Lightning-Flo 3
Polymer Liner

Raised Temperature
Polyketone (PK)

Product Evolution

- Originally developed by Shell as “Carilon” for offshore corrosion control and chemical resistance and acquired by Hyosung

- Thermoplastic Polymers

- Semi-crystalline aliphatic polyketones (PK)

- Its molecular chains are linear, perfectly alternating carbon monoxide and alpha olefin structures that possess a unique balance of strength, chemical resistance and barrier properties that make it well suited for a broad range of application:
    - Elevated temperatures
    - Harsh Chemical Environments

- 2015 Hyosung and **Lightning Rod & Pipe** develop and test the raised temperature PK resin for use in O&G down hole applications having a continuous working temperature of **220F**.

Benefits of LF-3 Raised Temp PK

- Heat Deflection Temperature (HDT) 220F or continuous working temperature performance
- High Melting Point up to 420F
- Excellent permeation performance – Wet H_2S and CO_2
- Resistance to Attack or Swelling
  - Hydrocarbons, Ketones, Esters and Ethers, Inorganic Salts, Acid/Base
- Mechanically Resilient
  - Excellent Ductility broad temperature range
  - Elongation and Impact
- Creep Performance
  - LF-3 RTPK can be subjected to larger cyclic deformations than other ETPs before irreversible deformation (fatigue)
- Hydrolysis Resistance

Application of LF-3 Raised Temp PK

- Reciprocating Rod Lift
- Progressing Cavity Pump
- Salt Water Injection Wells (SWD)
- Rod Guides
- Flow Lines

Combining **functionality** and **cost** to meet the demanding environment of today’s O&G applications.

1. Mechanical Properties

at Room Temperature

Tensile Property (ASTM D638)	PK	PA11 BESNO P40TL	PVDF Kynar 710	PVDF Solef 1010	HDPE PE3408
Modulus, Kpsi	223	35.8	322	333	158
Yield Stress, psi	8740	-	8000	7970	3900
Yield strain, %	24.5	-	7.92	8.42	12.4
Break Stress, psi	11900	5920	6180	5750	3350

1) Chemical resistance

at -30℃

Tensile Property (ASTM D638)	PK	PA11 BESNO P40TL	PVDF Kynar 710	PVDF Solef 1010	HDPE PE3408
Modulus, Kpsi	484.6	170.7	368.4	402.4	303.6
Yield Stress, psi	12380	6815	11320	11210	5889
Yield strain, %	13.3	34.8	6.98	7.27	10.1

at 120℃

Tensile Property (ASTM D638)	PK	PA11 BESNO P40TL	PVDF Kynar 710	PVDF Solef 1010	HDPE PE3408
Modulus, Kpsi	86.00	19.13	76.16	76.20	15.99
Yield Stress, psi	5600	-	2934	3064	-
Yield strain, %	22.97	-	12.3	12.8	-

PK samples (tensile bars taken from extruded liner) exposed at various temperatures for 4 month

Exposure Temp. ℃	Young's Modulus, Mpa (kpsi)		Yield Stress, Mpa (psi)		Elongation at Yield, %	
	Control	exposed	Control	exposed	Control	exposed
-20	3237 (466)		96.3 (13856)		20.1	
0	2322 (334)		77.8 (1119)		24.9	
20	1274 (183)	1173 (169)	61.6 (8863)	57.6 (8288)	33.8	34.4
40	1042 (150)	989 (142)	56.0 (8057)	54.4 (7827)	35.7	32.2
60	693 (100)	978 (141)	50.4 (7252)	54.8 (7885)	36.8	29.6
80	593 (85)	837 (120)	45.8 (6590)	50.7 (7295)	37.4	30.2
100	505 (72.7)	664 (95)	41.0 (5899)	40.2 (5784)	38.3	20.3
120	413 (59)	525 (75)	36.4 (5237)	30.3 (4360)	34.9	15.2

* Multicomponent Liquid: Benzene 1%; Toluene 7%; Xylene 11%; Cyclopentenes 6%; Cyclohexanes 6%; C4-C5 17%; C6-C10 42%; C11 10%

