

Open

LN₂

.Rankine Cycle

Expansion Stroke

.Isothermal Expansion

A Study for Design and Performance of a Cool and Zero Emission Engine Using Liquid Nitrogen as a Working Fluid

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Liquid Nitrogen LN₂ is used as a working fluid for an engine using an open Rankine cycle. Ambient heat exchangers are used to open power the engine that is configured to maximize heat transfer during the expansion stroke, where in this engine no combustion will occur, but only expansion to LN₂. If sufficient heat input during the expansion process can be realized, then this engine would provide greater automotive ranges and lower operating costs than those of electric vehicles currently being considered for mass production. This engineering challenges has been evaluated and several means of achieving isothermal expansion are discussed.

Nomenclature

m^2 ,	:A _p
m^2 ,	:A _c
m^2 ,	:A _w
اس لمكبس, m^2	:A _h
j/kg.K,	:C _p
m,	:d
,	:f
j/kg, enthalpy	:h
$W / m^2 .K$,	:h _x
$W / m.K$	:k
kg/s,	:m
(3)	:n,m
, $\frac{hd}{k}$,	:Nu
RPM,	:N
N/m^2 ,	:P
, $\frac{C_p \mu}{k}$	:Pr
W,	:Q
,	:R
, $\frac{\rho U_p d}{\mu}$	:Re
m, Stroke,	:S
, $\frac{h_x}{\rho U_p C_p}$	:St
K,	:T
m,	:t _r
m/s,	:U _P
m^3 ,	:V
m^3 ,	:V _c
m^3 ,	:V _h

j , $:W_f$

j , $:W$

Greek

$: \eta$

degree , Grank Angle $: \theta$

$\frac{C_p}{C_v}$, $: \gamma$

$\frac{kg}{m.s}$, $: \mu$

m , $: \delta S$

j , $: \delta W_f$

Subscripts

injection , $: i$

exhaust , $: e$

wall , $: w$

high, $: h$

Low $: L$

Introduction

LN₂

Atmosphere

. heat sink

:

$$\eta = \frac{W}{Q_h} = 1 - \frac{T_L}{T_h} \quad (1)$$

K

%74

$W = 769 \text{ kj/kg} - \text{LN}_2$

$T_L = 77\text{K}$

$T_h = 300$

180 - 300 kj/kg	—	
		%40
LN ₂	(1972) Hencey	Boese
Brayton Cycle	(1974) Scheider	Manning
, LN ₂	Reheat	
	N ₂	
	liquefaction	(1980) Oxley
O ₂		لمستخدمة
	He	Striling Engine
LN ₂	(1981)Boese	
		, Gas Turbine
	افتراضها	Receiver
	(1982)	latter
(....LPG		)
	LN ₂	
	%50	
System		.Braking
Adiabatic		
Isothermal		Expansion
		Expansion

LN₂ System

(1)

LN₂

Supercritical Pressure

. Frost

Receiver

LN₂

Cylinder-Piston –

(Williams et. el., (Williams, 1997) N₂

–

.1997)

Exhaust N₂

Gear Box

Analytical Analysis for Cylinder-Piston SystemLN₂

Theoretical Model

,Bore ,

.(Caton and West, 1996)RPM

Stroke

Simulation Procedure

.Piston-Cylinder Head –

Single Zone

(2)

State Equation

.P-V diagram –

N₂

Energy Equation

$$\frac{dP}{d\theta} = \frac{(\gamma-1)}{V} \left[\frac{dQ}{d\theta} - \frac{\gamma}{\gamma-1} P \frac{dV}{d\theta} + \frac{dm_i}{dt} h_i - \frac{dm_e}{dt} h_e \right] \quad (2)$$

Slider-

Crank

: (Hannah and Stephens, 1985)

$$V = V_h + V_c + \frac{\pi d^2 S}{8(1 - \cos \theta + R - \sqrt{R^2 - \sin^2 \theta})} \quad (3)$$

