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NEW APPROACH TO FLARE GAS RECOVERY SYSTEM USING INTEGRATED RECIPROCATING COMPRESSORS FOR SOLVING ENVIRONMENTAL ISSUE BY MONETIZING GAS

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ABSTRACT

Flare gas is light hydrocarbon gas, by product of any petroleum industry activities, that is flared; and it could not pass into production facilities due its to low pressure. The gas flare volume frequently is significant, causing greenhouse gas emissions which gives serious environmental issue. **Aims:** The purpose of this research is to utilize flare gas in oil and gas fields to reduce environmental issue. **Methodology and Results:** Flare gas in an oil producing field is compressed to produce higher pressure gas flow, by using three one-stage Integrated Reciprocating Compressors to enter the production trunk line. The gas is flown to CO₂ Removal Plant, as the gas would be gas sales. The subject field in West Java, the production wells experiences pressure decline; resulting the wellhead flowing pressure becomes low, so the gas is being flared. The gas flare recovery system is economically profitable both for purchase and rental scenarios. Renting the equipment is more profitable and has lower technical risk, because all risks is burdened to rental service provider. **Conclusion, significance and impact study:** Monetizing flare gas will reduce environmental issue, and it is utilized for own use or gas sales. The best Economics Scenario is rental scenario.

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- Environmental
- Flare Gas
- Gas Pressure
- Integrated reciprocating compressors
- Monetization

1. INTRODUCTION

Indonesia, in 2015 disposed gas flare for 273,402 MMSCF in one year, based on the Handbook of Energy & Economic Statistics of Indonesia in 2016 (Prabowo, 2016). This amount is equivalent to 8.7% of the total national gas production. The number of gas flare is quite large, so greenhouse gas emissions effect is also quite large which causes serious impacts on regional environmental sustainability (Iqbatayo, 2007). The subject oil field is located in "X" of West Java; as the reservoir pressure of the field is continuously declining, it requires artificial lift method to produce oil from the reservoir to the surface; thus, the flow pressure at the wellhead is low. The oil and its associated gas with low pressure enters the separator production facilities, and the released associated gas from the oil separation is discharged as gas flare (PT. Pertamina EP, 2015).

Flare gas is a hydrocarbon gas produced from exploration, exploitation and production or processing of oil or natural gas activities (Rukmana *et al.*, 2011). In this study, the gas is burned because the production facilities would not able to process the gas, due to low pressure. The gas flare is the associated gas from oil, as the result of petroleum operation activities. The use of gas flare is generally constrained by relatively small and spreading gas volumes, and it could not enter the network pipeline infrastructure (PT. Pertamina EP, 2015).

The environmental effect of the gas flare is widely studied around the world (Kadir, *et al.*, 2013), studied that volume of carbon dioxide in the air of several villages in Nigel Delta are directly affected by the gas flare; the higher volume of gas is being flared, the higher volume of carbon dioxide is in the air. There are ways to conserve the gas and also the energy, for example gas injection or gas monetizing the gas flare. It is well known, that conserving the gas by injecting the gas into reservoir, needs integrated study of Geophysical, Geological, and Reservoir Engineering study about the reservoir, and also needs high investment on surface facility; more over it needs high volume of gas (Kadir *et al.*, 2013). Gas monetization is a simple solution for reduction environmental issue and conserving the gas, since the subject field is close to gas sales facility; or the gas could be utilized as fuel gas for power generation of the field facility (Nurwahidi, 2015).

There are countries and oil companies that already have conducted flare gas recovery systems; they are:

1. Abu Dhabi Company for Onshore Oil Operation (ADCO) conducted a flare gas recovery system application with a pilot project in 1999 in the Middle East bay area (Wasfi, 2004).
2. ADCO experiences more than ten years of flare gas recovery systems (Saadawi, 2013).
3. Qatargas has also carried out a flare gas recovery system at Qatargas's LNG which operates in Ras Laffan Industrial City (RLIC) (Bawazir *et al.*, 2014).
4. Abu Dhabi Gas Industries Ltd. also implements a flare gas recovery system at the Gasco Plant (Allamaraju and Mukherjee, 2016).
5. Indonesia, gas flare recovery is applied at VICO Indonesia (Zainuddin, 2007).

