Preheaters for Xe and CO2 AMS internal note xx/06

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I. Preheater Function and Components

Gas preheaters were proposed 5/2005 by UB as to

a) heat small volumes of Xe above the critical temperature >24 degC and likewise CO2 to >32 deg.C. This will allow a better controlled transfer for mixing.
b) eliminate the need to heat the entire Xe and CO2 vessel permanently (except for the ~monthly occasions to determine the residual contents).

Presented at the TIM 5/2005 at CERN, preheaters were base-lined (T.Martin suggestion). Designed by R.B. and constructed by M.V. it is shown in Fig.1.

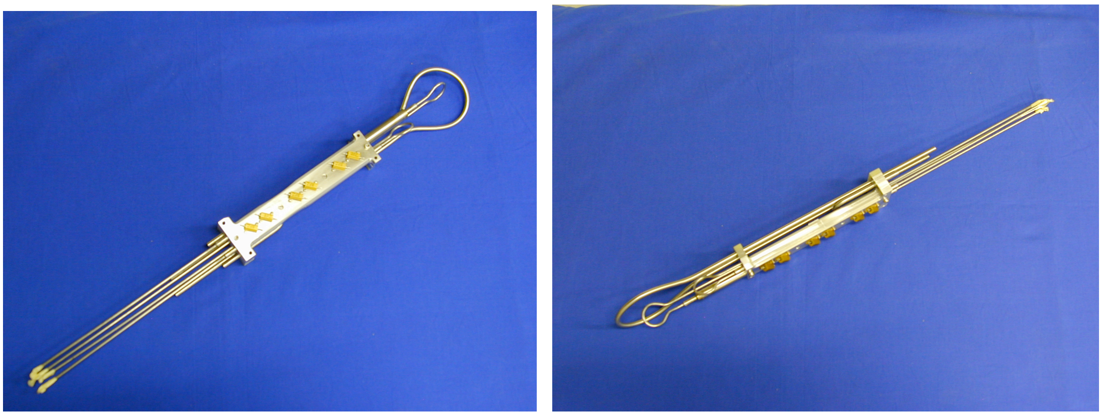

Fig.1 Top and side view of the preheaters with six resistors for heating

Requirements:

1. < 24W computer power from 30Vsupply controlled by duty factor
2. Increase the temperature by 40 deg.C above ambient (base plate).
3. < 2h heat up time, no operation of valves (power) during heating
4. one thermostat for mission success.
5. Max. temperature is uncritical, since all metal construction.

First measurements showed:

a) At 7.5W input the initial rise of temperature of 0.6 deg/min is compatible with the expectation from the heat capacity of the system, see Appendix A.
b) The heat transfer inAluminum is as expected, the transfer along the SS326 pipes is slow along the 1/8 pipes, which is desired.
c) Mounted on a cooled Alu plate and insulated by a Styropor box the temperature increase at 7.5 W on the gas volumes was only ~12deg.C and took about 1 hour.

To improve, we -

1. deleted the lower Alu shell, saving 99g of weight and heat reservoir,
2. replaced it at the supports only with heat insulating G10,
3. measured in vacuum with a thermal ballast of 10kg Aluminum and a vessel of ~15 kg Alu attached.

The Fig.2 gives the final assembly in exploded presentation.

