CHILLER ENERGY SAVINGS BY WASTE COLD RECOVERY FROM LIQUID NITROGEN BULK

OH YIN SENG

UNIVERSITI TEKNOLOGI MALAYSIA

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ABSTRACT

Waste cold energy generated from the liquid nitrogen vaporization is usually abandoned when the gas supply system is pre-designed without cold integration. The purpose of this study is to investigate the potential for energy savings in a chiller system through the integration of waste cold recovery with thermal energy storage. The waste cold recovery system captures the waste cold generated during the operation of the liquid bulk nitrogen system and transfers it to a thermal energy storage system. This stored energy can then be utilized to supplement the chiller system during the targeted periods of peak demand, reducing its load and increasing its efficiency. The minimum of thermal energy storage capacity is determined by targeting the maximum peak shaving load through Cold Energy Storage Cascade Analysis (CESCA). The study analyses the feasibility of the waste cold recovery method in terms of energy savings, payback period and cost-effectiveness with peak load shaving of air-cooled and water-cooled chiller. Case study of 500 kg/h of liquid nitrogen revealed the significant energy savings at 124 MWh annually and avoided of 83 tCO2/year with minimum thermal energy storage capacity at seven tones of refrigeration. The simple payback period on air-cooled chiller is slightly better than water-cooled chiller which ranged from four to five years. The study concludes that the integration of waste cold recovery with thermal energy storage is a promising solution for liquid bulk nitrogen users looking for energy savings efforts and reduce their carbon footprint.

ABSTRAK

Tenaga beku sisa yang dihasilkan dari vaporisasi nitrogen cair biasanya dibuang apabila sistem bekalan gas dipre-disesuaikan tanpa integrasi beku. Tujuan kajian ini adalah untuk menyiasat potensi penghematan tenaga dalam sistem penyejuk dengan melalui integrasi pemulihan tenaga beku sisa dengan penyimpanan tenaga termal. Sistem pemulihan tenaga beku sisa menangkap tenaga beku sisa yang dihasilkan semasa operasi sistem nitrogen cair dan memindahkannya ke sistem penyimpanan tenaga termal. Tenaga ini kemudian boleh digunakan untuk mengisi kembali sistem penyejuk pada tempoh puncak permintaan yang ditentukan, mengurangkan beban dan meningkatkan kecekapan. Kapasiti minimum penyimpanan tenaga termal ditentukan dengan menentukan beban puncak maksimum melalui Analisis Kaskad Penyimpanan Tenaga Beku (CESCA). Kajian ini menganalisis kemungkinan sistem pemulihan tenaga beku sisa dalam hal penghematan tenaga, tempoh pulangan dan keberkesanan dengan beban puncak dari penyejuk udara jenis air-cooled dan water-cooled. Kajian kes 500 kg/h nitrogen cair menunjukkan penghematan tenaga yang signifikan sebanyak 124 MWh setahun dan mengelakkan 83 tCO_2 setahun dengan kapasiti minimum penyimpanan tenaga termal sebanyak tujuh tan refrigerasi. Tempoh pulangan ringkas pada penyejuk udara jenis air-cooled sedikit lebih baik daripada penyejuk air jnies water-cooled yang berada dalam kisaran empat hingga lima tahun. Kajian ini menyimpulkan bahawa integrasi pemulihan tenaga beku sisa dengan penyimpanan tenaga termal adalah penyelesaian yang menjanjikan bagi pengguna nitrogen cair yang mencari usaha penghematan tenaga dan mengurangkan jejak karbon mereka.

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LIST OF ABBREVIATIONS

LN2	-	Liquid Nitrogen
GN2	-	Gases Nitrogen
LH2	-	Liquid Hydrogen
GH2	-	Gases Hydrogen
LNG	-	Liquid Natural Gas
AAV	-	Ambient Air Vaporizer
MHD	-	Magnetohydrodynamic
LAES	-	Liquid Air Energy Storage
TES	-	Thermal Energy Storage
SHS	-	Sensible Heat Storage
LHS	-	Latent Heat Storage
TCS	-	Thermo-Chemical Storage
WCR	-	Waste Cold Recovery
HEX	-	Heat Exchanger
GASCA	-	Gas System Cascading Analysis
TBPA	-	Time based Pinch Analysis
CESCA	-	Cold Energy Storage Cascade Analysis
HTF	-	Heat Transfer Fluid
GCC	-	Grand Composite Curve
NPV	-	Net Present Value
COP	-	Coefficient of Performance
ESCA	-	Electric System Cascade Analysis

LIST OF SYMBOLS

h	-	Enthalpy (kJ/kg)
Q	-	Heat Load (kJ)
p	-	Pressure
m	-	Mass
C_p	-	Specific heat

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The global climate changes are the key challenges to major environmental issues which resulting in higher temperatures, rising sea levels, and changes in weather patterns. Without the additional efforts to reduce the global greens house gases, it will cause the significant of damage to livelihoods, businesses, and homes in this earth. Improving energy efficiency is the vital strategy and contribution in reducing the energy use and greenhouse gases emissions.