Considering this potential, flare gas recovery system is necessary by utilizing Integrated Reciprocating Compressors. The burned gas could be monetized by compressing the flare gas to get high pressure and tie into the existing gas production network. This method would overcome environmental issue, and it uses the gas for own use of power generation (Allamaraju and Mukherjee, 2016)

Calculation of gas fuel requirements with the theoretical calculation method of internal combustion engine for discussed (Wasfi, 2004). Analysis to calculate the economic scenario of purchase or rental the gas recovery unit is performed, with the economic regime of production sharing contract with cost recovery (Indrawan, *et al.*, 2008).

Flare gas recovery unit for gas conservation, generally is in the form of gas compressors. In flare gas recovery unit technology development, it is divided into two types; Conventional Compressor of reciprocating, rotary, centrifugal and axial compressor, and Unconventional Compressor of hybrid screw compressor and surface jet pumps. The Unconventional Compressor usually is not called as compressors (Peeran and Beg, 2015). Flare gas recovery system compresses gas flare in order to meet network pressure requirement. Integrated Reciprocating Compressors in this study is a flare gas recovery unit consisting reciprocating compressors with single stage compression stages. Integrated Reciprocating Compressors with trademarks Gas Jack Compressor (Figure 1) could increase ratio between inlet and outlet of gas pressure up to 18 times.

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Figure 1 Gas jack compressor (Compressco, 2009)

Table 1 shows the Gas Jack Compressor specification. The gas fuel consumption is very small of 6 to 12 MSCF, as compare to the total flare gas.

Table 1 Technical data on gas jack compressor (Compressco, 2009)

Type	Integrated Reciprocating, Single stage
Package Model	Portable, C1D2
Power Draw	46 HP
Speed	1,100 - 2,200 RPM
Noise Level	< 85 dBa
Compression Ratio	Wide Range Ratio, up to 18
Suction Pressure	minus 18" Hg to plus 50 psig
Discharge Pressure	up to 400 psig
Discharge Temperature	90 – 100 °F (after cooler)
Flow Rate	up to 750 MCFD (depends on gas characteristics, suction pressure)
Blowcase Capacity	50 bbl/day
Dimension and Weight	L x W x H (cm): 375 x 198 x 250, Weight Gross: 7000 lbs
Fuel Consumption	6 - 12 MSCFD
Fuel Specs	> 800 - 1300 BTU, CO ₂ < 15%, H ₂ S < 50 ppm

The subject field, until June 2015 gas flare was around 1.2 MMscfd with CO₂ content of 33.38 mol %. Since the gross heating value is 1048.9 BTU/Scf; the total heating value of gas flare is 1,258.68 MMbtu/d, and the assumption of selling gas prices is 5 US\$/MMbtu; the gross

income from gas flare is around US\$ 6,293.5. Knowing this potential, a flare gas recovery system needs to be carried out by using Integrated Reciprocating Compressors.

The flare gas could be monetized by compressing one stage compressor, for the gas flare enter the production network (Iqbatayo, 2007). The gas could be used for the field utilities; such as gas fuel electric generators; for oil production enhancement; such as gas injection; or for gas sales to gas sales network as additions to the gas production capacity. The research is expected to provide solutions for oil and gas fields in Indonesia that waste gas flare, with volumes of gas flare ranging from 0.3 MMscfd to 2 MMscfd in each field. The area needed to put the gas compressor in place is small, and the compressor is easily to be installed and removed from the existing gas facility.

The gas flare data is limited to only form year 2015 until 2018, and the gas flare forecast is from year 2019 to 2022 at constant gas flare rate. The gas forecast is used to perform the economics of running the Integrated Reciprocating Compressors for 4 years.

The utilization of gas flare by converting the gas for better use would reduce the negative impact flare gas on environment, and off course the global warming.

