μ-separation

The New Technology of

Condensed Rotational Separation

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GLOBAL CCUS SUMMIT 2012

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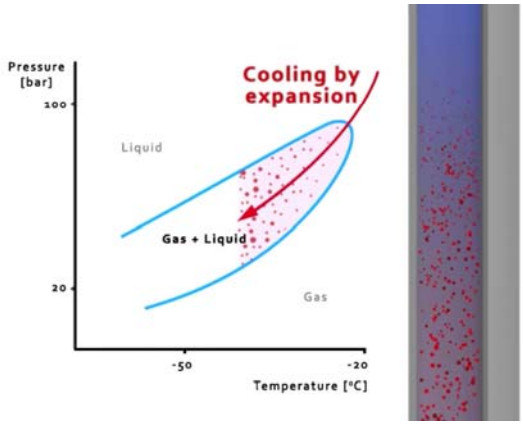
Contents

μ-separation 1 Principles of CRS and RPS

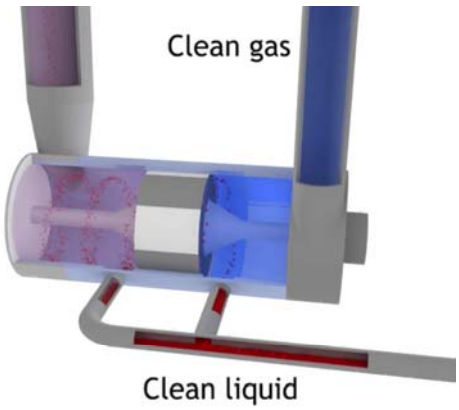


Innovation 1:

Fast cooling of mixture into the two phase region by expansion through J-T valve or turbine

One component becomes a mist of fine droplets.

μ-separation 1 Principles of CRS and RPS



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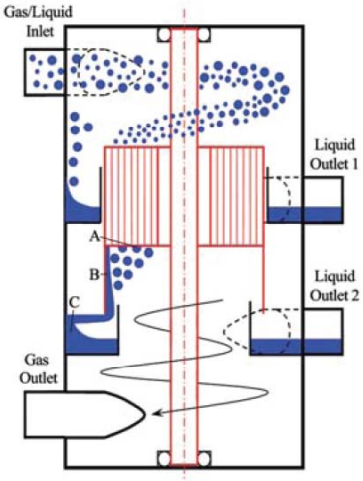
Innovation 2:

The fine droplets are separated by the Rotational Particle Separator

μ-separation — 2 RPS designs



The **rotational phase separator** (RPS) is a cyclonic device wherein a rotating element is placed. The rotating element is a simple cylinder consisting of a very large number of axial channels or pipes of a few millimeters in diameter.

The cylinder is freely mounted in an enclosed stationary housing. Rotation is generated by the tangential velocity of the gas entering the device.

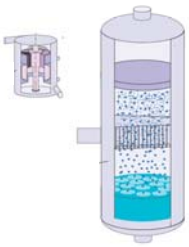
The micron-sized droplets are centrifuged to form a liquid film at the channel-wall. The film is ripped of at the exit of the channel in the form of droplets; typically 50 micrometer or larger. These droplets are separated according the working principles of ordinary axial cyclones.

Large droplets are centrifugated to the wall in the inlet part of the device. They leave via outlet 1. The fine droplets (1 to 10 micrometer) enter the channels of the RPS, coagulate, leave the channels as large droplets and leave the RPS via outlet 2

FILTRATION (2012) 12(1) 49-60

μ-separation — 2 RPS designs

Size advantage of the RPS



Selection Guide - Mist Elimination Equipment

	Knitted Mesh	Vane	Fiberbed	Cyclone	RPS
Cost	1	2-3	10	3-5	5-10
Gas Capacity	5	6-15	1	15-20	20-50
Liquid Capacity	5	10	1	10	20
Particle Size (micron)	3-10	10-40	< 0.1	7-10	0.5
Pressure Drop, WC	< 25 mm (1")	<10-90 mm (0.4" - 3.5")	50-500 mm (2" - 20")	200-240 mm (8" - 14")	200-240 mm (8" - 14")
Solid Handling	3	10	1	8	8
Relative scale based on 1 as the lowest. Others are scaled.					

adapted from: Koch-Glitsch "Mist Elimination"

The characteristics of the RPS makes it possible to separate particles below 10 micrometer especially under pressure in large throughput installations.

