



## Energy Efficiency Improvement in a Community-Scale Whisky Factory of Thailand

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### Abstract

There are 4,595 community-scale whisky producers in Thailand. Most of them are in rural area and lack of engineering knowledge in equipment design and operation. The objectives of this research are to improve energy efficiency by designing and installing a high efficiency whisky distillation set for a community-scale whisky factory and to use the facility for demonstration and dissemination. The implemented energy conservation measures were the following installations and modifications: insulation for the evaporator, heat recovery from waste water, pre-heating for fermented liquor, high efficiency evaporator, high efficiency condenser, and high efficiency stove & air-fuel ratio improvement. Besides the equipment improvements, the proper operation and maintenance procedure were provided to the operators as follows: rate of fuel feed into the stove (consistency of the rate), control of fuel feed during temperature raising period (before alcohol is evaporated) and temperature maintaining period (during alcohol is evaporated), and soot removal schedule. An estimate of the conserved energy of the modified unit with proper operation and maintenance is 1,025 GJ/year and the avoided CO<sub>2</sub> emission is 112 ton/year. The payback period of each measure ranges 0.36-6.33 years, while the overall financial parameters as NPV, B/C ratio, IRR, and PBP are 301,629 Baht, 5.47, 46.92 % and 2.23 years, respectively. The energy consumption of the conventional whisky distillation set was 1,413 GJ/Year. After implementation, the actual amount of energy consumption was evaluated, and the energy saving was determined to be 900 GJ/Year, which was 63.7% of saved energy compared to consumption of the conventional set. The major cause was the operation practices (operation errors) that did not allow the same level of precision in controlling as machinery. The other causes were the uncontrollable ambient humidity, and moisture content in wood chips which were used as fuel. It is evident that if all the community-scale whisky factories modify their facilities in accordance with this unit, a great positive financial and environmental improvement will be achieved.

**Keywords:** Energy efficiency, Whisky industry, Efficient whisky distillation.

## 1. Introduction

There are 4,595 enterprises in the community-scale whisky industry for all over Thailand (1). Most of them are in rural area, where most of their customers are low income villagers. Due to the demand and the expensive cost of transportation, most of the community-scale whisky factories are located in villages far away

from the city. Most of the factories belong to villagers and farmers. They run the business by themselves without technical knowledge, opportunity to access the information, nor government assistance. Figure 1 shows a conventional whisky distillation set in a factory in Lumphun, a province in the north of Thailand, which indicates low investment and the lack of engineering knowledge.



**Figure 1.** A conventional whisky distillation set in a factory.

The conventional process of whisky batch distillation starts from heating the raw material (the fermented liquor) up until vaporization temperature. Then, the vapor is condensed in the condensing coil, which immerses in cooling water. Heat will be released to cooling water, by which the vapor condenses and becomes whisky. The energy efficiency of the process is very low due to its poor engineering features. The evaporator is fabricated without insulation and with inadequate heat transfer area for receiving heat from the burner. The condenser is as badly constructed as the evaporator. The stove is made of massive materials

with thick walls, using chipped wood as fuel. The combustion chamber in the stove has an inappropriate shape for combustion, which connects to a short path of hot gas and does not allow adequate heat transfer before the gas is released into the chimney.

It was obvious that the conventional whisky distillation set could be improved for higher energy efficiency and less energy consumption. The objective of this study is to improve the energy efficiency of a whisky distillation set for a community-scale whisky factory with a newly designed whisky distillation set which can be used for demonstration and dissemination.

## 2. Materials and Methods

### 2.1 Conceptual Design of High Efficiency Distillation Set

The conceptual design of a high efficiency distillation set is shown in Figure 2. Firstly, the newly fermented liquor (raw material of distillation process) is sent to waste heat recovery unit in order to harvest energy from hot waste water which is drained from evaporator. Then, it will be pumped to pre-heating unit in order to

absorb heat which is released by vapor from evaporator. After being pre-heated, the liquor will gravitationally flow into the evaporator and be heated up again by heat transferred from flue gas in the stove. The vaporized mixture will move along the pipe through pre-heating unit and will condense in the condenser and become final product (spirits). Finally, the waste water will be drained from evaporator to waste heat recovery unit in order to transfer the left over energy to the new flow of raw material.

