

UL Certification of KoolSys R744 Transcritical System

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“What a Drag”

S.N.

Abstract

Systems operating with CO₂ are gaining preponderance in the refrigeration sector since the legislation enforces refrigerants with low GWP and ODP. CO₂'s high volumetric refrigeration capacity and non-toxicity make it viable for use in commercial and industrial applications. However, CO₂ low critical point forces the system to work transcritical with higher pressures. The design changes to improve efficiency lead to a booster system with different temperature levels. The KoolSys model is a CO₂ transcritical booster system with parallel compression with two temperature levels.

The present dissertation's goal is the UL certification of the KoolSys CO₂ transcritical booster model for sell in North America. System certification assures that the product quality and safety follow the requirements of the responsible entities. UL is an independent testing organization recognized, especially in the American market. The model was analyzed according to the applicable American standards, namely ASHRAE 15, CSA B52, ASME BPVC Div 1, ASME B31.5, and UL 60335-2-89.

For the most part, the KoolSys design meets the requirements, especially in protection against overpressure scenarios. The parallel PRVs placement provides the necessary relief in case of a power failure. Placing a pressure switch in each compressor discharge is necessary per ASHRAE 15 and CSA B52.

All the KoolSys components were studied to determine compliance with UL certification. For the components that do not have this certification, alternative brands were selected that meet the requirements. For the KoolSys piping systems, the minimum wall thickness was calculated for rigid piping under the scope of ASME B31.5 and UL 207. The PRVs were sized for the maximum capacity model after determining the design pressures for each stage following ASHRAE 15. The selected PRVs present a discharge area that surpasses the values calculated. After sizing the PRVs, and as required by ASME, the pressure losses in the inlet and discharge piping were determined and respect the 3 % and 10 % recommendation, respectively.

Every constructed model must be factory tested prior to sell with two tests: a pressure test, at the design pressure per ASHRAE 15 and CSA B52, and at 1.1 times the design pressure following ASME B31.5 for the piping system and a leak test, namely the liquid penetrant test, for the piping system and connections.

Keywords: Transcritical, booster, certification, conformity, pressure relief valves.

Resumo

Sistemas a operar com CO₂ estão a ganhar preponderância no setor da refrigeração uma vez que a legislação impõe o uso de fluidos frigorigéneos com baixo GWP e ODP. A elevada capacidade de refrigeração volumétrica e baixo grau de toxicidade fazem do CO₂ um fluido frigorigéneo viável para aplicações comerciais e industriais. O modelo KoolSys desenvolvido pela empresa RACE é um sistema transcrito *booster* com compressão em paralelo para operação com dois níveis de temperatura.

A presente dissertação tem como objetivo a certificação UL de uma central frigorífica baseada no modelo da KoolSys para venda na América do Norte. A certificação dos equipamentos é essencial para assegurar a qualidade e segurança do produto segundo parâmetros definidos por organizações responsáveis. A UL é um laboratório de certificação independente reconhecido especialmente na América do Norte. O modelo da KoolSys foi analisado em concordância com as normas americanas aplicáveis, nomeadamente, ASHRAE 15, CSA B52, ASME BPVC Div1, ASME B31.5 e UL 60335-2-89.

A central frigorífica segue os requisitos especialmente na proteção contra cenários de sobrepressão. As válvulas de segurança em paralelo proporcionam o alívio de refrigerante em caso de falha de energia. Os pressóstatos à saída de cada compressor verifica os requisitos das normas ASHRAE 15 e CSA B52.

Todos os componentes da KoolSys foram estudados no âmbito de determinar conformidade com os requisitos da certificação UL. Fornecedores alternativos foram escolhidos para todos os componentes de modo a cumprir os requisitos. Para o sistema de tubagem, o cálculo da espessura mínima para os materiais selecionados segue os requisitos da norma ASME B31.5 e UL 207. O dimensionamento das válvulas de segurança respeita o modelo de máxima capacidade e respeita as pressões de desenho atribuídas pela ASHRAE 15. As válvulas selecionadas apresentam uma área superior aos valores calculados. A queda de pressão a montante e a jusante das válvulas de segurança respeita os requisitos da ASME de 3 % e 10 % da pressão de descarga, respetivamente.

Cada modelo produzido tem de realizar um teste de pressão à pressão de desenho segundo a ASHRAE 15 e CSA B52, o sistema de tubagem, um teste de pressão a uma pressão de 1,1 vezes a pressão de desenho e um teste de fugas não destrutivo à tubagem e ligações, por exemplo, o teste dos líquido penetrantes.

Palavras-chave: Transcrito, certificação, normas, válvulas de segurança

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Table of Contents

1	Introduction.....	1
1.1	Refrigeration Global Context.....	1
1.2	RACE	3
1.3	UL Certification.....	4
1.4	Dissertation Objectives.....	4
1.5	Dissertation Structure.....	4
2	State of the Art	7
2.1	Refrigerants.....	7
2.2	Refrigeration Cycles	11
2.2.1	Carnot Refrigeration Cycle	11
2.2.2	Vapor Compression Cycle	12
2.2.3	Refrigeration Cycles Operating with CO ₂	13
2.3	Design Changes to R744 Systems	14
2.4	Safety concerns with R744 booster systems.....	20
2.4.1.	Asphyxiation	20
2.4.2.	High Pressures	20
2.5	Pressure Relief Valve.....	21
2.5.1	Spring Loaded Pressure Relief Valves	22
2.5.2	Pilot Operated Pressure Relief Valves	24
2.6	Conformity Assessment	25
2.6.1.	Applicable Standards.....	26
3	KoolSys Presentation	29
3.1	KoolSys	29
3.1.1	KoolSys Components	33
3.1.2	Design Conditions	34
4	Methods.....	35
4.1	KoolSys Analysis.....	35
4.2	Minimum Wall Thickness.....	35

4.2.1 Wieland K65	36
4.2.2 Stainless Steel 316.....	37
4.3 PRVs Sizing	38
4.4 Inlet and Discharge Piping	40
4.5 Required Tests.....	42
4.6 Marking and Instructions	44
5 Results and Discussion	47
5.1 KoolSys Analysis.....	47
5.1.1 Equipment Compliance	48
5.1.2 Design Pressure	49
5.2 Minimum Wall Thickness.....	50
5.2.1 Wieland K65	50
5.2.2 Stainless Steel 316.....	51
5.3 PRV Selection	52
5.3.1 PRV Protecting the LT compressors Suction Side (30bar)	52
5.3.2 PRV Protecting the MT compressors Suction Side (52bar)	52
5.3.3 PRV Protecting the Liquid Receiver (60bar).....	53
5.3.4 PRV Protecting the High side (120bar).....	54
5.4 PRV Inlet and Discharge Piping	54
5.4.1 PRV (30 bar).....	55
5.4.2 PRV (52 bar).....	57
5.4.3 PRV (60 bar).....	59
5.4.4 PRV (120 bar).....	62
6 Conclusion and Future Work.....	65
References	67

Figure Index

Figure 1 - Choice of Refrigerants Chronology	3
Figure 2 - ASHRAE 34 Safety Groups [16]	8
Figure 3 - Comparison of R744 and other refrigerants in typical systems: cooling capacity and pipe sizes [1]	10
Figure 4 - Carnot Refrigeration Cycle [21]	11
Figure 5 - Vapor Compression Cycle [23]	12
Figure 6 - R744 Subcritical and Transcritical Cycles [24]	13
Figure 7 - CO ₂ Transcritical Cycle: a) scheme of the refrigeration cycle; b) pressure enthalpy chart [25]	14
Figure 8 – Log(p)-h diagram for different Gas cooler Pressures [26]	14
Figure 9 - Transcritical cycle with an intermediate receiver [26]	15
Figure 10 – Log(p)-h diagram for a system with an intermediate receiver [26]	16
Figure 11 – Transcritical system with parallel compression [26]	16
Figure 12 – Log(p)-h diagram for a transcritical system with parallel compression [26] ...	17
Figure 13 – Commercial booster system [26]	18
Figure 14 – Log(p)-h diagram for a commercial booster system [26]	18
Figure 15 - ASME Single PRV, non-fire case [35]	22
Figure 16 - Generic Spring loaded PRV [33]	23
Figure 17 - Pilot Operated PRV [33]	24
Figure 18 - KoolSys refrigeration system	29
Figure 19 - Nelson Olbert Compressibility Chart	39
Figure 20 - Pipe bend illustration [39]	41
Figure 21 - Liquid penetrant examination [41]	43
Figure 22 - ISO 7000-1701 (2004-01) Symbol [42]	44
Figure 23 - ASME marking for PRVs [35]	45
Figure 24 - ASME marking for a pressure vessel Section VIII [35]	45
Figure 25 - BITZER 4FTE-20K working limits	49
Figure 26 - PRV (30 bar) discharge piping and placement	55

Figure 27 - PRV (52 bar) discharge piping and placement 57

Figure 28 – Placement of the PRV protecting the liquid receiver 59

Figure 29 - PRV (60 bar) discharge piping..... 60

Figure 30 - PRV (120 bar) discharge piping and placement 62

Table Index

Table 1 - Refrigerants Comparison [18, 19]	9
Table 2 - R744 advantages and disadvantages	10
Table 3 - Advantages and disadvantages of transcritical booster systems.	18
Table 4 - KoolSys Suppliers	33
Table 5 - Maximum Allowable Working Conditions for KoolSys	34
Table 6 - Maximum Allowable Working Conditions for KoolSys Oil Cycle	34
Table 7 - Wieland K65 Mechanical Properties.....	37
Table 8 - Chemical Composition (% of mass).....	37
Table 9 - Minimum Wall thickness for Wieland K65 piping	50
Table 10 - Minimum Wall thickness of Stainless Steel 316 piping.....	51
Table 11 - PRV 30 bar sizing parameters	52
Table 12 - PRV 52 bar sizing parameters	53
Table 13 - PRV 60 bar sizing parameters	53
Table 14 - PRV 120 bar sizing parameters	54

List of Abbreviations

ANSI - American National Standards Institute

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASME - American Society of Mechanical Engineers

CFCs – chlorofluorocarbons

COP - coefficient of performance

CSA – Canadian Standards Association

GWP - Global Warming Potential

GHG – Greenhouse Gas

HFCs - hydrofluorocarbons

IIR - International Institute of Refrigeration

MAWP - Maximum Allowable Working Pressure

ODP - Ozone Depletion Potential

OEL – Occupational exposure limit

OSHA - Occupational Safety and Health Administration

PRV – Pressure Relief Valve

PID – Piping and Instrumentation Diagram

RACE - Refrigeration and Air Conditioning Engineering

UL - Underwriters Laboratories

List of Variables

Variable	Definition	Units
A	Area of the pressure vessel	m ²
A _c	Minimum required discharge area	mm ²
A _{in}	Inlet area	mm ²
A _{out}	Inside area of outside tube	
c	Sum of the mechanical allowances	mm
C	Minimum required relieving capacity	kg/s
D ₀	Outside diameter	mm
f	Pressure relief capacity factor	kg/(m ² s)
H	Heat flux from an external or internal source	kW/m ²
h _{fg}	Refrigerant's latent heat of vaporization	kJ/kg
K	Coefficient of discharge	[-]
K _b	Back pressure correction factor	[-]
K _c	Combination factor for installations with a ruptured disc	[-]
K _{dr}	De-rated coefficient of discharge of PRV	[-]
M	Molecular Weight	kg/kmol
P	Internal design pressure	kPa
P ₁	Relieving pressure	bar
P ₂	Pressure at the outlet of downstream line	bar
P _c	Critical pressure	bar
P _r	Reduced pressure	[-]
R _m	Tensile strength	MPa
R _{p0,2}	Yield strength	MPa
S	Applicable allowable hoop stress	kPa
t	Pressure design wall thickness	mm
T	Relieving temperature	K
T _c	Critical temperature	K

t_m	Minimum required wall thickness	mm
T_r	Reduced temperature	[-]
W	Required relieving capacity	kg/hr
y	Coefficient for materials	[-]
Z	Compressibility factor	[-]
Δp_{in}	Pressure loss in the upstream line of pressure relief valve	bar
ζ	Pressure loss coefficient	[-]

1 Introduction

The introductory chapter is composed of five parts: (1) an overview of the refrigeration sector in the global economy and its environmental impact; (2) RACE presentation; (3) UL certification; (4) definition of the primary objectives; and (5) structure followed in the document.

1.1 Refrigeration Global Context

Refrigeration consists of obtaining and maintaining a space or product at a temperature below its surroundings. It requires extracting heat from the product or area and transferring it to another medium at a lower temperature. In most cases, the medium used is a refrigerant or working fluid. [2, 3]

The refrigeration sector is paramount for diminishing post-harvest losses and preserving food products, for the transportation and storage of pharmaceuticals and medicine, in numerous industrial processes (chemical, metallurgic, construction), and even in technology, for example, in the preservation of data centers. [2, 4]

According to the International Institute of Refrigeration (IIR), the total amount for refrigeration, air conditioning and heat pump systems operating in 2019 was roughly 5000 million, including 2000 million home refrigerators and freezers. Annual sales are approximately 500 billion US dollars, with over 15 million jobs worldwide relating to the refrigeration industry. These numbers illustrate the importance of the sector. [4]

The refrigeration sector was responsible for 17 % of the total electricity consumed in 2015. In 2019, that number increased to 20 %. Due to increasing demand and global warming, the expectation is that consumption will continue to grow. [4]

The refrigeration industry has some adverse environmental impact. There are two sources of greenhouse gas (GHG) emissions in the refrigeration sector: **indirect emissions** derive from the processes in charge of generating energy used to power these systems (representing approximately 63 % of the total emissions); **direct emissions** are mainly due to leaks during operation and non-controlled disposal of refrigerant (accounting for 37 % of the total emissions). [5]

The combination of direct and indirect emissions accounts for 4.14 GtCO₂eq, representing 7.8 % of global GHG emissions. The growth of the sector, expected especially in developing countries, must be sustainable. Two main objectives to reduce the negative effect of refrigeration on the environment are an investment in alternative refrigerants with no or negligible impact and improvement of the refrigeration systems efficiency to reduce primary energy consumption. [4, 5]

Ozone depletion and the atmospheric greenhouse effect due to refrigerant emissions have led to sizable changes. The type of refrigerants applicable respect global protocols based on two criteria:

- **Ozone Depletion Potential (ODP)**: represents the refrigerant potential to destroy the ozone layer;
- **Global Warming Potential (GWP)**: indicates how much a mass of a chemical contributes to global warming as a comparison to the same CO₂ weight over the same period (GWP CO₂=1). [6]

The Montreal Protocol targeted ozone-depleting refrigerants enforcing the phase out of production and consumption of chlorofluorocarbons (CFCs). Subsequent amendments to the Montreal Protocol also enforced the use of refrigerants with low GWP, with the Kigali Amendment emphasising the phase down of hydrofluorocarbons (HFCs) in developed and developing countries. [5, 7, 8]

The Kyoto Protocol, established in 1997, set objectives to limit and reduce GHG emissions with, 192 countries agreeing to its proposals. More recently, in the Paris Agreement of 2015, 196 countries decided on rules and incentives to reduce GHG emissions. The goal was to reduce global warming to 1.5 °C above pre-industrial levels. [9, 10]

The European Union enforces, since 2014, the fluorinated gases (F-gas) legislation which intends to reduce F-gas emissions by two-thirds of the values of 2014 by 2030. In the United States of America a law was passed in 2020 to phase-down production and consumption of HFCs to reach 15 % of the average annual levels from 2011-2013 by 2036. [11, 12]

Long term solutions fall on natural refrigerants such as C_3H_8 (R290), NH_3 (R717), CO_2 (R744), and some synthetic refrigerants with low GWP such as R1234yf. [6] Figure 2 shows the choice of refrigerants over the years and some significant milestones in legislation.

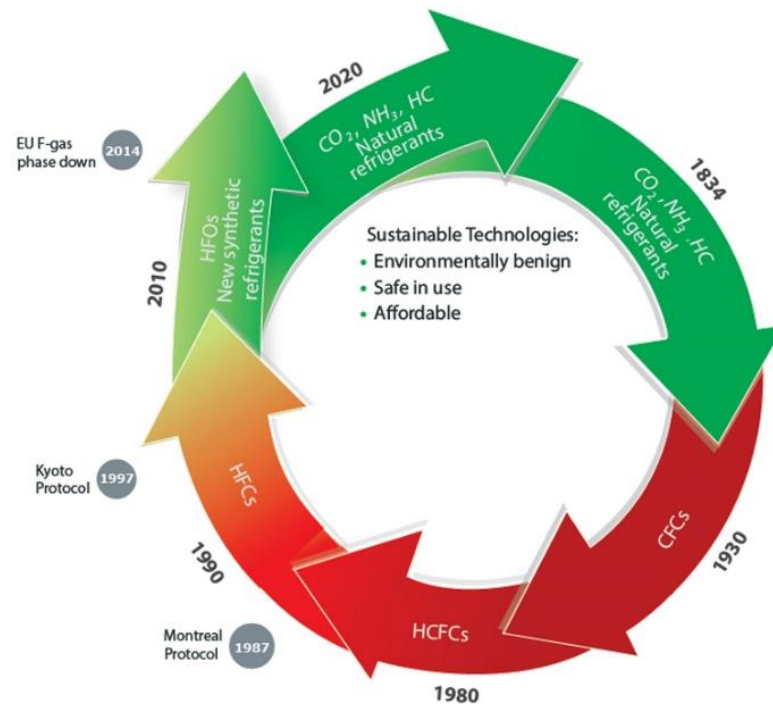


Figure 1 - Choice of Refrigerants Chronology [13]

Refrigerant choice influences the performance of refrigeration systems. Hence an accurate analysis of what properties they must possess and a comparison of the most used refrigerants is necessary. [2, 14]

The company that proposed and oversaw the dissertation considers the environmental impact and offers solutions with highly efficient refrigeration systems.

1.2 RACE

Refrigeration and Air Conditioning Engineering S.A. (RACE), located in Matosinhos, Portugal, is a company that focuses on the design, manufacture and execution of industrial and commercial refrigeration plants, using sustainable and innovative technologies to offer customers state-of-the-art solutions in international markets. [15]

The present dissertation was a collaborative effort between FEUP, Faculdade de Engenharia da Universidade do Porto and RACE. The challenge proposed to FEUP by RACE, consisted in analysing the KoolSys model conformity to American standards for further sale in North America.

KoolSys is the name given to the CO₂ transcritical booster system developed by RACE, and further explained in section 3. It is currently being certified for sale in the European Union and North America. The present dissertation concentrates on understanding and complying with the proposed standards and studying UL process of certification.

1.3 UL Certification

UL is an independent testing/inspection private organization founded in 1894 in the United States of America with the mission to promote safe living and working environments for people, along with aiding the production and use of products that are physically and environmentally safe. [16]

To achieve UL certification of the KoolSys model, the organization must be consulted, and a payment delivered prior to the UL organization evaluating the model. As a pre-requisite certificates of compliance of every component used in KoolSys were gathered.

The UL requirements used for refrigeration systems, such as KoolSys, are UL60335-1, UL60335-2-89 and UL207. The standards are further explained in section 2.6.1.

1.4 Dissertation Objectives

The dissertation primary objective was the analysis of the KoolSys model conformity with the American standards. The focal points to achieve this were: (1) grasping the certification process in North America; (2) finding the standards applicable to the KoolSys model; (3) recognizing the primary concerns in a refrigeration plant and how to proceed to minimize risk; (4) evaluating the KoolSys model conformity with the selected standards; (5) sizing the system pressure relief devices and piping; and (6) understanding the required tests.

1.5 Dissertation Structure

The dissertation is composed of five chapters. The first chapter, the introduction, presents the refrigeration sector global context, the company RACE, UL certification and the objectives of the study.

The second chapter introduces the theoretical principles behind refrigeration systems operating with R744. It also shows the certification process in the USA, along with relevant standards to R744 systems.

The third chapter describes the KoolSys model, its components and general design conditions.

The fourth chapter discusses the methods used to analyse and size the system and its pressure relief devices. It ends with a view of the required tests and necessary marking on KoolSys.

The fifth chapter displays the results of the KoolSys design analysis in light of the relevant standards. It presents the KoolSys components that possess UL certification and alternative models when necessary. It ends with the results of the minimum wall thickness calculation and the pressure relief valves (PRVs) selection.

The sixth chapter presents the conclusion to the certification procedure carried in the dissertation and suggests future works required to finalize the UL certification of KoolSys.

2 State of the Art

This chapter starts with analysing the types of refrigerants currently used, with a view on legislation requirements and long-term refrigerants. It follows with the presentation of the typical vapor compression cycles and design changes to arrive at the solution proposed by RACE for R744 transcritical cycles, focusing on safety concerns when implementing such a system. It ends with a view on the certification process in North America and entities that provide significant standards for refrigeration systems design and operation.

2.1 Refrigerants

As mentioned in section 1.1, the fluid used for energy exchanges in a refrigeration system is called a refrigerant. It usually absorbs heat, in the evaporator, at a lower temperature and pressure, from the product or space to refrigerate. After compression to a higher pressure and temperature, it dissipates energy in the condenser. [2, 14]

The appropriateness of the refrigerant usually depends on the thermodynamic, physical, and chemical properties and also its safety. [14]

Regarding thermodynamic properties, the following stand out:

- Latent enthalpy of vaporization: high enthalpy results in large refrigerating capacity per unit mass;
- Freezing temperature: should be low enough not to occur solidification in normal working conditions;
- Evaporating pressure: pressure should be higher than atmospheric to prevent air from leaking into the system;
- Condensing pressure: should be relatively low to avoid expensive equipment necessity and high energy consumption.

Important physical and chemical properties include:

- Heat transfer characteristics: viscosity should be as low as possible and thermal conductivity high to maximize heat transfer;
- Oil solubility: depending on the refrigerant chose, different solutions to prevent oil logging in the evaporator;
- Water solubility: refrigeration systems must be completely dehydrated before being charged with refrigerant to avoid freeze-up in the expansion devices and corrosion;
- Inertness and stability: the refrigerant must not react with the materials used and undergo chemical transformation with time.

For safety purposes the refrigerant requires the following characteristics:

- Flammability: the refrigerant should not be flammable independent of its concentration in the air;
- Toxicity: the working fluid should not be harmful to humans;
- Detection: in the event of a leakage the working fluid should be easily detectable to minimize losses.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) classifies the refrigerants in terms of toxicity and flammability. Letter A indicates that the refrigerant is nontoxic and B that the refrigerant is toxic. The higher the number, the more flammable the working fluid, with 2L expressing lower flammability. According to ASHRAE 34, R744 is the safest of the natural refrigerants. Figure 2 shows the safety groups and corresponding designation. [17]

SAFETY GROUP			
F L A M M A B I L I T Y	Higher Flammability	A3	B3
	Flammable	A2	B2
	Lower Flammability	A2L	B2L
	No Flame Propagation	A1	B1
		Lower Toxicity	Higher Toxicity
INCREASING TOXICITY			

Figure 2 - ASHRAE 34 Safety Groups [17]

Other significant properties when choosing the refrigerant are its cost and the environmental impact referred in section 1.1. [2, 14]

Table 1 displays the properties for R290, R717, R744, R22, R134a and R404A.