Piston-Cylinder Heat

-

Transfer

S ,d

N₂

, N

Emperical Equations

.Expansion

.Radiation

Turbulent Heating

:(Holman,1997)

 $m = 0.8$ for turbulent flow

$$Nu_d \sim Re_d^m Pr^n \quad \text{where } m = 0.3 \text{ for heating} \quad (4)$$

 $m = 0.8$ for coolingT N₂ μ k

(200-300K)

:

$$k \sim T^{0.85}, \quad \mu \sim T^{0.76} \quad (5)$$

U_ph_x

$$h_x = (0.1129) d^{0.2} P^{0.8} U_p^{0.8} T^{0.594} \quad (6)$$

Least Square

.(Prasad and Samira, 1970)

.U_P

N

S

,

.

h_x

.

T_w

:

$$\frac{dQ}{dt} = h_x A_w (T_w - T) \quad (7)$$

:

A_w

$$A_w = A_p + A_h + A_c + \frac{\pi d S}{2(1 - \cos\theta + R - \sqrt{R^2 - \sin^2\theta})} \quad (8)$$

Piston –Rings Friction

Rings

.Aspect Ratio

δW_f

.μ_r (Taylor, 1993)

:

$$\delta W_f = \mu_r P \pi dt_r \delta S \quad (9)$$

.

.dt

Warmant System

—

-.Ethylene Glycol

Automobile Radiator

90% . ن

Fuel-

Rejected Heat
Burning Engine

f . (())

.(Holman,1997) Reynold's analogy

$$f/8 = St . Pr^{2/3} \quad (10)$$

(Holman, 1997) Cross-Flow

$$Nu_d = (0.35 + 0.56 Re_d^{0.52}) Pr^{0.3} \quad (11)$$

Cylinder-Head

.(Holman,1997) Flat-Plate

$$Nu_d = 0.332 Re_d^{1/2} Pr^{1/3} \quad (12)$$

m

Warmant Fluid

Analytical Procedure

.(Rang-Kutta - (2) .

.((0-180°) P-V diagram -

(6) .

.(Expansion Stroke

(9) .

injection pressure

initial volume

$$\frac{P_2}{P_i} = \left(\frac{V_i}{V_2}\right)^\gamma = \left(\frac{T_2}{T_i}\right)^{\frac{\gamma}{\gamma-1}}$$

(adiabatic)

$$P_i V_i = P_2 V_2$$

(isothermal)

$$(V_c + V_h) \quad V_i$$

.TDC

Expansion Stroke

Results and Discussion

N (d/S) .(W/W_i) Isothermal Work

1-30MPa 1cm

(3) 290K P_{ex} = 0.11MPa

(d/S) N , (3)

.Expansion Process

, (3) d/S = 1/4 d = 10 cm

. bore

Cycle

. Isothermal

.

θ

N=1000RPM S=10cm 1cm

130 120 (4) . (40) Adiabatic

.Expansion Stroke

. 60°

.Isothermal Performance

(5) Injection

h_x .

U_p

.Expansion chamber Wetted Area

Simulation

. h_x = Const Adiabatic

Specific work

(6).

60

 h_x

(W/Wi=0.85)

(W/Wi=0.65)

 h_x

Heat Transfer

.Fins

(Reynolds,1992)Honda CRX

.7.8 kW 97 km/hr

6

RPM850

300K

290K

MPa

22kW

11 kW

(water / ethylene – glycol mixture)