Nitrogen gas is widely used in the process industrial and manufacturing plants which benefit from the inert properties of nitrogen, to prevent the interactions with oxygen that contribute to corrosion, soiling, fire, explosion, and others detrimental effects. Liquid nitrogen (LN2) is commonly produced by the separation and liquefaction of air. Liquid bulk nitrogen storage is commonly used to supply the gaseous nitrogen thought the ambient air vaporizer (AAV) to provide reliable, consistent, and high purity gas needed in fabs. In recent advanced fabs, consumption of nitrogen can reach 50,000 cubic meters per hours (Tolia, 2015).

Most of researchers investigated the cryogenics fluids to generate cooling and power however the focus primarily on liquid natural gas (LNG) (Jiang, 2017). The LNG cold energy utilization provides significant reductions in the economic and environmental calculations. For example, the cold utilization performances in China were projected that 2,356 million tons of the standard coal will be saved with 6.173 million tons CO_2 reduction in 2020 (Ahmad, Al-Dadah & Mahmoud, 2016).

Today, hydrogen gas (GH2) is widely used in chemicals production, petroleum refining, metals treating, electrical applications etc. hydrogen is often stored and transported by trucks in liquid hydrogen (LH2) form. Cold energy recovery system for LH2 vaporization is different from LNG vaporization process, while heating from -253.15^{o}C to room temperature, hydrogen absorbs heat mainly at variable temperature (sensible heat) rather than during constant temperature vaporization (latent heat). The different cold utilization approach while reconverting LH2 into GH2, Gas Turbine and magnetohydrodynamic (MHD) based energy recovery systems has produce electric energy with 64-77% recovery efficiency (Pike & Arrick, 1980).

Waste cold energy generated from the liquid bulk nitrogen is usually abandoned when the gas supply system is pre-designed from the supplier without considering the on-site heat integration opportunity. As liquid bulk nitrogen often in small and medium scale which range from 10 to 1,500 kg/h flow capacity, waste cold energy recovery could be challenge or ignored by considering the amount of useful cold energy and capital investment. The impact of the heat integration changes, and underlying benefits must be assessed and justified. The useful cold energy is subjected to the minimum end use of nitrogen gas demand and matching to the target cold load.

An energy efficiency opportunity is viable to recover the waste cold energy when the LN2 is vaporised through the ambient vaporiser or heating system to heat up the liquid and covert into gaseous for final use. Energy recovery system using heat exchanger can harvest the waste cold energy and integrate into cooling demand of the plant process or manufacturing facilities. This waste cold energy could reduce the cooling loads, improve cooling equipment’s performance, hence reduce energy used and improve energy efficiency.

1.2 Research Background

The vaporization of LN2 is required heat and the heat demand is vary upon the flow demand and required pressure at the points of use. Most of the onsite LN2 supply system is equipped with the ambient vaporizers and occasionally additional heating system is deployed for excessive high flow demand.

The production of LN2 is an energy intensive process, the high purity nitrogen gas from air separation column is being compressed and liquefy through the Joule-Thomson effect which change in the temperature with the expansion of gas without producing any work or heat transfer. Cool down process is generated as a work done to overcome the long-range attraction between farther apart gas molecules.

The intensive of amount of energy used in LN2 production has the high potential of energy recovery when its reverse change from liquid to gas. Cold energy utilization by heat integration can be done and the amount of recovered cold energy is vary upon the nitrogen gas flow demand, gas temperature, gas pressure and demand pattern which it could be continuous, batch, and interval basic. There are many cold energy recovery technologies, and they can be broadly group into the following categories:

Generate cooling - This type of technology involves capturing the waste cold energy generated during the vaporization of liquid nitrogen and using it to cool other systems or processes. This can be done through direct exchange or indirect exchange methods. In direct exchange, the waste cold energy is transferred directly from the nitrogen vaporization process to the cooling system. In indirect exchange, the energy is transferred to a thermal energy storage system, which then provides cooling to the targeted systems.

Generate power cycle - This type of technology converts the waste cold energy into electricity. This can be done using a thermodynamic cycle, such as the Rankine cycle, which converts the cold energy into mechanical work, which can then be converted into electricity.