Table 1 - Refrigerants Comparison [18, 19]

Properties	R290	R717	R744	R22	R134a	R404A
Classification	NR*	NR	NR	HCFC	HFC	HFC
Flammability	Yes	Yes	No	No	No	No
Toxicity	No	Yes	No	No	No	No
Detection	Current-transformer	Electro-chemical	Infrared	Semiconductor	Semiconductor	Semiconductor
ASHRAE 34 classification	A3	B2L	A1	A1	A1	A1
ODP/GWP	0/3	0/0	0/1**	0.05/1760	0/1300	0/3940
Temperature at atmospheric pressure [°C]	-42.1	-33.3	-78.4	-40.8	-26.2	-46.0
Critical temperature [°C]	96.7	133.0	31.1	96.0	101.1	72.1
Critical pressure [bar]	42.5	114.2	73.8	49.7	40.7	37.8
Refrigeration capacity at 0°C [kJ/m³]	3907	4382	22545	4356	2868	NF***

*NR: Natural Refrigerant

**CO₂ is the GWP reference (as mentioned in section 1.1)

*** NF: Value not found

R744 has a higher volumetric refrigeration capacity at 0 °C, leading to a lower quantity of refrigerant needed. However, the low critical point entails some design changes, as explained in section 2.3, namely the need to work transcritical in warmer climates. As stated in section 1.1, natural refrigerants are the long-term solutions due to low ODP and GWP, compared to R22, R404A, and R134a.

R744 has the following advantages and disadvantages as a refrigerant, Table 2. [1, 7, 20]

Table 2 - R744 advantages and disadvantages

Advantages	Disadvantages
High volumetric cooling capacity generates high refrigeration capacity.	Higher cost due to system complexity.
Higher heat transfer in evaporators and condensers due to higher pressure and density. These allow for smaller components or lower temperature difference between the refrigerant and air.	Higher pressures while operating and in standstill that leads to special designed components.
The compression ratio for R744 is less than for other HFCs resulting in higher isentropic efficiency.	Higher leak probability.
Pressure drops in heat exchangers and pipework is lower with higher pressure drop on the expansion valve. These allow for smaller suction lines, liquid lines, and lower pressure control in expansion valves.	Not as suitable for high ambient temperatures.
R744 is non-flammable and presents low toxicity falling in group A1 in ASHRAE 34 Standard for Refrigerants.	
High discharge temperatures allow for heat reclaim solutions.	
There is no legislation for phasing out R744, so it can be considered a long-term refrigerant.	
Low cost and widely available.	

Figure 3 shows the comparison between R744 and other refrigerants regarding cooling capacity and pipework diameters. As stated in Table 2, R744 allows for smaller suction and liquid lines. Compared with R134a and R404A, R744 has higher cooling capacity.

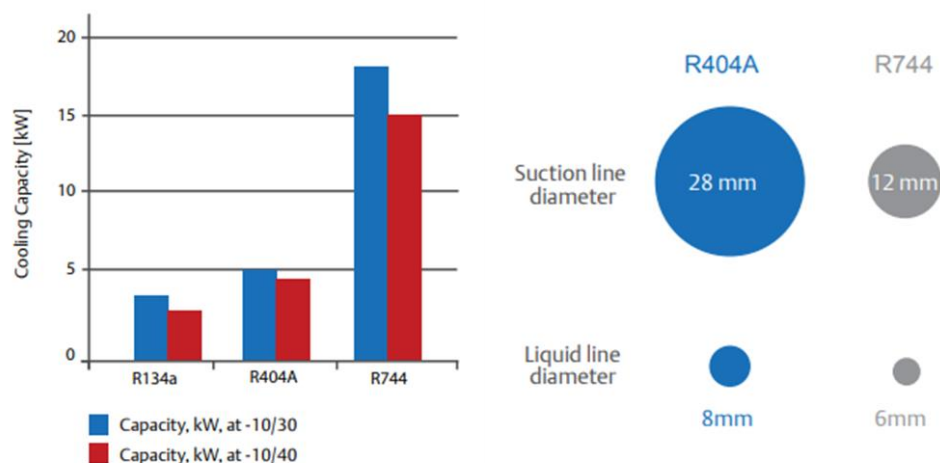


Figure 3 - Comparison of R744 and other refrigerants in typical systems: cooling capacity and pipe sizes [1]

2.2 Refrigeration Cycles

This section introduces the typical refrigeration cycles starting with the ideal Carnot cycle, followed by the vapor compression cycle, and finalizing with systems operating with CO₂.

2.2.1 Carnot Refrigeration Cycle

The ideal refrigeration cycle is the most efficient operating between two temperatures. It is the basis from which real cycle efficiency compares. [21] Figure 4 illustrates this cycle and the evolution of the working fluid in a temperature/entropy diagram.

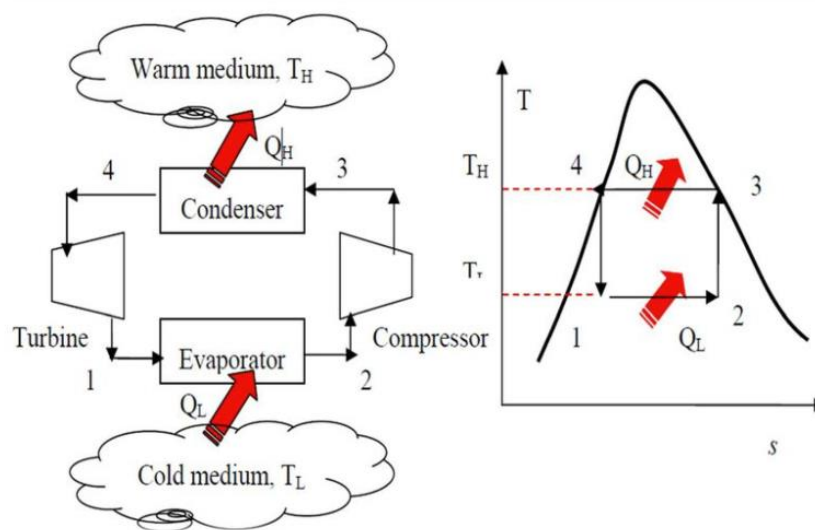


Figure 4 - Carnot Refrigeration Cycle [22]

The four components present in the Carnot Cycle are the condenser, the evaporator, the compressor, and the turbine.

The processes are as described:

- 1 → 2: the working fluid coming from the turbine vaporizes from heat absorption from the medium to refrigerate. The process is adiabatic with an infinitesimal temperature difference between the refrigerant and cold medium (reversible process);
- 2 → 3: refrigerant coming from the evaporator compresses to condensing pressure without friction and heat losses (isentropic process);
- 3 → 4: in the condenser, the vapor coming from the compressor, rejects heat to the warm medium, condensing, in a reversible process;
- 4 → 1: in the turbine, the liquid formed in the condenser expands to evaporating pressure with no friction or heat losses (isentropic process).

The purpose of the cycle is to absorb heat from the cold medium (cooling capacity, $\dot{Q}_L$). The Coefficient of Performance (COP) is the ratio between the heat absorbed from the cold medium and compression work ($\dot{W}$). [21]

$$COP = \frac{\dot{Q}_L}{\dot{W}} \quad (2.1)$$

2.2.2 Vapor Compression Cycle

Vapor compression cycles diverge from the Carnot cycle and present lower COP. Implementation of the Carnot cycle is not feasible due to:

- The heat transfer in the evaporator and condenser occurs with defined differences in temperature, making these processes irreversible;
- The compression of the working fluid should be dry to avoid damage to the compressor;
- The expansion in the turbine with double phase flow entails serious difficulties, especially with lubrication. The cost of the turbine is not viable for the work it generates. A thermostatic expansion valve is a typical choice for the expansion device. [21, 23]

These changes to the Carnot cycle result in the vapor compression cycle, as illustrated in Figure 5.

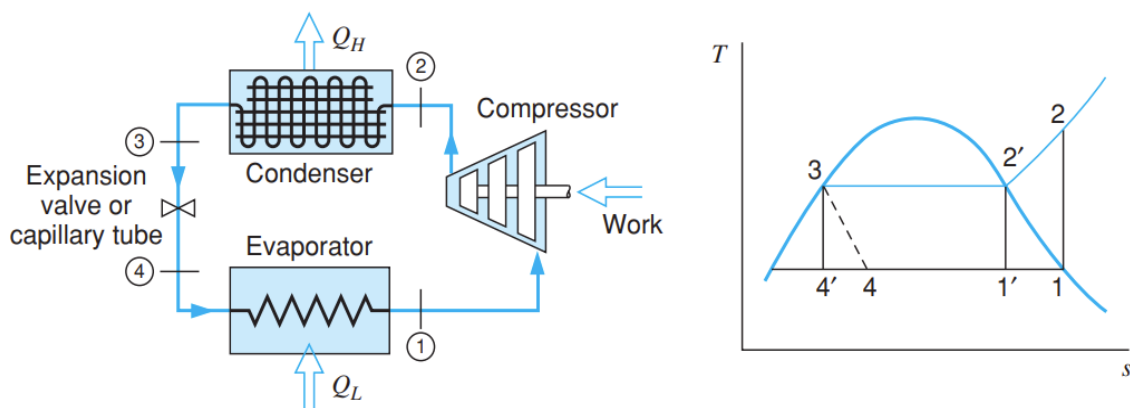


Figure 5 - Vapor Compression Cycle [24]

As seen in Figure 5 this cycle comprises two isobaric heat transfer processes in the evaporator and condenser, one isentropic process (compressor) and one isenthalpic (expansion device).

This cycle does not consider losses in compression, charge loss in the evaporator and condenser. All these changes to the vapor compression cycle reduce COP.

Subcooling, at the discharge of the condenser, and superheating, at the discharge of the evaporator, unintentional, may increase COP. [21, 23]

2.2.3 Refrigeration Cycles Operating with CO₂

As mentioned in section 1.1 the cycles working with R744 are gaining preponderance in the sector, and the system proposed by RACE is a booster system with parallel compression working with R744.

Refrigeration cycles operating with carbon dioxide divide into two main groups:

- Subcritical, with operation in the high-pressure side under the critical point of CO₂;
- Transcritical, with the high-pressure side over the critical point of CO₂. [2]

Figure 6 illustrates the pressure enthalpy chart for R744 and examples of transcritical and subcritical cycles.

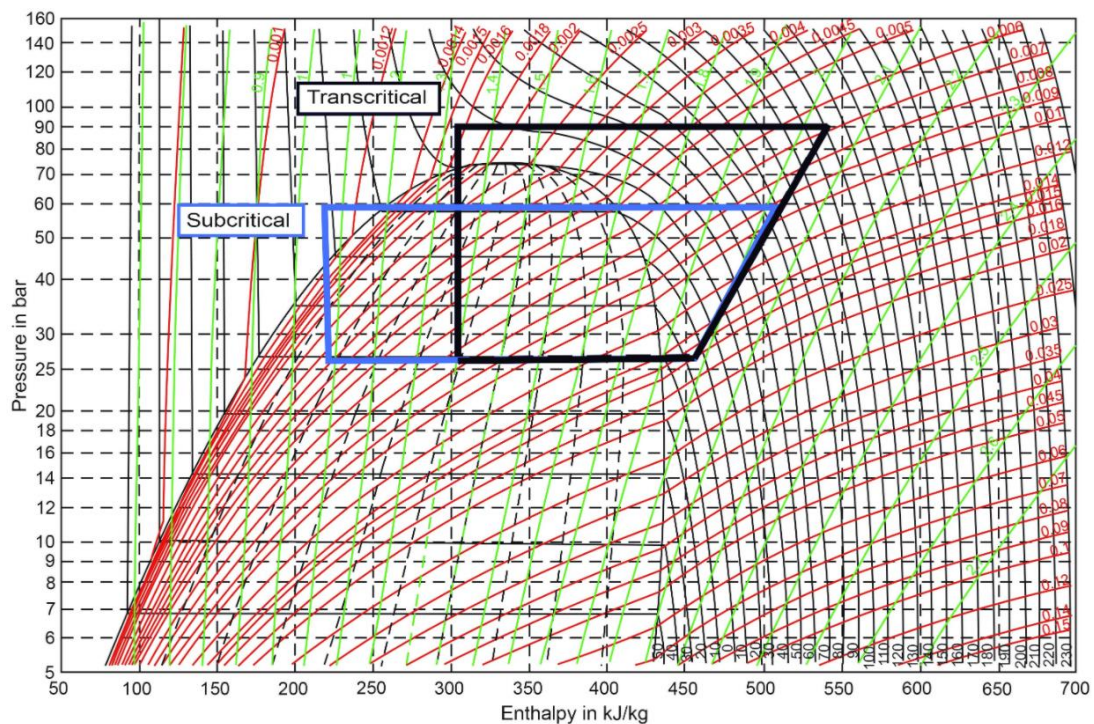


Figure 6 - R744 Subcritical and Transcritical Cycles [25]

The subcritical cycle is identical to the vapor compression cycle described in section 2.2.2. In transcritical operation, heat transfer in the condenser occurs without phase change. In this case, the condenser is called a gas cooler. The other processes and equipment are similar to the vapor compression cycle presented in Figure 5. [1]

Figure 7 shows a typical transcritical cycle and the corresponding pressure/enthalpy diagram.

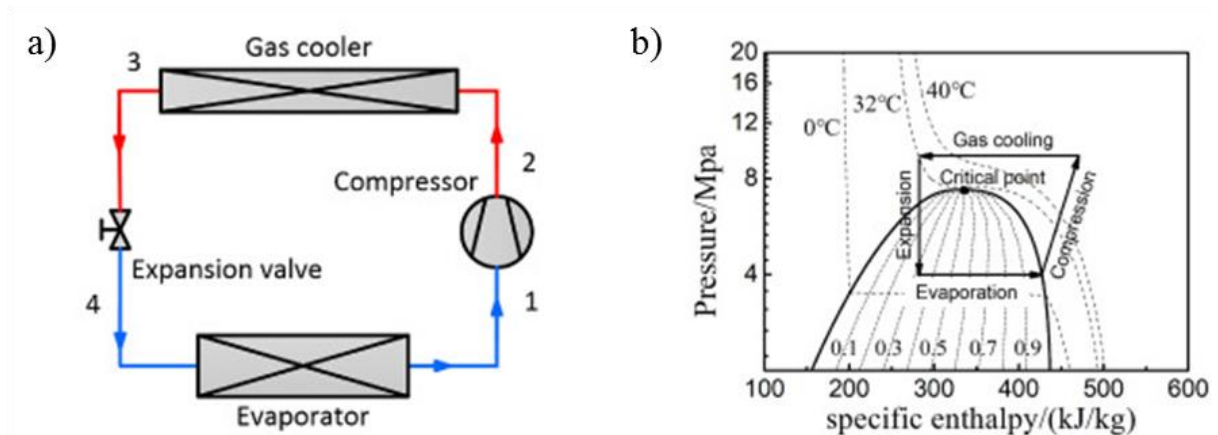


Figure 7 - CO₂ Transcritical Cycle: a) scheme of the refrigeration cycle; b) pressure enthalpy chart [26]

2.3 Design Changes to R744 Systems

Changes to the design of the generic transcritical cycle were the object of significant studies. This chapter presents the solutions that improve COP and establish CO₂ as a viable option in all climates and industries.

In subcritical operation, maximum COP occurs at minimum condensing pressure. However, in transcritical operation, defining optimum COP requires a cycle analysis. Above the critical point, temperature and pressure are independent. Setting the gas cooler outlet temperature and varying pressure results in different cycles, as shown in Figure 8. [1, 27]

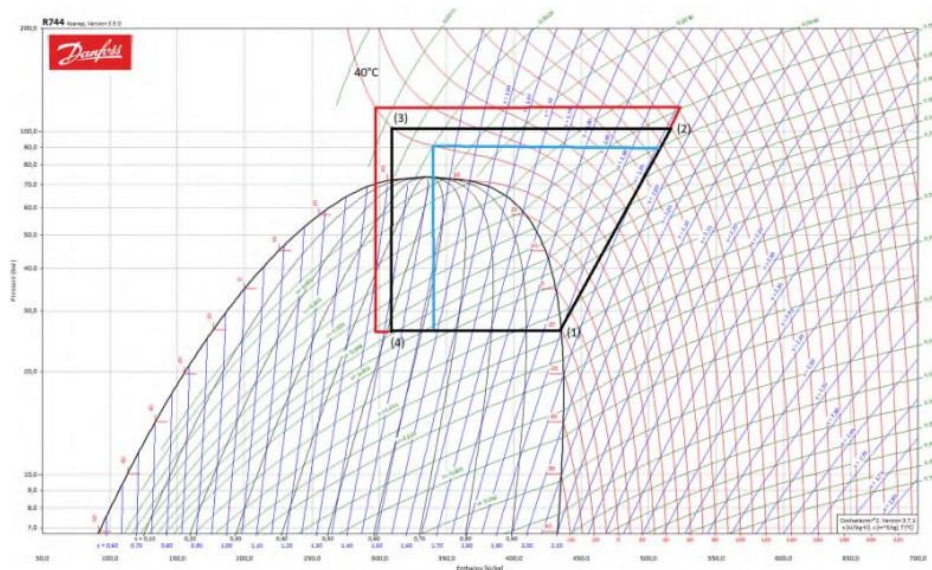


Figure 8 – Log(p)-h diagram for different Gas cooler Pressures [27]

For different gas cooler pressure, the cooling capacity and compression work vary. The relation between the two parameters optimizes COP for a specific temperature.

The expansion device is not able to control the gas cooler pressure and the amount of refrigerant supplied to the evaporator simultaneously. Implementing an intermediate receiver solves this problem. Figure 9 shows a transcritical CO₂ system with an intermediate receiver.

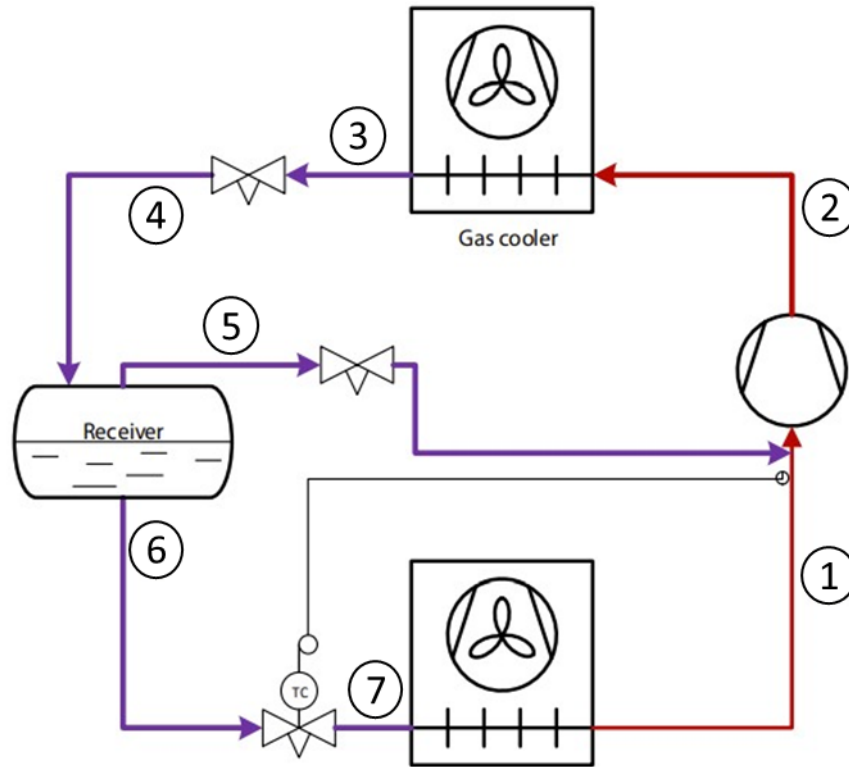


Figure 9 - Transcritical cycle with an intermediate receiver [26]

The transcritical valve expands the refrigerant from the gas cooler into the receiver and controls the gas cooler pressure to optimize COP. The receiver separates gas and liquid, flashing the liquid to the evaporators and the gas to the suction side of the compressor. Flash gas bypass valve regulates the liquid receiver pressure and opens wider when the pressure needs to be reduced and closes when it needs to increase. The expansion valve (7) regulates the refrigerant fed to the evaporator by controlling the superheating in the inlet of the compressor. [28-30]

Figure 10 represents the log(p)-h diagram for a system with an intermediate receiver.

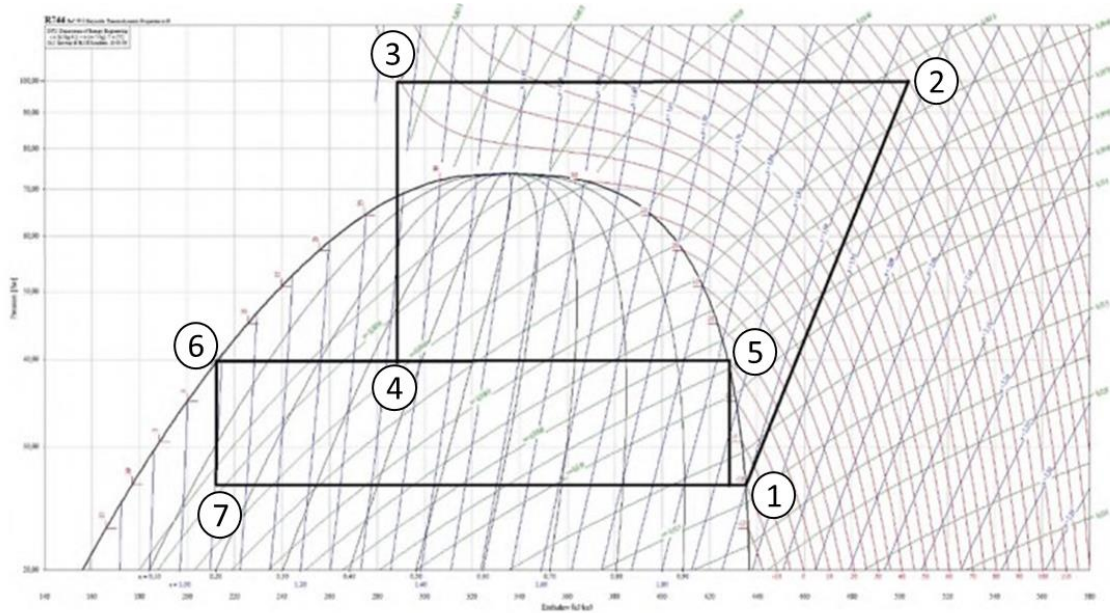


Figure 10 – Log(p)-h diagram for a system with an intermediate receiver [27]

To optimize this design a parallel compressor can be implemented instead of expanding the gas to the suction side of the main compressor. [1, 31, 32] Figure 11 illustrates a typical system with parallel compression. Figure 11 shows its corresponding log(p)-h diagram.