. 5K

1.1kg/s

245kg/kg - LN₂

Conclusions

%85

.LN₂

6Mpa

.190N.M

15KW

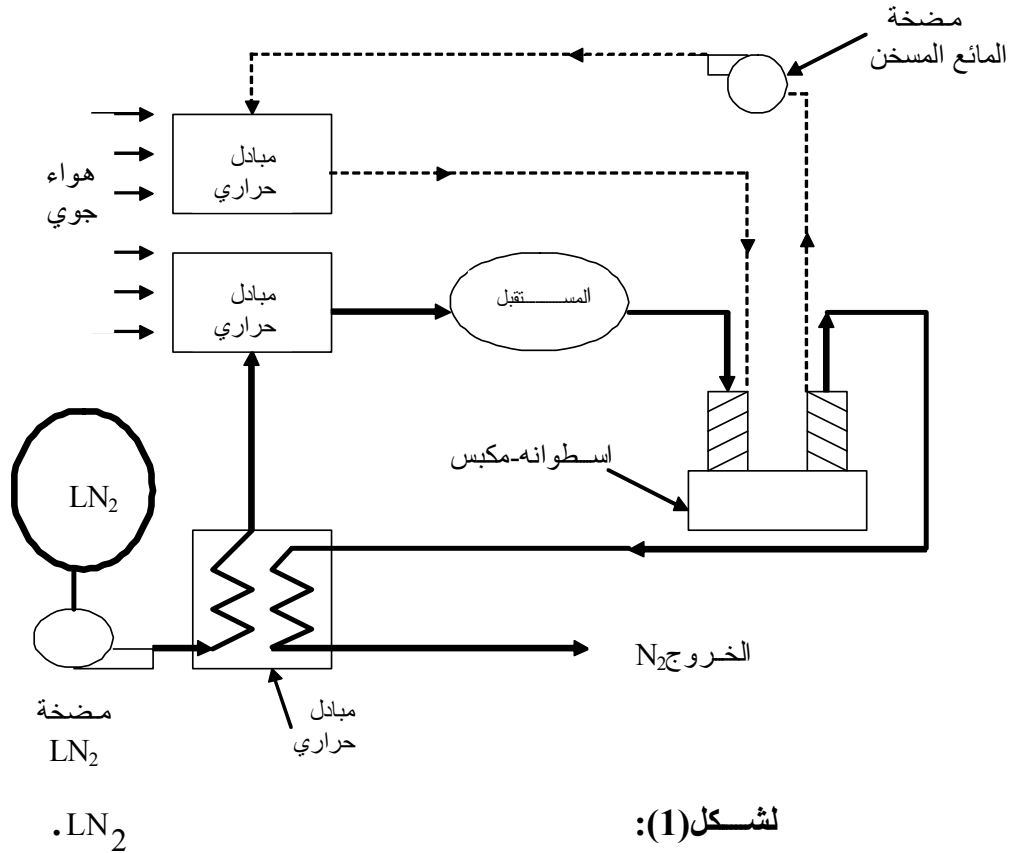
RPM850

200

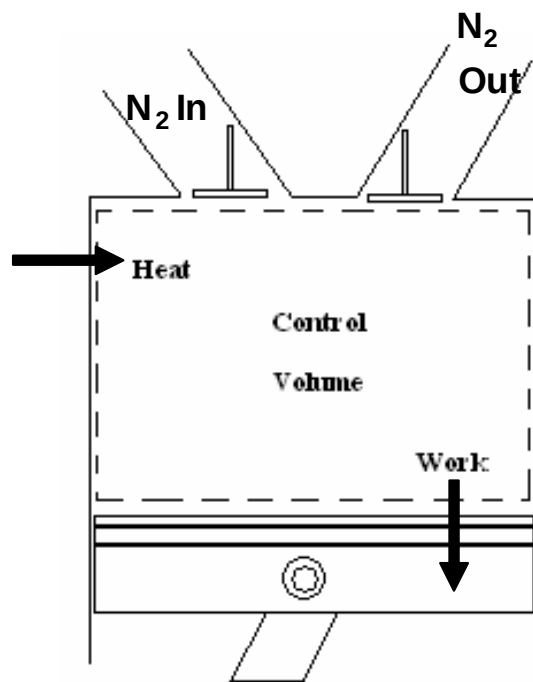