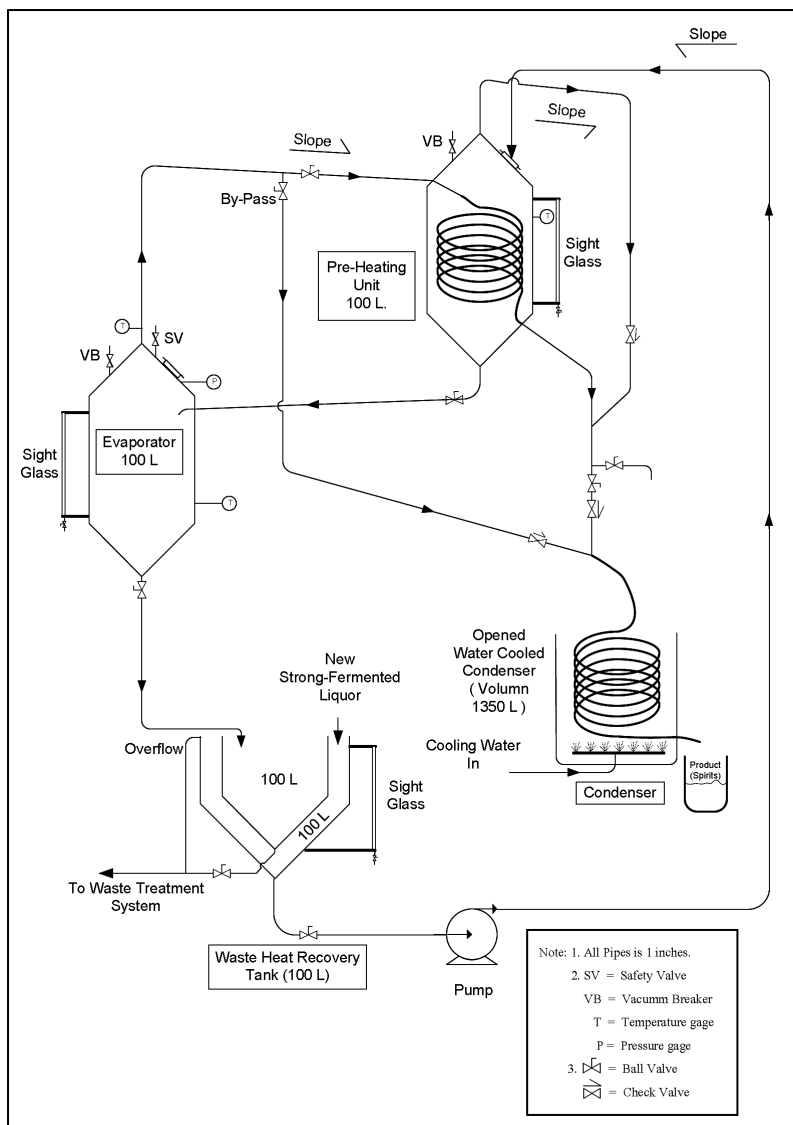


Figure 2. The conceptual design of a high efficiency distillation set

**2.2 High Efficiency Equipment Design.**

The design was based on the maximization of the heat transfer rate in order to increase energy efficiency, whereas minimized heat loss. The proper design and saving potential were considered and calculated based on heat transfer equations as follows (2, 3, 4):

- (i) overall heat transfer,  
 $q = UA(\Delta T)$  (a)
- (ii) thermal conduction,  
 $q = kA(\Delta T/\Delta x)$  (b)
- (iii) thermal convection,  
 $q = hA(t_s - t_f)$  (c)

Where q is heat transfer rate (W), U is overall heat transfer coefficient (W/(m<sup>2</sup>.K)), A is heat transfer area (m<sup>2</sup>), Δ T is temperature difference between two considered surface (K), k is thermal conductivity (W/(m.K)), Δ x is distance between two considered surface (m), h is convection coefficient (W/(m<sup>2</sup>.K)), t<sub>s</sub> is surface temperature (K) and t<sub>f</sub> is fluid temperature (K)