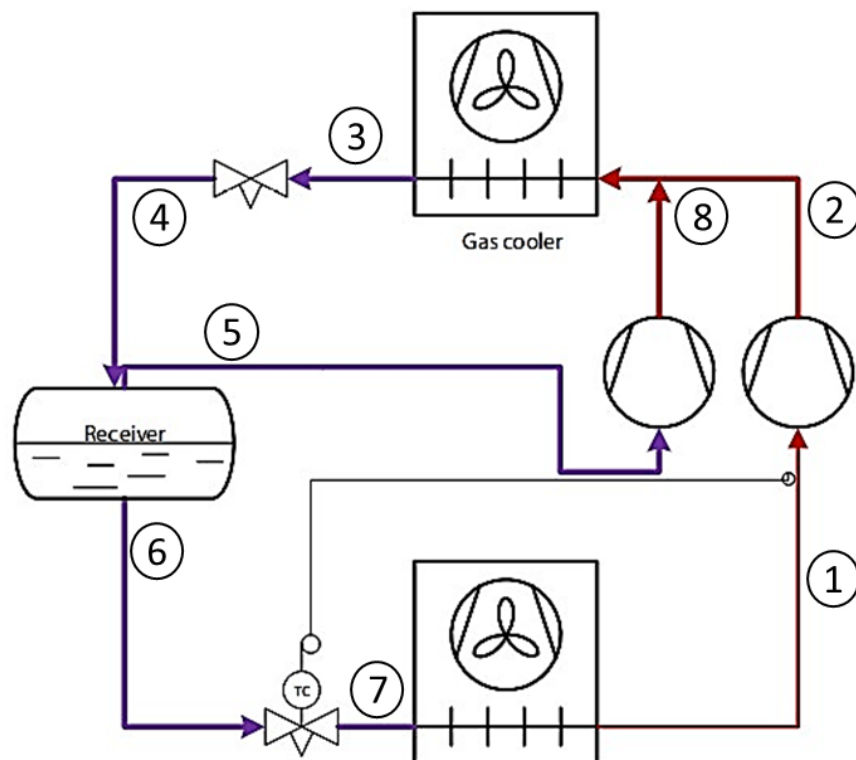


Figure 11 – Transcritical system with parallel compression [27]

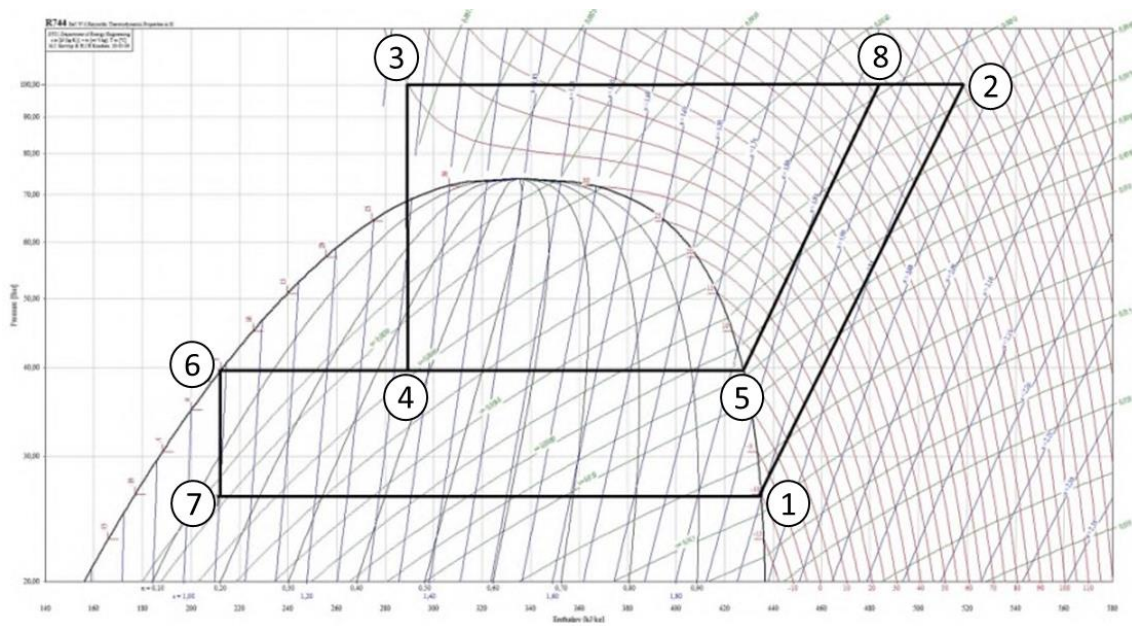


Figure 12 – Log(p)-h diagram for a transcritical system with parallel compression [27]

As seen in Figure 12 the parallel compressor takes advantage of the flash gas high pressure and compresses it to condensing pressure.

Other developments like using an ejector as an expansion device take advantage of the high pressure ratios in typical systems and improve efficiency. [31, 32]

For commercial applications there is usually the need of different temperature levels. One for the freezing applications and the other for the cold applications. To improve efficiency and avoid high compression ratios the choice is frequently a two-stage system. [27]

Two-stage systems feature two vapor compression stages. When using R744 as a refrigerant the two-stage system is designated a booster system. [27]

Booster systems display two different temperatures levels. Evaporation temperature is typically -6 °C to -10 °C for the medium-temperature (MT) evaporators and -30 °C to -35 °C for the low-temperature (LT) evaporators.

In a booster system the LT compressors discharge to the inlet of MT compressors. This design is standard practice in low-temperature applications. The two stages prevent lubricant breakdown due to high-temperature discharges of R744. [1, 27]

Transcritical booster systems present some advantages and disadvantages, Table 3: [1]

Table 3 - Advantages and disadvantages of transcritical booster systems.

Advantages	Disadvantages
Unlike cascade systems, in booster configuration only one refrigerant is used.	Requires two-stage compression.
Better efficiency in mild climates.	High operation pressures.
	Lower efficiency in warmer climates.

Figure 13 shows a typical two-stage compression system implementing the other design changes discussed in this section. Figure 14 displays the corresponding log(p)-h diagram.

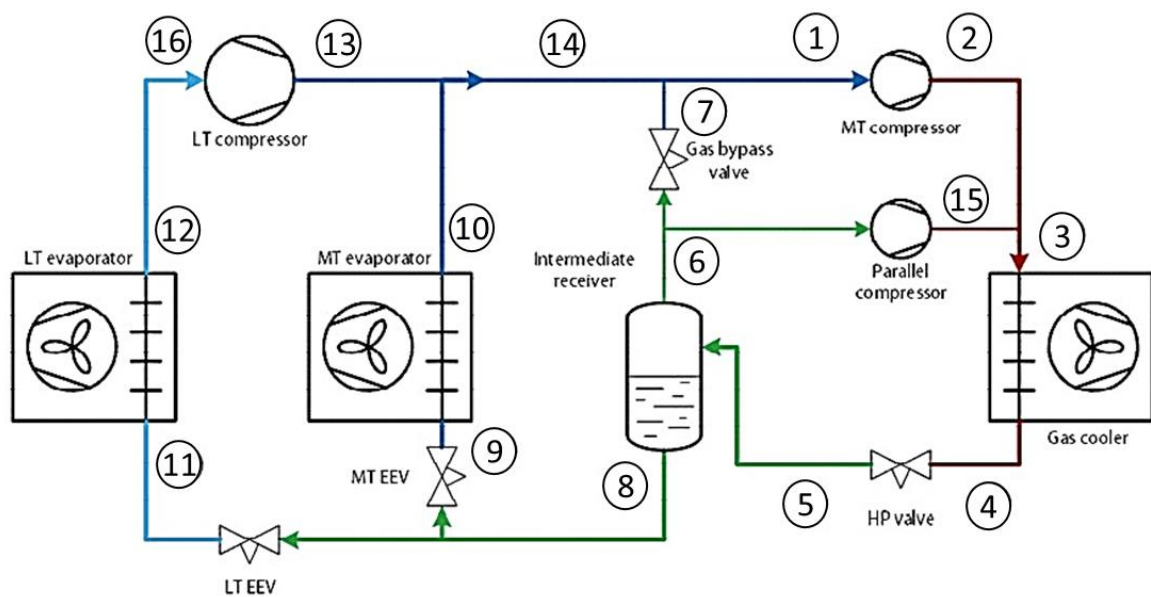


Figure 13 – Commercial booster system [27]

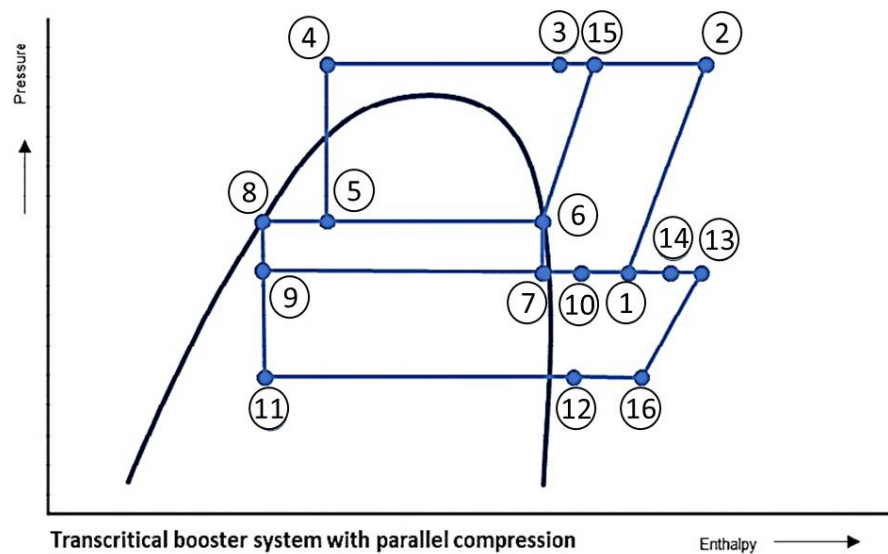


Figure 14 – Log(p)-h diagram for a commercial booster system [27]

Usually, in a multi-compressor system, one compressor displays a frequency converter, allowing for capacity control by varying the compressor speed. It has little impact on efficiency and applies to all kinds of compressors. The speed control combines with a step control, which starts and stops some compressors as the cooling load increases and decreases. [27]

The LT electronic expansion valve (EEV) and the MT EEV control the liquid supplied to the LT and MT evaporators based on the superheating at the inlet of LT and MT compressors. Superheat in commercial applications is usually 6 K to 10 K. The transcritical valve (HP valve) controls the pressure in the gas cooler for optimum COP as discussed in this section. In warmer periods, the amount of flash gas is higher and the parallel compressor takes a more prominent role saving energy consumption of the MT compressor. [27]

Intermediate pressure also influences the system behavior. Two parameters determine intermediate pressure: pressure as low as possible to minimize cost in piping and components; pressure higher than standstill pressure for maximum ambient temperature. Usually a compromise is necessary between cost and efficiency to respect normal operating conditions and maximum allowable pressures for each component. [1]

Typical intermediate pressures are 35 bar and 60 bar. For 35 bar the leakage potential is lower and so is the cost for pipework and components. The potential for flash gas is higher. However, in standstill or in case of a power failure PRVs will start to discharge. For 60 bar, despite the higher cost of the construction and higher leakage potential, pressures in standstill and in power failure will not lead to PRVs discharge. Flash gas formation is lower. [1]

As mentioned in section 2.1, the capacity for heat reclaim is high with CO₂. It is possible and frequently implemented a system to either heat community water or a space before the refrigerant enters the gas cooler. [1]

KoolSys R744 booster system developed by RACE includes some of these designs, as seen in Appendix A and explained in chapter 3.

2.4 Safety concerns with R744 booster systems

When applying and handling a transcritical booster system operating with CO₂, consideration must be given to certain aspects to ensure safety.

2.4.1. Asphyxiation

Although CO₂ is non-toxic and non-flammable and listed as an A1 class refrigerant in ASHRAE 34, a large leak of CO₂ in a confined space can reduce oxygen levels. If oxygen levels considerably fall, health hazards, including asphyxiation, may occur. CO₂ levels must be carefully monitored not to exceed values established by the Occupational Safety and Health Administration (OSHA). [1]

ASHRAE 34 sets occupational exposure limit (OEL) levels for 40 hours workweek at 5000 ppm. Other than for ventilated spaces, detection of R744 levels above OEL shall set an audible and visual alarm inside the machinery room and at each entrance and start mechanical ventilation. Leakage detection devices must be placed low due to CO₂ having higher density than air. [18, 33]

2.4.2. High Pressures

CO₂ systems work with significantly higher pressure than conventional cycles. System components, pipework and equipment must account for these working conditions.

Mechanical solutions for controlling and relieving pressure whenever it rises above design pressure shall be part of the refrigeration plant design.

Standstill pressure, i.e., the pressure when the system is shutdown may be accounted for when designing the system. In some cases, standstill pressure may be higher than set pressure for some segments of the cycle, thus making the use of PRVs indispensable.

In the case of a power failure, pressure may also spike, causing the PRVs to discharge. Some systems may include a small auxiliary cooling system with an alternate power supply to reduce refrigerant loss.

Trapped liquid is another cause for concern. Due to CO₂ high expansion coefficient, pressure increase is significantly higher when liquid temperature increases. Measure to safely relieve that pressure, to prevent leakage and possible bursting of components is essential. So, when designing the system, every part that may be susceptible to pressure build-up due to power failure or maintenance must be allowed to vent back to a section of the plant where pressure relief devices exist. [1]

Safety hazards when designing and operating a transcritical CO₂ system are the main focus of the certification process.

2.5 Pressure Relief Valve

The primary objective of a PRV is to protect a pressurized vessel, system, or piping by discharging process fluid to prevent any condition that would cause pressure to exceed design pressure or Maximum Allowable Working Pressure (MAWP). [34]

MAWP is an American Society of Mechanical Engineers (ASME) designation that establishes the maximum pressure that the most fragile part in a vessel can sustain. Industry uses MAWP to determine the PRV set pressure to ensure safe levels during operation. [35]

PRVs must be able to work in any circumstances, especially in case of power failure, that would render any other types of systems controls inoperative. It is typically the last measure to impede a catastrophic event. [34]

The general working principle of PRVs consists of three stages, namely:

- Opening at a predetermined pressure;
- Relieving the rated flow at specified overpressure;
- Closing when the system pressure comes back to safe levels.

They must work smoothly, securely and be suitable for a variety of working fluids. [34]

ASME Boiler and Pressure Vessel Code provides rules for design, fabrication, testing, materials, and certification of PRVs.

When only one PRV provides protection, the maximum accumulation allowed is 10 %, and the PRV can be set at the MAWP. PRV lift must be such that it blows the required capacity within 10 % overpressure. [36]

Figure 15 shows the case of one PRV protecting a pressure vessel, in non-fire case, according to ASME. The PRV is set at the MAWP of the vessel.

ASME defines the blowdown as the difference between the set pressure of a relief valve and its reseating pressure, i.e., the pressure at which the valve closes, 8 %.

Simmer pressure is the pressure at which there is visible or audible fluid leak from the valve before opening, 98 % of set pressure. Other prominent point is the leak test pressure, defined as 92 % of set pressure. ASME requires a quantitative seat leakage test to the PRV at simmer pressure. [36]

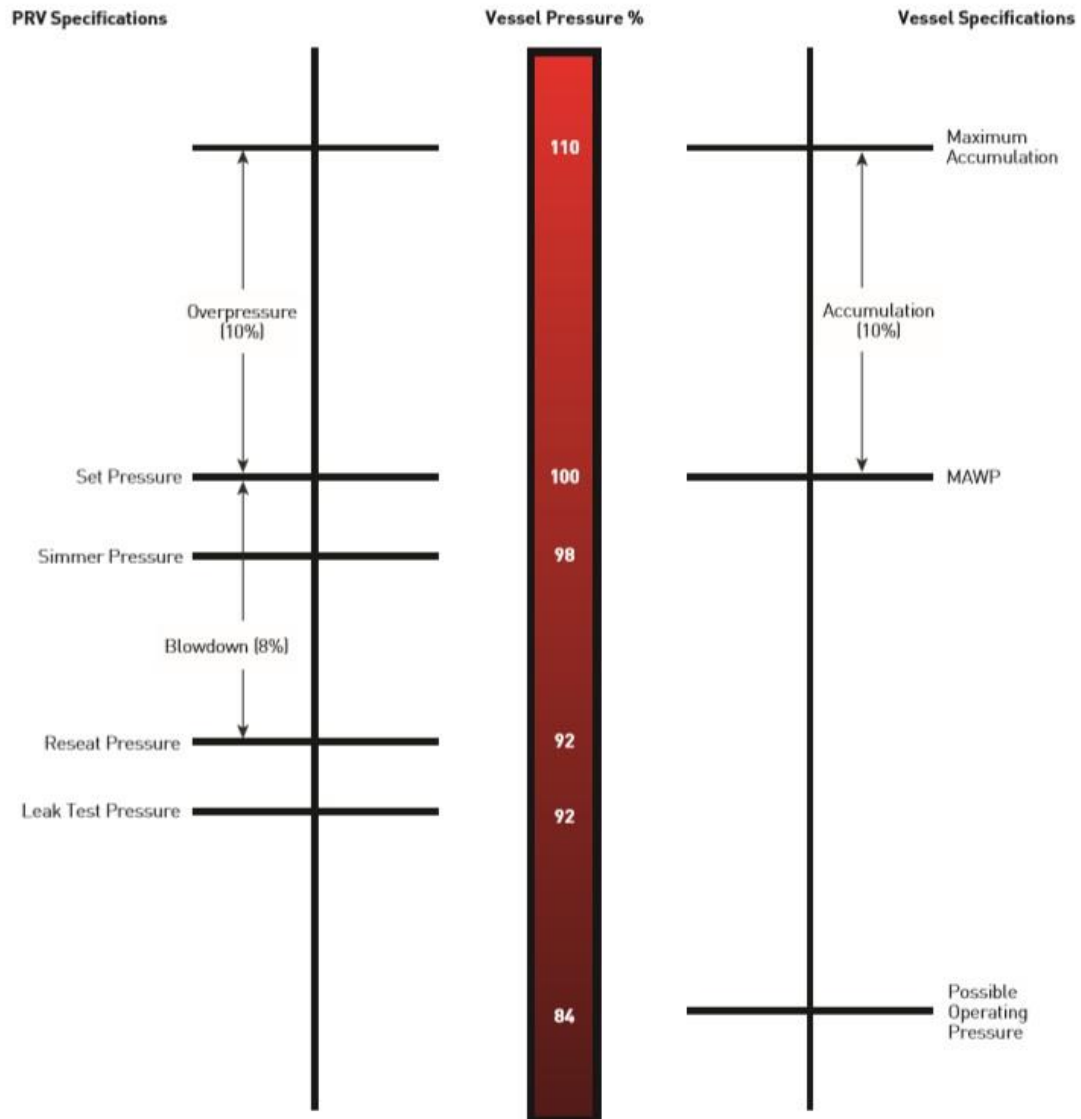


Figure 15 - ASME Single PRV, non-fire case [36]

Acceptable valves, according to ASME, are direct acting spring loaded PRVs and self-actuated pilot operated PRVs. [36]

2.5.1 Spring Loaded Pressure Relief Valves

Spring-loaded PRVs define set pressure by changing the force actuated by a compressed spring opposing the working fluid pressure. It is the most universally used safety valve and works from 0.345 bar up to 1380 bar. [34]

For a spring-loaded valve, the loaded spring compression determines the required force for the initial lift. Design of the valve must account for the rise in lifting pressure due to spring compression.

Usually, the huddling chamber (a chamber with a larger area) enhances lift. Pressure actuating in higher area increments force and allows for adequate lift. Figure 16 shows the design for a direct spring loaded PRV. [34]

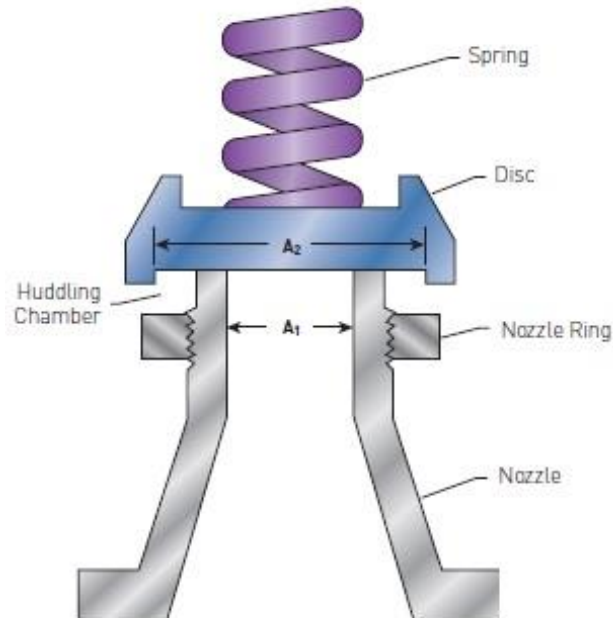


Figure 16 - Generic Spring loaded PRV [34]

Pressure losses in inlet and discharge piping of PRV are another influential factor when designing and selecting PRVs for a specific process.

For inlet piping, ASME offers a recommendation of pressure losses at 3 % of set pressure. Failing to account for the proper design may cause valve chatter and rapid firing of the PRV. When the PRV is activated, if the pressure loss in the inlet piping is higher than the blowdown, upon reseating of the valve, the equipment pressure plus the pressure losses in the inlet piping surpasses the set pressure, causing the valve to reopen. It is the cause of rapid cycling or chatter. Regarding the piping section, ASME requires for equal or greater than the PRV inlet area. [36]

In discharge piping, pressure losses occur when the PRV is open and discharging refrigerant, causing built-up backpressure that actuates in the top of the seat, causing additional force required to reopen the valve. Most recommended practices set the maximum built-up backpressure lower than the allowed overpressure of the PRV. ASME recommends 10 % of built-up backpressure above the set pressure. Another condition, when discharging to a disposal system is the pressure in this outlet. This pressure is called superimposed back pressure and is responsible for additional force in the PRV seat.

Some alternative designs may be necessary to prevent safety issues. The most common one is to add bellows around the spring, the same size as the PRV inlet area, to equalize the superimposed pressure actuating in the top and bottom of the seat. This alternative also aids in minimizing the effect of back pressure. [34, 36]

2.5.2 Pilot Operated Pressure Relief Valves

Pilot operated PRVs use system pressure to keep the disc closed, instead of a spring. The pilot operated PRV comprises a main valve and a pilot valve. The main valve is responsible for the appropriate relieving capacity, and the pilot valve controls the opening and closure of the main valve.

Figure 17 illustrates the generic design of these valves.