140 km

References

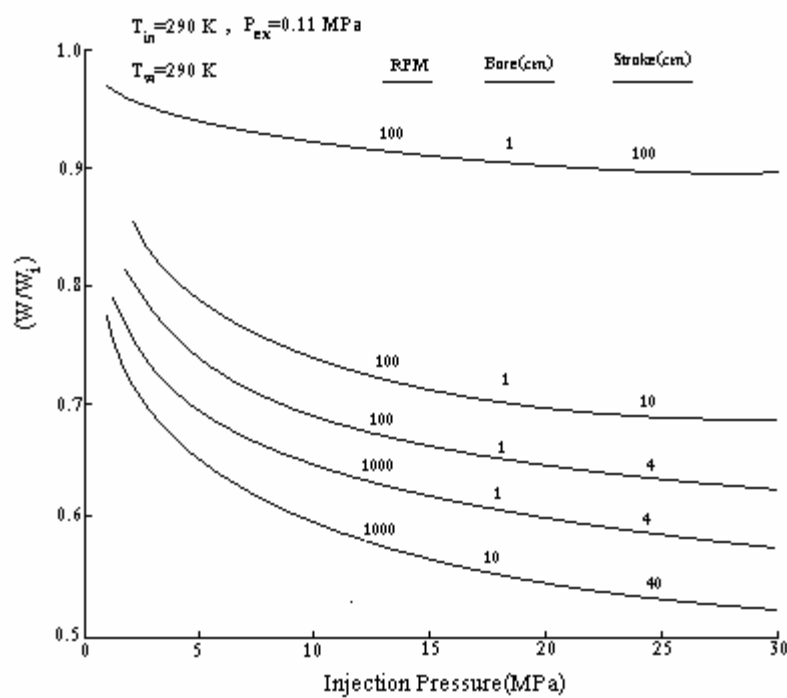
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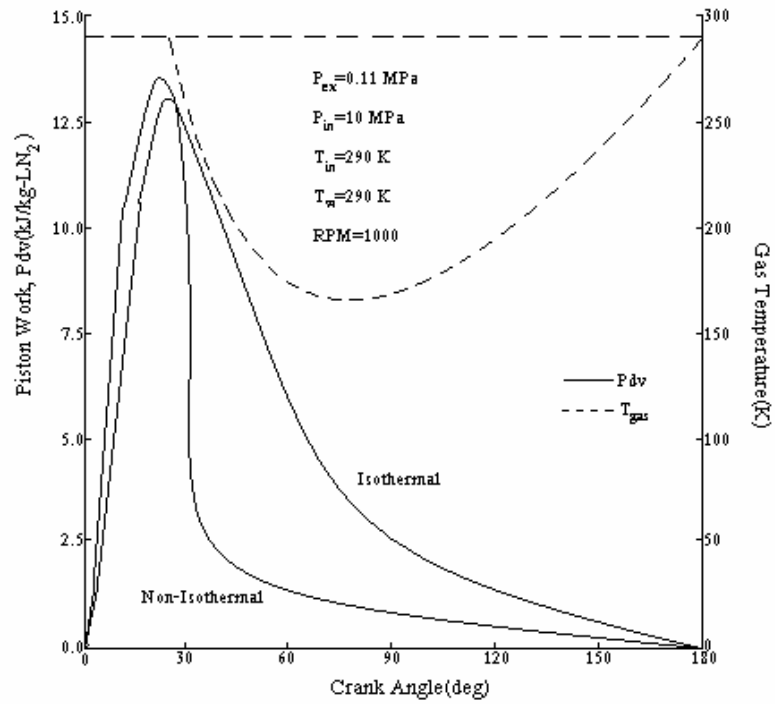
شكل (1):



C.V : (2)

