1982

An Analysis of a New Type Refrigeration Cycle (MICLOSS)

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(MICLOSS)

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1. ABSTRACT

We have developed a new type refrigeration cycle, which has greatly enhanced the efficiency for refrigeration cold storage equipment, room ACs, refrigerators, display cases, and air conditioning equipment.

The development of MICLOSS has aimed at improving the energy efficiency ratio (EER) during standard refrigerating or air conditioning equipment operation along with improving the SEER. Energy losses under compressor starting/stopping are usually considered to amount to 20 or 25% of the total energy consumption.

We conducted quantitative analyses of the operation of refrigeration cycles in connection with the lowering of the efficiency under nonsteady (transient) operating conditions, and as a result the following findings were made: The condition of the refreigerant under pressure - which corresponds to the refrigerating or air conditioning capacity of the compressor - undergoes a change when the compressor is stopped. When the compressor is restarted, there is a time lag before pressure reaches the required level for steady (normal) operation. As a result, during this period of time the compressor capacity is not fully utilized, and the subsequent loss of energy leads to a lowering of the machine efficiency.

Subsequently, we moved to remedy this situation by developing a new refrigeration cycle which would reduce the period required for the pressure within the compressor to regain its 'pre-stop' level to a minimum.

This new refrigeration cycle is a conventional cycle plus current cutoff and on/off elements (see Fig.1 and Fig.2). The operating principles are as follows: When the compressor is stopped, the current cutoff element and the on/off element combine to close the refrigerant circuit, thus dividing the refrigerant into high- and low-pressure segments and maintaining both at their 'pre-stop' levels. Concurrently, the current cutoff element connects the bypass circuit of the compressor to equalize the compressor's discharge (high) pressure with that of its suction (low) pressure.

When the compressor is restarted, the discharge pressure builds up, but when it rises above the preset pressure value, the current cutoff again closes the bypass circuit, connecting the compressor's discharge and suction segment, and opens the main refrigerating circuit. At the same time, the on/off element opens the refrigerant circuit so as to return the compressor to its normal refrigeration cycle.

2. TEST EQUIPMENT AND TEST CONDITIONS

The main merit of the new refrigeration cycle lies in the fact that with operation of the compressor with repeated start and stop, the pressure, the temperature, and the refrigerant distribution of the compressor at the time of stop are in about the same as during operation, and accordingly, a valve has been installed to keep the distribution condition of the refrigerant gas and to prevent pressure balance at the time of stop during the refrigeration cycle. In order to grasp and investigate the characteristics at the time of emergency stop, a small air conditioner with a built-in rotary compressor was used as the test equipment. The outline is shown in Fig.3. The symbol P in Fig.4 shows the pressure measuring point.

Testing was executed with the following three conditions for the compressor start and stop time.

(a) Operation time: 3 min,
stop time: 7 min (operation ratio: 30%)

(b) Operation time: 5 min,
stop time: 5 min (operation ratio: 50%)

(c) Operation time: 7 min,
stop time: 3 min (operation ratio: 70%)

Temperature measuring was executed every 30 sec with copper-constantan thermocouples soldered to the return bends of the evaporator and condenser heat transfer pipes in the middle in radial direction of the pipes. Fig.4 shows the measuring point for the evaporator. Small semiconductor pressure converters were used for pressure measuring, and recording was executed with a pen recorder via an amplifier. Fig.3 shows the measuring points. For the total input of the air conditioner, a precision integrating wattmeter was used to measure the integrated value for the specified time.