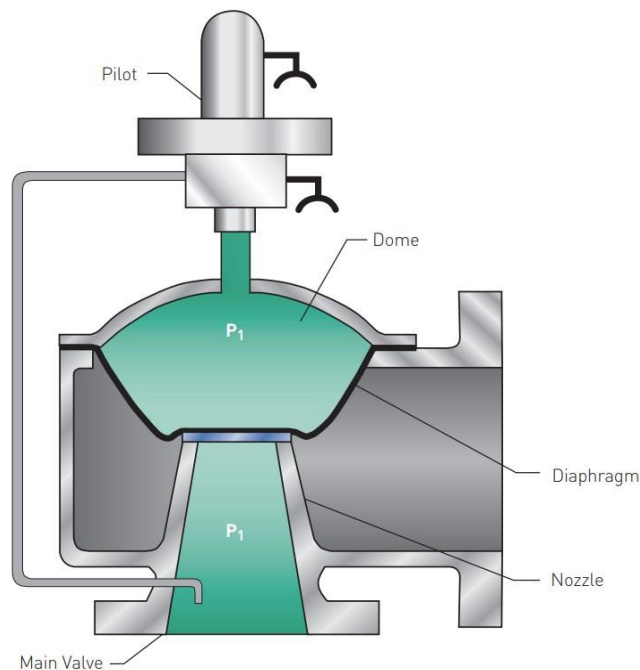


Figure 17 - Pilot Operated PRV [34]

ASME requires that the pilot valve uses the process itself, not an external device, to regulate set pressure.

The main advantages of this design are lower weights and dimensions. The primary disadvantages are the higher cost and complexity.

As seen in Appendix A, the PRVs used in KoolSys are the spring-loaded type.

2.6 Conformity Assessment

Conformity assessment is defined in ISO/IEC guide 2:1996 as *“any activity concerned with determining directly or indirectly that relevant requirements are fulfilled”*. [37] When proposing a system, it is necessary to undergo specific procedures to ensure the required characteristics.

Conformity assessment usually includes the following steps: sampling and testing, inspection, certification, quality, and environmental system assessment and registration. Third-party accreditation of the competence of those activities and recognition of an accreditation program capability is also essential. [37, 38]

Conformity assessment demonstrates that certain levels of quality and security meet specifications. It indicates, to buyers and users, that the performance and characteristics of a product/system follow appropriate standards. [38]

Impartial and competent product/system assessment is necessary for trading and selling in the global market. The adequacy of the standards used to validate the system is crucial. [38]

Standards define as *“A prescribed set of rules, conditions, or requirements concerning definitions of terms; classification of components; specification of materials, performance, or operations; delineation of procedures, systems, services, or practices”* to the National Standards Policy Advisory Committee.

They may be voluntary or mandatory, the difference being that a mandatory standard is part of a code or regulation by a government body and enforce specific obligations. Government regulations can adopt voluntary standards, turning them obligatory. [38]

Conformity assessment may be of three kinds:

- First-party assessment, or self-assessment, involves the manufacturer or supplier issuing a manufacturer declaration of conformance with applicable standards;
- Second-party assessment, required by the buyer, demands that the manufacturer undergoes different procedures to test the quality and safety of the products/systems they wish to purchase;
- Third-party assessment is the process in which a technically competent body evaluates and validates the manufacturer or supplier declaration of conformance. [39]

To ensure that the manufacturer has the ability and integrity to perform a declaration of conformity, self, and third-party assessments usually merge. The third-party must be independent of the supplier/manufacturer. Confidence in the evaluation relies on the number and quality of the tests performed. [39]

The method conducted by RACE, and explained throughout this document, is self-assessment of the compliance of the KoolSys design and possible third-party assessment from UL. So, it is crucial to examine which bodies are responsible for developing standards and those that apply to KoolSys.

2.6.1. Applicable Standards

UL issues standards for commercial refrigeration and essential components in the system. It defines requirements for the performance and safety of the system and each element individually. It also defines test procedures needing clearance before UL grants its marking.

The most pivotal standards used were UL 60335-2-89, Household and Similar Electrical Appliances – Safety – Part 2-89: Particular Requirements for Commercial Refrigerating Appliances with an Incorporated or Remote Refrigerant Unit or Compressor, UL 60335-1 Standard for Safety of Household and Similar Electrical Appliances, Part 1: General Requirements, and UL 207, Standard for Refrigerant-Containing Components and Accessories, Nonelectrical.

Other noticeable organizations supply standards relevant to refrigeration systems and refrigerants used, referred to by UL standards.

ASHRAE is a global organization advancing sustainable technology to improve human well-being through research and standards writing.

As for the standards used in this dissertation and referenced throughout the dissertation, ASHRAE 34, Designation and Safety for Refrigeration Systems, classifies the different refrigerants used, and ASHRAE 15, Safety Standard for Refrigeration Systems, provides parameters such as design pressure and required relieving capacity of pressure relief valves.

ASME “helps the global engineering community develop solutions to real world challenges” as a non-profit organization that provides codes, standards, conferences, and publications that enable information and practices share between all engineers and in multiple disciplines.

ASME Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels, Division 1, establishes requirements for the pressure relief devices necessary to protect pressure vessels manufactured under this standard and its sizing. ASME B31.5, Refrigeration Piping and Heat Transfer Components, and ASME B31.3, Process Piping, delineate methods for the design and sizing of the piping system.

ASTM International, formerly known as the American Society for Testing and Materials, is a global organization that provides standards that aid in product quality.

In this dissertation, ASTM B280, Standard Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service, ASTM A240, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and General Applications, and ASTM A480, Standard Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip, were consulted for the chemical composition of the material selected for system piping, nominal diameters and allowed tolerances for each material selected for KoolSys.

For the Canadian market, the leading organization developing standards for refrigeration systems is the CSA Group.

The standard B52, Mechanical Refrigeration Code, establishes requirements for the design pressure, the factory tests and necessary markings.

3 KoolSys Presentation

This chapter is dedicated to present the refrigeration plant proposed by RACE, KoolSys, its intricacies, and the general designing conditions. The design appears in Appendix A.

3.1 KoolSys

The KoolSys is a booster system with double-stage and parallel compression designed for commercial and industrial applications. The double-stage compression system, similar to the one presented in section 2.3, is designed for two different temperature levels. The system under certification does not include the evaporating unit and condensing unit. Figure 18 shows KoolSys refrigeration system.



Figure 18 - KoolSys refrigeration system

The plant divides in four segments at different pressure levels:

- **Low-temperature (LT) suction side** (30 bar): suction line of the LT compressors.
- **Medium-temperature (MT) suction side** (52 bar): suction line of the MT compressors, the discharge of the LT compressors and flash gas valve;
- **Intermediate-temperature (IT) liquid side** (60 bar): from the liquid receiver to the inlet of the parallel compressor and flash gas valve;
- **High-pressure side** (120 bar): discharge of the MT and parallel compressors to the transcritical valve.

Low-Temperature suction side

The LT suction side, also designated negatives suction line, represents one of the temperature levels, with temperatures around -30 °C. The refrigerant coming from the LT evaporators goes through a suction line filter to an internal heat exchanger. It receives heat and enters the compressors with the necessary superheat.

Two parallel PRVs protect the line against overpressure caused by liquid expansion and are set at 30 bar. The segment presents an instrumentation line containing a pressure transducer and a pressure gage. The pressure transducer sends signal of the pressure levels in the line. The pressure gage serves as a visible warning of the conditions of operation for outside personnel.

Medium-Temperature suction side

The MT suction side represents the other temperature level. The refrigerant compressed is a combination of five different outlets:

- Suction from the MT evaporators (positives suction line);
- Discharge from the LT compressors;
- Flash gas bypassed from the liquid receiver;
- Gas bypassed from the high-pressure side;
- Liquid bypassed from the liquid receiver.

The flash gas, the gas bypassed from the high-pressure side and the liquid bypassed from the liquid receiver are not continuous flow. The flash gas works as presented in section 2.3.

When the superheat at the MT compressors suction side is low, the solenoid valve (V-03) opens allowing for gas at a higher temperature to provide the required superheat. When the superheat is high, the solenoid valve (V-04) opens allowing for the liquid at a lower temperature to provide the necessary cooling.

Before entering the MT compressors, the refrigerant passes through a filter. Two parallel PRVs, set at 52 bar, protect the line. The segment possesses an instrumentation line similar to the LT suction side.

Liquid side

The refrigerant entering and leaving the liquid receiver constitute the liquid side. The liquid receiver is set at 38 bar, regulated by an electronic expansion valve, called a flash gas valve (V-02). The refrigerant enters the liquid receiver after expansion in the transcritical valve (V-01).

Liquid and gas separation occurs in the receiver. The gas goes to the flash-gas valve. When the amount of flash-gas is high, the valve (V-02) closes steering the refrigerant to the parallel compressor. Before entering the parallel compressor, the refrigerant gains heat in an internal heat exchanger from the discharge of the gas cooler.

The liquid is fed to the evaporators as required or to the valve (V-04), as explained in the MT suction side. Before going to the evaporators, the liquid enters a heat exchanger to reject heat to the suction side of the LT compressors. This line has a liquid filter and a sight glass to control the refrigerant humidity and flow.

The liquid receiver has two parallel PRVs to provide protection and an instrumentation line similar to the one described for the LT suction side.

The liquid receiver is connected to a heat exchanger with a mechanical cooling system with a freon circuit. The freon cycle prevents the safety valve from firing in case of a power failure.

High-pressure side

The high-pressure side divides in two sections: from the MT compressors and parallel compressor discharge to the gas cooler; and from the gas cooler outlet to the transcritical valve (V-01). The transcritical valve (V-01), controls the gas cooler pressure to optimize COP.

The refrigerant discharged from the MT and parallel compressors goes through an oil separator to retrieve oil that may have mixed with the refrigerant. Then it rejects heat to a water supply before entering the gas cooler or expands in V-03 as explained for the MT suction side. The discharge of the gas cooler rejects heat in an internal heat exchanger, as explained in the liquid side before expansion in the valve (V-01).

Two parallel PRVs protect the high-pressure side and are set at 120 bar. Similar to all other segments of KoolSys, the high-pressure side also encompasses an instrumentation line which includes a pressure switch. The pressure switch sets the maximum operating pressure and turns the system off if such pressure surpasses a determined value.

Oil Cycle

Parallel to the R744 cycle, KoolSys provides oil distribution for each compressor. The oil cycle has two sections: the high-pressure oil cycle (OL HP, 120 bar) and the oil cycle (OL, 90 bar).

The OL HP includes the oil separator and the oil regulating valve (V-05). The OL includes the vacuum valve, the oil deposit, and each compressor level regulator.

The oil deposit is connected to the liquid receiver by means of a pressure equalizing valve. This valve sets the oil deposit pressure 7 bar higher than the liquid receiver.

Other characteristics

A metallic structure supports the whole system. Every compressor shown in Figure 19 is the semi-hermetic type, with at least one in each stage incorporating a frequency converter. The parallel compressor is also equipped with a frequency converter.

Every part of the cycle capable of imprisoning fluid, with design temperatures below ambient, and deprived of safety valves has check valves parallel to stop valves. The check valve ensures that in the case of sectioning and subsequent increase in pressure, the fluid can flow to a safety valve.

As seen in Figure 19 KoolSys displays an electrical panel. All pressure and temperature transducers relay the signal to the incorporated controller. The electrical control certification is outside the scope of this dissertation.

The Piping and Instrumentation Diagram (P&ID) presented in Appendix A refers to the maximum capacity model with the design.

Piping

The plant piping may be of seamless copper, stainless steel, or flexible tubing. The types selected appear in section 4.2.

Section 4.2 exhibits the method for rigid piping minimum wall thickness calculation according to adequate standards. As for flexible tubing, the certificate of compliance is shown in Appendix C.

Equipment and piping attachments are mainly by permanent connections, namely brazing and welding, and a small part by threaded connections, as recommended by UL and ASHRAE. Connections are tested in accordance with the methods described in section 4.5.

The P&ID in Appendix A displays every piece of equipment of KoolSys. Appendix B shows the KoolSys components.

3.1.1 KoolSys Components

The equipment selected for KoolSys European certification falls on three groups: valves, instrumentation, and other equipment (compressors, vessels, heat-exchangers, oil separator, level detectors and regulators).

Table 4 displays the different KoolSys suppliers for each group of components.

Table 4 - KoolSys Suppliers

Equipment	Valves	Instrumentation
Bitzer	Danfoss	Danfoss
Tecnac	Castel	Alco Controls
Temprite	Refrigera	STAG
SWEP	Parker	
Teklab	GSR	
Carly	Nuova General Instruments	

The supplier for flexible tubing was Gomax. The supplier selected for copper tubing was Wieland.

Part of the UL certification depends on the use of equipment compliant with the UL requirements. Section 5.1.1 shows which suppliers manufacture UL certified products, determined after direct contact. Appendix B shows the different suppliers selected for KoolSys UL certification process, for each equipment.

3.1.2 Design Conditions

Table 5 shows the selected design pressures, minimum and maximum allowable temperatures for each KoolSys segment. The design conditions respect the normal operating conditions.

Table 5 - Maximum Allowable Working Conditions for KoolSys

KOOLSYS CO2 T_P	High-pressure side		Liquid Side (IT)	MT Suction Side (MT-ASP)	LT Suction Side (LT-ASP)
	MT Compressors Discharge (HPD)	Gas Cooler Return (HPR)			
Design Pressure (PS)	120 bar		60 bar	52 bar	30 bar
Minimum Allowable Temperature (Ts min)	0 °C	- 40 °C	- 10 °C	- 25 °C	- 25 °C
Maximum Allowable Temperature (Ts max)	130 °C	60 °C	50 °C	100 °C	80 °C

Table 6 displays the parameters for the oil cycle.

Table 6 - Maximum Allowable Working Conditions for KoolSys Oil Cycle

	High Pressure Oil Cycle (OL HP)	Oil Cycle (OL)
Design Pressure (PS)	120 bar	90 bar
Minimum Allowable Temperature (Ts min)	- 40 °C	- 10 °C
Maximum Allowable Temperature (Ts max)	125 °C	80 °C

4 Methods

This chapter is dedicated to present the methods followed in this dissertation to assess the KoolSys model conformity with the relevant American standards. It introduces the methodology for sizing the piping system wall thickness, selecting the PRVs protecting each pressure level, and assessing the PRV placement and pressure losses in the inlet and discharge piping. It ends with a presentation of the required tests and marking for the KoolSys model.

4.1 KoolSys Analysis

The KoolSys analysis, in conformity with the standards presented in section 2.6.1, consisted in the study of every KoolSys component compliance with the UL requirements and the design conditions. Section 5.1 presents the results and alternative suppliers selected.

4.2 Minimum Wall Thickness

Two materials were chosen as possible for appliance in every section of the assembly. The pressure and temperature conditions they must safely endure are those in Table 5.

According to ASME Standard B31.5, equation 4.1 and equation 4.2 give the minimum wall thickness for straight pipes under internal pressure:

$$t_m = t + c \quad (4.1)$$

Where,

t_m = Minimum required wall thickness (mm).

t = Pressure design wall thickness (mm).

c (for internal pressure) = sum of the mechanical allowances (thread depth, groove depth, and manufacturer minus tolerance) plus corrosion and erosion allowances (mm).

$$t = \frac{P \cdot D_0}{2 \cdot (S + P \cdot y)} \quad (4.2)$$

Where,

D_0 = Outside diameter of pipe (mm).

P = Internal design pressure (kPa).

S = Applicable allowable hoop stress (kPa).

y = Coefficient for materials. For austenitic steels, $y = 0.4$ and for ductile nonferrous materials, $y = 0.4$.

The standard assigns values for the maximum allowable hoop stress for different materials. When the material is not in table 502.3.1, standard B31.5, the value for the basic allowable hoop stress for unlisted materials is the lowest of the following parameters:

- 29 % of the tensile strength (R_m);
- 67 % of the yield strength ($R_{p0.2}$);
- The stress producing a creep rate of 0.01 % in 1000 hr;
- The stress producing rupture in 100 000 hr.

ASME cites ASTM International when referring to materials properties. ASTM provides standards for a multitude of materials and their properties.

4.2.1 Wieland K65

Having selected Wieland seamless K65 (CuFe2P) for piping it is necessary to understand which ASTM standard applies. However, there is currently no ASTM standard for seamless K65 (CuFe2P) tubes. A new standard that considers K65 properties and therefore allows for lower wall thickness is under development. Other standards closely applicable are ASTM B 543 for welded tubes and ASTM B 280 for seamless copper. Neither considers the advantages of the material chosen, resulting in lower pressure resistance values.

The values selected for calculating the maximum allowable hoop stress for the ASME method were the ones provided by Wieland, for K65 condition R300 (soft annealed), according to VdTUEV 567 and not C19400 condition WO61 according to ASME listing. Table 6 displays the yield and tensile strengths at elevated temperatures. The temperature chosen for the calculation is 150 °C representing the worst-case scenario. It is relevant to point out that these values are valid for hard soldered (brazed) temper.

Table 7 displays the mechanical properties of Wieland K65 at different test temperatures.

Table 7 - Wieland K65 Mechanical Properties

Type of test values	Test temperature [°C]			
	-100	20	100	150
	min.			
R_{p0,2} [MPa]	110	110	110	110
R_{p1,0} [MPa]	150	150	140	140
R_m [MPa]	300	300	270	250

After determining the maximum allowable hoop stress the next step is to determine the applicable tolerances. Although ASTM B280 does not incorporate the specific material, it does define the standard sizes for the outside diameter and allowable tolerances for seamless copper.

Section 5.2.1 shows the calculated wall thickness, allowable tolerances, and manufacturer wall thickness.

4.2.2 Stainless Steel 316

The second material chosen was an austenitic chromium-nickel stainless steel, type 316, UNS31600, with molybdenum to improve corrosion resistance. ASTM A240/A240M defines the chemical composition and mechanical properties for these types of stainless steels, including UNS31600. Table 8 shows the allowable chemical composition in % of the mass.

Table 8 - Chemical Composition (% of mass)

C	Mn	P	S	Si	Cr	Ni	Mo	N
0.08	2.00	0.045	0.030	0.75	16.0-18.0	10.0-14.0	2.00-3.00	0.10

For the maximum allowable hoop stress, B31.5 does not include the specified material. However, ASME Standard 31.3 indicates the hoop allowable stress for different operating temperatures.

For the appropriate tolerances for this material, there is the need to consult ASTM A480/A480M that attributes wall thickness and length tolerances for austenitic stainless steels with various types of heat treatments. Section 5.2.2 presents and discusses the results.

4.3 PRVs Sizing

As mentioned in section 2.5, proper sizing of a PRV is necessary to ensure system safety when working with high pressures. UL refers to the ASME Boiler and Pressure Vessel Code when sizing pressure relief devices and ASHRAE 15 when calculating the required flow capacity.

According to ASME, equation 4.3 determines the required PRV inlet area for gas flow with set pressures above 1.03 bar.

$$A = \frac{W}{CKP_1K_bK_c} \sqrt{\frac{TZ}{M}} \quad (4.3)$$

Where,

A = Minimum required discharge area (mm²)

C = Gas constant based in the ratio of specific heats of the gas at standard conditions

K = Coefficient of discharge

K_b = Back pressure correction factor

K_c = Combination factor for installations with a ruptured disc

M = Molecular Weight of the gas (kg/kmol)

P₁ = Relieving absolute pressure, bar. This is the set pressure plus overpressure plus atmospheric pressure minus the inlet pressure piping loss

T = Absolute relieving temperature of the gas (K)

W = Required relieving capacity (kg/hr)

Z = Compressibility factor

Equation 4.4 shows the required relieving capacity of a PRV protecting a pressure vessel, according to ASHRAE. This method only applies when the relieving pressure does not exceed 90 % of CO₂'s critical pressure:

$$C = fA \quad (4.4)$$

Where,

C = Minimum required relieving capacity of the relief device (kg/s)

f = Pressure relief capacity factor dependent on the type of refrigerant and vessel design pressure (kg/(m²s))

A = Area of the pressure vessel (m²)

Equation 4.5 calculates the capacity factor (f):

$$f = \frac{H}{h_{fg}} \quad (4.5)$$

Where,

H = Heat flux from an external or internal source (kW/m²)

h_{fg} = Refrigerant's latent heat of vaporization at relieving pressure (1.1 times the component design pressure)

Applying the Nelson Olbert Compressibility Chart, illustrated in Figure 19, determines the compressibility factor (Z), needing two parameters:

$$T_r = \frac{T}{T_c} \quad (4.6)$$

$$P_r = \frac{P}{P_c} \quad (4.7)$$

Where,

T_r = Reduced temperature

T = Inlet fluid temperature (K)

T_c = Critical temperature (K)

P_r = Reduced pressure

P_1 = Relieving pressure (bar)

P_c = Critical pressure (bar)

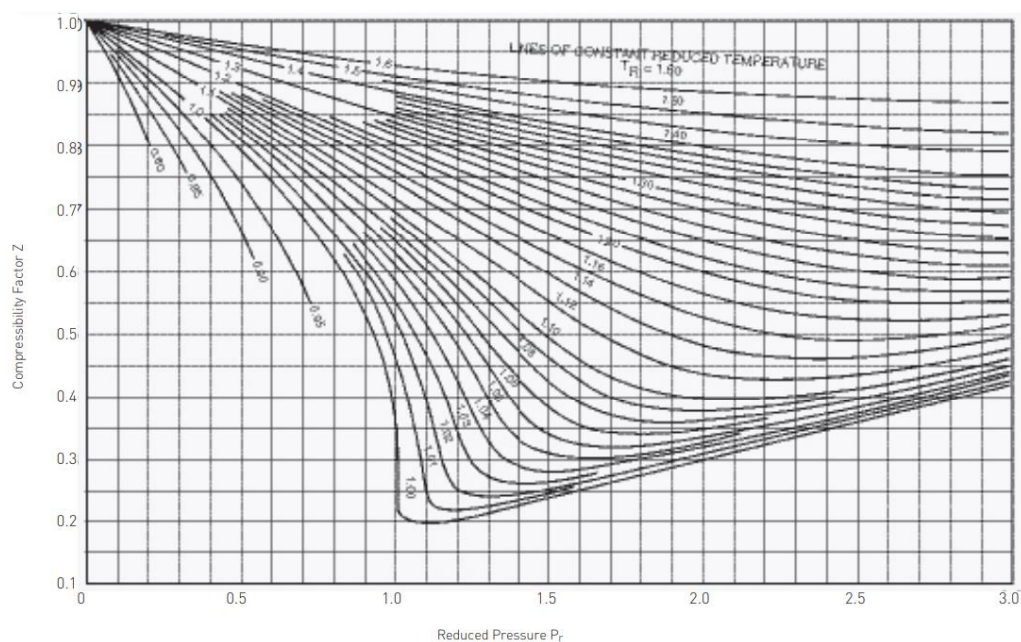


Figure 19 - Nelson Olbert Compressibility Chart

The capacity correction for back-pressure (K_b) is equal to 1 if the PRV back-pressure does not exceed 10 %. Molecular weight (M) for CO₂ is 44.01 kg/kmol. Section 5.3 shows the PRVs selection.