μ-separation 2 RPS designs

The RPS offers economic advantages in processes as:

Scrubbing systems	Inlet separators
Evaporators	Turbo-expander suction drums
Steam drums	Dew-point separators
Knock-out pots	Compressor suction drums,
Inert gas scrubbers	Glycol dehydration
MSF/MED desalination	
Sulfuric acid absorbers and dryers.	

The RPS is particularly applicable to systems where reduction in size / weight is advantageous such as offshore production. The rotating equipment used in CRS eliminates the need for high structures on deck and is not affected by the motion of the platform.

In NGL and LNG plants the RPS improves efficiency by reducing liquid carry-over and equipment volume.

The RPS improves efficiency and reduces size in all processes where droplets < 20 micrometer occur.

The RPS enables the use of efficient high pressure expansion processes for large throughput plants.

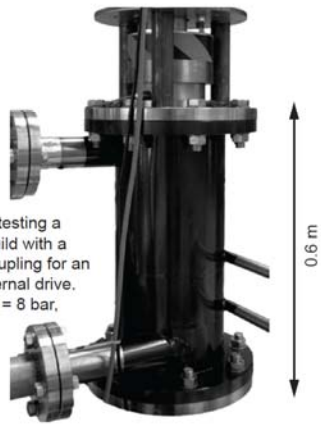
μ-separation 2 RPS designs

For evaluating the cryogenic pressure distillation process of Condensed Rotational Separation two gas- liquid versions are realized: one at lab scale for real process conditions and one at real scale but atmospheric conditions.

T = -60 °C, P = 27 bar, m = 0.02 kg/s

T = 20 °C, P = 1 bar, m = 0.3 kg/s

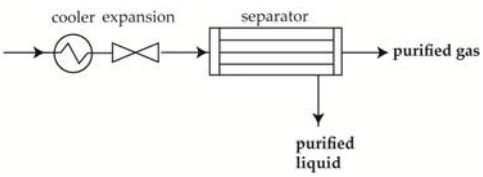
For general testing a version is build with a magnetic coupling for an optional external drive. T = 20 °C, P = 8 bar, m = 0.3 kg/s



All versions perform according to the design specifications

J. Fluids Eng (2010) 132(3) 031301-1 Chem Eng Techn (2012)

μ-separation 3 CRS for contaminated natural gas



Gas and liquid purification

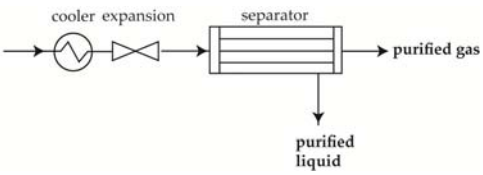
CRS uses pressure instead of temperature distillation:

- Low energy consumption
- Compact installation

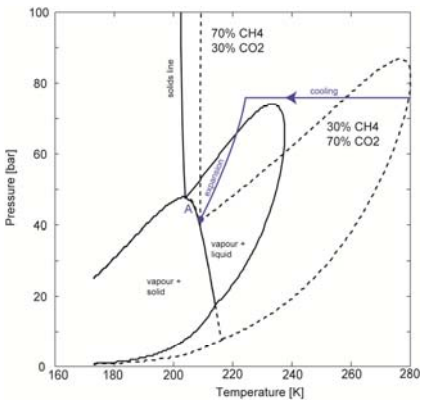
CRS is a break-through technology for bulk separation.

Oil & Gas J. (2006) 104(42)

μ-separation 3 CRS for contaminated natural gas



In CRS the gas mixture is chilled by a combination of cooling and expansion to a point in the phase diagram where the purity of the gas is maximal (A).