PK exposed for 3 months at 23℃ and 80℃

Exposure at 23℃ for 3 months

	PERCENT RETENTION			
	Drill Mud	**1% EC110A***	**1% Corexit***	**1.5% HF and 7.5% HCL**
Modulus	104%	80%	82%	
Yield Stress	100%	95%	96%	
Yield Strain	98%	104%	101%	
Break Stress	99%	98%	97%	
Break Elongation	70%	72%	58%	

Exposure at 80℃ for 3 months

	PERCENT RETENTION			
	Drill Mud	**1% EC110A***	**1% Corexit***	**1.5% HF and 7.5% HCL**
Modulus	103%	59%	60%	66%
Yield Stress	115%	101%	100%	109%
Yield Strain	68%	103%	102%	91%
Break Stress	118%	101%	99%	120%
Break Elongation	48%	51%	88%	36%

* Corrosion inhibitors: 1% EC110A in 3% NaCl
1% Corexit 6315 in 3% NaCl

PA11 exposed for 3 months at 80℃

	PERCENT RETENTION			
	Drill Mud	**1% EC110A***	**1% Corexit***	**1.5% HF and 7.5% HCL**
Modulus		70%	70%	
Yield Stress		101%	98%	
Yield Strain		88%	87%	
Break Stress		97%	94%	
Break Elongation		48%	48%	

* Corrosion inhibitors: 1% EC110A in 3% NaCl
1% Corexit 6315 in 3% NaCl

Weight Changes for PK and PA11 Exposures

	Weight Changes, %			
	Drill Mud	**1% EC110A***	**1% Corexit***	**HF and HCL**
PK at 23℃	0	0.7	1.8	1.8
PK at 80℃	0.4	4.8	4.9	5.6
PA11 at 80℃		-4.7	-3.8	

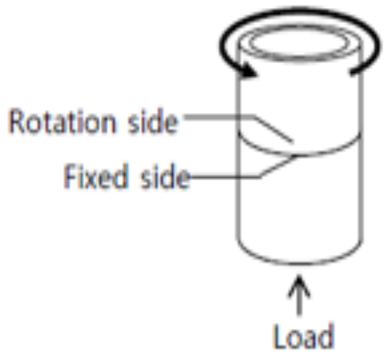
Axial Strain Recovery of PK Pipe from 8% Initial Elongation

Temperature ℃	Time Held	% Strain after 0.5 hr	% Strain after 1.0 hr	% Strain at elapsed time
-20	30 sec 2 hours	0.47 3.76	2.43 3.64	2.25 5 hrs 3.05, 12 hrs
Room Temperature	30 sec 1 hour 2 hours	1.52 1.59 1.73	0.96 1.45 1.46	0.93, 5 hrs 1.36 9 hrs 1.36 19 hrs
50	30 sec 1 hour	1.58 2.00	1.10 1.95	1.07, 4 hrs 1.60, 14 hrs
80	30 sec 2 hours	1.49 2.64	1.45 2.50	1.37, 5 hrs 2.03, 16 hrs

* Tensile bars cut from pipe were held at 8% elongation at given temperature & time.

① Test Method : JIS K7218

[Equipment : Neoplus ‘MPW-110’]



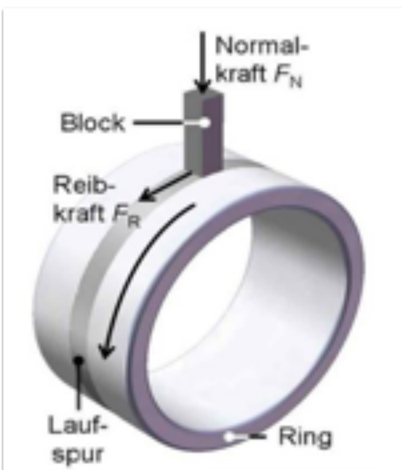
We set two pieces of specimens mesh and rotate to measure friction coefficient and abrasion loss, adjusting speed and pressure.