4.4 Inlet and Discharge Piping

As seen in section 2.5.1, the pressure loss in the inlet and discharge piping of a PRV must be determined for compliance with ASME standards and recommended practices. However, ASME does not specify guidelines to calculate those pressure losses. It instructs to use an appropriate method.

ASHRAE 15 offers a method to determine total allowable length of the PRV discharge piping. The method applies to PRVs discharging directly to the atmosphere. However, and as seen in section 5.4, all KoolSys PRVs discharge to a common header prior to discharging to the outside of the building.

Due to the lack of an American standard that defines methods for determining pressure loss in piping, the one used was EN 13136:2013: Refrigerating systems and heat pumps - Pressure relief devices and their associated piping - Methods for calculation.

According to EN 13136:2013, the pressure loss in PRV inlet piping is given by equation 4.8:

$$\Delta p_{in} = 0.0320 \left(\frac{A_c}{A_{in}} C K_{dr} K_b \right)^2 \zeta p_0 [bar] \quad (4.8)$$

Where,

A_c = Minimum required discharge area (mm²)

A_{in} = Inlet area (mm²)

C = Gas constant based in the ratio of specific heats of the gas at standard conditions

K_{dr} = De-rated coefficient of discharge of PRV

K_b = Theoretical capacity correction factor for sub-critical flow

p_0 = Actual relieving pressure (bar)

Δp_{in} = Pressure loss in the upstream line of pressure relief valve (bar)

ζ = Pressure loss coefficient

Equation 4.9 calculates the pressure loss in discharge piping:

$$p_1 = \sqrt{0.064\zeta \left(\frac{A_c}{A_{out}} C K_{dr} K_b p_0 \right)^2 + p_2^2} \quad (4.9)$$

Where,

p_2 = Absolute pressure at the outlet of downstream line (bar)

A_{out} = Inside area of outside tube (mm²)

For each PRV, its placement, inlet piping, and discharge line need defining. Three elements in the design of KoolSys cause pressure loss in the inlet and discharge piping: straight tubes, three-way valves, and pipe bends.

Equation 4.10 calculates the pressure loss coefficient of a straight pipe:

$$\zeta = \lambda \frac{L}{D} \quad (4.10)$$

Equation 4.11 calculates the pressure loss coefficient of the three-way valve:

$$\zeta = 2.592 \left(\frac{A_R}{K_{VS}} \right)^2 10^{-3} \quad (4.11)$$

Standard EN 13136:2013 attributes a pressure loss coefficient for pipe bends with different characteristics. KoolSys presents pipe bends according to Figure 20.

- Pipe bend:
 - Assuming $R = 2D_R$ the pressure loss coefficient, $\zeta = 0.3$.

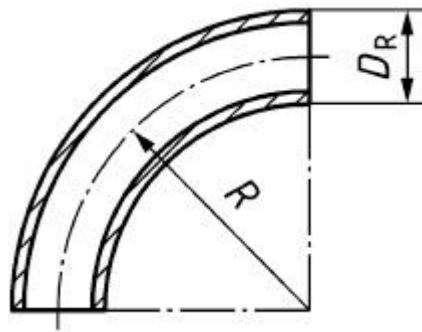


Figure 20 - Pipe bend illustration [40]

To apply equation 4.8, ζ is the total pressure loss coefficient in the inlet path of the PRV.

The tube connecting the PRV to the common discharge header, and the tube connecting the common header to the outside of the building, determine the total pressure loss coefficient.

Equation 4.9 determines the pressure loss, where ζ is the sum of the pressure loss coefficients of the tube and pipe bends.

The path from the discharge header to outside the facility is the responsibility of the installation company. However, for calculation purposes, the values attributed are shown in section 5.4.

For all PRVs, the method is consistent with the one presented in this section. Section 5.4 displays the sizing of the inlet and discharge piping of PRVs and determines total pressure losses according to EN 13136:2013.

4.5 Required Tests

ASHRAE, ASME and UL standards require testing of the system before installation.

ASHRAE 15 requires a pressure test at design pressure for each section of the system. The plant shall show no leakage or burst under these conditions. The system chosen to build-up pressure needs to have a pressure limiting device to prevent permanent damage to the refrigeration plant and a pressure gage. The fluid used is dry nitrogen. [33]

For KoolSys piping, ASME B31.5 requires visual examination of all piping joints, brazed and welded to determine if applicable requirements are met.

ASME B31.5 also requires a pressure test to the piping system between 110 % and 130 % of the design pressure. After the pressure test, the piping system undergoes a leak test specified in ASME BPVC Section V. The required test is a gas and bubble formation test. Due to KoolSys' size, immersing the system is inadequate. A similar test proposed by ASME is the liquid penetrant examination. [41]

Prior to the test, the surface shall be cleaned and dried. The penetrant liquid is applied by brushing and allowed to sit for 10 minutes before removing the excess remaining in the surface. A dye developer is applied to suck the liquid to the surface to enhance visibility. Figure 21 illustrates a generic liquid penetrant examination.

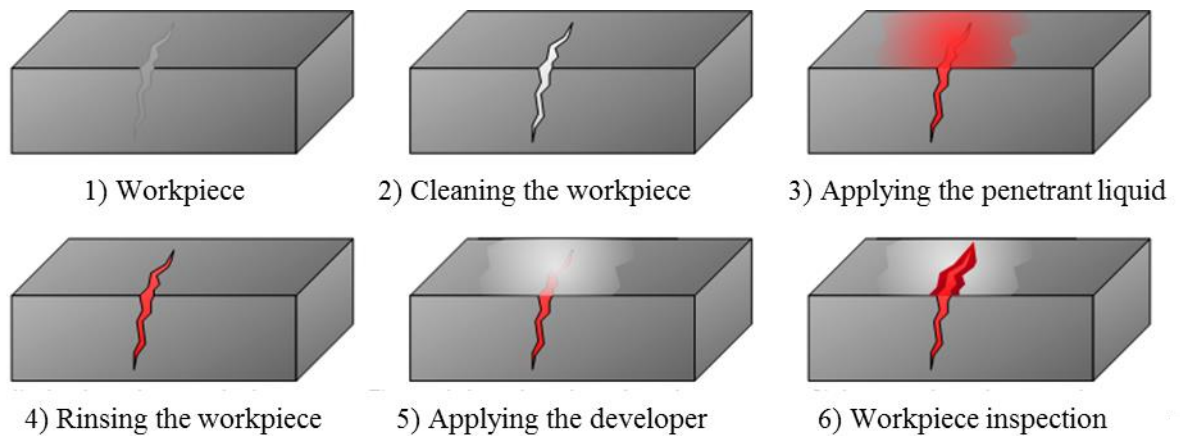


Figure 21 - Liquid penetrant examination [42]

After applying the developer and letting it actuate for more than 10 min the surface is examined. If a color contrasting penetrant is used, it will form a white coating in the surface with the discontinuities usually a deep red.

UL requires a heating test for the system. The KoolSys system is positioned in a test enclosure surrounded by walls and ceiling. The enclosure is painted dull black plywood, 20 mm thick. The system is charged at a voltage between 0,94 and 1,06 times the rated voltage. [43]

The temperature is continuously measured throughout the test and must not surpass the values established in UL 60335-2-89 for every equipment.

The behavior of the system under abnormal operation tests according to UL 60335-2-89 include the following:

- Operation with an empty container;
- Disconnection and reconnection of one or more phases of the supply during any part of the cycle;
- Open-circuiting or short-circuiting of components;
- Loss of heat-transfer medium flow (condenser fan failure, evaporator fan failure, cooling water failure).

The system operates at rated voltage, and all expected system failures are carried out consecutively. Temperatures and pressures are monitored to ensure that the system does not cause any mechanical or electrical hazards.

4.6 Marking and Instructions

Visible warnings on the system must respect the applicable standards. For R744 transcritical systems UL and ASHRAE demand some markings and instructions to inform possible users of the system characteristics.

KoolSys shall display the following visual warning: *“WARNING: The system contains refrigerant under high pressure. Do not tamper with the system. It must be serviced by suitably qualified persons only.”*. [43]

The system shall display the symbol ISO 7000-1701 (2004-01). Figure 22 shows the required symbol indicating that the system works with high pressures.

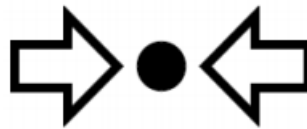


Figure 22 - ISO 7000-1701 (2004-01) Symbol [43]

The refrigerant tubing shall be painted or colored red in sections where the system charging is possible. Piping shall be marked with the flow content and flow direction.

According to ASHRAE 15 the complete system shall display a permanent sign indicating the name and address of the installer, the type and amount of refrigerant, the type and amount of lubricant, and the field test pressure.

Each compressor shall exhibit the name of the manufacturer, design pressure and refrigerant used. [33]

The system shall be provided with indications of the possible valves and controls capable of controlling the refrigerant flow and the system capacity. [33]

All PRVs and the liquid receiver shall show the corresponding ASME marking. Figure 23 displays the ASME marking for PRVs under the scope of ASME BPVC Section VIII. Figure 24 illustrates a form for marking pressure vessels under the scope of ASME BPVC Section VIII.



Figure 23 - ASME marking for PRVs [36]

 U or UM	Certified by _____ (Name of Manufacturer)
	(Pressure) ____ at (temperature) ____ Max. allowable working pressure (internal)
W (if arc or gas welded) RT (if radiographed) HT (if postweld heat treated)	(Pressure) ____ at (temperature) ____ Max. allowable working pressure (external) [if specified, see Note (1)]
	(Temperature) ____ at (pressure) ____ Min. design metal temperature
	_____ Manufacturer's serial number
	_____ Year built

Figure 24 - ASME marking for a pressure vessel Section VIII [36]

5 Results and Discussion

This chapter starts with an analysis of KoolSys system according to the different standards requirements. It also presents the results according to the methods described in chapter 4 for the piping minimum wall thickness, the sizing and PRV selection, and determining the inlet and discharge piping. It also discusses the results considering the relevant standards.

5.1 KoolSys Analysis

After analysing the appropriate standards, KoolSys system respects the majority of the ASHRAE, ASME and UL requirements.

As required by ASHRAE 15, at the compressor suction and discharge, there is a stop valve. KoolSys compressors are the positive displacement type and have a pressure switch set at 90 % of the high-side PRV.

As seen in Appendix A, KoolSys design presents high-pressure side and liquid receiver PRVs as required by UL and ASME, respectively. For the MT and LT suction sides the parallel PRVs are a RACE decision to protect the system against liquid expansion. In case of a PRV malfunction, the second PRV can relieve the necessary refrigerant. The sizing of these safety valves is presented in section 4.4 and represents the highest capacity model possible with the design.

UL 60335-2-89 requires that the PRV protecting the high-pressure side shall not have any component that induces a pressure loss from the discharge of the MT compressors to the PRV inlet. The oil separator induces a pressure loss prior to the high-pressure side PRV. However, the MT compressors are already equipped with an internal PRV that protects the discharge side. The high-pressure PRV protects the line after the oil separator.

As required by ASHRAE 15, at every outlet of the receiver, there is a stop valve.

5.1.1 Equipment Compliance

After contacting the different suppliers, as mentioned in section 4.1.1, the suppliers that possess UL certification are: Danfoss, Bitzer, SWEP, Temprite, Nuova General Instruments, Alfa Laval, Castel and Refrigerera. Gomax presents the necessary UL certificate for pressures up to 120 bar and Wieland for seamless copper tubing up to 130 bar.

Tecnac does not possess ASME certified products for the liquid and oil receivers, so it is necessary to find alternative suppliers with the necessary certification. For the liquid receiver, the alternative selected manufacturer was Delta Tee and Marefsup. They both possess ASME certification for all vessels that fall in the scope of ASME VIII Div 1. For the oil deposit the selected brand was Temprite, model RES17.

For the oil filters, MT and LT suction line filters, and liquid line filters Carly does not possess UL certification. The alternative suppliers include Danfoss model DMT for the oil filter, Temprite 48-2 for the liquid line filter and STAS 489T for the LT suction line filter. For the MT suction line filter the UL listed products are limited in maximum allowable pressure, under the design pressure of 52 bar. The alternative component selected was a strainer by Carel, model 4727E/9.

For the oil level regulators, Emerson does not possess UL certification. The alternative supplier selected was Kriwan model INT 280.

For the necessary level detectors, Teklab does not have the necessary UL certification. The alternative selected supplier was Henry Group, model S9420.

For the gas injection solenoid valve and oil equalizer valve, Castel does not have UL certified products. The alternative supplier selected for the gas injection valve was Carel, model E2V. For the oil equalizer valve, UL listed equipment could not be found. The choice fell on a check valve that keeps the oil receiver at a pressure constantly lower than the liquid receiver. The check valve selected was model NRV 10 from Danfoss.

For all service valves, Refrigerera and Castel supply UL listed components.

For the pressure gages STAG does not sell UL listed components. The alternative brand selected was WIKA, model 116.15.

Every certificate of compliance and catalog demonstrating that the product possesses UL certification appears in Appendix C.

5.1.2 Design Pressure

ASHRAE 15 and CSA B52 require establishing design pressures for transcritical CO₂ systems according to different criteria. For the high-pressure side, the design pressure is 110 % of the maximum pressure at the MT compressors outlet. [33, 44]

BITZER manufactures the selected compressors for KoolSys. Figure 25 displays the limits according to BITZER software for the selected compressor.

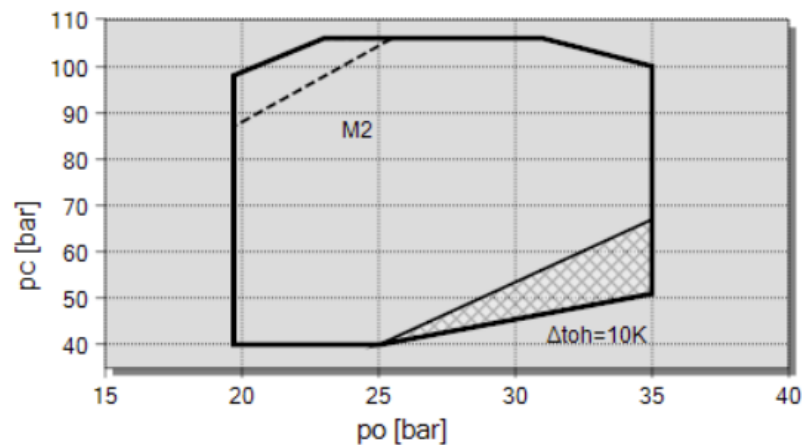


Figure 25 - BITZER 4FTE-20K working limits

The compressor 4FTE-20K (referenced as E-06) limits the pressure on the high-side and sets the pressure switch at 107 bar. The design pressure of 120 bar respects the ASHRAE requirement.

For the intermediate stages (liquid side and MT suction side) ASHRAE 15 and CSA B52 impose design pressures of 120 % of maximum operating pressures. The same parameter applies for the low-pressure side. [33, 44]

After simulation on BITZER software for the KoolSys system show maximum operating pressures of 16.8 bar for the LT compressors suction side, 28.0 bar for the MT compressors suction side and 38 bar for the liquid side. The selected design pressures follow ASHRAE and CSA B52 recommendations for each section.

5.2 Minimum Wall Thickness

This section shows the results of the method introduced in chapter 4.2 for piping minimum wall thickness.

5.2.1 Wieland K65

As mentioned in section 4.2, and since ASME B31.5 does not include the selected material, the values for 29 % of the tensile strength and 67 % of the yield strength at 150 °C are:

$$S = 0.67 * 110 = 73.7 \text{ MPa} \quad (5.1)$$

$$S = 0.29 * 260 = 75.4 \text{ MPa} \quad (5.2)$$

Table 9 shows the values for standard sizes, outside diameter, wall thickness calculated using equation 4.2 with the appropriate tolerance.

Table 9 - Minimum Wall thickness for Wieland K65 piping

Standard Size (in)	Outside Diameter (mm)	Design Pressure (MPa)	Wall Thickness Tolerance (mm)	t (mm)	Minimum wall thickness (mm)	Manufacturer wall thickness (mm)
3/8	9.52	12	0.08	0.728	0.808	0,66
1/2	12.7	12	0.09	0.971	1.06	0,85
5/8	15.9	12	0.1	1.22	1.32	1,05
3/4	19.1	12	0.11	1.46	1.57	1,3
7/8	22.3	12	0.11	1.70	1.81	1,5
1 1/8	28.6	12	0.13	2.19	2.36	1,9
1 3/8	34.9	12	0.14	2.67	2.81	2,3
1 5/8	41.3	12	0.15	3.16	3.31	2,7
2 1/8	54	12	0.18	4.13	4.31	3,55

The manufacturer's wall thickness is lower than the minimum wall thickness calculated according to ASME 31.5. The difference would usually indicate that Wieland products should have higher wall thickness to conform with ASME Standards and thus be safe for use under the conditions applicable to KoolSys. However, the method for determining the maximum allowable hoop stress for nonferrous materials, recommended by ASME, leads to over-dimensioned piping. Wieland has its products tested under UL 207, specifically, performance test (three times the design pressure) and fatigue test. Thus, the manufacturer wall thickness is appropriate for use in KoolSys.

5.2.2 Stainless Steel 316

According to ASME B31.3, for the worst-case scenario, 150 °C, and after interpolating and converting ksi to MPa:

$$S = 137.8 \text{ MPa}$$

Table 10 displays the values for minimum wall thickness calculated according to equation 4.2 along with standard size, outside diameter and allowed tolerances.

Table 10 - Minimum Wall thickness of Stainless Steel 316 piping

Standard Size (in)	Outside Diameter (mm)	Design Pressure (MPa)	Wall Thickness Tolerance (mm)	t (mm)	Minimum wall thickness (mm)	UL Minimum wall thickness (mm)
¼	13.72	12	0.06	0.577	0.637	0.62
3/8	17.15	12	0.06	0.722	0.782	0.62
½	21.34	12	0.06	0.898	0.958	0.62
¾	26.67	12	0.08	1.12	1.20	0.80
1	33.4	12	0.08	1.41	1.49	1.17
1 ¼	42.16	12	0.08	1.77	1.85	1.28
1 ½	48.26	12	0.1	2.03	2.13	1.41

Minimum wall thickness calculated according to ASME B31.5 is greater than the values attributed by UL 207. The difference is due to the method proposed by ASME leading to over-dimensioned piping. The minimum wall thickness respected is the last column of Table 10 for KoolSys piping unless UL 207 tests for performance and fatigue are performed.

5.3 PRV Selection

This section displays the results of the PRVs protecting each part of KoolSys sizing and selection. The selected supplier for the PRVs was Nuova General. The brand possesses ASME certification and the necessary marking.

5.3.1 PRV Protecting the LT compressors Suction Side (30bar)

The required relieving capacity of the PRV is the maximum flow on the LT compressors suction line, 618 kg/h.

The selected valve was:

- Model D7/CS;
- Coefficient of discharge, $K = 0.629$;
- Bore 7 mm;
- Area, $A = 38.48 \text{ mm}^2$.

The following values shown in Table 11, attributed according to ASME recommendations, define the necessary parameters:

Table 11 - PRV 30 bar sizing parameters

T_R	P_R	Z	K_C	$T [K]$	C	$P [\text{bar}]$	K
0.891	0.449	0.75	1	271	2.63	33.1	0.629

The minimum required area of discharge is calculated by applying equation 4.3 and is 24.3 mm^2 . The selected valve has a higher discharge area than the minimum required by the ASME method. The protection of the system is assured.

5.3.2 PRV Protecting the MT compressors Suction Side (52bar)

For the minimum required relieving capacity of the PRV, the maximum flow on the respective line being protected is 2765 kg/h.

The selected valve was:

- Model E10/LS;
- Coefficient of discharge, $K = 0.629$;
- Bore 10 mm;
- Area, $A = 78.54 \text{ mm}^2$.

The values displayed in Table 12 were either calculated or attributed according to ASME.

Table 12 - PRV 52 bar sizing parameters

T_R	P_R	Z	K_C	T [K]	C	P [bar]	K
0.961	0.768	0.64	1	292	2.63	56.6	0.629

The minimum required discharge area is 60.9 mm². The selected valve discharge area is greater than the minimum required.

5.3.3 PRV Protecting the Liquid Receiver (60bar)

As stated in section 4.3, the minimum required relieving capacity, determined according to ASHRAE 15, requires a heat flux value (H). ASHRAE attributes a value of no less than 25.1 kW/m². For the area of the liquid receiver, the characteristics of the selected vessel are:

- Diameter, $d = 406$ mm;
- Length, $L = 1.65$ m;
- Volume, $V = 180$ L.

$$A = 0.406 * 1.65 = 0.668 \text{ m}^2 \quad (5.3)$$

Relieving pressure is 65.2 bar, less than 90 % of CO₂ critical pressure 66.4 bar. The latent heat of vaporization at relieving pressure is 115 kJ/kg.

The capacity factor is then 0.247 kg/(m²s) and the minimum required relieving capacity 594 kg/h.

The selected valve has the following characteristics:

- Model E10/LS;
- Coefficient of discharge, $K = 0.629$;
- Bore 10 mm;
- Area, $A = 78.54$ mm².

For equation 4.3, the parameters shown in Table 13 apply:

Table 13 - PRV 60 bar sizing parameters

T_R	P_R	Z	K_C	T [K]	C	P [bar]	K
1.06	0.989	0.55	1	295	2.63	65.2	0.629

The minimum required discharge area is 10.6 mm². The selected valve has a higher discharge area than the one required making the PRV appropriate to protect the liquid receiver in case of overpressure scenarios.

5.3.4 PRV Protecting the High side (120bar)

To determine the minimum required relieving rate of the PRV, for this section of KoolSys, a determination of the maximum flow through the MT compressors and parallel compressors was necessary. The flow is 2765 kg/h and 2166 kg/h, respectively. Total flow is 4931 kg/h.

The selected valve has the following characteristics:

- Model E10/LS 150;
- Coefficient of discharge, $K = 0.629$;
- Bore 10 mm;
- Area, $A = 78.54 \text{ mm}^2$.

For the PRV set at 120 bar, the relieving temperature is unknown. The maximum allowable temperature considered was the worst-case scenario of 130 °C.

To apply equation 4.3, the parameters displayed in Table 14 apply:

Table 14 - PRV 120 bar sizing parameters

T_R	P_R	Z	K_C	$T \text{ [K]}$	C	$P \text{ [bar]}$	K
1.33	1.75	0.75	1	403	2.63	129.4	0.629

The minimum required discharge area is 60.5 mm². The selected valve has enough discharge area to protect the high side of KoolSys.

5.4 PRV Inlet and Discharge Piping

As stated in section 4.4, the method selected to determine pressure losses in the inlet piping and discharge piping of each PRV follows EN 13136:2013 directives. The three-way valves selected for the connection of the two parallel PRVs and shown in this chapter are model DB1012N0000 from Refrigerera.

5.4.1 PRV (30 bar)

Figure 26 portrays the PRV positioning in the low-temperature section of KoolSys, its inlet piping, and discharge piping.

