Burckhardt Compression

HIGH RELIABILITY OF THE LABY® LNG BOG COMPRESSOR WITH THE UNIQUE SEALING SYSTEM

Peter Ernst

Compressors for a Lifetime™

Peter Ernst received his degree as Mechanical Engineer (Dipl.-Ing. HTL) in 1969 from the Engineering Institute (ISZ), Zurich, Switzerland. He then started his professional career as mechanical engineer in the design department for labyrinth piston compressors of Sulzer in Winterthur, Switzerland. He played a leading role in compressor sizing and development. In 1989 he became manager of the engineering department, in 1992 head of the technical department of labyrinth piston compressors and in 2001, with the management buyout, Vice President Contracting of Burckhardt Compression AG.

Cover photo: One of two Laby® Compressors at the BBG Bilbao LNG receiving terminal in Spain, commissioned in August 2003.
Remark: Three identical compressor units have been delivered for the Sines LNG receiving terminal, Portugal, commissioned in November 2003.
Also for the Reganosa LNG receiving terminal, Coruña, Spain, Burckhardt Compression delivered three identical compressor units in 2005.

For LNG ship transportation, a cryogenic receiving terminal is required at the port of destination. Impressive installations are required for safe and economic storage and handling of LNG and associated boil-off gases created during unloading and storage.

Safe and environment-conscious handling of the cargo, prevention of leaks, exposure of materials to cryogenic temperatures and bone-dry gas, as well as rapid temperature changes, are of high concern to the plant and compressor designers.

Among the rotating machinery used in this field are reciprocating compressors. This paper presents the design features of labyrinth piston compressors (Laby®) specially designed for:

– Recovering LNG boil-off gas vapour in receiving terminals
– Design and material selection of compressor parts exposed to cryogenic temperatures
– Design features of the recently commissioned BOG compressors at Bilbao LNG, Spain **Fig. 1**, and Sines LNG, Portugal, receiving terminals
– Simple start-up and cool-down procedures with Laby® Compressors
– Capacity control for different flow requirements during ship unloading and storage
– Operating experience and maintenance reports after periods of remarkable running hours

Fig. 1
Bilbao LNG receiving terminal equipped with Laby® Compressors

CHAPTER 1

INTRODUCTION

An LNG boil-off compressor has to cope with a variety of basic physical problems for which a product designed to normal standards would be inadequate. Two aspects of special interest include:

1.1 EXPOSURE TO CRYOGENIC TEMPERATURES

LNG at barometric pressure boils off at minus 160 °C. This temperature is well below the limit where some of the common engineering materials alter their properties. For example, the loss of ductility of most unalloyed carbon steels within a temperature span from 0 °C to about minus 50 °C. **Fig. 2**

1.2 BONE-DRY GAS

Natural gas in form of boil-off is virtually free from water vapour as the dew point is as low as minus 160 °C. On the one hand it is a matter of experience that moisture in a tribological system is an important parameter. Together with a number of other factors it has a distinct bearing on wear rates under non-lubricated conditions.

If one decides to employ dry-running self-lubricating materials for piston rings, one must also accept their mechanical and thermal constraints under bone-dry running conditions. Consequently, the stroke and speed of the machine is set in accordance with the gas conditions, so that the wear rate of the sealing and guiding elements can be held within acceptable limits. Already the initial choice of the dry-running material is itself subject to error because the designer is faced with a multitude of available types. The optimization of the design of the compressor's individual parts is increased when the labyrinth principle is employed with the following main features:

- Avoidance of permanent mechanical friction
- Ability to use materials with known, easily certifiable qualities
- Simple design of the elements exposed to the process gas

CHAPTER 2

DESIGN AND MATERIAL

To a technically sophisticated client in the Middle East the explanation above has already proven convincing. A Laby® was installed for handling LNG boil-off gas in a terminal in 1985. The running time of this machine now approaches 145'000 hrs representing a valuable record of excellent experience in industrial operation. The process data which had served for the layout of this compressor are presented in Table 1 and 2. **Table 1, 2**