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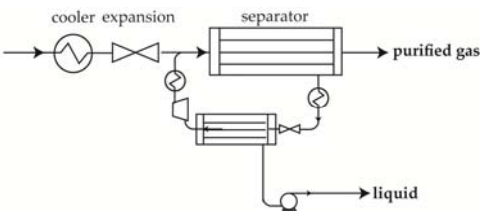
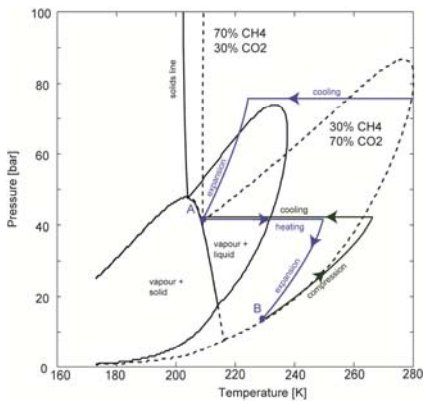


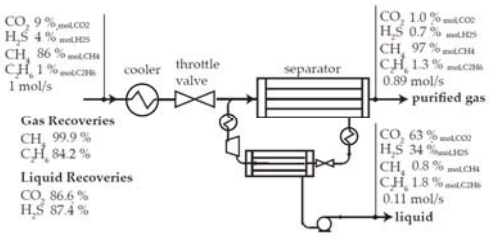


The liquid stream is subsequently heated and expanded to a point of maximum purity of liquid contaminant (B).

The gas from the second flash is compressed and refed to the first stage.

μ-separation 3 CRS for contaminated natural gas

Wasit gas plant Saudi Arabia



CRS Performance Summary:

Gas Purity:
- contaminant CO2+H2S : reduction to ~1%
- contaminant H2S only: reduction to < 1% but not ppm
- contaminant CO2 only: reduction to 12-15 % independent of incoming concentration

Liquid (H2S/CO2) purity: 95 - 99%

Methane recovery: 99.0% - 99%

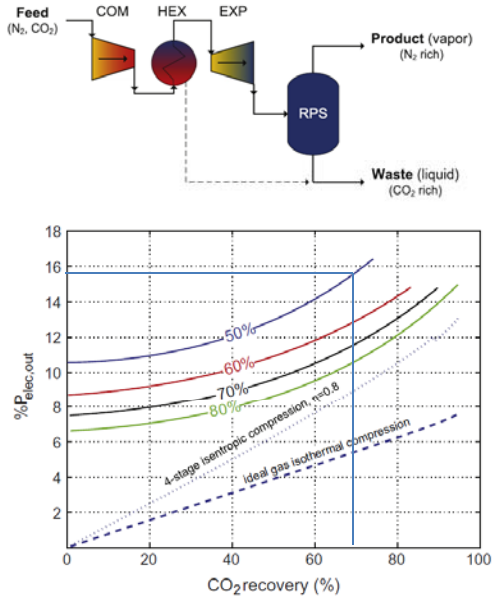
Energy consumtion: 1% - 3% of methane heating value

Residence time 0.1 s hence compact installation

CRS facilitates profitable exploitation of gas fields with contamination levels up to 70 %

J Petrol Explor Prod Technol (2012) 2:49–56

μ-separation 4 CRS for CO2 removal from flue gas



Requires enrichment of CO2 in the feed stream to only 50 % (i.e. by membranes) for a CO2 recovery of 70%.

The energy penalty of CRS is only slightly higher than the energy required to compress gaseous CO2: CRS consumes little extra energy

The advantage is that the capital and operation costs are relaxed on the enrichment step prior to CRS.

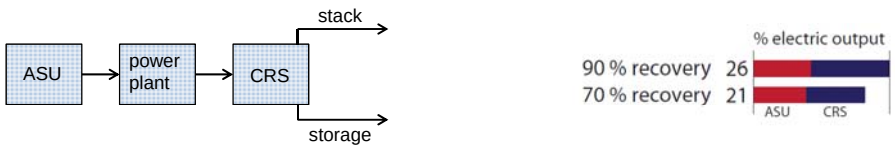
Net result: Size of installation and energy consumption because of CO2 capture become less when CRS is introduced.

