanger is 10 years [10].

Payback Period: The payback period can be found by dividing the cost saved with the cost of heat exchanger. Adding 47% [8], additional cost on the direct average cost of purchasing the heat exchanger for transportation and other related costs, the cost of having the heat exchanger will be 1.47 x 60,000 = 88,200 Ethiopian Birr (4240 USD).

Payback Period = Cost of heat exchanger/Cost Saved = 88,200 Birr/ 229,523.99 Birr per year = 0.4 Years (24)
The life time of the heat exchanger is range 10 to 15 years therefore, it is economically feasible ECO.

VII. Conclusion

According to detailed energy audit of the distillery columns (Recover Heat from Effluent), 259.43kW of energy is simply thrown away with the effluent. But most alcohol producing factories extract heat energy from hot effluent by using different types of heat exchangers for preheating fermented wine so we conclude that by using different kind of heat exchanger for extracting heat energy by hot fluent, the fermented wine temperature is increased by 23.18^{0}C and reduce steam consumption by the distillery columns.
By installing a double pipe heat exchanger to recover energy loss due to hot effluent, the technical and economic analysis were conducted which resulted in net energy gain by the fermented wine of 88.07 kW. As a result cost saving is 229,524 Birr (11034 USD) per year; implementation cost is 88,200 Birr (4240 USD) and payback period is 0.4 years and also the life time of the heat exchanger is range 10 to 15 years so we conclude that it is economically feasible ECO.

VIII. References

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