2. RESEARCH METHODOLOGY

Methodology of this research uses primary data collected in subject field; namely gas flare volume, gas characteristics, operating conditions and monthly reports of Integrated Reciprocating Compressors. Then, the technical aspects determine the unit requirements based on gas flare volume, analysed fuel requirements, horse power, availability and performance of the unit. Economic analysis with a production sharing contract (PSC) cost recovery is carried out by comparing purchase and rental scenarios. Figure 2 is the operating flow diagram of the subject field.

The Block Station of subject field is in West Java, which has CO₂ removal plant that serves to lower CO₂ levels up to less than 10% mole, because the subject gas field produces high CO₂ of 30% moles (Indrawan *et al.*, 2008). The main facilities in the subject field are Low Pressure, Medium Pressure, High Pressure Manifolds, and Low Pressure, Medium Pressure, High Pressure Test Separators, CO₂ Scrubber, CO₂ Plant Removal, Flare Stack, Tank, Transfer Pump. Figure 2 shows the flow operations diagram of subject field. The black and blue lines are the existing

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production pipe lines. The yellow lines are modified pipe lines, to accommodate the usage of gas flare by installing the Integrated Reciprocating Compressors.

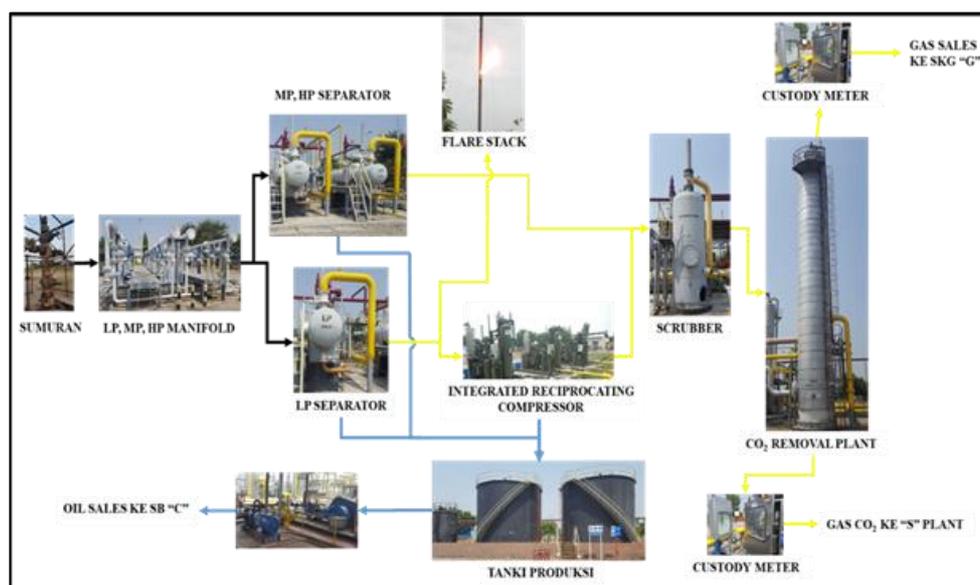


Figure 2 Flow diagram of surface facilities on subject field (Compressco, 2009)

Integrated Reciprocating Compressors consists of one engine block gas compressor type "V". The engine is modified for one bank of cylinders 46 HP power. Another bank of cylinders is for gas compression. The fuel gas needed is quite small; ranges from 0.006 to 0.012 MMscfd. The flow diagram of Integrated Reciprocating Compressor is depicted in Figure 3. Initially, pipe lines from low pressure separator was directly to the flare stack, where the gas was flared. Modification of the pipe lines was made to flow the gas from low pressure separator to the Integrated Reciprocating Compressors. Along with pipe line from medium and high pressure separators, the gas was flown to further processing to remove impurities. The Integrated Reciprocating Compressors is part of flare gas system.