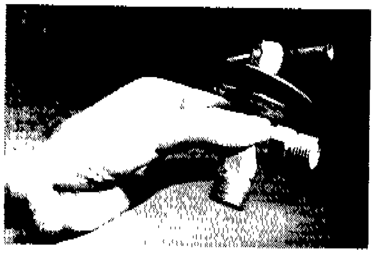

Fig. 1 Current cutoff element

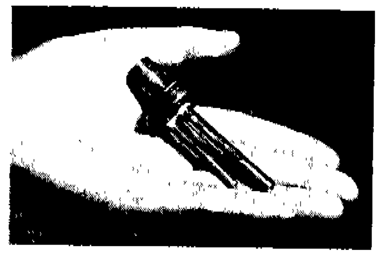

Fig. 2 On/off element

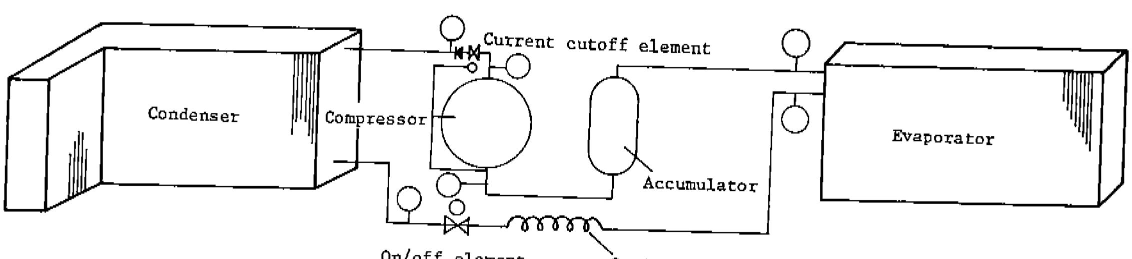

Fig. 3 Test equipment

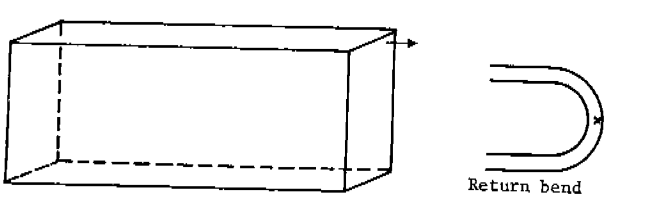

Fig. 4 Evaporator temperature measuring point

3. TEST RESULTS

The measuring results for the time characteristic of temperature, pressure, and input at the time of compressor start and stop with use of the test equipment shown in Fig.3 for the conventional refrigeration cycle and the MICLOSS refrigeration cycle are shown in the following. The test air conditions were set to a constant temperature of 35°C for the condenser side and 27°C for the evaporator and a relative humidity of 50%, independent of compressor start and stop.

(1) The values shown in the following were obtained for capacity, input, and EER at the time of compressor start and stop, and the EER of the MICLOSS refrigeration cycle has been improved by about 20%. (The values shown in the table are relative values.

Refrigeration cycle	Refrigeration capacity	Input	EER
Conventional	100	100	100
MICLOSS	111.7	92.7	120.4

(2) The time until steady state is reached is about 1 min with the MICLOSS cycle, while this is not reached by the conventional cycle even at the time 5 min before compressor stop (refer to Fig.5 and Fig.6).

(3) The evaporator temperature distribution becomes constant for about 80 to 90% from the time of start for the MICLOSS refrigeration cycle, and it was found that the evaporator is used effectively (refer to Fig.5 and Fig.6).

(4) In regard to the pressure characteristic, the conventional refrigeration cycle shows a pressure peak which can be taken as liquid compression on the high-pressure side and drawing in on the low-pressure side, while this does not occur with the MICLOSS refrigeration cycle, which soon reaches a stable state (refer to Fig.7 and Fig.8).

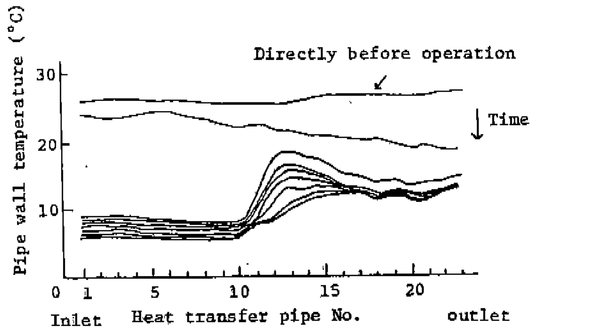

Fig. 5 Temperature characteristic during compressor operation (conventional refrigeration cycle, operation ratio: 50%)