Liquid air energy storage (LAES) - This type of technology involves capturing the waste cold energy generated during the vaporization of liquid nitrogen and storing it as liquid air. The stored liquid air can then be used as a source of energy to generate cooling or power, depending on the needs of the system. The advantage of LAES is that it can store a large amount of energy in a relatively small volume, making it a highly efficient form of energy storage.

Cold energy recovery during the vaporization of liquid nitrogen and converts it into useful cold energy to supplement the cooling demand. This can be achieved through various methods, such as using a heat exchanger and the stored energy into thermal energy storage can then be utilized to supplement the chiller system during peak demand periods, reducing its load and increasing its efficiency. The implementation of waste cold recovery systems can be expensive, which may not result in an immediate return on investment. This often results in the lack of consideration for waste cold recovery in heat integration analysis. Secondly, the technical complexity of waste cold recovery can be a barrier for companies without specialized knowledge or experience in this field. The combination of technical, financial, and strategic factors often hinders the widespread adoption of waste cold recovery systems in the industrial sector.

In this research project, the need of exploring the potential for energy savings through the integration of waste cold recovery from liquid bulk nitrogen into a chiller system, particularly for small and medium-scale users. By utilizing the peak shaving strategy with thermal energy storage, the study aims to optimize the benefits of waste cold recovery and reduce electricity consumption.

1.3 Problem Statement

The waste cold energy generated from the vaporization is usually abandoned when the gas supply system is pre-designed from the supplier without considering the on-site heat integration opportunity. The recovery of LN2 cold energy can be maximized through the recovery of latent heat and sensible heat when the nitrogen gas demand is used in ambient temperature. Typically, the LN2 is pressurized and stored at different tank pressure and the bulk supply capacity can be range from 100kg/h to 1,500kg/h.

Liquid bulk nitrogen is widely used in various industries, but the implementation of a waste cold recovery system may not always be cost-effective due to its small usage and lack integration analysis. To determine the feasibility of such a system, a cold integration analysis is necessary to evaluate the equipment's capacity, size, technology, and investment cost.

A cold integration analysis is needed to determine the optimal equipment capacity, size, technology, and investment cost. Every savings does matters and with continuous gas supply mode, cumulative energy saving could be significant and contribute to carbon emission reduction. Analysis tools can be used to target the maximum use of recovered cold energy and minimize the thermal energy storage capacity. Additionally, a peak shaving strategic analysis can be conducted to illustrate the energy savings that can be achieved with different types of chillers, such as air-cooled and water-cooled systems analysis to provide insight of techno-economic feasibility.

1.4 Objective of the Study

Based on the problem statements, the objectives in this research are as follows:

(a) Develop the numerical method to target the maximum peak shaving capability and determine the minimum thermal energy storage (TES) capacity.

(b) Evaluate the potential chiller energy savings by peak load shaving strategy with thermal energy storage.

(c) Perform economic analysis on return of investment and sensitivity analysis to the cost of implementation.

1.5 Scope of the Study

The scope of work has been drawn to accomplish the intended research objectives:

(a) Investigate the nitrogen gas demand and waste cold energy availability from liquid nitrogen (LN2) supply system with average hourly flow of gaseous nitrogen (GN2) at 250 kg/h ,500 kg/h & 1,000 kg/h.

(b) Evaluate the case study on the energy savings by peak shaving the cooling load demand at targeted period and duration.

(c) Perform cold energy storage cascade analysis (CESCA) to determine the minimum capacity thermal energy storage by targeting the peak shave load and duration.

(d) Evaluate techno-economic feasibility of waste cold recovery system with thermal energy storage for air-cooled and water-cooled chiller peak shaving.

1.6 Significance of the Study

The study focuses on investigating the benefits of waste cold recovery from liquid bulk nitrogen to reduce electricity consumption and support the National Energy Policy towards carbon neutrality by 2050 in Malaysia's 12th Malaysia Plan.

The waste cold recovery is achieved through the integration of peak shaving strategy and thermal energy storage. The study provides insight of techno-economic feasibility for small and medium scale liquid bulk-nitrogen gas users by supplement the cooling demand during periods of peak demand, reducing its chiller's load and increasing its efficiency.

The study analyses the feasibility of the waste cold recovery method in terms of energy savings, payback period, and cost-effectiveness. The findings of this study will help organizations understand the potential benefits of waste cold recovery and provide an insight of energy savings opportunity. This not only saves energy, but also reduces carbon emissions, hence inspire industry to adapt and stimulate the efforts in contributing to the goal of a more sustainable and carbon-neutral future.

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