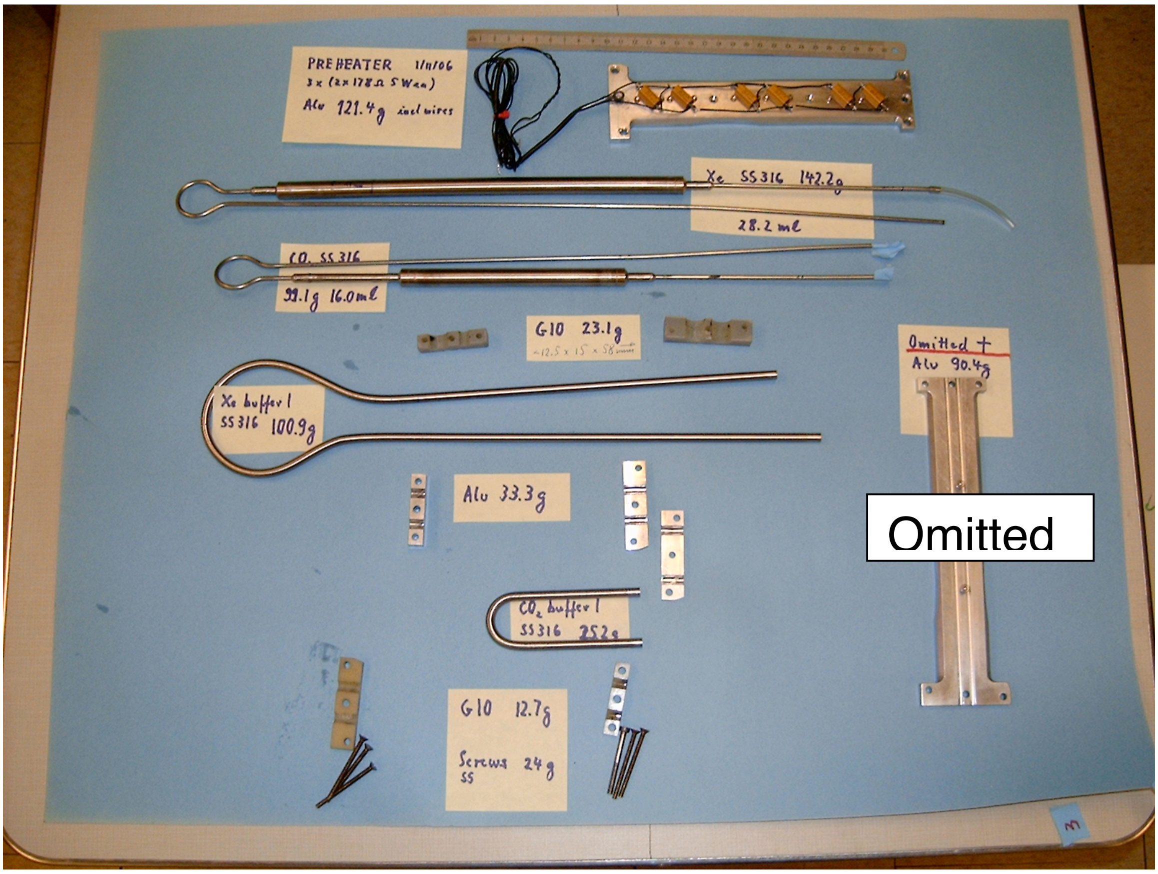

Fig.2 Exploded view of final assembly. Note all materials, weights and relevant volumes are labeled. The baseplate would be at the bottom, not shown.

AppendixA gives the relevant components and specific heat values.

The 1/2" tubes are in contact with the heating alu plate. The heat transfer is only marginally less good than with two alu shells. To reduce weight and thermal ballast it was omitted and replaced by G10 only at the attachment screws.

Measurements in **vacuum**:

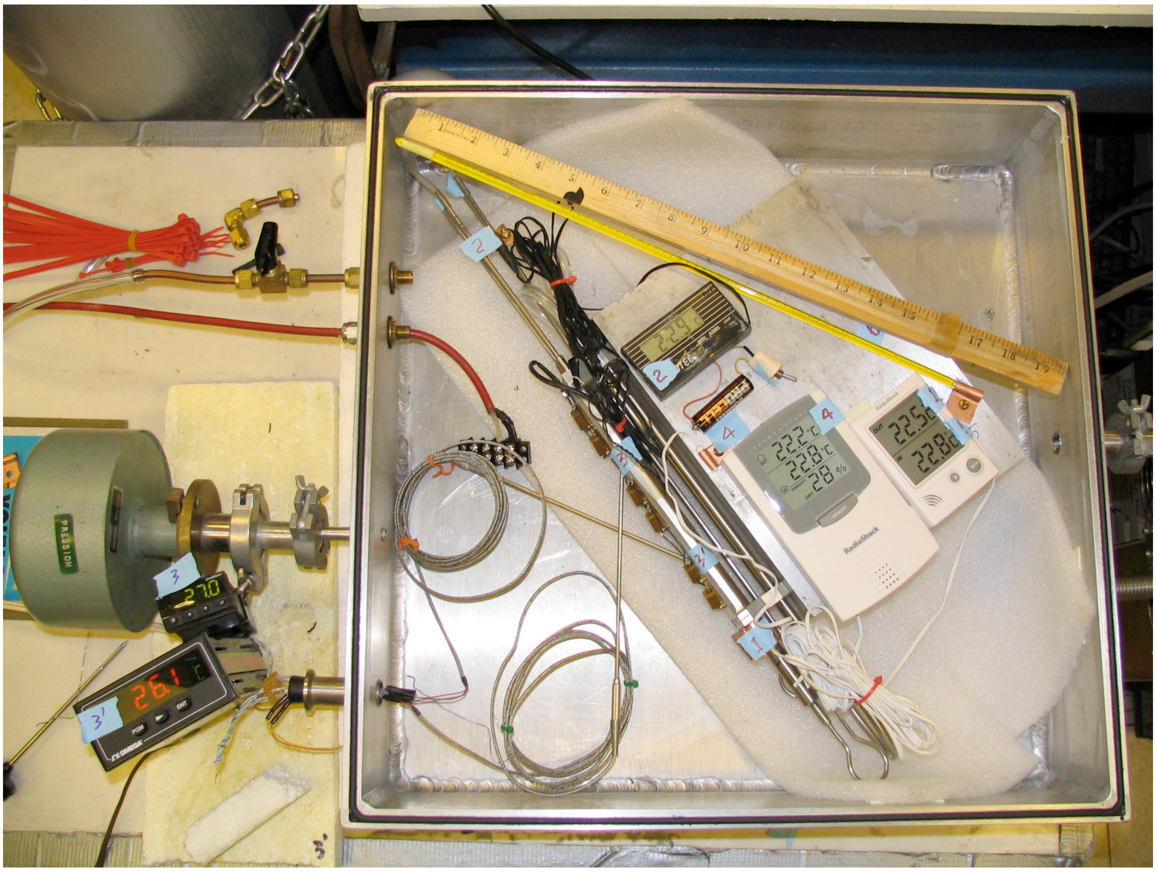

Fig.3 Preheater in vacuum vessel attached to 10+15kg cold mass.

Thermometer locations:

1 gas volume, temperature of interest
2 12 cm from volume on 1/8” tubing, low T signals small conduction loss
3 resistor plate, it has the highest temperature
4 3’, and 5 reference to the cold baseplate

All measurements were carried out with CO2 in the CO2 branch of the setup, since this constitutes the worst case.

All data were recorded manually by FZ. Thermometers were corrected at 0^0C to a NIST calibrated old conventional thermometer.

A) With 7.5W. an increase of ~25 deg.C is reached in ~ 1h, see Fig.4.