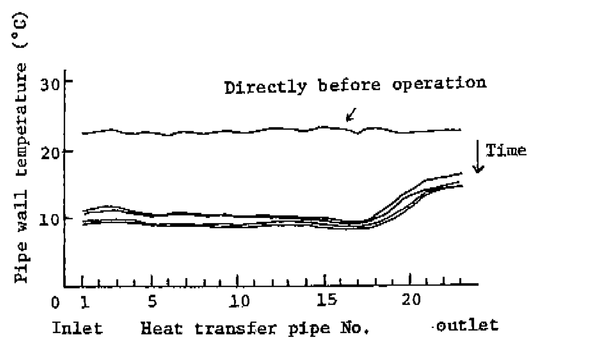

Fig. 6 Temperature characteristic during compressor operation (MICLOSS refrigeration cycle, operation ratio: 50%)

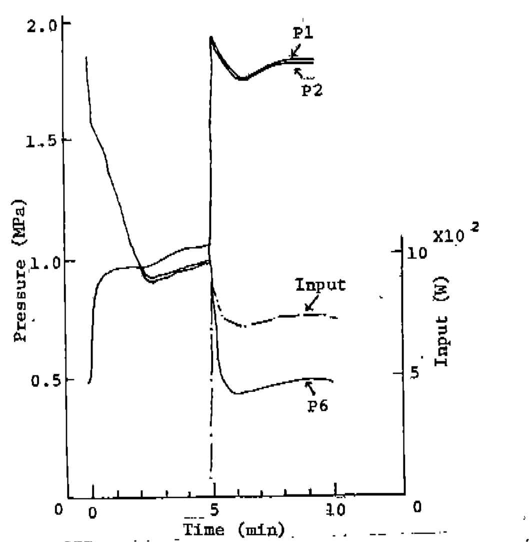

Fig. 7 Pressure-input characteristic (conventional refrigeration cycle, operation ratio: 50%)

4. ANALYSIS MODEL AND RESULTS

The time changes for the local heat flux αi:
the local flow quality Xk:
the local refrigerant distribution amount Gk:
the local density k:
and the local void fraction fgk:
were analyzed from the measuring results for the above evaporator pipe wall temperatures and the inlet and outlet pressures.

4.1 Local heat flux αi

Pipe outside: $Qk = Aok \cdot \alpha o \cdot (To - Tek)$
Pipe wall : $Qk = Aok \cdot \lambda \cdot (Tek - Teik)/\rho$
Pipe inside : $Qk = Aik \cdot \alpha ik \cdot (Teik - Terr)$
$Aok = x\ do \cdot \ell k$
$Aik = \pi(do - 2d) \cdot \ell k$
αo = Outer surface heat flux
αik = Local heat flux in the pipe

4.2 Local flow quality xk

Circulation flow G $\quad G = \sum_{k=1}^{22} Qk/(ho - hi)$

hi: Inlet enthalpy ho: Outlet enthalpy
Local enthalpy hk $\quad hk = Qk/G + hk-1$
$Xk = (hk - hs\ell)/(hsg - hs\ell)$ from $hsg = f(Pr, Terr)$ and $hs\ell = f(Pr, Terr)$

Here, Terr is the saturation of Pr.
hsg: Saturated gas enthalpy
$hs\ell$: Saturated liquid enthalpy

4.3 Local density γk

$\gamma k = 1/(Xk \cdot Vsg + (1 - Xk)\ Vs\ell)$ from the specific volume Vsg of the saturated gas at Pk, the specific volume $Vs\ell$ of the saturated liquid, and Xk.

4.4 Local void fraction fgk

$fgk = (1.0 + (1.0/Xk - 1.0) \cdot S \cdot \gamma g/\gamma\ell)^{-1}$ with $S = (\gamma\ell/\gamma g)^{1/3}$

4.5 Local refrigerant volume Gk

$Gk = x \cdot d^2 \cdot \ell k/4 \cdot [fgk/Vsg + (1.0 - fgk) \cdot /Vs\ell]$

4.6 Local pressure drop Fk

The local pressure drop is obtained from the following formula.