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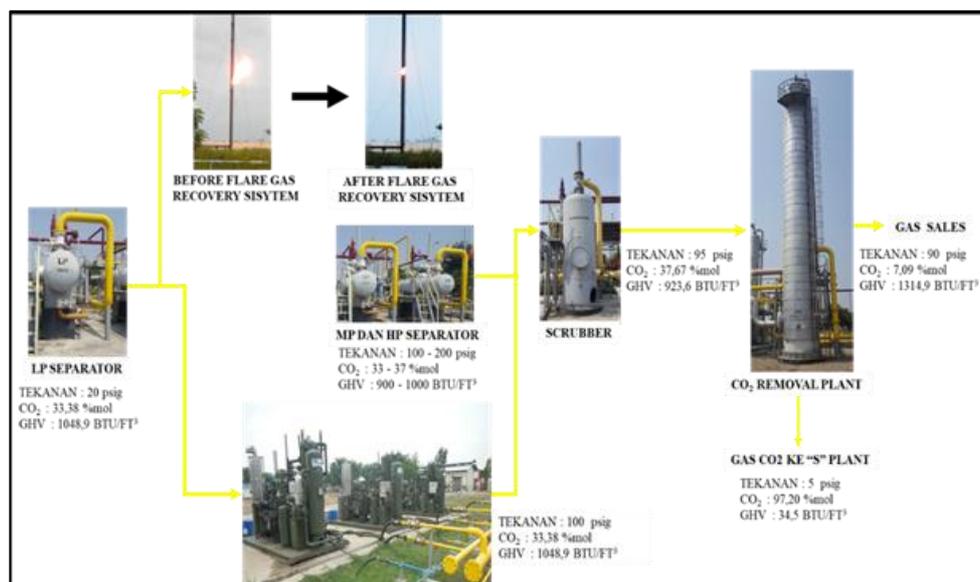


Figure 3 Flow diagram of flare gas recovery system (Compressco, 2009)

Field data gather from the field, consists of:

1. Flare gas volume or its characteristics.
2. Performance or integrated data of Compressors Reciprocating operation, which includes production rate from monthly report and daily report, and other pertinent data.

The research is carried out by observing the applications of Integrated Reciprocating Compressors usage to accommodate the gas flare; by evaluating and analysing the following data:

1. Analyse composition and characteristics of gas flare.
2. Calculate number of valve configuration units for Integrated Reciprocating Compressors according to gas flare operating conditions and its volume.
3. Analyse operating conditions and required gas compressor design.
4. Calculate and analyse actual power and compressor fuel gas usage.
5. Analyse performance of gas compressor during operation; which includes fuel gas, horse power for implementing Integrated Reciprocating Compressors.
6. Calculate and analyse Integrated Reciprocating Compressors economics for the following scenarios (Ghasemikafurdi, *et al.*, 2017):

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- a. Purchase three Integrated Reciprocating Compressors.
- b. Rent three Integrated Reciprocating Compressors.
- c. Without the use of any Integrated Reciprocating Compressors.

Evaluation of gas fuel requirements using the internal combustion engine's theoretical calculation method are as follows (Saadawi, 2013):

1. Amount of air for combustion (lb):

$$Gu = \frac{Pd.Vs}{Z.R.Td} \left(\frac{lb}{\text{Cylinder}} \right) \quad (1)$$

- Gu = Amount of air for Combustion (lb)
- Pd = Air pressure into Cylinder (lb/ft²)
- Vs = Volume of Piston Displacement
- Z = Compressibility Factor
- R = Constanta of Air = 53.5 lbf/lbm °R
- Td = Inlet temperature in combustion room (°R)

2. Total fuel consumption per day (Mscfd):

$$Gf = \frac{Gu(lb) \times N(rpm) \times i}{AFR \times Z} \times \left(\frac{2\pi}{60} \right) \times 3600 \times 0.00039 \text{ Mscfd} \quad (2)$$

- Gf = Amount of fuel used per day
- N = Rotation (rpm)
- i = Amount of Cylinder
- Z = Cycles Index
- AFR = Air to Fluid Ratio