2.1 MATERIAL SELECTION FOR CYLINDERS AND PISTONS

The above data were guidelines for the materials selected for cylinders, labyrinth pistons and other components of the machine. **Fig. 3**

The absence of tribological restrictions by using labyrinth sealing techniques allowed increased freedom in the selection of the best suited metals for the key components in each individual stage. For the first stage cylinders with exposure to the lowest temperatures resulted in the choice of GGG Ni35. This is a nodular cast iron containing 35% of nickel, also known under the trade name of Ni Resist D5. This alloy simultaneously exhibits remarkable ductility at low temperatures and one of the lowest thermal expansion coefficients known in metals. The corresponding pistons were made of nickel-alloyed cast iron with laminar graphite. **Fig. 4**

Reference is made to Table 2 from which the outstanding thermal shock behavior of GGG Ni 35 in relation to other candidate materials can be seen. This is another valuable virtue specially under transient temperature conditions, allowing the compressor to be started directly from ambient temperature without any precooling. **Table 2**

The less severe temperatures in the second stage allowed the use of ferritic nodular cast iron with good fracture toughness down to minus 100 °C and bronze for the piston. The third stage cylinder consists of normal cast iron grade GG20.

Table 1
Process data that served for the layout of the compressor

GAS: CH_4 (98%) + N_2 (2%)		
Suction first stage	1.036 bar	–90 to –160 °C
Discharge first stage	5.2 bar	+25 to –53 °C
Suction second stage	5.2 bar	+25 to –53 °C
Discharge second stage	13.6 bar	+38 to +102 °C
Suction third stage	13.6 bar	+38 to +48 °C
Discharge third stage	23.4 bar	+88 to +160 °C

Fig. 2
Transitions of impact energies of non alloyed C-steels and Ni-alloyed nodular iron

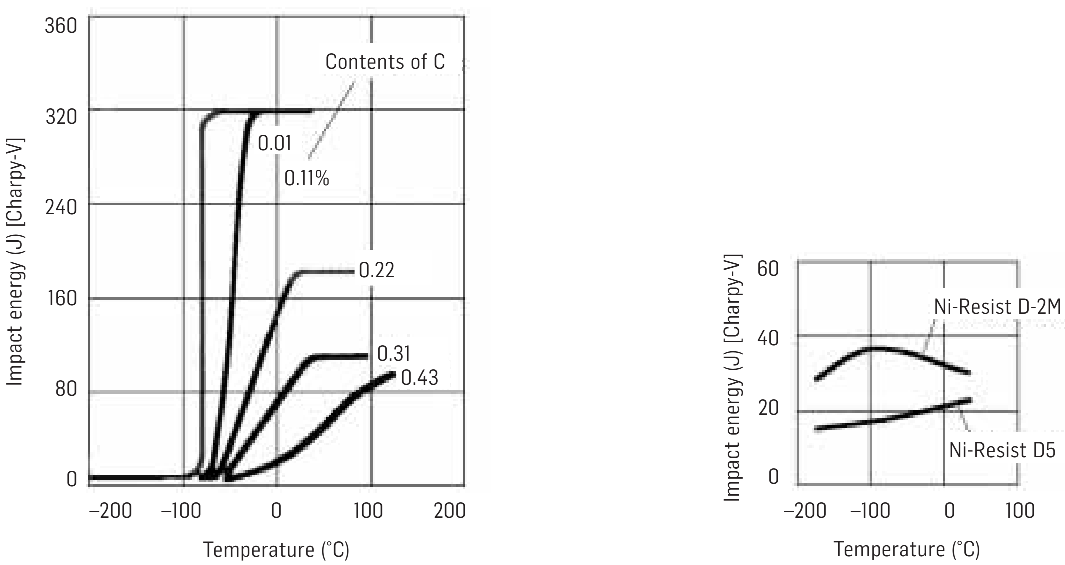


Fig. 3
Cross section view of a double acting labyrinth piston

Table 2
Candidate materials for low temperature components. Comparative combined properties.