CRS becomes more economical with increasing CO2 content in the flue gas (cement production, steel works etc)

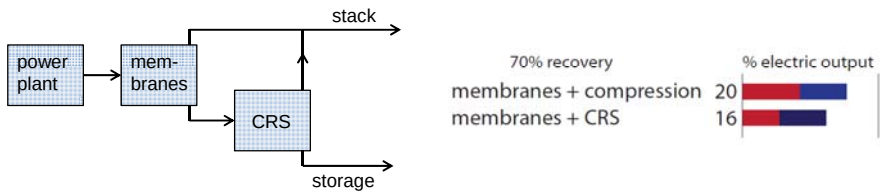
Applied Energy (2012) 93 457-465

μ-separation 4 CRS for CO2 removal from flue gas

Oxyfuel + CRS



Membranes + CRS



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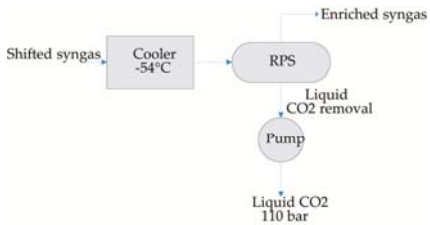
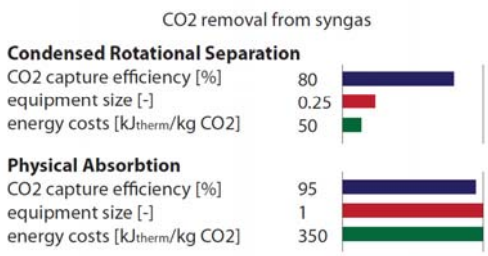
5 CRS for CO2 removal from syngases





Three sequential steps:

1 Cooling of syngas, leaving the coal gasifier, to -54ºC. Part of the CO_2 condenses into droplets

2 Separation of CO_2 droplets from the syngas stream with a Rotational Phase Separator (RPS)

3 Pressuring of the liquid CO_2 to the required sequestration pressure (110 bar). Furthermore the CO_2 is heated up to the supercritical regime which is required for sequestration.

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6 CO2 capture

Topics:

A realistic target for CO2 capture from coal fired units: emission of CO2 the same as that of latest natural-gas fired units having no CO2 capture. This criterion would imply a CO2-capture efficiency of 60-70% for coal based power production.

Can the new technology of CRS become a game changer?

Captured CO2 in liquid form: an interesting option for its transportation , storage, sequestration?

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7 Conclusions

Rotational Particle Separator (RPS) ready for application in hydrocarbon based processes.

Condensed Rotational Separation (CRS): ready for field test in
- upgrading H2S/CO2 contaminated natural gas fields
- CO2 removal from flue gases
- CO2 removal in H2 production

Literature

Buruma, R.C., Kemenade, H.P. van & Brouwers, J.J.H. (2012). *Rotational particle separator as a compact gas scrubber*. Chemical Engineering & Technology, DOI: 10.1002/ceat.201200188
Kemenade, H.P. van & Brouwers, J.J.H. (2012). *Hydrocarbon recovery by condensed rotational separation*. Journal of Petroleum Exploration and Production Technology, 2(1), 49-56.
Benthum, R.J. van, Kemenade, H.P. van, Brouwers, J.J.H. & Golombok, M. (2011). *Condensed Rotational Separation of CO2*. Applied Energy, 93, 457-465.

More on: www.mu-separation.com

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冷凝旋转分离新技术

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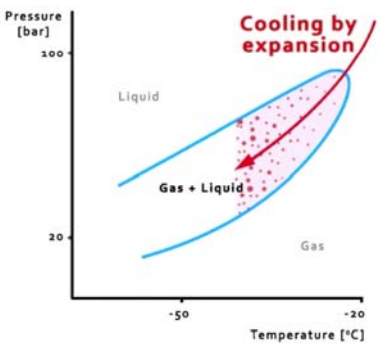
目录

μ-分离

1 CRS与RPS的原理



创新1：

通过J-T阀门或汽轮机膨胀将混合物快速冷却为两相区域.