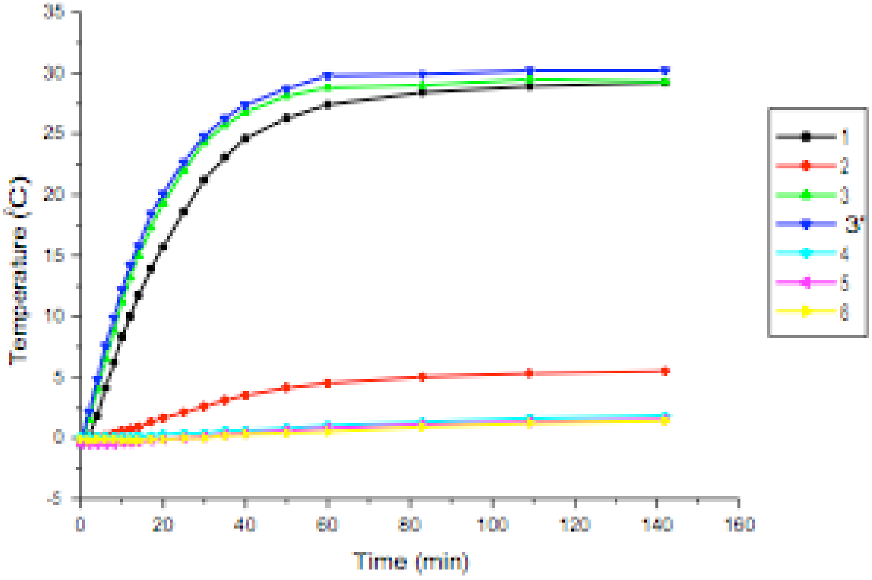

Fig.4 Temperature increase by 7.5w in vacuum. No radiation shield.

This is till not enough. Radiation could account for up to 4W, which helps. To create a safety margin we try 12 W see Fig.5.

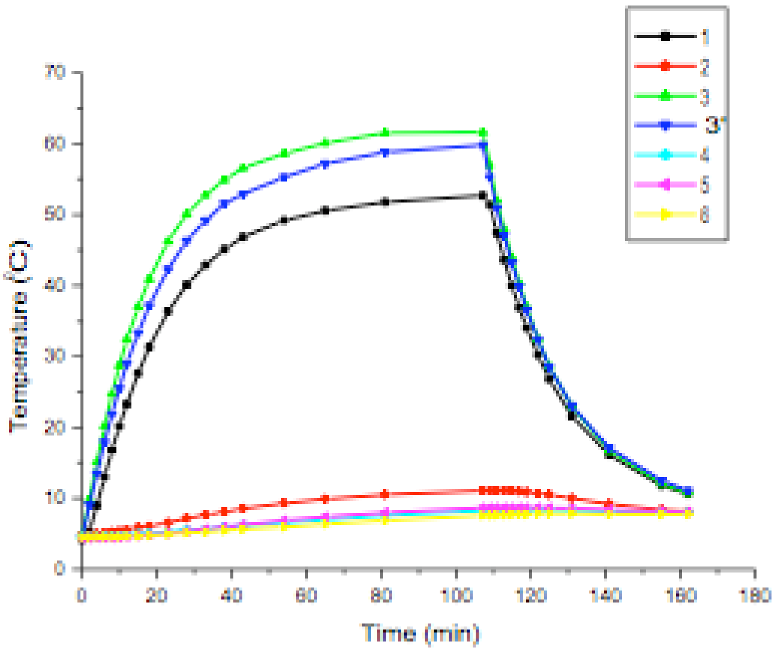

Fig. 5 Rise and fall of temperatures 12 W case.

This temperature rise of the gas volume #1 is sufficient!!

II. Test of Preheaters

Two different experimental setups at MIT were used to test the function of preheaters on control of gas transfer.

The first experiment was done with the prototype system shown in Fig. 6.