	Tensile strength N/mm²	Endurance limit N/mm²	Young's modulus N/mm²	Thermal expansion coefficient 10^{-6}/°C	Thermalshock stress N/mm² (Δt = 100 °C)	Ratio 1: Thermal shock stress divided by endurance limit	Ratio 2: Thermal shock stress divided by tensile strength
Cast iron, GG 18	180	80	85'000	11.70	100	1.25	0.55
Austenitic Steel, CrNi	460 : 600	230 : 300	204'000	20	410	1.80 : 1.40	0.89
GGG NiCr 20 2, Type D2	430	190	125'000	17.6	220	1.10	0.51
GGG Ni 35, Type D5	410	185	127'000	4.50	58	0.32	0.14

Fig. 4
Coefficient of thermal expansion for cast iron and steel in function of % Ni and temperature

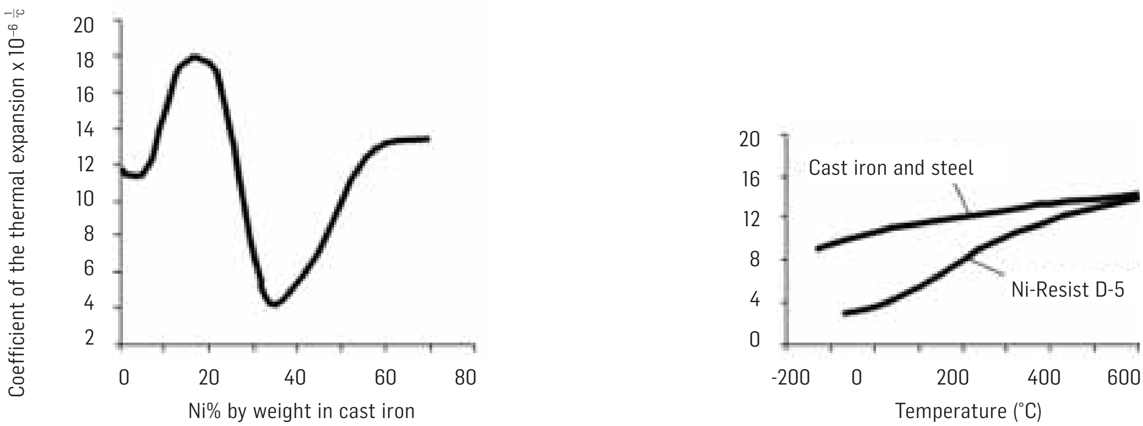


Fig. 5
Icing of first stage cylinder

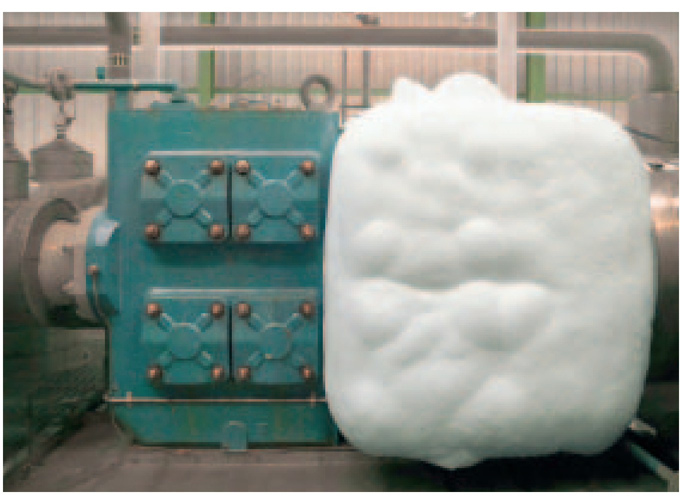


Fig. 6
Laby® for LNG boil-off, two double acting cylinders, two compression stages, closed gastight crankcase, design suction temperature minus 160 °C