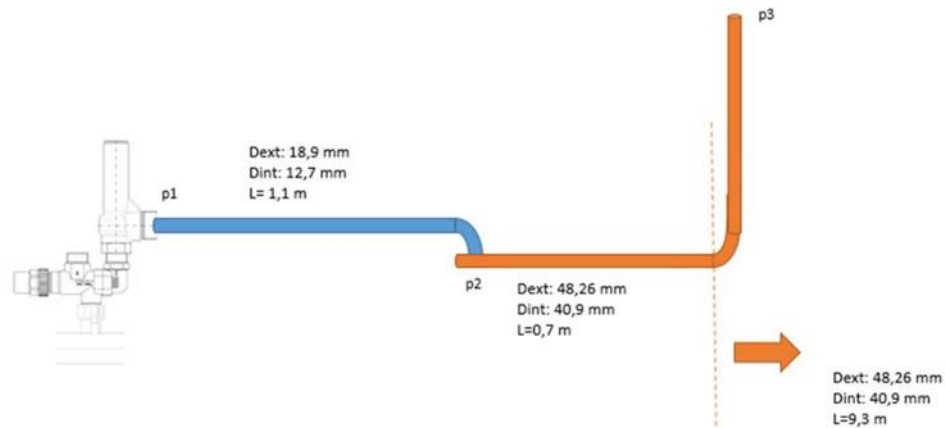


Figure 26 - PRV (30 bar) discharge piping and placement

Inlet Piping

As seen in Figure 26 the inlet piping of the PRV comprises the following:

- Connection to piping through very sharp-edged flush connection, $\zeta = 0.5$
- Tube:
 - Length, $L = 50 \text{ mm}$;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 14.5 \text{ mm}$.

$$\zeta = 0.069$$

- Three-way Valve:
 - Valve constant (the rate of water flow for a differential pressure Δp of 1 bar at the rated full opening), $K_{vs} = 5.7$;
 - Inside diameter, $d_R = 18 \text{ mm}$;
 - Inside area, $A_R = 254.47 \text{ mm}^2$.

$$\zeta = 5.17$$

Total pressure loss coefficient is 11.88. Pressure loss according to equation 4.8 is:

$$\frac{\Delta p_{in}}{p_0} = 0.0109 < 0.03 \quad (5.4)$$

Discharge Piping

The path connecting the PRV to the discharge header encompasses the following:

- Tube:
 - Length, $L = 1100$ mm;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 12.7$ mm.

$$\zeta = 1.73$$

- Pipe Bend:
 - $R = 2D_R$.

$$\zeta = 0.3$$

Equation 4.9 determines the pressure loss using the total pressure loss coefficient, $\zeta=2.03$:

$$p_1^2 - p_2^2 = 13.3 \text{ bar} \quad (5.5)$$

The line connecting the discharge header to the outside of the building includes:

- Tube:
 - Length, $L = 10000$ mm;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 40.9$ mm.

$$\zeta = 4.89$$

Pressure loss according to equation 4.9:

$$p_2^2 - p_3^2 = 0.297 \text{ bar} \quad (5.6)$$

$$p_1 = 3.82 \text{ bar} \quad (5.7)$$

$$\frac{\Delta p_{out}}{p_0} = \frac{2.81}{33.4} = 0.0849 < 0.10 \quad (5.8)$$

Pressure losses in the inlet piping are below the 3 % recommendation from ASME. In discharge, piping pressure losses are below 10 %.

Also, as recommended by ASHRAE 15 and ASME, the discharge piping area is higher than the PRV inlet area.

5.4.2 PRV (52 bar)

Figure 27 symbolizes the PRV placement on the medium temperature section and its inlet and discharge piping.



Figure 27 - PRV (52 bar) discharge piping and placement

Inlet Piping

For the line connecting the PRV to the protected section of KoolSys the following components were considered: connection to the pipe, the tube, the pipe bend and the three-way valve.

The connection is a very sharp-edged flush connection with a pressure loss coefficient of 0.5.

- Tube:
 - Length, $L = 250$ mm;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 22$ mm.
- Pipe Bend:
 - $R = 2D_R$
- Three-Way Valve:
 - Valve constant (the rate of water flow for a differential pressure Δp of 1 bar at the rated full opening), $K_{VS} = 5.7$;
 - Inside diameter, $d_R = 18$ mm;
 - Inside area, $A_R = 254.47$ mm².

The pressure loss coefficients are 0.227, 0.3 and 5.17, respectively. The total is 5.99.

The pressure loss according to equation 4.8 is:

$$\frac{\Delta p_{in}}{p_0} = 0.0135 < 0.03 \quad (5.9)$$

Discharge Piping

For the line connecting the PRV to the discharge header:

- Tube:
 - Length, $L = 2000$ mm;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 25.4$ mm.
- Pipe Bend:
 - $R = 2D_R$.

The total pressure loss coefficient is the sum of 1.58 and 0.3, pressure loss coefficient of the tube and pipe bend, respectively. Pressure loss according to equation 4.9 is:

$$p_1^2 - p_2^2 = 12.5 \text{ bar} \quad (5.10)$$

Piping connecting the discharge header to outside the building presents the following characteristics:

- Length, $L = 10000$ mm;
- Tube friction loss coefficient, $\lambda = 0.02$;
- Diameter, $d = 40.9$ mm.

$$\zeta = 4.89$$

Equation 4.9 determines the pressure loss:

$$p_2^2 - p_3^2 = 4.85 \text{ bar} \quad (5.11)$$

$$p_1 = 4.29 \text{ bar} \quad (5.12)$$

$$\frac{\Delta p_{out}}{p_0} = \frac{3.28}{56.64} = 0.0579 < 0.1 \quad (5.13)$$

The pressure loss in the inlet piping (equation 5.10) and discharge piping (equation 5.13) is lower than the 3 % and 10 %, respectively, ASME and ASHRAE recommendation.

The discharge area is higher than the PRV inlet area respecting the appropriate standards.

5.4.3 PRV (60 bar)

Figure 28 shows the PRV placement, and Figure 29 illustrates the discharge piping of the PRV protecting the liquid receiver.

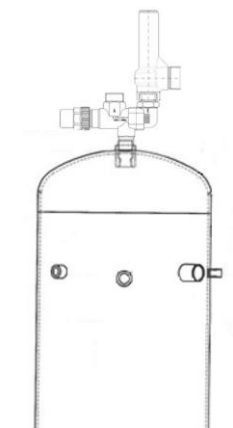


Figure 28 – Placement of the PRV protecting the liquid receiver

Inlet Piping

The pressure loss coefficients of the liquid receiver exit, the tube connecting to the three-way valve, and the valve itself determine the PRV inlet piping total pressure loss coefficient.

For the liquid receiver exit, EN 12136:2013 attributes values for different pipe elements. For an inserted connection with a broken edge pressure loss coefficient is:

$$\zeta = 0.56$$

For the tube, the dimensions are as follow:

- Length = 21 mm;
- Friction loss coefficient of tube, $\lambda = 0.02$;
- Diameter = 18 mm.

After selecting the corresponding three-way valve, the characteristics supplied by the manufacturer are as follows:

- Valve constant (the rate of water flow for a differential pressure Δp of 1 bar at the rated full opening), $K_{vs} = 5.7$;
- Inside diameter, $d_R = 18$ mm;
- Inside area, $A_R = 254.47$ mm².

Total pressure loss coefficient is 5.17.

Pressure loss according to equation 4.8:

$$\frac{\Delta p_{in}}{p_0} = 0.001 < 0.03 \quad (5.14)$$

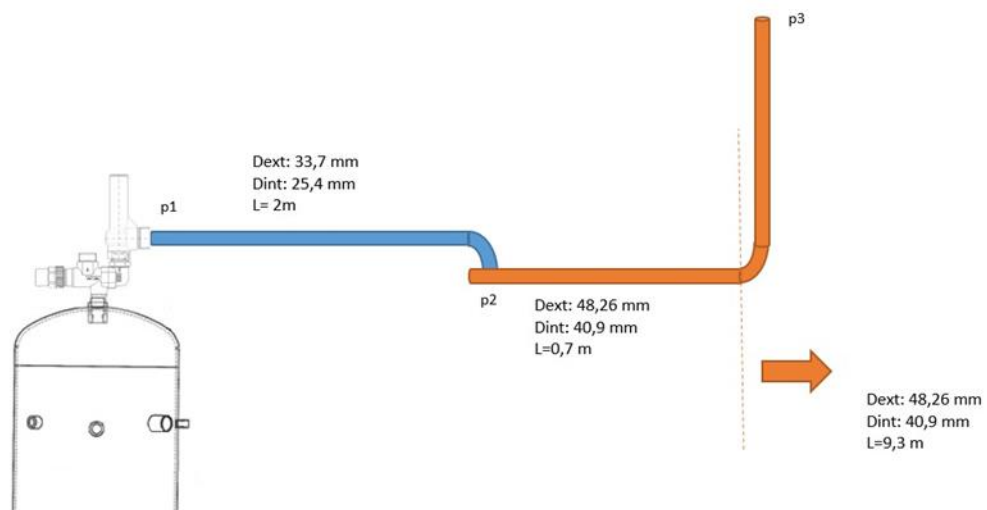


Figure 29 - PRV (60 bar) discharge piping

Discharge Piping

For the path from the PRV to the discharge header, the relevant elements and their respective characteristics are:

- Tube:
 - Length, $L = 2000$ mm;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 25.4$ mm.
- Pipe bend:
 - Assuming $R = 2 D_R$ the pressure loss coefficient, $\zeta = 0.3$.

Pressure loss coefficient from the PRV outlet to the discharge header is 1.875.

Thus, the pressure loss according to equation 4.9:

$$p_1^2 - p_2^2 = 0.85 \text{ bar} \quad (5.15)$$

The characteristics necessary to determine the pressure loss coefficient from the discharge header to the atmosphere are:

- Tube:
 - Length, $L = 10$ m;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 40.9$ mm.

The total pressure loss coefficient is 4.89.

The pressure loss, calculated with equation 4.9:

$$p_2^2 - p_3^2 = 0.33 \text{ bar} \quad (5.16)$$

To determine total discharge piping pressure loss and knowing p_3 is atmospheric pressure, 1 bar, p_1 is 1.48 bar and the pressure loss 0.48 bar.

$$\frac{\Delta p_{out}}{p_0} = \frac{0.48}{65.2} = 0.00736 < 0.10 \quad (5.17)$$

The pressure loss in the inlet and discharge piping is less than the ASME and ASHRAE recommendation of 3 % and 10 %, respectively. The selected path is in conformity with the requirements.

For the PRV protecting the liquid receiver, the discharge pipe area is higher than the PRV inlet area, in conformity with ASHRAE and ASME recommendations.

5.4.4 PRV (120 bar)

Figure 30 illustrates the PRV placement in the high-pressure section and displays the discharge piping of the PRV.

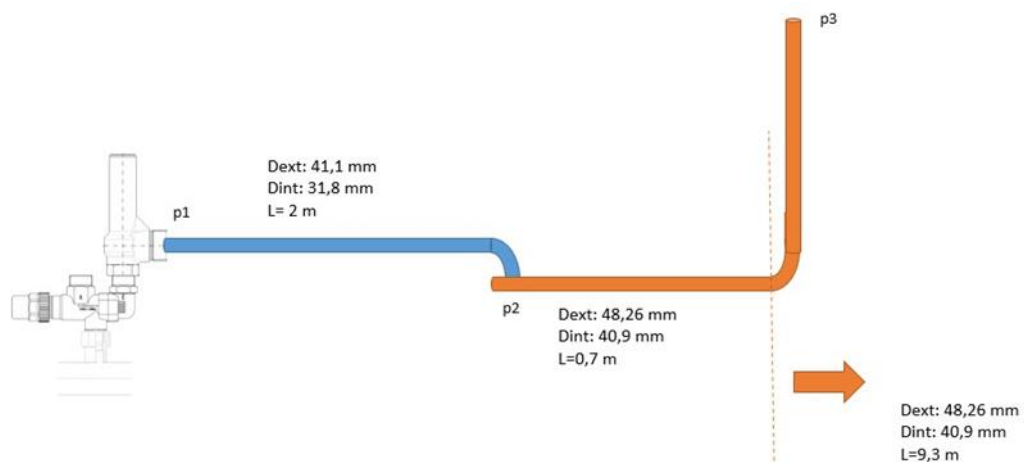


Figure 30 - PRV (120 bar) discharge piping and placement

Inlet Piping

For pressure loss coefficient calculation, the considered parts are the PRV connection to the pipe, the tube and the three-way valve.

The connection is a very sharpened edge flush connection with pressure loss coefficient of 0.5 according to EN 13136:2013.

The tube has the following characteristics:

- Length, $L = 60 \text{ mm}$;
- Tube friction loss coefficient, $\lambda = 0.02$;
- Diameter, $d = 22 \text{ mm}$.

The pressure loss coefficient according to equation 4.10 is 0.055.

Ultimately, the manufacturer divulges the following parameters for three-way valve:

- Valve constant (the rate of water flow for a differential pressure Δp of 1 bar at the rated full opening), $K_{vs} = 5.7$;
- Inside diameter, $d_R = 18$ mm;
- Inside area, $A_R = 254.47$ mm².

According to equation 4.11 the pressure loss coefficient is 5.17.

The pressure loss in the inlet piping according to equation 4.8 is:

$$\frac{\Delta p_{in}}{p_0} = 0.0133 < 0.03 \quad (5.18)$$

Discharge Piping

For the path connecting the PRV outlet to the discharge header, the components considered were:

- Tube:
 - Length, $L = 2000$ mm;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 31.8$ mm.
- Pipe Bend:
 - $R = 2D_R$

The total coefficient of pressure loss is the sum of the tube and pipe bend coefficients, 0.0013 and 0.3, respectively, and is 0.3013.

Pressure loss according to equation 4.9:

$$p_1^2 - p_2^2 = 4.64 \text{ bar} \quad (5.19)$$

For the line connecting the discharge header to outside the building:

- Tube:
 - Length, $L = 10000$ mm;
 - Tube friction loss coefficient, $\lambda = 0.02$;
 - Diameter, $d = 40.9$ mm.

The pressure loss applying equation 4.9:

$$p_2^2 - p_3^2 = 27.51 \text{ bar} \quad (5.20)$$

$$p_1 = 5.76 \text{ bar} \quad (5.21)$$

$$\frac{\Delta p_{out}}{p_0} = \frac{4.76}{129.4} = 0.0368 < 0.10 \quad (5.22)$$

As seen in equation 5.18 and equation 5.22 the pressure loss in the inlet and discharge piping is less than the 3 % and 10 % recommendation, respectively.

The discharge piping area is higher than the PRV inlet area as recommended by ASHRAE and ASME.

6 Conclusion and Future Work

Refrigeration systems operating with CO₂ have a lower climate impact than conventional cycles due to low GWP and ODP. The higher volumetric refrigeration capacity of CO₂ leads to smaller compressors and suction lines. However, for application in warmer climates the system needs to work above the critical point which entails higher pressures and higher compression ratios, which reduce efficiency.

The KoolSys CO₂ transcritical booster model developed by RACE presents some design changes that make the system competitive with other solutions for all climates. The design focuses and presents solutions regarding the safety of systems operating with CO₂, namely high pressures.

For the American industry, the leading organizations entrusted with the development of standards applicable to refrigeration systems are ASHRAE, CSA, ASME and UL. The KoolSys design respects most of the requirements set by the appropriate standards.

To protect against overpressure scenarios the system includes parallel PRVs in each of the four pressure levels. The PRVs are set for the design pressure of the line being protected.

Every compressor displays stop valves at the inlet and discharge, and a pressure switch operating at 90 % of the PRV set pressure, as required by ASHRAE. The liquid receiver possesses stop valves at every connection and a PRV above the liquid line, as required by ASME.

The equipment selected for KoolSys complies with the UL requirements. Alternative brands for the liquid receiver with ASME certification was Delta Tee. For the LT suction line filters the supplier was Stas and for the oil filter Temprite. For the MT suction line, a strainer from Castel was selected. For the oil level regulators, the supplier was Kriwan and for the level detectors Henry. All the KoolSys's valves suppliers are Carel, Danfoss, Refrigerera, Castel and GSR. For the pressure gages the brand selected was Wika, model 116.15.

The design pressures selected for each part follow the criteria set by ASHRAE and CSA.

For the KoolSys piping, minimum wall thickness respects the UL 207 requirements and the certificates of compliance for seamless copper and flexible tubing are shown in Appendix C. For stainless steel, any product selected will respect the values required by UL207.

The PRVs are properly sized for the KoolSys model maximum capacity and present the necessary ASME certification and marking.

As seen for each PRV, pressure losses in the inlet piping are below the 3 % recommendation from ASME. In discharge, piping pressure losses are below 10 %. Also, as recommended by ASHRAE and ASME, the discharge piping area is higher than the PRV inlet area.

For future work and to finalize the UL certification process, the KoolSys model must undergo the required pressure tests and leak tests presented in this dissertation. The electrical controls must be certified by UL to ensure mechanical and electrical safety of the system.

References

1. Emerson. *Commercial CO2 Refrigeration Systems: Guide for Subcritical and Transcritical CO2 Applications*. 2014; Available from: https://www.r744.com/files/675_commercial_co2_guide.pdf.
2. Afonso, C., *Sistemas Frigoríficos*. 2019.ISBN: 9789895435012.
3. Chandra, A.R., *Refrigeration and Air Conditioning*. 2012.ISBN: 9788120339156.
4. DUPONT J. L., D.P., LEBRUN P., ZIEGLER F., *38th Note on Refrigeration Technologies: The Role of Refrigeration in the Global Economy*. 2019.
5. IIF-IIR, M.V., COULOMB D., DUPONT J. L., *The impact of the refrigeration sector on climate change, 35th Informatory Note on refrigeration technologies*. 2017.
6. BITZER, *Refrigerant Report 21*. 2020.
7. Ciconkov, R., *Refrigerants: There is still no vision for sustainable solutions*. 2018.
8. IIF-IIR, C.D., DUPONT J. L., PICHARD A., *The Role of Refrigeration in the Global Economy, 29th Informatory Note on refrigeration technologies*. 2015.
9. Change, U.N.C. *What is the Kyoto Protocol*. 2021; Available from: https://unfccc.int/kyoto_protocol.
10. Change, U.N.C. *The Paris Agreement*. 2021; Available from: <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>.
11. Union, E. *Fluorinated greenhouse gases*. 2021; Available from: https://ec.europa.eu/clima/policies/f-gas_en.
12. Garry, M. *U.S. Enacts HFC Phase-Down Law as Part of COVID Relief Bill*. 2021.
13. Spletzer, S. *Tips for Surviving Refrigerant Transitions, Part 1*. 2016; Available from: <https://www.achrnews.com/articles/131667-tips-for-surviving-refrigerant-transitions-part-->.
14. Faye C. McQuiston, J.D.P., Jeffrey D. Spitler, *Heating, Ventilating, and Air Conditioning: Analysis and Design*. 2005.ISBN: 9780471470151.
15. RACE. 2020; Available from: <https://race.com.pt/pt/a-race>.
16. UL. *About UL*. 2020; Available from: <https://www.ul.com/about>.
17. American Society of Heating, R.a.A.-C.E., *Designation and Safety Classification of Refrigerants*, in *Standard 34*. 2019.
18. Danfoss, *Gas detection in refrigeration systems*. 2018.
19. Kim, M.-H., J. Pettersen, and C.W. Bullard, *Fundamental process and system design issues in CO2 vapor compression systems*. *Progress in Energy and Combustion Science*, 2004. **30**(2): p. 119-174.
20. B., P.A., *CO₂ as a Refrigerant*. 2014.
21. Stoecker, W.F., *Industrial Refrigeration Handbook*. 1998.ISBN: 9780070616233.
22. Simmons, E. *Reversed Carnot Cycle*. 2019; Available from: <https://slideplayer.com/slide/13502376/>.
23. Michael J. Moran, H.N.S., Daisie D. Boettner, Margaret B. Bailey, *Fundamentals of Engineering Thermodynamics, 9th edition*. 2018.ISBN: 978-1-119-39138-8.

24. Borgnakke, C. and R.E. Sonntag, *Fundamentals of Thermodynamics, 8th Edition*. 2012; Wiley.ISBN: 9781118476581.
25. Emerson. *CO2 as a Refrigerant — Introduction to Transcritical Operation*. 2015; Available from: <https://emersonclimateconversations.com/2015/05/28/co2-as-a-refrigerant-introduction-to-transcritical-operation/>.
26. Yu, B., et al., *An updated review of recent advances on modified technologies in transcritical CO2 refrigeration cycle*. Energy, 2019. **189**: p. 116147.
27. Danfoss, *Industrial Refrigeration: Ammonia and CO2 Applications*. 2020.
28. Evangelos Bellos, C.T., *A comparative study of CO2 refrigeration systems*. 2019.
29. Hussmann. *CO2 Transcritical Systems Training Manual*. 2018; Available from: [https://www.hussmann.com/ns/Technical-Documents/CO2 Transcritical Systems Training Manual 042718.pdf](https://www.hussmann.com/ns/Technical-Documents/CO2%20Transcritical%20Systems%20Training%20Manual%20042718.pdf).
30. Gullo, P., A. Hafner, and K. Banasiak, *Transcritical R744 refrigeration systems for supermarket applications: Current status and future perspectives*. International Journal of Refrigeration, 2018. **93**: p. 269-310.
31. Sanz, F., O. Fernandez, and I. Vadillo, *Aplicaciones con CO2 en Refrigeración Comercial*. 2015.
32. al, P.G.e., *Transcritical R744 refrigeration systems for supermarket applications: Current status and future perspectives*. 2018.
33. American Society of Heating, R.a.A.-C.E., *Safety Standard for Refrigeration Systems, in Standard 15*. 2019.
34. Emerson, *Pressure relief valve Engineering handbook*. 2012.
35. Stone, C. *Understanding Maximum Allowable Working Pressure (MAWP)*. 2020; Available from: <https://www.tfsheat.com/understanding-maximum-allowable-working-pressure-mawp/>.
36. ASME, *ASME Boiler and Pressure Vessel Code, in Rules for Construction of Pressure Vessels*. 2019.
37. ISO/IEC, *Standardization and related activities — General vocabulary, in ISO/IEC GUIDE 2:2004*. 2004.
38. Breitenberg, M.A., *THE ABC's OF THE U.S. CONFORMITY ASSESSMENT SYSTEM*. 1997.
39. ANSI. *National Conformity Assessment Principles For the U.S.* 2020; Available from: https://www.standardsportal.org/usa_en/conformity_assessment/conformity_assessment.aspx.
40. Standardization, E.C.f., *Refrigerating systems and heat pumps - Pressure relief devices and their associated piping - Methods for calculation* 2013.
41. ASME, *Refrigeration Piping and Heat Transfer Components*. 2016.
42. TEC-Sicence, *Dye penetrant inspection*. 2018.
43. Comission, I.E., *Household and similar electrical appliances – Safety –Part 2-89: Particular requirements for commercial refrigerating appliances and ice-makers with an incorporated or remote refrigerant unit or motor-compressor*. 2019.
44. CSA, *Mechanical Refrigeration Code, in B 52*. 2018.