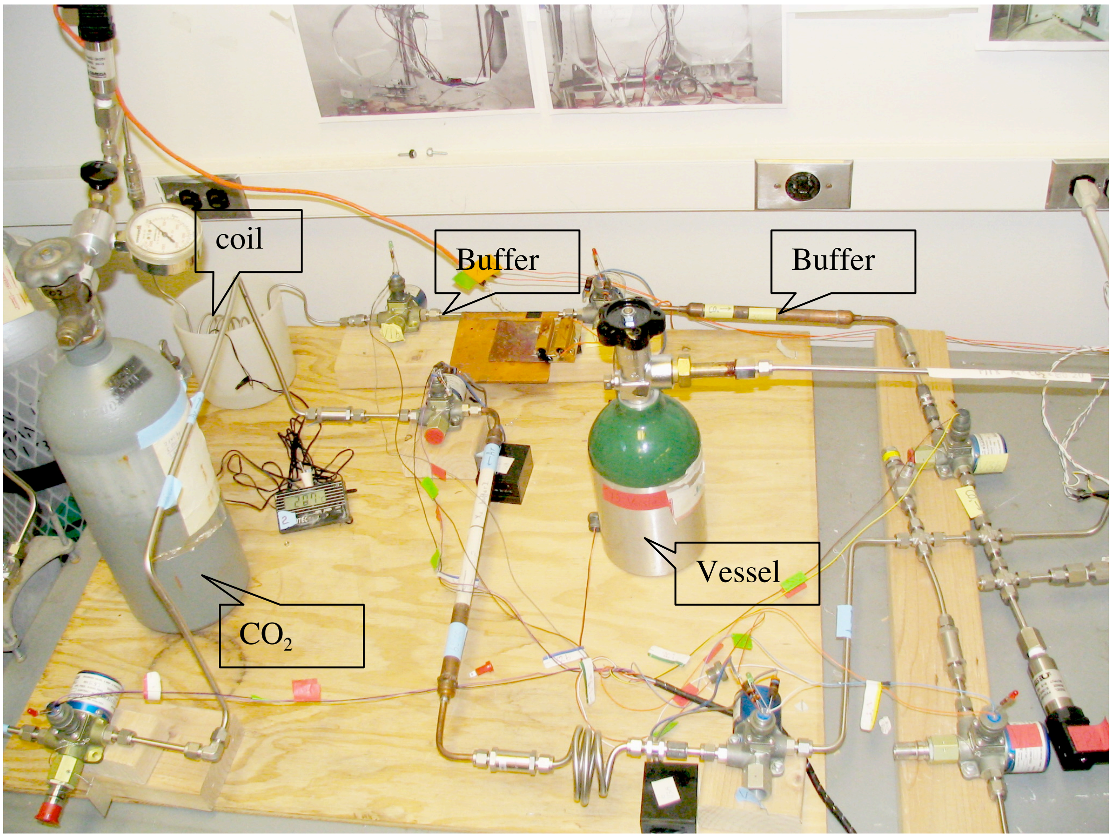

Fig.6 Prototype system for preheater test

The volume of CO_2 bottle is 3.45 liter and the density of CO_2 in the bottle is about 10 mol/l which is near the desired value 9.9mol/l.

The gas transfer is facilitated from the bottle with pressure sensor through 1/8" stainless steel in part as a coil to valve 1. The coil in water bath serves as a preheater in this case. Opening valve 1 transfers gas to buffer 1 (~6ml) and further by valve 2 into buffer 2 (~30ml) and via valve 3 into the mixing vessel D (1.2 l)

During the experiment, the CO_2 bottle was heated by water bath with the temperature ranging from 22^{0}C to 39^{0}C and the ambient temperature was about 22^{0}C. The coil and buffer 1 could be separately heated up to 55^{0}C.

Measurement results are shown in Fig. 7. The detailed data is listed in the Appendix B.