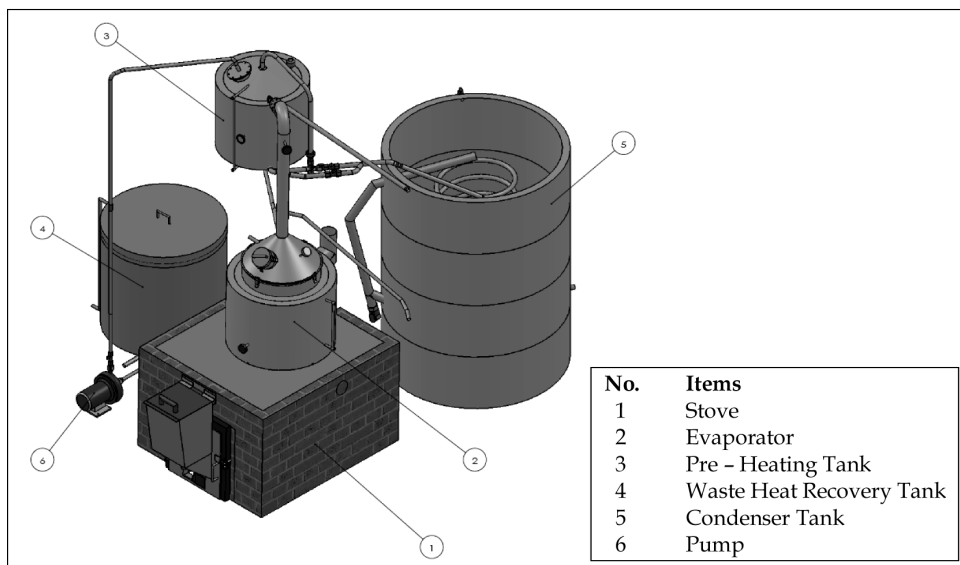
Energy loss through chimney due to flue gas loss was calculated by using the following equation (5):

$$\text{Loss (\%)} = \left[ \frac{A}{20.94 \% - O_2 (\%)} + B \right] * (FT - AT) + C \quad (d)$$

Where FT is flue gas temperature (K), AT is ambient temperature (K) and A, B, C is flue gas specific factors, for wood: A = 0.62, B = 0.0025, C = 10.43.

The key features of the newly designed high efficiency distillation set were as follows:

1. Stove: insulated with 4 inches thick dry ash and equipped with adjustable damper for the control of inlet air flow,
  2. Evaporator: insulated with rock wool and designed for larger heat transfer area (3.3 times compared with the conventional design),
  3. Pre-Heating Tank: insulated with 2 inches thick glass wool,
  4. Waste Heat Recovery Tank: insulated with glass wool and designed for larger heat transfer area,
  5. Condenser Tank: designed for 2 times heat transfer area of the condensing coil and 2.25 times of water surface compared with the conventional design,
- The high efficiency distillation set is shown in Figure 3.



**Figure 3.** The high efficiency distillation set

**2.3 Calculation of avoided CO<sub>2</sub> due to energy saving**

The avoided CO<sub>2</sub> was calculated regarding to 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. The result was obtained by using the following equation (6):

$$\text{Emissions}_{\text{GHG, fuel}} = \text{Fuel Consumption}_{\text{fuel}} * \text{Emission Factor}_{\text{GHG, fuel}} \quad (e)$$

Where Emissions<sub>GHG, fuel</sub> is emissions of a given GHG by type of fuel (kg GHG), Fuel Consumption<sub>fuel</sub> is amount of fuel combusted (TJ) and Emission Factor<sub>GHG, fuel</sub> is default emission factor of a given GHG by type of fuel (kg GHG/TJ).

**2.4 Implementation and Evaluation**

The energy efficiency improvement measures were implemented with close supervision. After the facilities were installed and commissioned, the actual conserved energy was measured in order to compare with the calculation. The evaluation was conducted by

using the same amount of raw material (the fermented liquor) as the conventional one, and determining the fuel (chipped wood) consumption of the distillation process by using a weight meter as a tool for measurement.