3. Evaluate the actual power of the gas compressor by using the Popan Method:
 - a. Comparison of compression:

$$r = \frac{Pd + \Delta Pd}{Ps + \Delta Ps} \quad (3)$$

R = Compression Comparing, Fraction

Pd = Outlet Pressure, Psig

ΔPd = Outlet Pressure Comparation, Psig

Ps = Static Inlet Pressure, Psig

ΔPs = Inlet Pressure Comparation, Psig

b. Weight of Gas:

$$W = \frac{Q \times \rho_{SC}}{1440} \quad (4)$$

c. Heat of Gas:

$$H = \frac{Zs \times R \times T \left(\frac{K}{K-1} \right) \{ r^{(K-1) \times K - 1} \}}{MW} \quad (5)$$

d. Power of Compressor:

$$HP = \frac{W \times H}{38000} \quad (6)$$

e. Actual Power of Compressor:

$$HP = HP \times Eff \quad (7)$$

3. RESULTS AND DISCUSSION

Flare Gas can be utilized commercially for gas sales by using three Integrated Reciprocate Compressors. The gas flare analysis shows that the feed gas with 33.38% mole CO₂ becomes fuel gas of 7.08% mole CO₂, after CO₂ Remover Plant. Table 2 is the gas composition before and after CO₂ Remover Plant.

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Table 2 Composition of feed gas and fuel (Pertamina, 2018)

No	Parameter	Feed Gas Composition				Fuel Gas Composition			
		% Mole	Mole	AFR	Mole × AFR	% Mole	Mole	AFR	Mole × AFR
1	Nitrogen	1.09	0.011	12	1.12535	1.5	0.015	12	0.1725
2	Carbondioxide	33.38	0.334	0	0	7.08	0.071	0	0
3	Methane	41.99	0.42	17	7.22228	66.5	0.665	17	11.438
4	Ethane	7.73	0.077	15	1.16723	12.54	0.125	15	1.89354
5	Propane	8.96	0.09	16	1.39776	6.1	0.061	16	0.9516
6	i-Butane	1.74	0.017	15	0.25752	1.05	0.011	15	0.1554
7	n-Butane	2.31	0.023	15	0.34188	1.04	0.01	15	1.15392
8	i-pentane	0.77	0.008	15	0.11319	1.08	0.011	15	0.15876
9	n-pentane	0.68	0.007	15	0.09996	1.08	0.011	15	0.15876
10	Hexane+	1.35	0.014	15	0.19845	2.03	0.02	15	0.29841
Natural Gas AFR		1		10.9236		1		15.3809	
Specific Gravity		1.133				0.88			
Compressibility Factor		0.996				0.995			

Analysis of data availability and performance of the three Integrated Reciprocating Compressors at operating conditions, based on average monthly production report for the year 2017, are depicted in Table 3a and 3b. The data consists of compressed gas flare total flow rate, compressor fuel gas calculation, and the actual compressor power.

Table 3a Results of technical calculations

Unit	Ps		Pd	Gu	Gf	Td		r
	Psig	Lb/ft ²				F	Ren	
Unit 1	12.72	1832.33	108.83	0.297	11.3647	108.47	568.14	8.7038
Unit 2	12.70	1828.18	108.94	0.297	11.3390	108.27	567.94	8.7464
Unit 3	11.77	1694.69	109.19	0.275	10.4361	108.05	567.72	9.4427
Average	12.40	1785.07	108.99	0.290	11.0466	108.26	567.93	8.9643

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Table 3b Results of technical calculations

Unit	Q MSCFD	Wg lb/min	Hg ft	HP	BHP	Availability Total Flowrate	
						%	Mscfd
Unit 1	332.69	19.979	71838.67	37.55	34.55	98.66%	108,772.49
Unit 2	318.91	19.152	71496.08	35.93	33.06	95.61%	103,306.03
Unit 3	305.97	18.375	74580.36	35.91	33.04	95.40%	96,937.69
Average	319.19	19.169	72638.37	36.47	33.55	96.56%	309,016.21

The detail of monthly production performance the three units of Integrated Reciprocating Compressors to compress flare gas in year 2017, is depicted in Figure 4.