一部分成为雾状的细小液滴。

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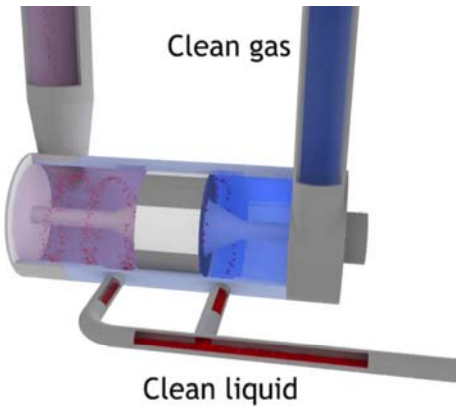
1 CRS与RPS的原理



animation: www.mu-separation.com

创新2：

旋转颗粒分离器将细小液滴分离。

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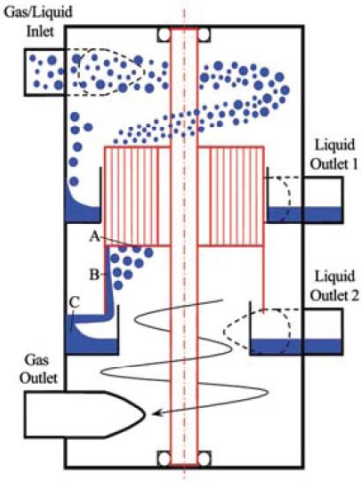
2 RPS设计



旋转相分离器（RPS）是一种气旋装置，其中设有一个旋转元件。旋转元件是一个由大量直径为几毫米的轴向通道或管道构成的简单的圆筒。

圆筒自由地安装在一个封闭的静止箱体内。通过进入装置的气体的切向速度，可以产生旋转。

微米级的液滴因为离心作用而在通道壁上形成一层液体薄膜。薄膜在通道出口处被撕开成为液滴的形式，典型直径为50微米或更大。根据普通轴向旋风分离器的原理，这些液滴被分离。

大的液滴因为离心力的作用汇集在装置入口部分的壁上，然后通过出口1离开。细小液滴（粒径1至10微米）进入RPS的通道，汇集之后作为大液滴通过出口2离开RPS。

FILTRATION (2012) 12(1) 49-60

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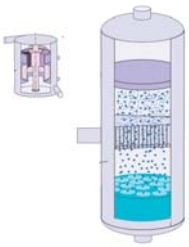
2 RPS设计

RPS的尺寸优势



Selection Guide - Mist Elimination Equipment					
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Gas Capacity	5	6-15	1	15-20	20-50
Liquid Capacity	5	10	1	10	20
Particle Size (micron)	3-10	10-40	< 0.1	7-10	0.5
Pressure Drop, WC	< 25 mm (1")	<10-90 mm (0.4" - 3.5")	50-500 mm (2" - 20")	200-240 mm (8" - 14")	200-240 mm (8" - 14")
Solid Handling	3	10	1	8	8
Relative scale based on 1 as the lowest. Others are scaled.					

adapted from: Koch-Glitsch "Mist Elimination"

RPS的特点使得它可以分离小于10微米的颗粒，特别是在吞吐量较大的装置中在一定压力下进行。

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2 RPS设计

RPS工艺中的经济优势有：

涤气系统
蒸发器
蒸汽锅筒
清箱罐
惰性气体涤气器
MSF/MED脱盐
硫酸吸收器和干燥器。

入口分离器
涡轮膨胀器吸入罐
露点分离器
压缩机吸入罐，
乙二醇脱水

RPS特别适用于需要较小尺寸/重量的系统，如离岸生产。CRS中使用的转动设备不需要在甲板上设立较高的结构，而且不会受到平台移动的影响。

在NGL和LNG厂中，RPS可以减小液体携带量和设备体积，从而提高效率。

在所有液滴小于20微米的工艺中，RPS都可以提高效率、减少尺寸。

RPS允许在大吞吐量装置中使用高效的高压膨胀工艺。

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2 RPS设计

For evaluating the cryogenic pressure distillation process of Condensed Rotational Separation two gas- liquid versions are realized: one at lab scale for real process conditions and one at real scale but atmospheric conditions.