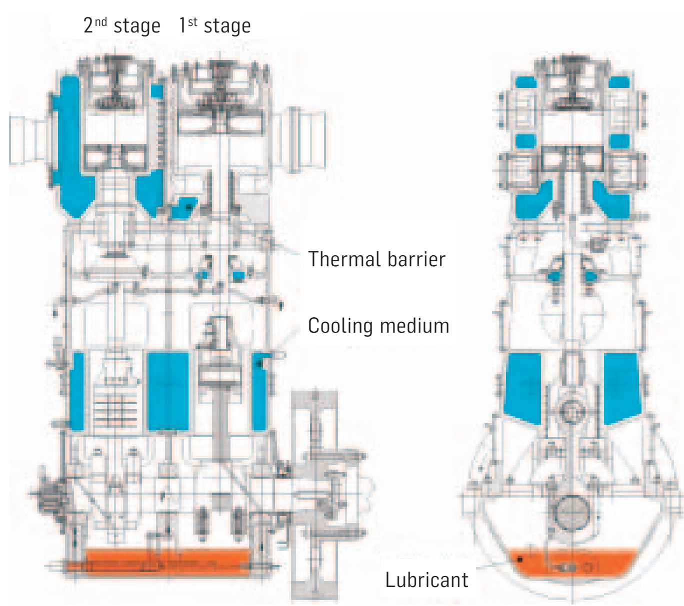


Fig. 7
Internal labyrinth sealing between double acting cylinder and distance piece of crankcase (piston rod sealing)

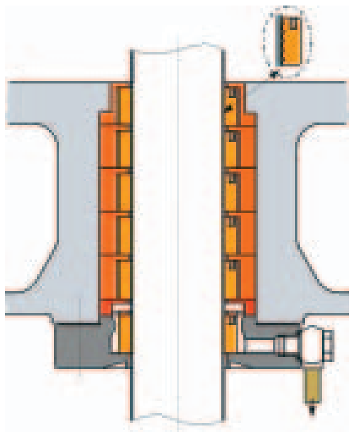
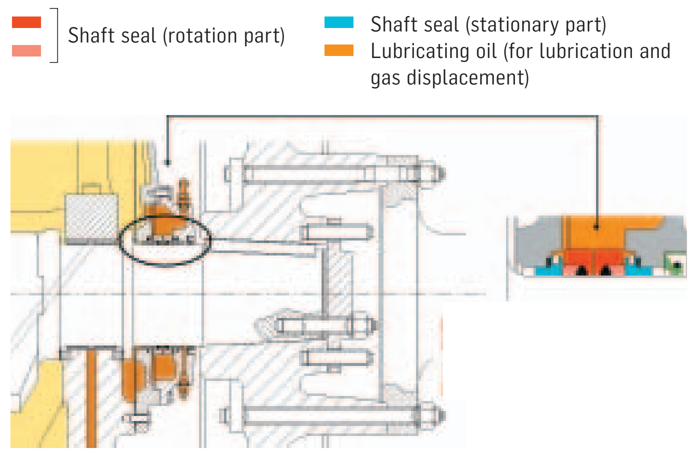


Fig. 8
Gas-tight sealing of crankshaft between crankcase and environment



CHAPTER 3

TEMPERATURE AND DEFORMATION OF CRANKCASE

Gas temperatures at the first stage inlet valves are so low that energy imparted to the cylinders during gas compression raises their mean temperature to a value still well below that of ambient air. Therefore they do not have cooling jackets. They cool down well below freezing point of the moisture in the natural atmosphere and consequently become covered with a thick layer of ice when the machine is running. **Fig. 5**
To ensure a good alignment of the path of the labyrinth pistons, cold deformation of the crankcase underneath the first stage cylinder is prevented by means of a special water jacket at the lower end of the cylinder bloc which acts as a thermal barrier. **Fig. 6**

CHAPTER 4

INTERNAL AND EXTERNAL LEAKAGE

Consistent with the design of the pistons, labyrinth seals are also used between the double acting cylinders and the distance piece at the upper end of the crankcase. **Fig. 7**
Each gland has a collector chamber before the lower end of the labyrinths from where the leak gas is internally returned to the suction up-stream of the first stage cylinders.