APPENDIX A: KoolSys Diagram

The KoolSys P&ID diagram is presented in this Appendix.



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APPENDIX B: KoolSys Equipment

HIGH PRESSURE SIDE - MT COMPRESSORS DISCHARGE (HPD)

Equipment Type	REF. N°	Fluid	Manufacturer (Model)
MT COMPRESSOR	E-04	R744	BITZER (SH 4HTC-20K)
MT COMPRESSOR	E-05	R744	BITZER (SH 4HTC-20K)
MT COMPRESSOR	E-06	R744	BITZER (SH 4FTE-20K)
PARALLEL COMPRESSOR	E-07	R744	BITZER (SH 4FTE-30K)
OIL SEPARATOR	E-09	R744	TEMPRITE (137A)
SANITARY WATER HEAT EXCHANGER	E-11	R744	SWEP (B18Hx60/1P-SC-U 4xS28.58&W35.1)
GAS INJECTION VALVE	V-04	R744	CAREL (E2V)
THREE WAY VALVE (HIGH SECURITY)	V-07	R744	REFRIGERA (DX1012N0000)
THREE WAY VALVE HEAT EXCHANGER	V-11	R744	REFRIGERA (BV31D118K0019)
HIGH-PRESSURE SECURITY VALVE	V-14	R744	NUOVA GENERAL
HIGH-PRESSURE SECURITY VALVE II	V-14'	R744	NUOVA GENERAL
DISCHARGE LINE BALL VALVE	V-22	R744	Castel(6597E/13)
MT DISCHARGE INSTRUMENTATION VALVE	V-68	R744	REFRIGERA (BV21Z038KS100)
HP COMPRESSOR PRESSURE SWITCH	I-04	R744	ALCO CONTROLS (CS3-S8S)
HP COMPRESSOR PRESSURE SWITCH	I-05	R744	ALCO CONTROLS (CS3-S8S)
HP COMPRESSOR PRESSURE SWITCH	I-06	R744	ALCO CONTROLS (CS3-S8S)
HP COMPRESSOR PRESSURE SWITCH	I-07	R744	ALCO CONTROLS (CS3-S8S)
HP PRESSURE GAGE	I-27	R744	WIKA (116.15)
HP PRESSURE SWITCH	I-10	R744	ALCO CONTROLS (CS3-WQS)
HP PRESSURE TRANSDUCER	I-15	R744	DANFOSS (AKS2050)

HIGH PRESSURE SIDE – GAS COOLER RETURN (HPR)

Equipment Type	REF. N°	Fluid	Manufacturer (Model)
IT HEAT EXCHANGER-HP	E-12	R744	SWEP (B18Hx24/1P-SC-U 4xS28.58&W35.1)
TRANSCRITICAL VALVE	V-01	R744	DANFOSS (CCMT-16)
GAS COOLER RETURN BALL VALVE	V-25	R744	CASTEL (6597E/9)
GAS COOLER RETURN TRANSDUCER VALVE	V-74	R744	REFRIGERA (BV21A038G2K00)
GAS COOLER OUTLET PRESSURE TRANSDUCER	I-18	R744	DANFOSS (AKS2050)

LIQUID LINE

Equipment Type	REF N°	Fluid	Manufacturer (Model)
LIQUID RECEIVER	E-08	R744	Delta Tee
LIQUID FILTER	E-16	R744	TEMPRITE (48-2)
LIQUID RECEIVER LEVEL DETECTOR	E-26	R744	HENRY (S9420)
FLASH GAS VALVE	V-02	R744	DANFOSS (CCMT-24)
LIQUID INJECTION VALVE	V-03	R744	DANFOSS (AKV 10P3 SOLDAR)
OIL RECEIVER PRESSURE EQUALIZER VALVE	V-06	R744	DANFOSS (NRV 10)
RECEIVER THREE WAY VALVE	V-08	R744	REFRIGERA (DX1012N0000)
LIQUID RECEIVER SAFETY VALVE I	V-15	R744	NUOVA GENERAL
LIQUID RECEIVER SAFETY VALVE II	V-15'	R744	NUOVA GENERAL
LIQUID LINE BALL VALVE	V-16	R744	CASTEL (6597E/9)
LIQUID LINE BALL VALVE	V-27	R744	CASTEL (6597E/9)
FLASH GAS BALL VALVE	V-33	R744	CASTEL (6597E/9)
LIQUID LINE BALL VALVE	V-35	R744	CASTEL (6597E/9)
LIQUID LINE BALL VALVE	V-37	R744	CASTEL (6597E/9)
FILTER ACCESS VALVE	V-55	R744	CASTEL (6110E/22)
LIQUID RECEIVER ACCESS VALVE	V-62	R744	CASTEL (6110E/22)
IT COMPRESSOR BALL VALVE	V-63	R744	CASTEL (6597E/9)
LIQUID RECEIVER INSTRUMENTATION VALVE	V-75	R744	CASTEL (6110E/22)
RECEIVER TRANSDUCER	I-19	R744	DANFOSS (AKS2050)
LIQUID RECEIVER PRESSURE GAGE	I-28	R744	WIKA (116.15)

MEDIUM TEMPERATURE SUCTION LINE (MT-ASP)

Type	REF.N°	Fluid	Manufacturer (Model)
MT SUCTION LINE FILTER	E-15	R744	CASTEL (4727E/9)
MT SUCTION LINE THREE WAY VALVE	V-10	R744	REFRIGERA (DX1012N0000)
MT SUCTION LINE SECURITY VALVE I	V-13	R744	NUOVA GENERAL
MT SUCTION LINE SECURITY VALVE II	V-13'	R744	NUOVA GENERAL
MT SUCTION LINE BALL VALVE	V-20	R744	CASTEL (6590E/13)
MT SUCTION LINE BALL VALVE	V-21	R744	CASTEL (6590E/13)
FLASH GAS BALL VALVE	V-32	R744	CASTEL (6579E/9)
FLASH GAS BALL VALVE	V-34	R744	CASTEL (6579E/9)
MT FILTER ACCESS VALVE	V-58	R744	CASTEL (6110E/22)
MT INSTRUMENTATION VALVE	V-66	R744	REFRIGERA (BV21Z038KS100)
LT COMPRESSOR PRESSURE SWITCH	I-01	R744	ALCO CONTROLS (CS3-WPS 46/42)
LT COMPRESSOR PRESSURE SWITCH	I-02	R744	ALCO CONTROLS (CS3-WPS 46/42)
LT COMPRESSOR PRESSURE SWITCH	I-03	R744	ALCO CONTROLS (CS3-WPS 46/42)
MT PRESSURE TRANSDUCER	I-14	R744	DANFOSS (AKS2050)
MT SUCTION LINE PRESSURE GAGE	I-26	R744	WIKA (116.15)

LOW TEMPERATURE SUCTION LINE (LT-ASP)

Equipment Type	REF N°	Fluid	Manufacturer (Model)
LT COMPRESSOR	E-01	R744	BITZER (SH 2KSL-1K)
LT COMPRESSOR	E-02	R744	BITZER (SH 2KSL-1K)
LT COMPRESSOR	E-03	R744	BITZER (SH 2KSL-1K)
LT-IT HEAT EXCHANGER	E-13	R744	SWEP (B12Lx8/1P-SC-D 4x28U)
LT SUCTION LINE FILTER	E-17	R744	STAS (489T)
LT THREE WAY VALVE	V-09	R744	REFRIGERA (DX1012N0000)
LT SUCTION LINE SAFETY VALVE I	V-12	R744	NUOVA GENERAL
LT SUCTION LINE SAFETY VALVE II	V-12'	R744	NUOVA GENERAL
LT SUCTION LINE BALL VALVE	V-17	R744	CASTEL (6570E/9)
LT SUCTION LINE BALL VALVE	V-18	R744	CASTEL (6570E/9)
LT FILTER ACCESS VALVE	V-50	R744	CASTEL (6110E/22)
LT INSTRUMENTATION VALVE	V-64	R744	CASTEL (6110E/22)
LT PRESSURE TRANSDUCER	I-11	R744	DANFOSS AKS2050
LT PRESSURE GAGE	I-25	R744	WIKA (116.15)

HIGH-PRESSURE OIL CIRCUIT (OL HP)

Equipment type	REF N°	Fluid	Manufacturer (Model)
OIL SEPARATOR LEVEL DETECTOR	E-27	Oil	HENRY (S9420)
OIL REGULATING VALVE	V-05	Oil	GSR (BR52)
OIL CIRCUIT BALL VALVE	V-39	Oil	REFRIGERA (BV21A014NFM07)

OIL CYCLE

Type	REF N°	Fluid	Manufacturer (Model)
OIL DEPOSIT	E-10	Oil	TEMPRITE (RES17)
OIL FILTER	E-18	Oil	DANFOSS (DMT)
OIL LEVEL CONTROLLER	E-19	Oil	KRIWAN (INT280)
OIL LEVEL CONTROLLER	E-20	Oil	KRIWAN (INT280)
OIL LEVEL CONTROLLER	E-21	Oil	KRIWAN (INT280)
OIL LEVEL CONTROLLER	E-22	Oil	KRIWAN (INT280)
OIL LEVEL CONTROLLER	E-23	Oil	KRIWAN (INT280)
OIL LEVEL CONTROLLER	E-24	Oil	KRIWAN (INT280)
OIL LEVEL CONTROLLER	E-25	Oil	KRIWAN (INT280)
OIL DEPOSIT LEVEL DETECTOR	E-28	Oil	HENRY (S9420)
OIL CIRCUIT BALL VALVE	V-40	Oil	REFRIGERA (BV21Z038KS100)
OIL CIRCUIT BALL VALVE	V-41	Oil	REFRIGERA (BV21Z038KS100)
OIL CIRCUIT BALL VALVE	V-42	Oil	REFRIGERA (BV21Z038KS100)
OIL CIRCUIT BALL VALVE	V-43	Oil	REFRIGERA (BV21Z038KS100)
OIL CIRCUIT BALL VALVE	V-44	Oil	REFRIGERA (BV21Z038KS100)
OIL CIRCUIT BALL VALVE	V-45	Oil	REFRIGERA (BV21Z038KS100)
OIL CIRCUIT BALL VALVE	V-46	Oil	REFRIGERA (BV21Z038KS100)
OIL CIRCUIT BALL VALVE	V-47	Oil	REFRIGERA (BV21Z038KS100)
OIL DEPOSIT INLET VALVE	V-71	Oil	REFRIGERA (BV21Z038KS100)
OIL DEPOSIT EXIT VALVE	V-73	Oil	REFRIGERA (BV21Z010XS100)
OIL DEPOSIT VACUUM VALVE	V-78	Oil	REFRIGERA (BV21Z038KS100)
OIL DEPOSIT FILLING VALVE	V-79	Oil	REFRIGERA (BV21Z038KS100)

APPENDIX C: UL Certificates of Compliance

Equipment

For the components listed in Appendix B, the certificates of compliance for the heat exchangers and oil separator.

For the liquid receiver, two brochures of the two different suppliers are displayed.

For all the Bitzer compressors, the models can be found in the UL Product iQ, file SA7219.

For the oil receiver and liquid line filter, manufactured by Temprite, the models can be found on the UL Product iQ, file SA2359. For the oil level regulators from Kriwan, the file on UL Product list is MH47382.

For the MT suction line filter the strainer from Castel can be found on the UL Product iQ, file SA7054. For the oil filter from Danfoss, the model can be found on the UL Product iQ, file SA6398. For the LT suction line filter from STAS, the file is SA7175.

For the level detectors, the manufacturer was Henry, model S9420, that displays UL certification as seen in Henry Group website.

Valves

For the transcritical, flash gas, liquid injection, and pressure equalizer valve from Danfoss, the corresponding files on UL Product iQ are MH7648 and SA7200.

For the gas injection valve, from Carel, model E2V, the model can be found on UL Product iQ, file E304579.

For the oil injection valve from GSR, model GSR 52 the catalog demonstrating UL certification is presented.

For the three-way valves from Refrigerera, model DX1012N00000, the component is found on UL Product iQ, file SA45030.

For the PRVs, from Nuova General, the certificate from ASME demonstrating compliance is presented.

For the ball valves from Refrigerera, the components models can be found on UL Product iQ, file SA45030.

For the selected valves from Castel, the products were selected from the catalog supplied by Castel for UL listed components and can be seen in file SA33319 on UL Product iQ.

Instrumentation

For the compressors pressure switches and high-pressure line pressure switch from Emerson, the file on UL Product iQ displaying the components is E85974.

For the pressure transducers from Danfoss, file E494625 on UL Product iQ contains the proposed component.

For the KoolSys pressure gauges, the certificate of compliance from Wika is presented.

Piping

The flexible tubing from Gomax, the catalog displaying UL certification is presented. For the K65 tubing the component can be found on UL Product iQ, file SA44215 and on a technical catalog supplied by Wieland.

CERTIFICATE OF COMPLIANCE

Certificate Number 20151124-SA8220
Report Reference SA8220-20130715
Issue Date 2015-NOVEMBER-24

Issued to: SWEP INTERNATIONAL AB
Stenorsvagen 90
SE-261 22 Landskrona SWEDEN

**This is to certify that
representative samples of**

HEAT EXCHANGERS, REFRIGERANT
Extreme high pressure for transcritical systems, Type one
or two suffixes followed by 9, 16DW-UT, 17, 18 and 185
followed by additionally numbers and suffixes.

Have been investigated by UL in accordance with the
Standard(s) indicated on this Certificate.

Standard(s) for Safety: UL 207, Refrigerant-Containing Components and
Accessories, Nonelectrical
CSA C22.2 no. 140.3-15, Refrigerant-Containing
components for use in electrical equipment

Additional Information: See the UL Online Certifications Directory at
www.ul.com/database for additional information

Only those products bearing the UL Certification Mark should be considered as being covered by UL's
Certification and Follow-Up Service.

Look for the UL Certification Mark on the product.



Bruce Mahrenholz, Director North American Certification Program

UL LLC

Any information and documentation involving UL Mark services are provided on behalf of UL LLC (UL) or any authorized licensee of UL. For questions, please
contact a local UL Customer Service Representative at <http://ul.com/aboutul/locations/>



CERTIFICATE OF COMPLIANCE

Certificate Number 20180727-SA8220
Report Reference SA8220-20070604
Issue Date 2018-JULY-27

Issued to: SWEP INTERNATIONAL AB
Hjalmar Brantings vag 5
SE-26122 Landskrona SWEDEN

**This is to certify that
representative samples of** HEAT EXCHANGERS, REFRIGERANT
See next page

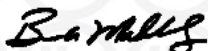
Have been investigated by UL in accordance with the
Standard(s) indicated on this Certificate.

Standard(s) for Safety: UL 207 Standard for Refrigerant-Containing Components
and Accessories, Nonelectrical and CSA C22.2 NO. 140.3-
15 Refrigerant-Containing Components for Use in Electrical
Equipment.

Additional Information: See the UL Online Certifications Directory at
www.ul.com/database for additional information

Only those products bearing the UL Certification Mark should be considered as being covered by UL's
Certification and Follow-Up Service.

Look for the UL Certification Mark on the product.



Bruce Mahrenholz, Director North American Certification Program

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contact a local UL Customer Service Representative at <http://ul.com/aboutul/locations/>



CERTIFICATE OF COMPLIANCE

Certificate Number 20180727-SA8220
Report Reference SA8220-20070604
Issue Date 2018-JULY-27

This is to certify that representative samples of the product as specified on this certificate were tested according to the current UL requirements.

Models:

USL, CNL – Refrigerant-Containing Components, Non-Electrical. Brazed plate basic Heat Exchanger type. Type designation for each USL and CNL Heat Exchanger can be read in the Denomination.

CBE (Compact Brazed Heat Exchanger) – Denomination

Group I, example: B16Hx30/1P-SC-S

B	16	H	x30	/1P	-SC	-S
I	II	III	IV	V	VI	VII

I : See Sec. Gen. for details followed by

II : 3, 4, 5, 5F, 5T, 5AS, 8, 8L, 8LAS, 8T, X8T, 10, 10T, 12, 15, 15T, 16, 20, 25, 25T, 26, 27, 28, 35, 35T, 45, 50, 56, 57, 60, 65, 80, 80AS, 85, 86, 120T, 200, 200T, 315, 320HT, 320LT, 400, 400T, 427, 439 or 500T followed by

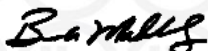
III : See Sec. Gen. for details followed by

IV : See Sec. Gen. for details followed by

V : See Sec. Gen. for details followed by

VI : See Sec. Gen. for details followed by

VII : See Sec. Gen. for details



Bruce Mahrenholz, Director North American Certification Program

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CERTIFICATE OF COMPLIANCE

Certificate Number 20190715-SA8220
Report Reference SA8220-20070608
Issue Date 2019-JULY-15

Issued to: SWEP INTERNATIONAL AB
Hjalmar Brantings vag 5, SE-26122 Landskrona SWEDEN

This certificate confirms that
representative samples of HEAT EXCHANGERS, REFRIGERANT
Refer addendum page for Models/Product

Have been investigated by UL in accordance with the
Standard(s) indicated on this Certificate.

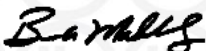
Standard(s) for Safety: UL 207 - Standard for refrigerant-containing components and
accessories, nonelectrical
CSA C22.2 no. 140.3-15 - Refrigerant-Containing components
for use in electrical equipment

Additional Information: See the UL Online Certifications Directory at
<https://iq.ulprospector.com> for additional information.

This *Certificate of Compliance* does not provide authorization to apply the UL Mark. Only the UL Follow-Up
Services Procedure provides authorization to apply the UL Mark.

Only those products bearing the UL Mark should be considered as being UL Certified and covered under UL's
Follow-Up Services.

Look for the UL Certification Mark on the product.



Bruce Mahrenholz, Director North American Certification Program

UL LLC

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contact a local UL Customer Service Representative at <http://ul.com/aboutul/locations/>



CERTIFICATE OF COMPLIANCE

Certificate Number 20190715-SA8220
Report Reference SA8220-20070608
Issue Date 2019-JULY-15

This is to certify that representative samples of the product as specified on this certificate were tested according to the current UL requirements.

Models/Product:

USL, CNL – Refrigerant-Containing Components, Non-Electrical. Brazed plate High Pressure (HP) Heat Exchanger type. Type designation for each USL and CNL Heat Exchanger can be read in the Denomination

CBE (Compact Brazed Heat Exchanger) - Denomination

Example : B15Hx30/D-SC-H

B	15	H	x30	/1P	-SC	-H
I	II	III	IV	V	VI	VII

I	:	See Sec. Gen. for details followed by
II	:	5, 5T, 8, 15, 10, 25, 10T, 25T, 12, 27, 30, 45, 47, 80, 80AS, 120T, 200,200T, 220, 250AS or 400 followed by
III	:	See Sec. Gen. for details followed by
IV	:	See Sec. Gen. for details followed by
V	:	See Sec. Gen. for details followed by
VI	:	See Sec. Gen. for details followed by
VII	:	See Sec. Gen. for details



Bruce Mahrenholz, Director North American Certification Program

UL LLC

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DECLARATION OF CONFORMITY

January 15, 2020

This Declaration of Conformity is issued under the sole responsibility of Temprite Company.

Temprite Company declares the following products comply with:

-Directive 2014/68/EU of the European Parliament and of the Council of 15 May 2014 on the harmonization of the laws of the Member States relating to the making available on the market of pressure equipment.

Quality Certificate No.: HSB IE-18-09-014

Classification: Group 2 Gases

T max.: +160°C, T min.: 0°C

Category I (PV: 50 to 200 bar-Liters): Conformity Assessment Procedure: Module A (No Notified Body Involvement)

Oil Separators: Models 501, 502, 503, 504, 505, 600, 601, 602, 603, 604, 605, 900, 901, 902, 903, 904, 905, 912, 914, 915, 920, 921, 922, 923 all with or without alpha/numeric prefixes and/or suffixes.

Receivers: Model 1.5, 2.8, 6 all with or without alpha/numeric prefixes and/or suffixes.

Category II (PV: 200 to 1000 bar-Liters): Conformity Assessment Procedure: Module H, Quality Certificate No.: HSB IE-18-09-014

Oil Separators: Models 133, 135, 506, 507, 606, 607, 632, 924, 925, 926, 927 all with or without alpha/numeric prefixes and/or suffixes.

Oil Reservoirs: Models 47058, 47080, 47115, 47154 all with or without alpha/numeric prefixes and/or suffixes.

Drier Shells: Model 48 with or without alpha/numeric prefixes and/or suffixes.

Receivers: Model V2, V7, 2, 8, 10 all with or without alpha/numeric prefixes and/or suffixes.

Category III (PV: 1000 to 3000 bar-Liters): Conformity Assessment Procedure: Module H, Quality Certificate No.: HSB IE-18-09-014

Oil Separators: Models 137, 138, 139 (at 130 Bar), 928, 930 all with or without alpha/numeric prefixes and/or suffixes.

Oil Reservoirs: Models RES 7, 12, 17, RES 23 all with or without alpha/numeric prefixes and/or suffixes.

Drier Shells: Models 148, 248 all with or without alpha/numeric prefixes and/or suffixes.

Receivers: Models 10, 12, 14, 20, 60, 80, 120 all with or without alpha/numeric prefixes and/or suffixes.

Category IV (PV: > 3000 bar-Liters): Conformity Assessment Procedure: Module H1, Quality Certificate No.: HSB IE-18-09-014

Oil Separator: Model 139 (at 140 Bar) with or without alpha/numeric prefix and/or suffix.

Receivers: Models 16, 18 all with or without alpha/numeric prefixes and/or suffixes.

Notified Body (for Categories II, III, and IV only):

Hartford Steam Boiler Ireland Ltd

28 Windsor Place, Lower Pembroke Street, Dublin 2.

Dublin

Ireland

Notified Body number : 2833

Safety Accessories:

Safety accessories and pressure relief devices to be provided and installed by others.

Compliance to Harmonized and Other Reference Standards:

EN 15614-1 – Specification and qualification of welding procedures for metallic materials

EN 9606, EN 287, and EN 14732 – Qualification of Permanent Joining Personnel

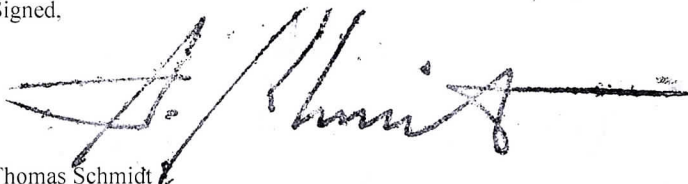
EN 10204:2004 – Metallic Materials – Types of inspection documents

ASME Code Section IX, Div. 1 – Qualification of Permanent Joining Personnel and Procedures.