**3. Results and Discussion**

**3.1 Energy Efficiency Improvement**

**Opportunities and Avoided CO<sub>2</sub> Potentials**

The energy saving of each measure is estimated by the increase in heat exchanging area and the heat transfer coefficient of the equipment. With the cost of fuel and the estimated consumption rate, the monetary saving in Baht/Year is determined. The amount of energy saving multiplying by the CO<sub>2</sub> emission rate obtained from IPCC guidelines results in the amount of CO<sub>2</sub> that can be avoided. The calculated energy saving potentials in MJ/Year and Baht/Year and avoided CO<sub>2</sub> in kg/Year are shown in Table 1

**Table 1.** Energy Efficiency Improvement Opportunities and Avoided CO<sub>2</sub> Potentials.

No.	Measures	Saving Potential (MJ/Year)	Saving Potential (Baht/Year)	AvoidedCO <sub>2</sub> (kg/Year)
1	Insulating the Evaporator	42,570	1,463	4,649
2	Heat Recovery from Waste Water	45,350	1,560	4,952
3	Pre-Heating of New Fermented Liquor	63,690	2,189	6,955
4	High Efficient Evaporator	642,275	22,078	70,136
5	High Efficient Condenser	33,480	1,151	3,656
6	High Efficient Stove & Air-Fuel ratio Improvement	197,820	6,800	21,602
	<b>Total</b>	<b>1,025,184</b>	<b>35,242</b>	<b>111,950</b>

Remark: The calculation is based on

1. Operating hours are 07:00-16:00 hr. (9 hours/day)
2. Business days are 310 days per year.
3. Conversion factor from MJ/Year to Baht/Year is 0.034 Baht/MJ (Fuel is chipped wood with pricing of 0.55 Baht/kg and 16 MJ/kg for heating value).
4. Conversion factor from energy used (MJ/Year) to CO<sub>2</sub> Avoided (kg/Year) is 1.7472 kg of CO<sub>2</sub> per kg of wood/wood waste (6)

The energy consumption of the conventional whisky distillation set was 1,413,005 MJ/Year which was correspondent to the CO<sub>2</sub> emission of 154,300 kg/Year. Therefore, the estimated energy saving potential of the newly designed unit is 72.55% of the conventional set.

### 3.2 Financial Analysis

The capital and maintenance costs, which are obtained from vendor's quotes and market information,

are used to calculate net present values, benefit to cost ratio, internal rate of return, and payback period, with different equipment lifetimes. The lifetimes of all the units are assumed to be 10 years, except the high efficiency stove for 5 years. Financial parameters are calculated and shown in Table 2:

**Table 2.** Financial parameters for each measure

No	Measures	Saving Potential (Baht/Year)	Capital Cost (Baht)	Maintenance Cost (Baht/Year)	Lifetime (Years)	NPV (Baht)	B/C Ratio	IRR (%)	PBP (Years)
1	Insulating the Evaporator	1,463	500	0	10	16,606	34.21	283.20	0.36
2	Heat Recovery from Waste Water	1,560	25,500	1,000	10	-16,123	0.37	-13.58	> 10
3	Pre-Heating of New Fermented Liquor	2,189	12,000	500	10	9,164	1.76	10.77	6.33
4	High Efficient Evaporator	22,078	22,500	1,500	10	222,308	10.88	91.79	1.14
5	High Efficient Condenser	1,151	3,000	500	10	6,024	3.01	23.31	4.20
6	High Efficient Stove & Air-Fuel ratio Improvement	6,800	4,000	1,000	5	59,220	15.80	131.64	0.79
<b>Total</b>		<b>35,242</b>	<b>67,500</b>	<b>4,500</b>	<b>10</b>	<b>301,629</b>	<b>5.47</b>	<b>46.92</b>	<b>2.23</b>

Remark: The high efficiency stove requires a re-investment in the sixth year of the project.

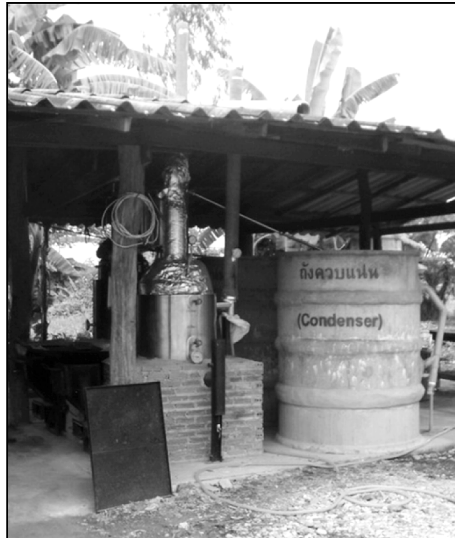
The financial analysis shows that all the measures are viable except the heat recovery from waste water due to its high capital investment and low energy saving potential.