To attain a perfect external tightness of the machine the passage of the crankshaft through the wall of the crankcase are sealed off by a rotating double sided ring seal immersed in oil. Thus, the entire inside of the frame is integrated into the gas containing system and can be pressurized at will with either natural gas or an inert gas. In the case presented here it is left at suction pressure level and filled with natural gas. The entire machine represents therefore one hermetically closed shell with no gas leakage to the environment. **Fig. 8**

4.1 VALVES

No precise records are available on lifetime of valve discs. However, orders for replacement parts indicate that the average lifetime expectance of a valve plate is 16'000 hrs, with no distinction between cold and warm running valves. These results are remarkable.

Fig. 9
Three Laby® Compressors for LNG boil-off in Taiwan

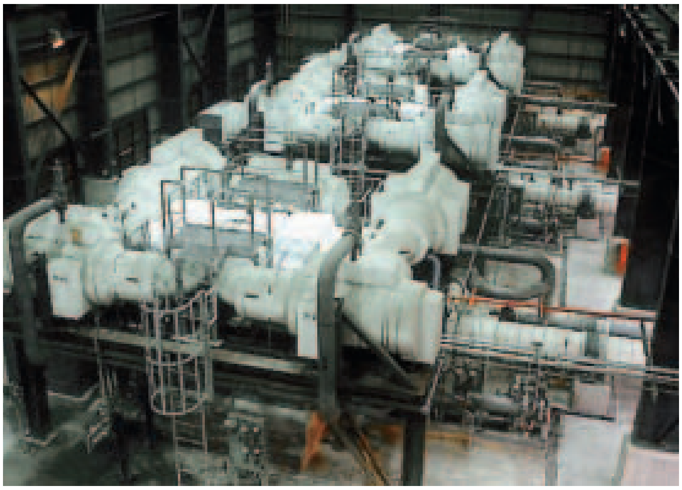


Fig. 10
Gas temperature readings taken during the start-up of a Laby® for LNG boil-off gas

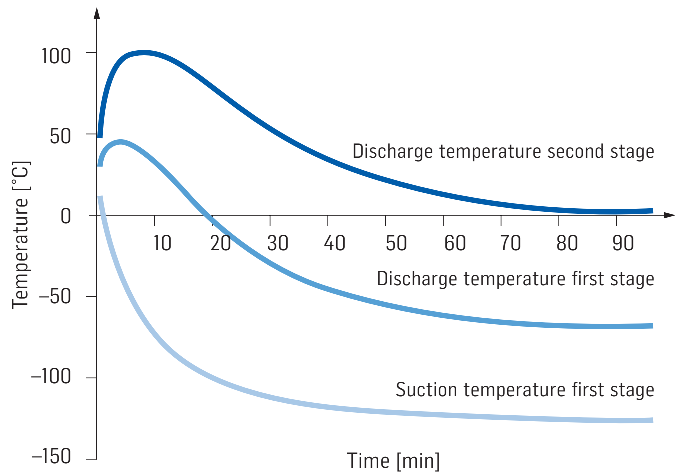


Table 3
Maintenance report on a period of 110'000 running hours (1998)

Pistons (total of 4)	**no replacement whatsoever**	
Piston rod seals	first replacement	after 14'350 hrs
	second replacement	after 36'993 hrs
	third replacement	after 61'790 hrs
	4th replacement	after 83'685 hrs
Piston rods	**no replacement whatsoever**	
Crankshaft seal	first replacement	after 14'350 hrs
	second replacement	after 36'993 hrs
	third replacement	after 83'685 hrs
Bearings		
Piston rods guide bearings	first replacement	after 36'993 hrs
	second replacement	after 61'790 hrs
Crossheads	**no replacement**	
Crosshead pin bearings	**no replacement**	
Connecting rod bearings	**no replacement**	
Crankshaft bearings	one bearing lost	after 14'350 hrs
	no further replacement	

CHAPTER 5

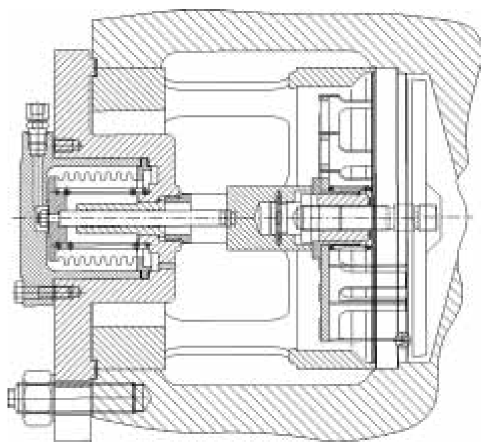
OTHER LNG TERMINALS

The successful performance of the Laby® in this market segment has encouraged other terminals to install new machines of the same kind built to the same principles.