Fk : $[1.0/(do - 2\rho) \cdot \lambda' \cdot u^2/(2 \cdot 0 \cdot g \cdot v) \cdot 10^{-4}] \cdot \zeta \cdot \ell k$
Fk : Local pressure drop
λ' : Corrected friction resistance coefficient
u : Flow speed
g : Newton's constant
v : Specific volume
ζ : Correction coefficient

Corrected friction resistance coefficient λ'
$\lambda' = \lambda \cdot Vs\ell \cdot (1.0 - x)^{1.75} \cdot \phi^2/[Vsg \cdot x + (1.0 - x) \cdot Vs\ell]$
λ : Friction resistance coefficient
ϕ : Correction item
x : Flow quality

Friction resistance coefficient λ
$\lambda = 0.316\ Re^{-0.25}$ Re: Reynold's number
$Re = u\ (do - 2)/\nu$ ν : Kinematic viscosity
$= \mu \cdot g/\gamma$ $\quad \mu = \mu\ell(1.0 - x) + \mu g\ x$
$\mu\ell$: Liquid viscosity μg : Vapor viscosity

Correction item ϕ
$\phi = 1.0 + 1.0/\sqrt{\chi} + 1.0/\chi$
$\chi = (\mu\ell/\mu g)^{0.1} \cdot (\rho sg/\rho s\ell)^{0.5} \cdot [(1.0 - x)/x]^{0.9}$
ρsg: Vapor density $\rho s\ell$: Liquid density

Correction coefficient ζ

This correction coefficient ζ is the correction coefficient includes the various pressure losses from bends in the piping, oil influence, refrigerant flow pattern, etc.

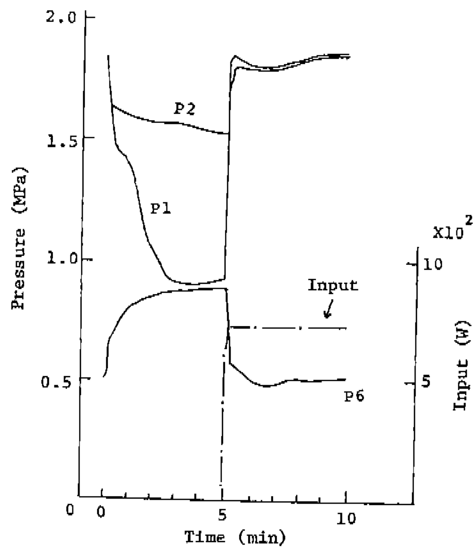

Fig. 8 Pressure-input characteristic (MICLOSS refrigeration cycle, operation ratio: 50%)

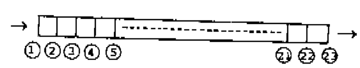

Fig. 9 Evaporator temperature measurement point model

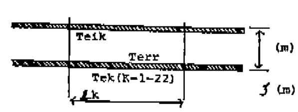

Fig. 10 Heat exchanger model

Analysis results

The time characteristics for the local heat exchange and heat transfer rates for the conventional refrigeration cycle and the MICLOSS refrigeration cycle are shown in Fig.11 to Fig.14.

The plot numbers in the figures indicate the data at intervals of 30 sec, and increasing numbers indicate a longer elapsed time from the start time. The plot number 1 indicates an elapsed time of 17 sec from the time of start. As shown in Fig.11 and Fig.12, the characteristic for the local heat exchange differs considerably, where the heat exchange amount of latter half of the evaporator decreases considerably for the conventional refrigeration cycle, while the entire evaporator executes uniform heat exchange with the MICLOSS refrigeration cycle, and the volume also is larger.

In regard to the local heat transfer characteristic, the operation of the evaporator with the MICLOSS refrigeration cycle is large and with good efficiency for nearly the entire operation. With the conventional refrigeration cycle, it is already small and the dry point is reached at the halfway point. The flow quality of this point is estimated to be about 0.7 to 0.8.

The local void fraction is about 0.8 near the evaporator inlet (flow quality 0.25) when the local slip ratio derived theoretically from Zivi is used. The analysis results for the local refrigerant amounts show that the total refrigerant amount directly before stop of the compressor is increased by about 10% at the time of the MICLOSS refrigeration cycle.