### 3.3 Evaluation of the actual conserved energy

After the installation and modification have been completed as shown in Figure 4., the evaluation was needed to verify the calculation compared with the actual measurement. The energy saving potential of

the 6 measures is 1,025,184 MJ/Year. The calculation is based on the fuel heating value of 16 MJ/kg and the proper operation and maintenance procedures provided to the operators as follows:

- (i) Consistent rate of fuel feed into the stove
- (ii) Control of fuel feed during temperature raising period (before alcohol is evaporated) to be 7.5 kg./hour and temperature maintaining period (when alcohol is evaporated) to be 4.25 kg./hour, and
- (iii) Soot removal schedule



**Figure 4.** The implemented high efficiency distillation set

The actual saving was determined after all of the measures in Table 2 were implemented. The measurement of the energy consumption was conducted for 7 days and the energy saving was determined to be 2,903.85 MJ/day or 900,192 MJ/Year, which was 63.7% of saved energy compared to consumption of the conventional set, of which the major cause was the behavior of the operator (operation inconsistency) that cannot have precision in controlling in the same level as machinery. The other factor contributing to the discrepancy was the moisture content in wood chips used as fuel.

#### 4. Conclusion

The energy consumption of the conventional whisky distillation set was 1,413,005 MJ/Year which emitted CO<sub>2</sub> at a rate of 154,300 kg/Year. The estimation of the conserved energy of the modified unit with proper operation and maintenance is 1,025,184 MJ/year and the avoided CO<sub>2</sub> emission is 111,950 kg/year. After all the measures were implemented, the energy saved which was the difference between the energy consumption of

the conventional unit and that of the newly installed unit was 900,192 MJ/Year, and the avoided CO<sub>2</sub> emission was 98,301 kg/year. The overall energy saving was 8.85% lower than the calculation. The major cause was the operation practices (operation inconsistency) that did not allow the same level of precision in controlling as machinery. The other causes were the uncontrollable ambient humidity, and moisture content in wood chips which were used as fuel.

Out of the six (6) measures under investigation, the calculated net present values (NPV) of five (5) of them are positive. Heat recovery from waste water requires a large amount of capital investment, while the energy saving potential is small, which causes the measure less attractive compared with the rest. The internal rates of return (IRR) of the other five measures range from 10.77% to 283.20%, while the payback periods (PBP) in the range of 0.36 to 6.33 years. The overall financial parameters of the six (6) measures as NPV, B/C ratio, IRR, and PBP are 301,629 Baht, 5.47, 46.92 % and 2.23 years, respectively.

It is inducible that the entire community-scale whisky industry in Thailand consumes a large amount of energy due to low efficiency. Most of the owners need to improve energy efficiency of their factories. Unfortunately, they lack of knowledge and opportunity to access technical assistance. If this unit can be disseminated effectively to all the community-scale whisky factories, in order that the facilities are modified in accordance with the recommended design, great positive financial and environmental improvements will be achieved.

## 5. Acknowledgement

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## 6. References

- (1) Department of Excise, Ministry of Finance, List of Community-Scale Whisky Enterprises in Thailand, Available online: <http://sdtb1.excise.go.th/wiki01.html?id=311>; 2010. Thai
- (2) American Society of Heating, Refrigeration, and Air-Conditioning Engineers. ASHRAE 2009 Fundamentals. Atlanta, Georgia; 2009.
- (3) Bureau of Human Resource Development. Senior People who Responsible in Energy. Department of Energy Development and Efficiency, Bangkok; 2010. Thai.
- (4) John H. Lienhard . A Heat Transfer Textbook. 3<sup>rd</sup> Edn., Phlogiston Press, Massachusetts; 2006.
- (5) Testo Incorporation. Testo Operation Instruction Manual. Testo Incorporation, New Jersey, USA; 2009.
- (6) Intergovernmental Panel on Climate Change. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Programme Technical Support Unit, Japan; 2006. p. 2.12-2.19.