T = -60 °C, P = 27 bar,
m = 0.02 kg/s

T = 20 °C, P = 1 bar,
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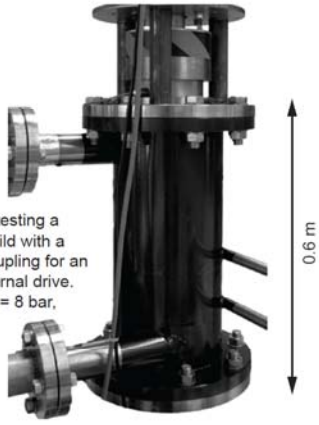
For general testing a version is build with a magnetic coupling for an optional external drive.
T = 20 °C, P = 8 bar,
m = 0.3 kg/s



All versions perform according to the design specifications

J. Fluids Eng (2010) 132(3) 031301-1 Chem Eng Techn (2012)

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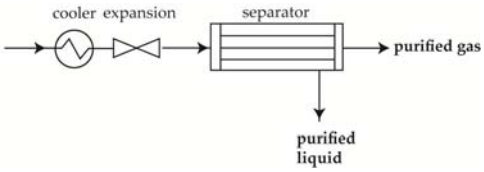
3 污染天然气的CRS



气体与液体提纯

CRS使用压力蒸馏，而不是温度蒸馏：

- 能耗低
- 装置紧凑

CRS是一项突破性的大批量分离技术。

Oil & Gas J. (2006) 104(42)

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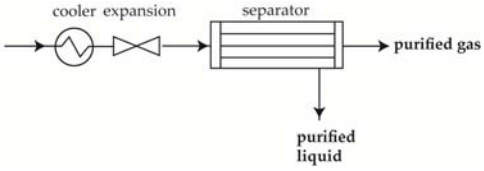
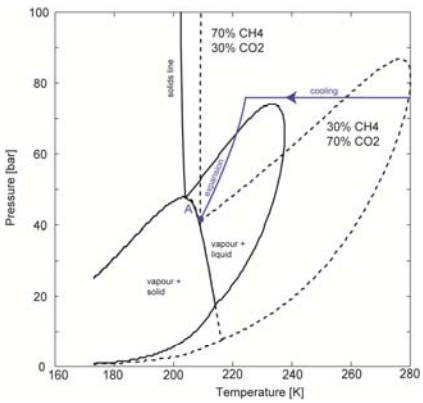
3 污染天然气的CRS



在CRS中，气体混合物被冷却和膨胀的组合作用冷却到相位图中的气体纯度最高的一个点（A）。



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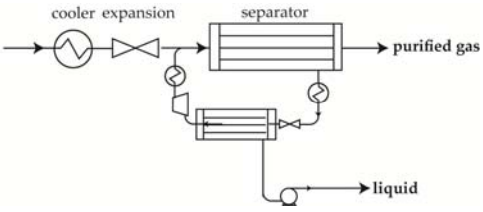

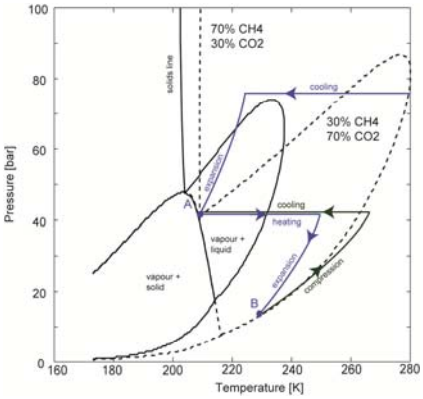

然后液态蒸汽被加热、膨胀到液体污染物纯度最高的一个点（B）。

第二次闪蒸的气体被压缩，重新送入第一级。

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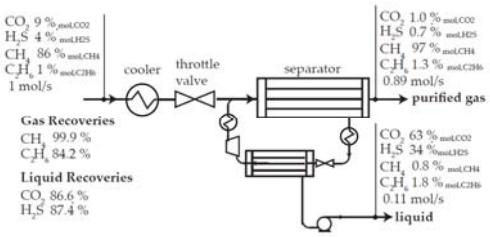
3 污染天然气的CRS

沙特阿拉伯的废气厂



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Liquid (H2S/CO2) purity: 95 - 99%