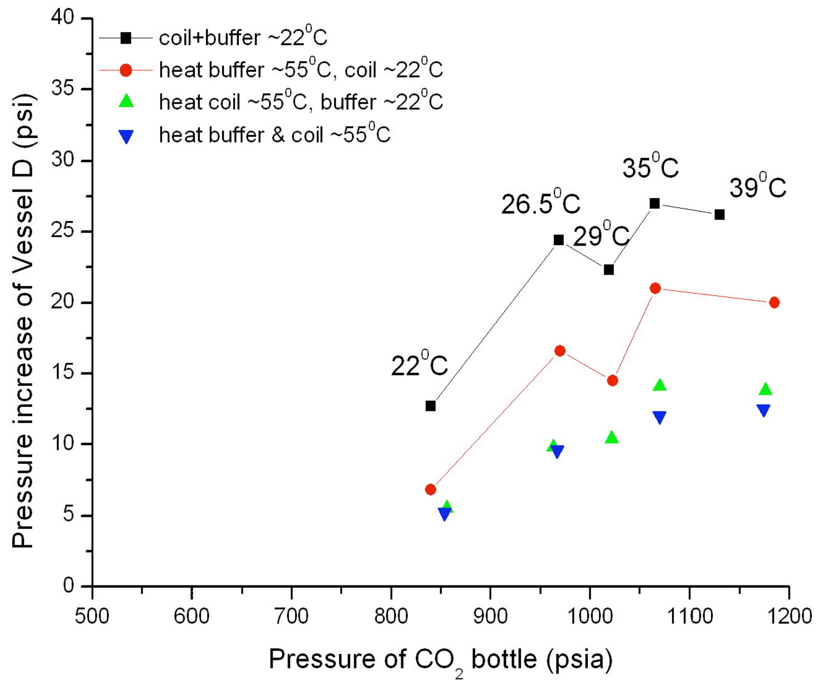

Fig.7 CO_2 transfer by one shot (1 cycle V1,V2,V3 in sequence). Temperatures refer to the supply bottle

We conclude that when we preheat the small volume of the coil between the gas vessel and first valve, the transfer amount of gas can be reduced by approximately 30-50%.

The improved experiment used the preheater of Figs. 1, 2 and a more compact setup see Fig.8.

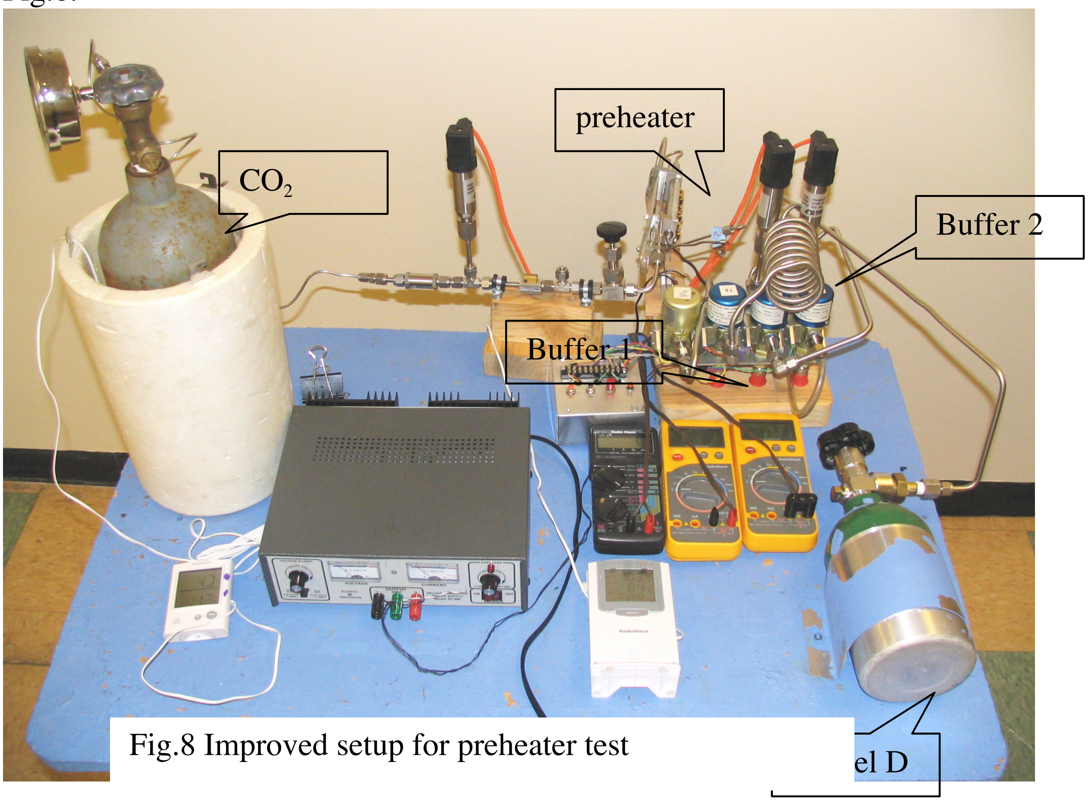

Fig.8 Improved setup for preheater test

Again, the volume of CO_2 bottle is 3.45 liter and density of CO_2 in the bottle is about 10 mol/l. The CO_2 bottle was heated by water bath from 2^0C to 33^0C. The entire setup was moved outside the building to obtain ambient temperatures lower than 3^0C. The measurement results are shown in Fig. 9 and table 1.