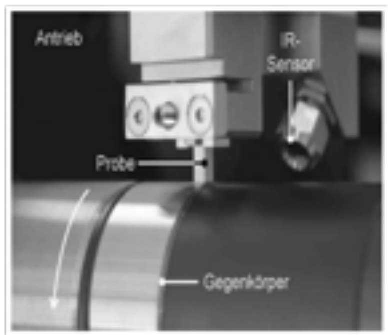
[standard of test specimen]

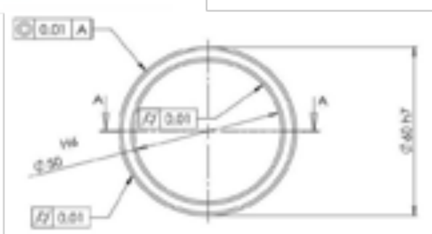
2) Certified test center (external agencies)

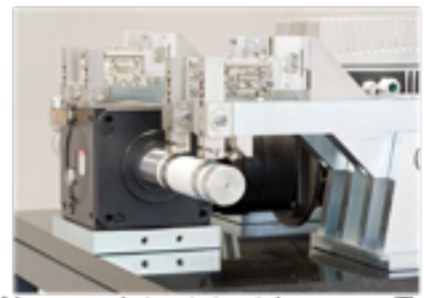
① Test method : ASTM G 137

- With the pressure on the block, total abrasion loss on the ring which rotates is measured.
- The condition is as below;
  Temperature of specimen (Room Temp. or 130~200℃), Rotational speed of rings (0.01~2m/s), Pressure on the block (5~30Mpa)
  On this condition, the linear wear rate of PK is measured
- Specimen Standard :
  Ring (50mm dia. x 28mm width), Block (6.35mm x 6.00mm x 12.7mm)









[Wear resistant test in room Temp.]

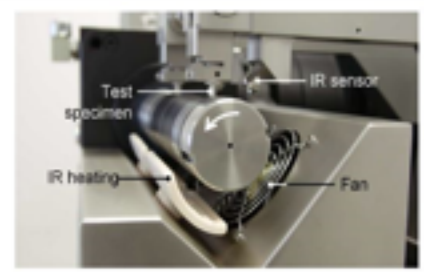


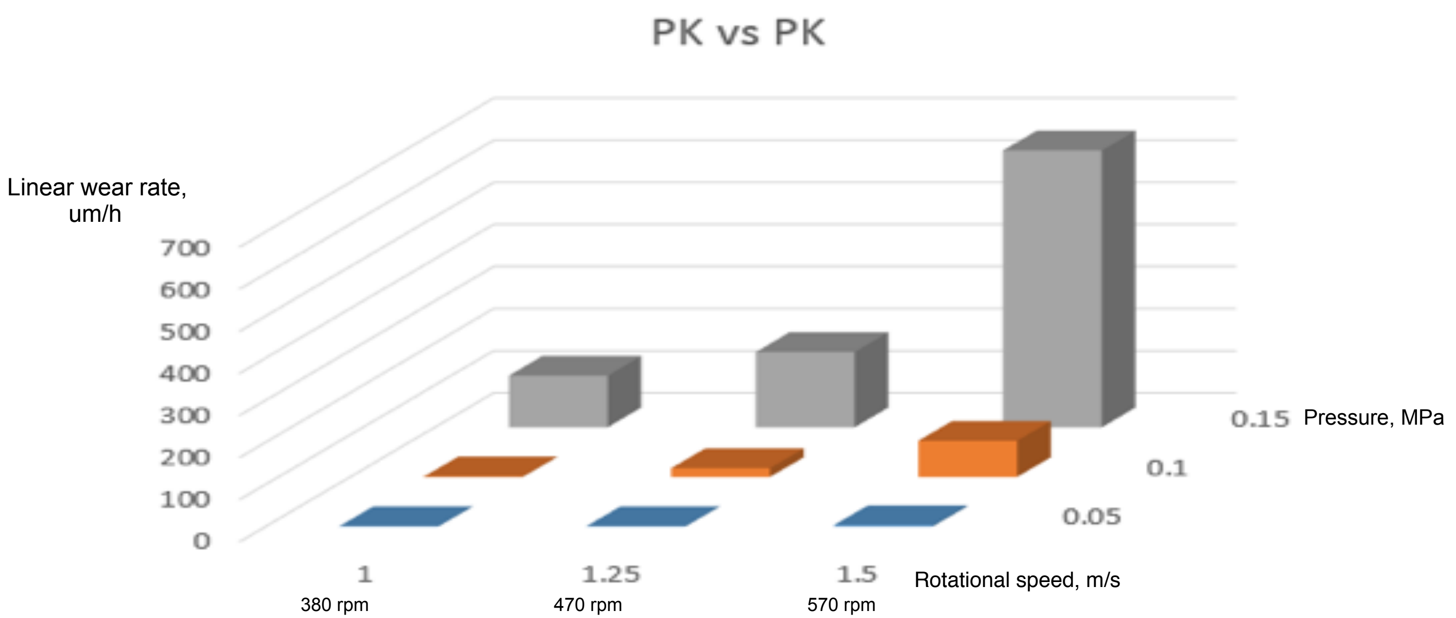
Figure 9: Temperature control unit of the Atlas TT, consisting of a powerful infrared radiator, an infrared thermometer and a cooling fan.