UL 207 – Refrigerant-Containing Components and Accessories

CSA STD. C22.2 NO 140.3-March 2015 – Refrigeration Equipment – Refrigerant Containing Parts

Signed,



Thomas Schmidt
President – Temprite Company



DELTA TEE



HEAT TRANSFER EQUIPMENT

Delta Tee International, Inc. specializes in the design and fabrication of heat transfer equipment for the refrigeration, petrochemical, gas processing, food and other related industries. Our shell and tube heat exchangers, pressure vessels and recirculator pump systems exist worldwide and they are all custom-engineered to meet the specific needs of our clients. We manufacture in accordance with ASME Code and capable to comply with other codes and standards.

We provide our clients with innovative designs, quality products and valuable service.

DELTA TEE PRODUCTS

PRESSURE VESSELS

- Receivers
- Economizers
- Accumulators
- Intercoolers
- Oil Separators
- Oil Filters
- Oil Pots
- Distillers
- Packed Columns
- Scrubbers
- Surge Drums

SHELL AND TUBE HEAT EXCHANGERS

- Evaporators
- DX Chillers
- Condensers
- Cascade Condensers
- Sub Coolers
- Desuperheaters
- Oil Coolers
- Reboilers
- Gas-to-Gas Heat Exchangers
- Gas-to-Liquid Heat Exchangers

PLATE AND FRAME HEAT EXCHANGERS

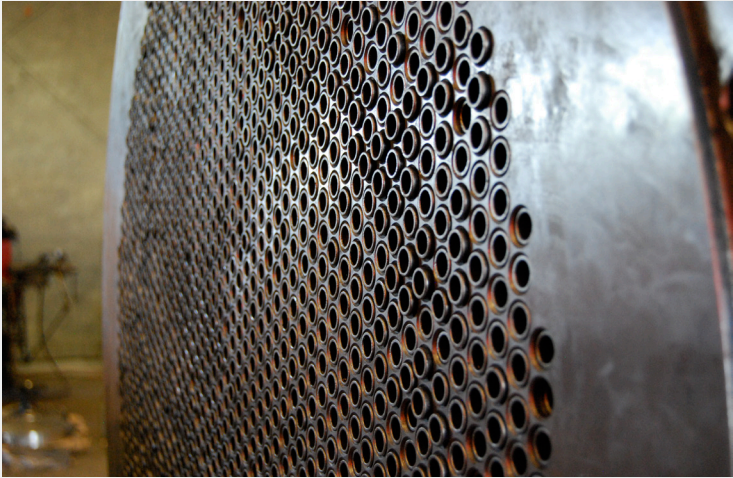
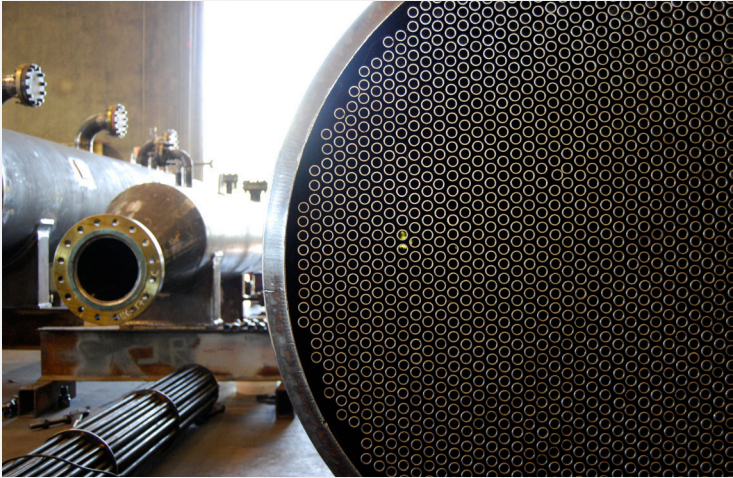
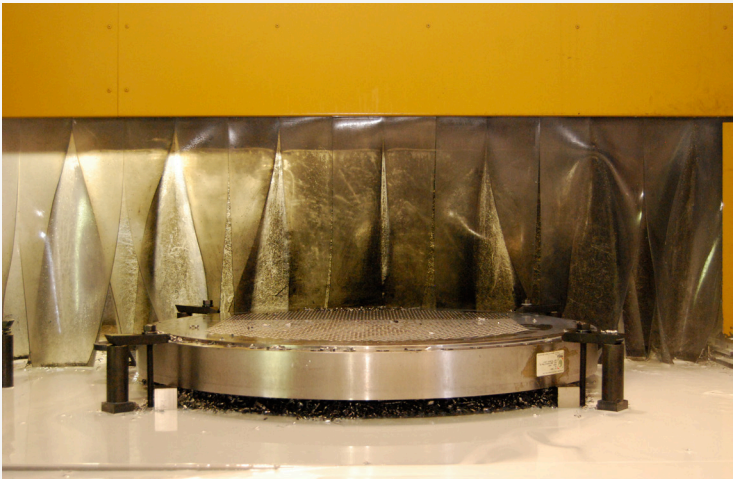
- General Purpose Liquid-To-Liquid Heat-Exchangers
- Oil Coolers
- Condensers
- Flooded Evaporators
- Direct Expansion Evaporators

SYSTEMS

- Pump Recirculators
- PHE / Surge Drum Assemblies
- Scrubber Skids

AVAILABLE VESSEL DIAMETERS

- Heat Exchangers from 6” to 60” O.D.
- Pressure Vessels up to 120”



WE DESIGN HEAT EXCHANGERS FOR:

- Cooling process Glycols
- Cooling Calcium Chloride brine in Ice Rink applications
- Cooling Seawater
- Cooling or Heating Hydrocarbons in various Chemical Processes
- Carbon Dioxide Purification
- Gas/Liquid Separation in Natural Gas Processing
- Heating process fluids with Steam

EXPERIENCE IN USING MANY DIFFERENT REFRIGERANTS SUCH AS:

- Ammonia
- Carbon dioxide
- R-23
- R-410a
- R-507
- R-508
- R-404a
- R-22
- R-134a
- Propane
- Propylene

TECHNOLOGICAL ADVANTAGE

We can competitively size heat exchangers by using internally and externally finned tubes with various geometries or with turbulating devices, whether it is for evaporating or condensing refrigerant inside or outside of the tubes, or for single phase fluids. We utilize special geometries to help increase the turbulence in highly viscous fluid flows. When reducing refrigerant charge in a flooded chiller becomes a critical issue, we can help achieve this goal by using externally enhanced tubes.

AVAILABLE MATERIALS

Carbon Steel, Stainless Steel, High Alloys, Titanium, Copper and its alloys

CODES / STANDARDS

- ASME
- NBIC
- PED
- CSA
- TEMA
- API
- ABS
- NACE

MAREFSUP BV
KLOMPENMAKER 12
5253RH NIEUWKUIJK

Tel. +31 73 3034120
www.marefsup.com
info@marefsup.com



Marine Refrigeration Supplies

Pressure vessels

Pressure vessels are considered to be simple and easy to produce. In many cases however specialized vessels are required such as liquid separators, oil separators and high pressure vessels for CO₂ that are used in refrigeration plants or industrial process plants for the chemical industry.

In these cases our knowledge to design such equipment can be essential to make a proposal to the specification of the client.



Good quality for a competitive price

LIQUID AND OIL SEPARATORS

We are proud that we have the design knowledge to calculate liquid separators for any kind of refrigerant, based on the required capacity, operating temperature, type and circulation rate of the refrigerant.

For oil separators for Ammonia screw compressors we can guarantee a maximum oil carryover of 5 to 10 and ppm.

Additionally we have designed and produced CO₂ oil separators for screw compressor packages with a design pressure of 48 Bar as well as CO₂ liquid separators with a design pressure of 34 Bar and a design temperature of -50 °C.



We can offer completely assembled liquid separators that are fitted on a frame together with the refrigerant circulation pumps, valves, filters and other belongings. Please check our PDF brochure "Unit assembly"

Technical information

<u>General:</u>		Remarks
Application	Marine, Offshore and shore	
Dimensions & Capacities	Acc. Requirements or calculations	
<u>Design:</u>		Remarks
Functional and Separation design	MAREFSUP	
Mechanical design and Production.	MAREFSUP	
<u>Refrigeration data:</u>		
Refrigerants	Ammonia, HFC's, CO ₂ , Propylene.	Others on request
Design temperatures	From -50 °C and higher	
Design Pressure	Up to 100 Bar	
<u>Execution:</u>		
Processed materials	CS CuNi 90/10 CuNi 70/30 Stainless; AISI 304, 316L, 316Ti Super duplex; SAF2205, SAF2507	Others on request
Covered standards, design codes and Classification societies.	Standards and design codes CE-PED ASME (U-Stamp) API PD5500 AD Merkblätter Stoomwezen CODAP	Classification societies American Bureau of Shipping Bureau Veritas Det Norske Veritas Germanischer Lloyd Lloyds Register of Shipping Russian register of Shipping Registro Italiano Navale Nippon Kaiji Kyokai Korean Register of Shipping Indian register of Shipping
<u>Quality assurance :</u>	Quality Management System	Certified by Classification societies
As pressure vessel and Heat Exchanger Manufacturer	UNE-EN-ISO 9001:2000	Det Norske Veritas ; Class I & II Certification
	According the requirements of Annex III, Module H&H1 of the Pressure Equipment Directive 97/23/EC. Certified by Lloyds Register	Lloyds Register of Shipping; Certification according to class 2.1. certificate for pressure vessels welding
		Germanischer Lloyd; Pressure vessels welding Certification
		Bureau Veritas; Mode II Surveyor certification



Technical Data Sheet Type 52



2/2-way solenoid valve
NC - Valve normally closed (as standard)
NO - Valve normally open (as option)

Direct operated piston design valve. No differential pressure is necessary for operation. When energized, the valve seat is opened directly.
In standard (NC) the valve closes with spring power.

■ Solenoid valve for gaseous and liquid media

Type 52

TECHNICAL SPECIFICATIONS

Type of control	Direct operated, no differential pressure necessary
Design	Piston design
Connection	Threaded G1/8 - G1/2 DIN ISO 228/1 (BSP) Further connections like NPT on request
Installation	Preferable with actuator upright
Pressure	0 - 90 bar (see table on page 2)
Medium	Clean, neutral, gaseous and liquid media
max. Viscosity	22 mm²/s
Temperature range	Medium: -10 °C up to +80 °C Ambient: -10 °C up to +50 °C In consideration of the restrictions described on page 4
Body material	Brass 2.0401 / 2.0402 Stainless steel 1.4305 Stainless steel 1.4571
Metallic inner parts	Brass and Stainless steel
Sealing	FKM, EPDM, PTFE
Supply voltage	AC~ 24V, 110V, 230V DC= 12V, 24V Other supply voltages on request
Voltage tolerance	-10% / +10%
Power consumption	.182 = 6,8 Watt .178 = 5,2 Watt ⚠ .032 = 11 Watt .148 = 10 Watt ⚠ .012 = 18,5 Watt
Protection class	IP65 acc. to DIN 60529
Duty factor	100% ED-VDE 0580
Connection type	Plug
Ex-proof	acc. to 2014/34/EU (ATEX) Further Ex-proof on request

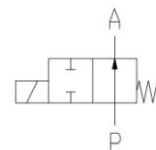
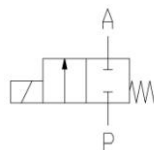
VALVE FEATURES

- No pressure difference required
- High life time
- Simple compact valve design
- Reliable and sturdy sealing elements
- Long-term availability of spare parts

FUNCTION

NC – non energized closed

NO – non-energized open

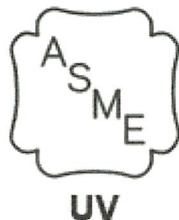


CERTIFICATES



ORDERING SYSTEM

Type	Conn.	Housing	Seal	Coil	Option
. 5 2	4 1	/ 1 0	0 2	/ . 1 8 2	- H A
3 - G 1/8 4 - G 1/4 5 - G 3/8 6 - G 1/2 0 - 1.0 mm 1 - 1.5 mm 2 - 2.0 mm 3 - 2.5 mm 4 - 3.0 mm 5 - 4.0 mm 6 - 5.0 mm 7 - 6.0 mm		10 Brass 2.0402 06 St.st. 1.4305 08 St.st. 1.4571	02 FKM 04 PTFE 06 EPDM	2 Standard IP65 8 Explosion proof acc. to directive 2014/34/EU (ATEX)	



CERTIFICATE OF AUTHORIZATION

The named company is authorized by the American Society of Mechanical Engineers (ASME) for the scope of activity shown below in accordance with the applicable rules of the ASME Boiler and Pressure Vessel Code. The use of the certification mark and the authority granted by this Certificate of Authorization are subject to the provisions of the agreement set forth in the application. Any construction stamped with this certification mark shall have been built strictly in accordance with the provisions of the ASME Boiler and Pressure Vessel Code.

COMPANY:

**Nuova General Instruments Srl
Localita Campasso
Pianello Val Tidone (PC) 29010
Italy**

SCOPE:

**Manufacture of pressure vessel pressure relief valves at the above location only
(This authorization does not cover welding or brazing)**

AUTHORIZED:

June 23, 2017

EXPIRES:

November 4, 2020

CERTIFICATE NUMBER: 35,510

A handwritten signature in black ink, appearing to read 'Richard R. Stevenson'.

Board Chair, Conformity Assessment

A handwritten signature in black ink, appearing to read 'Joseph J. L. L. L.'.

Director, Conformity Assessment



CERTIFICATE OF COMPLIANCE

Certificate Number 20151214-SA6444
Report Reference SA6444-20000601
Issue Date 2015-DECEMBER-14

Issued to: WIKA INSTRUMENT LP
1000 WIEGAND BLVD
LAWRENCEVILLE GA 30043

**This is to certify that
representative samples of**

GAUGES, HIGH-PRESSURE GAS
High pressure gauges, Model 116.15.36 (3000 and 4000 psi) and Model 116.15.41 (3000 and 4000 psi), for use with argon, helium, hydrogen, nitrogen, carbon dioxide, nitrous oxide and oxygen.

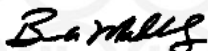
Have been investigated by UL in accordance with the Standard(s) indicated on this Certificate.

Standard(s) for Safety: UL 404, Gauges, Indicating Pressure, for Compressed Gas Service

Additional Information: See the UL Online Certifications Directory at www.ul.com/database for additional information

Only those products bearing the UL Certification Mark should be considered as being covered by UL's Certification and Follow-Up Service.

Look for the UL Certification Mark on the product.



Bruce Mahrenholz, Director North American Certification Program
UL LLC

Any information and documentation involving UL Mark services are provided on behalf of UL LLC (UL) or any authorized licensee of UL. For questions, please contact a local UL Customer Service Representative at <http://ul.com/aboutul/locations/>





GENERAL INFORMATION

read carefully before use

DESCRIPTION:

Assembled capillary hose made of thermoplastic material with polyester reinforcement and thermoplastic cover.

USE: Capillary hose for pressure gauges, pressostats, manometers, oil return lines, oil equalization systems.

OPERATING CONDITIONS

under standard requirements

Model designation	0780 - DN2 0789 - DN4 0786 - DN6
Refrigeration Types	R134a - R404a - R407a R407b - R407c - R410a R507 - R22 - R744
Design pressure, psig	1740 psig
Design pressure, bar	120 bar
Min Temperature	-40 °C
Max Temperature	+130° C

OPERATING CONDITIONS

under UL requirements



Model designation	0380 - DN2 0789 - DN4	0786 - DN6
Refrigeration Types	R134a R407b R407c R410a R507	R134a - R404a R407a - R407b R407c - R410a F507 - R744
Design pressure, psig	870 psig	1740 psig
Design pressure, bar	60 bar	120 bar
Min Temperature	-40°C	-40°C
Max Temperature	+130°C	+130°C

CLASSIFICATION OF QUADRA CAPILLARY HOSES ACCORDING TO 2014/68/UE

0780	QUADRA DN2	Paragraph 3 article 4
0789	QUADRA DN2	
0786	QUADRA DN2	

APPLICATION: QUADRA hoses are used in all applications where the connection of system service equipment (for example manometers and/or pressostats) is needed.

QUADRA hoses are compatible with:

GAS TYPE	OIL TYPE
HFC (R134a, R404a, R407a, R407b, R407c, R410a, R507)	Polyol ester
HCFC (R22)	Mineral oils
C0 ₂	Polyol ester

Use of suitable gas and oils is recommended.

Permeability classification according to the European Standard EN 1736:2008 for non metallic tubes used in air conditioning and refrigeration systems

CLASS 1

low permeability

CLASS 1

CLASS 2

CLASS 3

high permeability

TEST REPORT: BO-TIS-219890-TUV-01-03-12 ISSUED BY TÜV ITALIA

The test method and procedures have been verified by TÜV Italia as third party.

As a result of the assessment and inspection of the characteristics and performance of the permeability test machine, of the test procedures utilized, carried out at the premises of Transfer Oil S.p.A. - Italy, TÜV Italia confirms that it meets the requirements of EN 1736:2008



ATTENTION

Check the dimensions of QUADRA hose with the coupling parts of the system.

Pay attention not to assemble the QUADRA hose by compressing or subjecting it to traction to torsion, to excessive bending, or to contact with some parts that could damage the hose externally.

Once the hose has been installed in the system, do not move or rotate it, to avoid unscrewing of the nut or damaging the fitting and the risk of leakage.

Do not exceed maximum performance limits.

Respect the nut torque value:

- Torque wrench 14 7/16"-20 UNF for 1/4" SAE connections | 16 ± 18 N·m. Do not exceed 20 N·m

- Torque wrench 22 5/8"-18 UNF for 3/8" SAE connections | 30 ± 32 N·m. Do not exceed 34 N·m.

Do not use incompatible fluids or other fluids not mentioned in this report.

Do not clean the QUADRA hose with acids or with other corroding substances.

Keep carefully this report for future references and for the entire working life of QUADRA hose.

Where the fittings of a QUADRA capillary hose installed in a unit are subject to condensation, or ice, it is important to extend the insulation to the fitting and along the capillary hose up to 5 cm / 2 inches from the end of the ferrule.

STORING CONDITIONS:

QUADRA hoses have to be stored inside its packaging (unbroken), in a fresh and dry place and has not to stay under direct sun irradiation.

Do not waste the packaging or the product after using.

WARRANTY CONDITIONS:

The product warranty is valid for 12 months from the delivery date written on its delivery note.



QUADRA hoses are resistant to vibrations.

**NOTA INFORMATIVA****leggere attentamente prima dell'uso**

DESCRIZIONE: Tubo capillare raccordato realizzato in materiale termoplastico con rinforzo in fibra poliestere e rivestimento termoplastico.

DESTINAZIONE D'USO: Tubo capillare per prese di pressione, pressostati, manometri, circuiti di equalizzazione e linee ritorno olio.

Certificazione di permeabilità secondo gli Standard Europei EN 1736:2008 con riferimento ai tubi non metallici utilizzati in sistemi di aria condizionata e refrigerazione

CLASS 1

bassa permeabilità

CLASS 1**CLASS 2****CLASS 3**

alta permeabilità

TEST REPORT: BO-TIS-219890-TUV-01-03-12 ISSUED BY TÜV ITALIA

Il metodo e le procedure utilizzate nel test sono state verificate da TÜV Italia come terza parte. Come risultato della valutazione e controllo delle caratteristiche e prestazioni della macchina di prova di permeabilità, delle procedure di prova utilizzate, effettuate presso la sede di Transfer Oil S.p.A. - Italia, TÜV Italia conferma che esso soddisfa i requisiti della norma EN 1736:2008

CONDIZIONI D'IMPIEGO**secondo requisiti standard**

Modello	0780 - DN2 0789 - DN4 0786 - DN6
Tipo di refrigerante	R134a - R404a - R407a R407b - R407c - R410a R507 - R22 - R744
Pressione, psig	1740 psig
Pressione, bar	120 bar
Temperatura Min	-40 °C
Temperatura Max	+130° C

CONDIZIONI D'IMPIEGO**secondo requisiti UL**

Modello	0380 - DN2 0789 - DN4	0786 - DN6
Tipi di refrigerante	R134a - R407b R407c - R410a R507	R134a - R404a R407a - R407b R407c - R410a F507 - R744
Pressione, psig	870 psig	1740 psig
Pressione, bar	60 bar	120 bar
Temperatura Min	-40°C	-40°C
Temperatura Max	+130°C	+130°C

CLASSIFICAZIONE DEI TUBI CAPILLARI QUADRA SECONDO LA DIRETTIVA 2014/68/UE

0780	QUADRA DN2	Comma 3 articolo 4
0789	QUADRA DN2	
0786	QUADRA DN2	

APPLICAZIONI: I tubi QUADRA sono da utilizzare in tutte le applicazioni che richiedano il collegamento alle apparecchiature di servizio dell'impianto (per esempio manometri e/o pressostati).

I tubi QUADRA sono compatibili con:

TIPO DI GAS	TIPO DI OLIO
HFC (R134a R404a R407a R407b R407c R410a R507)	Poliolo base estere
HCFC (R22)	Mineral oils
C0 ₂	Polyol ester

Si raccomanda l'uso dei gas e degli olii appropriati

**ATTENZIONE**

Verificare la compatibilità dimensionale del tubo QUADRA rispetto alle parti di accoppiamento dell'impianto. Fare attenzione a non montare il tubo QUADRA comprimendolo o assoggettandolo a trazione, torsione, curvatura eccessiva o a contatto con parti che possano danneggiare il tubo dall'esterno.

Una volta installato il tubo sull'apparecchiatura, non cercare di muoverlo o ruotarlo, in quanto si corre il rischio di svitare il dado o danneggiare il raccordo compromettendone la tenuta in pressione.

Non superare i limiti massimi prestazionali consentiti.

Rispettare le coppie di serraggio del dado:

- **Dado chiave 14 7/16"-20 UNF per attacco**

1/4"SAE | 16 ± 18 N·m. Non eccedere 20 N·m

- **Dado chiave 22 5/8"-18 UNF per attacco 3/8"**

SAE | 30 ± 32 N·m. Non eccedere 34 N·m

Non utilizzare con fluidi non compatibili o non esplicitamente citati in questa nota informativa. Non pulire il tubo QUADRA con acidi o con altri detergenti corrosivi.

Conservare la presente nota informativa in modo che sia facilmente reperibile e per tutta la vita utile del tubo QUADRA.

Quando i raccordi di un tubo QUADRA installato in un impianto possono essere soggetti alla formazione di condensa o brina, è importante estendere la coibentazione anche al raccordo del tubo QUADRA e sul tubo flessibile fino a 5 cm / 2 pollici dalla fine della bocca.

CONDIZIONI DI CONSERVAZIONE:

I tubi QUADRA devono essere conservati all'interno della propria confezione (integra), in luogo fresco e asciutto e non devono subire l'irradiazione solare diretta. Non disperdere nell'ambiente il contenitore o il prodotto dopo l'uso.

CONDIZIONI DI GARANZIA:

La garanzia sul prodotto, avente decorrenza dalla data riportata sul relativo documento di consegna, è da considerarsi di 12 mesi.



Il tubo QUADRA non subisce l'effetto della vibrazione