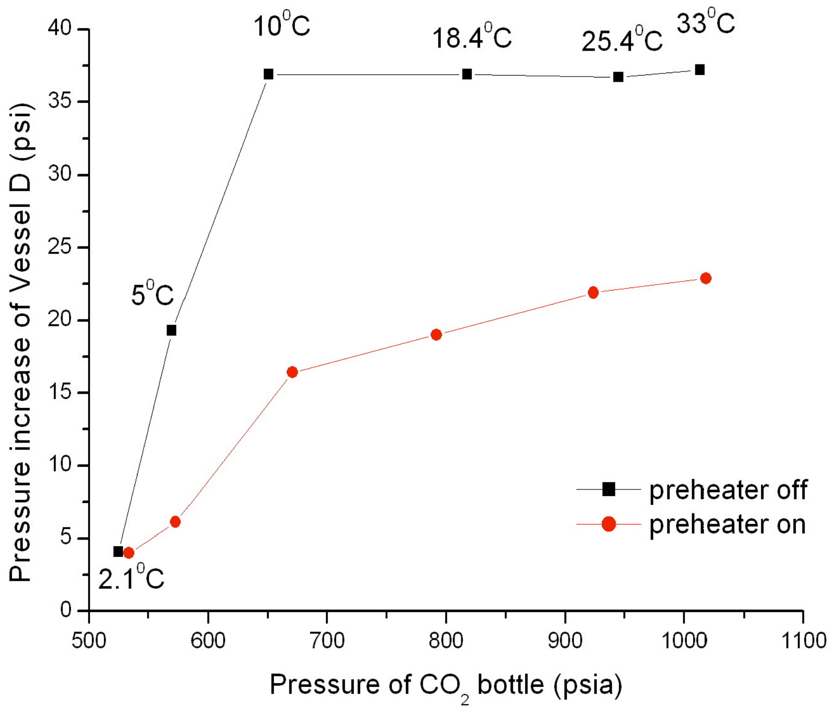

Fig.9 CO_2 transfer by one shot

Table 1. Measurement results of preheater test.

	Pressure(psi)	T_{bottle}(^{0}C)	$T_{ambient}$(^{0}C)	$T_{preheater}$(^{0}C)	ΔP(psi)
Heat only CO_2 bottle	1013	33	3.8	3.8	37.2
	945	25.4	2.8	5	36.7
	818	18.4	0.7	4	36.9
	651	10	-2	1.5	36.9
	570	4.3	2.7	2.7	19.3
	525	2.1	2.1	2.1	4.1
Heat CO_2 bottle and preheater	1018	31	3.4	40	22.9
	924	25.4	2	40	21.9
	792	18.7	0.4	37	19.0
	671	10	-1.8	31	16.4
	573	5	2.7	40	6.1
	534	2.5	2.5	35	4.0

Pressure means the pressure of CO_2 bottle; T_{bottle}, $T_{ambient}$ and $T_{preheater}$ are the temperature of bottle, ambient and preheater respectively;ΔP is the pressure increase of Vessel D

The preheater contains >16.1 ml for CO_2 (>28.2 ml for Xe, not used here) not accounting for 1/8 tubing. CO_2 buffer1 ~6 ml, buffer2 ~28 ml and the mixing vessel D 1.2 l.

When the temperature of CO_2 bottle is much higher than ambient, the CO_2 in the cold tubing between CO_2 bottle and the first valve is liquid at the high pressure. When the first valve is opened, the liquid CO_2 is pushed into buffer 1.