[Allowable limit Temp.: 225℃]

2) External Agencies (Certified test center)

① Resin on Resin (same materials)

- Rotational speed(1~1.5m/s), Pressure(0.05~0.15MPa) under Room Temp (23°C)



Case I.			Case II.			Case III.			Condition			
Pressure (MPa)	Speed (m/s)	Abrasion loss (um/hr)	Pressure (MPa)	Speed (m/s)	Abrasion loss (um/hr)	Pressure (MPa)	Speed (m/s)	Abrasion loss (um/hr)	Block	Ring	Temp. (°C)	Time (hr)
0.05 MPa	1.0	1.3	0.1 MPa	1.0	1.2	0.15 MPa	1.0	123	PK	PK	23	1
	1.25	1.3		1.25	21		1.25	179				1
	1.5	3		1.5	86		1.5	658				1

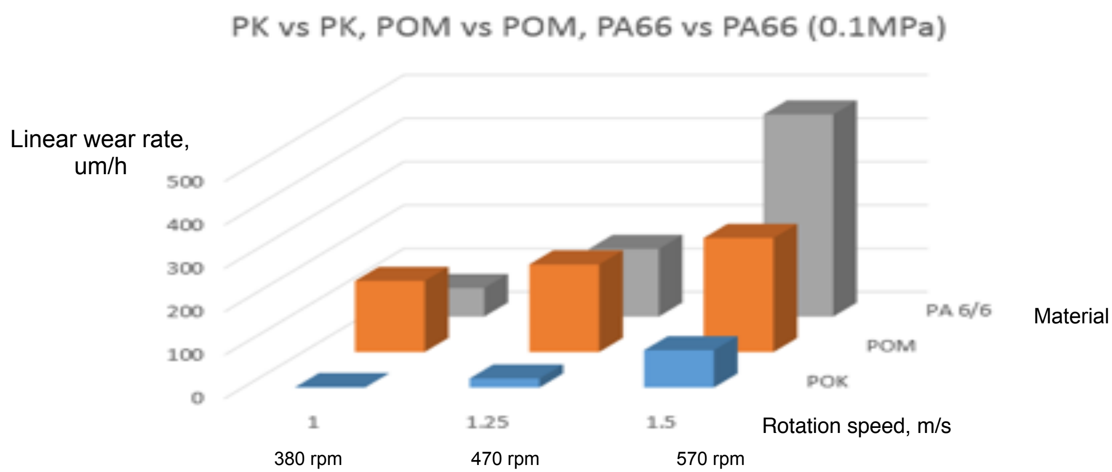
1) Materials: **PK = M630A base resin**
2) RPM (Revolution Per Minutes) = Perimeter (Ring Diameter 50mm X π (3.141592)) / Speed (m/s X 60min X 1,000mm)

2) External Agencies (Certified test center)

① Resin on Resin (same materials)

- Same Condition except maintaining 0.1 MPa

► **Under 1.5m/s, 0.1MPa Condition, PK abrasion loss is the lowest among the test materials.**