Methane recovery: 99.0% - 99%

Energy consumtion: 1% - 3% of methane heating value

Residence time 0.1 s hence compact installation

CRS可以使污染水平高达70%的气田的开发有利可图。

J Petrol Explor Prod Technol (2012) 2:49–56

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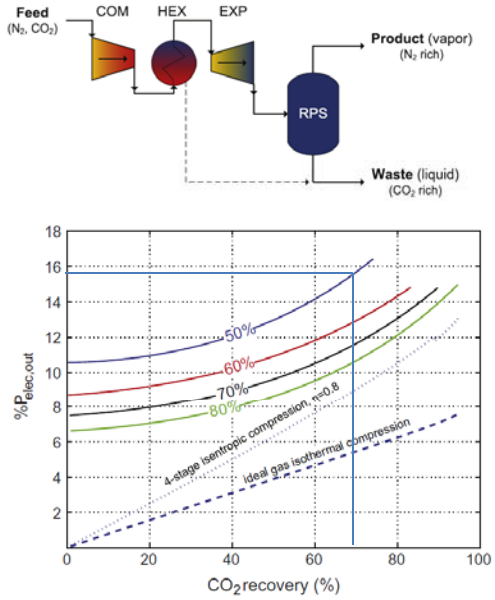
4 从烟道气中除去CO2的CRS



进气流中的CO2富含量只需要50%（即通过膜），就可以实现70%的CO2回收率。

CRS的能耗只是略高于压缩气体CO2所需的能量：CRS本身消耗的能量极少。

优点是放松了CRS之前的富集步骤的投资和运行费用。

净结果：由于引入CRS后捕集了CO2，因此装置规模和能耗都会减小。

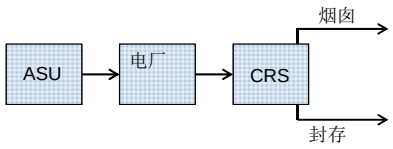
如果烟道气中的CO2含量提高（水泥生产、钢厂等），则CRS会变得更经济。

Applied Energy (2012) 93 457-465

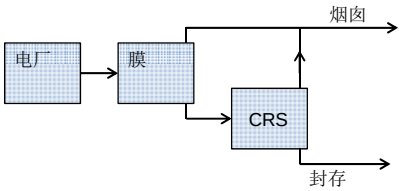
μ-分离

4 从烟道气中除去CO2的CRS

氧化燃料 + CRS



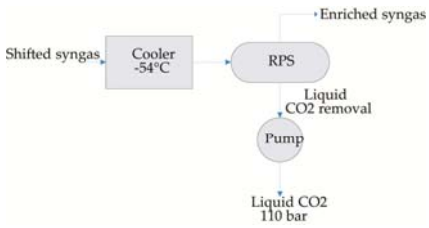
膜 + CRS

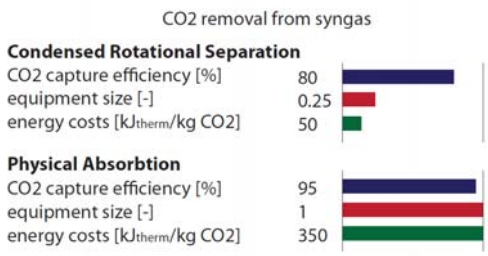


Applied Energy (2012) 93 457-465

μ-分离

5 从合成气中除去CO2的CRS





三个顺序步骤：

1 合成气体离开煤气化器时冷却到-54ºC。部分CO_2冷凝成液滴。

2 用旋转相分离器（RPS）将CO_2液滴从合成气体流中分离。

3 将液体CO_2压缩至要求的封存压力（110巴）。然后将CO_2进一步加热到封存要求的超临界状态，

μ-分离

6 CO2捕集

话题：

从燃煤装置中捕集CO2的现实目标：所CO2排放量与未采用CO2捕集措施的最新的燃天然气装置相同。此标准意味着煤基发电CO2捕集效率为60-70%。

CRS新技术是否会改变游戏规则？

以液体形式捕集的CO2：其输送、储存、封存的一个有趣选择？

μ-分离

7 结论

适用于烃基工艺的旋转颗粒分离器（RPS）。

冷凝旋转分离（CRS）：适用于以下现场试验：
H2S/CO2污染天然气田的升级
从烟道气中除去CO2
在氢气生产中除去CO2

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