The expected transfer in this case is

$$\rho_{liquid\ CO2} = 1032 g/l$$

$$m_{CO_2}(buffer1) = 1032 g/l * 6.2 ml = 6.40 g$$

$$\Delta m_{CO_2}(vesselD) = 6.40 g * \left(\frac{28}{6.2+28}\right) * \left(\frac{1200}{28+1200}\right) = 5.12 g$$

$$\Delta P(vesselD) = \frac{5.12 g}{44 g/mol} \cdot \frac{22.4 l/mol}{1.2 l} \cdot 14.7 psi = 31.9 psi$$

So, if we have an ambient temperature of 0^0C and the buffer 1 is full of liquid CO_2, the pressure increase in Vessel D is about 32 psi, which agrees with the measurement when the CO_2 bottle is above 10^0C.

Using the preheater to heat to 40^0C, the CO_2 in the tubing before the first valve is almost all in gas state which reduces the amount pushed into buffer 1. In this way we control the gas transfer to ensure it iss not more than 25 psi. Note that a 7l mix with 20% CO_2 requires $\Delta p = 21$ psi, however we have upward tolerance to 56psi.

When the CO_2 bottle is at the same or lower temperature than the ambient, the CO_2 transfer is quite small and not affected by the preheater.

This preheater will be considered the qualification module.

Appendix.A

For heat computation enthusiasts, heat capacity at ~0 deg.C is

Aluminum 890±10 Ws/(Kg deg.C) conductivity= 250± 35 W/(m deg.C)
Steel 500±30 Ws/(Kg deg.C) conductivity SS316 = ??

Partlist

plate w 6 resistors	121.4g	alu
Xe volume	142.2g 28.2ml	SS316
CO2 volume	99.1g 16.0ml	SS316
two Spacers	23.1g	G10
Xe buffer 1	100.9g	SS316
CO2 buffer 1	25.2g	SS316
three spacers	33.3g	alu
two spacers	12.7g	G10
Six screws	24.0g	SS
total	581.9g	

FZ made a rough estimate:
Radiation loss from T to To ambient: $H = \varepsilon\ 5.67\ 10^{-8}$ Ws/(s m K^4) A ($T^4 - To^4$)
where A = area ~ 100cm^2 $\varepsilon = 0.1 – 0.5$ surface emissivity

Very roughly ~4W is the difference in radiation loss going from 0 to 40 deg.C

Appendix B

Table.1 Detailed data of preheater test on prototype system

	Pressure (psi)	T_{bottle} (^0C)	$T_{ambient}$ (^0C)	ΔT_1 (^0C)	ΔT_2 (0C)	ΔP (psi)
Heat only CO_2 bottle	1130	39	23.4	15.6	-5.6	26.2
	1065	35	22.7	12.3	-12.3	27
	1019	29	25.2	3.8	-3.8	22.3
	969	26.5	22.7	3.8	-3.8	24.4
	840	20.1	20.8	-0.7	0.7	12.7
Heat CO_2 bottle and buffer 1	1176	39.7	24.8	14.9	15.3	13.8
	1070	35	22.8	12.2	20	14.1
	1022	29	25.2	3.8	26	10.4
	963	26.5	22.9	3.6	28.5	9.8
	856	22.4	22.1	0.3	32.6	5.5
Heat CO_2 bottle and coil	1185	39.4	25	14.4	15.6	20
	1066	35	22.7	12.3	20	21
	1023	29	25.6	3.4	26	14.5
	970	26.5	22.8	3.7	28.5	16.6
	840	20.6	21.1	-0.5	34.9	6.8
Heat CO_2 bottle, buffer and coil	1174	39.7	24.7	15	15.3	12.5
	1070	34.8	22.8	12	20.2	12
	No	No	No	No	No	No
	967	26.5	22.9	3.6	28.5	9.6
	854	22.1	22.3	-0.2	32.9	5.2

a) Pressure refers to the pressure of CO_2 bottle.
b) ΔT_1 is the difference of temperature between CO_2 bottle and ambient.
c) The buffer and coil are heated up to around 55^0C and ΔT_2 is the difference of temperature between CO_2 bottle and heated coil or/and buffer.
d) ΔP is the pressure increase of Vessel D