Case I.			Case II.			Case III.			Condition			
Block	Ring	Abrasion loss (um/hr)	Block	Ring	Abrasion loss (um/hr)	Block	Ring	Abrasion loss (um/hr)	Pressure (MPa)	Speed m/s (rpm)	Temp(°C)	Time (hr)
PK	PK	1	POM	POM	164	PA66	PA66	66	0.1	1.00 (380)	23	1
		21			202			156		1.25 (470)		1
		86			**263**			**466**		**1.50 (570)**		1

1) Materials : **PK** = M630A base resin, **POM** = Duracon M90-44 base resin, **PA66** = Zytel 101 base resin
2) PK is inferior than other materials under over 1.5m/s, 0.1MPa Condition.
- Abrasion loss (1.75m/s, 0.1MPa) : PK=1,078um/h, POM=619um/h, PA66=1,135um/h
- Abrasion loss (1m/s, 0.175MPa) : PK=48,226um/h, POM=49um/h, PA66=149um/h

2) External Agencies (Certified test center)

② Different Resin (Block PK or POM , Ring PA66)

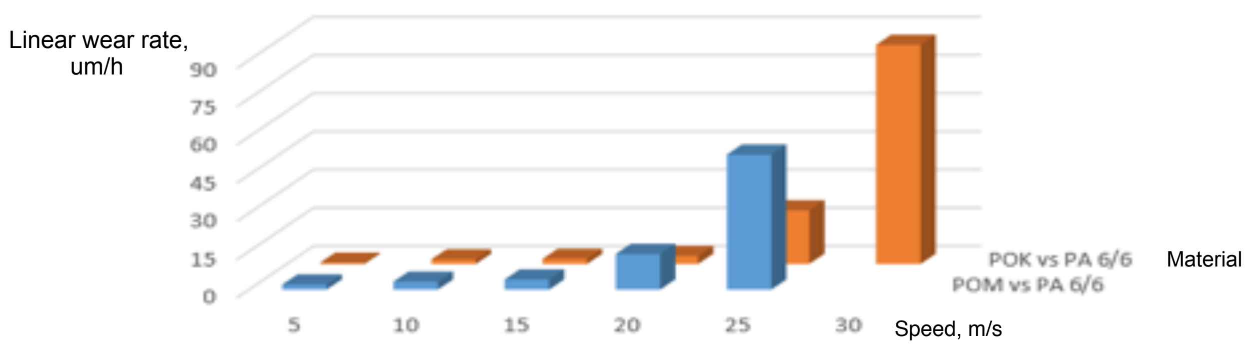
- Maintenance conditions Temp 130 ℃, High Pressure (5~30MPa), Rotational Speed (0.07m/s)

► **PK is superior than POM on abrasive wear performance under High Temp and Pressure**

- PK Abrasion loss (25MPa): 21um/hr, POM Abrasion loss (25MPa): 53um/hr

PK Abrasion loss (30MPa): 86um/hr, POM Abrasion loss (30MPa): Melted material was disappeared

PK vs PA66, POM vs PA66 (0.07m/s)