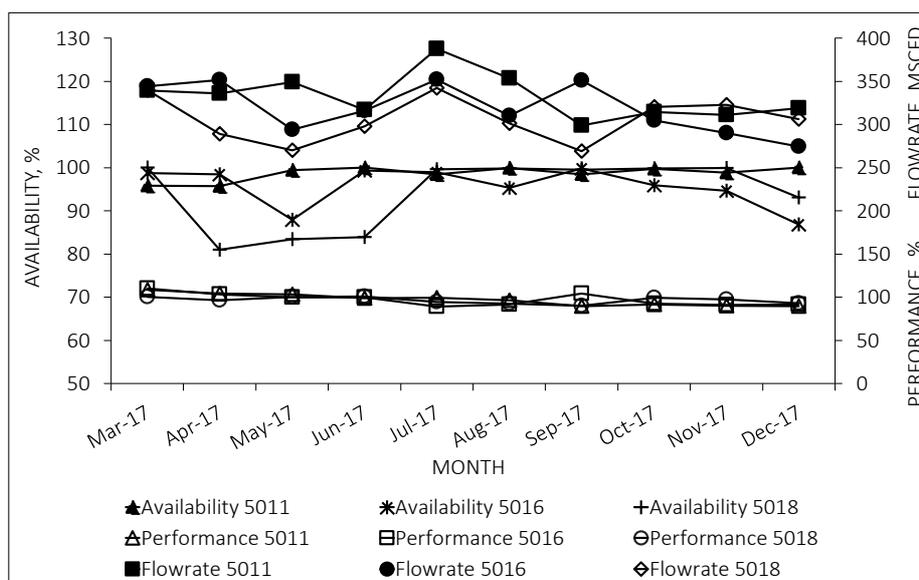


Figure 4 Performance and availability integrated reciprocating compressor

Gas flare in the subject field, as a fluctuating suction pressure of around 10 psig with a discharge pressure of around 100 psig, a compression ratio of 1:10. Data for calculating the economics to be used for analyzing the best scenario between purchase and rental, can be seen in Table 4. The economics assumes that there is flare gas production costs, since the cost is burdened by the existing gas facility.

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Table 4 PSC economic calculation data

Parameter	Value
Tangible Cost	US\$ 600,000
Intangible Cost	US\$ 422,000
Production Cost Gas	1.13 US\$/MMBTU
Rent per Day	US\$ 1,275/day
Over Head Cost	2.00% (Head Quarter, Approval, Admin, etc.)
Depreciation within 5 Years	25.00%
FTP	20.00%
Government sharing before Tax Split	28.57%
Contrator sharing before Tax Split	71.43%
Government sharing after Tax Split	60.00%
Contrator sharing after Tax Split	40.00%
Tax	44.00%

Usually, gas production is shared 70% for the government and 30% for the contractor, but in this study the share of profits for the government is 60% while for the contractor is 40%, because the contractor is a government-owned company. For the selling price of gas, refer to the reference on the www.indexmundi.com website at around US \$ 2.74 with the future price trend going up.

Table 5 Economic summary purchase and rental

Parameter	Purchase	Rental
Investment, \$	1,022,000	-
Gross Reserves, MMBTU	1,834,001	1,834,001
Gross Income, \$	5,264,424	5,264,424
Operating Cost	2,072,421	2,446,725
Government		
Net Cash Flow, \$	602,318	791,076
10% Neet Cash Flow, \$	439,502	608,368
10% Neet Cash Flow, \$	382,000	542,162
Contractor		
Net Cash Flow, \$	905,134	1,156,440
10% Neet Cash Flow, \$	505,955	889,779
10% Neet Cash Flow, \$	359,370	793,165
Pay Out Time, Years	3	-
DCF Rate of Retun, %	33	-

4. CONCLUSION

Based on the results and discussion, it can be concluded that three units of Integrated Reciprocating Compressors can reduce gas flare in the subject field by around 1 MMscf every day. Environmentally, the field operates sustainably, as the field reduces the negative impact on the environment. The subject field has 33.38 mol% CO₂ gas and becomes low CO₂ content gas after CO₂ Removal Plant; and this gas becomes gas sales gas. Flare gas in the oil production fields is compressed from around 10 psig to become around 100 psig, utilizing three one-stage Integrated Reciprocating Compressors for the gas being able to enter the gas production trunk line. Monetization gas flare for the period of 2015 to 2018 by gas flare recovery system is economically feasible for both purchase and rental scenarios. Rental is more profitable as compared to purchase; and rental has lower technical risk, as all risks are burdened by the rental service provider. Converting the gas flare becoming productive gas will eliminate environmental issue and reduce the subject field contribution to global warming.

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