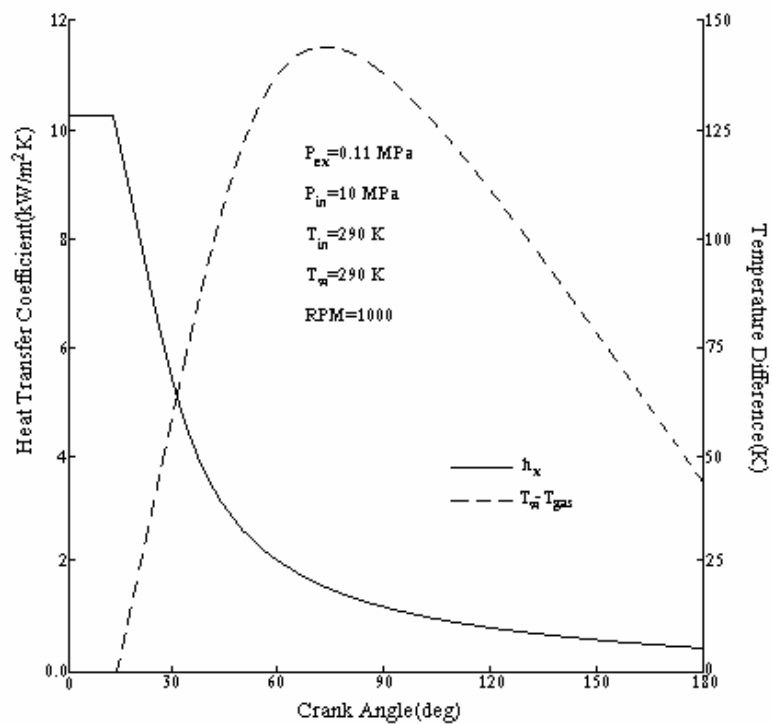


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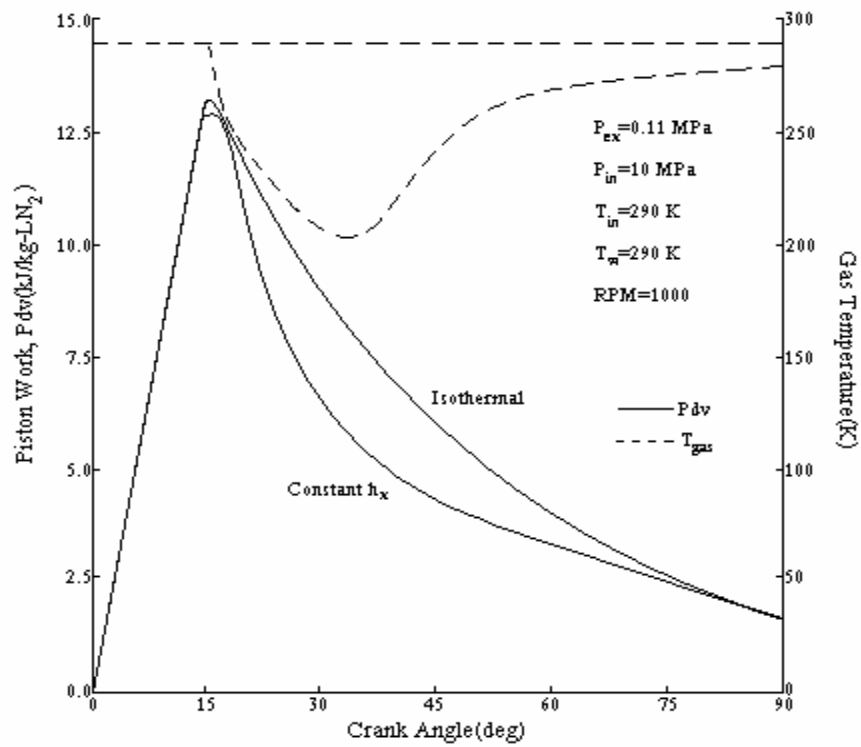


:(4)

1cm =) (10cm



:(5)



:(6)

$h_x = \text{Const.}$) $1\text{cm} =$ $10\text{cm} =$.