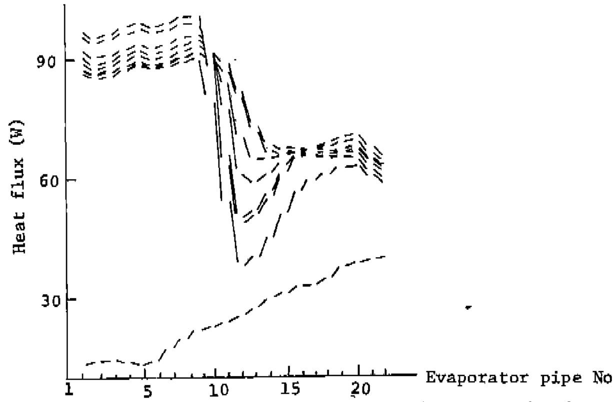

Fig. 11 Local heat exchange time characteristic (conventional refrigeration cycle, operation ratio: 50%)

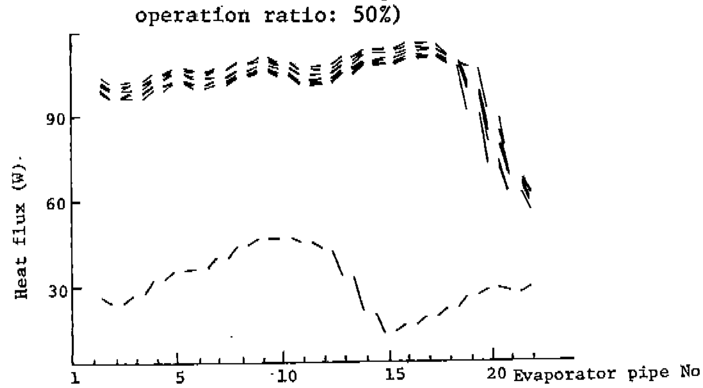

Fig. 12 Local heat exchange time characteristic (MICLOSS refrigeration cycle, operation ratio: 50%)

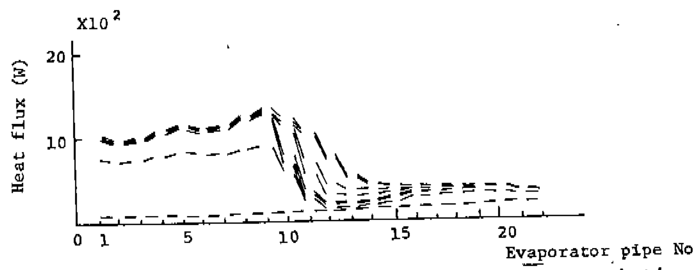

Fig. 13 Local heat transfer rate time characteristic (conventional refrigeration cycle, operation ratio: 50%)

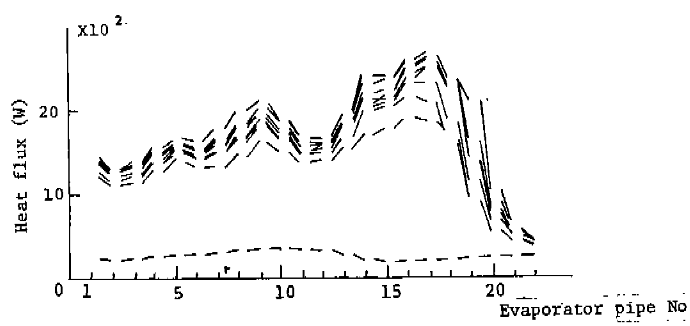

Fig. 14 Local heat transfer rate time characteristic (MICLOSS refrigeration cycle, operation ratio: 50%)

5. CONCLUSION

In regard to the MICLOSS refrigeration cycle with improved efficiency for the not steady state of the refrigeration cycle, the characteristics of a small air conditioner with a built-in rotary compressor have been introduced in comparison with the conventional refrigeration cycle, and it has been reported, that the efficiency and the characteristics have been improved, and it is believed that increased efficiency also can be reached for other refrigeration and air conditioning equipment.

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