Fig. 9 shows a group of three Laby® Compressors for LNG boil-off in a Taiwanese terminal where LNG is received, stored and evaporated for distribution by a pipeline system throughout the island of Taiwan. **Fig. 9**
The first three identical Laby® Compressors were delivered in 1988. When the terminal was extended in 1992, in view of the successful operation of these units an order for an additional compressor was placed. In this case a two stage machine was required. As the discharge temperature after the second stage reaches about minus 50 to 0 °C only, both stages have uncooled cylinders.

Two other LNG boil-off gas compressors of similar size were commissioned in December 1993 at Pyeong Taek Korea LNG receiving terminal. The maintenance reports for the above mentioned compressors show very similar satisfactory results. When considering all these seven LNG boil-off compressor units (4 cranks, 300 mm stroke) comprising 28 pistons, with a total running time of more a 450'000 hours (2003), there has been no replacement whatsoever of any labyrinth piston. This is a remarkable operating experience. **Table 3**

Fig. 11
Suction valve with gas actuated unloading device



CHAPTER 6

START-UP PROCEDURE

Special attention has been given to producing a simple start-up procedure. The low thermal expansion coefficient of the chosen cylinder material leads to low thermal stress. Together with carefully designed pulsation dampeners and a well engineered gas piping arrangement the system allows full automatic start-up of the compressors. The transition from ambient temperature down to boil-off temperature is achieved without any precooling. **Fig. 10**

CHAPTER 7

CAPACITY CONTROL

There are two main reasons, why compressor regulation is used: The most prevalent one is to adjust the suction flow to match the process demand. The second important reason is to save energy.

In contrast to many other compressor types, reciprocating compressors offer a large variety of capacity control systems. The correct type of capacity control is determined by many parameters. Not all types of capacity controls can be used with a given compressor model, a specific pressure range and gas composition. The engineer who has to specify a process compressor, should clearly describe the required turndown requirements and ask the compressor manufacturer to recommend the best applicable type of capacity control.

The compressors in the Taiwanese Terminal are equipped with valve unloaders 100/75/50/0%. For two stage compression without gas coolers and reliquefaction of the compressed gas, this is the favorite solution. **Fig. 11**

The described compressor in the Middle East, however, as an alternative to valve unloaders, is equipped with a bypass over the first stage. This system is very common for three stage compression in industrial gas applications. With an intercooler between second and third stage the discharge temperature of the third stage is well under control.

By using the superheating effect of the bypassed gas on the suction temperature of the first stage, the mass flow can be continuously turned down to 50 %. This system has demonstrated:

– Simple reliable low cost solution, as standardized components can be used
– Continuous and flexible capacity control with a good partial load efficiency. **Fig. 12**

Fig. 12
Capacity control

Capacity control with valve unloads 100 / 75 / 50 / 0% | **1st stage of three stage compressors**