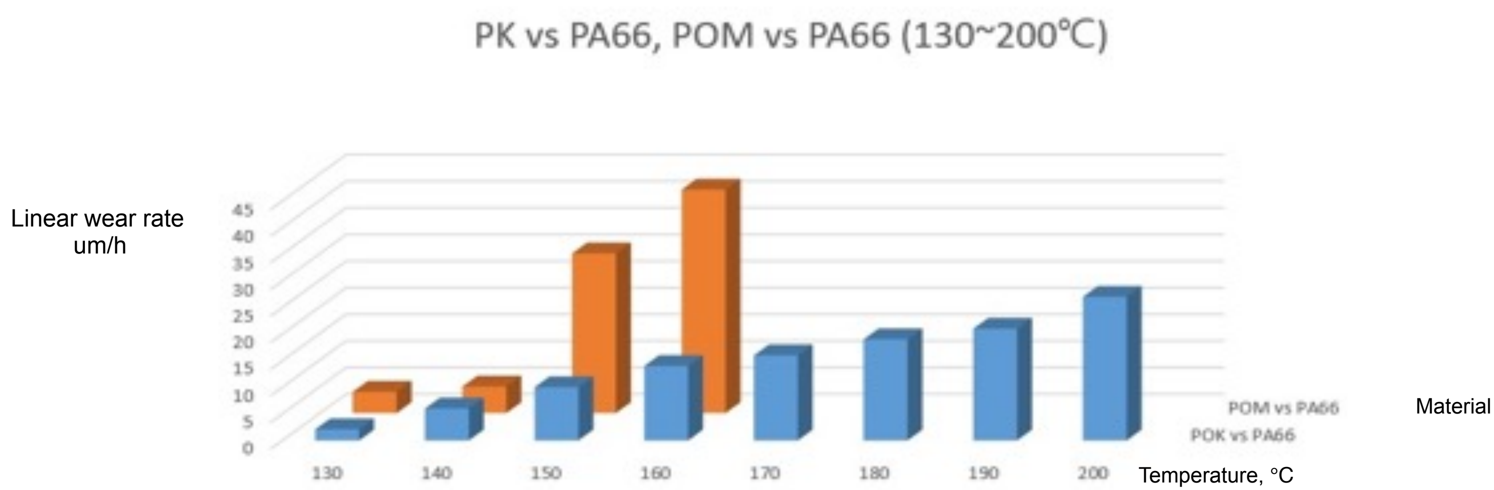
Case I.			Case II.			Condition			
Block	Ring	Abrasion loss (um/hr)	Block	Ring	Abrasion loss (um/hr)	Pressure (Mpa)	Speed	Temp (°C)	Time (hr)
PK	PA66	**0.5**	POM	PA66	**2.0**	5	0.07m/s (26.7 rpm)	130	1
		1.8			**3.1**	10			1
		2.0			**4.0**	15			1
		3.1			**14.0**	20			1
		21.0			**53.0**	25			1
		86.0			-	30			1
		-			-	35			1

1) Materal : **PK** = M630A base resin, **POM** = Duracon M90-44 base resin, **PA66** = Zytel 101 base resin

2) External Agencies (Certified test center)

② Different Resin – Pressure 15Mpa, Temp 130~190°C, Rotational Speed (0.07m/s)

▶ **POM's Abrasion loss is increased Dramatically over 140 ℃ on 15MPa, But PK Contains abrasive wear performance until 200 ℃ on same pressure.**
(※ From 15MPa to 30Mpa, POM's abrasive wear performance is decreased dramatically and thereby the pressure condition is set under 15MPa.)



Case I.			Case II.			시험 조건			
Block	Ring	Abrasion loss (um/hr)	Block	Ring	Abrasion loss (um/hr)	Pressure (MPa)	Speed	Temp (°C)	Time (hr)
PK	PA66	5	POM	PA66	6	15	0.07m/s (26.7 rpm)	140	1
		10			30			150	1
		14			42			160	1
		16			3,202			170	1
		19			-			180	1
		21			-			190	1
		27			-			200	1

1) Material : **PK** = M630A base resin, **POM** = Duracon M90-44 base resin, **PA66** = Zytel 101 base resin

The permeability, Pe $\left[\frac{cm^3(STP).cm}{cm^2.s.bar}\right]$, is described with an Arrhenius type equation:

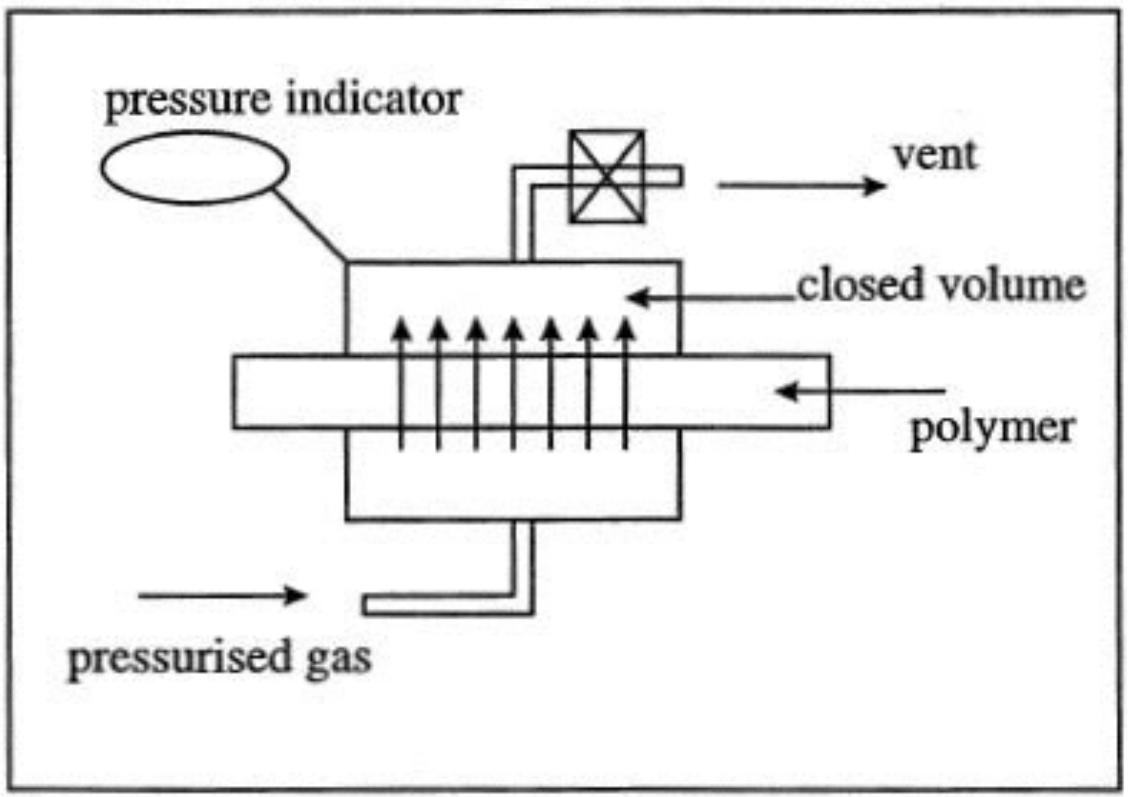


Figure 1 Experimental set-up for determination of permeability.

- Gas permeation resistance for these gases : N_2, He, CO_2, O_3 (ozone)

PVDF → PK → PA → HDPE

3.2. Comments on the simulation program

Table 2 shows the present known permeability's of Rilsan (Polyamide), Solef and Coflon (both PVDF's), HDPE and Carilon (note that not all values are known). The polymers with (Depl) are deplasticised polymer grades. Absence of plastisation components in the polymer has a tremendous reducing effect on the permeability. From these figures, one can already estimate the permeation rates. However, the extra information obtained with the simulation program, is the time scale of the pressure build up. Furthermore, the program allows gas consumption via corrosion of steel.

Table 2. Permeation constants for gases through polymers present in program.

		Rilsan	Solef	Solef (Depl.)	Coflon	Coflon (Depl.)	HDPE	Carilon
CH_4	Pe^0	1.30E-01	7.12E-02	1.60	3.87E-04	1.51E+00	3.76E-02	1.93E-03
	E_a (kJ/mol)	47.7	40.6	56.5	27.3	57.1	40.6	38.5
CO_2	Pe^0	7.91E-04	1.94E-03	-	6.88E-04	8.43E-01	5.06E-04	3.39E-03
	E_a (kJ/mol)	28.5	23.5	-	23.8	49.3	30.1	32.9
H_2S	Pe^0	2.40E-02	1.18E-03	3.00E-02	-	3.37E+00	7.00E-03	-
	E_a (kJ/mol)	32.9	20.6	51.3	-	49.3	39.7	-
N_2	Pe^0	-	-	-	-	-	9.91E-03	-
	E_a (kJ/mol)	-	-	-	-	-	39.7	-
O_2	Pe^0	-	-	-	-	-	4.23E-03	-
	E_a (kJ/mol)	-	-	-	-	-	35.1	-
H_2O	Pe^0	3.26E-04	3.23E-07	-	-	-	2.87E-07	-
	E_a (kJ/mol)	30.2	14.5	-	-	-	18.5	-