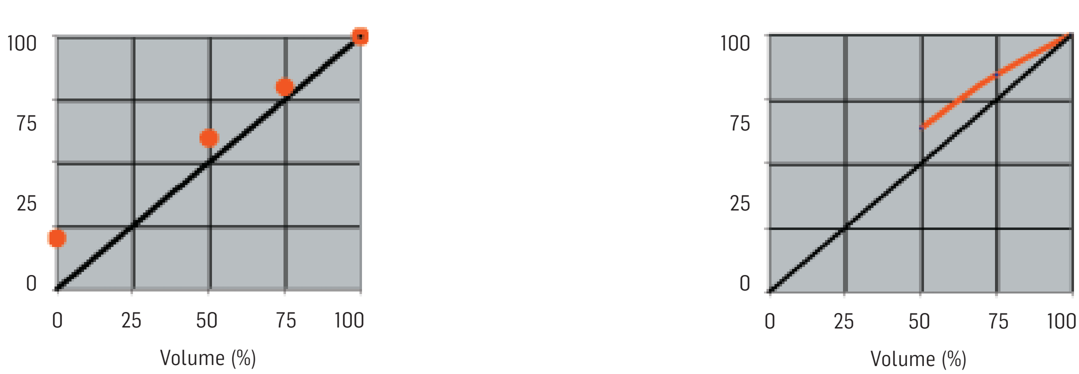
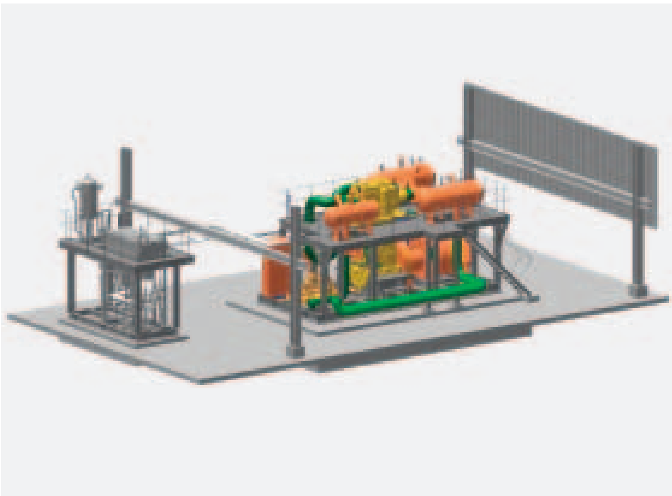


Fig. 13
One of two LNG boil-off gas compressors in the design stage and as installed on-site at the BBG Bilbao LNG receiving terminal, Spain



CHAPTER 8

PLANT DESIGN

In addition to being a compressor designer and manufacturer, Burckhardt Compression also engineers, procures and provides commissioning of whole systems. The use of their systems is demonstrated in every nut and bolt from suction to discharge side of the compression unit, comprising pulsation equipment, filters, lube oil systems, motor driver, gas and water piping, pulsation studies, mechanical- and thermal stress analysis of the gas pipings, as well as complete control systems. **Fig. 13**

CHAPTER 9

CONCLUSION

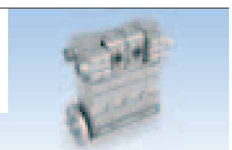
Low gas temperature challenges gas compressors in two ways:
– Physical contact with cold gas and consequences for material properties
– Absence of humidity (low dew point) with a strong bearing on tribology in non-lubricated areas

The application of labyrinth seals in reciprocating compressors is a logical answer to these problems. Laby® Compressors have demonstrated this in industrial operation successfully down to boil-off temperature of natural gas at minus 160 °C. Such machines can be built with zero leakage to the environment, combining reliability with low maintenance.

Burckhardt Compression

RECIPROCATING COMPRESSORS
LEADING TECHNOLOGY FOR
LOWEST LIFE CYCLE COSTS

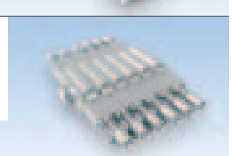
Laby® Compressors
Contactless
and oil-free



Laby®-GI Compressors
Fully balanced

Process Gas Compressors
API 618 –
full compliant

Hyper Compressors
Safe and reliable
up to 3'500 bar



COMPRESSOR COMPONENTS
BEST PERFORMANCE
AND LONGEST LIFETIME

Valves:
- Burckhardt Poppet Valve™
- Burckhardt Plate Valve™
- Manley® valve, licensed by Burckhardt Compression

Piston rings

Guide rings

Piston rod packings

Packing rings

Oil scrapers

Hyper/secondary compressor parts

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THE FULL RANGE OF SERVICES

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